PERFORMANCE ANALYSIS OF FIXED AND MOBILE WIMAX SYSTEMS

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Submitted by

PANKAJ VERMA
2K09/MOC/09

Under the Supervision of

MR. AVINASH RATRE
Asst. Professor
Department of Electronics & Communication Engineering

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
IN ASSOCIATION WITH
DEPARTMENT OF APPLIED PHYSICS

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Main Bawana Road, Shahabad Daulatapur, New Delhi – 110042
June-2011

CERTIFICATE

This is to certify that the dissertation titled **"Performance Analysis of Fixed and Mobile WiMAX Systems"** is the bonafide work of Pankaj Verma (2K09/MOC/09) under our guidance and supervision in partial fulfillment of requirement towards the degree of Master of Technology in Microwave and Optical Communication Engineering from Delhi Technological University, New Delhi.

Mr. Avinash Ratre
Assistant Professor & Supervisor
Electronics and Communication Engineering
Delhi Technological University
Delhi
Date: /06/2011

Dr. Rajiv Kapoor
Head of Department
Electronics and Communication Engineering
Delhi Technological University
Delhi
Date: /06/2011

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Pankaj Verma
2K09/MOC/09
M.Tech (Microwave and Optical Communication Engineering)
Department of Electronics and Communication Engineering
Delhi Technological University

Abstract

The common feature of the next generation of wireless communications technologies (or 4G) will be the convergence of different wireless networks with multimedia services such as speech, audio, video, image, Internet services, and data at high data rates and with high mobility, high capacity and high QoS. There are many techniques that fulfill these requirements. One of the most important technique is Orthogonal Frequency Division Multiplexing (OFDM) .

OFDM has recently gained a lot of attention and is a potential candidate for 4G wireless systems because it promises data rates up to one Gbps or less under stationary conditions and up to about 100 Mbps under vehicular conditions and it has robustness against multipath fading channels effects. A variation of OFDM is Multi-Carrier Code Division Multiple Access (MC-CDMA) which is an OFDM technique where the individual data symbols are spread using a spreading code in the frequency domain. The spreading code associated with MC-CDMA provides multiple access technique as well as interference suppression.

WiMAX (Worldwide Interoperability for Microwave Access) is OFDM-based technology that supports point to multi-point (PMP) Broadband Wireless Access (BWA) for the next generation radio access. Main application (fixed and mobile) of WiMAX today is for MAN/WAN base stations and link stations. It delivers the maximum range (50 km) and higher data rates (up to 75 Mbps) than Wi-Fi. WiMAX has been implemented depending on IEEE 802.16 standard which was designed by Institute of Electrical and Electronic Engineers (IEEE).

This thesis aims to analyze and simulate a MC-CDMA system to be used in WiMAX instead of OFDM system. A MATLAB code had been written to simulate both Fixed WiMAX (IEEE 802.16d) and Mobile WiMAX (IEEE 802.16e). The analysis part includes a comparison between them in performance evaluation.

The simulation results include the performance analysis based on bit error rate (BER) versus bit energy to noise rate (E_b/N_o) plots and spectral efficiency of different modulation and channel coding schemes according to the standard IEEE 802.16. The results show that MC-CDMA outperforms OFDM in WiMAX system and enhances the performance more when spreading factor increases.

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List of Abbreviations

1D	One-Dimensional
1G	First Generation
2D	Two-Dimensional
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
AAS	Adaptive Antenna System
ACF	Autocorrelation Function
ACI	Adjacent Channel Interference
ADC (A/D)	Analog to Digital Conversion
ADSL	Asymmetric Digital Subscriber Line
AP	Access Point
ARQ	Automatic Repeat Request
ATM	Asynchronous Transfer Mode
AWGN	Additive White Gaussian Noise
b/s/Hz	bits per second per Hertz
BER (P_e)	Bit Error Rate
BPSK	Binary Phase Shift Keying
BS	Base Station
BWA	Broadband Wireless Access
C/I	Carrier to Nose power ratio.
CC	Convolutional Code
CCI	Co-channel interference
CDMA	Code Division Multiple Access
COST	European Cooperation in the Field of Scientific and Technical Research
CP	Cyclic Prefix
CPE	Customer Premises Equipment
DAC (D/A)	Digital to Analog Conversion
DFT	Discrete Fourier Transform
DSL	Digital Subscriber Line
DSP	Digital Signal Processing
ETSI	European Telecommunications Standards Institute
EV-DO	Evolution-Data Optimized
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FH	Frequency hopping
FIR	Finite Impulse Response
FM	Frequency Modulation
GPRS	General Packet radio Service
GSM	Global System for Mobile Communication
HDTV	High Definition Television
HIPERMAN	High PERformance Metropolitan Area Network
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access
Hz	Hertz or Cycles per Second
IDFT	Inverse Discrete Fourier Transform
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
IOFDM	Inverse OFDM(OFDM demodulation)

IP	Internet Protocol
ISI	Inter Symbol Interference
ISP	Internet Service Provider
ITU	International Telecommunication Union
LAN	Local Area Network
LOS	Line of Sight
LPF	Low-pass filter
LS	Least Squares
LSB	Least Significant Bit
LSE	Least Squares Estimation
LTE	Long Term Evolution
MAC	Medium Access Control
MAN	Metropolitan Area Network
Mbps	Mega bits per second
MC	Multi-Carrier
MC-CDMA	Multi Carrier - Code Division Multiple Access
MCM	Multi-Carrier Modulation
MIMO	Multiple Input Multiple Output
NLOS	Non Line of Sight
NMT	Nordic Mobile Telecommunication System
ODU	Out Door Unit
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PAM	Pulse Amplitude Modulation
PAN	Personal Area Network
PAPR	Peak to Average Power Ratio
PC	Personal Computer
PDA	Personal Digital Assistant
pdf	Probability Density Function
PHY	Physical Layer
PN	Pseudo random noise
PRBS	Pseudo-Random Binary Sequence
PSD	Power spectral density
PSTN	Public Switched Telephone Network
PTP	Point- to-Point
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift keying
RF	Radio Frequency
rms	root-mean-square
RS	Reed-Solomon
Rx	Receiver
S/P	Serial-to-Parallel (converter)
SC	Single Carrier
SIMO	Single-Input Multiple-Output
SINR	Signal-to-Interference-plus-Noise Ratio
SIR	Signal to Interference Ratio
SISO	Single-Input Single-Output
SMS	Short Messaging Services
SNR	Signal to Noise Ratio
SOFDMA	Scalable Orthogonal Frequency Division Multiple Access
SOHO	Small-Office Home-Office

SUI	Stanford University Interim
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
Tx	Transmitter
UL	Uplink
UMTS	Universal Mobile Telecommunication System
UTD	Uniform Theory of Diffraction
UWB	Ultra-Wide Band
VCO	Voltage Controlled Oscillator
VoD	Video on Demand
VoIP	Voice over IP
WAN	Wide Area Network
WCDMA	Wideband Code Division Multiple Access
WH	Walsh–Hadamard
Wi-Fi	Wireless -Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
Wireless MAN	Wireless Metropolitan Network
WLAN	Wireless Local Area Network
WLL	Wireless Local Loop
WMAN	Wireless Metropolitan Area Network
WWAN	Wireless Wide Area Network

Chapter – 1
Introduction

1.1 Wireless Broadband Beyond 3G

Wireless communication is facing one of the fastest developments of the last years in the fields of technology and computer science in the world. Third Generation (3G) mobile communication systems are already in deployment in several countries and this has enabled whole new ways to communicate, access information, conduct business and be entertained, liberating users from slow, cumbersome equipment and immovable points of access. In a way, 3G has been the right bridge for mobile telephony and the internet. 3G services enable users to make video calls to the office and access to the internet simultaneously, or play interactive games wherever they may be second and third generation systems like EDGE, IS-95 and WCDMA can provide nominal data rates of about 50 – 384 Kbps. While 3G is just transforming itself into a reality from an engineer's dream, research efforts are already on to look into systems that can provide even higher data rates and seamless connectivity.

The current and future mobile systems are shown in Figure 1.1 where noted that the increasing in data rates and mobility is a major goal in wireless communication systems advance.

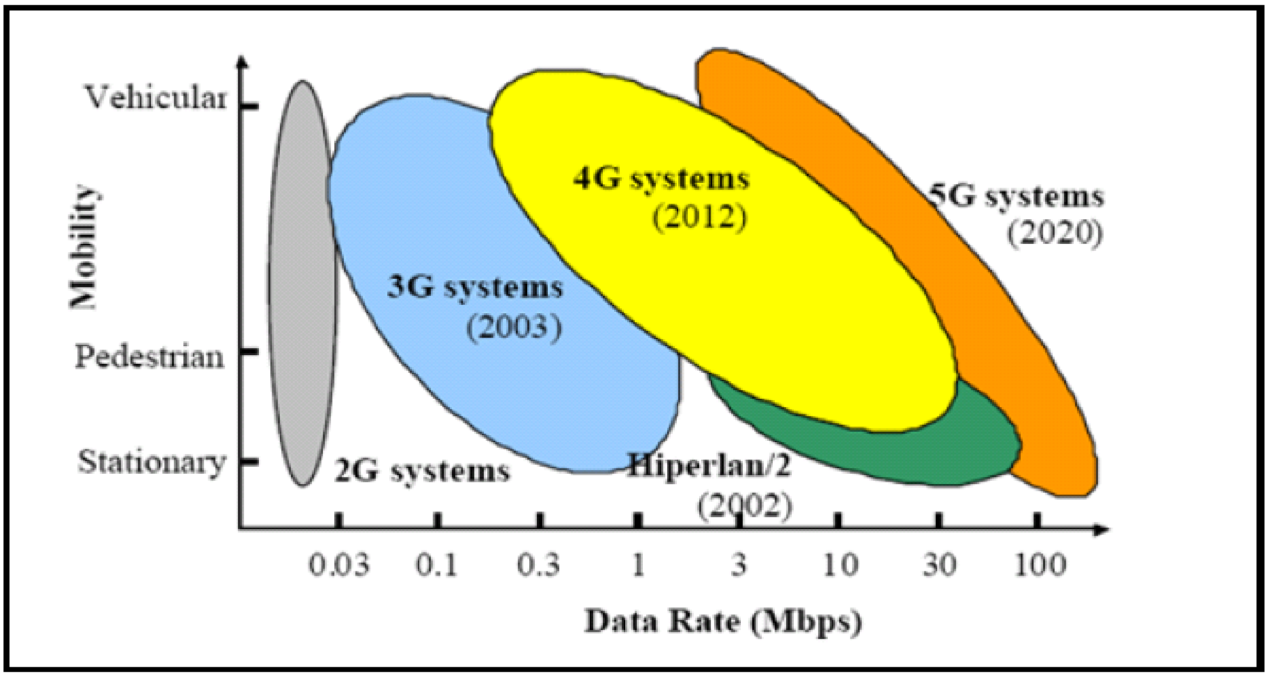

Figure 1.1 Current and future mobile systems

Before describing the requirements of the next generation ,we can look at Figure 1.2 that shows the evolution of radio access. The first generation systems were analog and could not provide data access. The second generation systems, which were launched around 1995, had digital technologies and could work with data access. However, the data transmission rate of these systems was not sufficient to provide multimedia services. The third generation systems were launched around 2000 to provide multimedia services.

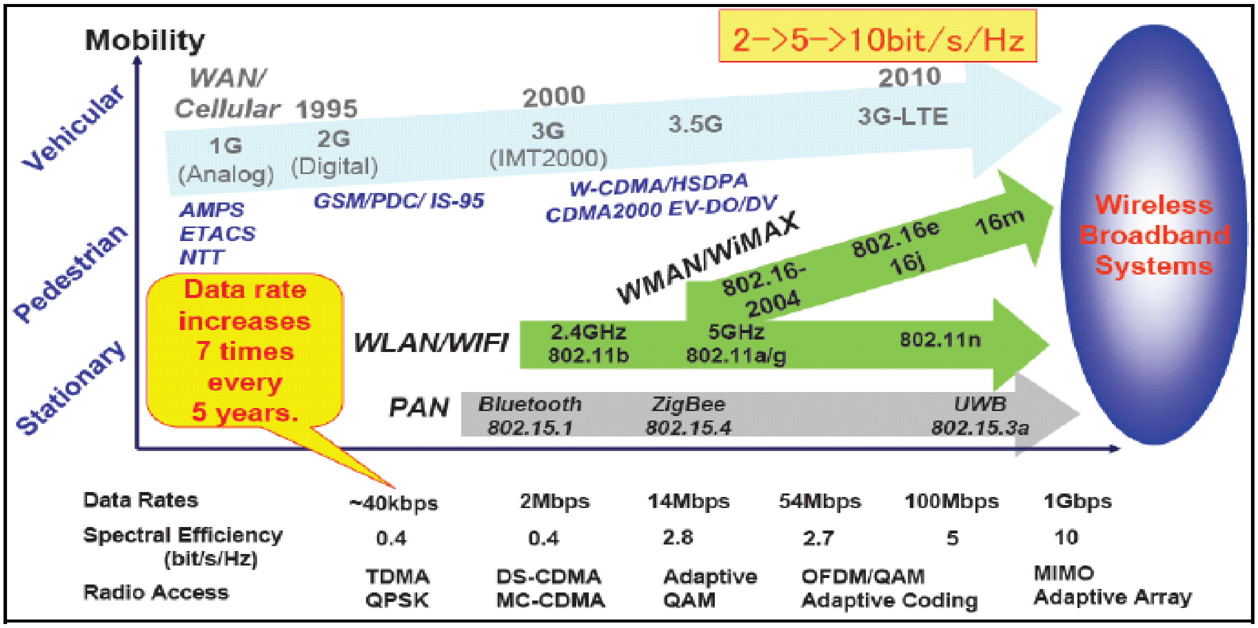

Figure 1.2 Mobile Multimedia services

The rapid growth of internet and increasing interest in portable computing devices are likely to push demand for high-speed wireless data services with aggregated higher information bit rates. High throughput is needed especially in the downlink because the number of downloads of large data files from web sites and servers are expected to increase. 3G and Wireless broadband technologies are converging to accommodate these requirements by Beyond 3rd Generation (B3G) systems.

Such systems are categorized under Fourth Generation (4G) and are predicted to provide packet data transmission rates of 100 Mbps in outdoor macro-cellular environments and up to 1 Gbps in indoor and microcellular environments. While wide-band systems could be a natural choice to provide high data rates, service providers have to pay dearly for the spectrum necessary. Hence, spectrum efficiency is always a factor on the choice of any wireless technology. Very wide-band systems usually require complex receivers as the channel is frequency selective due to the presence of large number of resolvable multipaths . Table 1.1 shows a comparison between 2G , 2.5G , 3G and 4G

TABLE 1.1 Comparison of 2G, 2.5G, 3G and 4G

	GSM (2G)	**GPRS (2.5G)**	**3G**	**4G**
Radio Transmission Tech.	Circuit-switched	Circuit-switched, packet-switched	Packet-switched	
Architecture	MS, BSS , NS	Base on GSM	Base on GSM	Hybrid
Frequency	1850~1990 MHz	1800~2400 MHz	2~8 GHz	
Data Rate	9.6~19.2 kbps	64~115 kbps	115~384 kbps / 384~2000 kbps	2~20/100 Mbps
Access Method	TDMA / FDMA	TDMA	W-CDMA	OFDM, MC-CDMA

Research has just recently begun on the development of 4th generation (4G) mobile communication systems. Currently, there are several ongoing research projects regarding the design and development of a high flexible and scalable next generation (4G) mobile radio access concept with respect to high data rates and spectral efficiency. For these 4G systems, several attractive candidates of transmission systems exist. Figures 1.3 and 1.4 show 4G objectives and 4G networks respectively. 4G aims to optimal connectively anywhere, anytime, with any person / object, through any network and on any device.

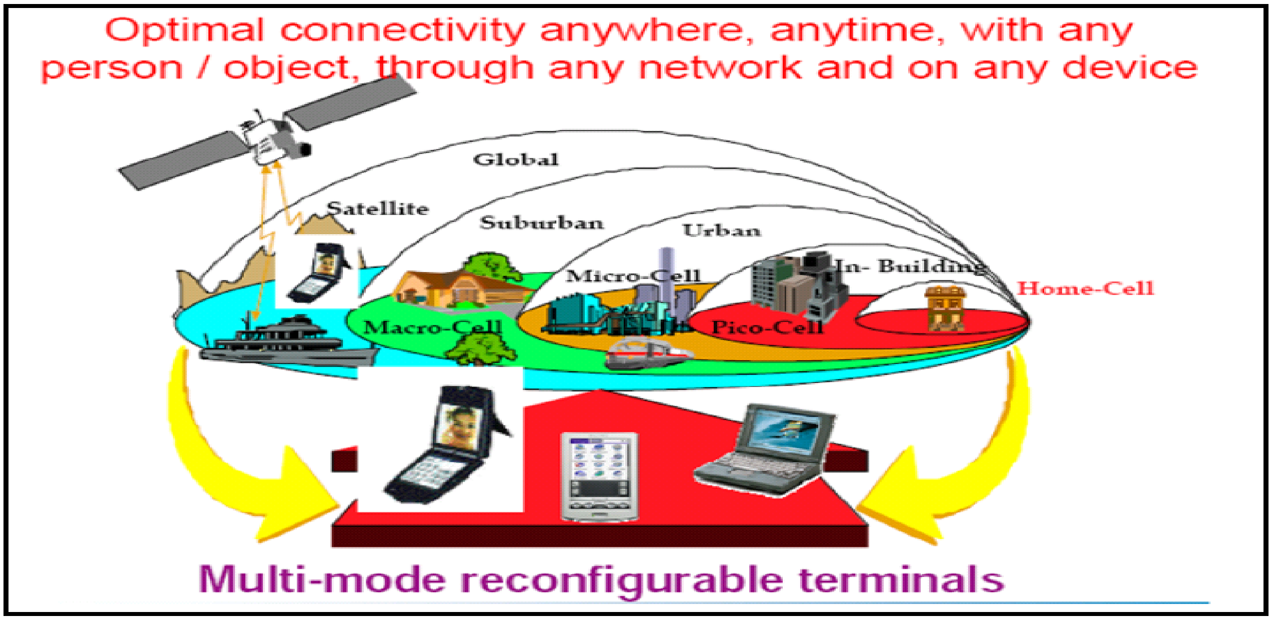

Figure 1.3 4G Objectives.

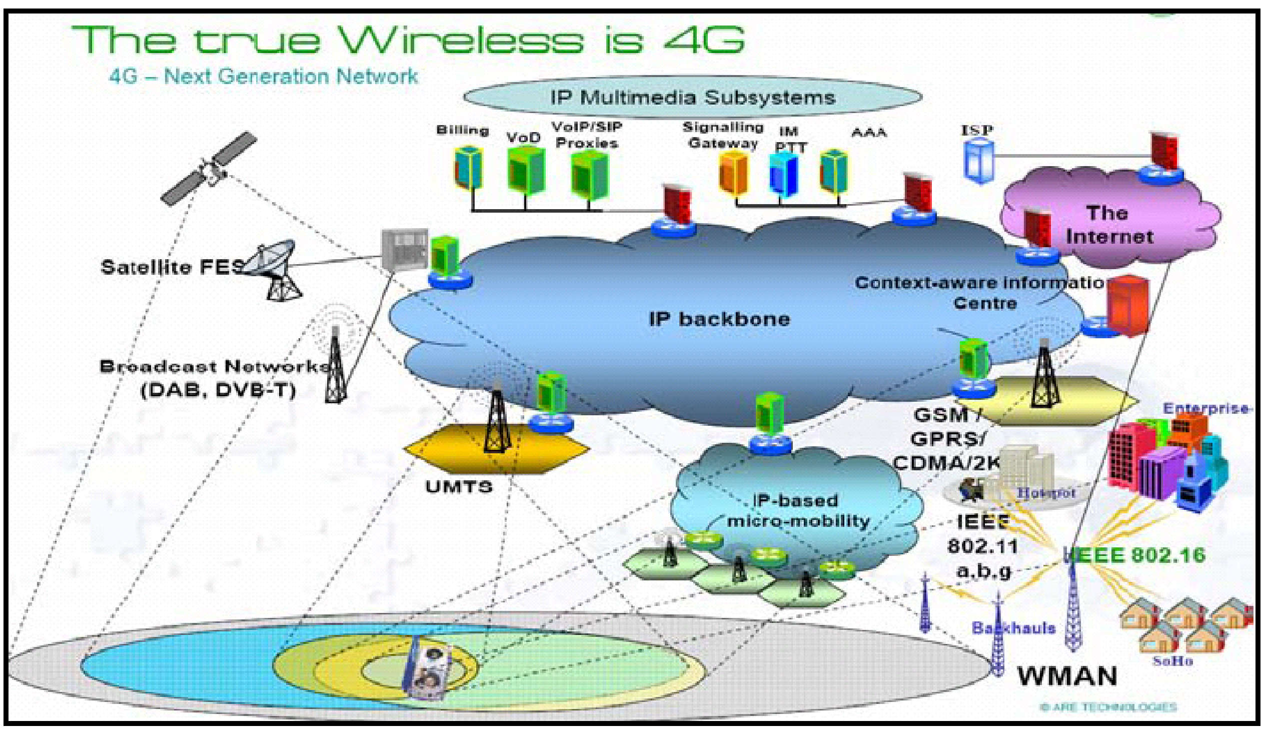

Figure 1.4 4G Networks.

1.2 Motivation

What has been seen and observed in recent years is a remarkable increase in the Broadband Wireless Access (BWA) networks as the need for broadband and mobile services are getting into demand. BWA is increasingly acquiring a great deal of popularity as an alternative "last-mile” technology to DSL and cable modems.

In today’s world a large number of wireless transmission technologies exist. These technologies are distributed over different network families depending upon the network scale such as PAN, WLAN, WMAN and WAN. As the demand for data transmission with higher rates changed so is the focus on the deployment of wireless networks. Technologies that promise to deliver higher data rates are attracting more and more vendors and operators towards them. One of the most promising candidates of such arising technologies is WiMAX. Many researchers do believe that WiMAX can move the wireless data transmission concept into a new dimension.

There are basically three limiting factors for transmitting high data rate over the wireless medium that mainly include multipath fading, delay spread and co-channel interference. The published WiMAX standard (802.16d) describes a MAC layer and five physical layers, each suitable for particular application and frequency range. Wireless MAN-OFDM is one of them. The Wireless MAN-OFDM interface can be extremely limited by the presence of fading caused by multipath propagation and as result the reflected signals arriving at the receiver are multiplied with different delays, which cause Intersymbol interference (ISI). OFDM basically is designed to overcome this issue and for situations where high data rate is to be transmitted over a channel with a relatively large maximum delay. If the delay of the received signals is larger than the guard interval, ISI may cause severe degradations in system performance. To solve this issue multiple antenna array can be used at the receiver, which provides spectral efficiency and interference suppression. Adaptive Antenna System (AAS) is an optional feature in IEEE 802.16d standard but to enhance the coverage, capacity and spectral efficiency, it should be essential for an OFDM air-
interface. It has an advantage of having single antenna system at the subscriber station and all the burden is on base station. An array of antenna is installed at the base station to reduce inter-cell interference and fading effects by providing either beamforming or diversity gains. When small spacing is adopted, the fading is highly correlated and beamforming techniques can be employed for interference rejection as compared to Diversity-oriented schemes. As a result receiver can separate the desired LOS signal from the multipath signals and nulls are formed at the interfering signals.

1.3 Objective

The main objective of this thesis is to implement and simulate the fixed and mobile WiMAX using OFDM and MC-CDMA by MATLAB and study the system performance for the two systems to see the enhancement of MC-CDMA over OFDM. Thesis plan is as following :

1. Understanding the WiMAX
2. Understanding the theory and principle of OFDM and MC- CDMA.
3. Understanding multi-path fading channels.
4. Choosing the system models parameters that makes the simulation possible.
5. The complete system will be simulated and tested by MATLAB.
6. Results are analysed and Conclusion is given.

1.4 Structure of The thesis

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

Chapter 2 gives a background of WiMAX technology including its various standards, equipments , advantages and disadvantages .

Chapter 3 discusses in detail the OFDM and MC-CDMA techniques. The principles of OFDM and

MC-CDMA are given in general view.

Chapter 4 discusses the multipath fading channels and presents the method to model the channel in wireless communication. SUI channel models ,which are widely used in Fixed WiMAX simulation , and COST 231 which is used for Mobile WiMAX are given in this chapter.

Chapter 5 explains in details the simulation models. The block diagram of every part of the system is given and how it works.

In Chapter 6 we present the simulation results of Fixed and Mobile WiMAX using OFDM and MC -CDMA. The results are discussed and compared for different modulation schemes.
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Chapter 7 concludes the thesis work and also includes the future work that can be conducted by using the useful information presented in this thesis.

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Chapter 2
Overview of WiMAX

This chapter presents an overview of WiMAX technology. It also highlights some of the key issues related to WiMAX technology such as : standards, services, equipment, costs and advantages / disadvantages of WiMAX. Also, we will compare WiMAX with some other wireless technologies such as Wi-Fi, LTE (Long Term Evolution), Ultra-Wide Band (UWB) technology and 3G systems.

2.1 What is WiMAX ?

World Wide Interoperability for Microwave Access (WiMAX) is the synonym given to the IEEE 802.16 standard, that specifies a frequency band in the range between 2 GHz to 66 GHz. Basically, WiMAX is a wireless internet service that is capable of covering a wide geographical area by serving hundreds of users at a very low cost. It particularizes a metropolitan area networking protocol that not only provides a wireless alternative for cable, Digital Subscriber Line (DSL) and T1 level services for last mile broadband access but also provides a backhaul for 802.11 hotspots and due to its higher data rates WiMAX is also gaining interest in cellular sector as well.

2.2 History of WiMAX

The history of WiMAX began several years ago to find suitable alternative of traditional wireline broadband technology that can serve wireless internet access and other broadband services and can easily deploy in rural and under developing areas where wired infrastructure was difficult to install and economically not suitable. The result of this finding is the creation of NII (National Information Infrastructure) bands of range 5-6 GHz and 30 GHz Local Multipoint Distribution Service (LMDS). LMDS promised to offer broadband Internet together with entertainment services that got the attention of the investors but unfortunately it failed to achieve its goal. After that IEEE takes initiatives and formed a committee, IEEE 802.16 which is also known as IEEE Wireless MAN to identify how the technology should work. This committee explores LMDS and the licensed and unlicensed band of 2-66 GHz which provide the standard of fixed wireless broadband. After that it includes mobile broadband application with its fixed service. In June 2001, a private organization named WiMAX Forum was established to coordinate the components and equipment development so that company equipment will compatible and interoperate. It also began certifying the products and in January 2006 it announced its first certified product for fixed application. In February 2006, WiMAX Forum established its second lab in Seoul, south Korea to certify interoperability of WiMAX product. In 2007, mobile WiMAX equipment which is based on IEEE802.16e got certificate and it was expected that in 2008, mobility and nomadicity supported advance WiMAX equipment will get certificate and WiMAX will spread widely. Nowadays, the mobile WiMAX system may be viewed as an early version of the 4^{th} generation (4G) wireless systems, and in fact it is taken as a 4G standards candidate together with the LTE system.

2.3 WiMAX – How does it work ?

WiMAX uses radio microwave technology to provide wireless internet service to computers and other devices that are equipped with WiMAX compatible chips for example PDA's, cell phones etc. It works more or less like cellular network technology, because WiMAX technology also involves the use of a base station to establish a wireless data communication link just as in the same way it is required in cellular networks like GSM and UMTS. The theoretical range of WiMAX is up to 30 miles and achieves data rates up to 75 Mbps, although at extremely long range that is greater than 30 miles the throughput is closer to the 1.5 Mbps. WiMAX operates in similar manner as Wi-Fi but with two very convincing differences as compared to Wi-Fi, these are data rate and data range. The typical WiMAX scenario involves a base station normally mounted on top of the building or at some place high where it can provide optimum coverage and a WiMAX receiver that can be in any form like for example CPE, or a chip installed in laptops or home PCs just like a Wi-Fi chip. Now, there are two steps that make up the whole communication model in WiMAX, these steps are :

- Data transmission from WiMAX Receiver (CPE or WiMAX Chip) to the WiMAX base station (BS).
- Data transmission from BS to backbone Internet.

Data transmission between two towers can be through a microwave transmission link and WiMAX BS can also be connected to the IP backbone network using a wired connection as shown in Figure 2.1. Communication between WiMAX BS and subscriber can be point to multipoint where as communication between two WiMAX BSs could be in form of point to point LOS.

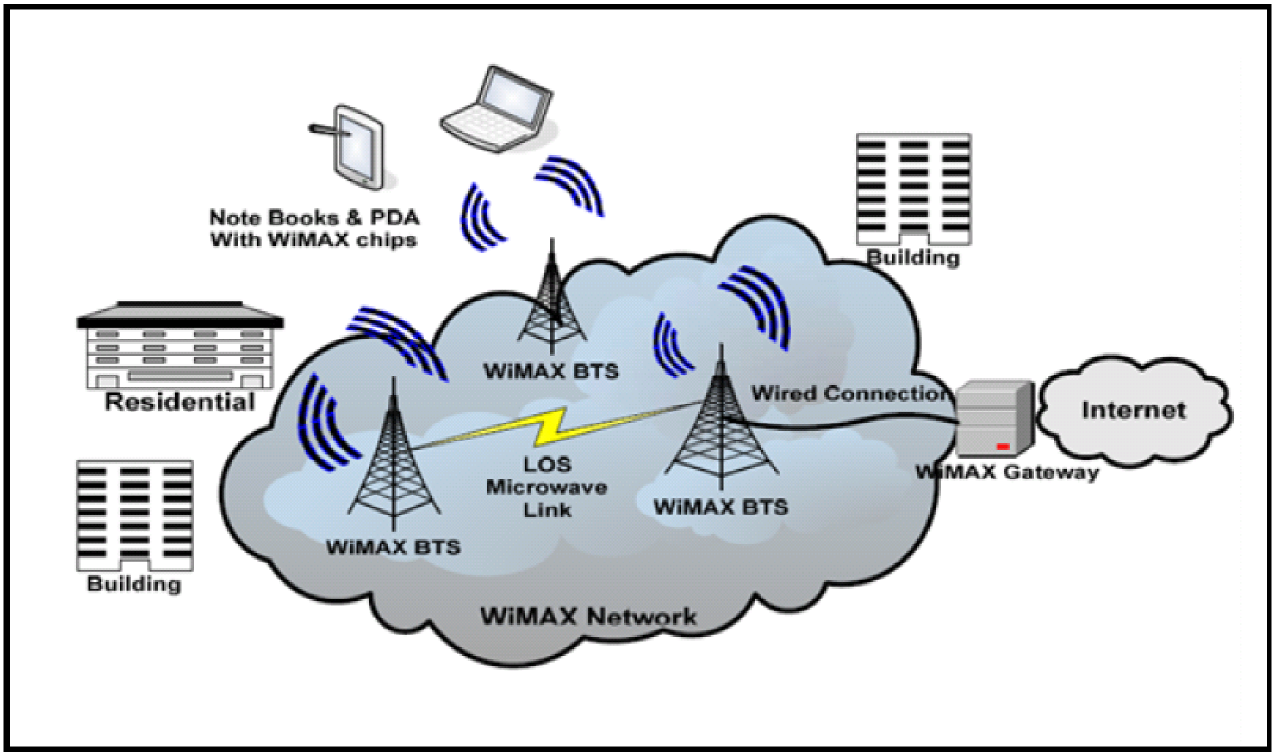


Figure 2.1 Point to multipoint deployment scenario with WiMAX BS

2.4 WiMAX Standards

Before, there have been several different standards that defines WiMAX, such as 802.16a, 802.16d, and 802.16e. However, nowadays there are two ratified standards that are addressed by WiMAX technology, the following two standards are:

• Fixed WiMAX (IEEE 802.16-2004).
• Mobile WiMAX (IEEE 802.16-2005).

The original WiMAX standard IEEE 802.16 specified WiMAX for the 10 to 66 GHz range and after the updation it became the 802.16-2004 standard specified for 2 to 11 GHz range. The amendment to the 802.16-2004 standard which is the 802.16-2005 standard will initially operate at 2.3 GHz, 2.5 GHz, 3.3 GHz, 3.4 to 3.8 GHz spectrum bands. Although the above two terminologies (Fixed and Mobile WiMAX) are not WiMAX standards but these are basically two general terms that are used commonly all over to define the basics standards related to WiMAX technology. Both these standards have addressed various issues. A brief comparison of these two standards is shown in Table 2.1.

TABLE 2.1 Comparison between Fixed and Mobile WiMAX

Standard	**802.16d WiMAX**	**802.16e WiMAX**
Release	802.16d or 802.16-2004 (June 2005)	802.16e or 802-16-2005 (December 2005)
Services Supported	Fixed, Limited Portability	Mobile, Portable and Fixed
Applications	Data connectivity, VoIP	Data connectivity, Fixed and mobile VoIP
Service Providers	DSL and cable modem	Mobile Operators
Targeted	Service Providers, Wireless and Wired ISPs	DSL and Cable Modem service providers, Wireless and Wired ISPs
Subscriber Unit	Outdoor or Indoor CPE, PCMCIA card for Laptops	Outdoor or Indoor CPE, PCMCIA card, mini-card built in laptops, PDA, Smart Phone
Certification	Started in August 2005 Certified products in January 2006	2007

2.4.1 IEEE 802.16d

Earlier version known as 802.16a that was updated to 802.16-2004 (also known as 802.16d) is a WiMAX standard that supports fixed non-line of sight (NLOS) wireless internet services thus forming a point to multipoint deployment scenario. The basic goal of 802.16-2004 standard was to provide a stationary wireless transmission with data rates higher than those provided by DSL and T1. This feature makes fixed WiMAX an alternative for cable, DSL and T1. IEEE 802.16-2004 uses Orthogonal Frequency Division Multiplexing (OFDM) for transmission of data thus serving a large number of users in time division manner in round robin fashion. Some of the silent features of 802.16-2004 standards are :

- Designed to provide fixed NLOS broadband services to fixed, nomadic and portable users .
- 256 OFDM PHY with 64-QAM, 16-QAM, QPSK, and BPSK modulation techniques.
- Support for advance antenna and adaptive modulation & coding techniques.
- Facilitates the use of point-to-multipoint mesh topology .
- Low latency for delay sensitive services, thus improving on QoS parameters.
- Support for both TDD and FDD.

2.4.2 IEEE 802.16e

IEEE 802.16-2005 formally known as 802.16e or Mobile WiMAX is basically an improvement of the 802.16-2004 standards. It is a bit more complex technology as compared to its predecessor 802.16-2004 standard. The Mobile WiMAX allows the convergence of mobile and fixed broadband networks through a common wide area broadband radio access technology and flexible network architecture.

Some silent features of 802.16-2005 standards are:

- 802.16-2005 standard offers support both fixed and mobile access over the same infrastructure .
- Provides improved coverage range with the use of Adaptive Antenna System (AAS) .
- It uses scalable orthogonal Frequency Division Multiple Access (SOFDMA) for transmission to carry data supporting channel bandwidths between 1.25 MHz & 20 MHz with up to 2048 sub-carriers.
- Combining SOFDM and MIMO: an improved spectral efficiency is obtained by combining SOFDM with Multi-input and Multi-output (MIMO) technology.
- Provides resistance to multipath interference by deploying FFT algorithms.
- Provides support for optimized roaming and handover schemes to facilitate real time VoIP applications without any degradation in service.

2.4.3 IEEE 802.16m

The last amendment of IEEE 802.16 standard is IEEE 802.16m which is expected to be approved or authorized in 2011. IEEE 802.16e with migration to IEEE 802.16m will enhance WiMAX performance to over 5 b/s/Hz as has been already demonstrated in a number of field testes. We are waiting IEEE 802.16m for faster mobile WiMAX. In fact, the IEEE802.16m follows the MAC architecture of current IEEE802.16e and includes additional functional blocks for IEEE802.16m specific features. The additional functional blocks include routing, self organization, multi-carrier and multi-radio coexistence.

2.5 WiMAX Physical Layer

The focal point of this thesis work is mainly on the WiMAX physical layer so in this context a brief description of WiMAX physical layer is presented. Physical layer set up the connection between the communicating devices and is responsible for transmitting the bit sequence. It also defines the type of modulation and demodulation as well as transmission power. WiMAX 802.16 physical layer considers two types of transmission techniques OFDM and OFDMA. Both of these techniques have frequency band below 11 GHz and use TDD and FDD as its duplexing technology. The WiMAX physical layer depends upon OFDM . This technique will be explained in Chapter 3 but, in brief, the channel bandwidth is divided into multiple sub- channels and information on each channel is transmitted using different frequencies.

Why WiMAX uses OFDM technology for data transmissions? The answer is pretty simple, because the huge benefits provided by this technique are far more than those provided by existing wireless data transmission techniques.

However, it must be kept in mind that the OFDM physical layer is implemented differently in Fixed and Mobile versions of WiMAX. Fixed WiMAX uses 256 – FFT based OFDM physical layer where as the Mobile WiMAX uses a scalable OFDMA (SOFDMA) based physical layer and the FFT sizes in this case can vary from 128 bits up to 2048 bits.

In the case of Fixed WiMAX, the number of sub-carriers is fixed to 256. Out of the 256 sub-carriers, 192 sub-carriers are used for carrying data, 8 are used as pilots subcarriers to estimate the channel and the rest of the carriers are used as guard band sub-carriers. However, in this case the spacing between the sub-carriers is directly proportional to the channel bandwidth. It means that higher the channel bandwidth is, the greater would be the sub-carrier spacing which ultimately results in decrease of symbol time.

On the other hand, in case of Mobile WiMAX, the FFT size is scalable from 128 to 2048 points, thus with the increase in the available bandwidth the FFT size also increases . In order to enhance the range and performance of the Fixed WiMAX, a limited form of sub-channelization is allowed in the uplink (only). It helps in link budget improvements that can be used to enhance the range performance. However, in case of Mobile WiMAX the sub-channelization occurs in both directions (i.e. uplink and downlink). Thus different sub-channels are assigned to number of different users by using a specific type of an access mechanism and this particular access mechanism is called OFDMA.
The establishment of the sub-channels is carried out in two different ways ; in form of contiguous sub-carriers or sub-carriers distributed in a pseudo-randomly manner. Its noticeable here that sub-carriers formed in contiguous manner, are useful in exploiting the multi-user diversity which provides significant gain in overall system capacity. That is the reason why contiguous sub-carriers are more applicable and suited for fixed and low mobility. On the other hand, if channels are distributed randomly across the frequency spectrum and more supportive for frequency diversity then they are well suited for mobile applications. Besides these key attributes that WiMAX physical layers perform, there is another important function that physical layer performs and that is allocation of slots and framing for wireless communication channels. The slots that are formed using the contiguous series assigned to a particular user are called "data region". These data regions are assigned to different users by various scheduling algorithms on basis of various channel conditions and some QoS demand parameters.

2.5.1 Features of IEEE 802.16d OFDM PHY Layer

The following context will incite few very important features that constituent the WiMAX 802.16d OFDM PHY layer.

• **Flexible Channel Bandwidth**

The 802.16d Standard offers a flexible channel bandwidth so that WiMAX technology can be compatible with other wireless technologies, which means that the bandwidth of the channel can be adjusted according to the user requirements. The scale for bandwidth channel flexibility starts from 1.25 MHz up to 20 MHz with channel bandwidth selection parameters as 1.25 MHz, 1.50 MHZ, 1.75 MHz,……., 20 MHz .

• **Adaptive Modulation and Coding**

Adaptive modulation and coding process involves the radio link adjustments in accordance with various signal coding, modulation schemes keeping in mind the environmental factors involved (Interference, Multipath propagation, Doppler Effect etc) affecting the signal strength during transmission .
Four schemes to modulate the transmitted bits have been used, and afterwards the comparison on the transmitted data rates is taken into account for all of these four modulation schemes. The modulation schemes used in this thesis work are :

- Binary Phase Shift keying (BPSK)
- Quadrature Phase Shift keying (QPSK)
- 16 Quadrature Amplitude Modulation (16-QAM)
- 64 Quadrature Amplitude Modulation (64-QAM)

The various Modulation and Coding scheme indulge in WiMAX 802.16d standard are given below in TABLE 2.2

TABLE 2.2 WiMAX 802.16 d: Uplink & downlink with different Modulation & Coding Schemes

	Downlink	**Uplink**
Modulation	BPSK, QPSK, 16 QAM, 64 QAM; BPSK optional for OF-DMA-PHY	BPSK, QPSK, 16 QAM; 64 QAM optional
Coding	**Mandatory:** convolutional codes at rate 1/2, 2/3, 3/4, 5/6 **Optional:** convolutional turbo codes at rate 1/2, 2/3, 3/4, 5/6; repetition codes at rate 1/2, 1/3, 1/6, LDPC, RS-Codes for OFDM-PHY	**Mandatory:** convolutional codes at rate 1/2, 2/3, 3/4, 5/6 **Optional:** convolutional turbo codes at rate 1/2, 2/3, 3/4, 5/6; repetition codes at rate 1/2, 1/3, 1/6, LDPC

- **Forward Error Correction Control Mechanism (FEC)**

The 802.16d PHY layer provides a very robust technique for making sure the correct data has reached the destination by using Forward Error Correction (FEC) control mechanism which encloses redundancy in transmitted data. The 1st stage in FEC is Reed-Solomon Encoder that encapsulate the data with coding blocks and these coding blocks are helpful in dealing with the burst errors, once that is achieved the data is then passed towards the next process which is the convolution coding of the data. Furthermore, before the transmission the number of transmitted bits are reduced by deleting certain bits and upon reaching at the receiver replacing the deleted bits with certain fixed values through the process of Puncturing, so that the overall number of bits that needed to be sent on the channel is reduced.

- **Adaptive Antenna System**

WiMAX PHY layer also provides an additional feature of adding Adaptive Antenna System (AAS). As described earlier that the insertion of Guard Interval (GI) the OFDM provides a resistance to multipath propagation problem, but in case if the delay caused by multipath exceeds that GI length then Inter Symbol Interference (ISI) happens thus resulting in signal loss. To deal with this problem of ISI, AAS are used, AAS basically subdue those multipath waves that are causing delays.

2.5.2 Features of IEEE802.16e OFDM PHY Layer

• **(S)-OFDMA PHY:**

OFDM offers improved performance in time and frequency selective channels. OFDM transmission systems perform well in NLOS conditions and in channels experiencing severe multipath effect. Furthermore, when subcarrier permutation schemes are combined with coding, they help improve error-recovery.

• **High Throughput** :

WiMAX is capable of supporting very high peak data rates. In fact, the peak PHY data rate can be as high as 63 Mbps on a 20 MHz wide bandwidth, using 64-QAM modulation and 2 x 2 MIMO transmission. Under very good signal conditions, even higher peak rates may be achieved using multiple antennas and spatial multiplexing.

- **Scalable data rate:**

SOFDMA combined with Adaptive Modulation and Coding (AMC) enables users to be apportioned spectrum based on bandwidth/data rate requirement. Flexible and dynamic per user resource allocation.

- Adaptive Modulation and Coding: The system adjust modulation and coding parameters dynamically to maximize throughput and minimize Bit Error Rate (BER) in the face of changing channel conditions.
- Link layer retransmission: using Hybrid Automatic Repeat Request (H-ARQ)
- Support for TDD and FDD: including variable DL/UL ratios.
- Support for advanced antenna techniques.
- Embedded Quality of Service (QoS) scheduling.
- Full terminal mobility.
- Full support for IP.

2.6 WiMAX MAC Layer

Medium Access Control layer (MAC) provides an interface between the physical layer and the upper layer. It takes packets from the upper layer and prepares it for the transmission over the air. It also maintains the scheduling and multiple access connection.

