ÇANKAYA UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
ELECTRONIC AND COMMUNICATION ENGINEERING

MASTER THESIS

STUDY AND DESIGN OF MIMO - OFDM SYSTEM OPERATING OVER WIRELESS CHANNEL

YOUSIF IBRAHIM HAMMADI

OCTOBER 2013

Title of the Thesis: **Study and Design of MIMO- OFDM SYSTEM OPERATING OVER WIRELESS CHANNEL**

Submitted By: **Yousif Ibrahim Hammadi**

Approval of the Graduate School of Natural and Applied Sciences

Prof. Dr. Taner ALTUNOK
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Celal Zaim ÇİL
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Dr.wail A.H. Hadi
Co-Supervisor

Prof. Dr. Halil T.EYYUBOGLU
Supervisor

Examination Date : October 10, 2013

Examining Committee Members

Dr.wail A.H. Hadi (University of Tech. Baghdad)

Prof. Dr. Halil T. EYYUBOĞLU (Çankaya Univ.)

Assistant Prof. Dr. Barbaros PREVEZE (Çankaya Univ.)

STATEMENT OF NON-PLAGIARISM

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name : Yousif HAMMADI

Signature

Date : October 10,2013

ABSTRACT

STUDY AND DESIGN OF MIMO- OFDM SYSTEM OPERATING OVER WIRELESS CHANNEL

Yousif HAMMADI

M.S.c., Department of Electronic and Communication Engineering

Supervisor : Prof. Dr. Halil Tanyer EYYUBOGLU

Co-Supervisor: Dr. Wail A.H. HADI

October 2013, 94 Pages

In this thesis, a new MIMO-OFDM model has been introduced. The performance of this model using PSK and QAM digital modulations for different antenna configurations is analyzed and evaluated under Rayleigh fading channel. MIMO-OFDM system can be implemented using higher order modulations to achieve large data capacity and remarkable enhanced performance.

The main purpose of using high order antenna configuration is to increase the space diversity, which will further decrease the BER at given Eb/N0 as compared to lower order Antenna configurations. It is found effectively the diversity order increases as number of receiving antenna increases regardless the number of transmitting antennas , also the lowest BER can be obtained at highest number of transmitting and receiving antenna configurations. MIMO-OFDM using PSK modulation provide remarkable lower bit error rate as compared to QAM technique at same constellation and antenna configuration.Finally , the effect of channel order on MIMO-OFDM system has been reported.

Keywords: OFDM , MIMO, Rayleigh Fading Channel,Channel Order, BER

ÖZ

KABLOSUZ KANAL ÜZERİNDE TASARIM VE MIMO OFDM VE ÇALIŞMA

Yousif HAMMADI

Yüksek Lisans, Elektronik ve Haberleşme Mühendisliğ Bölümü

Tez Yöneticisi : prof. Dr. Halil Tanyer EYYUBOGLU

Ortak Tez Yôneticisi : Dr. Wail A.H. HADI

Ekim 2013, 94 Sayfa

Bu tezde, PSK ve farklı anten konfigürasyonları için QAM dijital modülasyon kullanarak MIMO-OFDM sistemlerinin performansını analiz ve Rayleigh kanal altında değerlendirilmiştir. MIMO-OFDM sistemi büyük veri kapasitesine ulaşmakiçin yüksek mertebeden modülasyon kullanılarak uygulanabilir.

Yüksek mertebeden anten yapılandırma kullanmanın temel amacı alt sipariş Anten yapılandırmaları ile karşılaştırıldığında daha verilen Eb/N0 de BER azalacak alanı çeşitliliği, artırmaktır. Bu alıcı anten sayısı ne olursa olsun verici antenler, aynı zamanda en düşük BER anten konfigürasyonları gönderme ve alma en yüksek sayıda elde edilebilir sayısı arttıkça etkili çeşitliliği için artırır bulunur. Aynı takımyıldızı ve configuration.Finally anten QAM tekniği ile karşılaştırıldığında PSK modülasyonu kullanan MIMO-OFDM olağanüstü düşük bit hata oranı sağlamak, MIMO-OFDM sisteminde kanal düzenin etkisi bildirilmiştir.

Anahtar Kelimeler: OFDM , MIMO, Rayleigh Fading Kanal, kanal order, BER

ACKNOWLEDGEMENTS

I would like to thank my thesis advisors Prof. Dr. Halil Tanyer Eyyuboglu and Dr. Wail A.H. Hadi . I am very thankful for their supervision, continued encouragement and guidance to achieve the correct end during my MSc research study.

And also, I thank Çankaya University, and especially the Department of Electronic and Communication Engineering, for their support and facilities.

I wish to express my deepest thanks to my loving family, thanks to my mother, my father, my brothers and Sisters whom without their unlimited patience this work might never see the light.

The best brother BASHAR who raised me up and made me who I am who died before this date. I wish his dream to become in reality. I hope for everyone who read this thesis pray for him.

Finally, special words of thanks with gratitude are devoted to the dear Noor Abd Al-lateef Hassan who supported me and all my friends who provided me any kind of help during the period of the study, and I couldn’t mention them all in these few lines.

TABLE OF CONTENTS

LIST OF TABLES

LIST Of FIGURES

FIGURES

LIST OF ABBREVIATIONS

Abbreviations	Definition
2G	Second Generation
3G	Third Generation
4G	Fourth Generation
AMPS	Advanced Mobile Phone Service
AWGN	Additive White Gaussian Noise
BEP	Bit Error Probability
BER	Bit Error Rate
BLAST	Bell Labs Layered Space -Time
BPSK	Binary Phase Shift Keying
CDMA	Code Division Multiple Access
CSI	Channel State Information
D-AMPS	Digital AMPS
dB	Decibel
D-BLAST	Diagonal-Bell Labs Layered Space-Time
DOA	Direction-of-Arrival
DSL	Digital Subscriber Line
EGC	Equal Gain Combining
EVD	Eigen Value Decomposition
FDMA	Frequency Division Multiple Access
GSM	Global System for Mobile Communication
I.I.D.	Independent and Identically Distributed
IEEE	Institute of Electrical and Electronic Engineers
IMT-2000	International Mobile Communications-2000
IP	Internet Protocol

ISI	Inter Symbol Interference
ITU	International Telecommunication Union
LOS	Line of Sight
MIMO	Multiple-Input Multiple-Output
MISO	Multiple-Input Single-Output
MMSE	Minimum Mean Square Error
MRC	Maximal Ratio Combining
MRT	Maximal Ratio Transmission
MS	Mobile Station
OFDM	Orthogonal Frequency Division Multiplexing
PDF	Probability Density Function
QoS	Quality of Service
SC	Selection Combining
SIMO	Single-Input Multiple-Output
SISO	Single-Input Single -Output
SM	Spatial Multiplexing
SMS	Short Message Service
SNR	Signal to Noise Ratio
SOS	Sum of Sinusoidal
STBC	Space -Time Block Code
STC	Space -Time Coding
SVD	Singular Value Decomposition
TDMA	Time Division Multiple Access
UMTS	Universal Mobile Telecommunication System
V-BLAST	Vertical Bell Labs layered Space -Time
WCDMA	Wideband Code Division Multiple Access
WF	Water-Filling
WLAN	Wireless Local Area Networks
WMAN	Wireless Metropolitan Area Networks
ZF	Zero Forcing

LIST OF SYMBOLS

Symbol	Definition
B_C	Channel coherence bandwidth
B_W	Bandwidth
T_s	Symbol duration
T_C	Coherence time of the channel
v	Signal velocity
c	Speed of light
C	Channel capacity
f_s	Sampling frequency
f_c	Carrier frequency
f_d	Doppler frequency
N_o	Noise power spectral density
E_b/N_o	Bit energy to noise ratio
γ_b	Effective bit energy to noise ratio
K	*Ricean K-factor* : power ratio between line-of-sight and scattered components
$I_0(\cdot)$	Zero order modified Bessel function of the first kind
M	Number of paths for fading channel
M_R	The number of receive antennas
M_T	The number of transmit antennas
$erfc(\cdot)$	Complementary error function
P_b	Bit error probability
h	Vector of channel coefficients
H	A MIMO flat-fading channel
I_m	$m \times m$ Identity matrix
τmax	Maximum delay spread of channel
λ	Wavelength

$(\cdot)^*$	Conjugate of a matrix
$(\cdot)^T$	Transpose of a matrix
$(\cdot)^H$	Conjugate transpose (Hermitian) of a matrix
$(\cdot)^P$	Pseudo-inverse of a matrix
$\lambda(\cdot)$	Eigen values of matrix
$\|a\|$	Absolute value of scalar *a*
$\|\|\cdot\|\|$	Norm. of a vector or a matrix
$\|\|\cdot\|\|^2$	Norm. of matrix (sum of squared magnitudes of elements)
$diag(\cdot)$	Elements placed along the diagonal of a matrix
$\log_2(\cdot)$	Base 2 logarithm
$\tilde{x}$	Estimate of signal *x*

CHAPTER 1

INTRODUCTION

Modern wireless technologies have rapidly developed to find their way into commercial and industrial applications. The increase in the number of wireless devices and the requirement for higher data rates places an increasing demand on bandwidth. This necessitates the need for communication systems with increased throughput and capacity. Multiple input multiple output orthogonal frequency division multiplexing (MIMO-OFDM) is one way to meet this need. MIMO-OFDM is considered a key technology in high-data rate systems such as 4G, IEEE 802.16, and digital video broadcasting (DVB-T). The use of MIMO-OFDM into these standards make possible the increased data throughput and range required by many devices without increases in transmit power or bandwidth.In this chapter , basic concepts and literature survey on MIMO-OFDM systems will be introduced . In addition to this, a short overview of this thesis will be given at the end of this chapter.

1.1 Background

Wireless communication is, by any criterion, the fastest growing part of the communications industry. As it has captured the attention of the media and the imagination of the public [1]. In recent years, communications researches have seen an unprecedented growth, especially related with cellular phones, due to the increasing demand for the wide variety of end user applications. In addition to accommodating standard voice, personal mobile communication services must now be able to satisfy the consumer demand for text, audio, video, multimedia and Internet services [2]. To meet these demands, there have been various modern mobile communication networks that have evolved from analog to digital [3].

In the mid of 1980s, the first generation (1G) systems were characterized using analog transmission technology and they were simple to use multiple access technologies, such as frequency division multiple access (FDMA), which is divided into a specific frequency bandwidth that is assigned to each call. The first generation of communication systems, such as Advanced Mobile Phone Service (AMPS), only provide voice communications, they do not have enough users for a high density city. They also suffer from low user capacity rate of 2.4 kbps problems and security issues due to use of a simple radio interface [4,5].

In the beginning of 1990s, The second generation (2G) systems based on digital modulation technology was introduced to provide a more powerful communication. Over 1G , 2G digital transmission system provides significant improvements in the system, better voice quality, capacity, global roaming and data services such as the Short Message Service (SMS). The second generation (2G) systems provide low-rate circuit and packet data at a rate of 9.6 and 14.4 kbps, medium rate packet data is 76.8 kbps [6]. Second generation made up of first digital mobile communication systems such as time division multiple access (TDMA)

system, the GSM, D-AMPS (Digital AMPS), and code division multiple access (CDMA) basis [5].

Third-generation (3G) such as Wideband CDMA or WCDMA network, in October 2001 was initiated in Japan [3]. 3G has become a generic description of cellular data communications with the target data rate of 2 Mbps (actually 64 ~ 384 Kbps) of [4]. This makes a lot of new services, including video streaming, web browsing and file transfer to the client's interests, the new service should be cheap and high quality. To achieve these goals , it is necessary to select the multiple access approach. WCDMA has been selected as the air channel of these networks. In Europe , 3G systems are called Universal Mobile Telecommunications System (UMTS) [7].

The fourth-generation (4G) systems can be available before the full development of 3G, because 3G is a critical mix of standards. In 4G systems, the expected target data rate up to 1 Gbps and 100 Mbp will apply to indoor and outdoor environments respectively. 4G will use a channel capacity greater than 10 times of 3G by complete support of the Internet Protocol (IP).

The high data rate signal processor and new modulation techniques such as orthogonal frequency division multiplexing (OFDM) and multiple-input multiple-output (MIMO) technology are promising solution and can be combined to provide high speed wireless data transmission [4,8].

1.2 The Literature Survey

In 1998, S. M. Alamouti [9] developed diversity scheme using two transmit antennas and one receive antenna, the scheme gives the same diversity order as a maximal - ratio combining (MRC) at the receiver side, with one transmit antenna, and dual antennas. There is no need for any bandwidth expansion in this new scheme, all feedbacks from the receive to the transmit antennas, and its degree of computation complexity is same as MRC.

In 2002, K. Kalliola [10] presented a new system for radio links measurements including space and polarization dimensions to analyze the radio propagation in wideband mobile communication systems. He verified the advantage of the developed measurement systems by achieving channel measurements at 2 GHz and analyzing the experimental data. He also studied the spatial channels in mobile and base stations, as well as the double-directional channel that completely characterizes the propagation between two antennas.

In 2004, A. H. Al-Hassan [11] studied the data transmission over the mobile radio channel. He introduced a software radio receiver design and simulation, then he attempted to develop this software over the mobile radio channel. He also used many techniques to improve the performance of the data transmission like equalization and diversity. Selection Switching Combining (SSC) diversity technique was used in his simulation test.

In 2005, S. H. Krishnamurthy [12] studied on the electromagnetic (EM) waves properties of antennas and the scattering environment in terms of dependent capacity, the limitation on performance parameter of estimation algorithms at the receiver side and the basic limits on the capacity that volume-limited multiple-antenna systems may be achieved. He used the theoretical methods to derive a channel propagation scheme for multi antennas in the multi fading channel .

In 2006, M. R. McKay [13] considers the analysis of current and future wireless communication systems. The main focus is on Multiple-Input Multiple-Output (MIMO) antenna technologies. The goal of his work is to characterize the fundamental MIMO capacity limits, as well as to analyze the performance of practical MIMO transmission strategies, in realistic propagation environments.

In 2008, D. Q. Truing, N. Prayongpun, and K. Roof [14] considered new two models of antenna selection in Rayleigh channels such the Maximal Ratio Transmission (MRT) and Orthogonal Space-Time Block Code technique (OSTBC). The simulated results show that, the proposed antenna selection scheme may get a performance near by the optimum selection with low level of complexity.

In 2009, A. Lozano, and N. Jindal [15] provided principals on the tradeoff property between transmit antenna diversity and spatial multiplexing . They showed the difference between the techniques of transmission that using full spatial multiplexing and MIMO communication techniques for diversity purposes.

In 2010, J. Jayakumari [16] analyzed MIMO-OFDM system using Quadrature Amplitude Modulation (QAM) in Rayleigh channel for next generation and promising wireless communication systems.

In 2011, P. Bhatnagar,et.al [17] , submitted an improvement for MIMO-OFDM system employing Space Time Block Coding (STBC) over Rayleigh channels using BPSK and QPSK digital modulation techniques to overcome subchannel interference. Results showed that SNR increases with decrease in bit error rate (BER) magnitudes while it is decremented by increasing throughput of the system.

In 2012, N. Sreekanth and M. N. Giriprasad [18], introduced new evaluations of MIMO-OFDM performance using Minimum Mean Square Error (MMSE) equalization .

Maximum likelihood methods are proposed and iterative solutions are developed. BER study and analysis for BPSK digital modulation in Rayleigh fading channel with (2 x1) transceiver antennas as well as (2 x2) transceiver antennas for Alamouti STBC case clarifies higher performance. The used maximum likelihood is related on least squares iterations and projection .

1.3 Aim of the Work

The main goal of this thesis is to show the analysis and impact of using different antenna lengths on the performance of bit error rate in new proposed model MIMO-OFDM system employing different levels of PSK and QAM modulation techniques with comparisons to each other. Also, the effect of the channel order on a MIMO - OFDM system has been introduced and analyzed by using Matlab software version 2012.

1.4 Thesis Outline

This thesis is arranged in five chapters as follows:

Chapter one presents an introduction with literature survey and aim of this thesis.

Chapter two gives a description of wireless fading channel characteristics including, multipath propagation mechanisms, large scale fading and small scale fading and OFDM basics.

Chapter three begins with a brief description of MIMO communication system. Then, methods of transmission from multiple antennas are introduced. Later, STBC diversity technique is introduced for MIMO system. Capacity enhancements from using multiple antennas are studied and analyzed. Also, a suggested block diagram of MIMO-OFDM and channel order explanation have been presented and analyzed.

Chapter four presents the simulation results and discussions using proposed MIMO-OFDM models which are used in all the simulations and measurements.

Chapter five includes the conclusions and suggestions for future work.

CHAPTER 2

WIRELESS CHANNEL CHARACTERISTICS AND OFDM SYSTEM

2.1 Introduction

wireless communications technology is going to be increasingly developed that allows for widespread deployment. By the way, data and wireless services, such as various multimedia needs steady growth, high capacity and data rates are being growing strong demand. Such a high demand for wireless communications services, the need to increase system capacity. Thus, enthusiasm, medical imaging, real-time road map, each time a new transmission method and optional services, video conferencing anytime, world video, Internet access has been recognized by the people. Now Wireless technology reaches on the Earth's surface and it can be achieved almost anywhere and anytime [21].

Multi-carrier schemes may supply large data transfer rate at some resonant frequency, are continuously being common in video/audio broadcasting, mobile phones, local area networks and next-generation broadband cellular systems. The principle of multi-carrier communication is to divide whole signal bandwidth into the number of subcarriers , and the message sent on each subcarrier . As compared to traditional multi-carrier communication system, each subcarrier spectrum does not overlap and uses a bandpass filter to extract the desired frequency [19] . In the OFDM subcarriers , the frequency interval is chosen by such manner in order to be mathematically orthogonal subcarriers to each other .

Spectrum of subcarriers overlaps each other , but individual subcarriers can be processed from the baseband . This attribute enables more overlapping spectral efficiency than conventional OFDM multi-carrier communication OFDM has been used in many applications, such as digital audio broadcasting (DAB) systems, broadcasting IEEE 802.11a and 4G wireless mobile communication In this chapter, wireless channel characteristics and models are presented. Moreover, OFDM design principles are presented with their operation in frequency selective fading channel.

2.2 Concept of Radio Channels

Wireless transmission may use space or air through medium. Wireless transmission is not as smooth as the received signal from wired transmission from which is not directly from coming transmitter, but the combined groups of reflection, diffraction, scattering of the transmitted signal replica. This is interesting to check the effects of radio signal propagation, since that limits data transfer rate [21]. Reflected and Diffracted signal during scattering may be weaker than the reception of signal in which its energy spread in all directions . The receiver can receive signals and power at different stages of multiple paths, thereby providing multiple copies of additional energy. Figure 2.1 illustrates the propagation mechanisms [21].

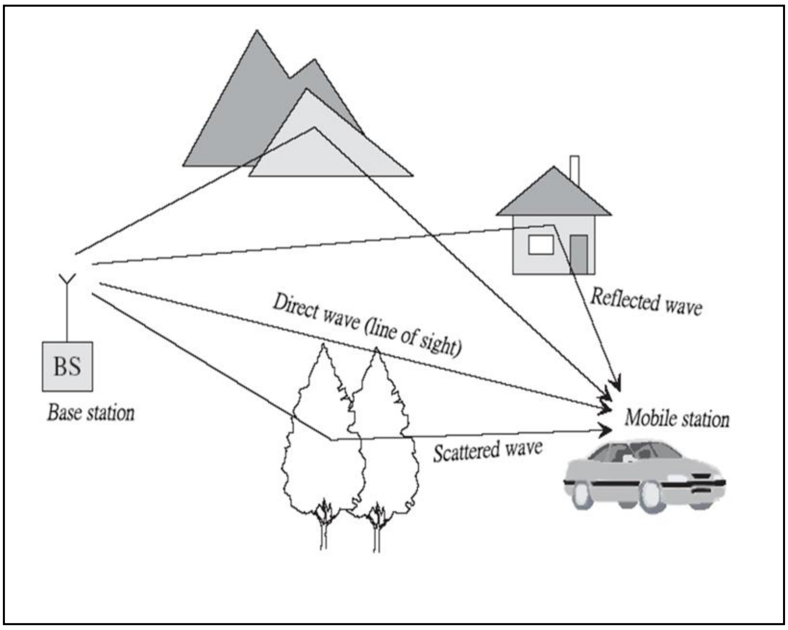


Figure 2.1. Propagation Mechanisms

Mobile channel of the wireless communication system performance has basic limitations. Transmitter and receiver wireless link between the different lines of sight (LOS) is a serious impediment to buildings, mountains, and thus suffer severe multipath fading. Mobile channel is very different from a fixed and predictable cable channel, due to its random mechanism.There are several factors to determine the behavior of channels such as topographical features, the relative speed between the sender and receiver, weather conditions, etc [22].

2.2.1 Large-scale Fading Versus Small-scale Fading

The changed amplitude of the received signal in time and frequency, known as fading. Fading is due to multipath propagation, known as multipath fading (induction), or shadowing disorders affect propagation of radio waves, called shadow fading. Based on what is known causes signal fading, cellular mobile radio (CMR) channel is characterized by either the large or small-scale statistics [23,24].

Large-scale fading is the rate of attenuated signal power, since the movement of a long distance up to thousands of kilometers, and small-scale fading is experienced as asmaal varied amplitude and phase of signal with the rapid fluctuations result in a spatial distance between transmitter and receiver especially in half wave length systems [25,26].

Large-scale and small-scale envelope fading channel models are usually distributed by a Rayleigh distribution and science [26]. In this study, is considered to be only a small scale fading.

2.2.2 Fading Parameters

They classified as follows [26]:

2.2.2.1 Delay Spread and Coherence Bandwidth

When a narrow pulse by a multipath propagation channel, distorted signal of transmitted pulse at various times will get to the receiver, so that the received signal width in the time domain greater than the original sent signal pulse. This is called propagation delay. Often expressed as an excess of the maximum delay time (T_m) which is time span from first and last path recognized from receive side [27].

The maximum additional delay (T_m) is related in the frequency domain to coherence bandwidth which is level of delay spread. Coherence bandwidth, B_{coh} shows how far the signal frequency varying degrees of discoloration. It can be seen that B_{coh} is related to T_m by [27,28]:

$$B_{coh} \approx \frac{1}{T_m} \quad (1)$$

2.2.2.2 Doppler Spread and Coherence Time

For mobile communications case where the mobile receiver travels through the standing wave propagation pattern of the channel, the fading nature of the received signal at the mobile can be quantified by Doppler frequency [26,28]:

$$f_d = f_c \frac{V_{sr}}{C_{lig}} \quad (2)$$

where, f_c is carrier frequency, V_{sr} is speed between the transmitter and receiver, C_{lig} is the speed of light, θ is the incident angle of signal reception. Note that, Doppler frequency is maximum (f_{max}) when cos(θ) is +1 or −1. Signal getting direction of motion will exhibit a positive Doppler shift, but those reaches the opposite direction of movement will show a negative Doppler shift. Therefore, arriving from different directions for the multipath components of a received signal is relied on Doppler spread which leads to more bandwidth of the signal. This phenomenon is referred to as Doppler spread, denoted by B_d [26,28].

To describe the channel over varied time , useful property of coherent time, referred as T_{coh} is defined as the channel impulse response duration which is substantially constant. Doppler spread and coherence time are related to each other by following expression [27]:

$$T_{coh} \approx \frac{1}{B_d} \quad (3)$$

2.2.3 Types of Scale Fading of Small Values

The bandwidth and symbol period of signal as well as RMS delay spread, Doppler spread for channel between the different transmission signals will suffer from various fading. The dispersion of time and the dispersion of mobile radio channel frequency mechanism are in four possible different effects, depending on the transmitted signal, the channel, the nature and speed of performance. When multipath delay spread resulting flat fading and frequency selective fading, Doppler shift will lead to fast fading and slow fading. Figure 2.2. shows a tree of the four different types of small scale fading [28].

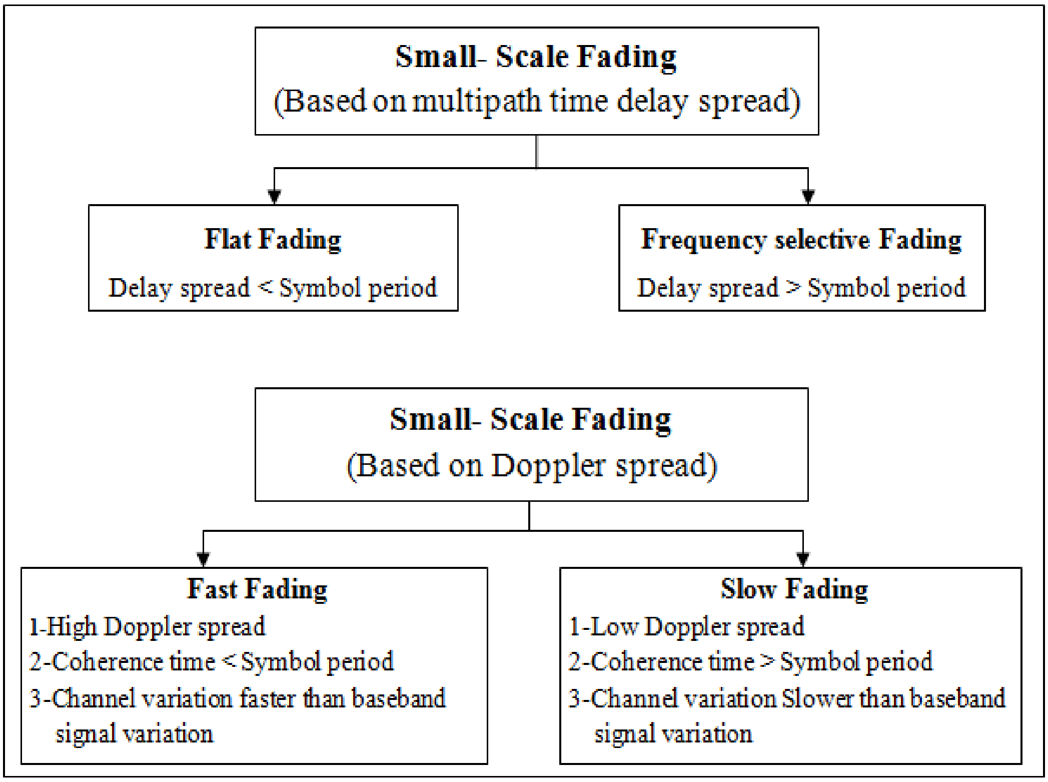


Figure 2.2. Fading of Small Scale Tree [28]

2.2.3.1 Frequency non-selective Fading Vs. Frequency Selective Fading

If transmitted signal bandwidth (B) is small unlike coherence bandwidth (B_c), so all of the signal frequency components are substantially through the same degree of fading. Then, the channel is divided into flat fading frequencies . Noted that, since (B_c), is inversely proportional to (T_m) for non-selective channel symbol duration , (T_s) is higher than (T_m). So, the delay between different paths relative to the symbol duration is relatively small. It is assumed that there is only one copy of the received signal can gotten. The magnitude of phase and gain for signal coming with (T_m) can be found by superposition of all these copies.

If the signal sent with big bandwidth unlike (B_c) , the various frequency components of the signal (which is different by more than (B_c) would suffer different levels of fading. This channel is called as frequency selective. Because of reciprocal relationships, (T_s) is small compared with (T_m).Large delays between different paths may be big values with respect (T_s).Then , multiple copies of the signal could be received [22,29].

2.2.3.2 Slow Fading Versus Fast Fading

If (T_s) is small (T_{coh}) , then the channel is known as slow fading. Slow fading channel, are often modeled in interval time-invariant channels for symbol intervals. If (T_{coh}) close to or less than (T_s) , the channel must be called as quick fading[29,30].

When the Doppler spread bigger (B_d) than the bandwidth of the sent nal (B), changing in channel is speedy or speedier than changing in signal. It is known as fast fading .When (B_d) is much smaller than the bandwidth of the sent signal (B), the channel will change slowly to varying signal. This is mostly referred as slow fading [28,30].

2.3 Wireless Channel Distributions

2.3.1 Rayleigh Distribution

Rayleigh distribution is the most widely used to describe the distribution of the received envelope value. Rayleigh flat fading channel model assumes that all of the components that make up the resulting received signal is reflected or scattered, and there is no direct path from the transmitter to the receiver. Rayleigh distribution envelope of the received signal is given by the following formula [22].

$$P(x) = \begin{cases} \frac{x}{\sigma^2} \exp\left(-\frac{x^2}{2\sigma^2}\right) & , 0 \leq x \leq \infty \\ 0 & , x < 0 \end{cases} \quad (4)$$

where σ is the received root-mean-square (RMS) envelope level and σ^2 is the a.c power of the received signal.