The primary objective of MAC is to provide an interface between the physical layer and the higher layers of the system model. The WiMAX MAC layer takes data packets called MAC service data units or MSDUs and in order to send MSDUs over the interface they are organized into MAC protocol data units (MPDUs). When it comes to Compatibility WiMAX is quite compatible with existing data communication protocols such as ATM , IP, and Ethernet etc. For this purpose, WiMAX MAC layer has a sub layer also known as a "Convergence layer". This layer allows WiMAX enabled devices to communicate with devices using different protocols such as ATM , IP or Ethernet etc. Besides providing an interface with higher protocols the convergence layer also reduces the over heads for the higher layer by suppressing the MSDU header. In order to address QoS parameters with even high data rates the WiMAX MAC layer offers variable length MPDUs which means that multiple MPDUs can be sent over the air interface in a single burst, thus resulting in even reduce over head for the PHY layer also.

As from the name MAC, it can be concluded that MAC layer is responsible for defining the mechanism in which the medium will be accessed. WiMAX being successful mainly because of the reason that it provides a different kind of a medium access control mechanism unlike its predecessors like Wi-Fi where the medium or the channel is accessed in a pseudo randomly manner. Every station tries to gain the attention of the access point (AP), so the stations nearer to AP affect the performance of the stations that are far from AP. In contrast WiMAX has a different mechanism for accessing the channel. Unlike the contention based MAC layer used in Wi-Fi; WiMAX basically has a request – grant access mechanism similar to that used by DOCSIS cable modem. In WiMAX, the bandwidth to be used in the uplink as well as in the downlink channels is allocated by the Base Station (BS).

Upon receiving the amount of allocated bandwidth it is the mobile station (MS) that can distribute the aggregate bandwidth among the multiple connections if needed to. Based on the type of traffic, the bandwidth required for the downlink is allocated without involving the MS and the uplink bandwidth is allocated on the type of the demand the MS requested for. The BS allocates dedicated or shared resources in periodic manner among multiple Mobile stations through a process known as polling. The time slot (capable of expanding and contracting) allocated to a client remains reserved in at least a minimal level whether the client is actively utilizing the channel or not.

2.7 Differences Between Fixed and Mobile WiMAX

Due to media\marketing buzz, there is a seeming confusion as to what the 802.16e standard caters-for. At the moment, the 802.16e standard is fondly referred as Mobile WiMAX while the 802.16d

(Rev 2004) is called the Fixed WiMAX. In technical terms, while the 802.16d standard supports fixed and roaming applications, the 802.16e standard supports fixed, roaming, portable, and mobile solutions. The 802.16e covers both the 802.16d standard and adds new major specifications that enable full mobility at vehicular speed, enhanced QoS, power control amongst other features. 802.16e devices are not backward compatible with 802.16d base stations and vice versa. This is due to the fact that 802.16e mainly adopts TDD while 802.16d adopts FDD. Other compatibility issues arise as a result of 802.16e adopting S-OFDMA and 2048-FFT size.

2.8 Spectrum Influence in WiMAX Network

The best advantage of WiMAX system is that, it can operate in both license and license free frequency bands which helps for global deployment of WiMAX and have certain advantages over the wired network. It's another advantage is flexible radio frequency (RF). Channel bandwidth which increases the capacity of the WiMAX network by reusing the frequency. WiMAX standard 802.16 -2004 also support channel quality measurement which effectively manages the spectrum uses. So one RF channel can support thousands of subscribers and it can handle the subscriber growth by reallocating the frequency by sectoring the coverage area.

2.8.1 WiMAX License Spectrum

Most of the country around the world uses 2.5 GHz band as a license frequency band for WiMAX application. Since allocation of spectrum varies among country to country, so spectrum allocation can varies between 2.6 to 4.2 GHz. To deploy license spectrum, WiMAX service provider must procure spectrum from regulatory authority which could be a lengthy and awkward process and auctioning spectrum delivery process raises the price and it could be billions of dollars.

License spectrum has many advantages over unlicensed band. It can effectively deliver point-to-multipoint spectrum to large number of users. It has strong bandwidth capacity. Low range of license frequency band 2.5 GHz and 3.5 GHz can easily penetrate the obstacles which is effective for NLOS communication. It is also good for interference free services and better QoS.

2.8.2 WiMAX Unlicensed Spectrum

The globally available unlicensed spectrum is 2.4 GHz Industrial, Scientific and Medical band (ISM). Another license-exempt spectrum uses most of the country is the 5 GHz band. Around 300 MHz is available between 5.15 and 5.85 GHz band for license exempt services. Lots of services uses license free spectrum could have interference and affect important government communication like radar system. So unlicensed spectrum should be maintained properly to minimize the interference level.

Unlicensed spectrum is better for lower cost network deployment in rural areas, developing countries, emerging markets and developed countries with underdeveloped areas. It is also good to quickly deployed the services rather that wasting time for the license permit. In this case service provider can provide the services by controlling the output power adequately. It can be used in a point to point (PTP) communication in a small population area or a point-to-multipoint (PMP) communication in a rural areas or a place like college campus, large enterprise where interference can be controlled. Figure 2.2 shows that 2 to 6 GHz centimeter bands are available for Broadband Wireless Access (BWA).

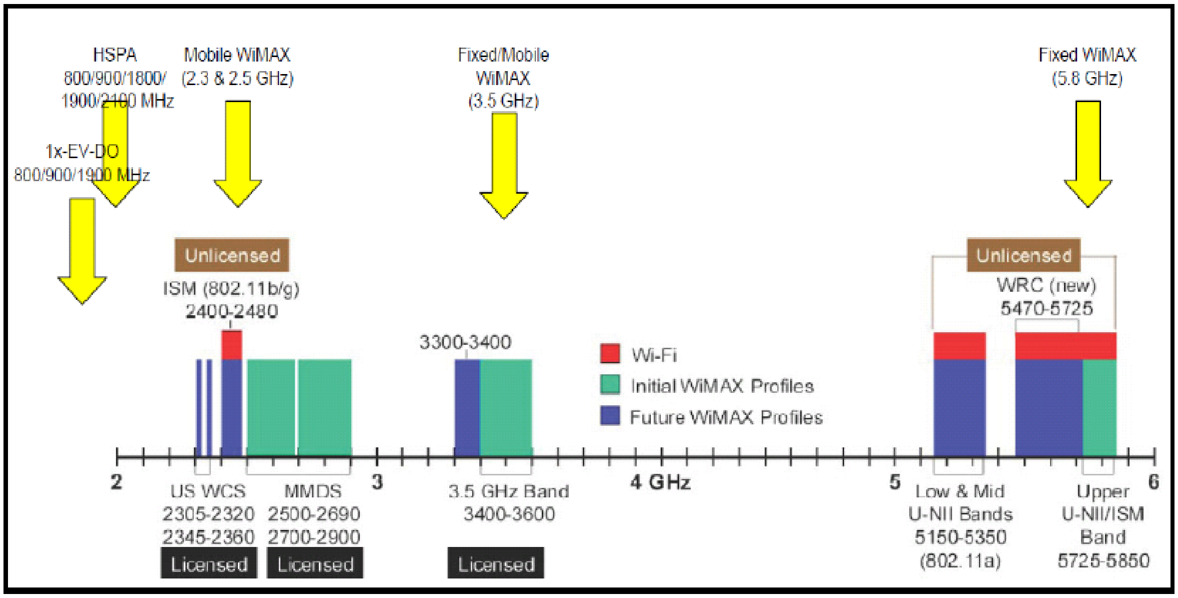


Figure 2.2 2 to 6 GHz centimeter bands available for BWA

2.9 Comparison of WiMAX with Other Wireless Technologies

Before WiMAX came into existence there was IEEE 802.11 standards addressed by the Wi-Fi Forum , providing the users with wireless internet services. When WiMAX was taken into consideration for replacing the DSL and cable modems and providing an enhanced solution to the exiting solution (802.11 standards), no one thought that WiMAX could be so strong and powerful that it could replace or even proves to be a good competitor for 3G and beyond cellular networks. It's a well known fact that WiMAX achieves better spectral efficiency as compared to other existing wireless communication technologies due to its higher bandwidth feature. However , when it comes to mobility WiMAX falls behind 3G network and this is basically due to the fact that when 3G networks are designed the mobility or roaming part is one of the essential features that 3G network must address where as in WiMAX design the main goal was to provide higher bandwidths to fixed, roaming, portable and mobile users with the certain mobility capabilities as an extra feature. In IEEE 802.11 standard, the major problem was QoS parameters, as Wi-Fi Forum was unable to address QoS parameters in IEEE 802.11 standard. Table 2.3 depicts a comparison between WiMAX and other wireless communication technologies . Figure 2.3 illustrates an example of Wireless Metropolitan Area Network (WMAN).

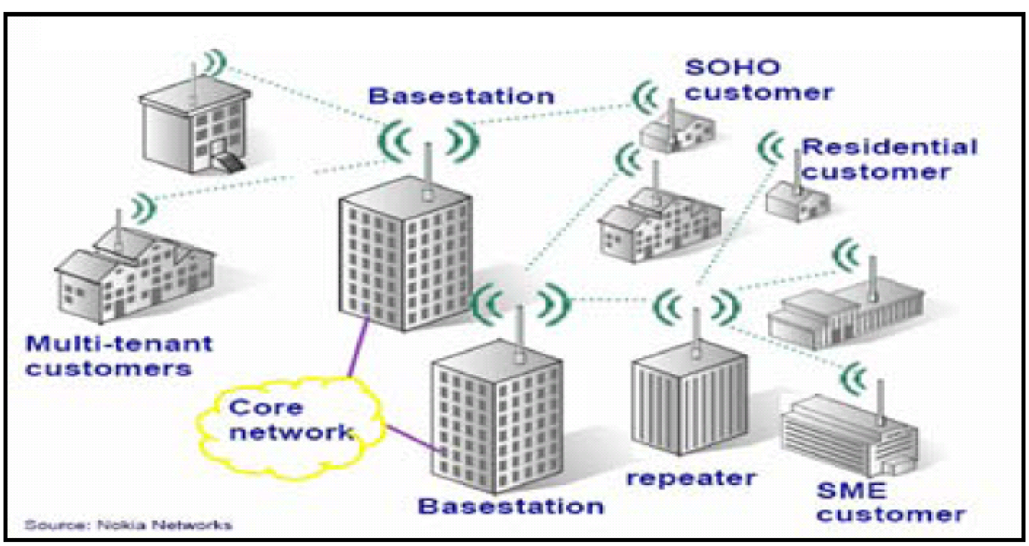


Figure 2.3 Wireless Metropolitan Area Network.

2.9.1 A Comparison of WiMAX and 3G

Here, we draw a comparison of WiMAX with other wireless technologies. The Mobile WiMAX system was standardized in February 2006. According to several industry sources, the key features of Mobile WiMAX are that it uses OFDMA, MIMO, beam-forming and a number of other recent technology advancements that are labeled as features in 4G. Due to that, WiMAX has some key advantages in comparison to other 3Gs, which were set up 7 years ago. It supports several new features necessary for delivering mobile broadband services at vehicular speeds greater than 120 km/hr with QoS. Some of WiMAX key new features and benefits over other wireless technologies are :

1. Introduces OFDMA, which improves spectrum efficiency (the amount byte transferred on given width of frequency) around two times more than current 3G technologies or Wi-Fi. For the same service, WiMAX only need about half of the base station as would for HSPA.
2. Enables a wide range of advanced antenna systems including MIMO, beam-forming, space-time coding and spatial multiplexing. It thus increases the covering range of WiMAX ; it also can dynamically allocate frequency band (from 1.5 to 20 MHz) based on user's signal strength, band-width requirement. By this it makes better use of available frequency to support more users, so have better spectral efficiency.
3. Dynamic Power Conservation Management (DPCM) ensures power efficient operation of battery operated mobile handheld and portable devices in Sleep and Idle modes. This may be critical for small devices like cell phones.
4. With 5 millisecond latency between hand hold devices and cellular tower, plus the support of QoS , make WiMAX good for high quality VoIP, this wireless data network also competes with 2G and 3G on voice service. This is the reason why Qualcomm and Ericsson are strongly against it.
5. Another important feature of WiMAX is that it defines a Framework or APIs and leave implement details to individual company. It thus makes it possible to plug in those most recent progresses and keep itself up-to-date, and this also encourage competition to develop better system.
6. The industry is working fast to offer high-speed data connection to portal devices, but the market has split into two camps: one stands by wireless standards such as WiMAX and Wi-Fi, while the other supports mobile technology 3G and HSDPA. Wireless broadband technologies Wi-Fi and WiMAX are among the hot favorites. WiMAX can support Web connection of up to 75 Mbps and a single base station can cover an area with a radius of up to 30 miles. Comparison of WiMAX with other wireless technologies is given in Table 2.3. The comparison contains standards, bandwidth, modulation schemes, multiplexing, duplexing, frequency, coverage and mobility. The wireless technologies compete with each other to introduce the better services with high QoS and reliable connectivity. A trade-off between these parameters is performed depending on the situation of the wireless environments. We note that WiMAX has flexible bandwidth and different modulation schemes.

Table 2.3 Comparison of WiMAX with other wireless technologies .

Parameter	**Fixed Wi-MAX**	**Mobile Wi-MAX**	**HSPA**	**1xEV-DO Rev A**	**Wi-Fi**
Standards	IEEE 802.16 -2004	IEEE 802.16 -2005	3GPP Release 6	3GPP2	IEEE 802.11a/g/n
Bandwidth	3.5MHz and 7 MHz in 3.5GHZ band, 10MHz in 5.8GHz band	3.5MHz, 7MHz, 5MHz, 10MHZ and 8.75MHz initially	5MHz	1.25 MHz	20MHz for 802.11g; 20/40MHz for 802.11n
Modulation	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM	QPSK, 16QAM	QPSK, 8PSK, 16QAM	BPSK, QPSK, 16QAM, 64QAM
Multiplexing	TDM	TDM/ OFDMA	TDM/ CDMA	TDM/CDMA	CSMA
Duplexing	TDD, FDD	TDD initially	FDD	FDD	TDD
Frequency	3.5GHz and 5.8GHz ini-tially	2.3GHz, 2.5GHz and 3.5GHz ini-tially	800/900/1,800/1,900/2,100MHz	800/900/ 1,800/ 1,900MHz	2.4GHz, 5GHz
Coverage (Typical)	3-5 miles	< 2 miles	1-3 miles	1-3 miles	<100ft in-door; <1000ft out-doors
Mobility	Not Applicable	Mid	High	High	Low

Wi-Fi and WiMAX have been largely confined to facilitating high-speed connectivity to laptops and PDAs, while 3G and HSDPA have focused on mobile phones. However, there are now suggestions that 3G can be extended to laptops, particularly as the data speeds offered by these mobile standards catch up to those provided by WiMAX or Wi-Fi. But mobile standards 3G and HSDPA are fast becoming hot buzzwords.

HSDPA is a beefed up version of the Wideband CDMA (WCDMA) 3G technologies that specifically improves the downlink speed, and is capable of supporting data connection of up to 1.4 Mbps.

Nevertheless, many of the technologies incorporated by equipment vendors are very new and much more complicated than people think. There has been fierce competition of WiMAX talents recently.

WiMAX, and there will be huge changes to the wireless technology landscape going forward, with huge money won and lost. In any case, the consumer will be the eventual beneficiary of more competition in wireless space. Currently, the front runners of Mobile WiMAX are Alvarion, Samsung and Motorola.

2.9.2 WiMAX vs. Wi-Fi

WiMAX operates on the same general principles as Wi-Fi. It sends data from one computer to another via radio signals. A computer (either a desktop or a laptop) equipped with WiMAX would receive data from the WiMAX transmitting station, probably using encrypted data keys to prevent unauthorized users from stealing access.

The fastest Wi-Fi connection can transmit up to 54 megabits per second under optimal conditions. WiMAX should be able to handle up to 70 megabits per second. Even once that 70 megabits is split up between several dozen businesses or a few hundred home users, it will provide at least the equivalent of cable-modem transfer rates to each user.

The biggest difference isn't speed; it's distance. WiMAX outdistances Wi-Fi by miles. Wi-Fi's range is about 100 feet (30 m). WiMAX will blanket a radius of 30 miles (50 km) with wireless access. The increased range is due to the frequencies used and the power of the transmitter. Of course, at that distance, terrain, weather and large buildings will act to reduce the maximum range in some circumstances, but the potential is there to cover huge tracts of land. WiMAX is not designed to clash with Wi-Fi, but to coexist with it. WiMAX coverage is measured in square kilometers, while that of Wi-Fi is measured in square meters. The original WiMAX standard (IEEE 802.16) proposes the usage of 10-66 GHz frequency spectrum for the WiMAX 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 WiMAX base station can be accessed by more than 60 users. WiMAX can also provide broadcasting services.

WiMAX specifications also provides much better facilities than Wi-Fi, providing higher bandwidth and high data security by the use of enhanced encryption schemes. WiMAX can also provide service in both Line of Sight (LOS) and Non-Line of Sight (NLOS) locations, but the range will vary accordingly. WiMAX will allow the interpenetration for broadband service provision of VoIP, video, and internet access – simultaneously. WiMAX can also work with existing mobile networks. WiMAX antennas can "share" a cell tower without compromising the function of cellular arrays already in place.

2.9.3 WiMAX vs. UMTS

UMTS is identified with the so-called third generation of cellular networks standardized by the 3GPP. The frequency bands that are assigned to this technology are the licensed frequencies from 1885 to 2025 MHz, and from 2110 to 2200 MHz. It uses wideband code division multiple access (WCDMA) as the carrier modulation scheme, and it has been specified as an integrated solution for mobile voice and data with wide coverage area, offering data rates that may decrease while the velocity of the user increases. This system provides for theoretical bit rates of upto 384 kbps in high mobility situations, which rise as high as 2 Mbps in stationary user environments, employing a 5 MHz channel width. Moreover, HSDPA technology further increases the throughput speeds, providing theoretical data rates as high as 14 Mbps. WiMAX is becoming a serious threat for 3G cellular networks because of its broadband and distance capabilities, as well as its ability to effectively support voice with full QoS. WiMAX is also able to offer higher data rates than UMTS, but it does not allow the same grade of mobility. Figure 2.4 show that WiMAX fills the gap between Wi-Fi and UMTS with respect to data rates and mobility. However, WiMAX is expected to be set up as an alternative to cellular networks, as the investments the operators need to carry out for its deployment are not so high.

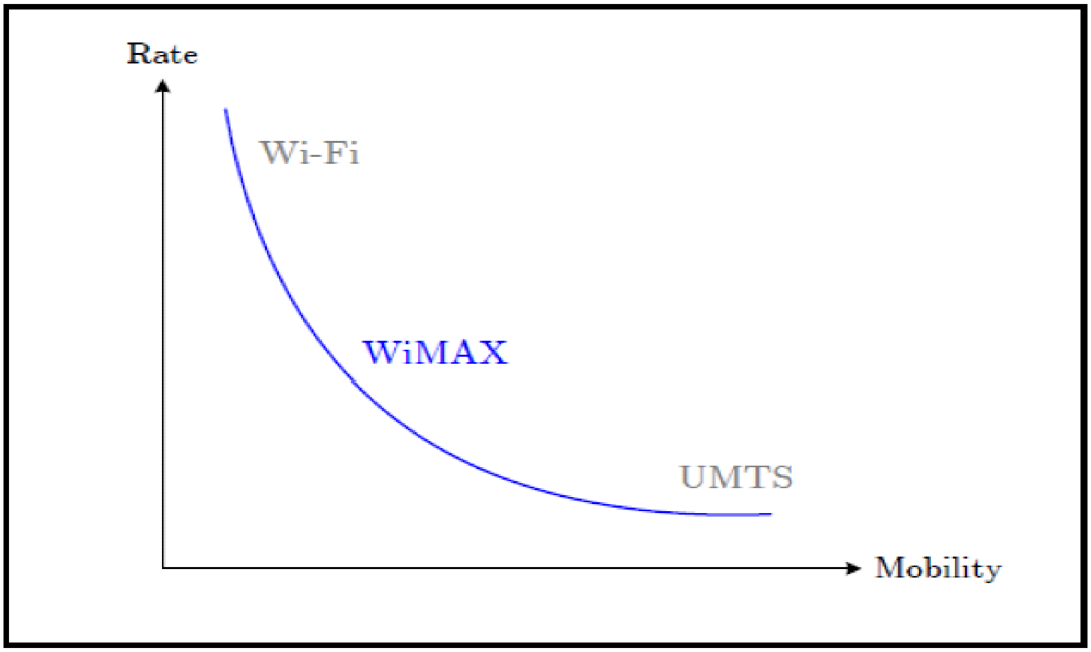


Figure 2.4 WiMAX fills the gap between Wi-Fi and UMTS.

2.9.4 WiMAX vs. LTE

WiMAX and LTE (Long Term Evolution) are two competitors to meet the requirements of 4G to the broadband services. Both depends on OFDM PHY layer but WiMAX standard is IEEE 802.16x while LTE depends on 3GPP (3G Partnership Project). 3GPP Release 8 has yet to be ratified as a standard and much of the standard will be oriented around upgrading UMTS to 4G. As for speeds, LTE will be faster than the current WiMAX, but, WiMAX with IEEE 802.16m that should be ratified in 2009 is fairly similar in speed. LTE test equipment has been shipping from several vendors since early 2008 and at the Mobile World Congress 2008 in Barcelona Ericsson demonstrated the world's first end-to-end mobile call enabled by LTE on a small handheld device. The performance and capabilities of WiMAX and LTE will only get better over time, and represent a direct competitive threat to the existing broadband services. The true battle is not between the competing 4G networks, but between wireless and wired broadband. Table 2.4 gives a comparison between WiMAX with IEEE802.16m and LTE with 3GPP.

Table 2.4 Comparison of WiMAX with LTE.

	WiMAX 802.16m	**LTE**
Network Equipment availability	2010	2009
Handset availability	2011	2010
Standard body	IEEE &WiMAX Forum	3GPP
Spectrum band plan	TDD, FDD	TDD , FDD
Frequency	Under 6 GHz	700 , 850 , 900 , 1800, 1900, 2100, 2500 MHz
Channel Bandwidth	5-20 MHz	1.4,1.6,3.5,10,15,20 MHz
Spectrum Type	Licensed	Licensed
Radio technology	OFDMA	OFDMA
Antennas	MIMO & Advanced Antenna Techniques	
Core Technology	Flat , All IP	Flat , All IP
Application	VoIP , Data , Video	VoIP , Data , Video
User plan Latency	< 5 ms	< 5 ms
Control Plane Latency	< 100 ms	< 100 ms

2.9.5 WiMAX vs. Ultra-Wide Band (UWB) Technology

As the name implies UWB, ultra wide band technology, is a form of transmission that occupies a very wide bandwidth. Typically this will be many Gigahertz, and it is this aspect that enables it to carry data rates of Gigabits per second. UWB technology offers many advantages, especially in terms of very high data transmission rates which are well beyond those possible with currently deployed technologies such as 802.11a, b, g, WiMAX and the like.

Ultra-wideband (UWB) technology is termed as such since it occupies large swathes of spectrum and uses very low power to communicate. UWB's intended use is in the 3-10 GHz bands for short range (>>10m) communications for implementing Wireless Personal Area Networks (WPAN). WiMAX, on the other hand, is the commercialization of the IEEE 802.16 standard and is meant to provide high speed wireless data services over a much wider area (>> 5 miles). The target bands for WiMAX deployment are the 2.4 GHz, 3.5 GHz and 5.8 GHz bands. The 3.5 GHz band is free in most countries except the United States. In fact, there is a big difference between WiMAX and UWB. WiMAX provides services for Metropolitan Area Network (MAN) but UWB is for Personal Area Network (PAN).

2.10 Elements in WiMAX Network

The following definitions are about WiMAX network components:

1. Customer Premises Equipment (CPE) basically refers to telephones, DSL modems or cable

modems, or purchased set-top boxes to communicate with service providers.

2. Backhaul, in telecommunications, refers to transporting traffic between distributed sites (access points) and central main networks.

3. Base Transceiver Station (BTS) is the equipment which establishes the wireless communication between user equipments and the network. User equipments are devices like mobile phones (handsets), WLL phones, computers with wireless internet connectivity, Wi-Fi (wireless adapters) and WiMAX chipset card. The network could be of any wireless communication technologies like GSM, CDMA, WLL, WAN, WiMAX, Wi-Fi. BTS is also known as RBS (Radio Base Station), or just BS (Base Station).

4. Date and network management refers to administration and maintenance of telecommunication networks at large scale.

Mainly WiMAX consists of two parts:

- A WiMAX tower, similar as used in a cell-phone tower - A single WiMAX tower can provide coverage to a very large area.
- A WiMAX receiver - The receiver and antenna could be a small box or PCMCIA card, or they could be built into a laptop like Wi-Fi.

A WiMAX tower station can connect directly to the Internet using a high-bandwidth, wired connection and it can also connect to another WiMAX tower using a LOS microwave link which is also called backhaul (look at Figure 2.5).

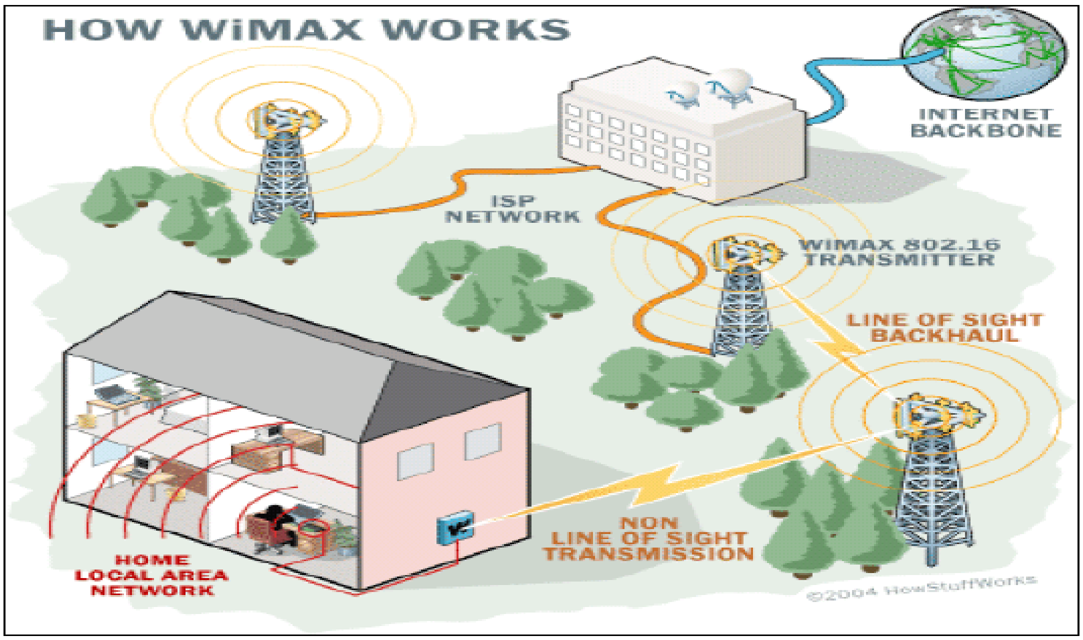


Figure 2.5 How WiMAX works

2.10.1 WiMAX Radios

At the core of WiMAX is the WiMAX radio. A radio is a device which consists of both transmitter and receiver and produces electrical oscillations at the carrier frequency (in WiMAX that is normally between 2 to 11 GHz). A radio is just like a router which is run and operated by a software and includes circuits boards containing complex chip sets. WiMAX architecture is built upon two components: radios and antenna. Most WiMAX products offer a base station radio separate from the antenna. Conversely, many CPE devices are also two piece solutions with an antenna on the outside of the building and subscriber station indoors. The chief advantage of this is that the radio is protected from extremes of heat, cold and humidity all of which detract from the radio's performance and durability. In addition, having the antenna outdoors optimizes the link budget between transmitter and receiver especially in LOS scenario. The antenna is connected to WiMAX radio via a cable known as a "pigtail" (see Figure 2.8)

2.10.1.1 Macro and Micro Base Station

The macro base station comprised of network, radio modules, power supply and power feeding modules. Macro base station are used when coverage is provided up to large areas while micro base stations are applicable for low density and rural areas. These base stations provide effective WiMAX solution to the service providers in their network installation. Figure 2.6 shows macro and micro base station elements.

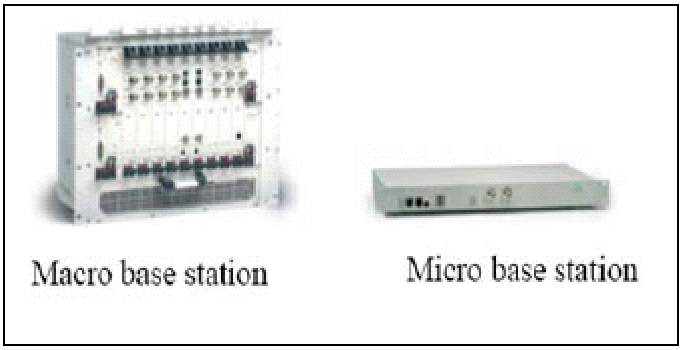


Figure 2.6 Macro and Micro base stations

2.10.1.2 WiMAX CPE

There are two main types of customer premises equipment one is indoor CPE (IDU) and other is outdoor CPE (ODU) , these both types support many features like :

- Self install and outdoor for extended coverage.
- Integrated smart card.
- Dual mode FDD/TDD software defined ratio.
- Data, voice, Wi-Fi, and E1/T1 interfaces.
- Full indoor NLOS deployment.
- For urban suburban and rural deployment scenarios.
- Multiple antenna options.
- Support for fixed and nomadic applications.
- Dynamic resource allocation protocol for quality voice services.
- 10 Mbps net throughput per CPE.
- SNMP management .

CPE includes following equipment (see Figure 2.7) :

- Broadband data IDU : It is the basic CPE unit which provides wireless connectivity. It connects subscriber or network with standard Ethernet interface.
- Networking gateway IDU : It includes advanced broadband integrated router with extensive IP sharing and security capabilities. It is a very good solution for both home and small business users.
- CPE ODU : CPE ODU contains the modern, radio, integral or external high gain flat antenna.
- Voice gateway IDU : It provides integrated voice and data services.

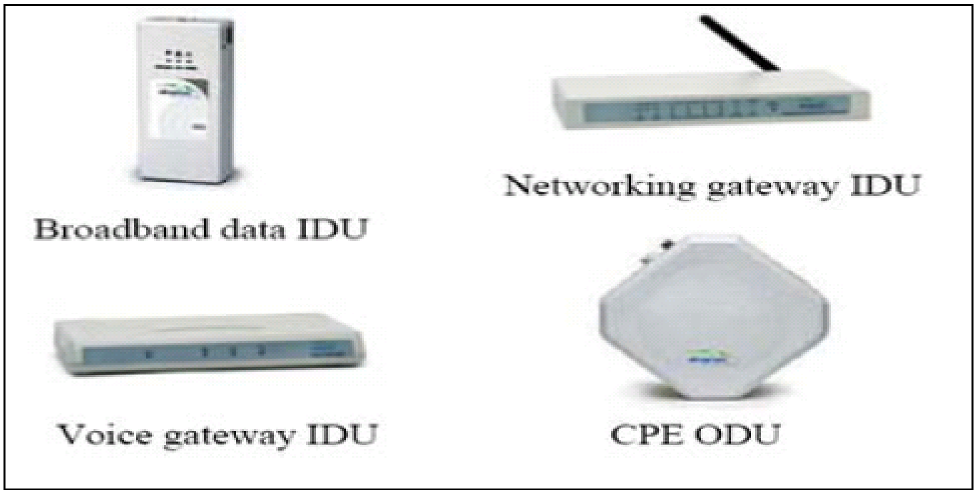


Figure 2.7 IDU elements

2.10.2 WiMAX Antennas

Antennas to be used with WiMAX are not defined in the standard, but have a crucial impact on the system operation especially in an interference rich environment. WiMAX antennas, just like the antennas for car radio, cell phone, FM radio, or TV, are designed to optimize performance for a given application. Figure 2.8 below illustrates three main types of antennas used in WiMAX deployments. WiMAX radio shown above is connected to the antenna via the "pigtail" cable.

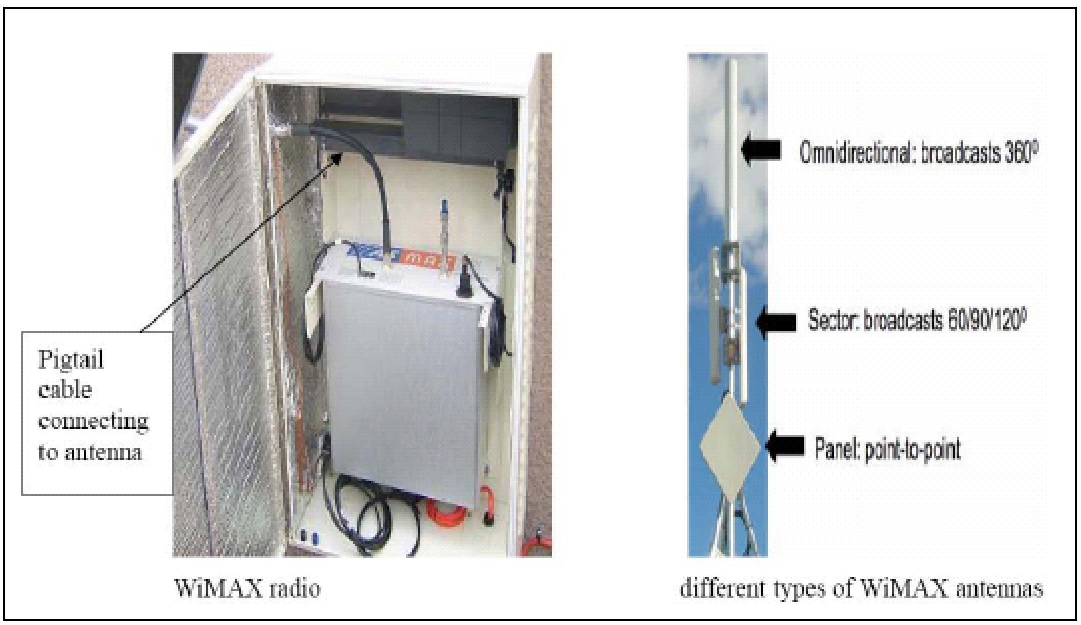


Figure 2.8 WiMAX radio and antenna

The types of WiMAX antennas are :
1. Omni directional Antenna (broadcast 360°).
2. Sector Antenna (broadcast 60°/90°/120°).
3. Panel antenna (point-to-point).

Omni directional antennas are used for point to multipoint configurations. The main drawback to an omni directional antenna is that its energy is greatly diffused in broadcasting 360°. This limits its range and ultimately signal strength. Omni directional antennas are good for situations where there are a lot of subscribers located very close to the base station. An example of omni directional application is a Wi-Fi hotspot where the range is less than 100 meters and subscribers are concentrated in a small area.

A sector antenna, by focusing the beam in a more focused area, offers greater and throughput with less energy. Many operators will use sector antennas to cover a 360-degree service area rather than use an omni directional antenna due to the superior performance of sector antennas over an omni directional antenna. The basic sectorization of the BTS provides some resistance against interference coming from directions other than that of the SS (Figure 2.9). Naturally, the more sectors we use, the better the protection. Typically a WiMAX base station covering the entire radius (360 degrees), uses e.g. three (120°) or four (90°) sector antennas.

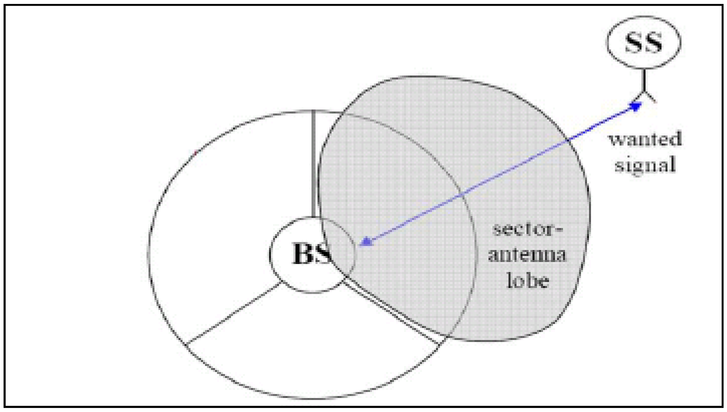


Figure 2.9 Sector antenna radiation pattern

Furthermore, by narrowing the lobe of the antenna vertically, we can reduce the harmful impact of interference coming for example from helicopters and other airborne jamming sources. For example, the sector antenna provided with the measured WiMAX system offers a gain of 16 dB. Other possibilities include high gain antennas (gain e.g. 50 dB), which are always aimed directly at the other part of the connection. This usually requires both the BS and the SS not to move in order to stay within the lobe of the antenna. Smart antennas, where radiation pattern can be constantly electrically modified, are an important research topic especially in the field of military communications. The process of controlling directionality of an antenna is generally called beamforming.
An effective means to exploit the spatial dimension is through the use of adaptive antenna arrays also referred to as *intelligent antennas* or *smart antennas*. To increase the range and reliability of WiMAX , the IEEE 802.16 standard supports technology which is multiple antenna techniques which of them are Alamouti Space Time Coding , Adaptive Antenna System and Multiple Input Multiple Output systems. Currently WiMAX supports several multiple antenna techniques in which includes Space time coding, Multiple input multiple output antenna systems and Adaptive Antenna System .

2.11 Applications of WiMAX

• **Backhaul Links:**
Long range and high-capacity backbone links for base stations regardless of access technology e.g. GSM, Wi-Fi etc.
• **Broadband Access:**
WiMAX base stations can directly provide mobile devices such as laptops and handheld with IP-based broadband connectivity in a range of 5 to 6 miles.
• **Extend the Corporate LAN:**
A single WiMAX base station can replace several scores of Wi-Fi hotspots thus reducing administration overhead.
• **Ad-hoc Networks:**
WiMAX can be used in disaster recovery scenes where the wired networks have broken down.

Figure 2.10 below shows the applications of WiMAX to provide Internet access over big geographical area.

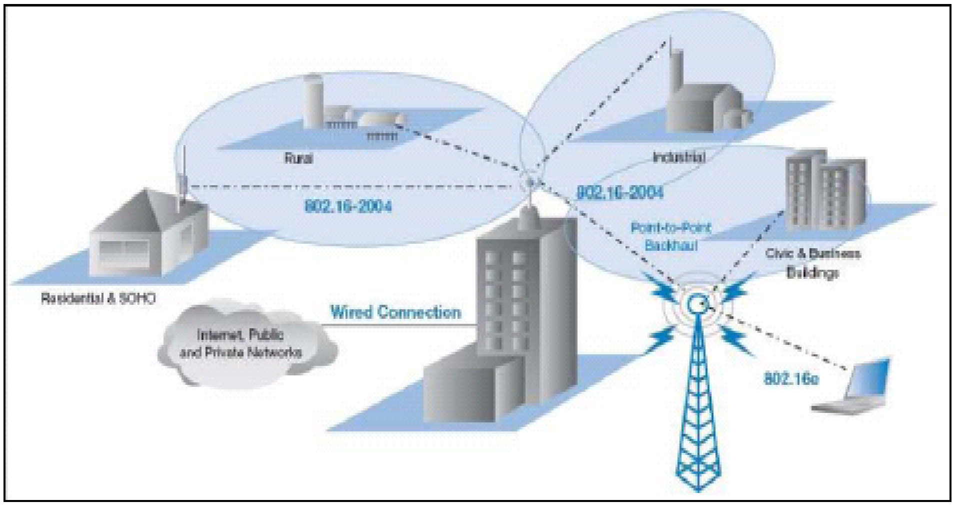


Figure 2.10 IEEE 802.16 applications

2.12 WiMAX Advantages and Drawbacks

Although the technology is new and yet there is lot more still to come but experts have already mentioned certain advantages of WiMAX technology, along with the advantages there is set of certain critics that have different views about WiMAX technology. This section will highlight certain advantages and disadvantages of WiMAX technology.

Some of the advantages of WiMAX technology are:

• **Long Range :** Perhaps the most significant advantage of WiMAX over other wireless technologies is the range it provides. WiMAX has a communication range of up to 30 miles. This can cover over 2800 square miles meaning that it is enough to cover a medium size city.

• **Higher Bandwidth** : Before WiMAX, the existing wireless technologies have various issues that are mostly related to the bandwidth. WiMAX provides data rates of 40 Mbps which makes WiMAX a perfect solution capable of replacing DSL and T1 services thus allowing a single base station to serve hundreds of users.

• **Low cost** : Although the cost to install a WiMAX base station would be around 20,000 $ but still it would be much less cheaper when it comes to the deployment of wireless network that is capable of providing services as those provided by T1 networks. The new addition of users in the network would cost less as compared to what seen in case of DSL based networks. The cost of some WiMAX installation projects are expected to be more than 80,000 $. According to, the total project cost of WiMAX installation at different educational institution in various campuses in Gaza strip in Palestine is expected to be about two million dollars.

On the other hand WiMAX do have certain drawbacks some of them are :

- **Power Sensitive :** WiMAX is basically a power sensitive technology, meaning that it heavily relies on strong electrical support.
- **LOS Requirement :** A Line of sight is required in order to make a wireless data communication connection extending over 6 miles or more.

Besides the above mentioned drawbacks, some other factors are also there that can affect WiMAX efficiency. As WiMAX is wireless communication technology so like all the other wireless technologies, its performance is also affected by changes in weather conditions such as rain, fog etc.
In the next section, challenges of deploying WiMAX are given including PAPR, multipath fading effects and phase noise.

2.13 Challenges of Deploying WiMAX

• **Peak to Average Power Ratio (PAPR) and Power Amplifier Linearity :**
OFDM has a high Peak to Average Power Ratio; an analysis of its waveform reveals rapid and large fluctuations in amplitude. This poses a costly challenge of designing a power amplifier with appropriate power back-off i.e. sensitive enough for low power levels, robust enough for high power levels without saturating and fast enough to track these changes. Several methods have been exploited to combat this effect such as clipping, and use of coding to create a more sublime spectrum.

• **Multi-path fading :**
One of the greatest challenges to wireless systems has been managing multi-path fading environments. Multi-path fading is the resulting signal degradation due to obstructions between a wireless transmitter and its intended destination. In a Non Light of Sight (NLOS) environment, a transmitted signal may bounce off of a myriad of obstacles including buildings, roads, and manmade structures as well as trees, hills, and natural occurring impediments. With each bounce, a separate instance of the signal makes it way to the destination receiver with a variation in time. The multiple, 'bounced' signal interfere with one another resulting in a degraded signal at the receiver.

• **Phase Noise :**
Local oscillators are usually based on VCO Phase Locked Loops, and each subcarrier is designed to be very narrow. Phase noise impairment on a subcarrier is more severe than a Single-carrier application because the bandwidth is very small.

Chapter 3
MC CDMA and OFDM

Recent advances in multimedia mobile communications have sparked much research in techniques that can deliver very high data rates. High data rate is really what broadband is all about. Traditional single carrier modulation techniques can achieve only limited data rates due to the restrictions imposed by the multipath channel and the receiver complexity. Multi-carrier techniques can provide high data rates at reasonable receiver complexities and are increasingly becoming popular in audio/video broadcasting, mobile local area networks and future generation wideband cellular systems. Since the PHY layer of WiMAX uses OFDM and MC-CDMA is proposed , in this thesis, to be used in WiMAX , the discussion, in this chapter, is about the principles of these two techniques.

3.1 Advantages of Multicarrier Modulation (MCM)

Before giving the definition and advantages of the multicarrier modulation, we will see the need for this system to reduce the effects of the channel in wireless systems.