2.3.2 Ricean Distribution

In micro-cellular environments, there usually exists a dominant line of sight (LOS) path in addition to numerous diffused multipath components between the transmitter and receiver. In such a case, the other faded signal components are superimposed on the dominant component and the resultant signal amplitude follows Rician distribution with the ratio between the LOS and diffused components denoted by the Rice factor K_R. The complex envelope of the received signal following a Rician distribution is given by [22]

$$p(x) = \begin{cases} \frac{x}{\sigma^2} \exp\left(-\frac{x^2 + A^2}{2\sigma^2}\right) I_0\left(\frac{xA}{\sigma^2}\right) & , \ A \geq 0, x \geq 0 \\ 0 & , \quad x < 0 \end{cases} \tag{5}$$

where A is the peak amplitude of the dominant component, and $I_0(.)$ denotes the modified Bessel function of the first kind and zero order. The distribution can also be expressed in terms of the Rice factor $K_R = A^2/(2\sigma^2)$ which is the ratio of the dominant components power to the variance of the combined power of all the multipath components. As the power in the dominant component decreases to zero, the Rician distribution can be seen to approach the Rayleigh distribution [22].

2.4 Jakes Fading Wireless Channel Model

Jakes fading model is used for simulating time-correlated Rayleigh fading wireless communication channels. This method was determined by Jakes in 1974 and it is commonly used nowadays. The model has been slightly reformulated in order to ensure multiple uncorrelated waveforms [26].

The Jakes fading model uses a sum of weighted oscillators with discrete frequencies spanning the Doppler spectrum. First, the model assumes that there are equally strong N_{ray} rays getting at a moving receiver with uniform arrival angles, α_r . This assumption places the arrival angles at [22]

$$\alpha_r = \frac{2\pi r}{N_{ray}} \quad , \qquad\qquad 1 \leq r \leq N_{ray} \qquad\qquad (6)$$

the ray r would then experience a Doppler shift of

$$w_r = 2\pi f_{max} \, cos(\alpha_r) = w_{max} \, cos(\alpha_r) \qquad\qquad (7)$$

where the maximum Doppler shift w_{max} is given by:

$$w_{max} = 2\pi \left(\frac{V_{sr}}{C_{lig}}\right) f_c \qquad\qquad (8)$$

where f_c is the carrier frequency, V_{sr} is the velocity difference from the sender to the receiver, C_{lig} is the speed of light. Note that using the definition for α_r given above, the magnitudes of the Doppler shifts possess quadrantal symmetry except at the angles 0 and π. Due to this quadrantal symmetry, the fading waveform with (N_{osc}+1) complex oscillators can be modeled, where [26]

$$N_{osc} = \frac{1}{2}\left(\frac{N_{ray}}{2} - 1\right) \qquad\qquad (9)$$

The (N_{osc} +1)st complex oscillator has the frequency w_{max} and is used for the purpose of frequency shifting from the carrier.

The in-phase and quadrature components are derived from the oscillators by summing the outputs of the available individual oscillators multiplied by proper gain factors. The quadrature components are in the same phase and appear as [26].

$$X_i(t) = 2\sum_{r=1}^{N_{osc}} \cos(\beta_r)\cos(w_r t) + \sqrt{2}\ \cos(\alpha)\cos(w_{max} t) \qquad (10)$$

$$X_q(t) = 2\sum_{r=1}^{N_{osc}} \sin(\beta_r)\cos(w_r t) + \sqrt{2}\ \sin(\alpha)\cos(w_{max} t) \qquad (11)$$

and the final output waveform is [26]:

$$Y(t) = X_i(t)\,cos(w_c t) + X_q(t) sin(w_c t) \qquad (12)$$

Jakes selects $\alpha = 0$ or $\pi/4$, and $\beta_r = \frac{\pi r}{N_{osc} + 1}$.

With this model, the use of large number of weighted oscillators leads to a more accurate Rayleigh fading model. It has been shown that Rayleigh fading can be accurately simulated with this method using $N_{osc} \leq 8$. The complete model block diagram of Jakes model is shown in Figure 2.4 [31].

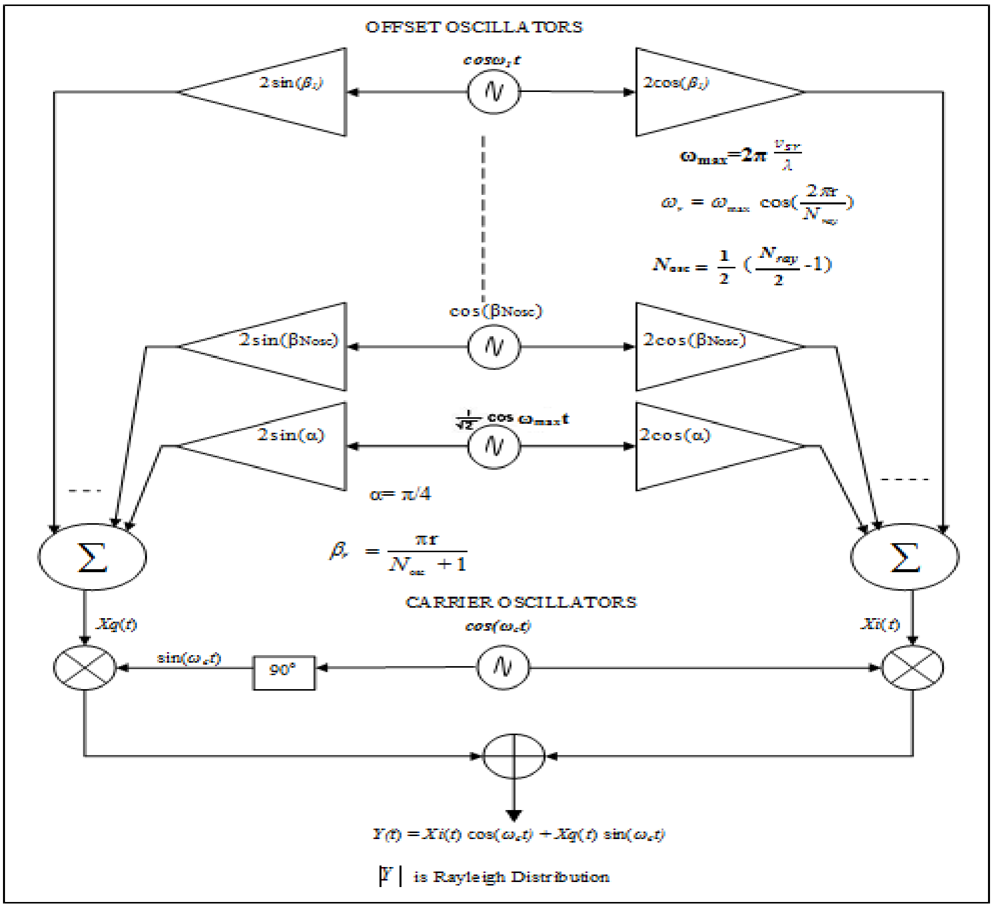


Figure 2.3. Block Diagram of Jake's Model [31]

2.5 Single Carrier Modulation (SCM)

A single carrier (SC) system is well-known digital transmission scheme where data symbols are travelled as a constant symbol-rate serial stream of modulated amplitude and/or phase pulses, which in turn modulate a sinusoidal carrier [32].The transmission of high data rates generally implies a small symbol duration T_s. Due to multipath propagation in the radio channel, distortions are observed in the received signal, which appear as inter-symbol-interference (ISI) of the successive modulation symbols. This situation is technically very critical when the maximum delay T_m is very large, unlike T_s.In this case, the ISI affects many adjacent transmitted symbols [33]. That limits the highest data rate of single-carrier systems in multipath fading wireless channels [34].

To enhance the efficiency and robustness to overcome frequency selective fading narrow band interaction that occurs in single carrier modulation, multicarrier modulation (MCM) is used. For unity carrier system, one interferer may cause the whole link fail, but in a multicarrier system, just a small rate of subcarriers will be failed. By error correction technique ,false subcarriers can be corrected . As shown in Figure 2.5, in single carrier modulation system, the fading channel does not allow any signal to pass, data symbol is lost sporadically [34].

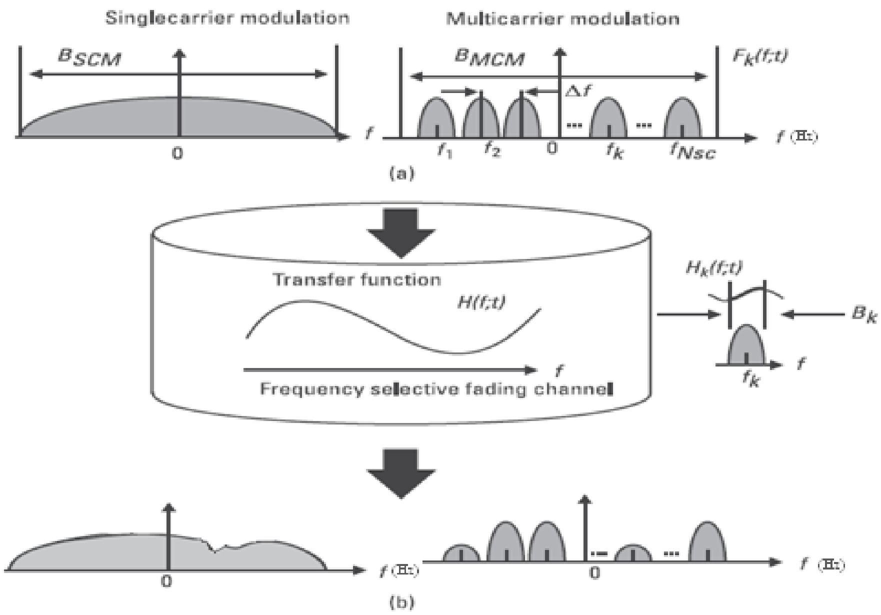


Figure 2.4. Comparison of SCM and MCM (a) Sent Signals in Frequency Domain Spectrum. and (b) Received Signals in Frequency Domain Spectrum. [34]

2.6 OFDM System

2.6.1 Overview of OFDM System

A channel will be far more liable to ISI. This is due to the small time interval signal element and its noisy generated wider band as compared to the duration of a signal element of a long and narrow bandwidth of a parallel system subchannels [21]. The OFDM concept is based on the divided message stream with a big-rate into a number of lower rate streams that are sent on time over a number of subcarriers. Thus, there is an increase in symbol duration for the lower rate parallel subcarriers which in turn reduces the relative amount of dispersion, that is generated by multi-path delay spread, in time.

However, in an attempt to completely eliminate the inter symbol interference (ISI), a guard time is introduced in every OFDM symbol. As such, OFDM technology is seen as a scheme that converts a frequency selective fading channel to a set of parallel flat fading sub-channels. Consequently, the receiver structure is drastically simplified, and the time domain waveforms of the sub-carriers become orthogonal to each other. In contrast to the normal Frequency Division Multiplexing (FDM)scheme where the subcarriers are non-overlapping, the signal frequency spectrum associated with different subcarriers hit in frequency domain, as shown in Figure 2.5. The introduction of guard band among various carriers in the conventional FDM, in a bid to get rid of the interchannel interference, results in an inefficient use of the scarce and costly frequency spectrum resource. The overlapping of these subcarriers in the OFDM systems makes possible efficient utilization of available bandwidth without causing the inter-carrier interference (ICI) [35].

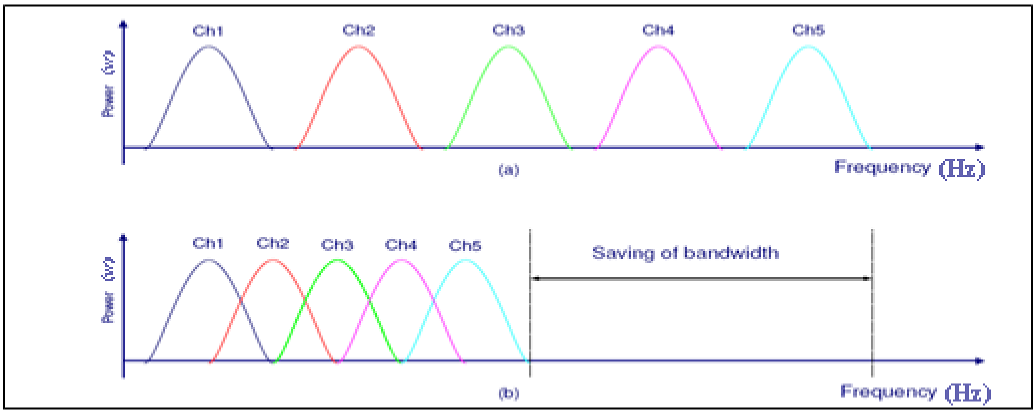


Figure 2.5. (a) Conventional FDM (b) OFDM

Consider the system in Figure 2.6 . The sent spectral shape is selected so that Inter Carrier Interference (ICI) does not take place. That is, the spectra of single sub-carriers are maximum at their frequency and zero at other subcarrier frequencies. The N_c serial data element, with R_s symbol rate (T_s symbol duration), modulate N_c sub-carrier frequencies, are then frequency division multiplexed. The OFDM symbol duration (T_u) is increased to ($N_c T_u$), This makes the system less vulnerable to delay spread damage [11,28].

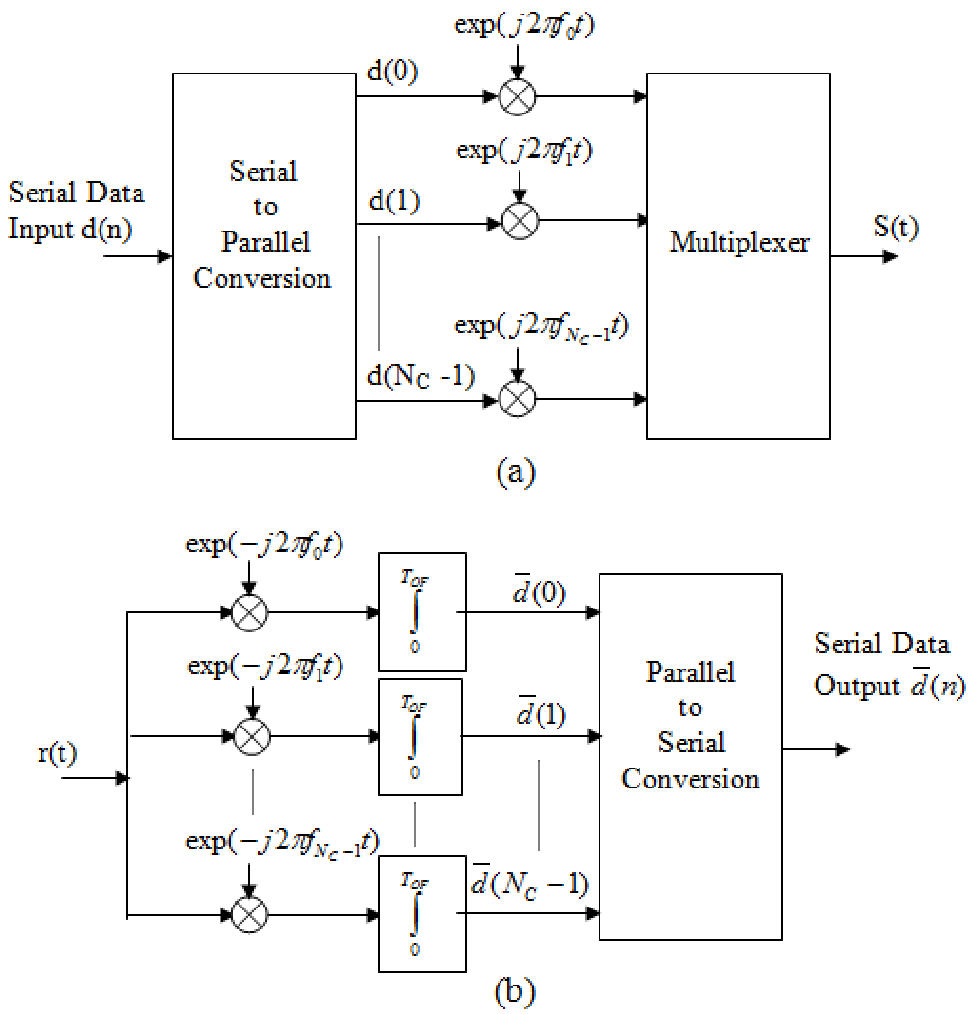


Figure 2.6. Basic OFDM System (a) Transmitter (b) Receiver

The frequencies of subcarrier are spaced by multiples of ($\frac{1}{N_C T_S}$) so that, in transmission with free signal distortion, the coherent detection of a signal element in any subcarrier of OFDM system gives no response for a received element for other subcarriers. Hence, the N_c received signal elements, corresponding to the N_c subcarrier of OFDM system, are said to be orthogonal, and, no further filtering is needed to separate the different subcarriers. In other words, the power density spectrum has a central positive peak at an individual carrier frequency, and zeros at all other subcarrier frequencies .Using digital modulation format, the transmitted complex baseband OFDM signal is given by [11,28].

$$S(t) = \sum_{n=0}^{N_c-1} d(n)\, exp(j2\pi n\Delta f t) \qquad (13)$$

d(n) represents the modulated data symbol and Δf is the spacing of subcarrier ($1/N_C T_S$). At the receiver, all operations in the transmitter are reversed.

2.6.2 OFDM System Description

Figure 2.7 shows an OFDM system block diagram [28,34]. At sender, in coming binary data are mapped firstly to multiple symbols using 4PSK,8PSK ,QAM ,…etc. ,digital modulations and they will be modulated into N_c orthogonal subcarriers. Subcarriers are sampled with sampling rate N_c/T_u, where T_u is useful OFDM symbol duration. At last, samples for every subcarrier are combined together to act as OFDM symbol. An OFDM symbol, created by N_c-subcarriers OFDM system, consists of N_c symbols, and integer number (K^{th}) of sample of an OFDM symbol is written as [25,36]

$$x_k = \sum_{n=0}^{N_c-1} X_n\ exp\left\{j\frac{2\pi kn}{N_c}\right\} \qquad 0 \le k \le N_c - 1 \qquad (14)$$

Wherein the symbol X_n is the nth sub-carrier modulated data symbols. Formula (14) is the equivalent to N_c point Inverse Discrete Fourier Transform (IDFT) operation on the data sequence. Theoretically , IDFT may be performed properly using Fast Fourier Transform (IFFT); IFFT formula is used to convert the frequency domain signal into a time domain signal [3].Then, the guard interval is inserted in front of sent symbol to remove inter symbol interference (ISI). Then, the transmitted symbols are passed through the channel [37].

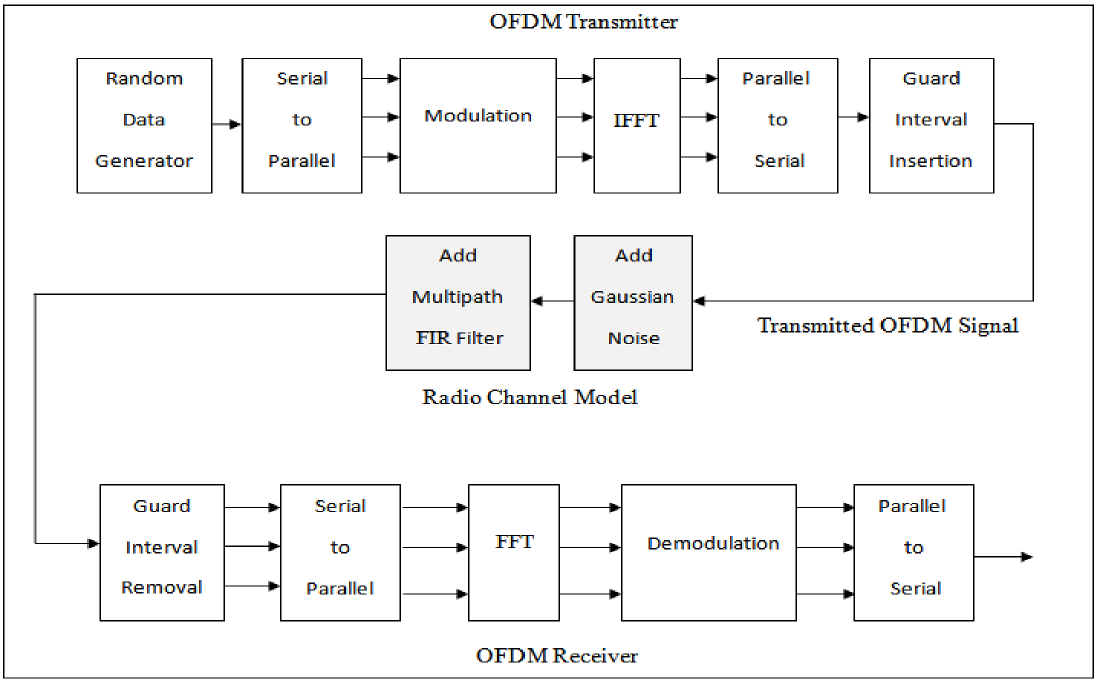


Figure 2.7. Basic OFDM System Block Diagram

At receiving side , the demodulation process takes inversely manner achieved at the sending side [38]. The guard interval is omitted from the received symbols, then the symbol is transferred by FFT from the time domain to the frequency domain. Lastly, the binary information data is obtained back after the demodulation and parallel to serial signal converter [20].

2.6.3 Inter symbol Interference (ISI) and Inter carrier Interference (ICI)

In a multipath surrounding, the sent symbol with different propagation time is required to get the path to the receivers. From the receiver's principle, the dispersion of the channel, wherein the received symbol duration is compressed. Extended symbol duration makes the currently received symbol during inter-symbol interference (ISI) overlap with the previously received symbols. In OFDM, ISI interference of the OFDM symbol is usually defined by the previous OFDM symbol [11,28].

In OFDM point of view, sub-carriers the spectrum may overlap, but stay orthogonal to each other. This means that, in each sub-carrier of the maximum value of the spectrum, all of the other sub-carrier spectrum is zero. The receiver has function to sample information message for each sub-carrier symbols highly point and demodulates them without interactions from the subcarriers. Adjacent subcarriers of the data symbol is called inter carrier interference (ICI) [11,28]. ICI takes place in the case of the multi-path channel changes over one OFDM symbol time. As it occurs, the Doppler frequency shift for each multipath component introduce frequency offset that causes loss of orthogonality between them, where integer number of cycles will not remain for current symbol during FFT process, due to a phase change of the previous symbol .ICI may exist when OFDM symbol produces ISI, this situation from the perspective of the time domain .At last, all offset of the sub-carrier frequency between the sender and the receiver may give introduction of inter-carrier interference in OFDM symbol**.**

2.6.4 Guard Time and Cyclic Prefix

The duration of the OFDM symbols, as its serial data stream is longer than the data symbols because it is flexible to ISI. N_c subcarriers of an OFDM transmitter, if a data symbol duration T_s of IFFT,the resultant OFDM symbol duration is [36]

$$T_u = T_s N_c \qquad (15)$$

Thus, if the delay spread of a multipath channel is greater than T_s then the data symbol in the serial data stream will experience frequency-selective fading, while the data symbol on each subcarrier will experience only flat-fading. Figure 2.8 illustrates the influence of frequency-selective channel on OFDM transmission [36,39].

Guard time T_g Is added at the first of each OFDM symbol before transmission to reduce ISI, T_g will be omitted before FFT process at receiver. The guard interval means an empty tab between the two OFDM symbols which is used in the situations of multi-path reflection. Practically, the empty T_g may exhibit ICI. ICI happen during the changes of multi-path channel over one OFDM symbol time. As this occurs, the Doppler frequency shift for each multipath component introduce frequency offset that causes loss of orthogonality between them, where integer number of cycles will not remain for current symbol, due to a phase change of the previous symbol [31]. This problem can be solved by the cyclic extension of OFDM symbol or CP. CP or in general, guard interval is replica of ending part of OFDM symbol that is attached to the front of sent OFDM symbol, as shown in Figure 2.9 [39].

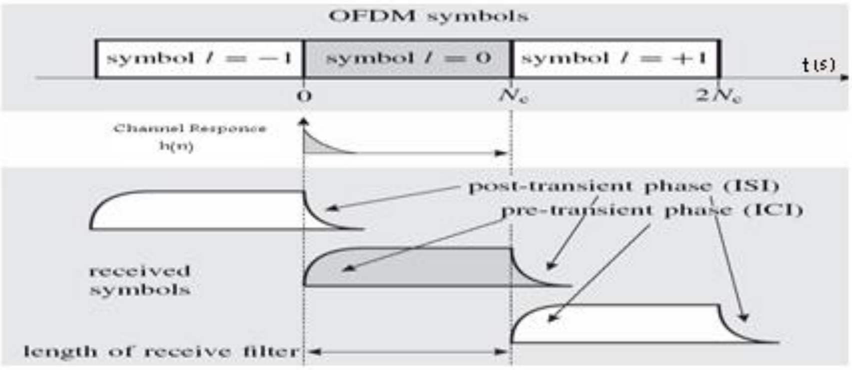


Figure 2.8. Influence of Frequency-selective Channel on OFDM Transmission

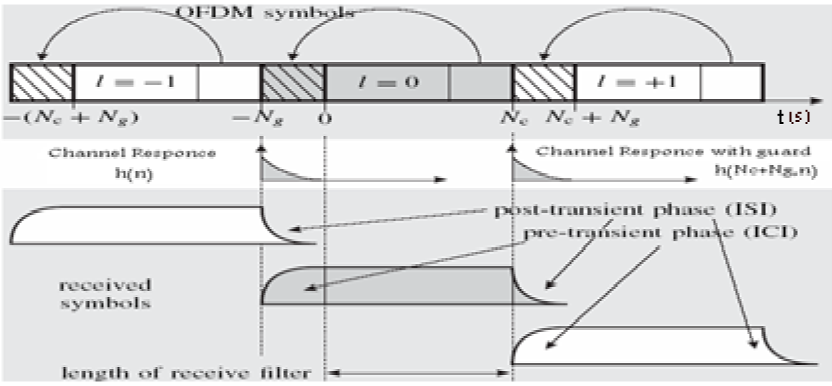


Figure 2.9. Effect of Guard İnterval

To protect the orthogonality between the subcarriers, this can be done by adding guard time through cyclic extension of the OFDM symbol. When the delay spread is smaller than the guard time, the delay spread only describes the type of each sub-carrier phase shift, but does not damage the orthogonality among subcarriers [36].

2.6.5 OFDM System Orthogonality

Orthogonal signals are independent of each other. Orthogonality is a feature that permits a plurality of information signals on a common channel to be sent, detected without interference. Among decayed data communication signals ,there is huge percentage for orthogonality loss . OFDM signal is a sinusoidal signal, and every related to one subcarrier. Each sub-carrier at the baseband frequency is selected to be of an integer multiple of the reciprocal of symbol interval, resulting in whole subcarriers having uniform integer cycles for each symbol. Thus, the subcarriers have orthogonality for each other [28,38], as shown in Figure 2.10 .

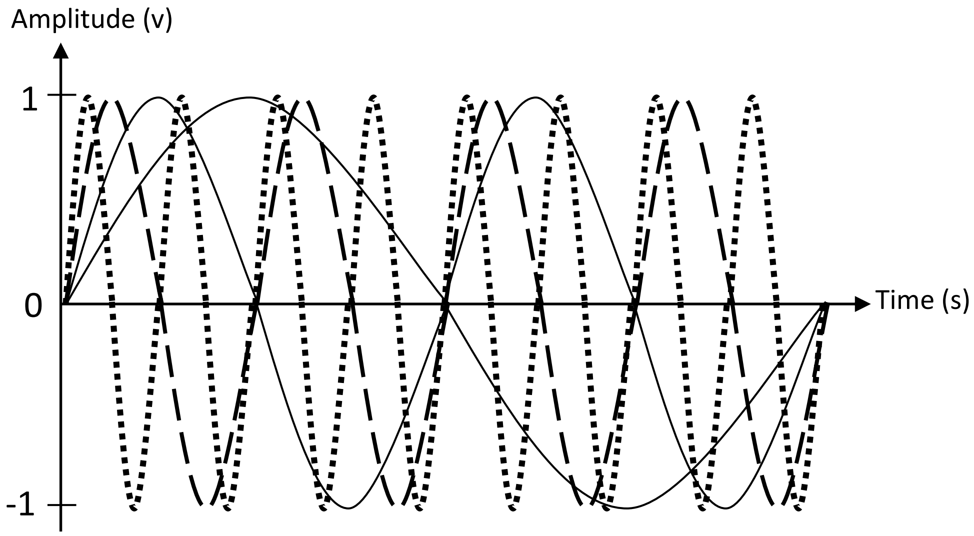


Figure 2.10. OFDM Orthogonality in Time Domain with Four Subcarriers [28]

Other possible way to see the orthogonality nature of OFDM signals is to view at its spectrum. By frequency domain,each OFDM subcarrier has (sin(x)/x),also known as a sinc function, frequency response, as shown in Figure 2.11. The sinc figure has a narrow main multiple side lobes and narrow main lobe which decrease gradually with frequency difference values as far from the center [28,38].