Mobile radio channels introduce severe multipath propagation due to multiple scattering from objects in the vicinity of the mobile. This scattering introduces rapid fluctuation of the received signal envelope as well as phase variations. Measurements and theoretical analysis have shown that the envelope of the signal received is typically Rayleigh distributed. Also the motion of the mobile unit introduces a Doppler shift which causes a broadening of the signal spectrum. The multipath channel can also be frequency selective in which case the fading envelope of the received signal at one frequency might not be correlated with the envelope at another frequency. This is due to the fact that the symbol duration might be less than the maximum delay spread. The received signal consists of overlapping versions of the transmitted symbols, i.e. it suffers Inter Symbol Interference (ISI). Also, if we consider a cellular environment or military applications, there is the effect of co-channel interference due to the frequency reuse of the available spectrum. In addition to this, the received signal is subjected to large scale fading also called shadow fading due to propagation effects. Given these adverse effects of the mobile environment, it is necessary to look for intelligent transmission and reception techniques. In a conventional serial data transmission, the symbols are transmitted sequentially with the frequency spectrum of the each transmitted symbol occupying the entire bandwidth available. The delay spread due to the channel constrains the symbol duration or alternatively the data rate that can be achieved to prevent the effects of ISI .

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 3.1. Each subcarrier is separated by a guard band to ensure that they do not overlap with each other. we will see that FFT (IFFT) implements the operation of OFDM and, hence, no need of oscillators in the transmitter and receiver.

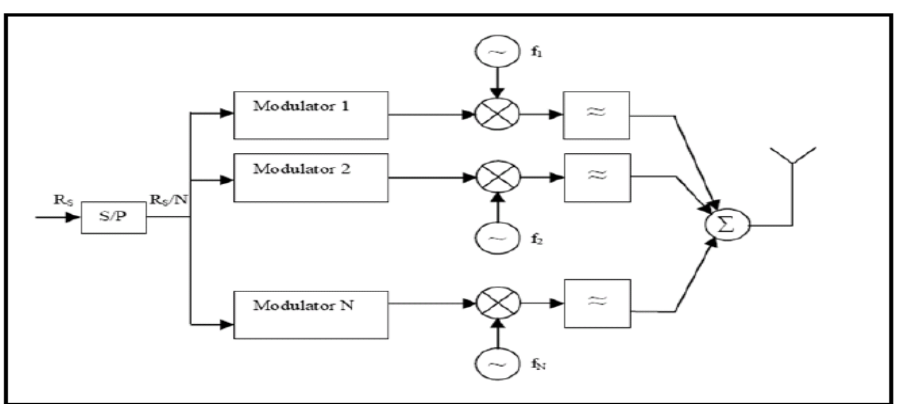


Figure 3.1 block diagram of a generic MCM transmitter.

In the receiver side, bandpass filters are used to separate the spectrum of individual subcarriers. This means that the multiple low data rate carriers are combined by a transmitter to form a composite high data rate signal. In the parallel transmission system several sequential streams of data are transmitted simultaneously. In the classical parallel transmission system, the available spectrum is split into several non-overlapping frequency sub channels. The individual data elements are modulated into these sub-channels and are thus frequency multiplexed.
The main advantage is that the parallel transmission increases the symbol time by modulating the symbols into narrow sub-channels. This increase in symbol time makes it more robust to the channel delay spread effects.
In modern wireless transmissions, the foremost method to combat the restrictions in data rates is to incorporate a technology used called OFDM, short for Orthogonal Frequency Division Multiplexing. OFDM is an FDM modulation technique for transmitting large amounts of digital data over a radio network. Figure 3.2 below shows the channel frequency response for a single carrier and multi carrier system

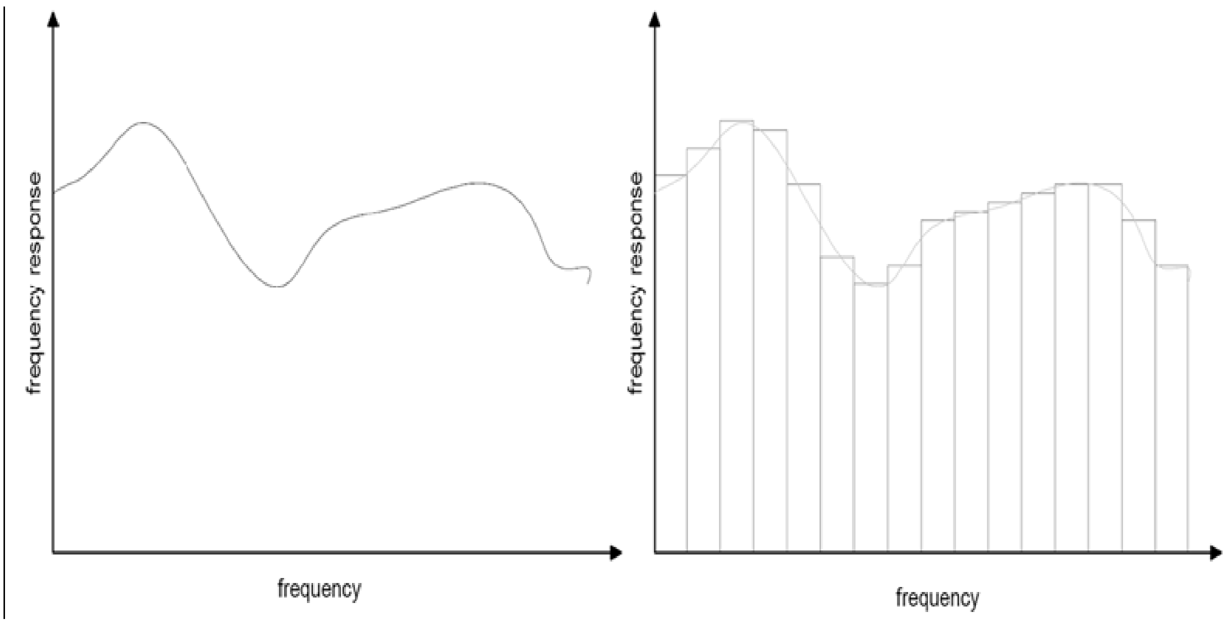


Figure 3.2 Channel frequency responses for a single and multi-carriers systems.

3.2 Orthogonal Frequency Division Multiplexing (OFDM)

In this section, we will discuss about the OFDM method and its design consideration

3.2.1 OFDM Basic

The idea of OFDM comes from Multi Carrier Modulation (MCM) transmission technique. OFDM is a special form of spectrally efficient MCM technique, which employs densely spaced orthogonal subcarriers and overlapping spectrums. The use of bandpass filters are not required in OFDM because of the orthogonality nature of the subcarriers. Hence, the available bandwidth is used very efficiently without causing the Inter-Carrier Interference (ICI). In Figure 3.3, to get OFDM system, 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 (will be defined in Chapter 4), 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, but it also introduces a loss in

SNR and data rate.

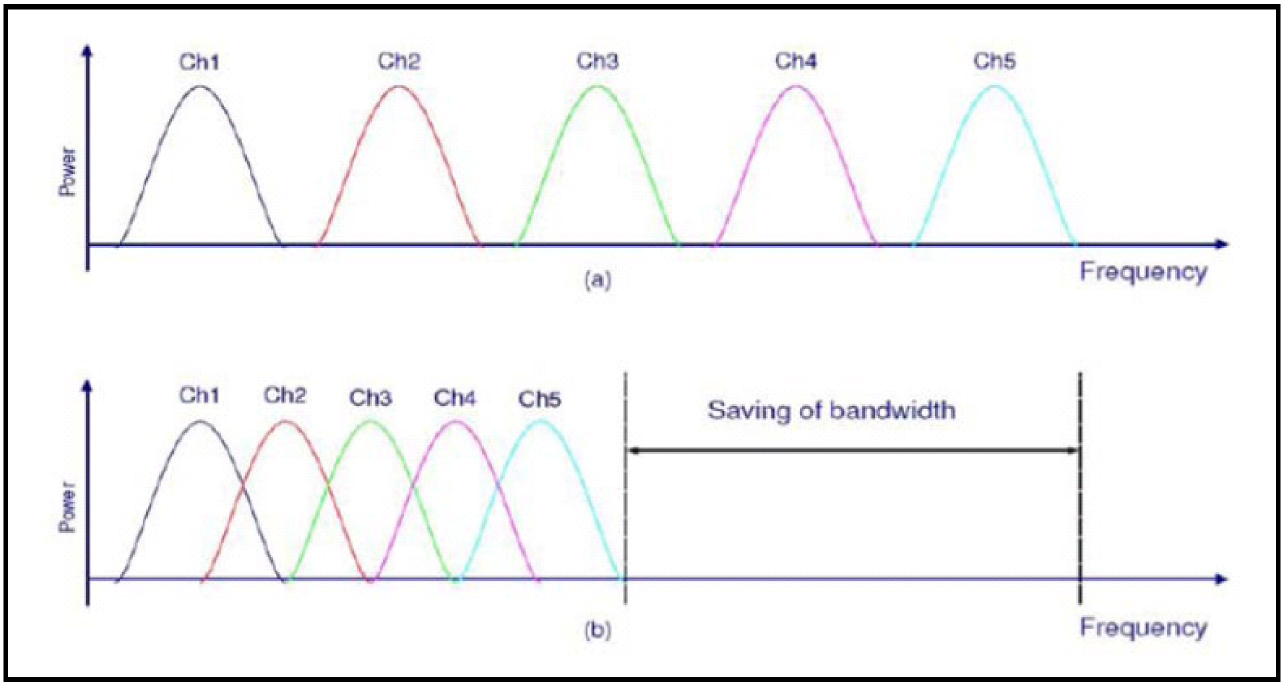


Figure 3.3 Comparison between conventional FDM and OFDM.

Figure 3.3 illustrates the difference between the conventional non overlapping multicarrier technique and the overlapping multicarrier modulation technique. As shown in Figure 3.3, by using the overlapping multicarrier modulation technique, we save almost 50 % of the bandwidth. The Figures 3.4 and 3.5, below, compare single carrier and OFDM signals

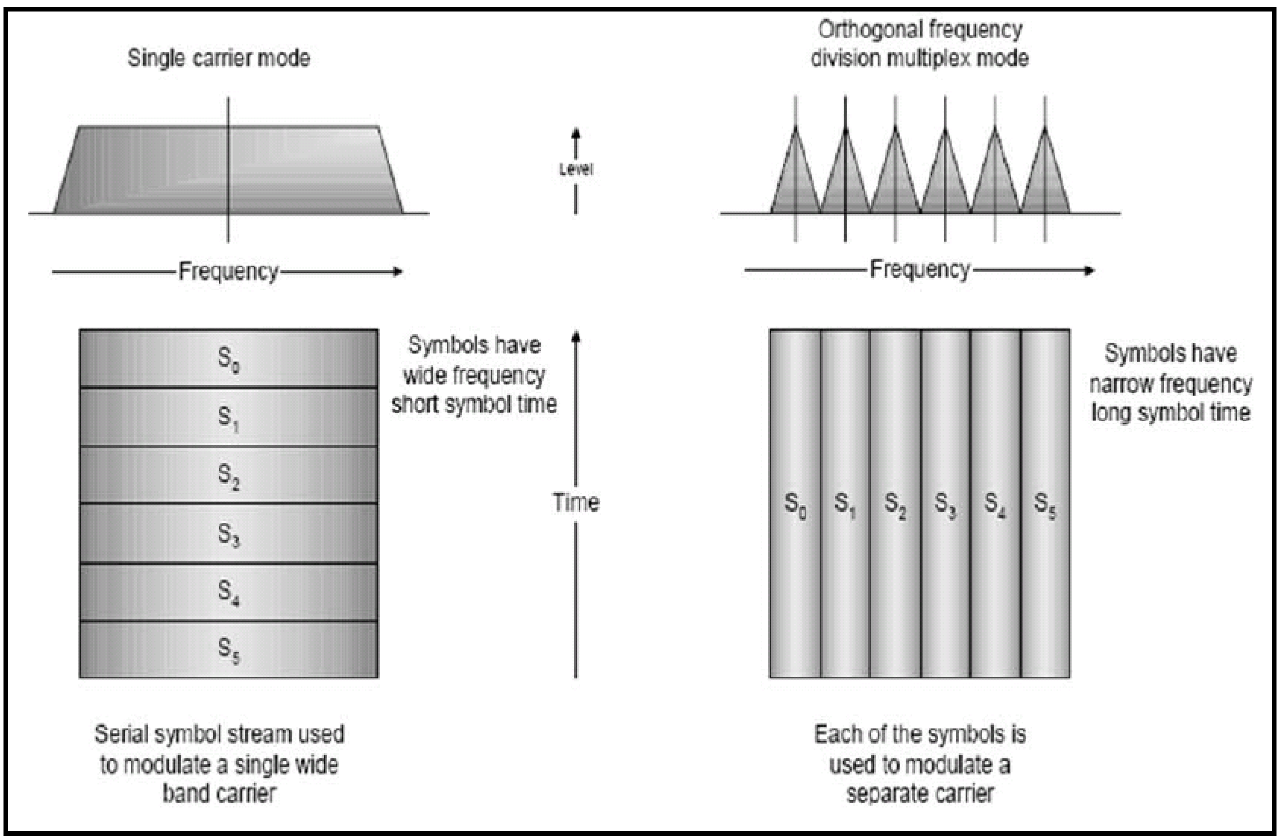


Figure 3.4 Single carrier and OFDM.

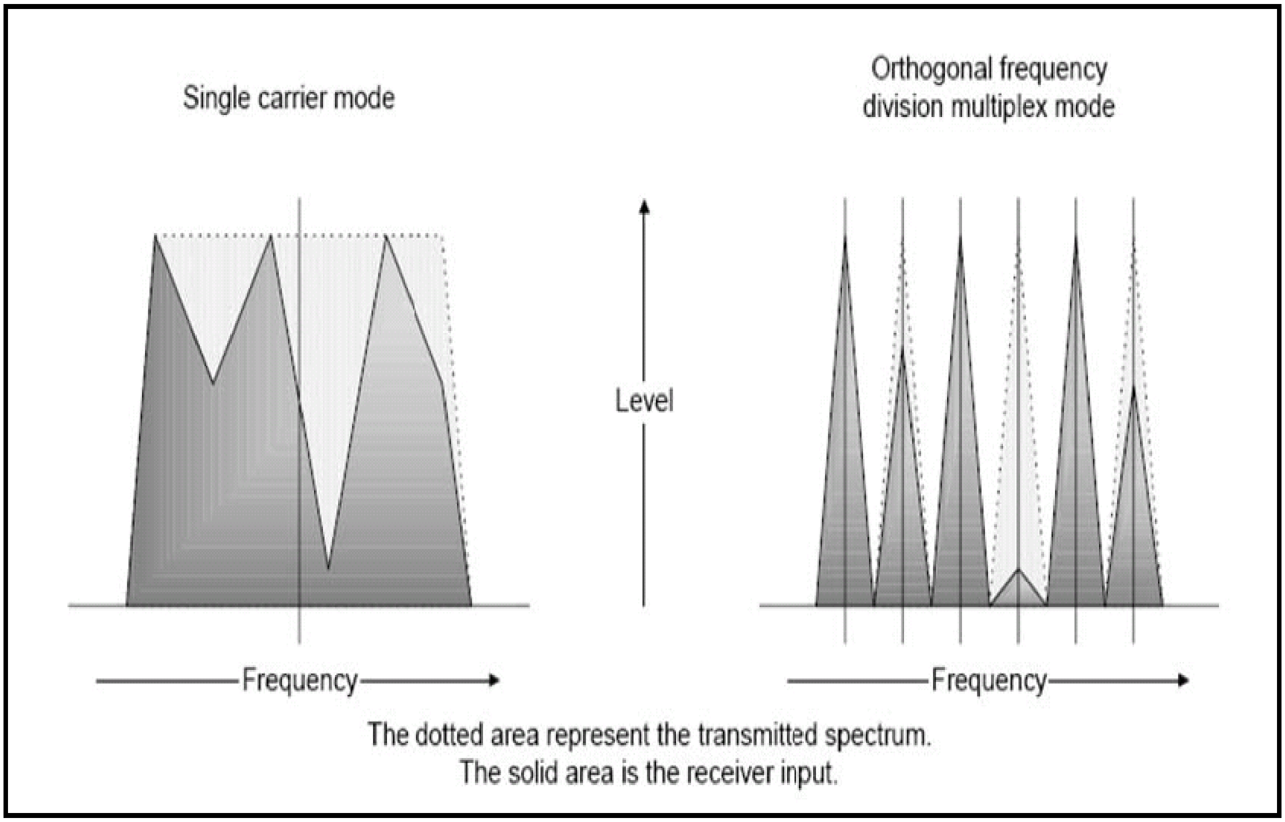


Figure 3.5 Single carrier and OFDM received signals.

3.2.2 Orthogonality of Signals

Signals are orthogonal if they are mutually independent of each other. Orthogonality is a property that allows multiple information signals to be transmitted perfectly over a common channel and detected, without interference. Loss of orthogonality results in blurring between these information signals and degradation in communications. Many common multiplexing schemes are inherently orthogonal. Time Division Multiplexing (TDM) allows transmission of multiple information signals over a single channel by assigning unique time slots to each separate information signal. During each time slot only the signal from a single source is transmitted preventing any interference between the multiple information sources. Because of this TDM is orthogonal in nature. In the frequency domain most FDM systems are orthogonal as each of the separate transmission signals are well spaced out in frequency preventing interference.

Although these methods are orthogonal, the term OFDM has been reserved for a special form of FDM. The subcarriers in an OFDM signal are spaced as close as is theoretically possible while maintain orthogonality between them. OFDM achieves orthogonality in the frequency domain by allocating each of the separate information signals onto different subcarriers. OFDM signals are made up from a sum of sinusoids, with each corresponding to a subcarrier. The baseband frequency of each subcarrier is chosen to be an integer multiple of the inverse of the symbol time, resulting in all subcarriers having an integer number of cycles per symbol. As a consequence, the subcarriers are orthogonal to each other. Figure 3.6 is an example depicts the construction of an OFDM signal with four subcarriers. Figure (1a), (2a), (3a) and (4a) are the subcarriers in the time domain , while (1b), (2b), (3b) and (4b) are the subcarriers in the frequency domain.

Figures (1a), (2a), (3a) and (4a) show individual subcarriers, with 1, 2, 3, and 4 cycles per symbol respectively. The phase on all these subcarriers is zero. Note that each subcarrier has an integer number of cycles per symbol, making them cyclic. Adding a copy of the symbol to the end would result in a smooth join between symbols. (1b), (2b), (3b) and (4b) show the FFT of the time waveforms in (1a), (2a), (3a) and (4a) respectively. (4a) and (4b) shows the result for the summation of the 4 subcarrier

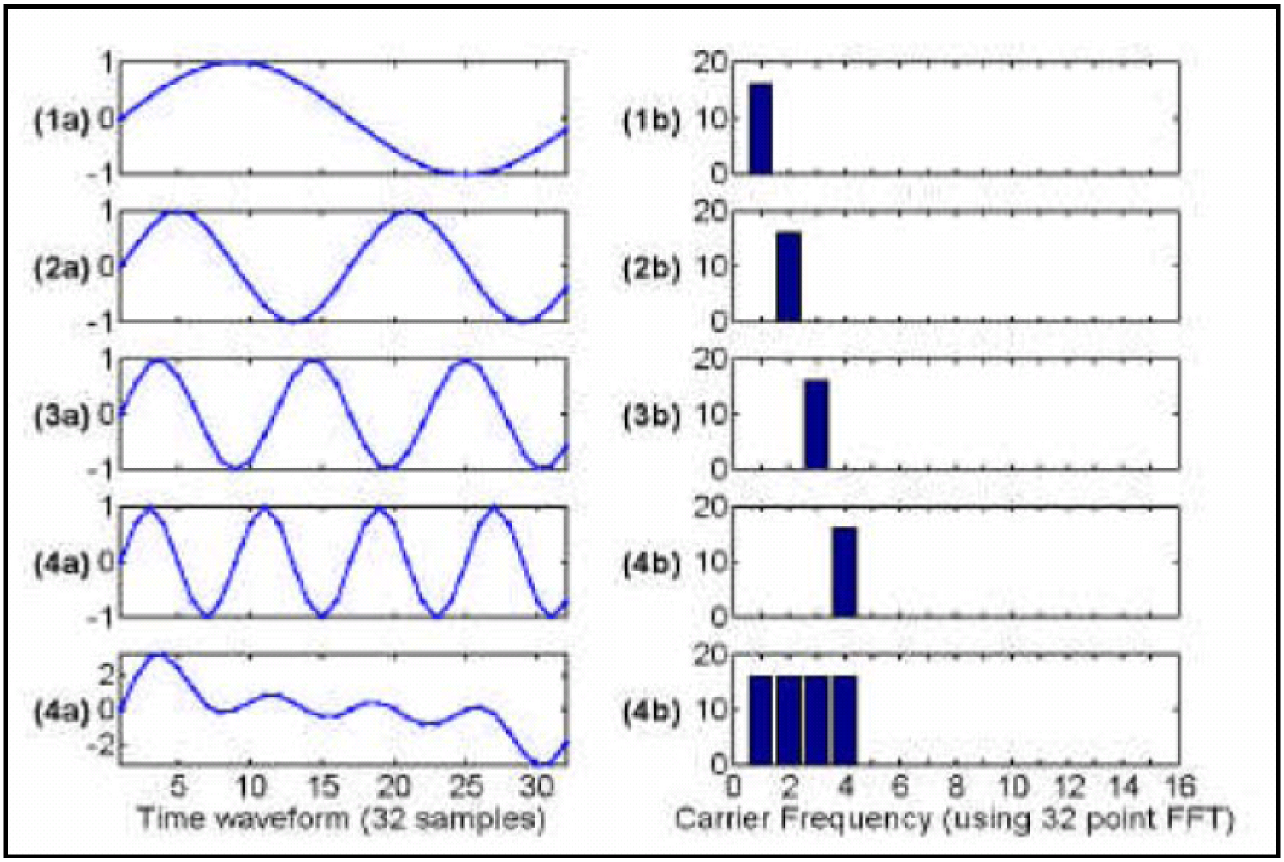


Figure 3.6 Time domain construction of an OFDM signal.

3.3 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 Fast Fourier transform and Inverse Fast Fourier transform (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 FFT and 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_c numbers of subcarriers are chosen for the system, the basic functions for the IFFT are N_c orthogonal sinusoids of distinct frequency and IFFT receive N_c symbols at a time. Each of N_c 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_c sinusoids and makes up a single OFDM symbol. The length of the OFDM symbol is N_cT_b where T_b is the IFFT input symbol period. In this way, IFFT block provides a simple way to modulate data onto N_c orthogonal subcarriers.

At the receiver side, The FFT block performs the reverse process on the received signal and bring it back to frequency domain. The block diagram in Figure 3.7 depicts the switch between frequency domain and time domain in an OFDM system.

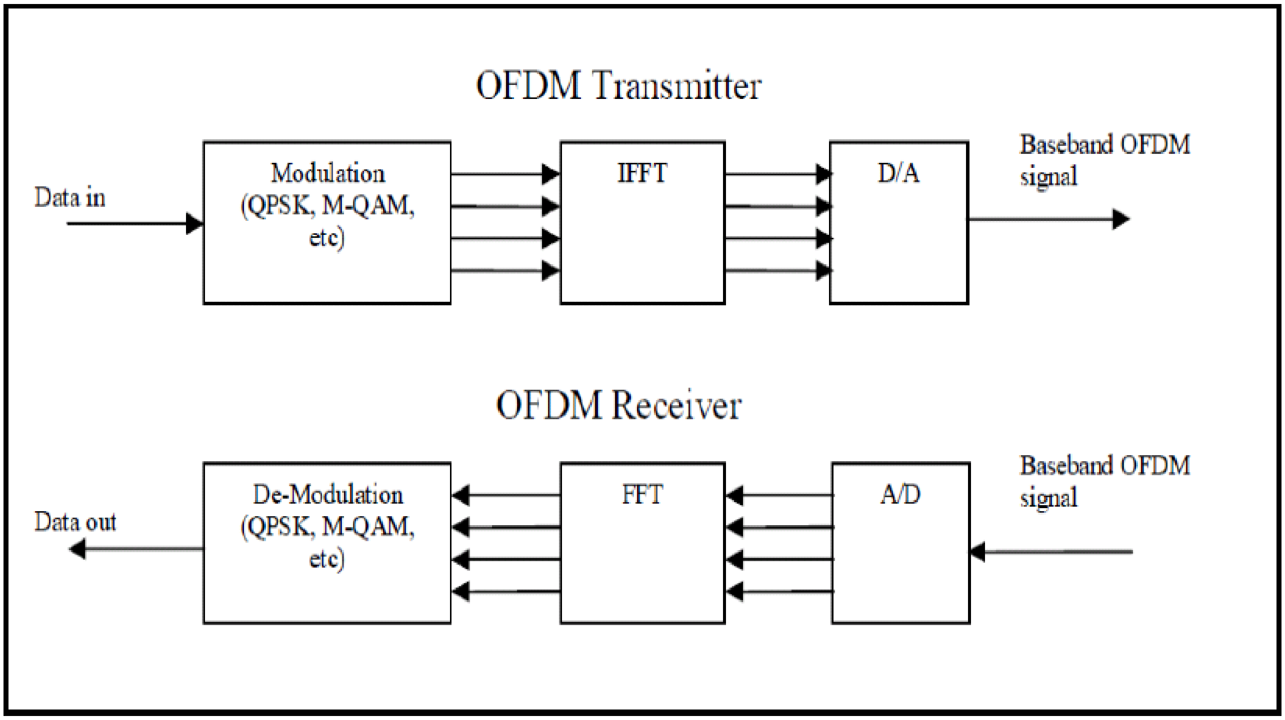


Figure 3.7 Basic OFDM transmitter and receiver.

IFFT performs the transformation from frequency domain to time domain in the transmitter while FFT converts from time domain to frequency domain in the receiver. FFT and IFFT have less number of calculations than DFT and IFFT, so the number of points must be chosen as a power of 2 (16, 64, 128, 256, 512, …etc.).

3.4 OFDM System Design Consideration

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 tradeoff between these two parameters must be done to obtain a reasonable system design.

3.4.1 OFDM System Design Requirements

OFDM system depends on the following four requirements :

- **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** : An 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.

3.4.2 OFDM System Design Parameters

The design parameters are derived according to the system requirements. Table 3.1 summarize the relations between OFDM parameters.

TABLE 3.1 OFDM Parameters.

Type	Parameter	Symbol or Formula
Primitive	Nominal Channel Bandwidth	BW
	Number of data Subcarriers	N_{data}
	Number of pilot Subcarriers	N_{pilot}
	Number of guard Subcarriers	N_{guard}
	Sampling Factor	n
	Ratio of Guard time to useful symbol time	G
Derived	Number of used Subcarriers , N_{used}	$N_{data} + N_{pilot}$
	N_{FFT} (smallest power of 2 greater than N_{used})	$2^{\lceil log_2 N_{data} \rceil}$
	Sampling Frequency, F_s	$\left\lfloor \frac{n.BW}{8000} \right\rfloor .8000$
	Subcarrier Spacing , Δf	$\frac{F_s}{N_{FFT}}$
	Used bandwidth, BW_{used}	$N_{used} \cdot \Delta f$
	Useful Symbol Time, T_b	$\frac{1}{\Delta f}$
	CP Time, T_g	$G \cdot T_b$
	OFDM Symbol Time, T_{sym}	$T_b + T_g$
	Sampling Time, T_s	$\frac{1}{F_s}$

The design parameters for an OFDM system are as follows:

- **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 depend 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. Adaptive modulation can be used to support the performance requirements in changing environment.
- **FEC coding**: A suitable selection of FEC coding will make sure the robustness of the channel to the random errors.

3.5 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 FFT.
- 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 a ccess(OFDMA).
- It is possible to use maximum likelihood detection with reasonable complexity.
- OFDM provides robustness against burst errors through the exploitation of frequency diversity schemes.
- OFDM provides less complex equalization as compared to the equalization in single carrier systems.
- OFDM provides effective robustness in multi-path environments.

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

- An OFDM system is highly sensitive to timing and frequency offsets.
- 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 .

Superposition of a large number of subcarrier signals results in a power density with Rayleigh distribution which has large fluctuations. OFDM transmitters therefore require power amplifiers with large linear range of operation which are expensive and inefficient. Any amplifier non-linearity causes signal distortion and inter-modulation products resulting in unwanted out-of-band power and higher BER

Although the PAPR is moderately high for OFDM, high magnitude peaks occur relatively rarely and most of the transmitted power is concentrated in signals of low amplitude, e.g. maximum PAPR for an OFDM system with 32 carriers and QPSK modulation will be observed statistically only once in 3.7 million years if the duration of an OFDM symbol is 100 μs . Therefore, the statistical distribution of the PAPR should be taken into account.

3.6 Application

OFDM has gained a big interest since the beginning of the 1990s as many of the implementation difficulties have been overcome. OFDM has been in use 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. 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 and ETSI HIPERLAN2 has employed OFDM as their PHY technologies. IEEE 806.16 standard for Fixed/Mobile BWA has also accepted OFDM for PHY technologies.

It is also possible to use OFDM for multiple-access too. This technique is called OFDMA and is implemented by providing each user with a small number of sub-carriers. Even though this technique is similar to FDMA, it avoids the use of large guard bands that are used to prevent adjacent channel interference.

3.7 The MC-CDMA Principle

Recently a new proposal for a system based on a combination of CDMA and OFDM has gained increasing attention in the research community. This system is called the Multi-Carrier CDMA (MC-CDMA) system and it combines the advantages offered by both OFDM and CDMA. This section describes the basic architecture and the advantages of this system .

Recent studies have combined CDMA with Orthogonal Frequency Division Multiplex (OFDM) to allow efficient use of available spectrum while retaining many advantages available in the CDMA system. This combination of OFDM-CDMA (MC-CDMA) is a useful technique for 4G systems where you need variable data rates as well as reliable communication systems. A MC-CDMA system applies the OFDM type of transmission to a Direct Sequence (DS)-CDMA signal.

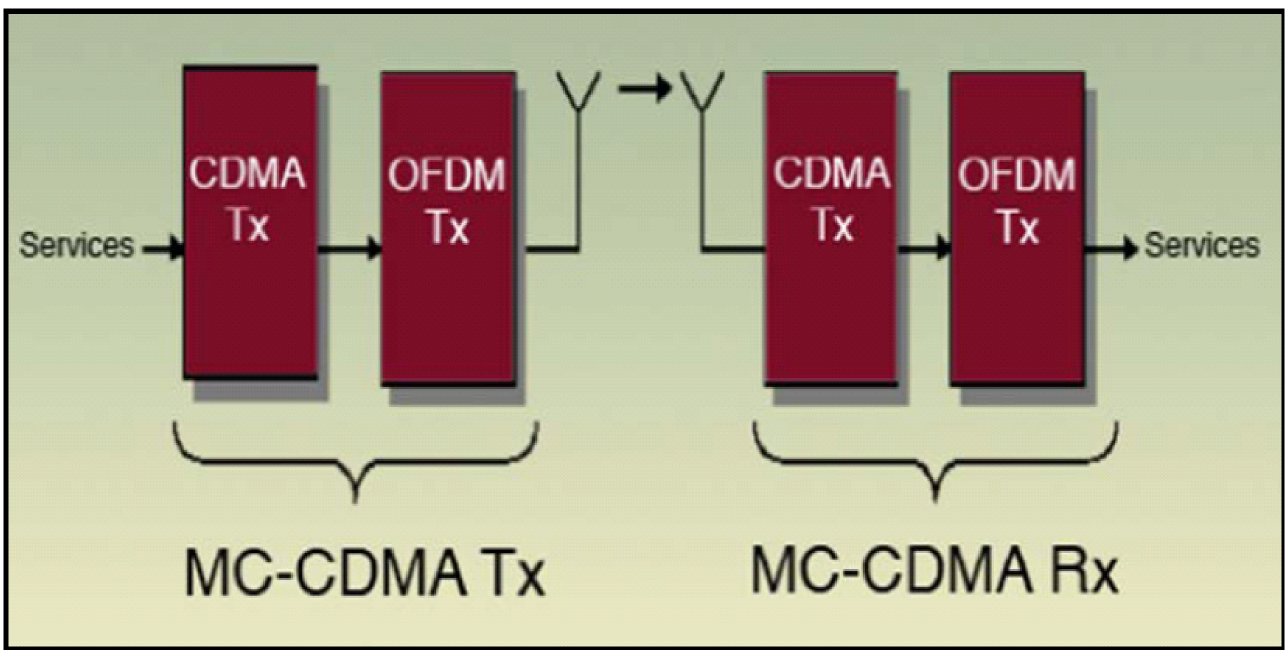


Figure 3.8Combining CDMA with OFDM

3.7.1 CDMA Basics

It is a digital cellular technology that uses the spread spectrum technique. Each channel uses the entire available spectrum. Each user is assigned a unique code sequence. Individual conversations are encoded with a pseudo-random digital sequence. The receiver, knowing the code sequences of

the user, decodes a received signal after reception and recovers the original data. This is possible since the cross correlations between the code of the desired user and the codes of the other users are small. CDMA consistently provides better capacity for voice and data communications compared to other commercial mobile technologies, allowing more subscribers to connect at any given time. It is no wonder then that it is the common platform on which 3G technologies are built. The advantages of CDMA are :
• No requirement for a specific time slot (as in TDMA) or frequency slot.
• Allows multiple access.
• Spreading the signal over a large spectrum reduces multipath fading.
• Offers high signal security.
• Is immune to interference and signal distortion.

3.7.2. Advantages of MC-CDMA

Combining OFDM with CDMA has a lot of advantages when compared to using DS-CDMA alone.
Some of them are discussed in this section :

- The transmitted symbol duration is much larger than the chip duration of DS-CDMA ,this makes the job of *synchronization* much easier.
- Provided there is an adequate guard interval provided, the *multi-path correction* in the form of Rake combining is not necessary.
- The OFDM-CDMA system provides inherent frequency diversity, since a single symbol is spread over a wide range of frequencies that may fade independently and a diversity combiner can be used to improve the fading performance of the system.
- Finally, it must be noted that all these advantages are in addition, to what is already offered by CDMA.

3.7.3 Applications

By making a hybrid combination of OFDM and CDMA, MC-CDMA enjoys the advantages of both systems. Main advantages include efficiency and flexibility in spectrum usage. This means that others users are allowed to use the spectrum or sub-carriers in the MC-CDMA design if it is not used by the current user.
However, it thus introduces complexity in the system in terms of assigning proper spreading codes and reassigning them to the correct users. Besides that MC-CDMA is robust to frequency selective fading. This is because the symbol period is larger than the delay spread resulting in no ISI. So you really need an equalizer.
The MC-CDMA has a uses simple transmitter and receiver designs with the addition and usage of FFT and IFFT. This opens the systems to a wide variety of applications. Capable of providing bit rates up to 100 Mbps, it is a leading candidate for 4G wireless communication systems. MC-CDMA can also be adopted effectively for critical real-time applications such as telemedicine and space communications.

3.7.4 MC-CDMA System Model

A MC-CDMA transmitter spreads the data signal using a given spreading code in the frequency domain. In other words, each chip of the signal is transmitted over a separate sub-carrier. In the MC-CDMA transmitter, as shown in Figure 3.9, the input data stream is first converted into a parallel symbol stream, using a serial to parallel converter. Each data symbol is spread using a spreading code. All the data in total, are now transmitted in parallel using OFDM. In the MC-CDMA receiver, as shown in Figure 3.10, after down-conversion, the sub-carrier components corresponding to the received users data is first coherently detected with the DFT and combined (using various diversity combining strategies) to yield the received data.

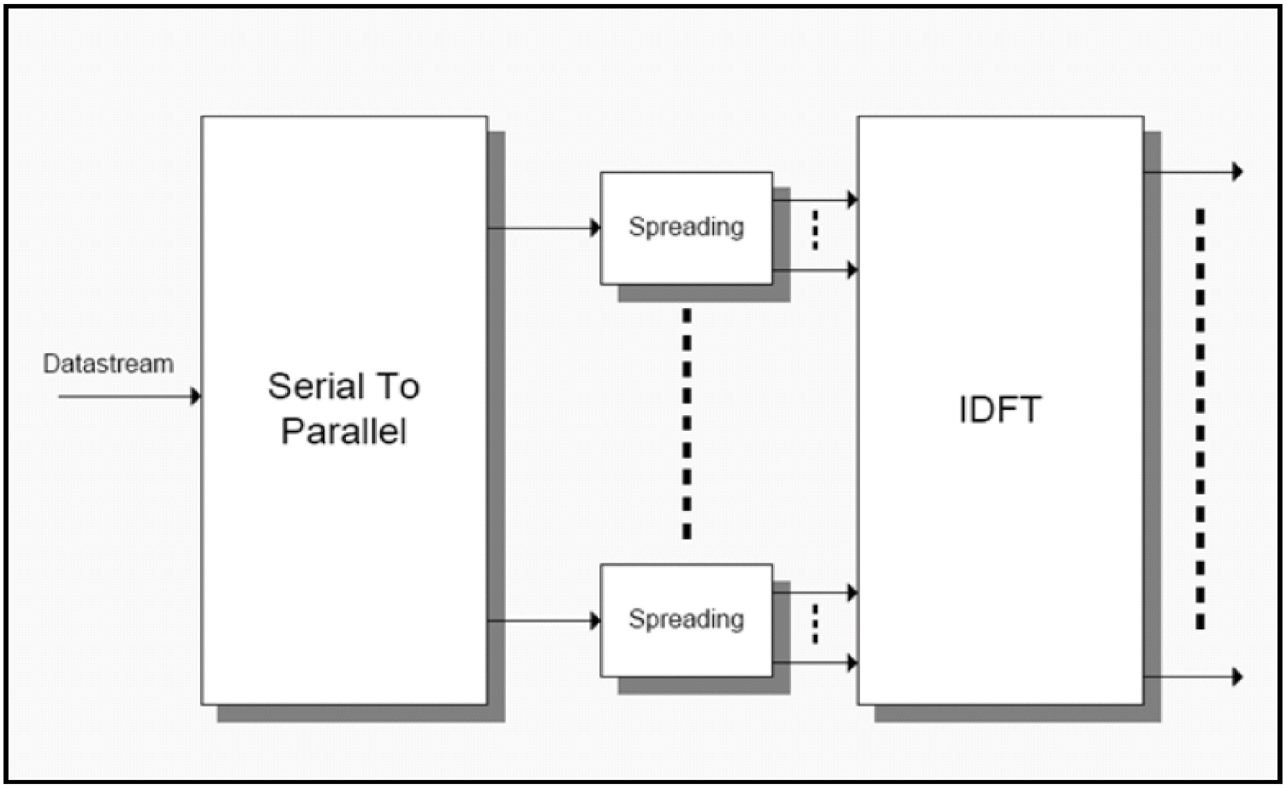


Figure 3.9 MC-CDMA transmitter

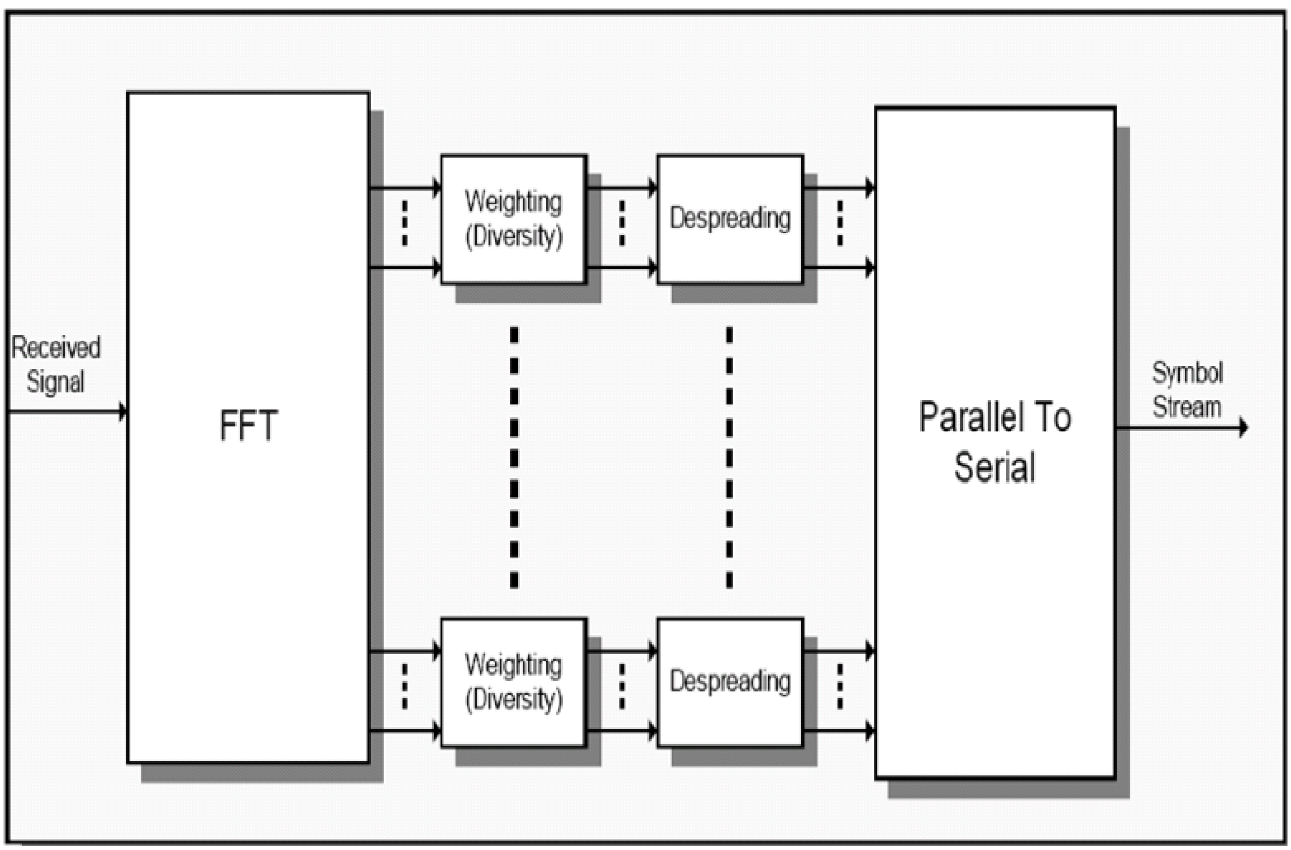


Figure 3.10 MC-CDMA receiver.

3.8 MC-CDMA System Implementation

A general block diagram of a multi-carrier transceiver employed in a cellular environment with a central base station (BS) and several terminal stations (TSs) in a point to multi-point topology is depicted in Figure 3.11 .

For the downlink, transmission occurs in the base station and reception in the terminal station and for the uplink, transmission occurs in the terminal station and reception in the base station. Although very similar in concept, note that in general the base station equipment handles more than one terminal station, hence, its architecture is more complex .

We note that the block diagram of the MC-CDMA transceiver, in Figure 3.11, contains the following :

1. Channel encoding / decoding
2. Symbol Mapper / demapper
3. Spreader / Despreader
4. Framing / Deframing
5. OFDM modulator / demodulator
6. D/A & A/D converters
7. Synchronization & channel estimation at the receiver.