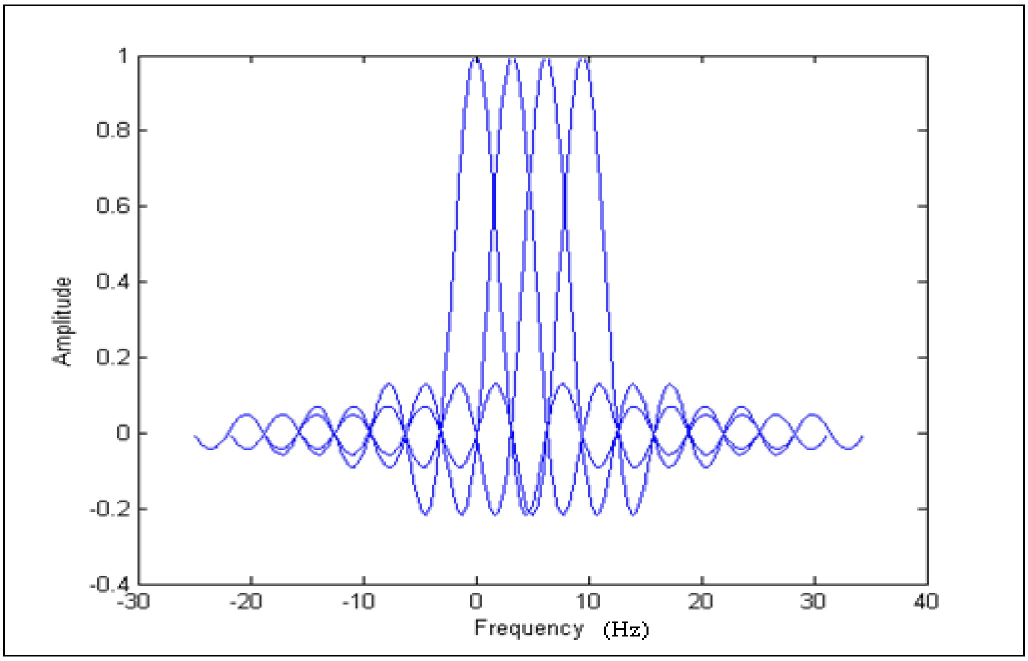


Figure 2.11. Orthogonality of OFDM in Frequency Domain with Four Subcarriers [28]

The center frequency of each carrier as maximum amplitude and null values evenly spaced intervals equal to the carrier frequency gap. Orthogonality during transmission is resultant of maximum amplitudes (peaks) of each sub-carrier related to other nulls of these subcarriers[28].

2.6.6 Advantages of OFDM System

OFDM has some inherent useful properties over the single-carrier modulation system, a wireless communication. Important reasons for OFDM growing and popularity nowadays and in the future for wireless industry's will be presented in this section[28].

i- Multipath Delay Spread Tolerance

OFDM is highly protected against multi-path delay spread and inter-symbol interference caused by a radio channel. As the symbol duration is longer (high data rate signal is converted into "N_c" low rate signal), the influence of delay spread is decreased by the same factor. In addition, by introducing the guard time, the concept of cyclic extension, inter-symbol interference (ISI) and the inter-carrier interference (ICI) are wholly deleted [28].

ii- Frequency Selective Fading Channels Protection

If the channel experiences frequency selective fading, you need complex equalization techniques at the receiver for single-carrier modulation case. However, in the case of OFDM, the available bandwidth is divided in a number of orthogonal subcarriers at narrow intervals. Then to be converted into a usable channel bandwidth of many narrow flat fading subchannels. Therefore, we can assume that, through flat fading subcarriers, may change the associated subcarrier channel gain / phase. At the receiving end, each sub-carrier only needs to it encounters the channel gain / phase weighting. In the huge case of amplitude distortion, simplest equalizer structure may be enough to correct the distortion in each sub-carrier [28].

iii- High Spectral Efficiency

By allowing overlapping subcarriers of the OFDM frequency domain ,it is possible to achieve high spectral efficiency. At the same time, to enhance ICI for demodulation of subcarriers which they are orthogonal to each other. For given number of subcarriers is N_c, the total bandwidth is determined by [28]

$$B_{total} = \frac{(N_c + 1)}{T_u} \tag{16}$$

where T_u is the subcarrier duration that equals the symbol duration of the OFDM symbol. In the case of big values of N_c, the complete bandwidth can be calculated by[28]

$$B_{total} \approx \frac{N_c}{T_u} \tag{17}$$

On the other hand, the serial transmission bandwidth for same message is given by [28]

$$B_{total} = \frac{2N_c}{T_u} \qquad (18)$$

Thus, this achieves a spectral gain of approximately hundred percent in OFDM as compared to unity carrier serial sending case.

iv- Efficient Modulation and Demodulation

Subcarrier modulation and demodulation are done using IFFT and FFT ways respectively . In the digital domain by the modulation and demodulation, there is avoiding the need for high frequency stabilization of the oscillator [28].

2.6.7 OFDM System Disadvantages

i- High Peak-to- average Power

OFDM transmission is one of the most really problems that it shows a high peak to average power ratio (*PAPR*). There is a problem of huge outing of sent signal amplitude. OFDM signal is essentially combined complex random variables of N_c , each of which can be considered a complex modulated signals at different frequencies. In some cases, whole signal components with same phase added to each other and produce a large output, and sometimes , they cancel each other , resulting in zero output. Accordingly, *PAPR* is very large, which increases the complexity of the analog - digital and digital - analog converter, reducing the efficiency of the RF amplifier. In each symbol period of *PAPR* of the OFDM signal S(t) can be defined as [28]

$$PAPR = \frac{1}{P_{av}} \max_{0 \leq tT \leq_{OF}} |s(t)|^2 \qquad (19)$$

where $s(t)$ is series of complex output signals, and P_{av} is its average. Many techniques have been suggested to reduce $PAPR$ such as clipping, and coding methods [25].

ii- Synchronization

One of the most effective issue in receiver is how to sample the input signal. If you use the wrong sample sequence processing by using FFT, received data cannot be properly restored on the carriers.If sent signal is truly time cyclic domain for FFT use ,the time offset can be properly applied by a known amount to modify all phases of the carrier. This is due to the time shift theorem of convolution transform theory. By the way, the effect of the time shift, the phase shift not only to add, but also to add ISI with close symbols. This interference may be difficult to reduce the reception level. For obtaining a good synchronization technique there is need to add null for OFDM symbols. This method can be used for time synchronization in DAB [21,40].

iii- More sensitive to phase noise, timing, and frequency offsets

Noisy phase and frequency offset of the OFDM receiver may produce effective amount of ICI. The erroneous time offset is resulted by the introduction of inter-symbol interference and inter-carrier interference at the receiver where the OFDM symbol boundaries are not correctly identified. The transmitter and receiver carrier frequency mismatch induced frequency offset and Doppler effect and they will be intensified. Frequency offset error may damage ICI of orthogonal subcarriers [7]. These are the worst things in OFDM as compared with the single-carrier system, . An robust frequency and estimated phase methods may help to eliminate the use of these effects [25,28].

iv-Greater complexity

More advantages absolutely implies more degrees of complexity for enhanced OFDM systems that are adopted in different wireless application [11].

v- More expensive transmitter and receiver

Since more complicated components are used to construct OFDM system configurations for better performance , the average costs for related transmitter and receiver will be relatively increased [28].

2.6.8 Calculation of OFDM Parameters

For given bit rate R, number of bit for each subcarrier ,m, number of subcarriers (N_c), and the multipath delay spread of the channel , T_m , the OFDM system parameters can be determined, as shown [28,41]

- Useful OFDM symbol duration , T_u is:

$$T_u = \frac{mN_c}{R} \qquad (20)$$

- The complete OFDM duration for each block is:

$$T_{bk} = T_u + T_g \qquad (21)$$

- The frequency spacing between dual close subcarriers Δf is:

$$\Delta f = \frac{1}{T_u} \qquad (22)$$

- To minimize (SNR) loss because of T_g,OFDM symbol duration must be bigger than T_g.Although,long symbol duration is flexible to Doppler spread, phase noise, frequency offset. By thumb principle , the OFDM symbol duration of T_u must be five times at least, namely

$$T_u \geq 5T_g \qquad (23)$$

In wireless systems, a guard interval of 25% of OFDM symbol duration is often met and seems to be a good compromise [28].

- For a given data rate R, the number of information bits per OFDM symbol B_{info} is:

$$B_{info} = R\, T_u \qquad (24)$$

- From B_{info} and average bits per symbol per subcarrier R_{sub},the number of subcarriers N_c calculated by :

$$N_c = \frac{B_{info}}{R_{sub}} \qquad (25)$$

- Theoretically , T_g must be two times the delay
Spread at least to reduce ISI mostly , i.e.

$$T_g \geq 2T_m \qquad (26)$$

- The OFDM signal bandwidth can be calculated by:

$$BW_{OFDM} = N_c\ \Delta f \qquad (27)$$

In the multicarrier modulation scheme, the sent behavior is more sensitive to the increase in N_c due to time selectivity, because the larger symbol duration is less reliable to random FM noise, while reduced N_c is not well enough because a wider range of the power spectrum of each subcarrier frequency selectivity is not very reliable. The transmission performance deteriorates as the length of the guard interval (T_g) increases because of protected duration of the signal transmission and exhibits the power loss, but, it becomes more sensitive to the frequency selectivity as T_g decreases because a shorter protected propagation time is less reliable to delay spread. Figure 2.12 and Figure 2.13[42], show the best number of subcarriers and best length of the guard interval.

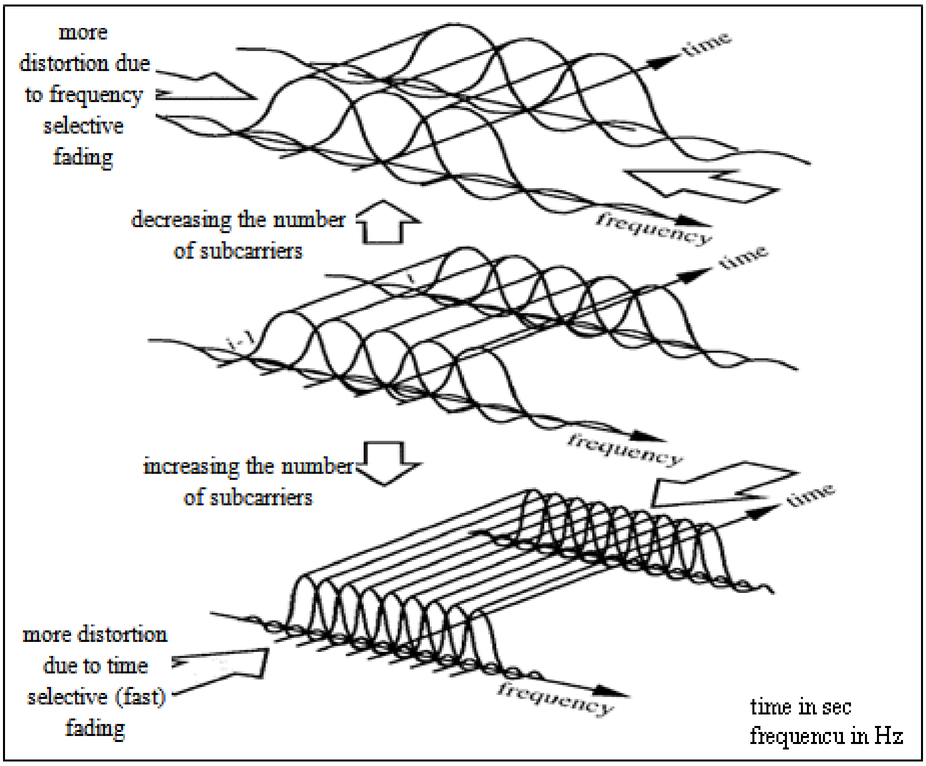


Figure 2.12. Optimum in the Number of Subcarriers [42]

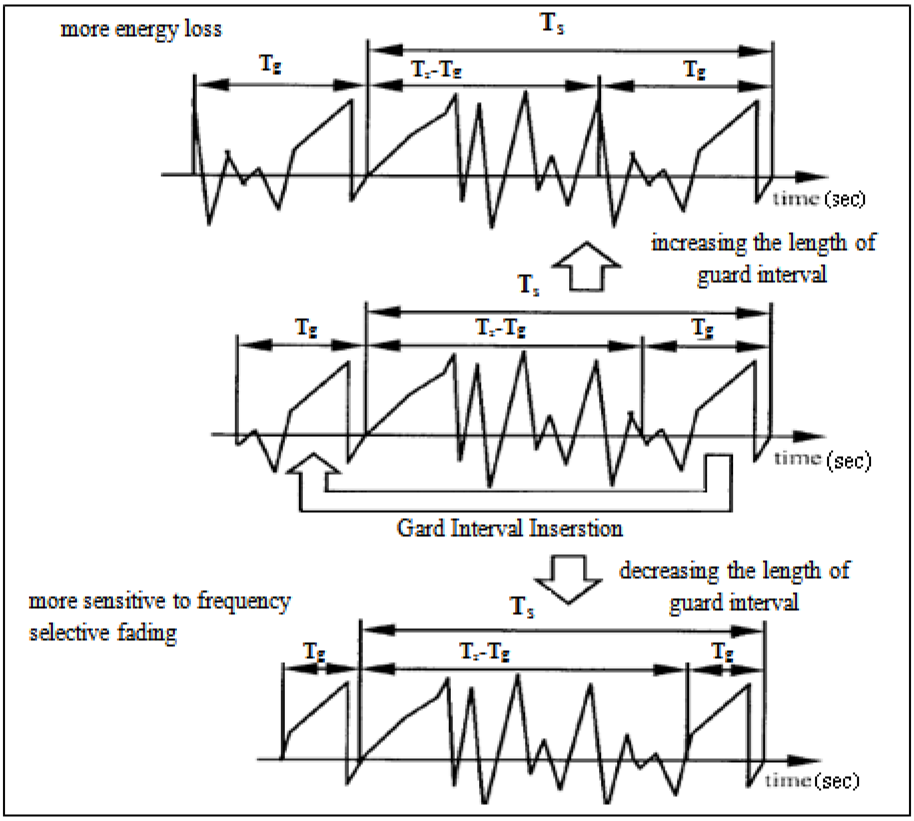


Figure 2.13. Optimum in the Length of Guard Interval [42]

2.7 Modulation

In digital modulation schemes, binary bit '1' can be stood for a cosine wave with specific phase and frequency whereas '0' can be stood for same wave with phase difference of 180 degree . This is known as binary phase shift keying(2PSk or BPSK). A number of phases may be used although one typically related only to powers of two (e.g., 2-PSK, 4-PSK). The system comprises an adaptive modulation scheme using 2PSK, 4PSK and quadrature amplitude modulation (QAM). In QAM modulation, the bit group is mapped into a complex sinusoidal signal having a pacific phase and amplitude [14].

Figure 2.14 represents a graph of the 16 QAM modulation method, using four bits of information to send sixteen symbol. Other QAM scheme using different number of information bits to generate a message Symbols, therefore, different modulation schemes may perform various spectral efficiency and various BER curves.