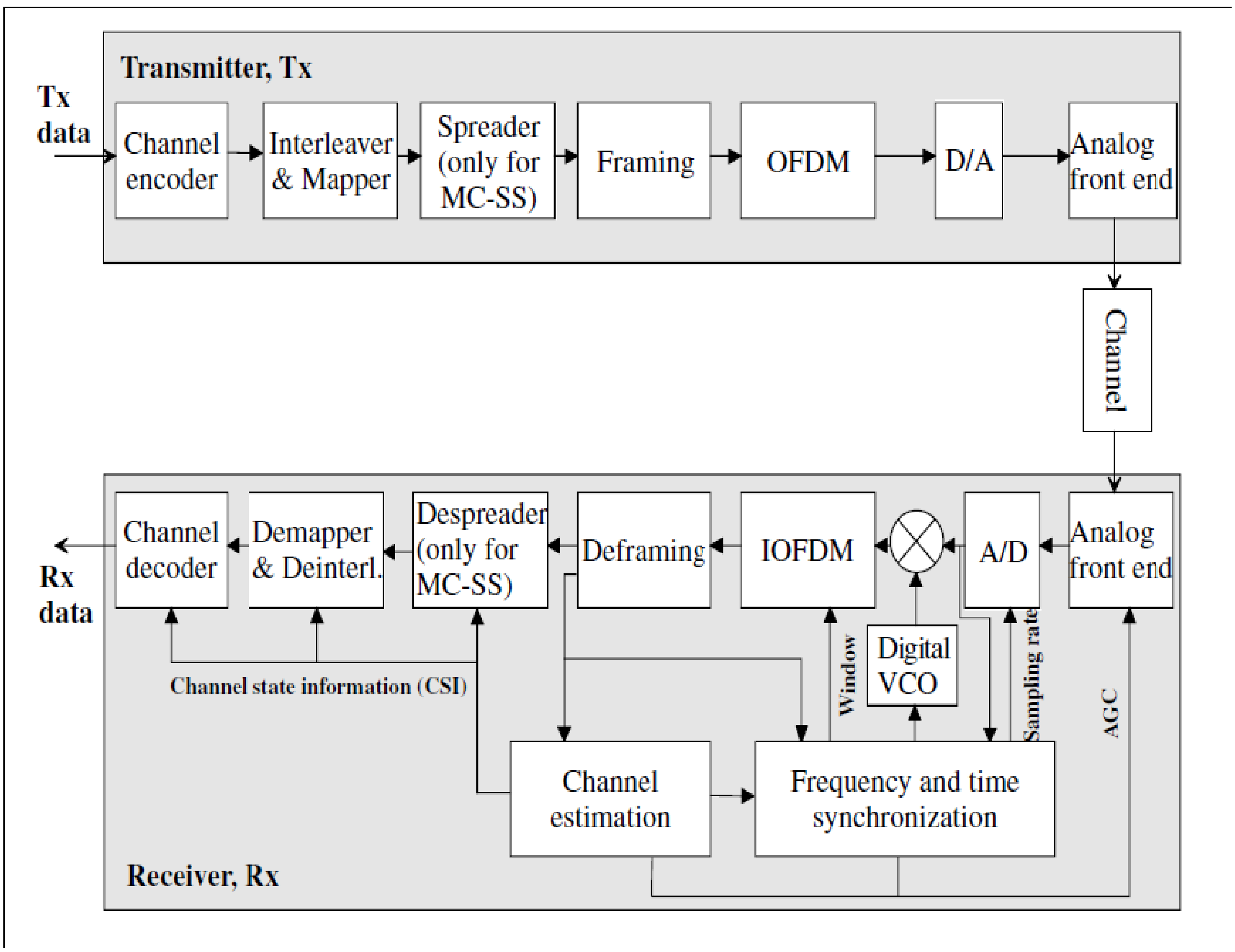


Figure 3.11 General block diagram of a multi-carrier transceiver .

The transmission operation starts with a stream of data symbols (bits, bytes or packets) sent from a higher protocol layer, i.e., the medium access control (MAC) layer. These data symbols are channel encoded, mapped into constellation symbols according to the designated symbol alphabet, spread (only in MC-SS) and optionally interleaved. The modulated symbols and the corresponding reference/pilot symbols are multiplexed to form a frame or a burst. The resulting symbols after framing or burst formatting are multiplexed and multi-carrier modulated by using OFDM and finally forwarded to the radio transmitter through a physical interface with digital-to-analog (D/A) conversion.

The reception operation starts with receiving an analog signal from the radio receiver. The analog-to-digital converter (A/D) converts the analog signal to the digital domain. After multi-carrier demodulation (IOFDM) and deframing, the extracted pilot symbols and reference symbols are used for channel estimation and synchronization. After optionally deinterleaving, despreading (only in the case of MC-SS) and demapping, the channel decoder corrects the channel errors to guarantee data integrity. Finally, the received data symbols (bits, bytes or a packet) are forwarded to the higher protocol layer for further processing.

Although the heart of an orthogonal multi-carrier transmission is the FFT/IFFT operation, synchronization and channel estimation process together with channel decoding play a major role. To ensure a low-cost receiver (low-cost local oscillator and RF components) and to guarantee a high spectral efficiency, robust digital synchronization and channel estimation mechanisms are needed. The throughput of an OFDM system not only depends on the used modulation constellation and FEC scheme but also on the amount of reference and pilot symbols spent to guarantee reliable synchronization and channel estimation.

Now, it is suitable to analyze the spreading codes that can be used in MC-CDMA system. Various spreading codes exist which can be distinguished with respect to orthogonality, correlation properties, implementation complexity and peak-to-average power ratio (PAPR). The selection of the spreading code depends on the scenario. In the synchronous downlink, orthogonal spreading codes are of advantage, since they reduce the multiple access interference compared to non-orthogonal sequences. However, in the uplink, the orthogonality between the spreading codes gets lost due to different distortions of the individual codes. Thus, simple PN sequences can be chosen for spreading in the uplink.

Chapter 4
Multipath Fading Channels

Understanding the characteristics of the communications medium is crucial for the appropriate selection of transmission system architecture, dimensioning of its components, and optimizing system parameters, especially since mobile radio channels are considered to be the most difficult channels, since they suffer from many imperfections like multipath fading, interference, Doppler shift, and shadowing. The choice of system components is totally different if, for instance, multipath propagation with long echoes dominates the radio propagation. Due to imperfections of the wireless channel noise, inter-symbol interference and co-channel interference are introduced, which causes errors in the transmission and degrades the quality of wireless communications .
Therefore, an accurate channel model describing the behavior of radio wave propagation in different environments such as mobile/fixed and indoor/outdoor is needed. This may allow one, through simulations, to estimate and validate the performance of a given transmission scheme in its several design phases. One of the main problems faced by the wireless networks is deal with the environmental challenges once the signal is on air from its way towards the receiver. So in this chapter, the immense challenges presented by time-varying broadband wireless channels are presented in addition to channel models.

4.1 Propagation Characteristics of Mobile Radio Channels

The mobile radio channel is assumed to be a time-variant, frequency-selective fading channel. It is modeled by a tapped delay line with non-zero taps .
In an ideal radio channel, the received signal would consist of only a single direct path signal, which would be a perfect reconstruction of the transmitted signal. However in a real channel, the signal is modified during transmission in the channel. The received signal consists of a combination of attenuated, reflected, refracted, and diffracted replicas of the transmitted signal (see Figure 4.1). On top of all this, the channel adds noise to the signal and can cause a shift in the carrier frequency if the transmitter, or receiver is moving (Doppler effect). Understanding of these effects on the signal is important because the performance of a radio system is dependent on the radio channel characteristics

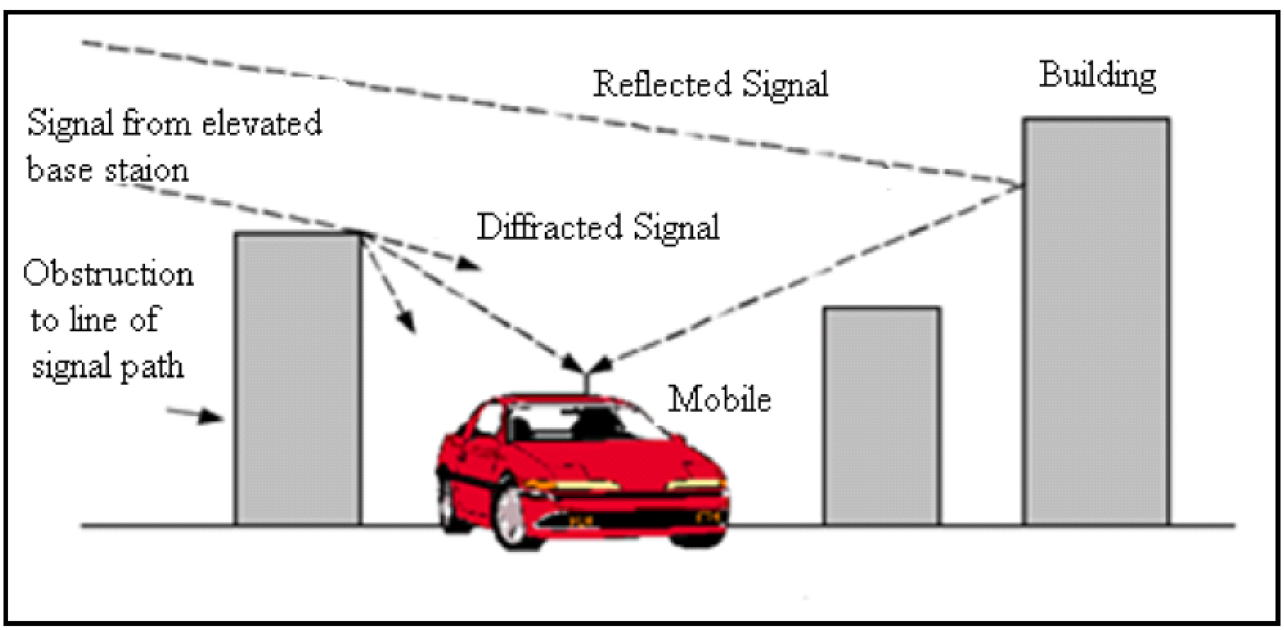


Figure 4.1 Radio Propogation effects.

In order to evaluate the performance of the developed communication system, an accurate description of the wireless channel is required to address its propagation environment. The radio architecture of a communication system plays very significant role in the modeling of a channel. The wireless channel is characterized by :

1. Path loss (including shadowing)
2. Multipath delay spread
3. Fading characteristics
4. Doppler spread
5. Co-channel and adjacent channel interference

All the model parameters are random in nature and only a statistical characterization of them is possible, i.e. in terms of the mean and variance value. They are dependent upon terrain, tree density, antenna height and beam width, wind speed and time of the year. The previous factors are explained in the following sections.

4.1.1 Path loss and Shadowing

When an electromagnetic wave propagates through a free space, there is a reduction in the power density of the wave, which results in path loss or signal attenuation. The simplest channel is the free space line of sight channel with no objects between the receiver and the transmitter or around the path between them. In this simple case, the transmitted signal attenuates since the energy is spread spherically around the transmitting antenna.

Path loss indicates how the mean signal power decays with distance between transmitter and receiver. Theoretically, the power falls off in proportion to the square of the distance. In practice, the power falls off more quickly, typically 3^{rd} or 4^{th}power of distance .

In a mobile radio channel, where often no line of sight (LOS) path exists, signal power decreases with a power higher than two and is typically in the order of three to five. Shadowing is caused by obstruction of the transmitted waves by, e.g., hills, buildings, walls, and trees, which results in more or less strong attenuation of the signal strength. Compared to *fast fading*, shadowed areas tend to be large, resulting in the rate of change of the signal power being slow. For this reason, it is termed *slow-fading*, or *log-normal shadowing*.

To overcome the problem of shadowing, transmitters are usually elevated as high as possible to minimize the number of obstructions. Typical amounts of variation in attenuation due to shadowing are shown in Table 4.1.

There are certain factors which affect path loss such as terrain contours, different environments, propagation medium, distance between the transmitter and the receiver, the height and location of their antennas, etc. Path loss is a major component that plays a vital role in analysis and design of the link budget. So it is not considered in our model.

TABLE 4.1 Typical shadowing in radio channel

Description	Typical Attenuation due to shadowing
Heavily built-up urban centre	20 dB variation from street to street
Sub-urban area (fewer large buildings)	10 dB greater signal power than built-up urban center
Open rural area	20 dB greater signal power than sub-urban areas
Terrain irregularities and tree foliage	3-12 dB signal power variation

4.1.2 Multipath Delay Spread

Due to the non line of sight (NLOS) propagation nature of the wireless channels, we have to address multipath delay spread in our channel model. It results due to the scattering nature of the environment.

Multipath propagation occurs as a consequence of reflections, scattering, and diffraction of the transmitted electromagnetic wave at natural and man-made objects. Thus, at the receiver antenna, a multitude of waves arrives from many different directions with different delays, attenuations, and phases. The superposition of these waves results in amplitude and phase variations of the composite received signal.

Delay spread is a parameter used to signify the effect of multipath propagation. It depends on the terrain, distance, antenna directivity and other factors. The rms delay spread value can span from tens of nano seconds to microseconds.

The previous key components of the channel response , path loss, shadowing, and multipath effect are shown clearly in Figure 4.2, where Pt and Pr are the transmitted and received power respectively . The thick dashed line represents the path loss. The lognormal shadowing changes the total loss to that shown by the thin dashed line. The multipath finally results in variations shown by the solid thick line. Note that signal strength variations due to multipath change at distances (d) in the range of the signal wavelength .

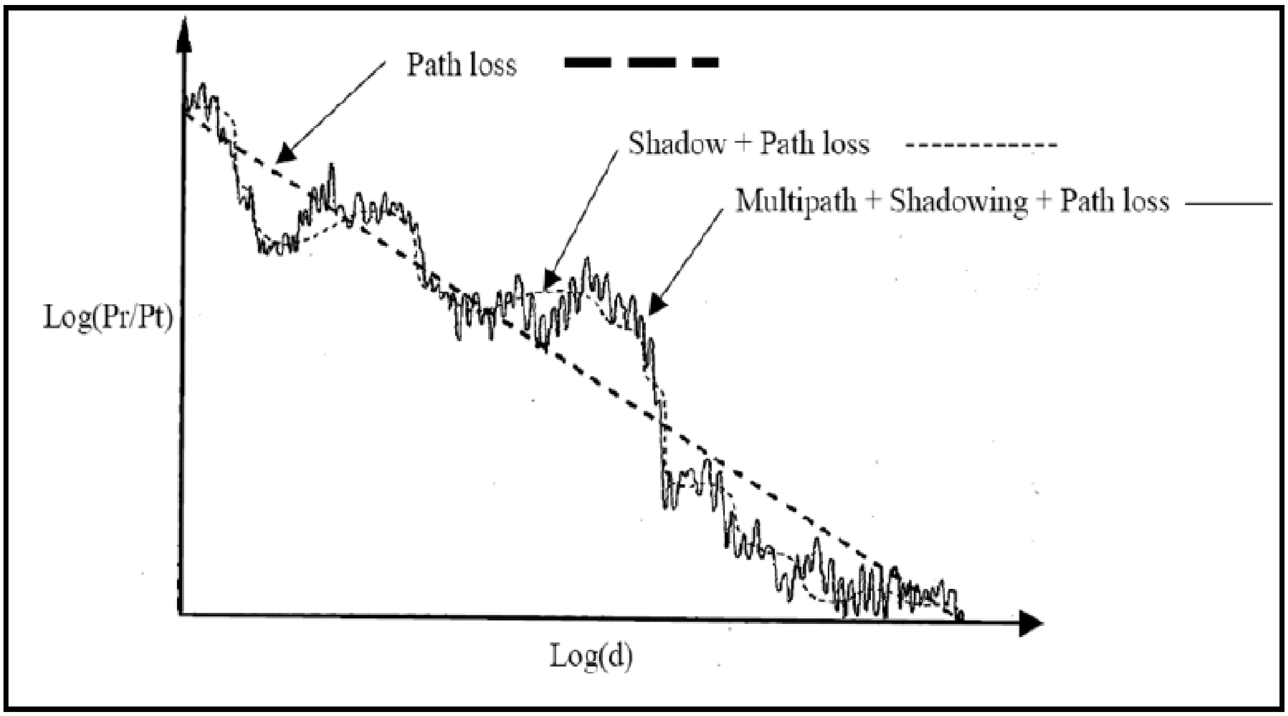


Figure 4.2 Path loss, shadowing, and Multipath

4.1.3 Multipath Fading Characteristics

Fading is rapid changing in signals amplitude , phase and frequency. This effect is caused by the random nature of the wireless propagation channel. More importantly in a wireless channel , a signal can travel over multiple paths between transmitter and receiver and can contribute to *multi path fading* . Main types of radio channels fading are classified in Figure 4.3

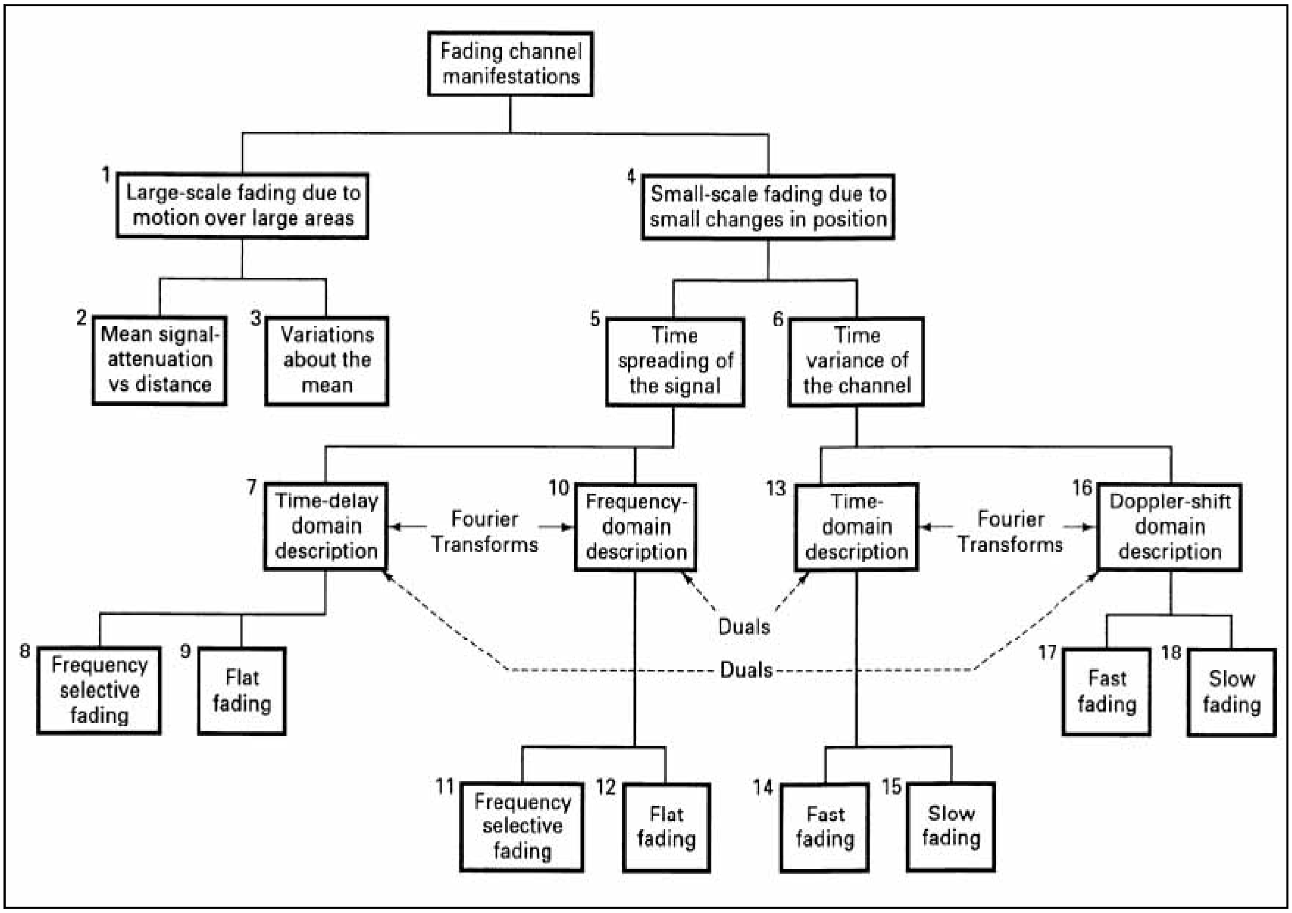


Figure 4.3 Types of fading in wireless channel

Small scale fading refers to the dramatic changes in signal amplitude and phase that can be experienced as a result of small changes (as small as a half wavelength) in the spatial positioning between a receiver and a transmitter.

Small scale fading is called *Rayleigh fading* if there are multiple reflective paths that are large in number and there is no line of sight signal component. The envelope of such a received signal is statistically described by a *Rayleigh* probability density function (pdf). When a dominant non fading signal component is present, such as a line of sight propagation path, the small scale fading envelope is described by a *Rician* pdf .

In other words, the small scale fading statistics are said to be Rayleigh whenever the line of sight path is blocked, and Rician otherwise. The key parameter of Rician distribution is the K factor, defined as the ratio of the direct component power and the scatter component power.

On the other hand, long-term variation in the mean signal level is called *large-scale fading*. The latter effect is a result of movement over distances large enough to cause gross variations in the overall path between the transmitter and the receiver.

Large-scale fading is also known as *shadowing*, because these variations in the mean signal level are caused by the mobile unit moving into the shadow of surrounding objects like buildings and hills.

Small-scale fading can be further classified as *flat* or *frequency selective*, and *slow* or *fast*. A received signal is said to undergo *flat fading*, if the mobile radio channel has a constant gain and a linear phase response over a bandwidth larger than the bandwidth of the transmitted signal. Under these conditions, the received signal has amplitude fluctuations due to the variations in the channel gain over time caused by multipath. However, the spectral characteristics of the transmitted signal remain intact at the receiver.

On the other hand, if the mobile radio channel has a constant gain and linear phase response over a bandwidth smaller than that of the transmitted signal, the transmitted signal is said to undergo *fre-*

quency selective fading.
In this case, the received signal is distorted and dispersed, because it consists of multiple versions of the transmitted signal, attenuated and delayed in time. This leads to *time dispersion* of the transmitted symbols within the channel arising from these different time delays resulting in *intersymbol interference* (ISI).
When there is relative motion between the transmitter and the receiver, *Doppler spread* (will be discussed later) is introduced in the received signal spectrum, causing *frequency dispersion*. If the Doppler spread is significant relative to the bandwidth of the transmitted signal, the received signal is said to undergo *fast fading*. This form of fading typically occurs for very low data rates. On the other hand, if the Doppler spread of the channel is much less than the bandwidth of the baseband signal, the signal is said to undergo *slow fading*.

4.1.4 Doppler Spread

The *Doppler frequency* is basically due to the movement of the communicating devices or due to the relative motion of objects in the environment. This change of transmitted signal frequency occurs because the distance between the transmitter and the receiver changes over time. Due to Doppler effect of the wireless channel ,when a wave source and a receiver are moving relative to one another, the frequency of the received signal will not be the same as the source frequency. When they are moving toward each other the frequency of the received signal is higher than the source, and when they are approaching each other the frequency decreases. This is called the *Doppler effect*. An example of this is the change of pitch in a car's horn as it approaches then passes by. This effect becomes important when developing mobile radio systems. The Doppler frequency is primary influenced by wind speed and traffic density .
In fixed wireless access, a Doppler frequency shift is induced on the signal due to movement of the objects in the environment. Doppler spectrum of fixed wireless channel differs from that of mobile channel. It is found that the Doppler is in the 0.1-2 Hz frequency range for fixed wireless channel. The shape of the spectrum is also different than the classical Jake's spectrum for mobile channel. **.**
The Doppler shift in frequency can be given by :

$$f_d = f_c\,(v/c)\cos(\alpha_n) \qquad (4.1)$$

where :
f_d : frequency shift (Doppler frequency)
f_c : carrier frequency of the transmitted signal
v : the speed difference between the source and transmitter
c : the speed of light (3×10^8)
α_n: angle value of arrival wave with horizontal plane

4.1.5 Spatial Characteristics, Coherence Distance

Coherence distance is the minimum distance between points in space for which the signals are mostly uncorrelated. This distance is usually grater than 0.5 wavelengths, depending on antenna beamwidth and angle of arrival distribution. At the BTS, it is common practice to use spacing of about 10 and 20 wavelengths for low-medium and high antenna heights, respectively (120^{o}sector antennas). Channel characteristics and measurement parameters including channel spread, channel selectivity and measure of selectivity are summarized in Table 4.2 .

TABLE 4.2 Channel characteristics and measurement parameters.

Channel spread	Channel Selectivity	Measure of selectivity
Delay Spread	Frequency Selective	Coherence Bandwidth
Doppler spread	Time Selective	Coherence Time
Angle Spread	Space Selective	Coherence Distance

A long with the above discussion, *co-channel interference* and *antenna gain reduction factor* should be addressed for channel modeling. Co-channel interference is illustrated in the following section.

4.1.6 Co-Channel Interference

One of the main obstacles that engineers have to deal with during wireless communication scenario is co-channel interference. It occurs when a same frequency from two different transmitters reaches the same receiver simultaneously, thus creating problem for the receiver to determine that the signal actually came from which user.
Earlier on broadcast antennas were used with lot of signals being scattered thus resulting in wastage of signal strength and bandwidth so with the passage of time research was made on the use of more focused antennas (sectorized antenna).
However problem with both these approaches were that signal intended for one user present in a cell could cause interference for the other user present in same or adjacent cell. Thus the use of sectorized antennas although increase the use of bandwidth by resulting in increase in number of channels, however they were still not effective in dealing with co-channel interference problem as the use of sectorized antenna promotes the co-channel interference.
To deal with this problem of co-channel interference smart antennas are used. Smart antennas provide strong resistance against co-channel interference by throwing NULL towards unwanted users and directing a beam towards the desired user, thus resulting in increased bandwidth and signal strength.

4.2 Wireless Channel Modeling

In order to design and analyze wireless communication systems, channel models should be developed that incorporate their variations in time, frequency and space. A channel model basically predicts what will happen to the transmitted signal while in transit to the receiver. Actual environments are too complex to model accurately but we can model approximately a specific channel scenario by appropriate model. There are many wireless channel models and in our simulation we have used SUI-n channel model for fixed WiMAX and COST-231 channel model for mobile WiMAX which are explained as follows :

4.2.1 Stanford University Interim (SUI) Channel Model

This model can be used for simulations, design, and development and testing of technologies suitable for fixed broadband wireless applications. The parameters for the model were selected based upon some statistical models. This model is based on the Stanford University's proposal for broadband wireless access path loss estimation. The complimentary development is made under IEEE802.16d standard based on the AT&T measurements in the frequency band of 1.9 GHz over 95 macro cells for fixed access across US, while a frequency correction factor is introduced for other frequencies. In this model a set of six channels was selected to address three different terrain types that are typical of the continental US. The model is applicable to suburban areas while the cell radius is under 8 km and categorizes the area under study into three different terrains as below :

- **Terrain A**: Hilly with moderate-to-heavy tree densities
- **Terrain B**: Mostly flat terrain with moderate-to-heavy tree densities, or hilly terrain with light tree densities
- **Terrain C**: Flat terrain with light tree densities

Terrain types for SUI channel are given in Table 4.3. In our simulation, SUI-3 is used which type is hilly terrain with light tree density or flat terrain with moderate-to -heavy tree density.

TABLE 4.3 Terrain type for SUI channel.

	Terrain Type	SUI Channels
A	Hilly terrain with moderate-to-heavy tree density	SUI5, SUI6
B	Hilly terrain with light tree density or flat terrain with moderate-to -heavy tree density	SUI3,SUI4
C	Mostly flat terrain with light tree densities	SUI1,SUI2

The SUI-1, SUI-3 and SUI-6 channel parameters are shown in Table 4.4, 4.5 and 4.6

TABLE 4.4 SUI-1 Channel Parameters.

	Tap1	Tap2	Tap3	units
delay	0	0.4	0.9	µs
Power (omni ant.)	0	-15	-20	dB
90 % K Factor(omni ant.)	4	0	0	(linear scale)
Doppler	0.4	0.3	0.5	Hz

TABLE 4.5 SUI-3 Channel Parameters.

	Tap1	Tap2	Tap3	units
delay	0	0.4	0.9	µs
Power (omni ant.)	0	-5	-10	dB
90 % K Factor(omni ant.)	1	0	0	(linear scale)
Doppler	0.4	0.3	0.5	Hz

TABLE 4.6 SUI-6 Channel Parameters

	Tap1	Tap2	Tap3	units
delay	0	14	20	µs
Power (omni ant.)	0	-10	-14	dB
90 % K Factor(omni ant.)	0	0	0	(linear scale)
Doppler	0.4	0.3	0.5	Hz

We assume the scenario with the following parameters:

- Cell Size : 7 Km
- BTS antenna height: 30 m
- Receive antenna height: 6 m
- BTS antenna beamwidth: 120˚
- Receive antenna beamwidth: omnidirectional
- Polarization: Vertical only
- 90 % cell coverage with 99.9 % reliability at each location covered

4.2.2 COST-231 Hata Model

A model that is widely used for predicting path loss in mobile wireless system is the COST-231 Hata model. It was devised as an extension to the Hata-Okumura model. The COST-231 Hata model is designed to be used in the frequency band from 500 MHz to 2 GHz. It also contains corrections for urban, suburban and rural (flat) environments. Although its frequency range is outside that of the measurements, its simplicity and the availability of correction factors has seen it widely used for path loss prediction at this frequency band. This model is restricted to the following range of parameters given in Table 4.7 and Table 4.8 gives paths delays and power.

TABLE 4.7 COST 231 Parameters

Carrier Frequency	1.5 GHz to 2 GHz
Base Antenna Height	30 m to 300 m
Mobile Antenna Height	1m to 10 m
Distance d	1 km to 20 km

TABLE 4.8 Path delays and power for COST (Hilly terrain)

Path #	Delay (µs)	Power (dB)
1	0	0
2	0.1	-1.5
3	0.3	-4.5

Chapter 5
Simulation Model

This chapter discusses the simulation model employed by this research. As we have stated before, our research goal is to evaluate performance of physical layer for fixed and mobile WiMAX using OFDM and MC-CDMA, then the comparison between the two systems is evaluated. This task involves modeling of the physical layer as well as the propagation environment.
In this thesis work , a system model is created and then implemented in MATLAB. The basic of creating this model was to understand OFDM system in general and to evaluate the performance of 802.16d&e. OFDM and MC-CDMA. PHY layers used for fixed and mobile WiMAX both.
In this chapter, a system model will be introduced along with the detailed steps performed during implementation, i.e. creating and simulating the transmitter, channel and receiver modules in MATLAB.
Before going for our simulation, let us, first, define the OFDM symbol parameters used in our study. The parameters values are taken from the IEEE 802.16d&e standards developed for WiMAX. The relations between these parameters are illustrated in the following section.

5.1 OFDM Symbol Description

The IEEE 802.16d PHY layer is based on OFDM modulation. OFDM waveform is created by Inverse Fast Fourier transforming (IFFT). Once the OFDM signal is converted into time domain, this time duration is referred to as useful symbol time T_b. A copy of the last part of the useful symbol period (T_b), termed cyclic prefix (CP), is appended at the beginning of each symbol to maintain the orthogonality of the tones. From all these OFDM symbol characteristics, some parameters can be defined. Figure 5.1 shows the OFDM symbol representation in the time domain.

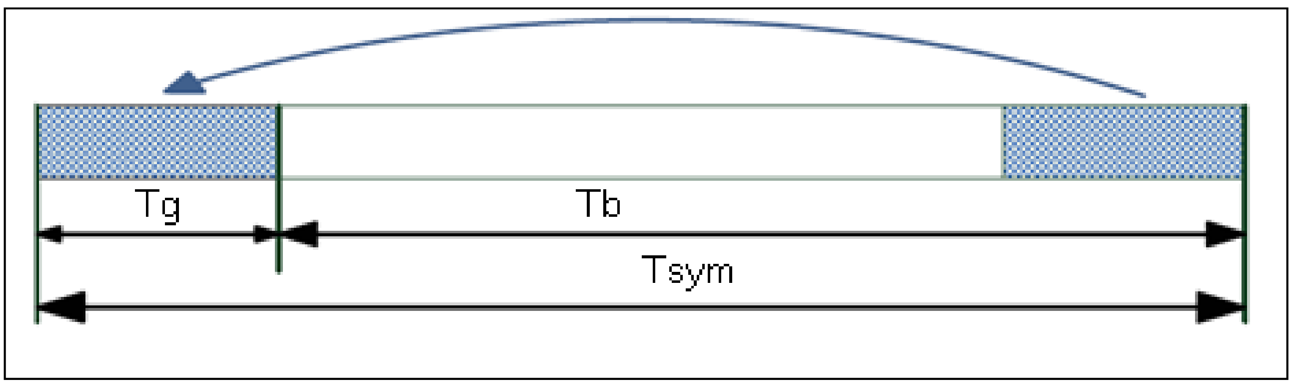


Figure 5.1 Time domain structure of OFDM symbol.

The basic structure of an OFDM symbol is represented in frequency domain. In the frequency domain, an OFDM symbol is composed by three types of subcarriers :

- Data subcarriers : For data transmission.
- Pilot subcarriers : For various estimation purposes.
- Null subcarriers : no transmission at all, for guard bands and DC carrier.

The number of these subcarriers will determine the required size for the FFT (or IFFT) algorithm. Data is sent in the form of OFDM symbols. The purpose of the guard bands is to enable the signals to naturally decay and create the FFT 'brick wall' shaping. It can also be used for canceling the Inter-channel interference. Figure 5.2 shows the OFDM symbol representation in frequency domain. Note that the DC subcarrier is left zero and put in the middle.

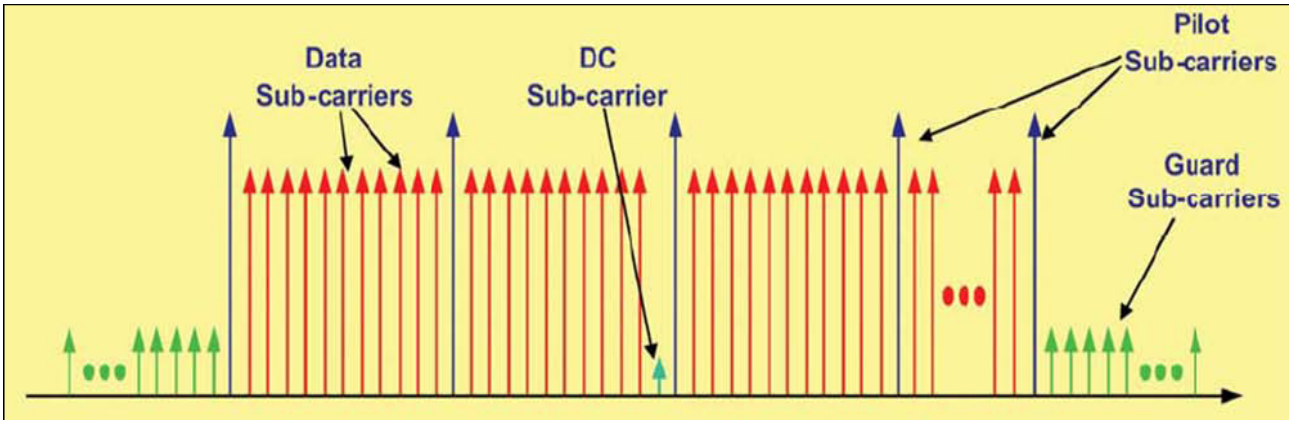


Figure 5.2 Frequency domain structure of OFDM symbol

5.2 OFDM Symbol Parameters for WiMAX

In order to describe an OFDM system , a number of terms are used to specify the parameters of the physical properties.

We can summarize primary OFDM parameters in Table 5.1 for fixed and mobile WiMAX according to IEEE 802.16 standards.

TABLE 5.1 OFDM Symbols parameters for WiMAX

Type	Parameter	Symbol or Formula	Value: Fixed WiMAX	Value: Mobile WiMAX	Units
Primitive	Nominal Channel Bandwidth	BW	5	5	MHz
	Number of data Subcarriers	N_{data}	192	380	
	Number of pilot Subcarriers	N_{pilot}	8	60	
	Number of guard Subcarriers	N_{guard}	56	92	
	Sampling Factor,	n	144/125	144/125	
	Ratio of Guard time to useful symbol time,	G	1/4	1/8	
Derived	Number of used Subcarriers , N_{used}	$N_{data} + N_{pilot}$	200	420	
	N_{FFT} (smallest power of 2 greater than N_{used})	$2^{\lceil log_2 N_{data} \rceil}$	256	512	
	Sampling Frequency, F_s	$\left\lfloor \frac{n.BW}{8000} \right\rfloor .8000$	5.76	5.76	MHz
	Subcarrier Spacing , Δf	$\frac{F_s}{N_{FFT}}$	22.5	11.25	kHz
	Used bandwidth , BW_{used}	$N_{used} \,.\, \Delta f$	4.5	4.725	MHz
	Useful Symbol Time, T_b	$\frac{1}{\Delta f}$	44.444	88.889	μs
	CP Time, T_g	$G \,.\, T_b$	11.111	11.111	μs
	OFDM Symbol Time, T_{sym}	$T_b + T_g$	55.556	100	μs
	Sampling Time , T_s	$\frac{1}{F_s}$	0.1736	0.1736	μs

The simulation contains two systems, the first one is Fixed and Mobile WiMAX with OFDM system, the other is Fixed and Mobile WiMAX with MC-CDMA.
They are described as following.

5.3 Simulation of WiMAX with OFDM System

The baseband PHY transmitter/Receiver consists of three major parts :
1. Channel Coding / Decoding.
2. Modulation / Demodulation.
3. OFDM transmitter / Receiver.

Explanation of each module is presented in the next subsections. General block diagram of OFDM system is shown below in Figure 5.3.

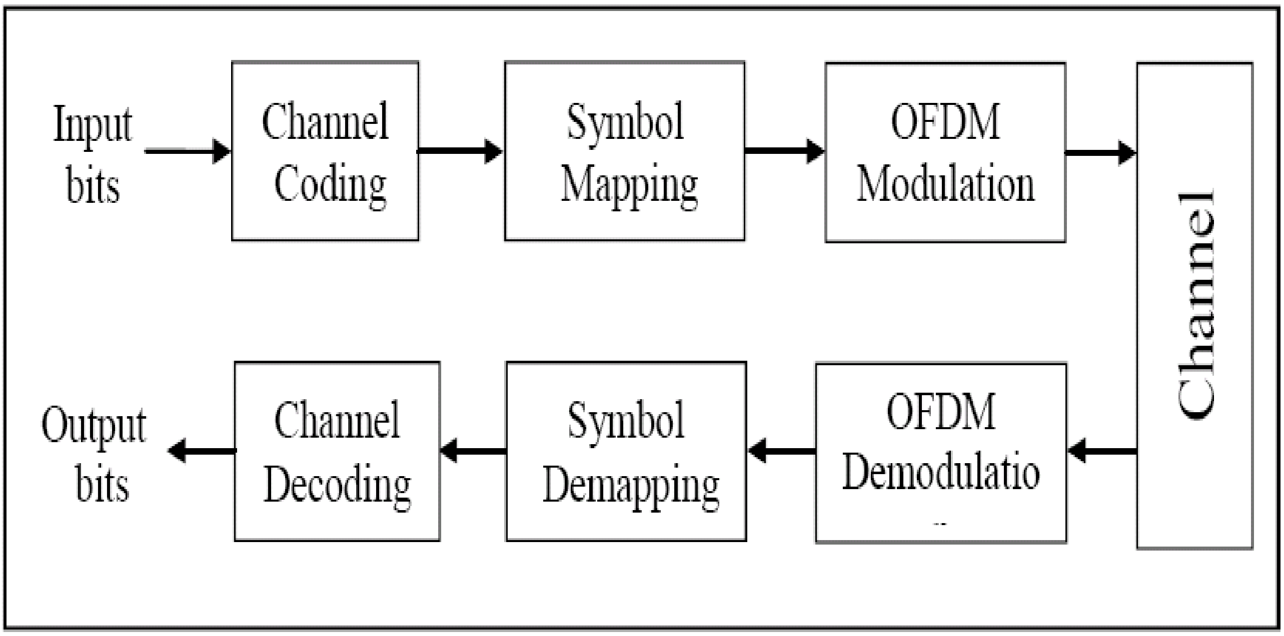


Figure 5.3 General block diagram of OFDM system

In brief , the simulation can be summarized in the following steps:
Step-1: Implementation of OFDM Transmitter Module.
Step-2: Implementation of Channel Module
Step-3: Implementation of Receiver Module.
Step-4: BER plots for OFDM Physical layer .
Step-5: Complete system implementation .
Step-6: BER and spectral efficiency plots for the complete system model.
Step-7 : Do the same steps with MC-CDMA (just add spreading to OFDM system).
The structure of the implemented transmitter and receiver is shown in Figure 5.4

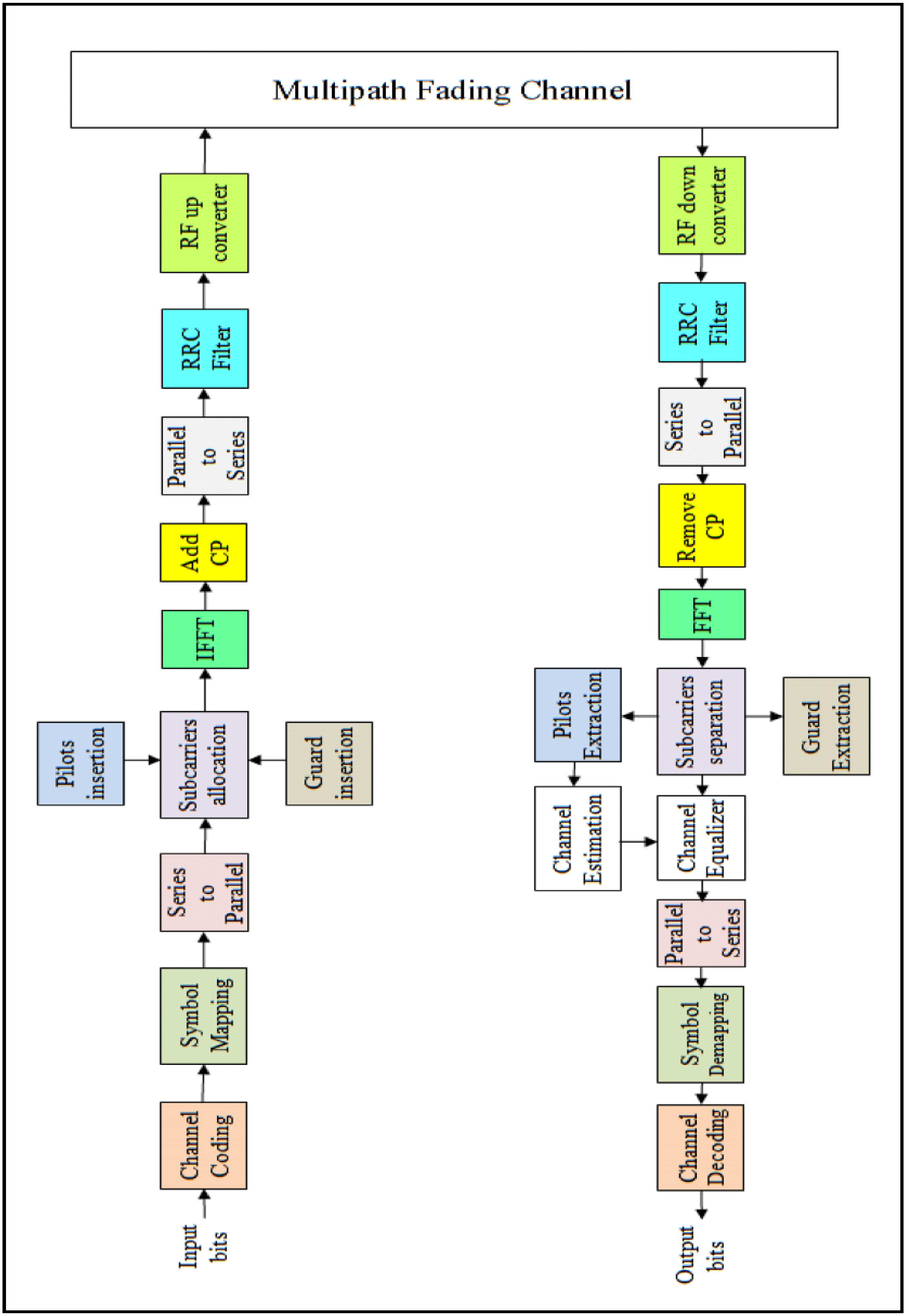


Figure 5.4 The block diagram of OFDM WiMAX.

This structure corresponds to the physical layer of the IEEE 802.16 Wireless MAN OFDM air interface. The blocks in the fig 5.4 are explained as follows :

5.3.1 Random Data Generation

The input data is generated in the form of random numbers i.e. series of ones and zeros. The length of the information bits depends upon the type of the modulation scheme used to map the bits to symbols (BPSK, QPSK, 16-QAM, 64-QAM). In MATLAB, the function *randn* generates the bits.

5.3.2 Channel Coding

Redundancy needs to be added to the data bits so that the receiving end can recover from errors by correcting them. Forward Error Correction (FEC) is implemented in the IEEE 802.16 standard in three phases: Randomization, Forward Error Correction and Interleaving as shown in Figure 5.5.

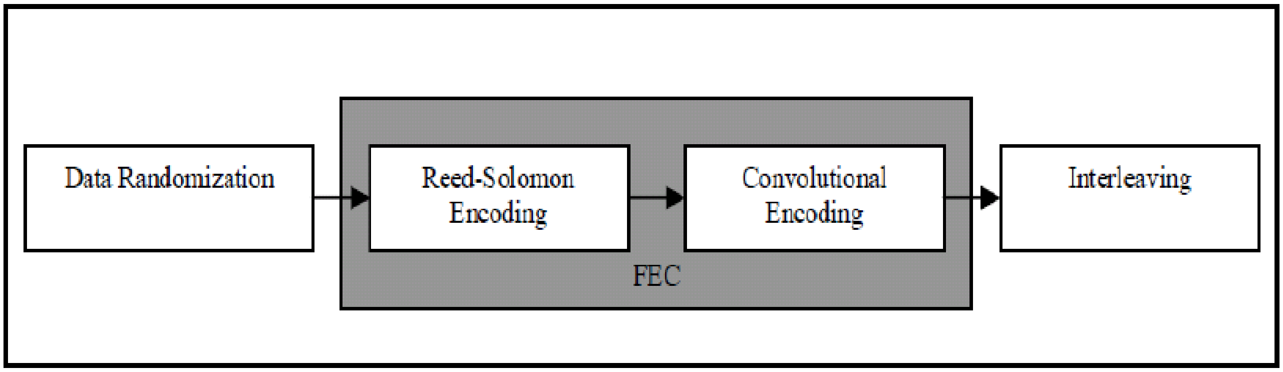


Figure 5.5 Channel coding in WiMAX transmitter.

5.3.2.1 Randomization

This stage of error correction ensures that there is a high level of entropy in the data. In other words, the probability of occurrence of a '0' is the same as that of a '1', locally and over a long range. A Pseudo Random Binary Sequence generator is used to implement randomization. It uses a 15-stage shift register with a generator polynomial of $1+x^{14}+x^{15}$ with XOR gates in feedback configuration as shown in Figure 5.6.

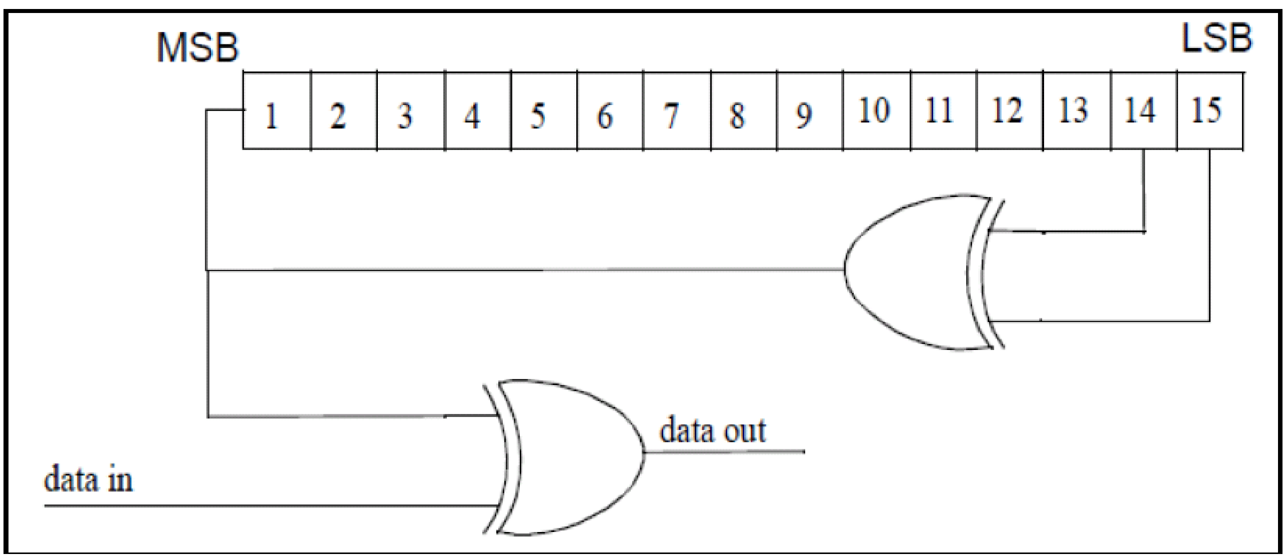


Figure 5.6 Randomizer with polynomial $1+x^{14}+x^{15}$

5.3.2.2 Forward Error Correction

This block consists of two layers – an outer Reed-Solomon code and an inner Convolutional code. Reed Solomon codes are block codes that are good for correcting burst errors. Convolutional codes are good for correcting random errors. Together, the combination effectively corrects most errors caused by the hostile wireless channel.

5.3.2.3 Interleaver

RS-CC encoded data are interleaved by a block interleaver. The size of the block is depended on the numbers of bit encoded per subchannel in one OFDM symbol, N_{cbps} . In IEEE 802.16, the interleaver is defined by two step permutation. The first ensures that adjacent coded bits are mapped onto nonadjacent subcarriers. The second permutation ensures that adjacent coded bits are mapped alternately onto less or more significant bits of the constellation, thus avoiding long runs of unreliable bits.

5.3.3 Data Symbols Modulation Mapper

The bit interleaved data are then passed to the constellation mapper, where depending upon its size the data was modulated using the following four different modulation schemes: BPSK, Gray-mapped QPSK, 16-QAM and 64-QAM. Modulation is done by dividing the incoming bits into groups of i bits to represent a modulated signal. As a result there are 2^i points, and the total number of points represents a constellation. The size of i for BPSK, QPSK, 16-QAM and 64-QAM are 1, 2, 4 and 6 respectively. The constellations are presented in the I-Q plane, where I and Q denote the in-phase and quadrature component as shown in Figure 5.7 where b_0 denotes the Least Significant Bit (LSB) for each modulation. The constellation mapped data are assigned to all allocated data subcarriers of the OFDM symbol in order of increasing frequency offset index .

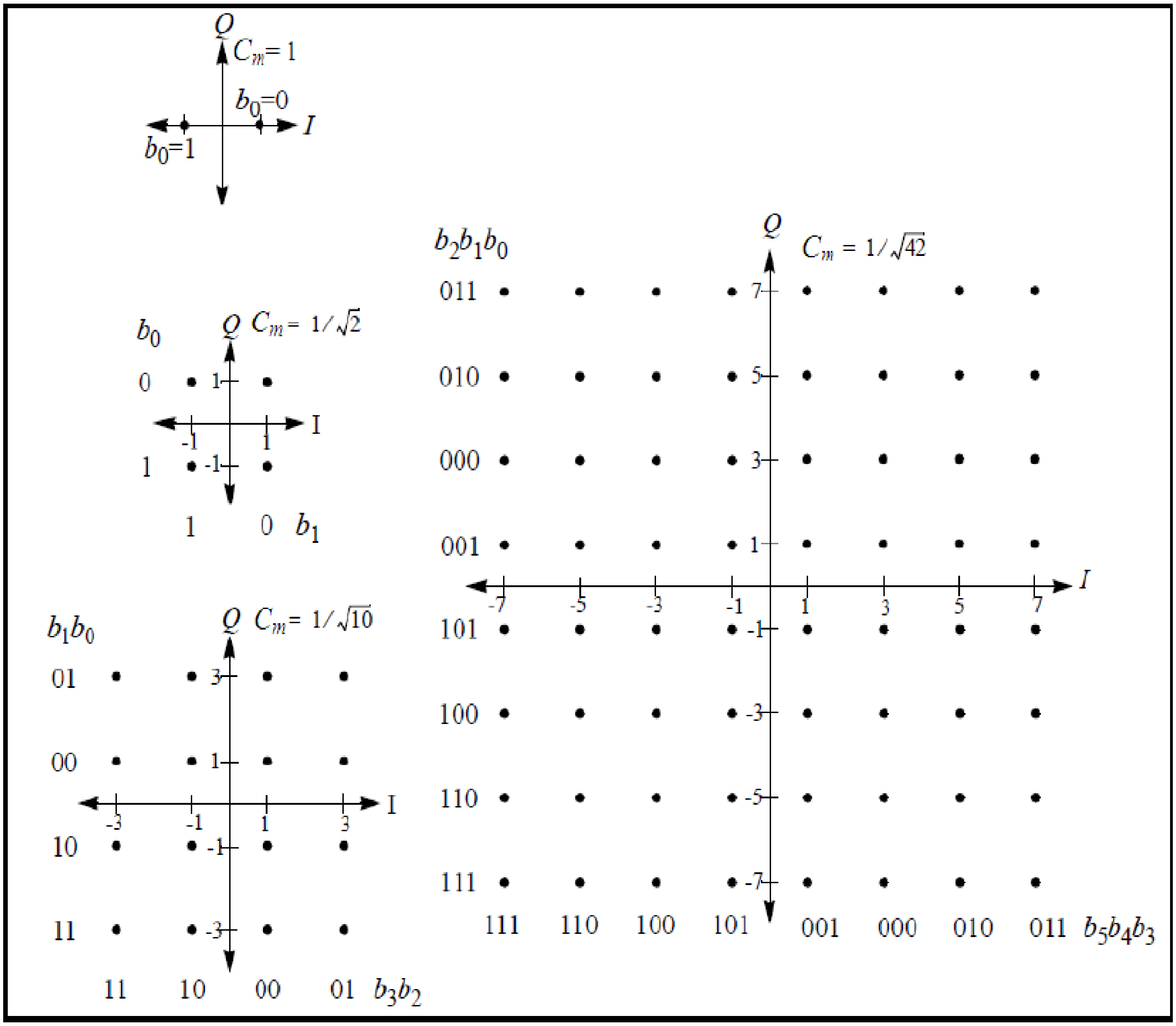


Figure 5.7 BPSK ,QPSK , 16-QAM and 64-QAM constellations

5.3.4 Subcarriers Allocation

WiMAX specifications define three types of subcarriers: data, pilot and null subcarriers. The mapped data symbols from the last step are arranged to be a matrix where its rows number is equal to the number of data subcarriers. The pilot and null subcarriers are then inserted to form the total subcarriers. Table 5.2 below shows the number and type of subcarriers for both fixed and mobile WiMAX systems according to the IEEE 802.16 d&e standards .

TABLE 5.2 Subcarriers in Fixed and Mobile WiMAX simulated systems

Subcarriers type	Fixed WiMAX	Mobile WiMAX
N_{data}	192	360
N_{pilot}	8	60
N_{guard}	56	92
N_C	256	512

5.3.5 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. Besides ensuring the orthogonality of the OFDM subcarriers, the IFFT represents also a rapid way for modulating these subcarriers in parallel, and thus, the use of multiple modulators and demodulators, which spend a lot of time and resources to perform this operation, is avoided. Furthermore, the FFT (or IFFT) should be of length given by

$$N_{FFT} = 2^{\lceil log_2 N_{data} \rceil} \qquad (5.1)$$

The t-th time domain sample at the n-th subcarrier at the output of IFFT is given by

$$x_t = \sum_{n=0}^{N_c-1} X_n \, e^{j\frac{2\pi tn}{N}} \qquad 0 \le t \le N_C - 1 \qquad (5.2)$$

Where N_c is the number of subcarriers and Xn is the data symbol on the n-th subcarrier. As a result an OFDM symbol is generated. FFT is just a computationally fast way to calculate the DFT. We can move back and forth between the time domain and frequency domain without loosing information (see Figure 5.8 below).

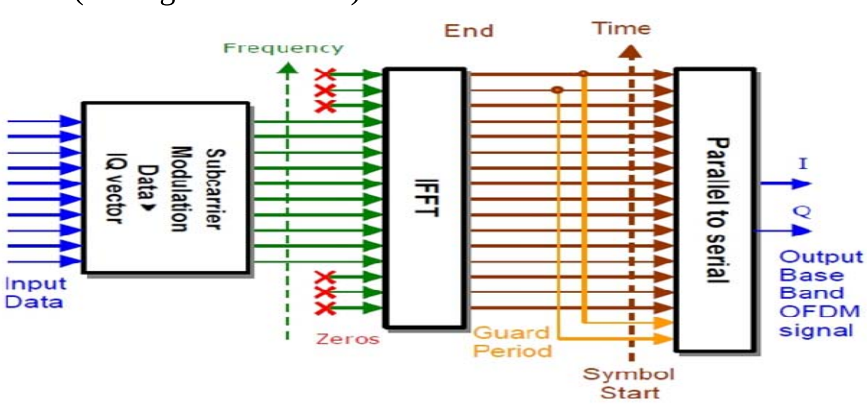


Figure 5.8 OFDM generation, IFFT stage.

5.3.6 Cyclic Prefix Insertion :

A cyclic prefix (CP) is added to the time domain samples to combat the effect of multipath. Four different duration of CP are available in the standard. G is the ratio of CP time to OFDM symbol time, this ratio can be equal to 1/32, 1/6, 1/8 and 1/4.

5.3.7 The Transmitter and Receiver Filters

The OFDM signal is made up of a series of IFFTs that are concatenated to each other. At each symbol boundary, there is a signal discontinuity due to the difference between the end of one symbol and the start of another one. These very fast transitions at the boundaries increase the side-lobe power. In order to smooth the transition between different transmitted OFDM symbols, windowing (Hamming, Hanning, Blackman, Raised Cosine etc.) is applied to each symbol.

So, data transmission over band limited channels requires a technique of pulse shaping at the transmitter. Since the pulse shaping filter does not cause inter-symbol interference (ISI), this implies the fundamental shapes of the pulses to be such that they do not interfere each other. A criteria that ensures non-interference specifies the shape of the pulses to be such that its amplitude decays rapidly outside the pulse interval. A widely used filter for this purpose is the well known raised cosine filter, which satisfies Nyquist's first criterion. However, in practical applications the overall magnitude response of the raised cosine spectrum is equally split between the transmitter and the receiver, thus obtaining square-root raised cosine filters, also known as root-raised cosine (RRC) filters. The advantage of such subsystems is that if the transmit side filter is stimulated by an impulse, then the receiver one is forced to filter an input pulse with a shape that is identical to its own impulse response, therefore setting up a matched filter and maximizing the SNR while at the same time minimizing ISI .

In our simulation , we want to split the filtering equally between the transmitter's filter and the receiver's filter. To do this, we can use a pair of square-root raised cosine filters to perform pulse shaping and matched filtering at the transmitter and receiver, respectively without introducing inter-symbol interference (ISI). In theory, the combination of two square-root raised cosine filters is equivalent to a single normal raised cosine filter. By this method, we split the filtering between transmitter and receiver.

In practice, discrete-time OFDM signals will be generated by IFFT and then processed by a digital -to-analog converter (DAC). It is well known from signal processing theory that a discrete-time signal has a periodic spectrum from which the analog signal has to be reconstructed at the DAC by a low-pass filter (LPF) that suppresses these aliasing spectra beyond half the sampling frequency $F_s/2$. The LPF must be flat inside the main lobe and the side lobe must decay steeply enough so that the alias spectra will be suppressed. This analog filter is always a complexity item. It is a common practice to use oversampling to move complexity from the analog to the digital part of the system. Oversampling can be implemented by using a higher FFT length and padding zeros at the unused carrier positions .

In MATLAB , *rcosine* function used to design the FIR square root raised cosine filter and the *rcosflt* function to filter the signals. At the transmitter ,the signal will be upsampled by zero-padding before filtering. If the sampling frequency of the input signal is F_s, and the sampling frequency of the filter is F_f, then the upsampling factor is F_f/F_s. Before filtering ,the initial parameter of the filter such as , filter order , up sampling factor , roll off factor and group delay must be given. The group delay of the filter can be calculated by (filter order/(2*F_f)).

In our simulation , we choose the sampling factor to be equal to 2 and we put the filter order is equal to 40. Now, from Table 5.1, we can find that F_s = 5.76 MHz, so the filter sampling frequency will become F_f = 11.52 MHz and the group delay is equal to 10. The properties of the filter are depicted in Table 5.3. Impulse response of root-raised cosine filter is illustrated in Figure 5.9

Table 5.3 FIR Root-Raised Cosine Filter properties.

Property	value
order	40
Up sampling factor	2
Roll off factor	0.25
Group delay	10

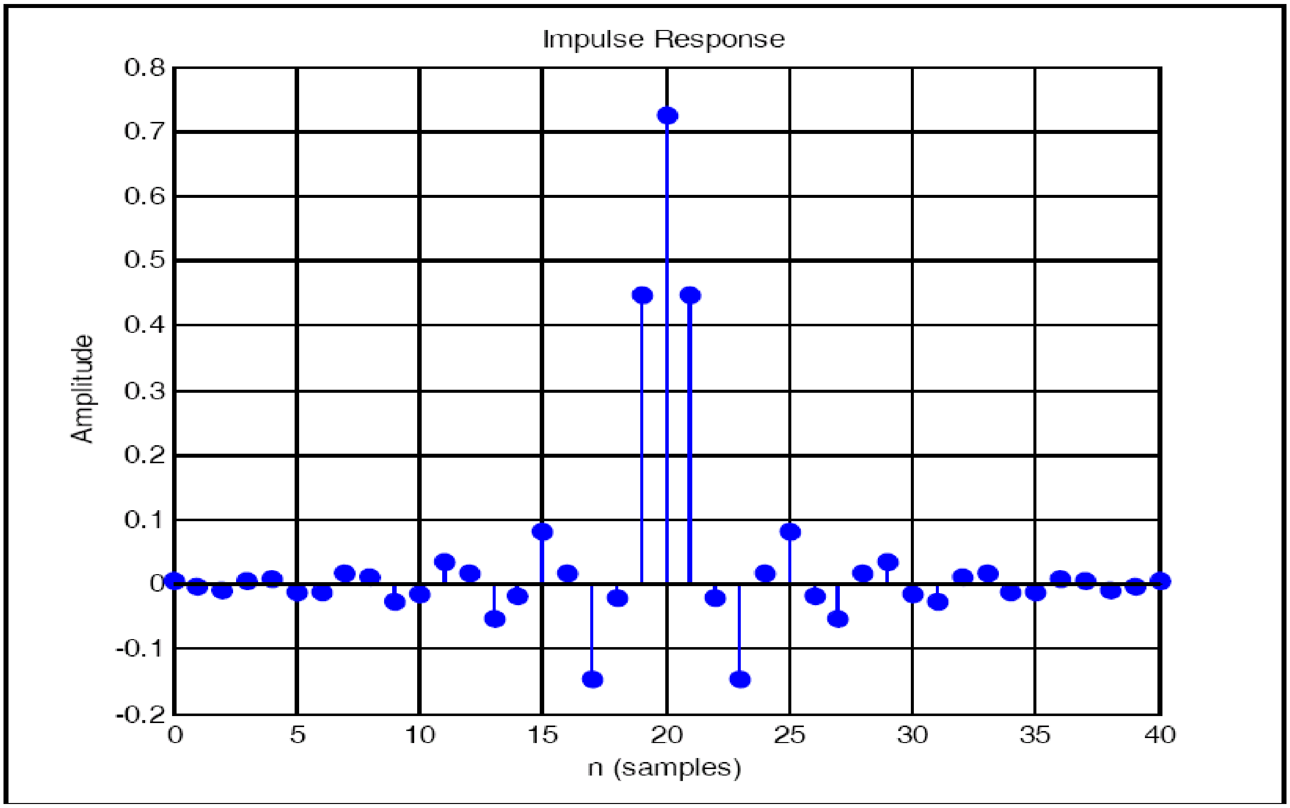


Figure 5.9 Impulse response of Root-Raised Cosine Filter.

5.3.8 RF Up-Converter

The output of the OFDM modulator generates a base band signal, which must be mixed up to the required transmission frequency. The main advantage of an OFDM transmission and reception is its digital implementation using digital FFT processing. Therefore, at the transmission side the digital signal after digital IFFT processing is converted to the analog domain with a D/A converter, ready for IF/RF up-conversion and vice versa at the receiver side. After discrete symbols converting to analogue by low-pass filtering , it is fed to RF up-converter.

5.3.9 The Channel

As we stated in Chapter 4, we used SUI3 model for fixed WiMAX simulation and COST 231 Hata model for mobile WiMAX. Here, we will talk about the actual model simulated by MATLAB .
In our simulation , we used the *ricianchan(Ts, fm, kFactor, tau, pdb)* function to create a *Rician* channel object *chan* with an input sample period *Ts*, a maximum Doppler shift *fm*, a vector of Rician k–factor *kFactor*, a vector of path delays *tau*, and a vector of average path power gains *pdb* (in dB). It then uses the *doppler.rounded* function to create a rounded Doppler object for fixed WiMAX and *doppler.jakes* function to create jakes Doppler object for mobile WiMAX .
The following is an example from our MATLAB simulation of fixed WiMAX using SUI-3 model

of three paths.

```
fm=0.5;
Ts=0.1736e-6;
pdb=[0 -5 -10];
tau=[0 0.4 0.9]*1e-6;
k=[3 0 0];
k=10.^(k/10);
chan = ricianchan(Ts,fm,k,tau,pdb)
dop=doppler.rounded;
chan.DopplerSpectrum=dop;
chan.StoreHistory=1;
chan.ResetBeforeFiltering=1;
chan.NormalizePathGains=1;
```

Now , the channel object *chan* has a set of properties. If we print chan , in command window in Matlab ,we will get the following.

```
chan =
ChannelType: 'Rician'
InputSamplePeriod: 1.7361e-007
DopplerSpectrum: [1x1 doppler.rounded]
MaxDopplerShift: 5.0000e-001
PathDelays: [0 4.0000e-007 9.0000e-007]
AvgPathGaindB: [0 -5 -10]
KFactor: [1.9953e+000 1 1]
DirectPathDopplerShift: [0 0 0]
DirectPathInitPhase: [0 0 0]
NormalizePathGains: 1
StoreHistory: 1
StorePathGains: 0
PathGains: [30764x3 double]
ChannelFilterDelay: 4
ResetBeforeFiltering: 1
NumSamplesProcessed: 30764
```

The properties InputSamplePeriod, MaxDopplerShift, PathDelays, and AvgPathGaindB are set equal to Ts, fm, tau, and pdb, respectively. The property NormalizePathGains, which is set to 1, specifies that the sum of the average path gain powers should be 1. The property ChannelFilterDelay contains the value of a delay of 4 is incurred in the simulation.

Figure 5.10 illustrates the channel impulse response, whose amplitudes are time-varying because of the fading. The vertical lines correspond to the delays of the actual channel impulse response, as specified in PathDelays. The solid points along the solid curve (which is the smoothed bandlimited impulse response)correspond to the delays of the transformed, symbol-spaced channel impulse response. Figure 5.11 shows the frequency response in dB of the channel with the cited parameters.

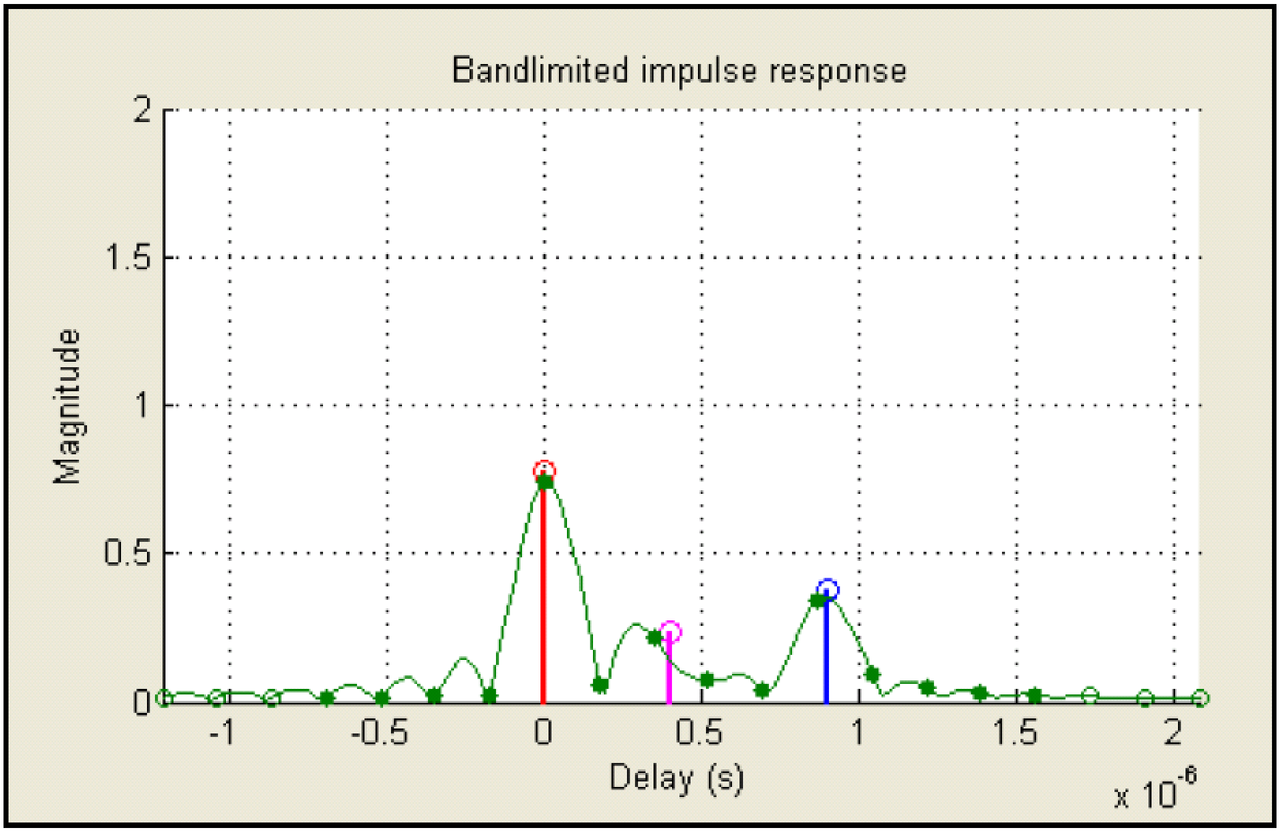


Figure 5.10 The channel impulse response for SUI-3.

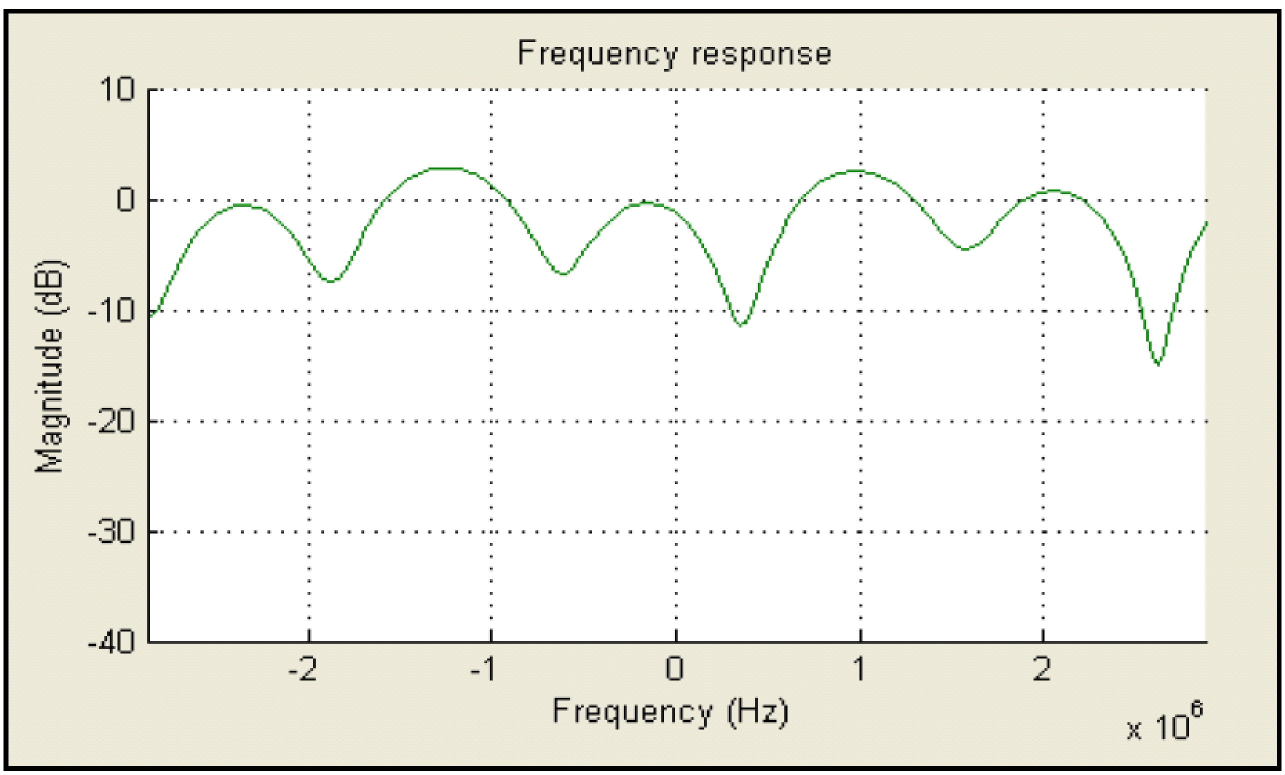


Figure 5.11 The frequency response for SUI-3.

5.3.10 Receiver

As illustrated in Figure 5.6, the receiver basically performs the reverse operation as the transmitter as well as a channel estimation necessary to reveal the unknown channel coefficients. This section explains the different steps performed by the receiver to reconstruct the transmitted bits.

Firstly, after down converter and filtering , the CP is removed and the received signal is converted to the frequency domain using, in this case, the FFT algorithm. As it has been previously explained before, an OFDM symbol is composed by data, pilots, a zero DC subcarrier, and some guard bands. Thus, a process to separate all these subcarriers is needed. First, the guard bands are removed, and then, a disassembling is performed to obtain pilots and data. The pilots subcarriers are used in the channel estimator, which calculates the channel coefficients. The estimated channel coefficients can be used in the demapper to perform an equalization of the data, and so, compensate the frequency selective fading of the multipath propagation channel. Once the data has been demapped , it enters the decoder block.

At the receiver ,we need *equalization* to reconstruct the original signal because the signal was distorted by the multipath fading channel. In an OFDM system, this is done by *channel estimation* and *interpolation*. The pilot subcarriers are extracted that can be used for channel estimation and synchronization at the receiver. In the simulation least squares (LS) estimate has been used for channel estimation at the pilot subcarriers.

If the cyclic prefix is longer than the maximum delay spread of the channel, we can model the effect as a complex multiplication in frequency domain. The equalization thus simplifies to a complex division of the received signal by the estimated channel. If X(f) is the transmitted data (known by channel estimation using pilots then interpolation), *Y* is the received data, and *C* is the unknown channel response, then

$$C(f) = \frac{Y(f)}{X(f)} \tag{5.3}$$

The following section illustrates the channel estimation in OFDM system .

5.3.10.1 Channel Estimation and Equalization

The two basic 1D channel estimations in OFDM systems are illustrated in Figure 5.12. The first one, block-type pilot channel estimation, is developed under the assumption of slow fading channel, and it is performed by inserting pilot tones into all subcarriers of OFDM symbols within a specific period. The second one, comb-type pilot channel estimation, is introduced to satisfy the need for equalizing when the channel changes even from one OFDM block to the subsequent one. It is thus performed by inserting pilot tones into certain subcarriers of each OFDM symbol where the interpolation is needed to estimate the conditions of data subcarriers.

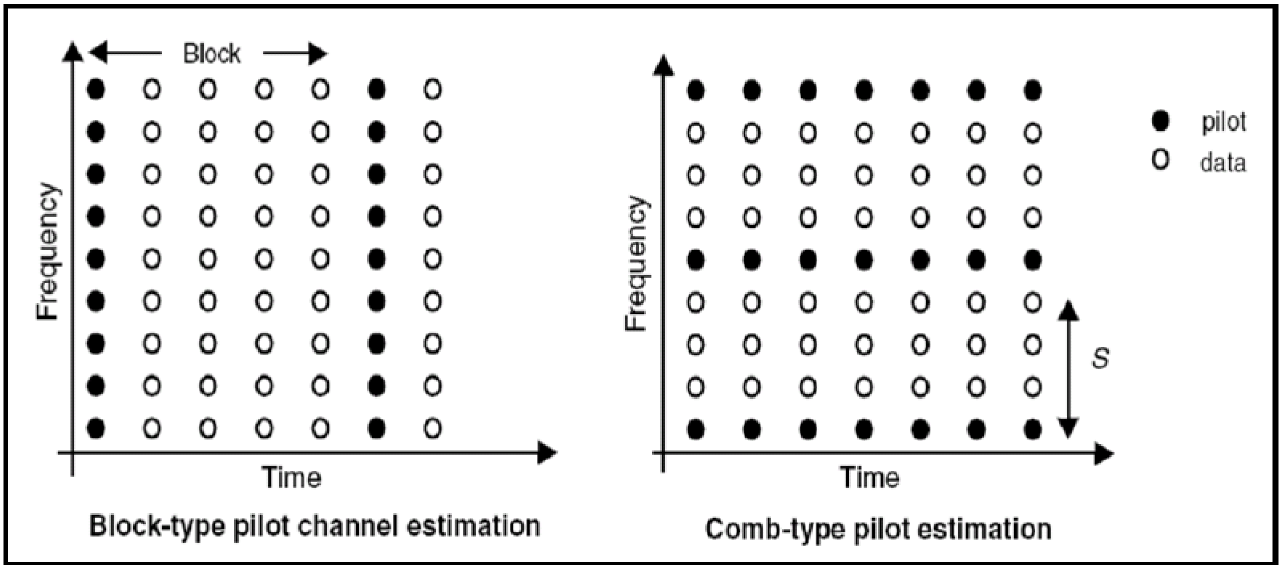


Figure 5.12 Two Basic Types of Pilot arrangement for OFDM channel Estimation.

We have used comb-type pilot based channel estimation in our simulation. As shown in Figure 5.12, in comb-type , for each transmitted symbol, N_{pilot}pilot signals are uniformly inserted with subcarriers apart , *S* ,from each other, where

$$S = N_{\text{used}}/N_{\text{pilot}} \quad (5.4)$$

For our simulation and depending on the number of used and pilots subcarriers, as shown in Table 5.1 , we can find that S = 25 for Fixed WiMAX and S = 7 for Mobile WiMAX.
After channel estimation at pilots locations , we need to estimate the channel at data symbols locations. We can do this by interpolation. There are many types of interpolations. The one dimension interpolation is used here by Spline Cubic Interpolation (SCI) method. The SCI method produces a smooth and continuous polynomial fitted to given data points.
In MATLAB ,the *interp* function performs the interpolation and the *spline* function is used for SCI method. Then, the following step is to perform the equalization by a complex division of the received signal by the estimated channel. We will see in the results of our simulation that the equalization is very essential because of the strong effect of multipath fading channel.

5.3.10.2 BER Calculations

After channel equalizer ,the data symbols are parallel to series converted , and then symbol demapping is done to get the data bits. Channel decoding is performed with Viterbi decoder and we can calculate bit error rate (BER). At the end of this chapter, MC-CDMA simulation is simply explained in the next section. In the next chapter, the simulation results are given and discussed.

5.3.10.3 Spectral Efficiency Plot

The spectral efficiency of a channel is a measure of the number of bits transferred per second for each Hz of bandwidth. Spectral efficiency for various modulation levels as a function of short-term average SNR is depicted in Figure 5.13
The spectral efficiency is presented in many ways in the literature. We derived the spectral efficiency using the relation :

$$\eta = (1 - BER)^n \; k \; r \quad (5.5)$$

where ,
BER : the bit error rate.

n : the number of bits in the block.
k : the number of bits per symbol.
r : the overall code rate.

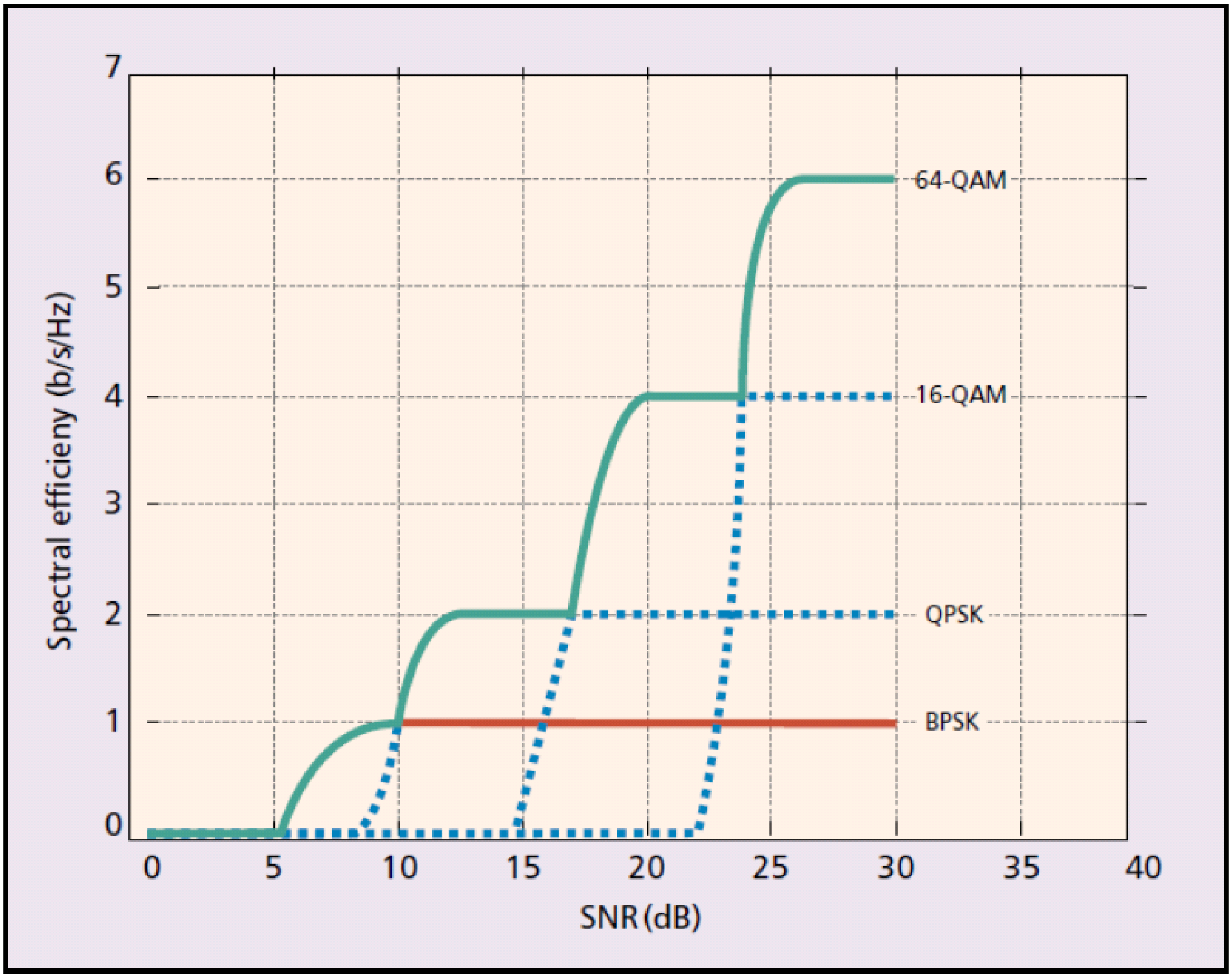


Figure 5.13 Spectral efficiency for various modulation levels as a function of short-term average SNR

5.4 Simulation of WiMAX with MC-CDMA System

To implement MC-CDMA system, we just add spreading process before OFDM block in the OFDM system and dispreading process after OFDM block in the receiver as shown in Figure 5.14 below. In our simulation, we use Hadamard code in spreading process. In MATLAB, the function *Hadamard(L)* gives Hadamard matrix of size *L*, where *L* can be the number of users. We use Hadamard codes because they are orthogonal and easy to generate. Also, it is preferred in the downlink transmission.

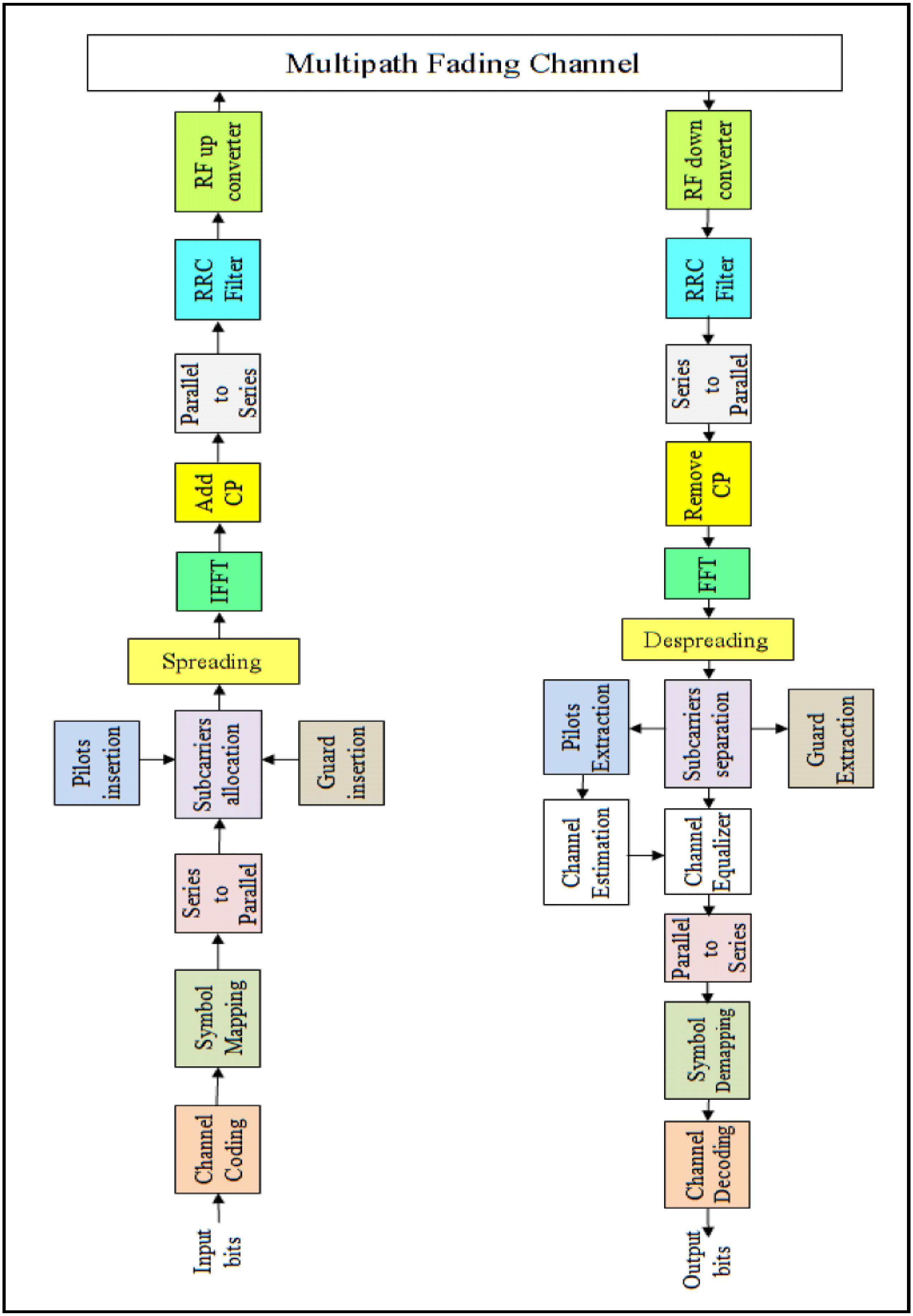


Figure 5.14 The block diagram of MC-CDMA WiMAX

CHAPTER 6
Simulation Results and Analysis

In this chapter, the simulation results along with the underlying assumptions are presented and discussed. The simulations implemented in this thesis are all done in MATLAB. The simulation is carried out for downlink transmissions at a carrier frequency of 2.5 GHz and a 5 MHz channel bandwidth and the parameters of the simulation are shown in Table 5.1 in Chapter 5.