This diagram clarifies all modulation symbols in form of a constellation diagram. The phase of symbol is the two dimensional angle of the point, whereas the magnitude stands for amplitude of symbol. This Figure shows the received signal points without noise. The bit mapping points are also called ‘constellation points'. Namely, the decoded symbol represents the constellation point which is nearest to the received symbol on plane of two dimension.

16-PSK is another example of M-ary digital modulation which 16 various possible output phases are defined. In 16-PSK, quad bits are emerged, resulting 16 different output angels. By the way; the smallest baud and bandwidth equal 1/4 of bit rate .

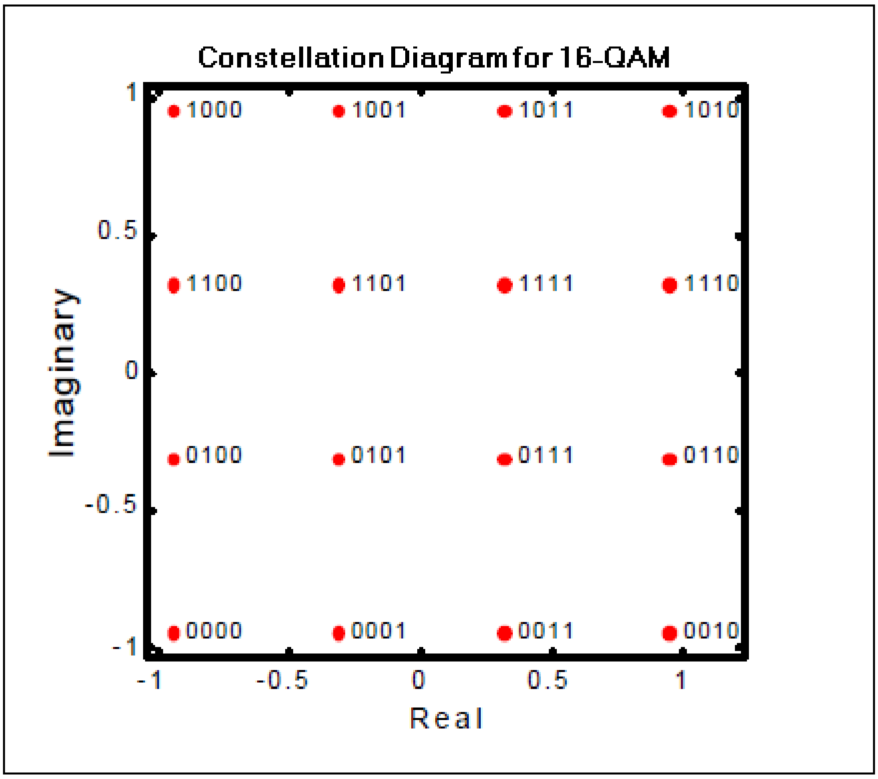
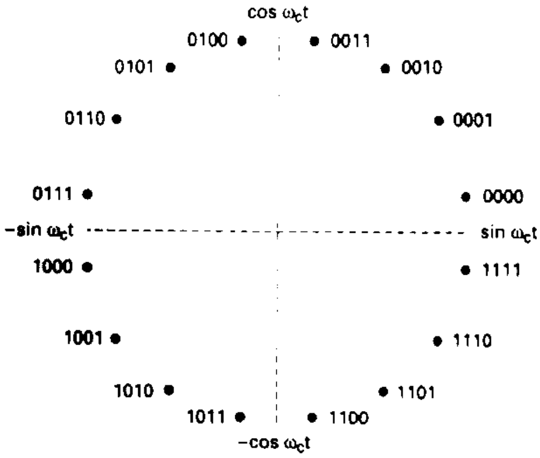


Figure 2.14. Constellation Diagram for 16 QAM

Bit code	Phase	Bit code	Phase
0000	11.25°	1000	191.25°
0001	33.75°	1001	213.75°
0010	56.25°	1010	236.25°
0011	78.75°	1011	258.75°
0100	101.25°	1100	281.25°
0101	123.75°	1101	303.75°
0110	146.25°	1110	326.25°
0111	168.75°	1111	348.75°

(a)



(b)

Figure 2.15. 16-PSK: (a) Truth Table ; (b) Constellation Diagram

CHAPTER 3

MIMO WIRELESS COMMUNICATION

3.1 Overview of MIMO Wireless Technology

In a conventional mobile radio communication system , there is one transmitting antenna and one receiving antenna. The system is known as single -input single- output (SISO) antenna system which suffers some problems of capacity , because Shannon - Nyquist rule . The modern telecommunication systems need higher data rate ,better quality and greater network capacity. In order to increase the capacity of single-input single -output system , in order to meet this special request , its bandwidth and transmit power must be increased. In modern recent developments show that the use of MIMO (Multiple Input Multiple Output) system in wireless communication raises the capacity with no need to change the requirements of transmitted power and original bandwidth .

The concept of MIMO is to sample signal in the spatial domain of the ends of the transceiver combination , in such a way that they either have an effective spatial data of plurality of parallel tubes (therefore increasing the data transfer rate) , and / or insert diversity to raise the quality (bit error rate or BER) of the communication . Generally Rayleigh fading links are considered to be a serious problem in the wireless communication caused by multipath signal propagation . But, in the MIMO system a multi -path signal is utilized in order to enhance system capacity. Multi-antenna transmitter and/ or receiver with clients emerging MIMO-OFDM which is a main technology in the applications of 4G, IEEE802.16,Digital Video Broadcasting(DVB-T)[43,44].

3.2 MIMO Technology Advantages

The most important advantages of MIMO schemes are gain of array, gain of spatial diversity, gain of spatial multiplexing and interaction suppression. A brief describes each of these gains as following [45,46]

i-Array gain: Average radio signal reception gain of the array is measured according to increased SNR at the receiver due to the effect of a coherent combining wireless system. Array gain increases the resistance to noise thereby enhancing the coverage range of the wireless network. The improvement can be done with the exactly handle ends of sending or receiving signals, so the coherent combining of transmission signals are at the receiver .

ii-Spatial diversity gain: In a wireless system ,a receiver signal powers are randomly fluctuates. Diversity is an effective way to combat fading, and provide the receiver with multiple copies of sent signal spatial frequency or time to be achieved .As more and more independent copies(copy number is often referred to as the diversity order), at least one, there is no exhibited deep fading increases, thereby increasing the probability of reception quality and reliability. A MIMO channel with$N_T$sending antennas andN_R receiving antennas exhibit $N_T N_R$ independently fading links, and most big diversity gain equals to $N_T N_R$.

iii-Spatial multiplexing gain: MIMO system provides a linear raising in capacity(average bit rate), with no need to use of additional spectrum or increase in transmit power. Referred to as spatial multiplexing gain, the gain of the antenna scan be gotten from a single independent data streams. In the appropriate channel conditions, such as wealthy scattering environment, the receiver can separate data stream. In addition, each data stream channel undergoes at least the same quality as compared with a single-input single-output system to effectively increase capacity by of multiplied factor equals to the number of streams. Generally, it is possible to safely obtain the MIMO channel which is equal to the smallest number of streams of sending antennas and receiving antennas, i.e., $\min\{N_T, N_R\}$. The Spatial Multiplexing (SM) gain enhances the capacity of a wireless network exploiting similar carrier and time duration .

iv-Interference suppression: The interaction phenomena sin the wireless channel result by a plurality of users to share time and frequency resources. MIMO system interference may resist the use of spatial dimensions to enlarge the separation between users. Therefore, the system can be adjusted to be not liable to interference and the distance between the base station using the same time /frequency channel is possibly decreased in the sake of requirements of system capacity improvement.

3.3 MIMO Fading Channel Model

Figure 3.1 shows a MIMO system with N_T sending and N_R receiving antennas. For a narrowband channel can be represented by matrix H with dimensions $N_T \times N_R$, the complex transmission coefficient between element $i \in [1,2,\ldots, N_T]$ at the transmitter and element $j \in [1,2,\ldots, N_R]$ at the receiver at time t is represented by h_{ij} . The MIMO channel with time domain can be acted as [45]

$$H = \begin{bmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,N_T} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,N_T} \\ \vdots & \vdots & \ddots & \vdots \\ h_{N_R,1} & h_{N_R,2} & \cdots & h_{N_R,N_T} \end{bmatrix} \quad (28)$$

Hence, a system transmitting the signal vector x = $[x_1, x_2,\ldots,x_{N_T}]^T$, where $x_i(t)$ is the sent signal from the ith element would result in the signal vector y = $[y_1, y_2,\ldots,y_{N_R}]^T$ being received, where $y_j(t)$ is the signal received by the jth element, and

$$y = Hx + z \quad (29)$$

The received signal vector y is the $N_R\times1$ and x is the $N_T\times1$ sent signal vector while $z$is the noise vector [44] .

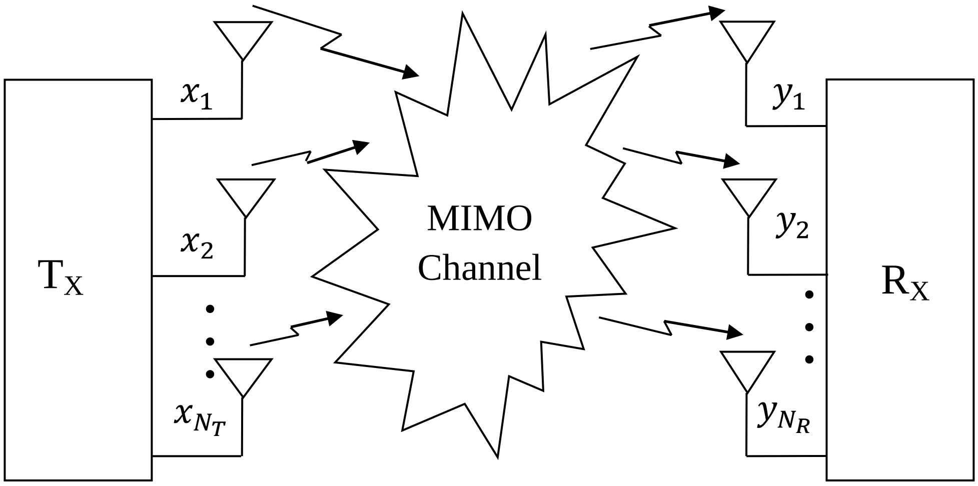


Figure 3.1. General MIMO System with N_T Sending Antennas and N_R Receiving Antennas

3.4 MIMO Transceiver Design

Transceiver algorithms for MIMO systems can be broadly classified into dual groups: diversity maximization rate schemes and maximization schemes. MIMO systems within these categories are called *Spatial Multiplexing (SM)* techniques and *spatial diversity* techniques, respectively. Spatial multiplexing techniques such as *Bell Labs layered Space-Time (BLAST)* predominantly aim at a multiplexing gain, (i.e., an increasing in speed as compared to a SISO system). In spatial diversity techniques a maximum diversity gain are provided, for fixed transmission rate, (i.e., decreasing error rates) such as, space-time coding techniques, that are based on the principle of appropriately sending redundant symbols over the channel, from different antennas to increase reliability of transmission [44].

3.4.1 Spatial Diversity Techniques

The basis of diversity is to supply the receiver with many types of similar sent signal. Every one of these types is referred as a diversity branch. If these types are influenced by non-dependent fading situations, in this case the probability will be decreased effectively for these fading branches [22].

3.4.1.1 Alamouti Scheme

The easiest format of space time block codes was developed by Alamouti in 1998. He proposed this technique for dual sending antennas and one receive antenna .In the Alamouti encoder, dual consecutive symbols x_1 and x_2 are encoded , and the code matrix is given as in [9]:

$$X = \begin{bmatrix} x_1 & -x_2^* \\ x_2 & x_1^* \end{bmatrix} \tag{30}$$

In equation (30), the column in the beginning stands for the first transmission period (T) and the 2nd column the 2nd transmission period (2T). The 1st row related to the symbols sent from the 1st antenna and the 2nd row related to the symbols sent from the 2nd antenna . Namely, the encoding is done in both the space(across dual antennas) and time (dual sending durations) domains. This represents as space-time coding [46].

The encoder outputs are sent in two consecutive transmission periods from dual transmit antennas as shown in Figure 3.2. During 1st transmission period, dual nals x_1 and x_2 are sent at same time from 1st and 2nd antenna, respectively. In the 2nd transmission period, two signals $-x_2^*$ and x_1^* are sent on time from 1st and 2nd antenna, respectively, where $*$ denotes the complex conjugate [45].

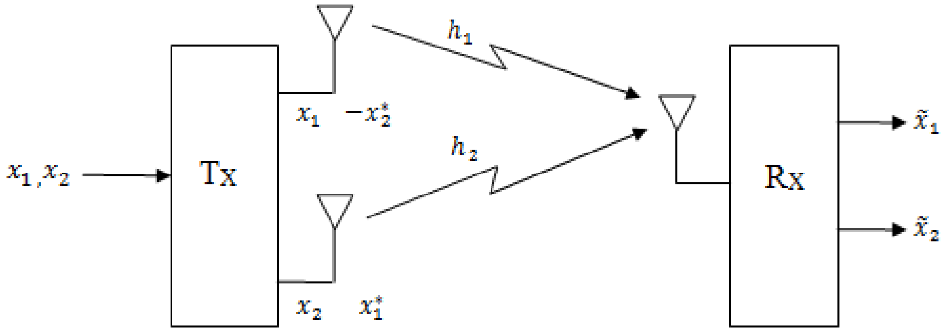


Figure 3.2. Alamouti Encoder

$$X^1 = [x_1, -x_2^*] \quad \text{and} \quad X^2 = [x_2, x_1^*] \tag{31}$$

Where X^1 and X^2 is the data sequence from 1st antenna and 2nd antenna, respectively [18].The basic property of the Alamouti scheme is the sent sequences from the dual sending antennas are orthogonal, because of zero inner product value of the sequences X^1 and X^2, This inner product is given by [47]

$$X^1.X^2 = x_1x_2^* - x_2^*x_1 = 0 \tag{32}$$

The code matrix in Equation (30) is a complex-orthogonal matrix, that is[44]

$$X.X^H = \begin{bmatrix} |x_1|^2 + |x_2|^2 & 0 \\ 0 & |x_1|^2 + |x_2|^2 \end{bmatrix} = (|x_1|^2 + |x_2|^2)I_2 \tag{33}$$

where I_2 is a 2 × 2 identity matrix.

At the receiving side, single receive antenna is used and the diversity analysis is based on maximum likelihood signal detection. Figure 3.3 explains the block diagram of the receiver for the Alamouti scheme. The fading channel parameters from 1st and 2nd sending antennas to the receive antenna at time *t* are symboled by $h_1(t)$ and $h_2(t)$, respectively.