The main procedure of the code contains initialization parameters and input data. The parameters that can be set at the time of initialization are the number of subcarriers, the nominal bandwidth, CP length, symbol modulation level and coding rate, range of the bit energy to noise (E_b/N_o) values (from 0 to 40 dB) and channel model parameters for simulation. The input data stream is randomly generated. In our model, the simulation of the system is repeated and the number of transmitted bits and bit errors are calculated for each simulation. At the end, BER is estimated as the ratio of the total number of observed errors and the total number of transmitted bits.

The performance of the system model is tested using different modulation schemes i.e., BPSK, QPSK and 16-QAM with an SUI-3 channel model for Fixed WiMAX and COST 231 Hata model for Mobile WiMAX with various mobile receiver speeds.

We can summarize our main simulation into 4 types:

1. Fixed WiMAX with OFDM system.
2. Mobile WiMAX with OFDM system.
3. Fixed WiMAX with MC-CDMA system.
4. Mobile WiMAX with MC-CDMA system.

We have developed MATLAB codes to perform the simulation with flexibility of changing the system parameters.

The objective behind simulation in MATLAB is to study BER performance under different parameters that characterize the performance. These parameters are taken from standard IEEE802.16 which is designed for WiMAX. After the simulation of OFDM system, we just add the spreading to the system to get MC-CDMA system. We chose Hadamard code with different spreading code lengths.

Through numerous comparisons between simulation results obtained with different simulation parameters, some discussions about the use of these different parameters and options are given with the purpose of offering a complete view on the better performance of the transmission. The next sections present a set of plots to identify trends in reception quality as we vary different parameters. These plots are BER vs. E_b/N_o, scatter plots and spectral efficiency vs. E_b/N_o plots. Briefly, we have two main systems, OFDM system and MC-CDMA system and we will see the effect of MC-CDMA system on the WiMAX system performance.

The following subsections will visualize the simulation results and analyze the performance of the system in different cases.

6.1 Simulation Results of Fixed WiMAX with OFDM system

In this section, we have presented various BER vs. E_b/N_o plots for all the mandatory modulation and coding profiles as specified in the standard on same channel models.

Figures 6.1, 6.4 and 6.7 shows BER vs. E_b/N_o of BPSK, QPSK and 16-QAM for Fixed WiMAX with OFDM.

Scatter plots are shown in Figures 6.2, 6.5 and 6.8. The '*' symbol denotes the transmitted symbols and the '×' symbol denotes the received symbols without equalization. The '•' symbol denotes the equalized received symbols. We observe from these plots the effect of the multipath fading channel on the amplitude and phase of the transmitted symbols. It is clear that equalization is required at the receiver to compensate fading effects.

Figures 6.3, 6.6 and 6.9 illustrate the spectral efficiency and Figure 6.10 shows the comparison of the three techniques.

We note that BPSK is more power efficient and need less bandwidth amongst all other modulation techniques used in this OFDM adaptive modulation. In case of bandwidth utilization, the 16-QAM modulation requires higher bandwidth and gives an excellent data rates as compared to others while the QPSK is in the middle of these two and need higher bandwidth and less power efficient than BPSK.BPSK has the lowest BER while the 16-QAM has highest BER.

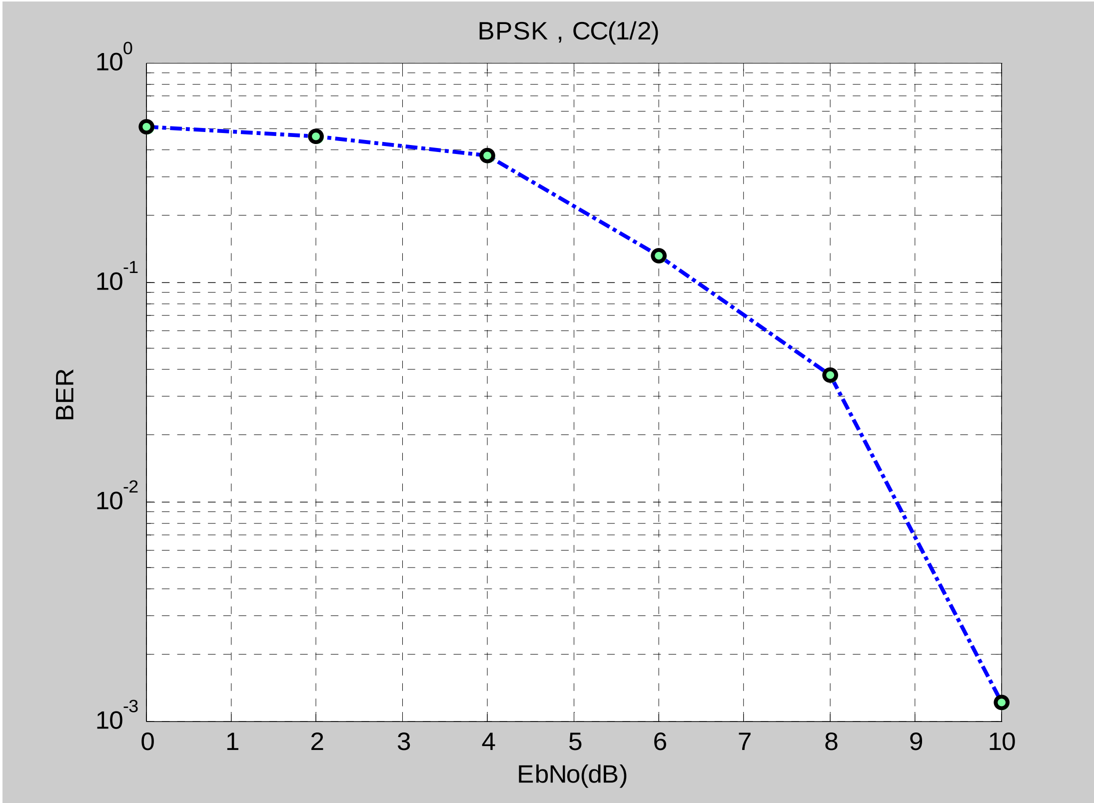


Figure 6.1 BER vs. E_b/N_o for BPSK , CC 1/2

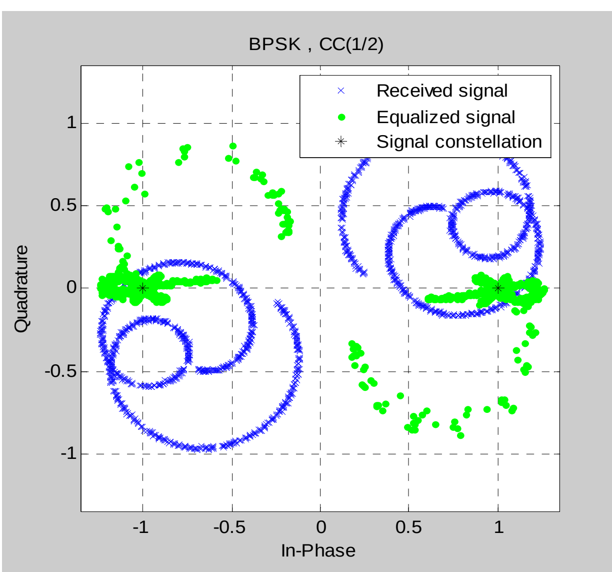
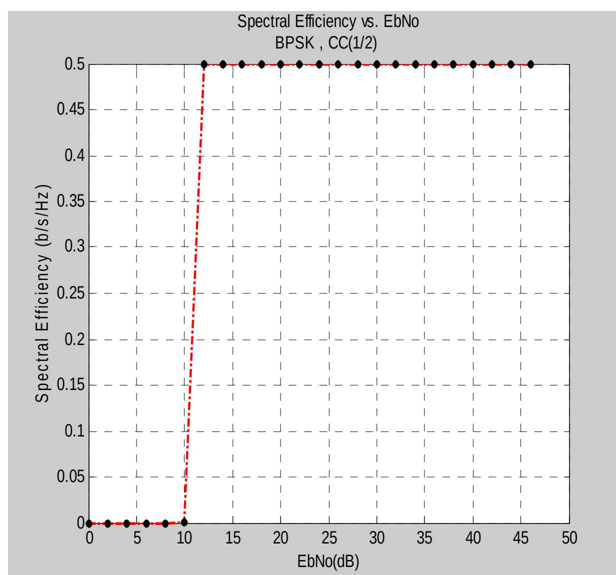


Figure 6.2 Scatter plot of BPSK modulation.



Figures 6.3 Spectral efficiency of BPSK modulation.

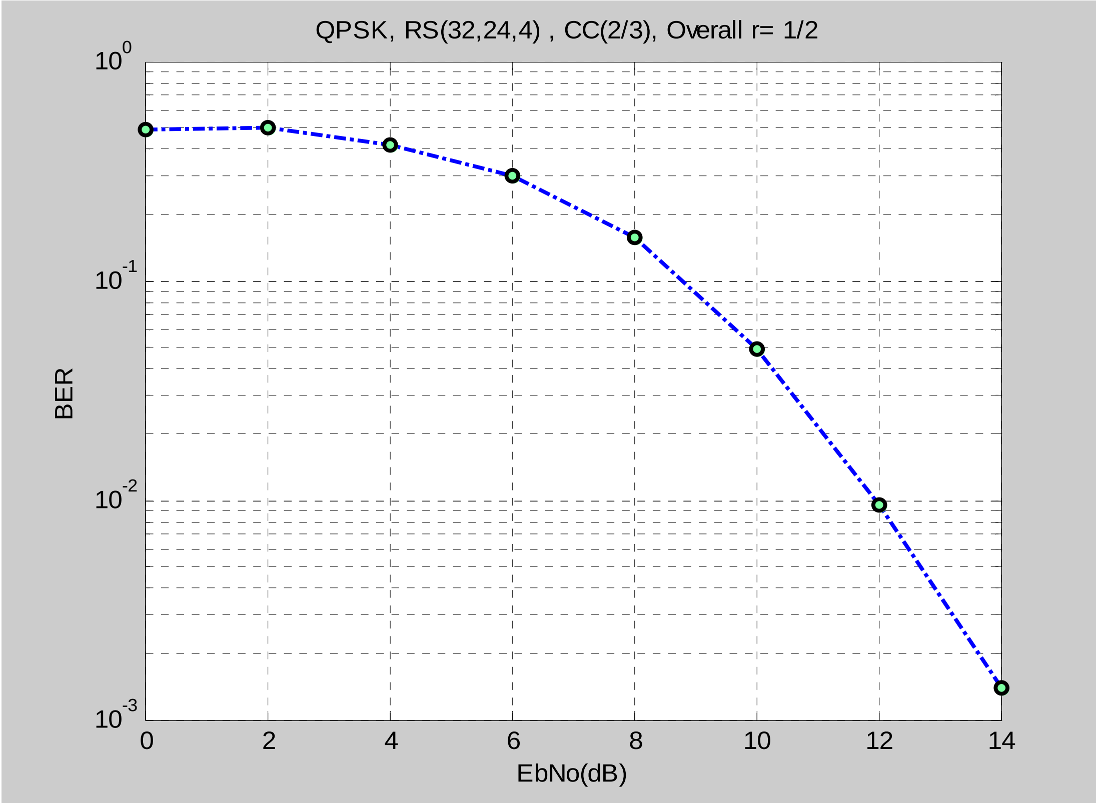


Figure 6.4 BER vs. E_b/N_o for QPSK RS(32,24,4),CC(1/2)

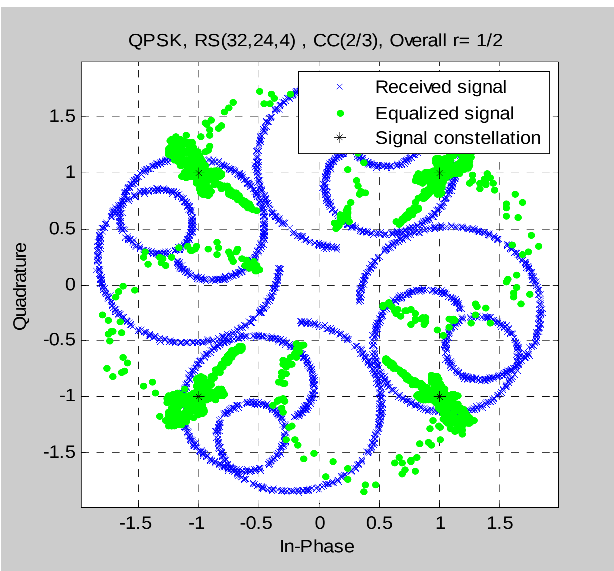
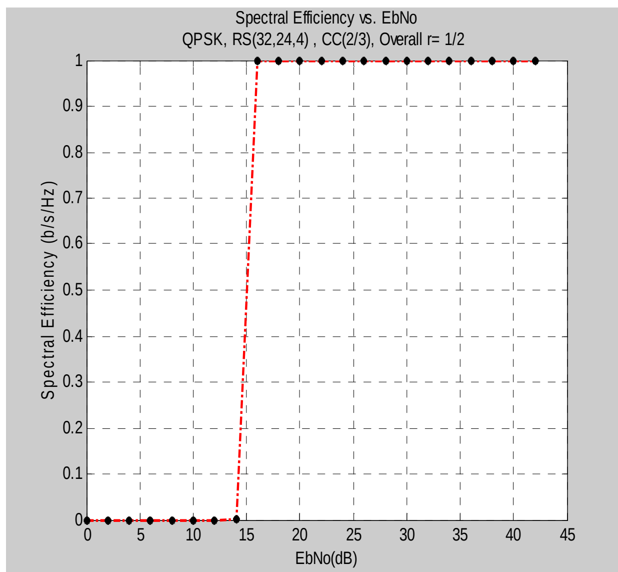


Figure 6.5 Scatter plot of QPSK modulation.



Figures 6.6 Spectral efficiency of QPSK modulation.

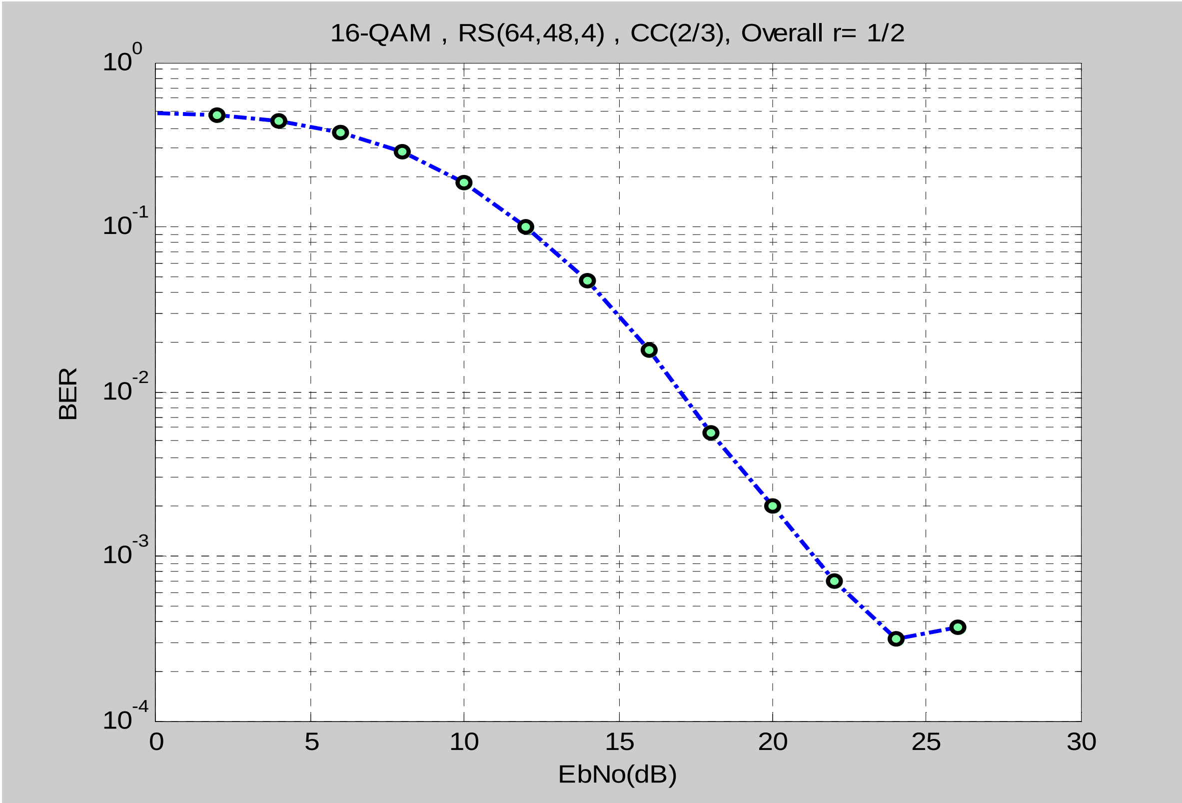


Figure 6.7 BER vs. E_b/N_o for 16 QAM RS(64,48,4),CC(2/3)

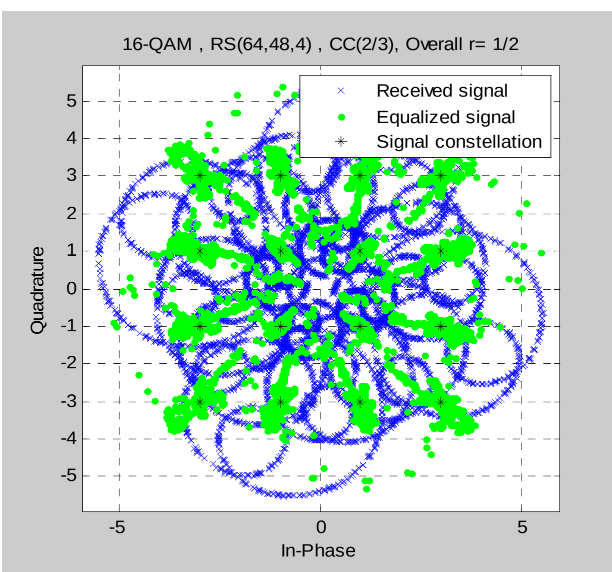
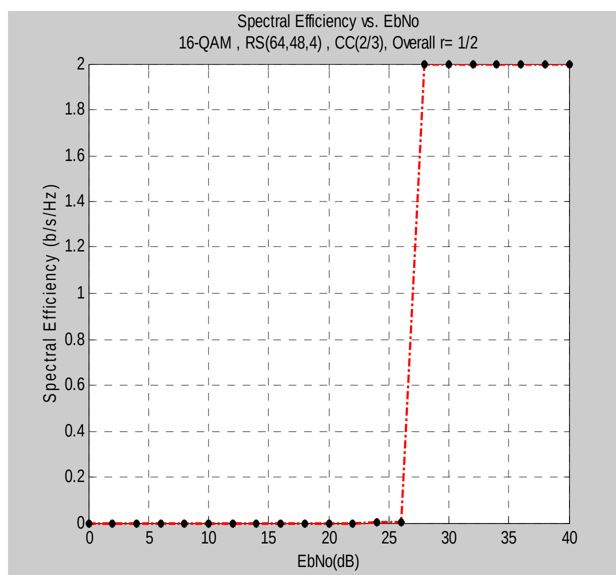


Figure 6.8 Scatter plot of 16 QAM modulation.



Figures 6.9 Spectral efficiency of 16 QAM modula-

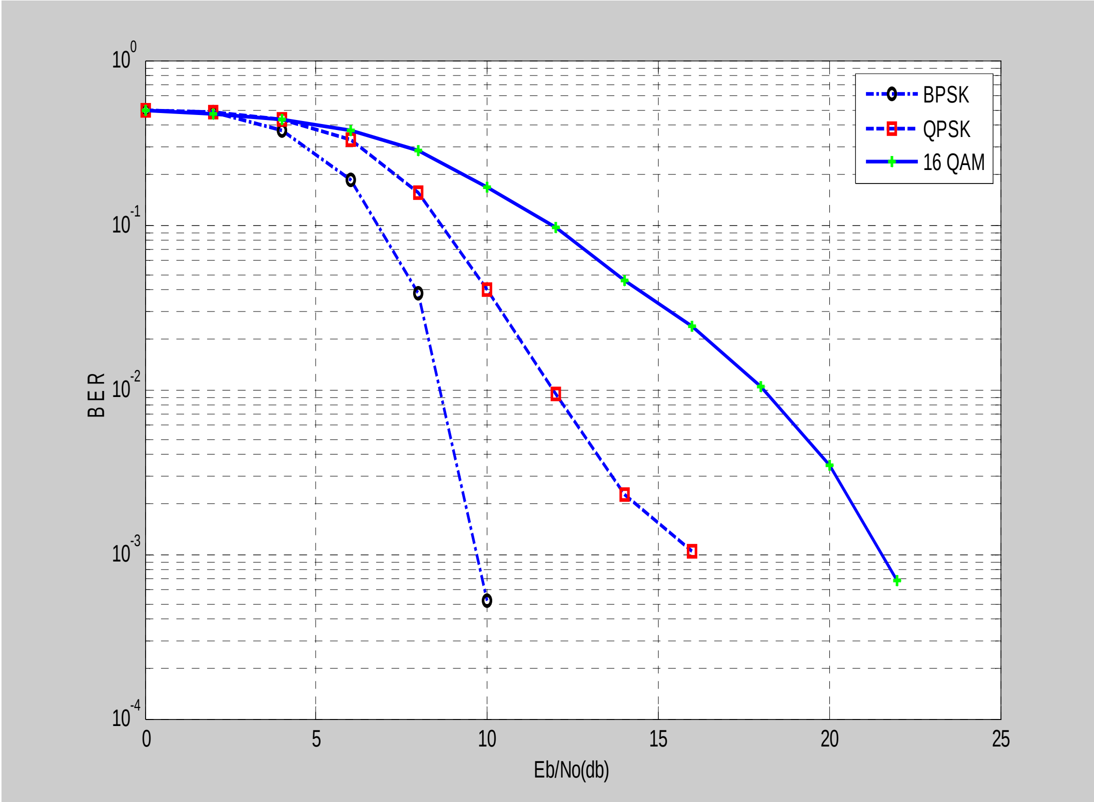


Figure 6.10 BER vs. E_b/N_o for different modulation schemes.

6.2 Simulation Results of Mobile WiMAX with OFDM system

The following results are for Mobile WiMAX simulation. The simulation was performed for the receiver speeds of 30, 60 and 120 km/hr

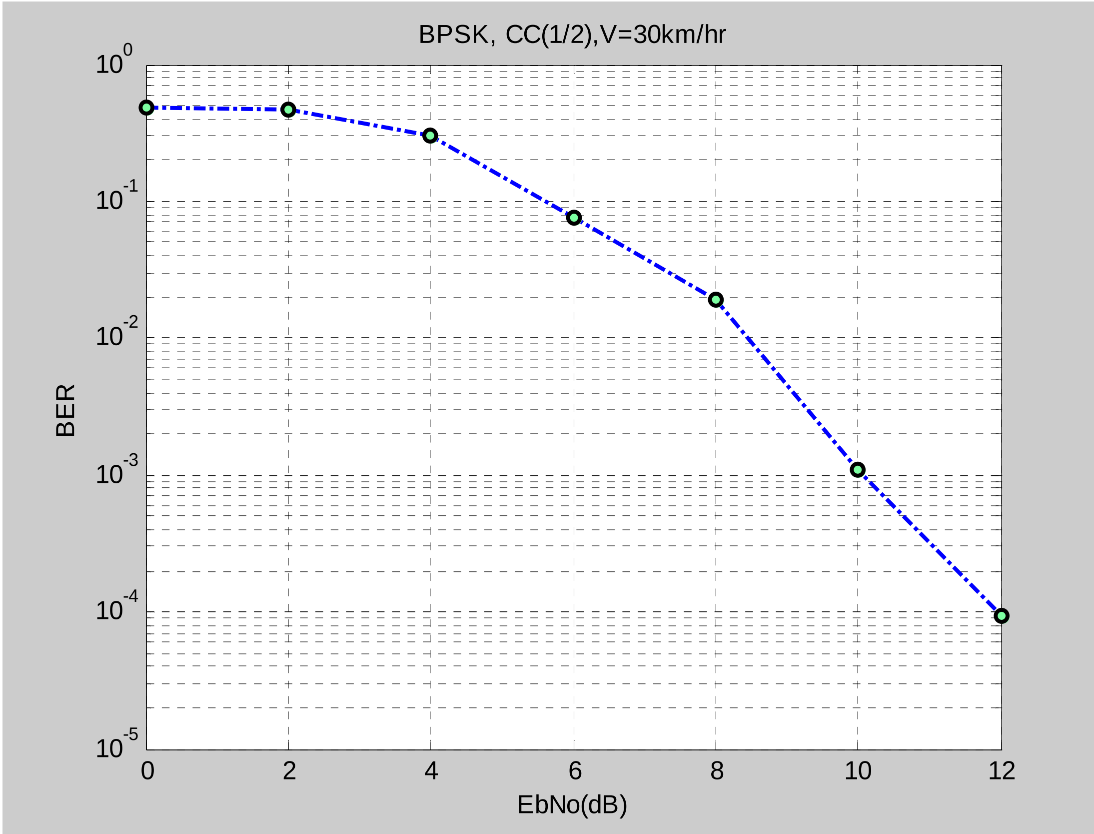


Figure 6.11 BER vs. E_b/N_o for BPSK ,CC(1/2), v=30 km/h

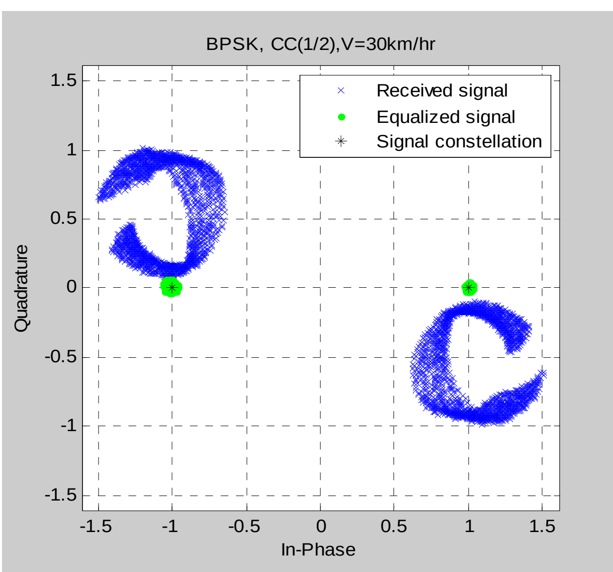
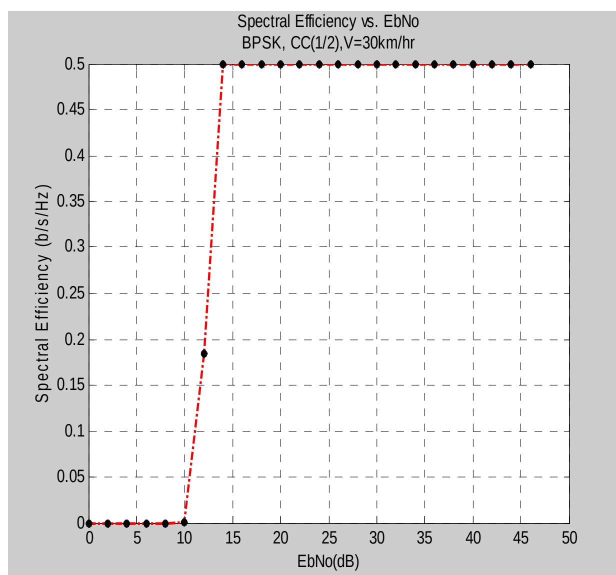


Figure 6.12 Scatter plots of BPSK, v=30km/hr



Figures 6.13 Spectral efficiency of BPSK, v=30 km/h.

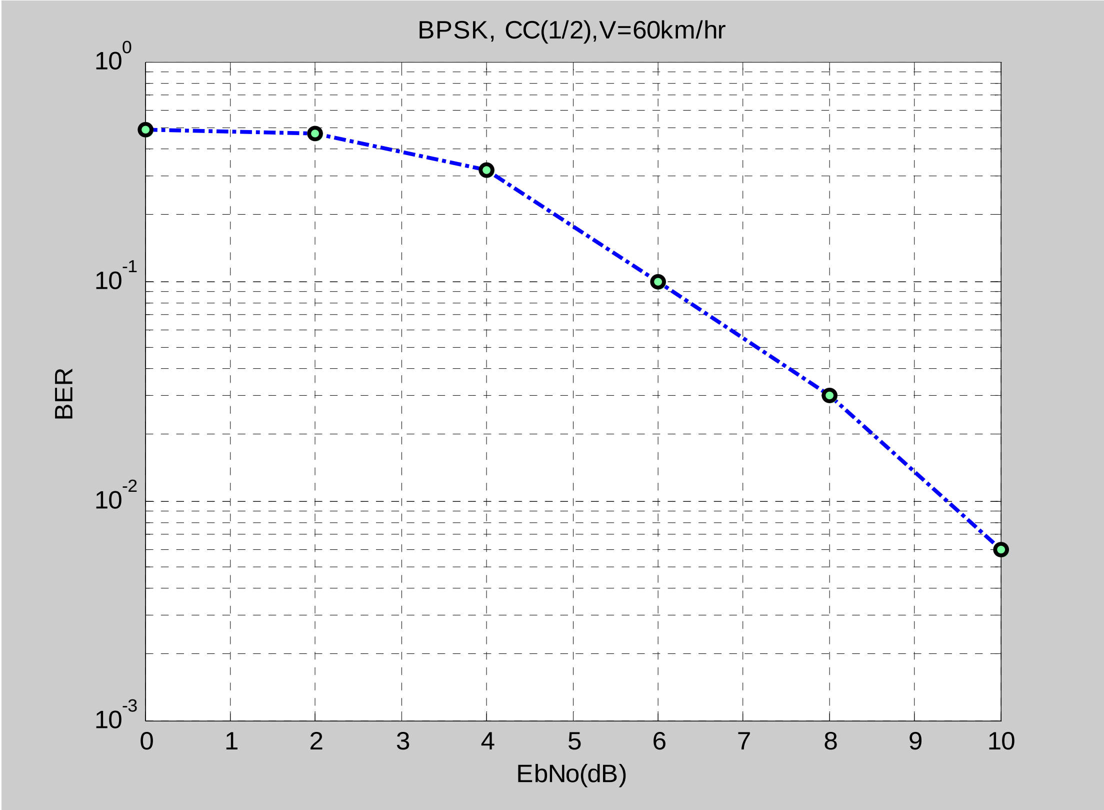


Figure 6.14 BER vs. E_b/N_o for BPSK ,CC(1/2), v=60 km/h

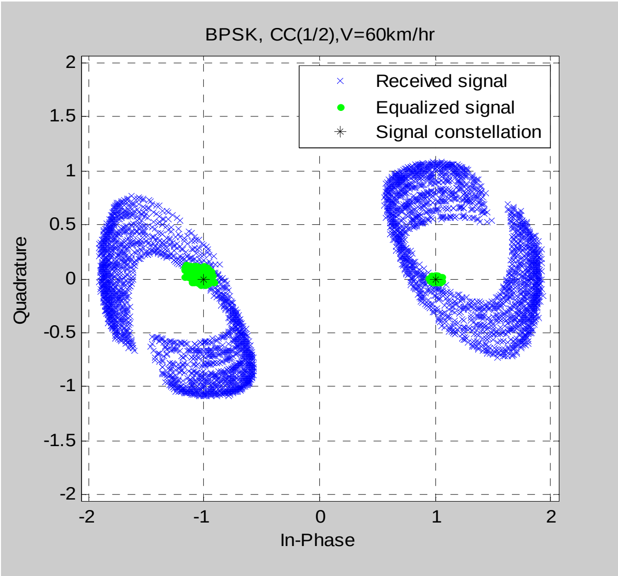
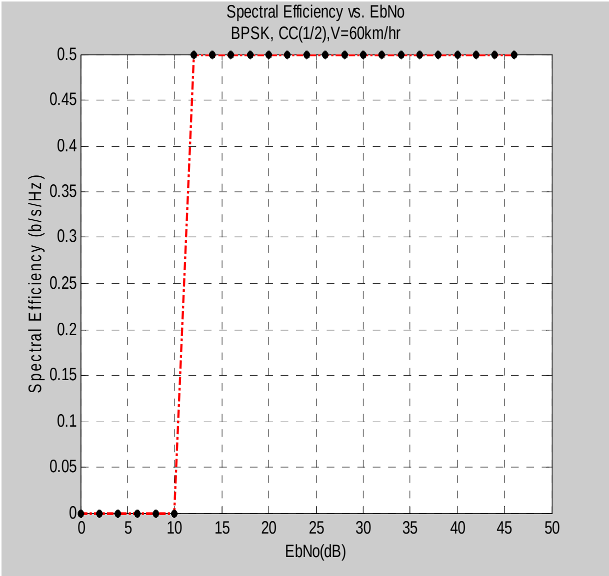


Figure 6.15 Scatter plots of BPSK, v=60km/hr



Figures 6.16 Spectral efficiency of BPSK, v=60 km/h.

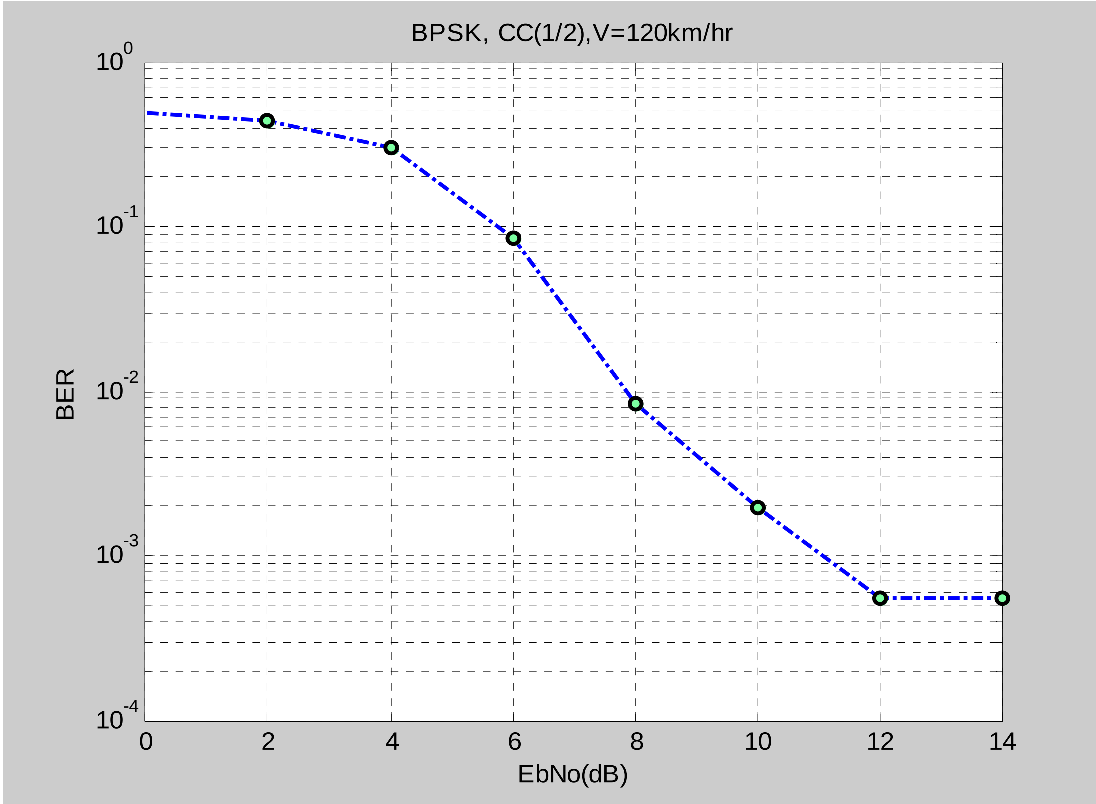
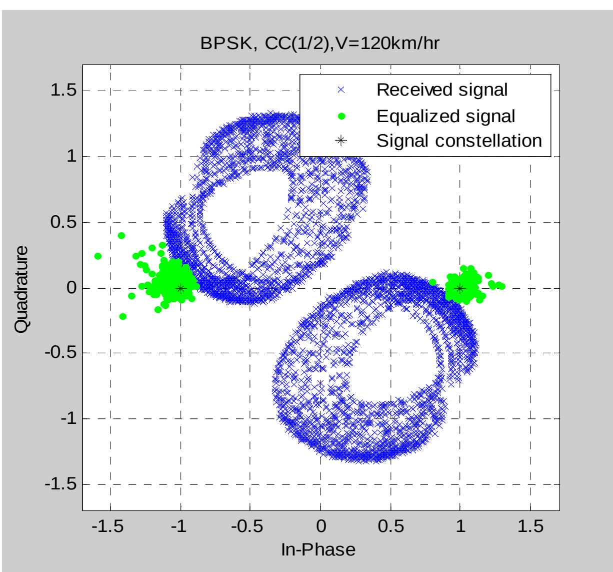


Figure 6.17 BER vs. E_b/N_o for BPSK ,CC(1/2), v=120 km/h



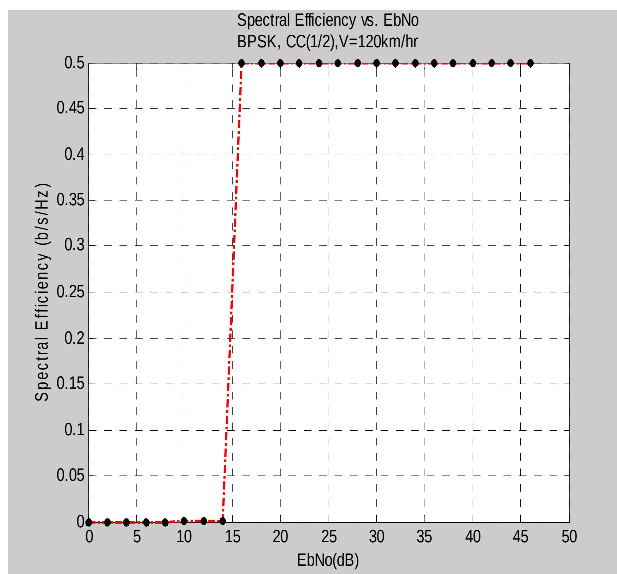


Figure 6.18 Scatter plots of BPSK, v=120km/hr

Figures 6.19 Spectral efficiency of BPSK, v=120km/

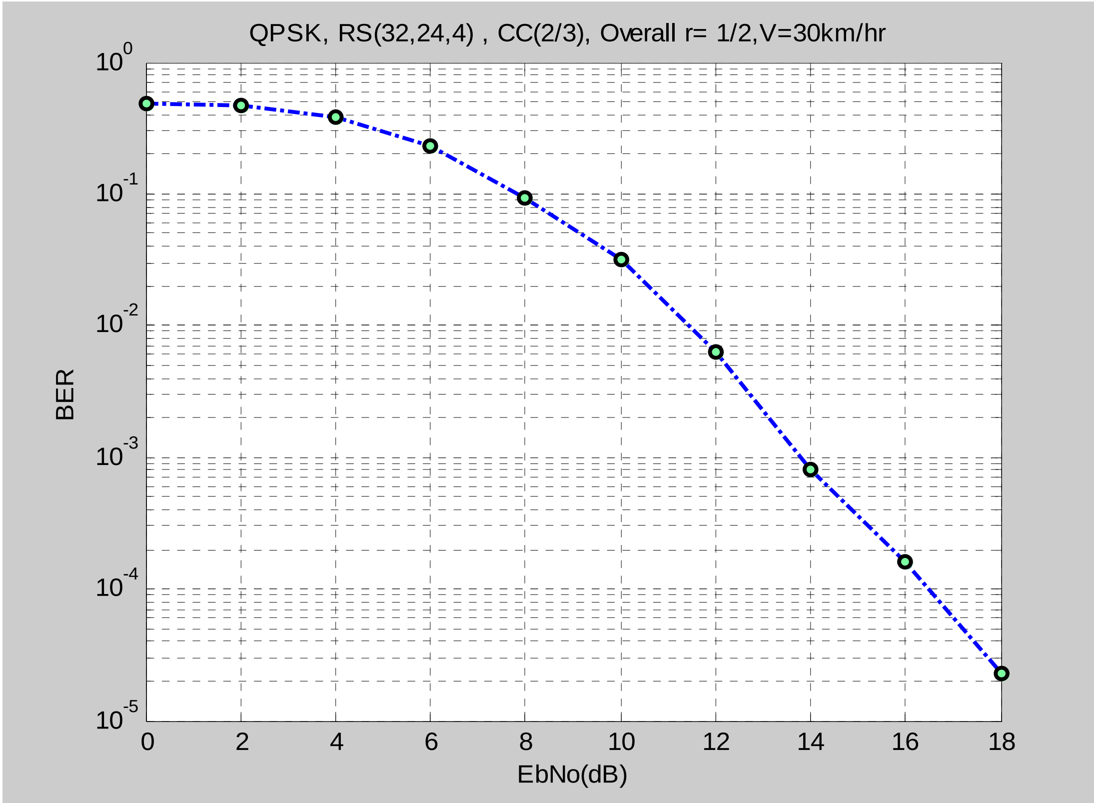


Figure 6.20 BER vs. E_b/N_o for QPSK , CC(2/3), RS(32,24,4) , v=30 km/h.

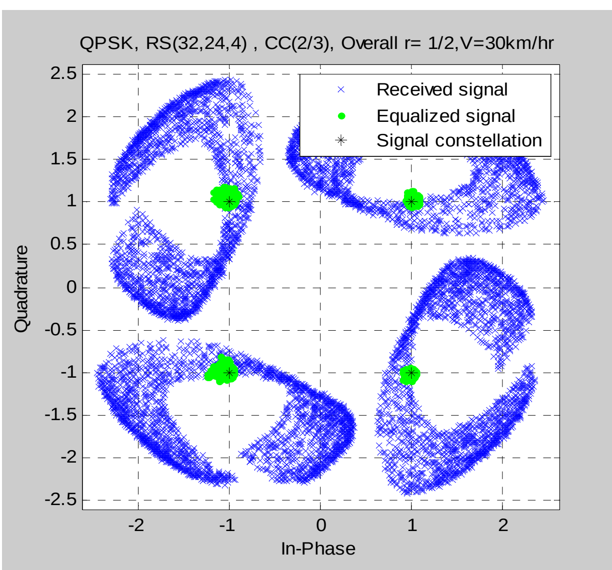
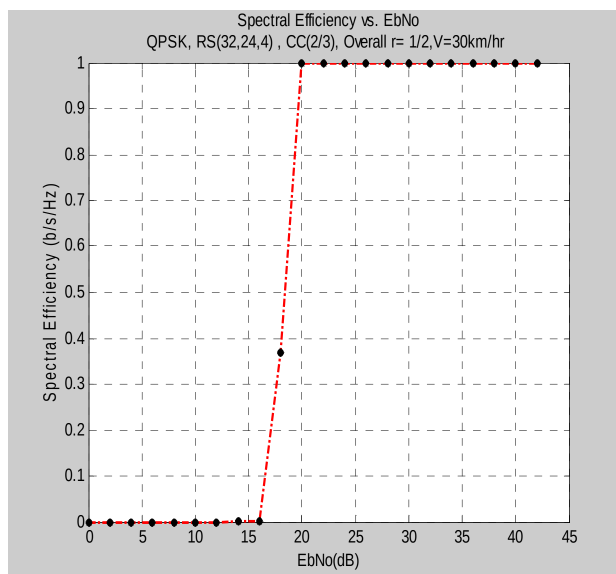


Figure 6.21 Scatter plots of QPSK, v=30km/hr



Figures 6.22 Spectral efficiency of QPSK, v=30 km/h.