Consider two sent consecutive symbols for fading coefficient are fixed, they can be written as :

$$h_1(t) = h_1(t+T) = h_1 = |h_1|e^{j\theta_1} \tag{34}$$

$$h_2(t) = h_2(t+T) = h_2 = |h_2|e^{j\theta_2} \tag{35}$$

Where $|h_i|$and θ_i ,i = 0, 1, are the amplitude gain and phase shift for the path from sending antenna i to the receiving antenna, and T is the symbol duration. The receiver receives y_1 and y_2 denoting the two received signals across two consecutive symbol intervals for time t and $t+T$, respectively .The received signals may be written as [44,47] :

$$y_1 = h_1 x_1 + h_2 x_2 + n_1 \tag{36}$$

$$y_2 = h_1 x_2^* + h_2 x_1^* + n_2 \tag{37}$$

Where n_1 and n_2 are independent complex variables with zero mean and unity variance, representing AWGN samples at time t and $t + T$, respectively. In the combiner-aided by the channel estimator, which provides perfect estimation in which the channel coefficients, h_1 and h_2 , are sufficiently familiar to the receiver [47].

For this instance ,easy signal processing is performed so as to separate the signals x_1 and x_2. Specifically, the maximum likelihood detector reduces highly the decision metric:

$$|y_1 - h_1\breve{x}_1 - h_2\breve{x}_2|^2 + |y_2 + h_1\breve{x}_2^* - h_2\breve{x}_1^*|^2 \tag{38}$$

By whole possible magnitudes of $\breve{x}_1$ and $\breve{x}_2$. Substituting (36) and (37) into (38), the maximum likelihood decoding can be stood for

$$(\breve{x}_1, \breve{x}_2) = arg_{(\breve{x}_1,\breve{x}_2)\in C}^{min}(|h_1|^2 + |h_2|^2 - 1)(|\breve{x}_1|^2 + |\breve{x}_2|^2) + d^2(\tilde{x}_1, \breve{x}_1) + d^2(\tilde{x}_2, \breve{x}_2) \quad (39)$$

C stands for all possible groups for modulated symbol pairs $(\breve{x}_1, \breve{x}_2)$, $\tilde{x}_1$ and $\tilde{x}_2$ are two decision statistics built by emerged received signals with channel state information.

The following statistics are used for decision and they calculated by:

$$\tilde{x}_1 = h_1^* y_1 + h_2 y_2^* \quad (40)$$

$$\tilde{x}_2 = h_2^* y_1 - h_1 y_2^* \quad (41)$$

h_1 and h_2 are channel realization, the decision statistics $\tilde{x}_i$, *i* = 1, 2, is only a function of x_i, *i* = 1, 2. By the way, the maximum likelihood decoding principle in equation (41) may composed of dual independent decoding equations for x_1 and x_2, by [47]

$$\breve{x}_1 = arg_{\breve{x}_1\in S}^{min}(|h_1|^2 + |h_2|^2 - 1)|\breve{x}_1|^2 + d^2(\tilde{x}_1, \breve{x}_1) \quad (42)$$

$$\breve{x}_2 = arg_{\breve{x}_2\in S}^{min}(|h_1|^2 + |h_2|^2 - 1)|\breve{x}_2|^2 + d^2(\tilde{x}_2, \breve{x}_2) \quad (43)$$

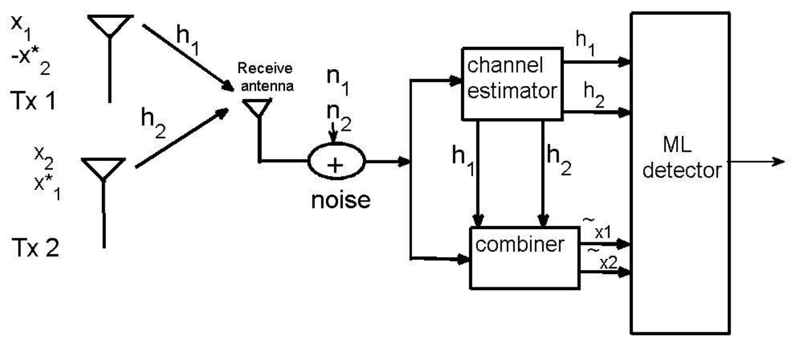


Figure 3.3. The Alamouti Scheme Receiver

Alamouti STBC have been used in multiple wireless standards such as WCDMA and CDMA2000 because of the following features. Firstly, it implements the full diversity of any signal (real or complex) constellation in the full transfer rate. Secondly, it does not require the CSI at sender . Thirdly, the maximum likelihood decoding at the receiver includes just linear processing because of orthogonal code nature [45].

3.4.1.2 The Alamouti Scheme with Multiple Transmit Antennas

The Alamouti scheme brought in a revolution of sorts in multi antenna systems by providing full diversity of two without (CSI) at the sender and a very simple maximum likelihood decoding system at the receiver may be performed by simple linear processing. Maximum likelihood decoders provide full diversity gain of N_R receive antennas. Hence, such a system provides a guaranteed overall diversity gain of $2N_R$, in the case of not using CSI at the sender. This is achieved by orthogonally feature among the sequences produced by two sending antennas. Due to these reasons, the approach was used generally to an arbitrary number of sending antennas using the orthogonal designs theory. This approach is known as space-time block codes (STBCs) [46].

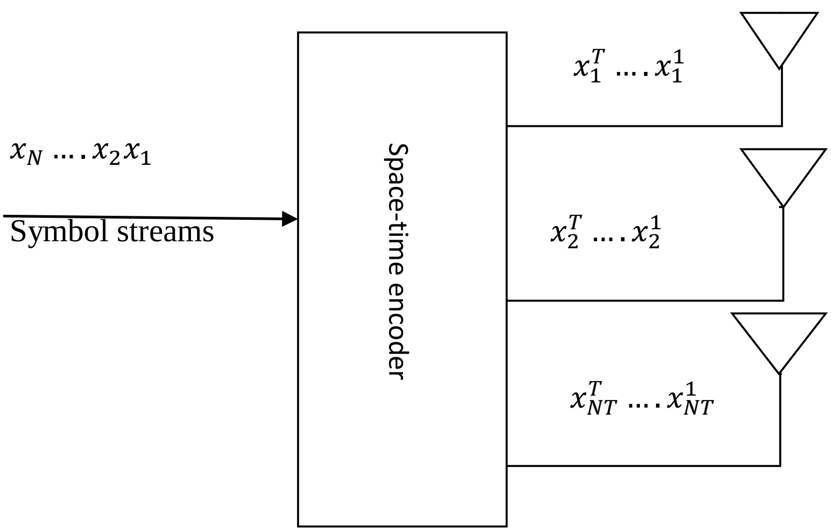


Figure 3.4. Space-time Block Encoder

generally, the resultant space time block encoder is a code word matrix **x** with dimension of $N_T \times T$. Here N_T is the number of sending antenna and T represents the number of symbols for each block. The matrix **x** is based on orthogonality. designs such that [47]

$$\mathrm{x}.\mathrm{x}^H = c(|x_1|^2 + |x_2|^2 + \cdots + |x_i|^2)I_{N_T} \quad (44)$$

Where *c* is a constant, N_T representssending antennas number, $\mathbf{x}^H$ is the Hermitian of **x**, and I_{N_T} is and $N_T \times N_T$ unity matrix. The *i*th row of x stands for the symbols sent from the *i*th sending antenna respectively in T transmission intervals, whereas the *j*th column of **x** stands for the symbols sent same time by N_T sending antennas at time *j*. The *j*th column of x is related as a space-time symbol sent at time *j*. The element of **x** in the *i*th row and *j*th column, $x_{i,j}$, *i* = 1, 2, . . . , N_T & *j* = 1, 2, . . . ,T, represents the signal sent from the antenna *i* at time *j*. The property in equation (38) indicates that the transmission matrix row vectors **x** are orthogonal to each other, which is [44]

$$\mathrm{x}_i.\mathrm{x}_j = \sum_{t=1}^{T} x_{i,t}.x_{j,t}^* = 0\,, i \neq j\,, \quad i,j \in \{1,2,\ldots,N_T\} \quad (45)$$

Where $\mathbf{x}_i.\mathbf{x}_j$ stands for the inner product of the sequences $\mathbf{x}_i$ and $\mathbf{x}_i$.The orthogonality activates to implements the complete sending diversity for specified sending antennas. In addition, it permits the receiver to separate the sent signals from various antennas and hence, a casual maximum likelihood decoding which is relied on linear processing of the received signals.[47]

3.4.1.3 The Alamouti Scheme with Multiple Receive Antennas

The Alamouti scheme may be used for a system with dual sending and N_R receive antennas. The encoding sending process for this scheme is similar to the case of one receive antenna. It is considered that r_1^i and r_2^i are the received signals at the i^{h} receive antenna at 1st and 2nd symbol period ,consecutively [47].

$$r_1^i = h_{i,1}x_1 + h_{i,2}x_2 + n_1^i \tag{46}$$

$$r_2^i = -h_{i,1}x_2^* + h_{i,2}x_1^* + n_2^i \tag{47}$$

Where $h_{i,j}$ ($j = 1, 2$; $i = 1, 2, . . . , N_R$) is the fading coefficient for the path from sending antenna j to receiving antenna i, and n_1^i and n_2^i are the noise signals for receiving antenna i at 1st and 2nd symbol periods, respectively.

The receiver emerger produces dual decision statistics according to linear set of the received signals. The decision statistics, represented by $\tilde{x}_1$ and $\tilde{x}_2$, are written as [47]

$$\tilde{x}_1 = \sum_{j=1}^{N_R} h_{j,1}^* r_1^j + h_{j,2}\left(r_2^j\right)^* \tag{48}$$

$$\tilde{x}_2 = \sum_{j=1}^{N_R} h_{j,2}^* r_1^j - h_{j,1}\left(r_2^j\right)^* \tag{49}$$

3.4.2 Spatial Multiplexing (SM)

In the spatial multiplexing MIMO system, independent data streams on the same time sent by various antenna as of a MIMO system to maximize the transmission rate .The total bit rate as compared to one antenna system is improved by N_T factor in the case of no additional transmission power. The output gain acts as bit rate (in comparison to one antenna system) is known as multiplexing gain [47].

The earliest known spatial-multiplexing receiver was invented and prototyped in Bell Labs and is called *Bell Labs layered Space-Time* (BLAST). There are two different BLAST architectures, the *Diagonal BLAST* (D-BLAST) and its subsequent version, *Vertical BLAST* (V-BLAST). The encoder of the D-BLAST is very similar to that of V-BLAST. However, the main difference is in the way the signals are transmitted from different antennas. In V-BLAST, all signals from each layer are transmitted from the same antenna, whereas in D-BLAST, they are shifted in time before transmission. This shifting increases the decoding complexity.V-BLAST was subsequently labeled so as to decrease the complexity and malfunction of D-BLAST . In this work only V-BLAST is considered.

3.5 Transceiver Structure

Figure 3.3 presents a basic SM scheme , where the sender and receiver have plurality of antennas i.e.($N_T = N_R$). At sender, the message bit sequence is divided into N_T sub-sequences, which are modulated and the antenna configurator takes symbols from the modulator, and transmits just single symbol to each antenna. The antennas send the symbols on same time and frequency band. In the receiver, the sent information message are separated by using an interference-cancellation type of algorithm [43,48].

The sent signals from different antennas propagate through autonomous distributed path with interference to each other during reception .Signal detection at the receiver of linear and nonlinear receiver technology is characterized by performance and complexity mutual relation.

A low complex option is to adopt a linear receivers, for example, relied on zero-forcing (ZF) or minimum mean square error (MMSE rules. However, the error performance is usually low, especially during using the ZF method. generally, it is necessary that $N_R \geq N_T$, in order to reliably separate the received data stream. However, if the number of receive antennas bigger than the number of sending antennas (NR> NT) ,in the case, it is satisfied to achieve spatial diversity gain [44,45].

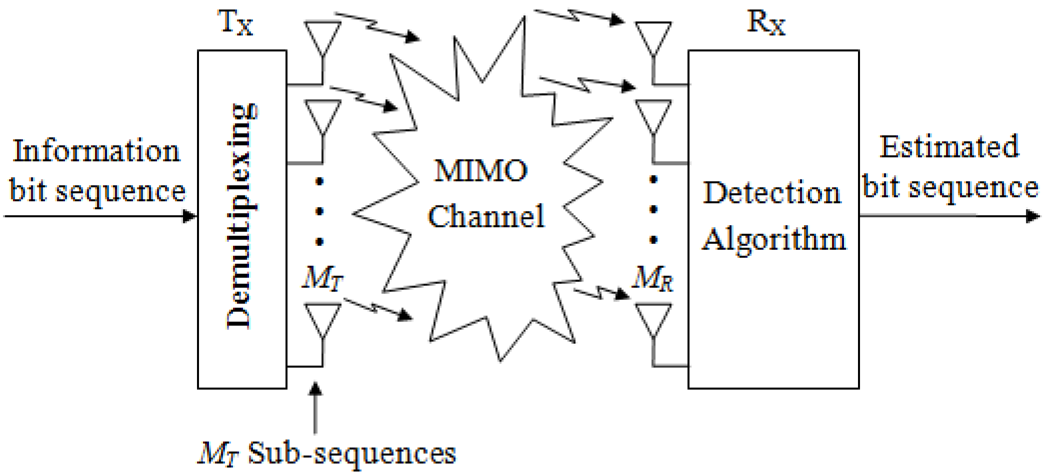


Figure 3.5. Basic Principle of Spatial Multiplexing (SM)

3.6 Zero-Forcing (ZF) Method

The simplest , but at least efficient decoding method using inversed matrix. As matrix inversion exists only for square matrices, there is a more general expression known as, pseudo-inverse matrix, which can be used for a square and non square matrices. The interference is suppressed by multiplication in the received signal with the inversed pseudo of the channel matrix. This may be also known as Zero Forcing (ZF) approach. Hence, the ZF combiner weight W_{ZF} is given by [44]

$$W_{ZF} = \left(H^H H\right)^{-1} H^H \tag{50}$$

Where $(.)^H$ referred as Hermitian transpose operation and H is the channel matrix. The zero-forcing detector totally nullifies the interference from sent signal by multiplying the received signal y given in Equation (29) with the ZF weight W_{ZF}, giving an estimated received vector $\tilde{x}$:

$$\tilde{x} = W_{ZF}y = W_{ZF}(Hx + z) = x + \left(H^H H\right)^{-1} H^H z \tag{51}$$

The main drawback of this approach is the noise enhancement. If the matrix $H^H H$ has too small eigenvalues, its inverse probably very big values that boost the noise samples. A better performance may be performed using same method called Minimum Mean-Square Error (MMSE), where the SNR is determined during evaluating the inversed matrix to implement MMSE [49].