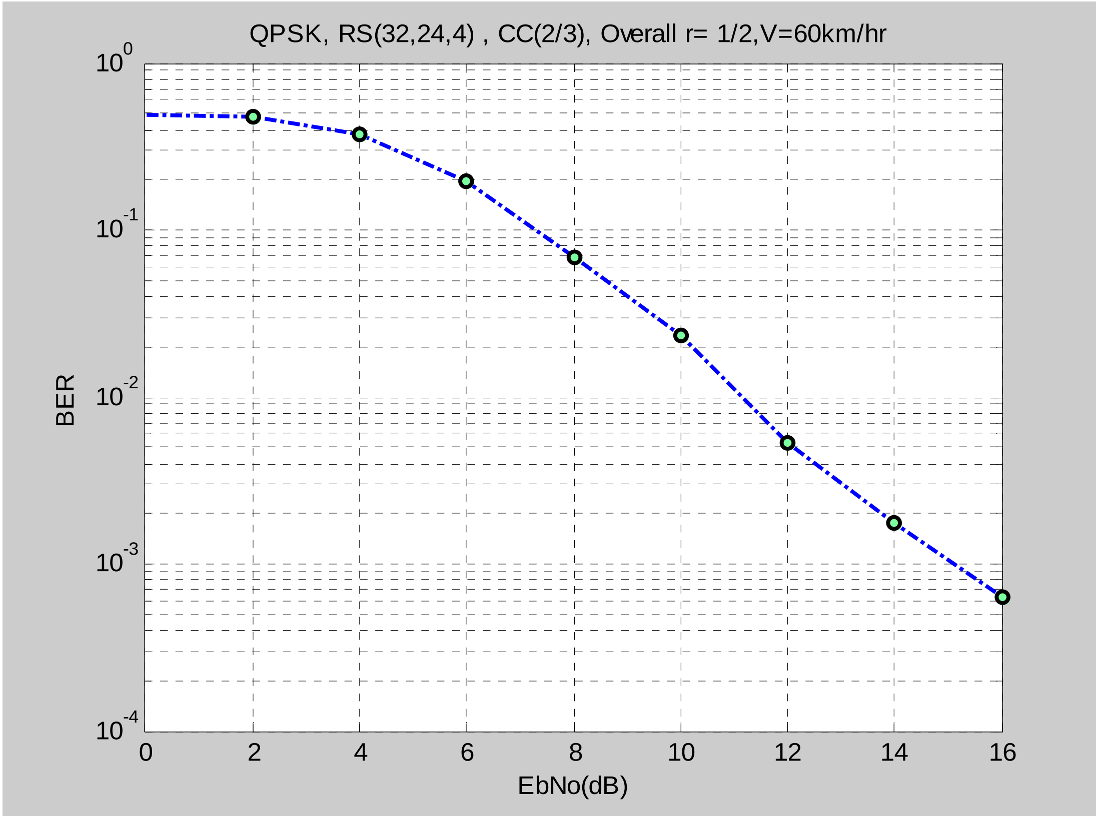


Figure 6.23 BER vs. E_b/N_o for QPSK , CC(2/3), RS(32,24,4) , v=60 km/h.

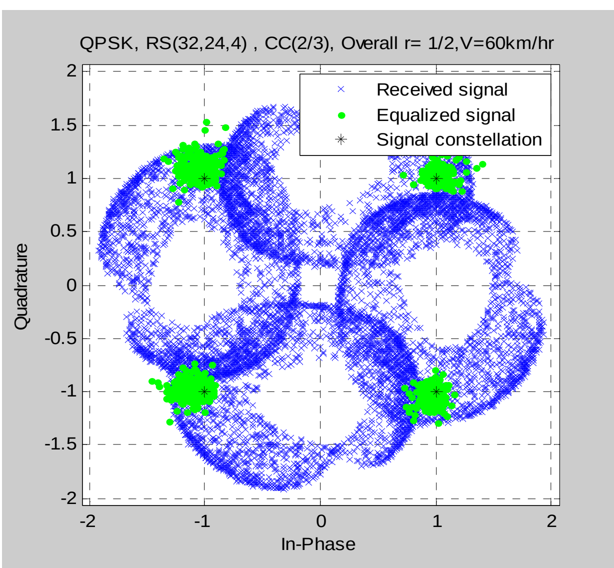
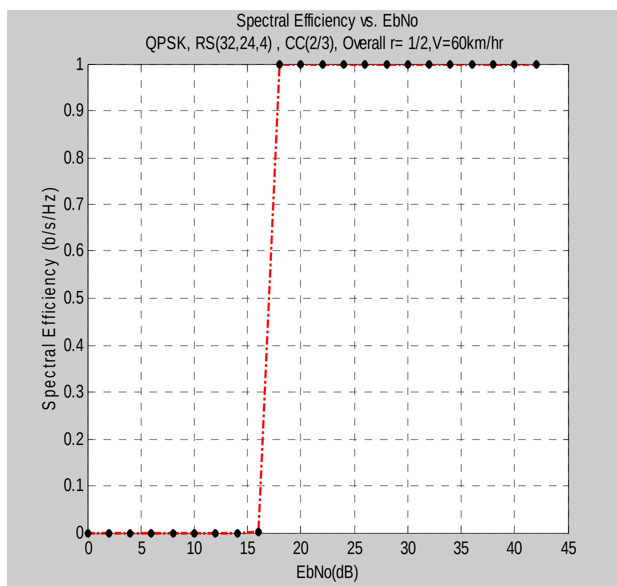


Figure 6.24 Scatter plots of QPSK, v=60 km/hr



Figures 6.25 Spectral efficiency of QPSK, v=60 km/hr

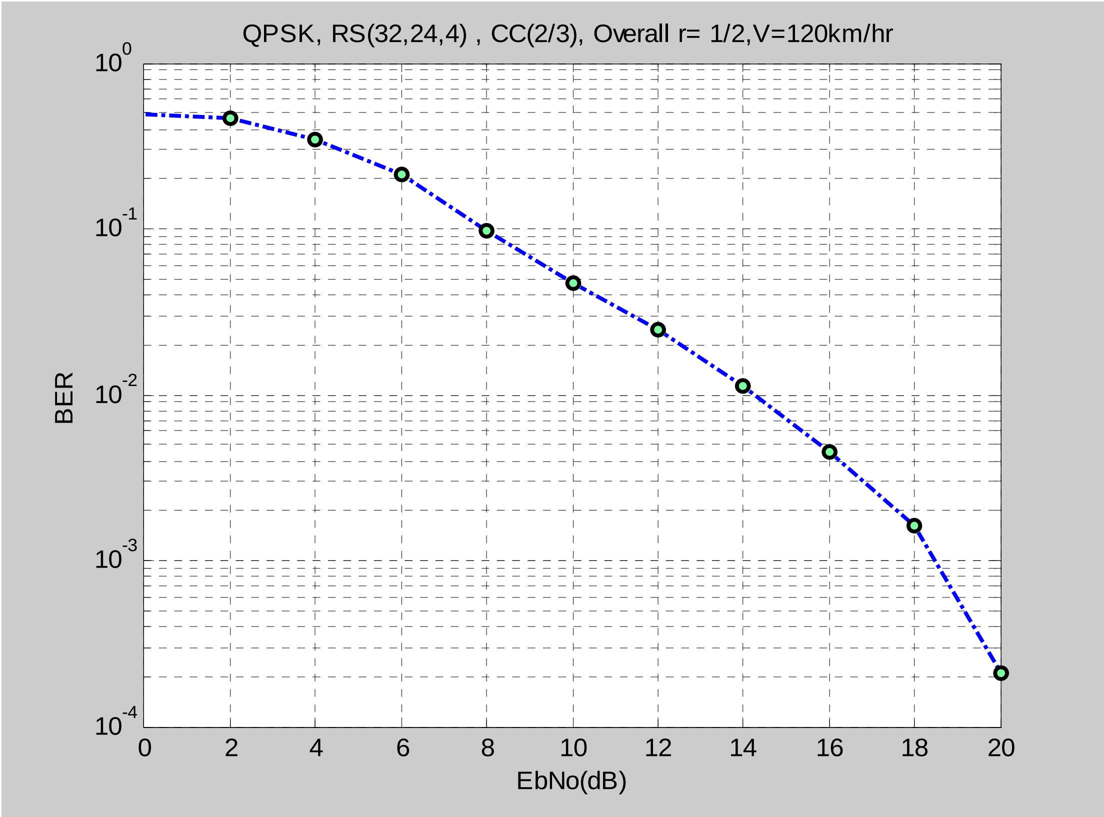


Figure 6.26 BER vs. E_b/N_o for QPSK , CC(2/3), RS(32,24,4) , v=120 km/h.

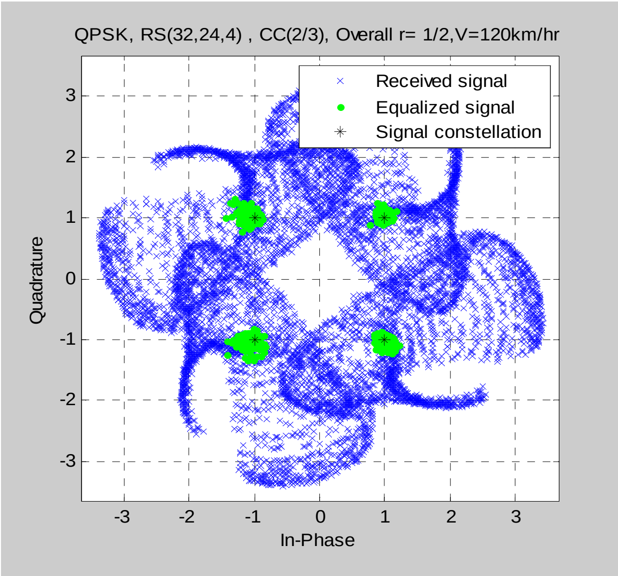
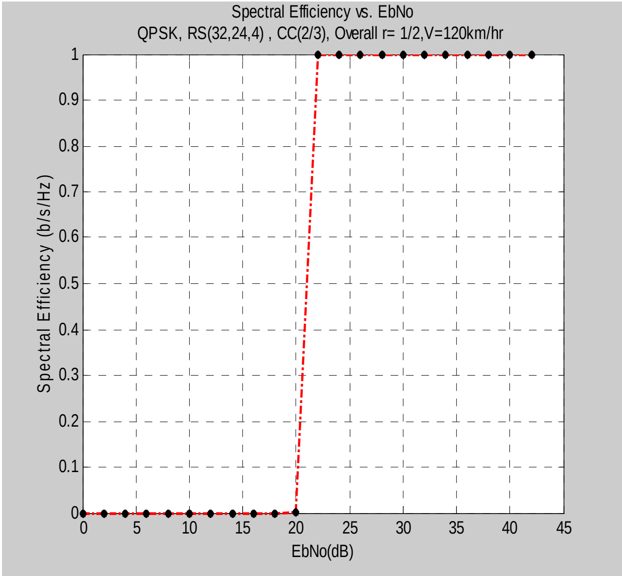


Figure 6.27 Scatter plots of QPSK, v=120km/hr



Figures 6.28 Spectral efficiency of QPSK, v=120 km/hr

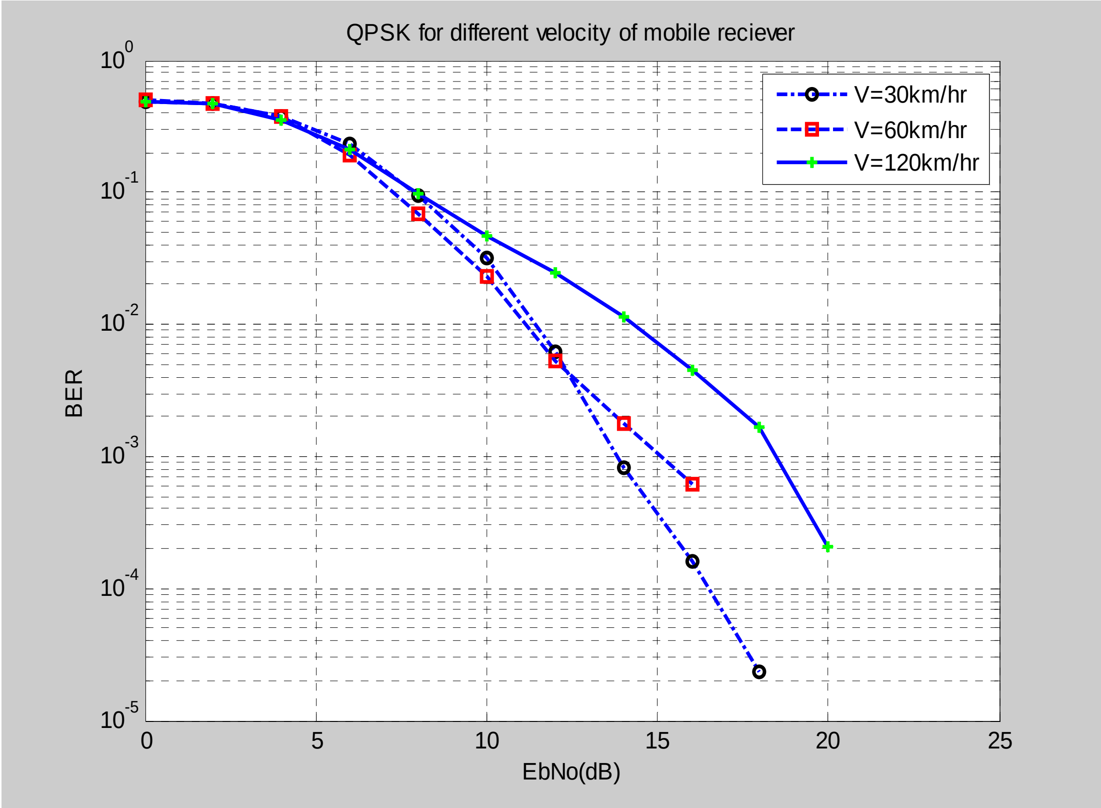


Figure 6.29 BER vs. E_b/N_o for QPSK , CC(2/3), RS(32,24,4) , v=30, 60, 120 km/h.

The figures above of Mobile WiMAX simulation depict results obtained for different velocities. It is shown that the velocity of the user plays an essential role in the coded BER curve, where, as expected, the lower the velocity the better the results. That happens because when the velocity increases, the Doppler shift will be larger.

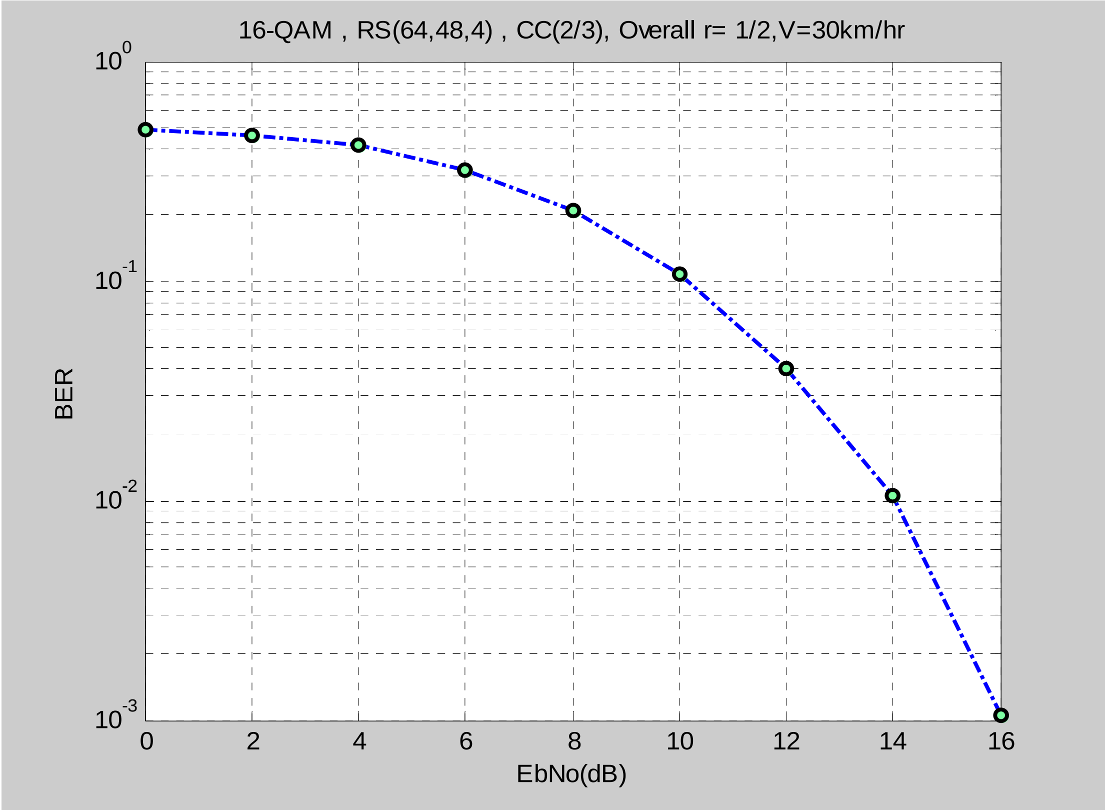


Figure 6.30 BER vs. E_b/N_o for 16 QAM, CC(2/3), RS(64,48,4) , v=30 km/h.

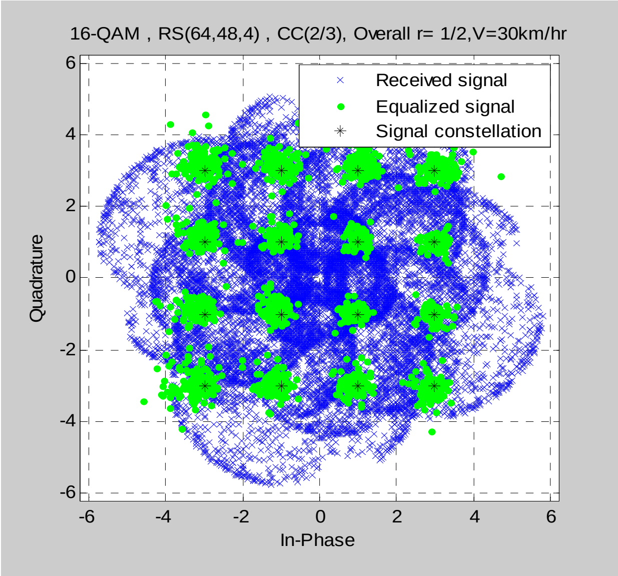
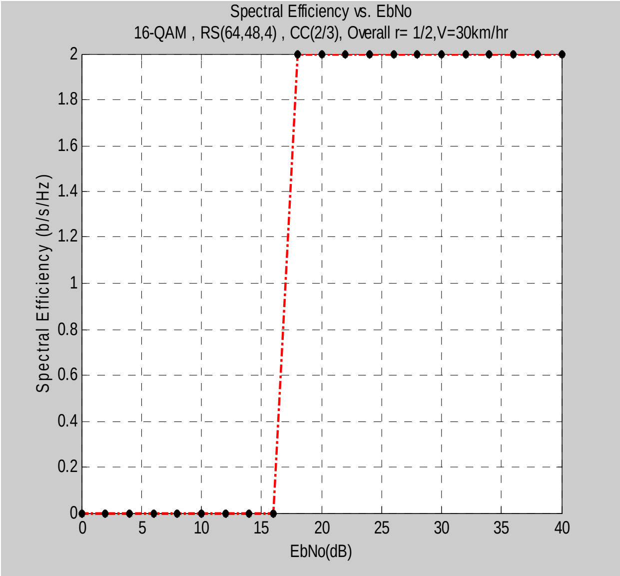


Figure 6.31 Scatter plots of 16 QAM, v=30km/hr



Figures 6.32 Spectral efficiency of 16 QAM, v=30 km/hr

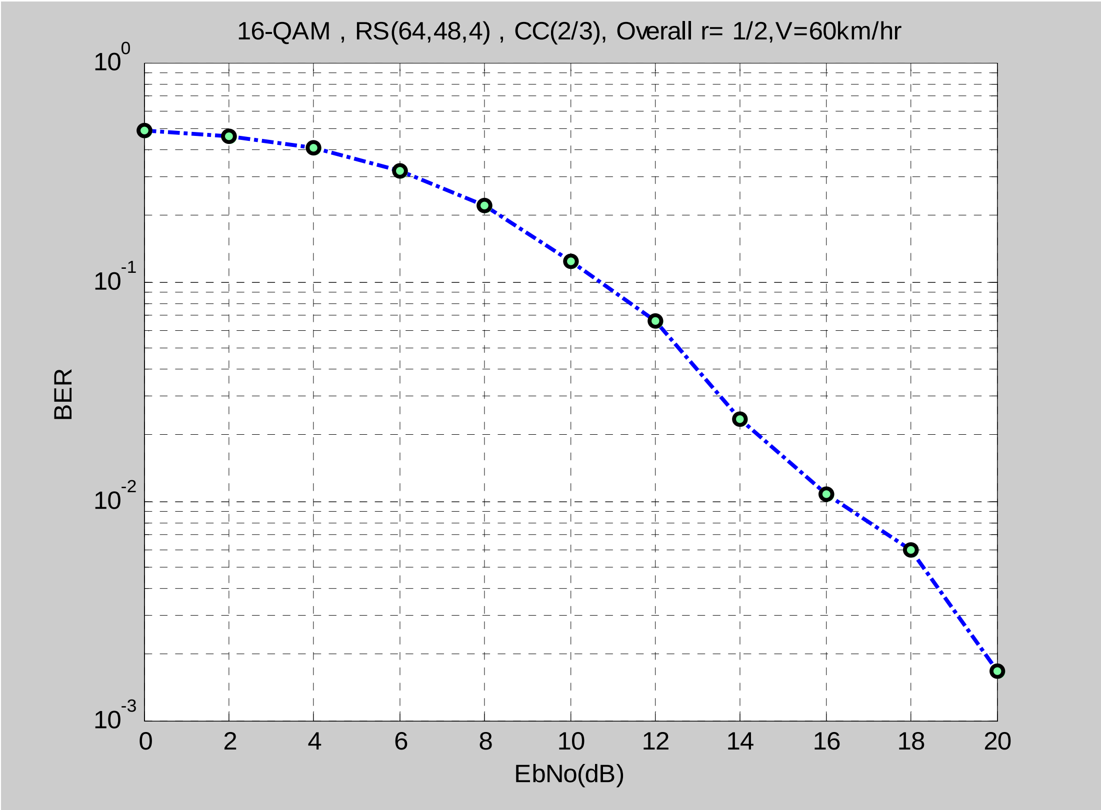


Figure 6.33 BER vs. E_b/N_o for 16 QAM, CC(2/3), RS(64,48,4) , v=60 km/h.

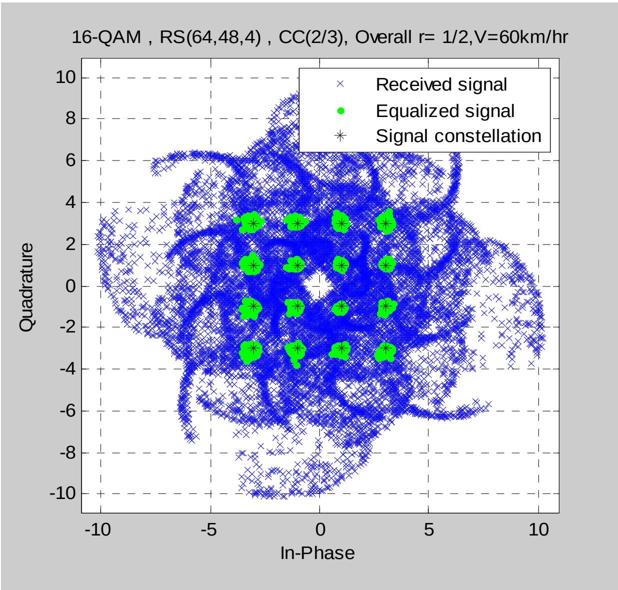
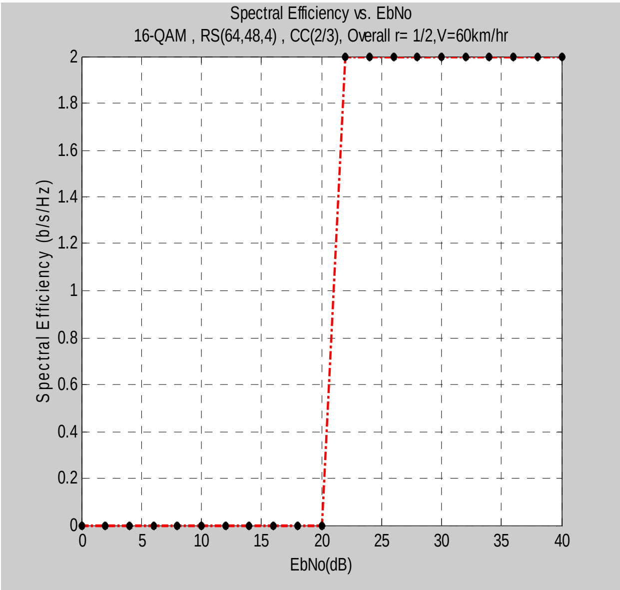


Figure 6.34 Scatter plots of 16 QAM, v=60km/hr



Figures 6.35 Spectral efficiency of 16 QAM, v=60 km/hr

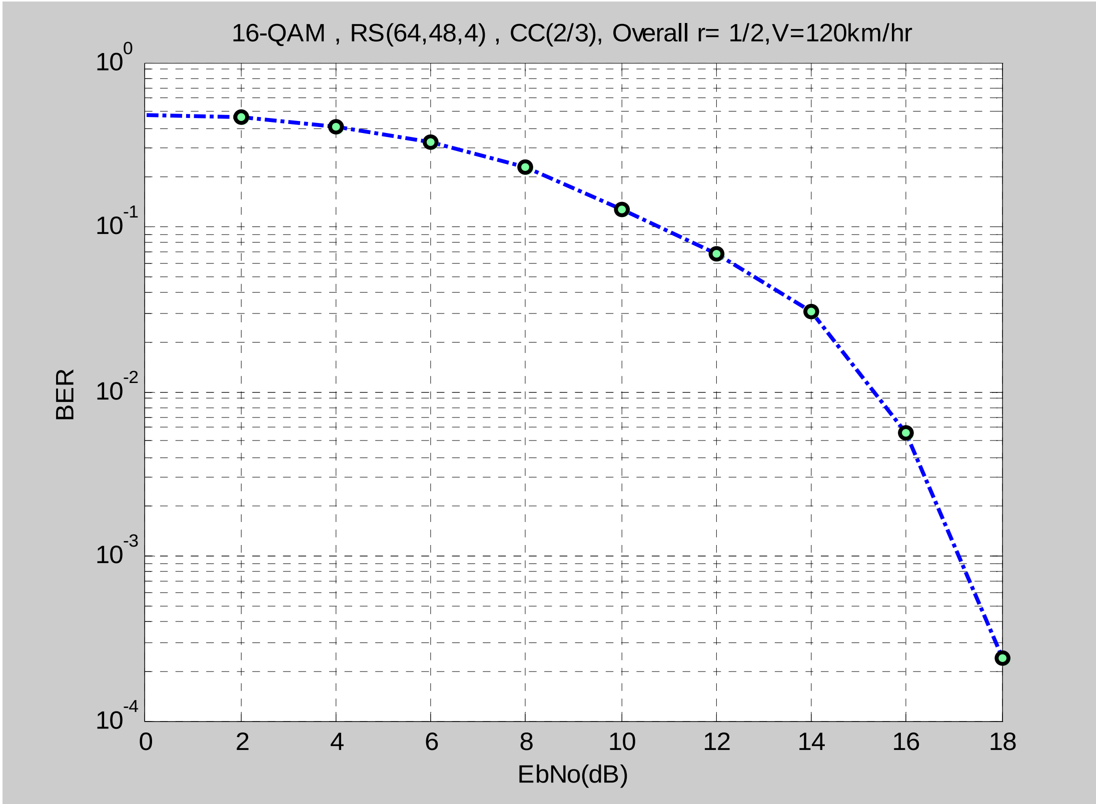


Figure 6.36 BER vs. E_b/N_o for 16 QAM, CC(2/3), RS(64,48,4) , v=120 km/h.

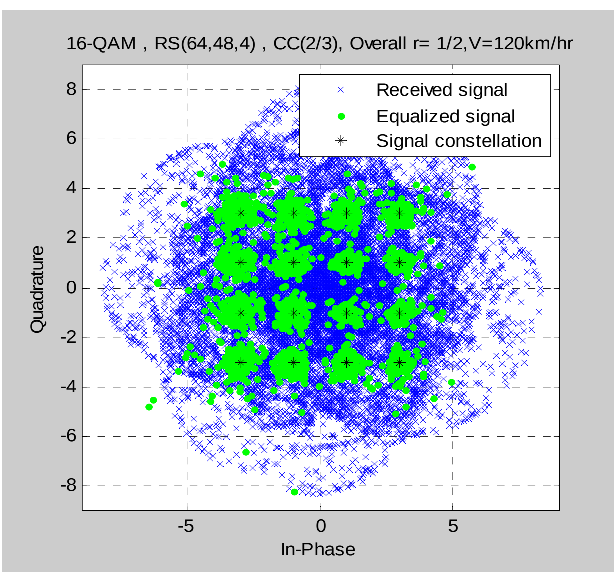
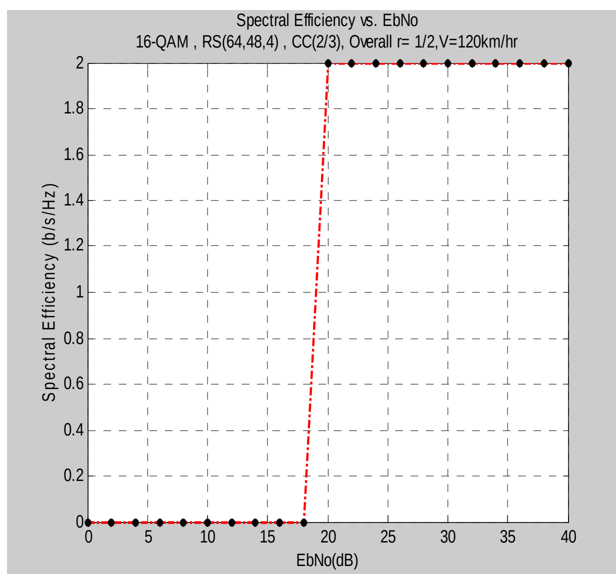


Figure 6.37 Scatter plots of 16 QAM, v=120km/hr



Figures 6.38 Spectral efficiency of 16 QAM, v=120 km/h.

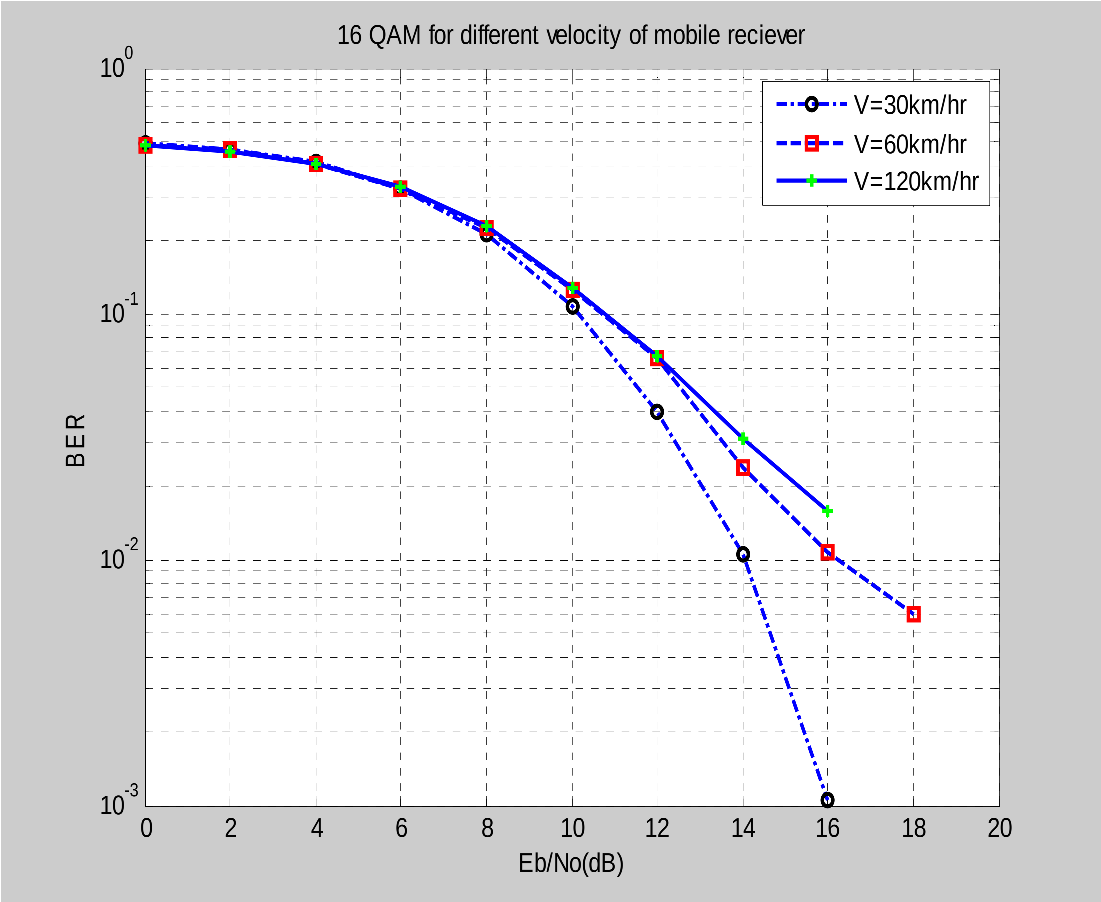


Figure 6.39 BER vs. E_b/N_o for 16 QAM, CC(2/3), RS(64,48,4) , v=30, 60, 120 km/h.

6.3 Simulation Results of Fixed WiMAX with MC-CDMA system

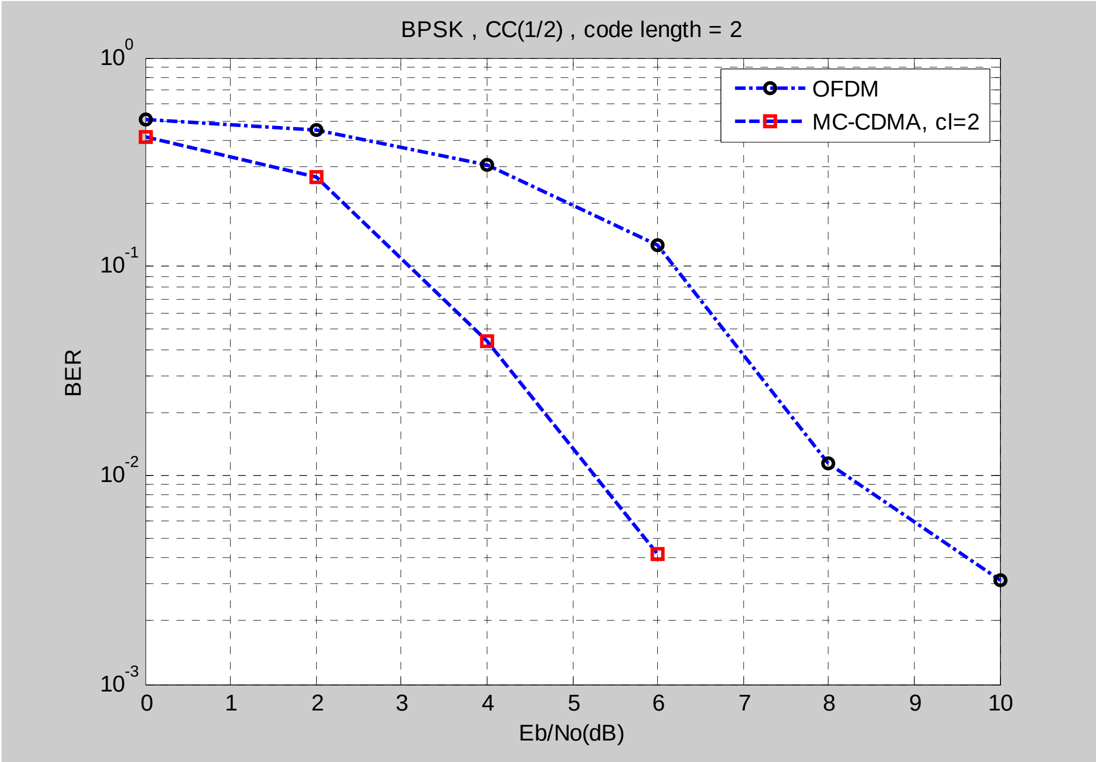


Figure 6.40 BER vs. E_b/N_o of BPSK for OFDM and MC-CDMA, cl =2.

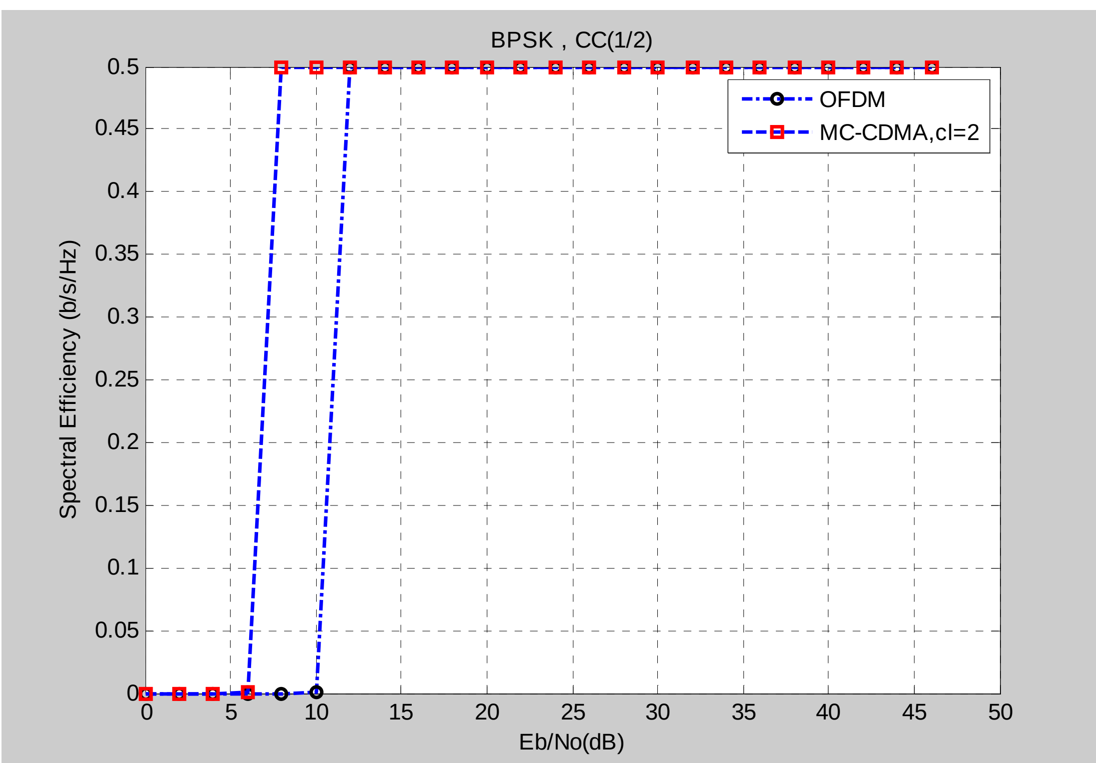


Figure 6.41 Spectral Efficiency of BPSK for OFDM and MC-CDMA, cl =2.

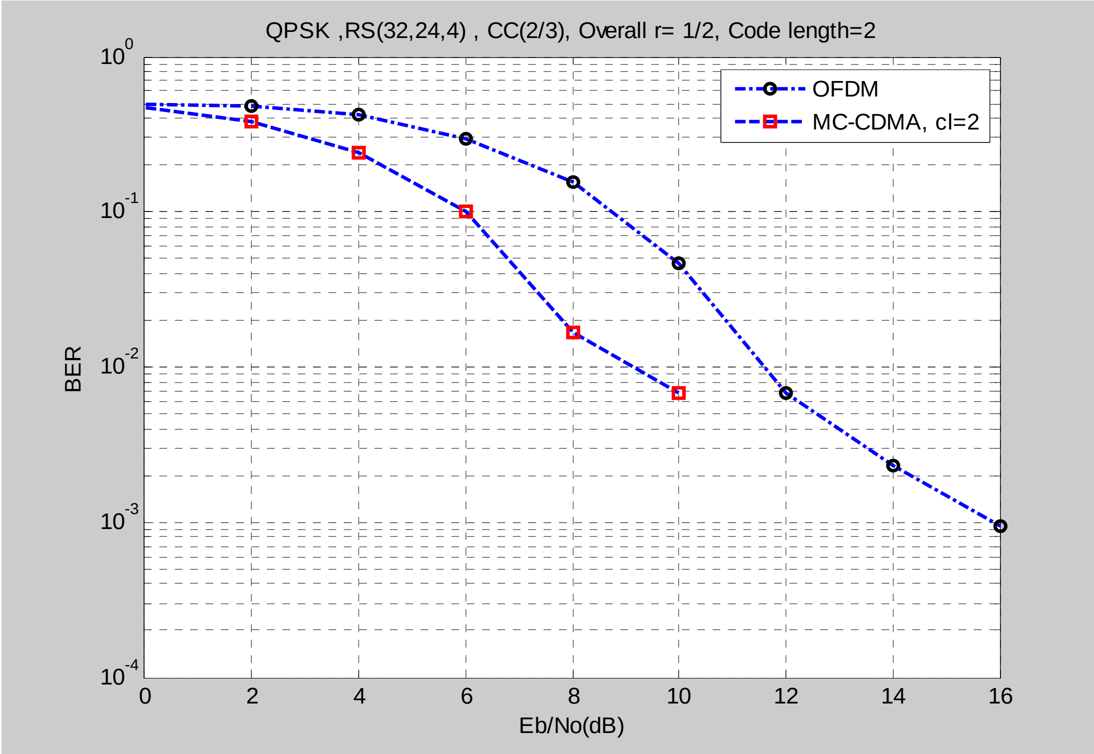


Figure 6.42 BER vs. E_b/N_o of QPSK for OFDM and MC-CDMA, cl =2.

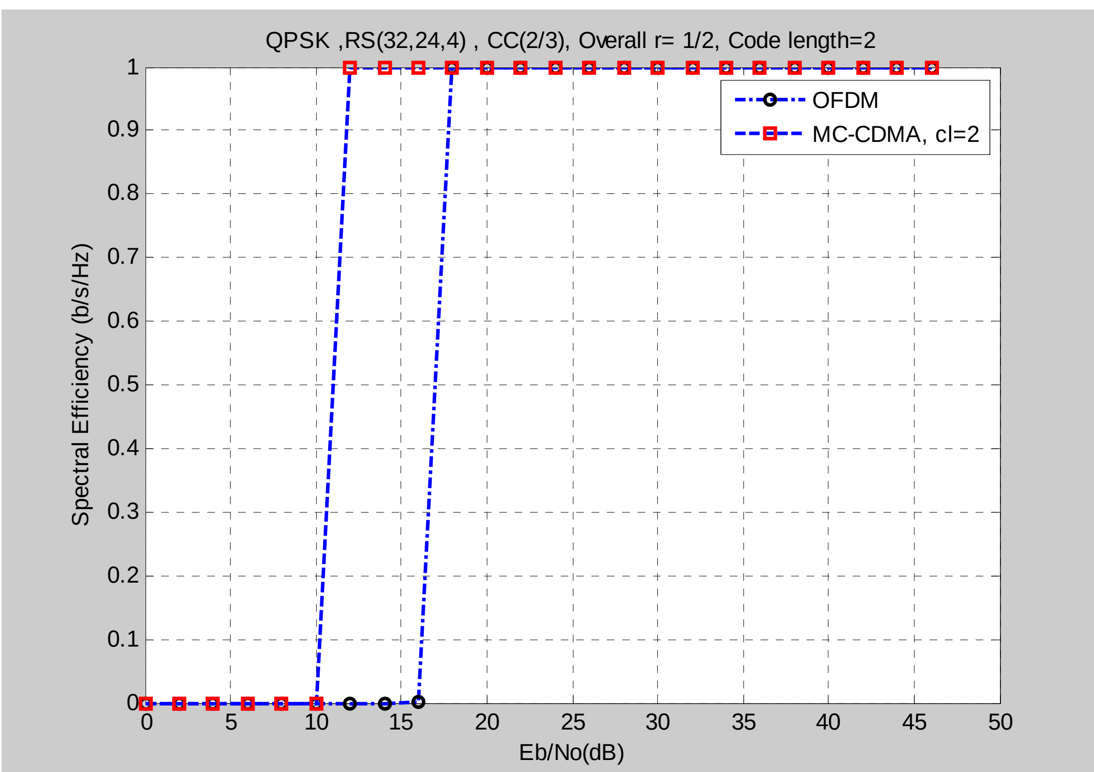


Figure 6.43 Spectral Efficiency of QPSK for OFDM and MC-CDMA, cl =2.

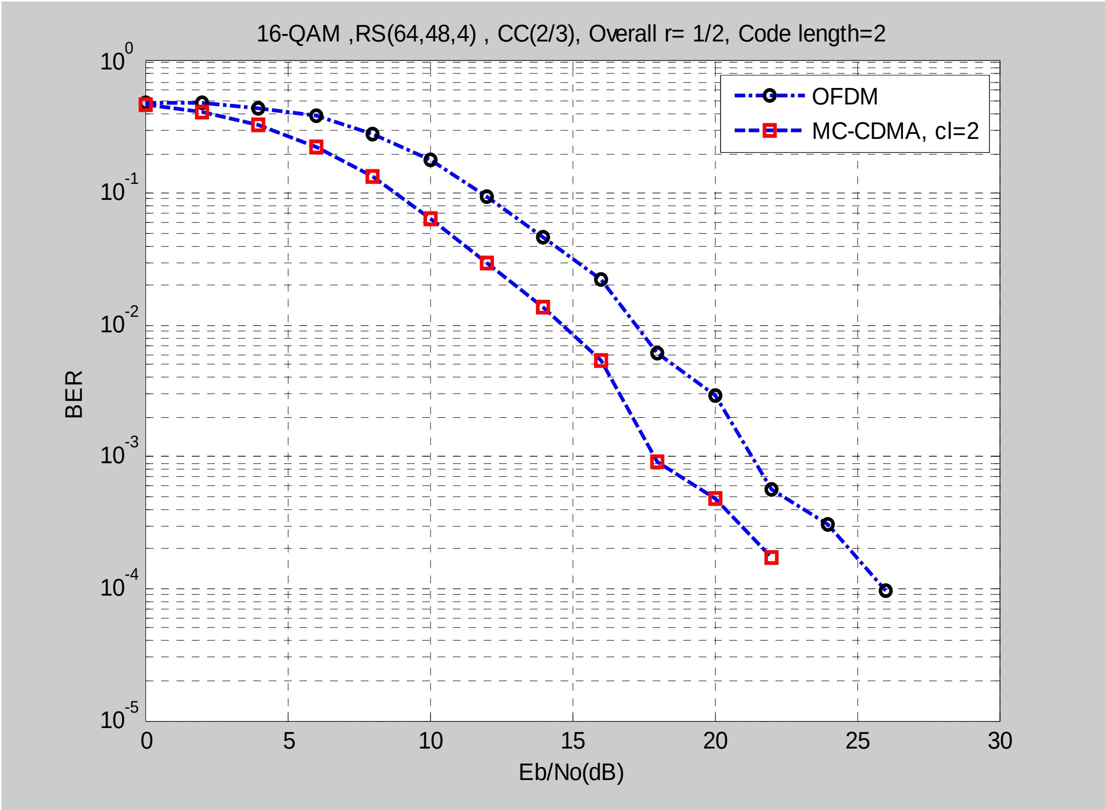


Figure 6.44 BER vs. E_b/N_o of 16 QAM for OFDM and MC-CDMA, cl =2.

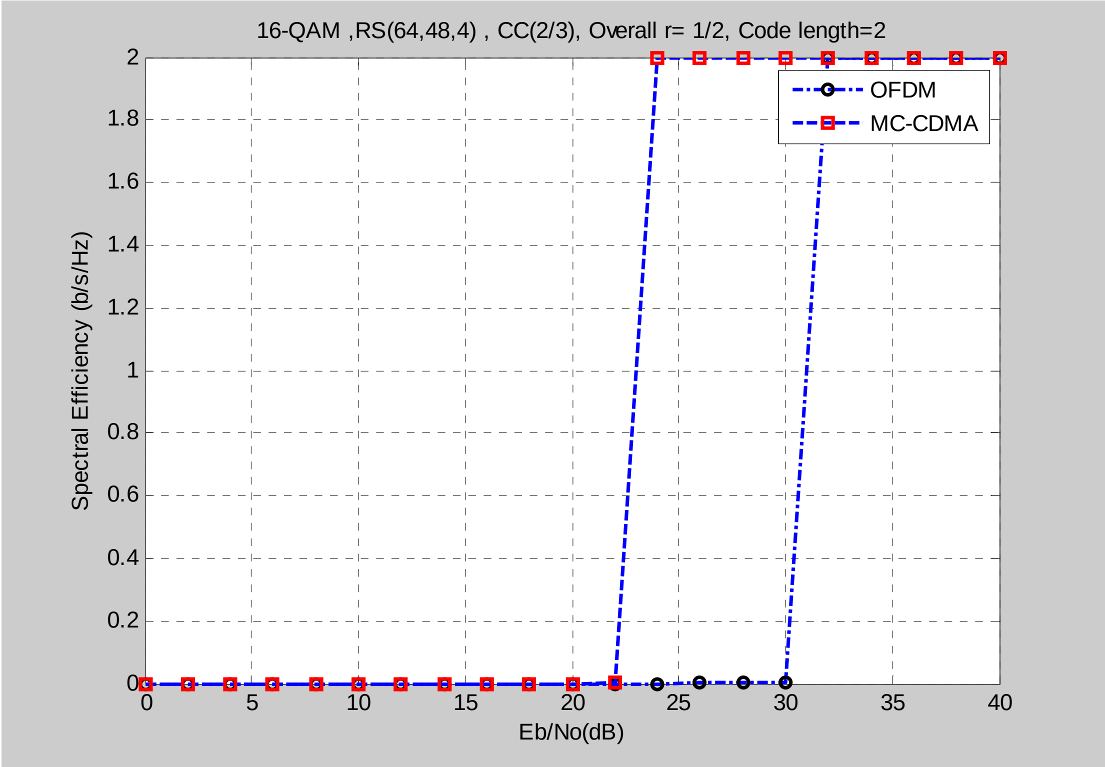


Figure 6.45 Spectral Efficiency of 16 QAM for OFDM and MC-CDMA, cl =2.

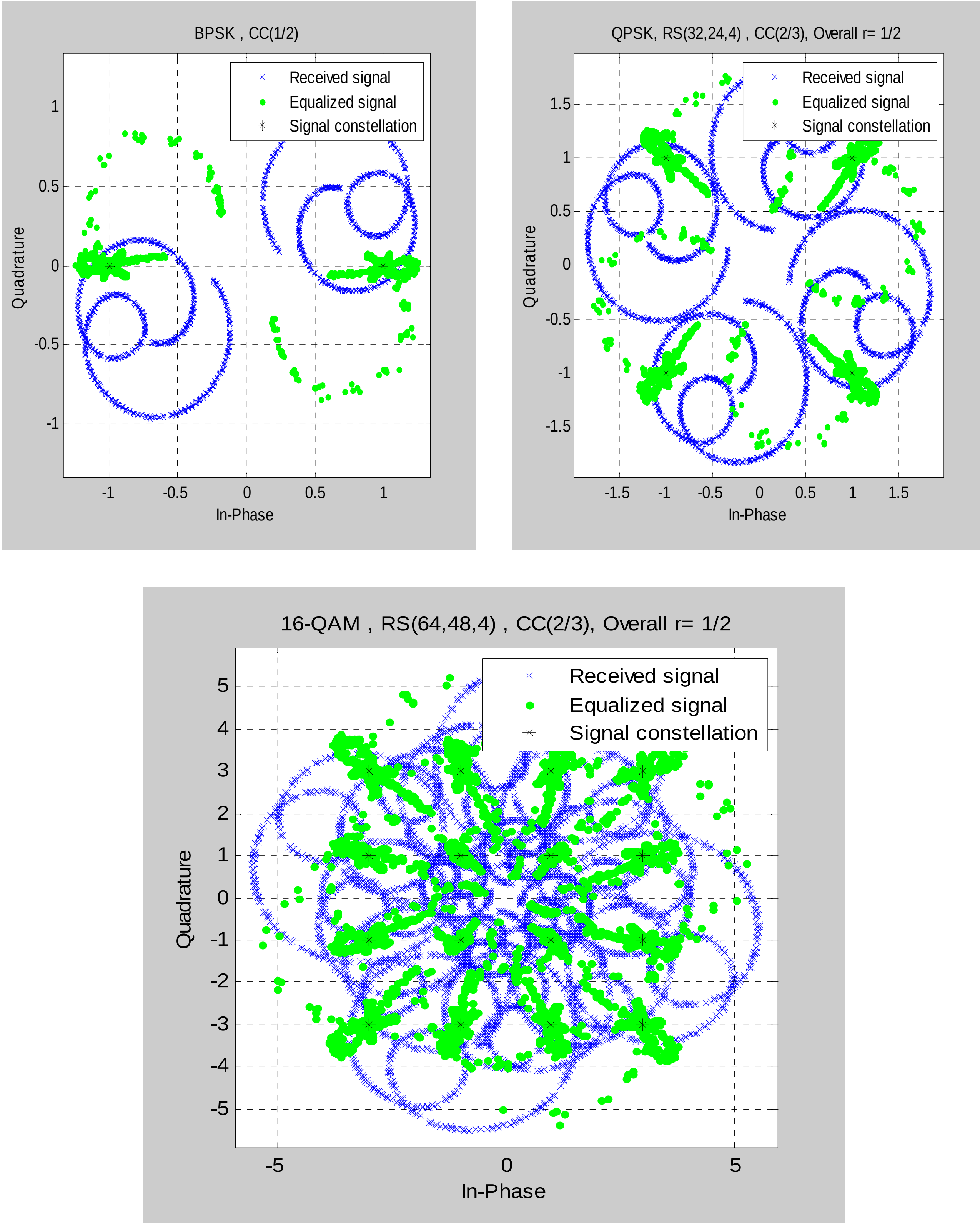


Figure 6.46 Scatter plots of MC-CDMA for BPSK,QPSK & 16 QAM modulation

6.4 Simulation Results of Mobile WiMAX with MC-CDMA system

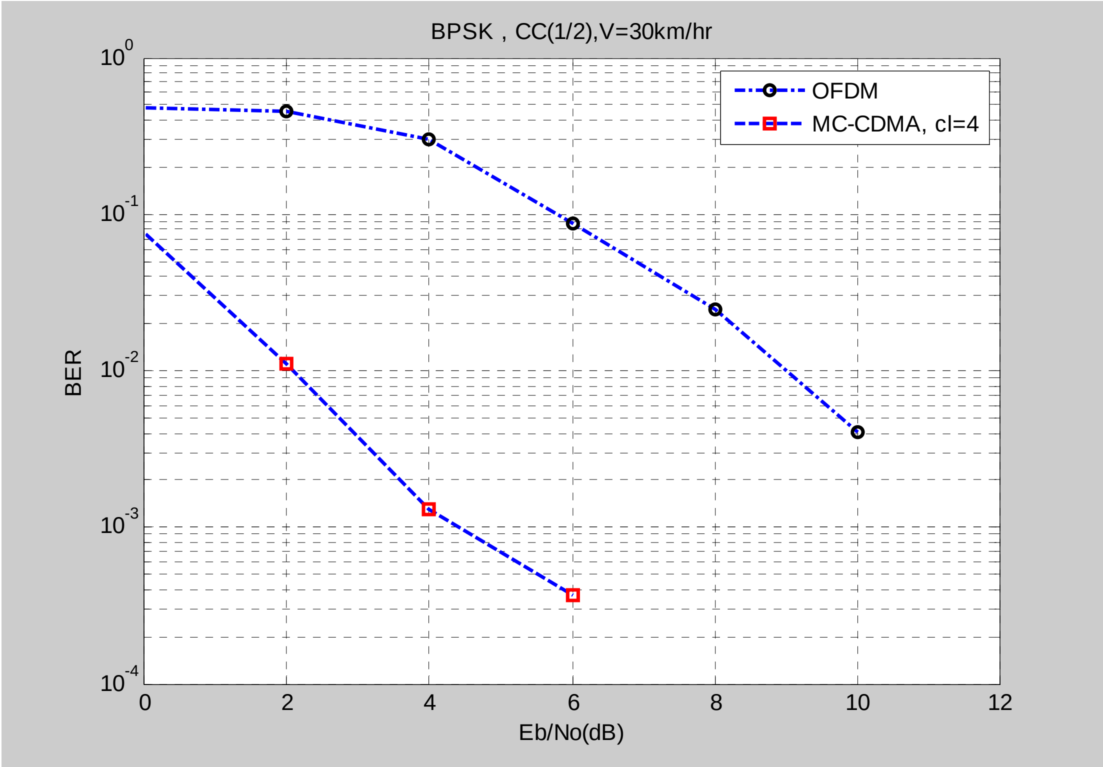


Figure 6.47 BER vs. E_b/N_o of BPSK for OFDM and MC-CDMA, (cl = 4, v = 30 km/h)

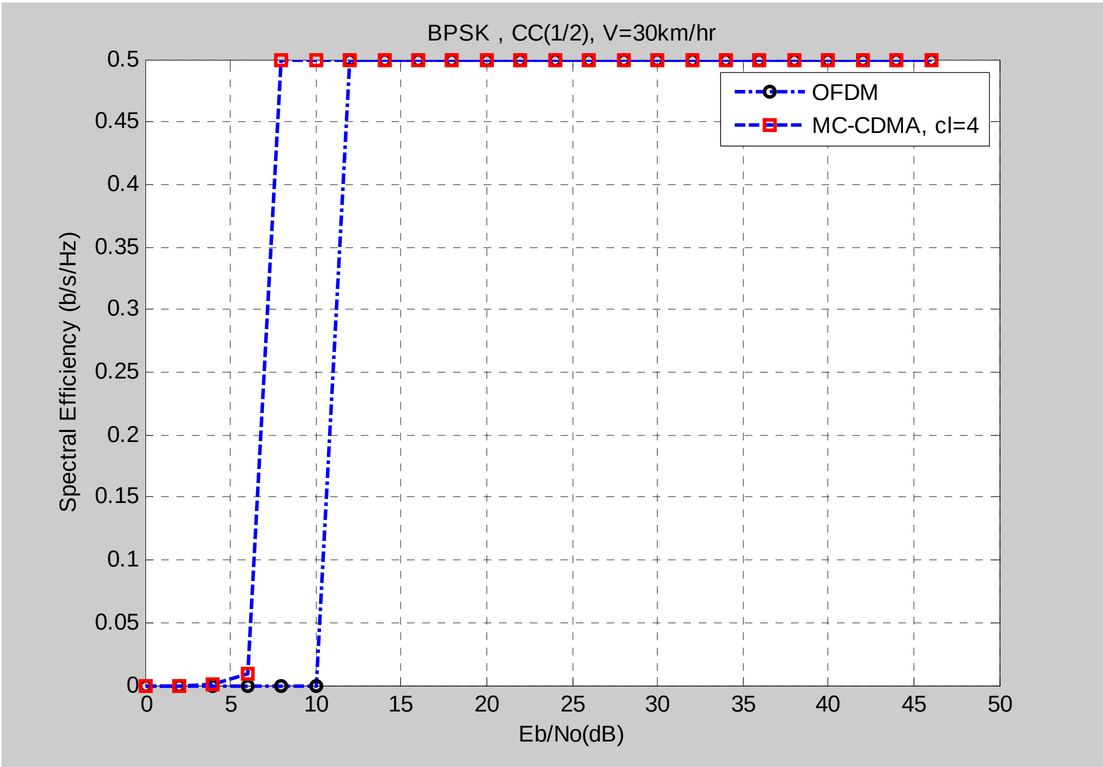


Figure 6.48 Spectral Efficiency of BPSK for OFDM and MC-CDMA, (cl = 4, v = 30 km/h)

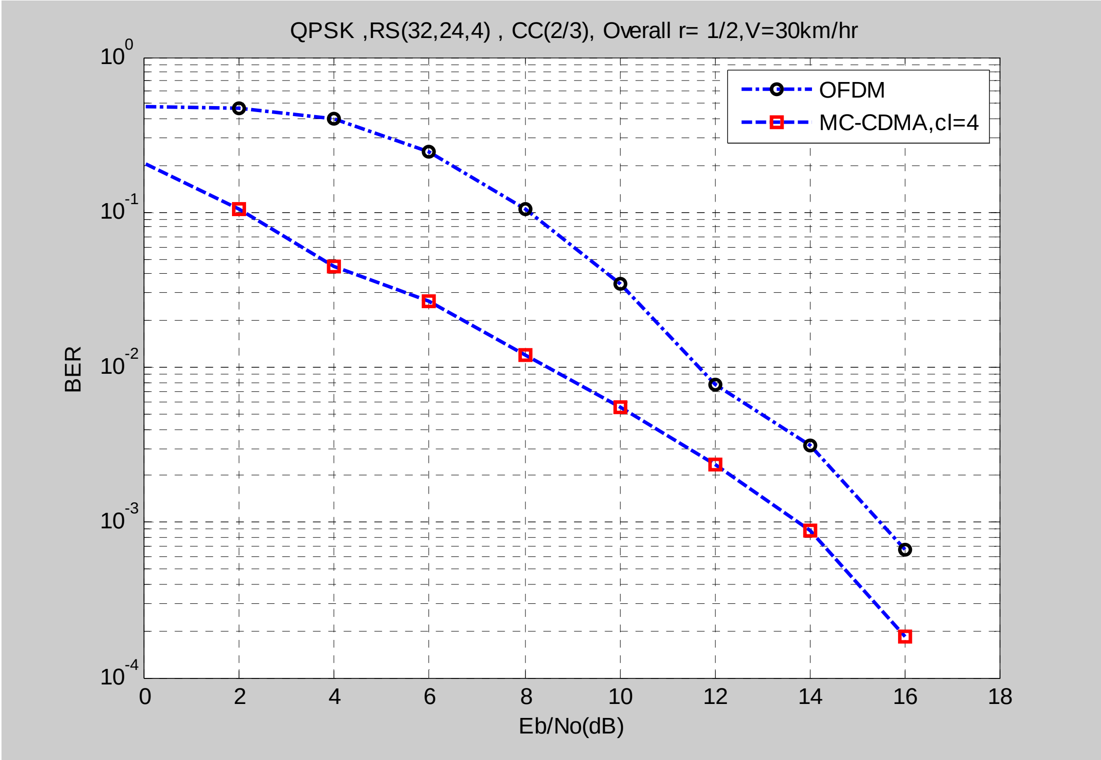


Figure 6.49 BER vs. E_b/N_o of QPSK for OFDM and MC-CDMA, (cl = 4, v = 30 km/h)

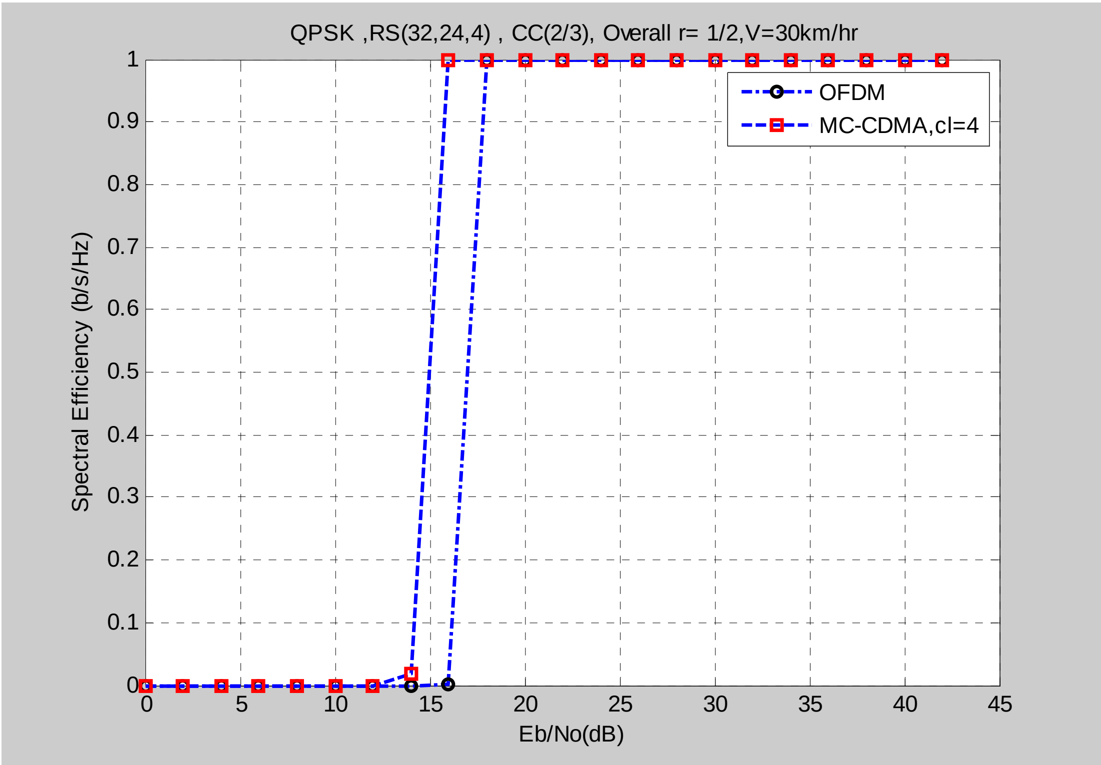


Figure 6.50 Spectral Efficiency of QPSK for OFDM and MC-CDMA, (cl = 4, v = 30 km/h)

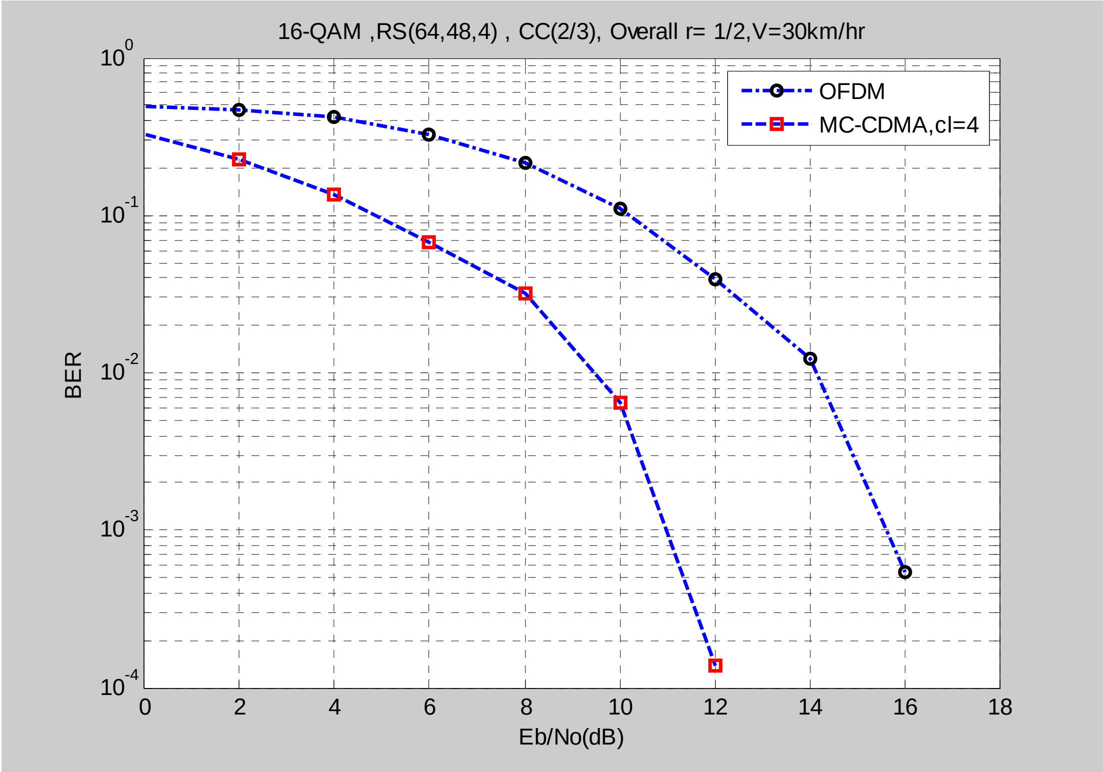


Figure 6.51 BER vs. E_b/N_o of 16 QAM for OFDM and MC-CDMA, (cl = 4, v = 30 km/h)

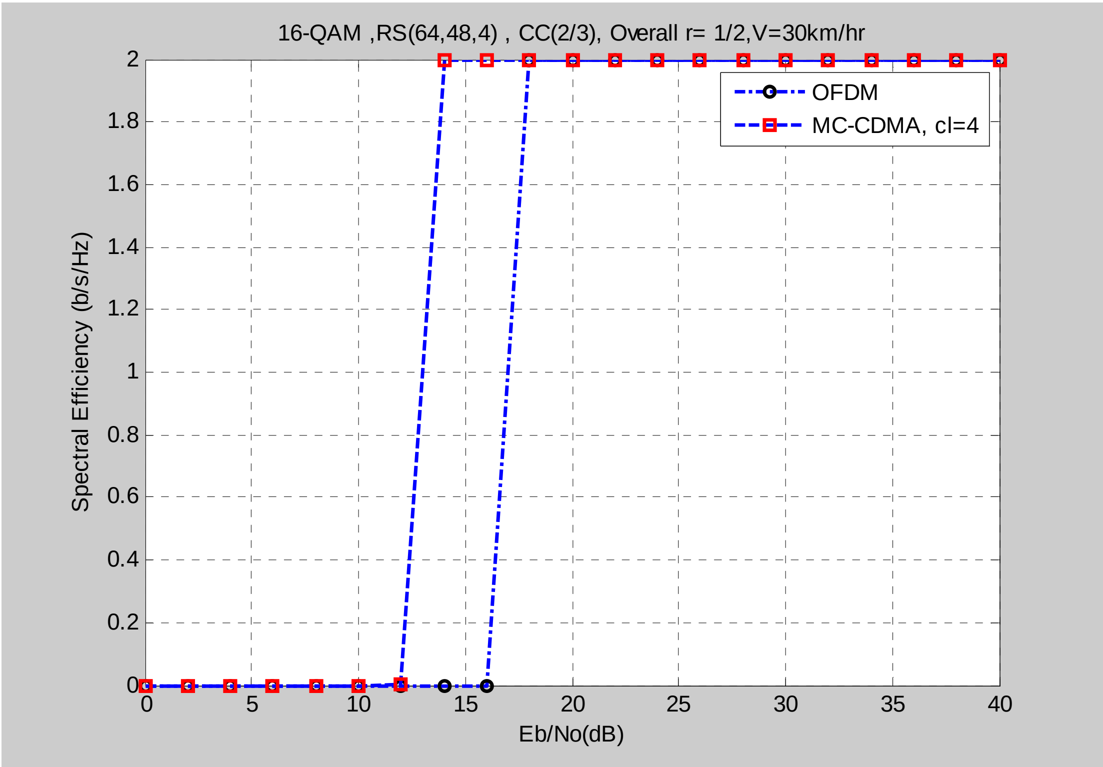


Figure 6.52 Spectral Efficiency of 16 QAM for OFDM and MC-CDMA, (cl = 4, v = 30 km/h)

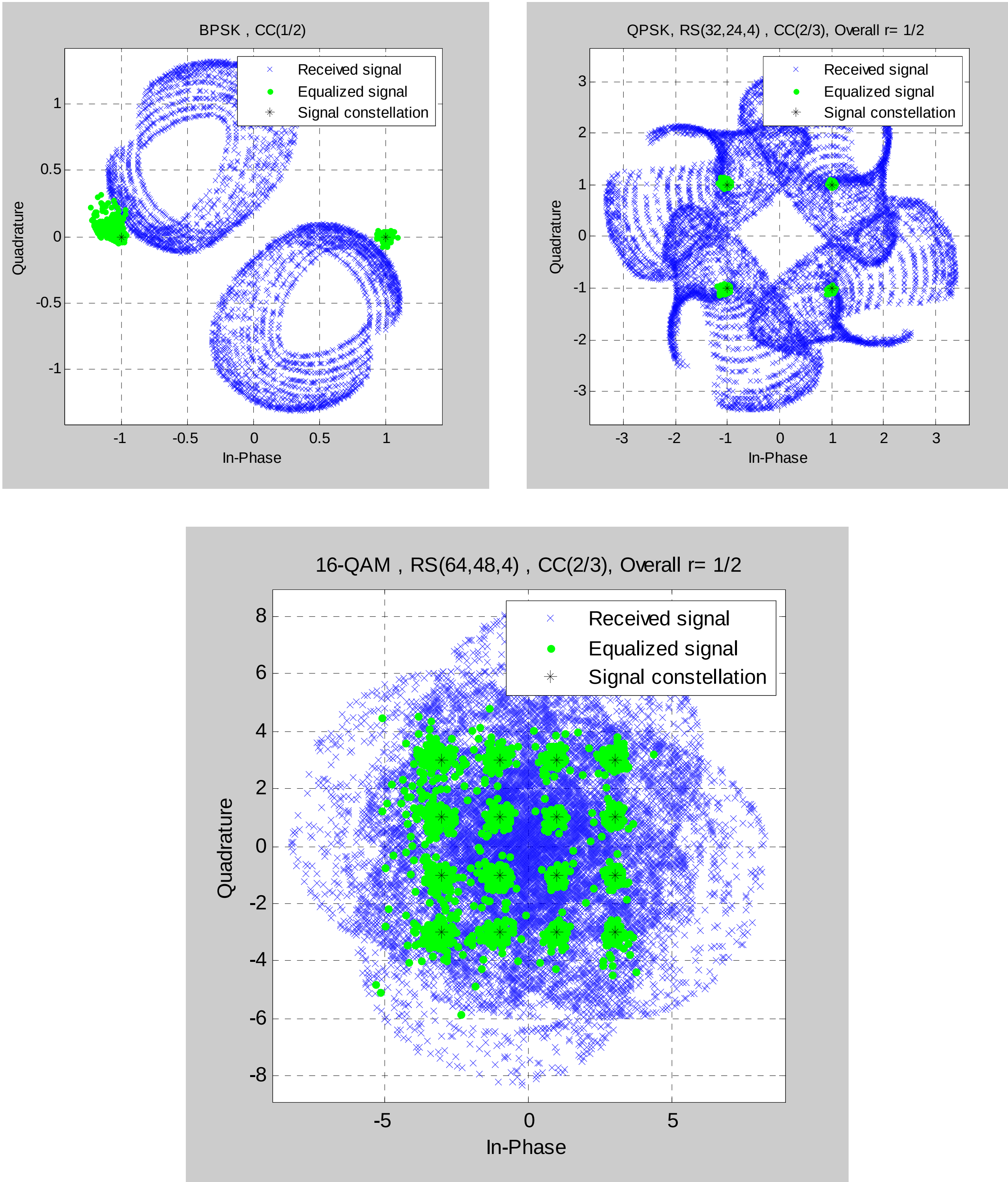


Figure 6.53 Scatter plots of MC-CDMA for BPSK,QPSK & 16 QAM modulation with V=30km/hr

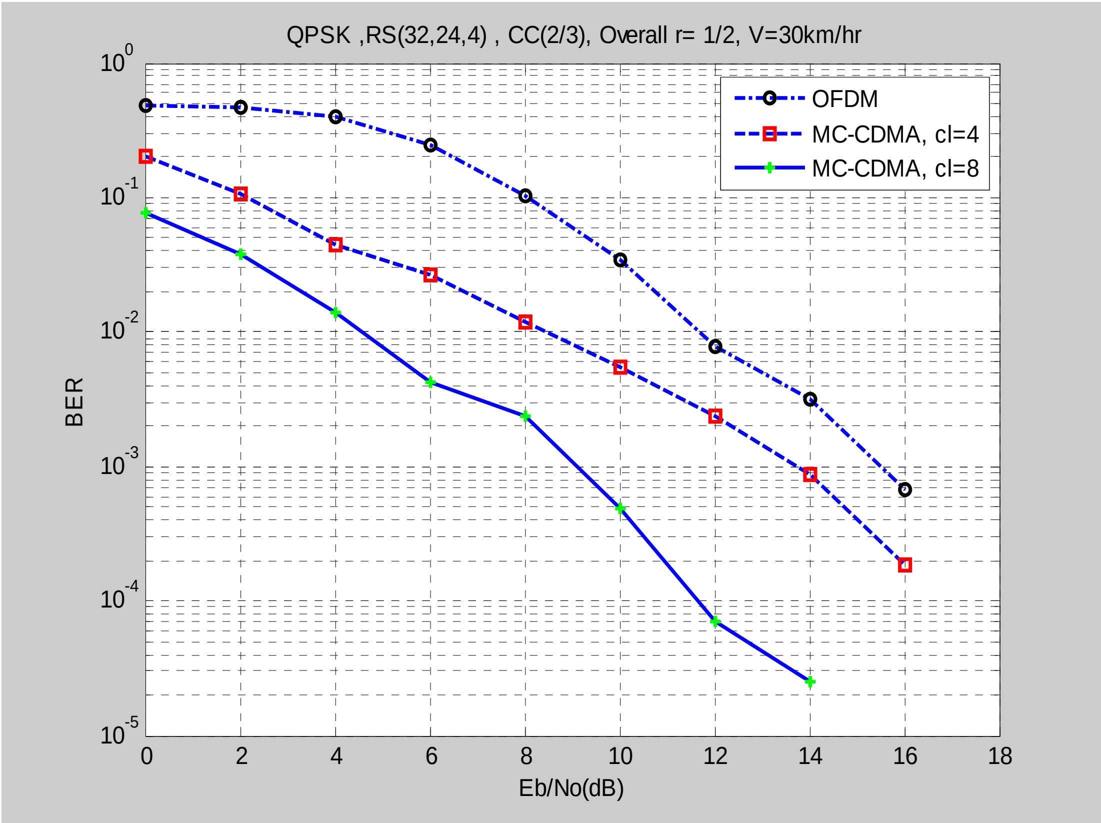


Figure 6.54 BER vs. E_b/N_o of QPSK for Different Code Length, V=30km/hr

6.5 Comparing Fading Channel and AWGN channel Performance

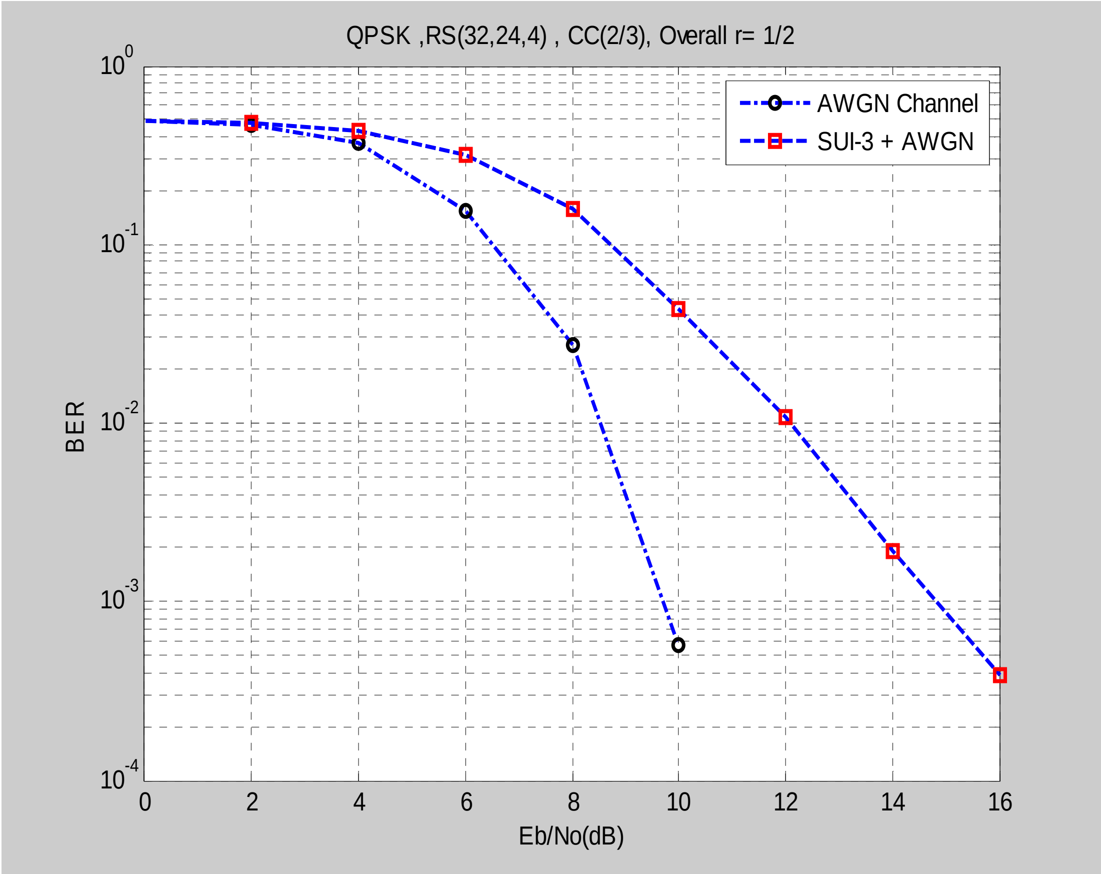


Figure 6.55 BER vs. E_b/N_o of QPSK for AWGN and Fading channels.

6.6 Comparing Different SUI Channel Performance

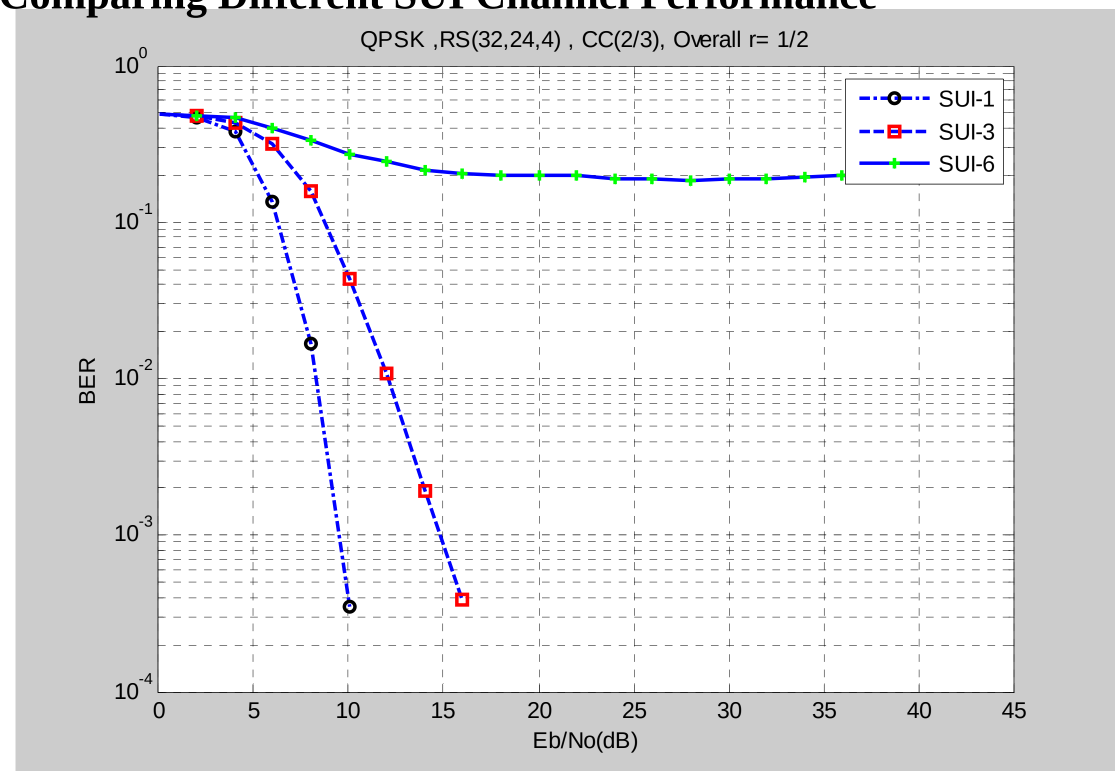


Figure 6.56 BER vs. E_b/N_o of QPSK for Different SUI Channels

Chapter 7
Conclusion and Future Work

7.1 Conclusion

This thesis concentrates on the performance analysis of fixed and mobile WiMAX MC-CDMA based system. This work can be summarized in following steps:

- Study of the WiMAX physical layer, its features and the techniques used in this technology
- Study of the SUI-3 channel for fixed WiMAX & COST-231 channel for mobile WiMAX and its implementation in MATLAB
- Study of the OFDM & MC-CDMA technology and its implementation for both fixed and mobile WiMAX
- Mobile WiMAX is more affected by the channel because of Doppler shift. To study the effect, we used the speeds of 30, 60 and 120 km/h and we have found that as the speed increases, the performance of the system degrades.
- MC-CDMA, which takes the advantages of OFDM and CDMA techniques, improves the performance, as it clear from the BER curves. MC-CDMA is a promising candidate for the downlink for the fourth generation of mobile radio systems. MC-CDMA systems offer the spectral efficiency of OFDM combined with CDMA to combat multiuser interference losses and to offer a flexible multiuser access scheme. However, in a fully loaded system, MC-CDMA experiences a significant loss of performance due to multiple-access interference.
- Hadamard spreading codes are used to spread the transmitted symbols in the frequency domain and we have seen that as the code length increases by two, about 3 dB enhancement will be achieved. Spreading codes give us multiple access, that is when the spreading matrix size being larger , the number of users increases. Although, multiuser interference must be considered when we use spreading techniques.

7.2 Future Work

In the foreground of above mentioned context a lot of related work can be done in future for the optimization of wireless communications systems. The future work can be summarized in following points:

- Adaptive antenna systems (AAS) can be used to enhance the performance of the system. AAS includes DOA (Direction of Arrival) estimation and then beamforming.
- In our MC-CDMA, we applied the spreading in the one dimension only, but in future it can be done for two dimensional spreading.
- Our simulation is for a bandwidth of 5 MHz, but the system can be simulated for other bandwidths up to 20 MHz
- We have used SUI-3 and COST 231 channel models but the simulation can be done for other practical channel models also
- Adaptive subcarriers and power allocation is another field of study in WiMAX. Although the IEEE 802.16 channel is frequency-selective, presently all subcarriers are constrained to carry the same modulation type. It has been demonstrated extensively in both academics and practice, for DSL systems in particular, that adaptive subcarrier loading and modulation can substantially increase the capacity of a multicarrier system. Further gains can be attained in a multi -user OFDM system where different users contend for different subcarriers, since the different users channels are typically independent.

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