3.7 Minimum Mean-Square Error (MMSE) Method

Zero-forcing receiver is a logical alternative MMSE receiver, which tries to hit a balance between the spatial suppressed interaction and noise enhancement by reducing as far as possible mean square error sent vectors x and the received vector which is a linear combination and referred as $W_{MMSE}\, y$ [47]

$$\min E\{(x - W_{MMSE} y)^2\} \tag{52}$$

Where W_{MMSE} is an $N_R \times N_T$ matrix representing the MMSE combiner weight and it is given by [44]

$$W_{MMSE} = \left(H^H H + \sigma_Z^2 I\right)^{-1} H^H \tag{53}$$

Where σ_Z^2 represents noise variance and I is an $N_T \times N_T$ unity matrix. An estimated received vector $\tilde{x}$ is therefore given by [44].

$$\tilde{x} = W_{MMSE} y = W_{MMSE}(Hx + z) = x + (H^H + \sigma_Z^2 I)^{-1} H^H z \tag{54}$$

When the SNR gets big, the MMSE detector will reach to the ZF detector at low SNR, it inhibits the case of inverted eigenvalues.

3.8 Channel Capacity

As known, the channel capacity is defined as the maximum possible transmission rate such that the probability of error is arbitrary small [28,47].In 1948, the mathematical foundations of information transmission were established by Shannon. In his work, he demonstrated that, by suitable information encoding, errors generated by a noisy channel can be eliminated to any wanted level without need of information rate transfer. In case of, Additive White Gaussian Noise (AWGN) channel, he derived the most famous formula of channel capacity, which is given by [7]

$$C = B_W \log_2\left(1 + \frac{E_s}{N_o}\right) \tag{55}$$

C represents the channel capacity [bit/s] unit, B_W stands for the channel bandwidth in Hertz [Hz], E_s is the total transmitted energy, and N_o is the noise power spectral density, which equivalent to the total noise power divided by the noise equivalent bandwidth (i.e, $N_o=N/B_W$).

The mobile wireless channels are under other impairments (i.e., channel fading) as mentioned in chapter two, which reduces the channel capacity significantly. Thus, channel capacity becomes as follows [50,51]

$$C = B_W \log_2\left(1 + \frac{E_s}{N_o}|h|^2\right) \tag{56}$$

Where $|h|^2$ is the average channel fading gain. For deep fading conditions, the channel capacity degrades significantly. The capacity in Equation (56) depends on Channel State Information (CSI) which is defined by whether the value of instantaneous channel gain *h* is familiar to the sending and receiving sides or not. Channel State Information (CSI) at transmitter plays an important role to maximize the channel capacity in MISO and MIMO systems, but it is difficult to be obtained. However, CSI at receiver can be obtained through the transmission of a training sequence [50]. Throughout this section, CSI is assumed to be known to the receiver. On the other hand, the sender CSI is studied for two cases (i.e. known and un known CSI).

In the next sections, channel capacity of Rayleigh fading channels for various system architectures such as SISO, SIMO, MISO and MIMO is studied. Then, the analytical model that analyzes the behavior of these systems over flat fading channel is presented.

3.8.1 SISO Channel Capacity

In Single-Input Single-Output (SISO) systems, the normalized Shannon capacity formula per unit bandwidth (i.e., B_W =1Hz) of such systems is given by [51]

$$C = \log_2 \left(1 + \frac{E_s}{N_o} |h|^2\right) \tag{57}$$

where C is the capacity in bit per second per Hertz [bit/sec/Hz] of channel bandwidth. The limitation of SISO systems is the capacity raises very slowly with the log of SNR and in general it is low. Moreover, fading can cause large fluctuations in the signal power level.

Only temporal and frequency domain processing are possible for SISO system. Spatial domain processing cannot be applied for this system [52].

3.8.2 SIMO Channel Capacity

Single-Input Multiple-Output (SIMO) systems have one antenna at the sender and plurality of antennas at the receiver. While SIMO system includes only a single transmit antenna, the Channel State Information (CSI) at the sender provides no capacity increase. Thus, the capacity can be derived by making use of matrix determinant as follows [50]

$$C = \log_2 det \left(I_{M_R} + \frac{E_s}{N_o} H^H H\right) = \log_2 \left(1 + \frac{E_s}{N_o} \sum_{i=1}^{M_R} |h_i|^2\right) \tag{58}$$

Where, $H^H H = \sum_{i=1}^{M_R} |h_i|^2$, which is the summation of channel gains for all receive antennas [46]. If the channel matrix elements are normalized and similar as $|h_1|^2 = |h_2|^2 = \cdots |h_{M_R}|^2 = 1$, then channel capacity becomes

$$C = \log_2 det\left(1 + M_R \frac{E_s}{N_o}\right) \qquad (59)$$

Therefore, by using multiple receive antennas, the system can achieves a capacity increases of M_R relative to the SISO case. this increment of SNR is known as array gain [50].

3.8.3 MISO Channel Capacity

Multiple-Input Single-Output (MISO) systems have plurality of antennas at sender and just one antenna at the receiver. When the sender does not have the CSI, the transmission power is distributed equally between whole sending antennas (M_T).Hence, the capacity is calculated by [50]

$$C = \log_2\left(1 + \frac{E_s}{M_T N_o}\sum_{j=1}^{M_T}\left|h_j\right|^2\right) \qquad (60)$$

Where $\sum_{j=1}^{M_T}\left|h_j\right|^2$ is the summation of channelgains for all transmit antennas. In Equation (48), while the power is equally divided among M_T transmit antennas, when the channel coefficients are equal and normalized as $\sum_{j=1}^{M_T}\left|h_j\right|^2 = M_T$, then the maximum value of MISO capacity approaches the ideal AWGN channel with single antenna at sender and receiver (SISO system) [46,50].

It is important to note here there is no array gain in transmit diversity. Unlike the receive diversity case (SIMO system) where the total received SNR is increased due to array gain [30]. However ,as the CSI is familiar to the sender, the capacity of MISO system becomes [52]

$$C = log_2\left(1 + \frac{E_s}{N_o}\sum_{j=1}^{M_T}\left|h_j\right|^2\right) \tag{61}$$

Therefore, the MISO capacity equals the SIMO capacity as the CSI is familiar to the sender [50].

3.8.4 MIMO Channel Capacity

With the advent of the Internet and rapid proliferation of computational and communication devices, the demand for higher data rates is ever growing. In many circumstances, the wireless medium is an effective means of delivering a high data rate at a cost lower than that of wire line techniques (such as cable modems and digital subscriber line (DSL) modems) [46]. Limited bandwidth and power makes the use of plurality of antennas at sending and receiving ends of the link (i.e. MIMO system) indispensable in meeting the increasing demand for data and it offers a significant capacity gains over single antenna systems, or transmit/receive diversity systems [53]. In this section, detailed studies and analysis of MIMO capacity is covered, with channel not familiar to the sender and with channel familiar to the sender.

3.8.5 Channel Unknown to the Transmitter

When there is no feedback in the system, and the channel is familiar for receiving side but not known at the sender. The sent power is distributed equally likely into M_T sending antennas [30,8], and the MIMO channel capacity is given by [30,29].

$$C = \log_2 det\left(I_{M_R} + \frac{E_s}{M_T N_o} HH^H\right) \tag{62}$$

The MIMO channel is usually interpreted as a group of parallel eigen-channels, by using the eigenvalues of the MIMO channel matrix H. The matrix HH^H with $M_R \times M_R$ dimensions is usually diagonal zed using Eigen value decomposition (EVD) to find its eigenvalues [46].

The eigen value decomposition (EVD) of such a matrix is given by $Q\Lambda Q^H$ (i.e., $HH^H = Q\Lambda Q^H$) . Based on this fact, Equation (57) may be rearranged as [8]

$$C = \log_2 det\left(I_{M_R} + \frac{E_s}{M_T N_o} Q\Lambda Q^H\right) \tag{63}$$

Q is a matrix of eigenvectors of $M_R \times M_R$ dimensions satisfying, $QQ^H = Q^H Q = I_{MR}$, while $\Lambda = diag\{\lambda_1, \lambda_2, ..., \lambda_{MR}\}$, is a diagonal matrix with a non-negative square roots of the eigenvalues. These eigenvalues are ordered so that, $\lambda_i \geq \lambda_{i+1}$ [8,46].

By applying identity property, $det(I + AB) = det(I + BA)$, and the property of Eigen vectors , $QQ^H = I_{MR}$, Equation (63) can be reduced to [2,46]

$$C = \log_2 det\left(I_{M_R} + \frac{E_s}{M_T N_o} \Lambda\right) = \sum_{i=1}^{r} log_2\left(1 + \frac{E_s}{M_T N_o}\ \lambda_i\right) \tag{64}$$

r represents the rank of the channel, which implies that, $r \leq min\ (M_R, M_T)$ and $\lambda_i (i = 1, 2, ..., r)$ are the not negative eigenvalues of HH^H.

Equation (56) shows of the MIMO channel capacity as a summation of the capacities of r SISO channels as illustrated in Figure 3.6, everyone as power gain of λ_i ($i = 1, 2, ..., r$) and transmit energy of E_s / M_T [8,46].

3.8.6 Channel Known to the Transmitter

If the channel is familiar for sender and receiver ends, so Singular Value Decomposition (SVD) may be used to convert the MIMO channel into combination of parallel sub channels . Hence, the MIMO channel matrix H can be written as [54]

$$H = U\Sigma V^H \tag{65}$$

Where Σ is an $M_R \times M_T$ non-negative and diagonal matrix, U and V are $M_R \times M_R$, and $M_T \times M_T$, each one is unitary matrix. That is, $UU^H = I_{MR}$, and $VV^H = I_{MT}$. The diagonal entries of Σ are not negative square roots of the eigenvalues of matrix HH^H. The eigenvalues on the diagonal are positive numbers with a descending order, such that $\lambda_i \geq \lambda_{i+1}$ [8]

By multiplying the inverse of U and V at sending and receiving sides respectively, the channel with interaction can be transformed into a group of independent singular value channels, as shown in Figure 3.7 and the input-output relationship given [54].

$$\tilde{y} = \sqrt{\frac{E_s}{M_T}} U^H H V \tilde{x} + U^H n = \sqrt{\frac{E_s}{M_T}} \sum \tilde{x} + \tilde{n} \tag{66}$$

Where $\tilde{y}$ is the transformed received signal vector of size $r \times 1$ and $\tilde{n}$ is the transformed AWGN vector with size of $r \times 1$. The rank of the channel H is r. Equation (66) explains that with the channel knowledge at the sender, H can be easily broken into r parallel SISO channels satisfying [46].

$$\tilde{y}_i = \sqrt{\frac{E_s}{M_T}} \sqrt{\lambda_i} \tilde{x}_i + \tilde{n}_i , \quad i = 1, 2, \dots, r \tag{67}$$

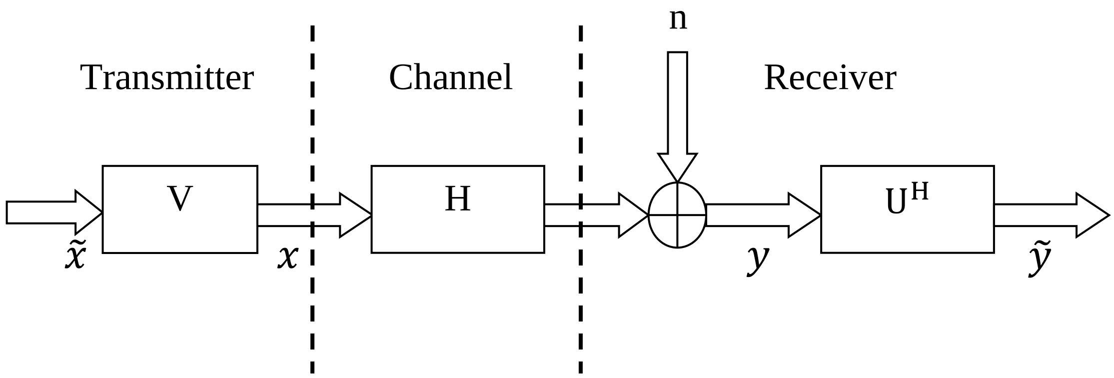


Figure 3.7. Decomposition of H as the Channel Parameters are Familiar to the Sender and Receiver

3.8.7 Water-Filling (WF) Method

While the channel parameters are familiar to the sender, the capacity given by Equation (64) can be raised by allocating the sent energy to different antennas dependent on "Water-Filling" rule [39].WF is an energy distribution strategy based on SVD, derived to provide the upper bound on data throughput across the MIMO channel [54]. It allocates more energy when the channel is in good condition and less when the channel state gets worse. By using this method, the capacity of the system is given by [47]

$$C = \max_{\sum_{i=1}^{r}\gamma_i} \sum_{i=1}^{r} \log_2\left(1 + \frac{E_s\gamma_i}{M_T N_o}\,\lambda_i\right) \tag{68}$$

Where $\gamma_i (i = 1, 2, \ldots, r)$represents the transmitted energy amount in the i^{th} sub channel such that [28].

$$\sum_{i=1}^{r} \gamma_i = M_T \tag{69}$$

By applying Lagan gain method, the best possible allocated energy policy, ${\gamma_i}^{opt}$, satisfies [28,58].

$$ {\gamma_i}^{opt} = \left(\mu - \frac{M_T N_o}{E_s \lambda_i}\right)^+ , \qquad i = 1, 2, \dots, r \tag{70} $$

Where μ is chosen so that $\sum_{\mathrm{i}=1}^{\mathrm{r}} {\gamma_i}^{opt} = M_T$ and $(x)^+$implies [28,58]

$$ (x)^+ = \begin{cases} x & if\ x \geq 0 \\ 0 & if\ x < 0 \end{cases} \tag{71} $$

The constant μ given in Equation (70) is calculated by [46]

$$ \mu = \frac{M_T}{r}\left[1 + \frac{N_o}{E_s}\sum_{i=1}^{r}\frac{1}{\lambda_i}\right] \tag{72} $$

Some remarks on Water-Filling (WF)method [28,61]:

1. μ is usually taken as reference to water level. It determines the power distribution for all sub channels [54].
2. If the power allotted to the channel with the lowest gain is negative (i.e.λ_i< 0),this channel is discarded by setting $\gamma_i^{opt} = 0$.the best possible allocated energy strategy, therefore, allocates power to those spatial sub channels that are non-negative. Figure 3.8 illustrates the WF algorithm [46].
3. Because this algorithm only focuses on fair-quality channels and stops the bad ones during each realized channel, it is to be supposed that this criteria aims a capacity which is equivalent or more than the situation during the channel is not known to the sender [46].

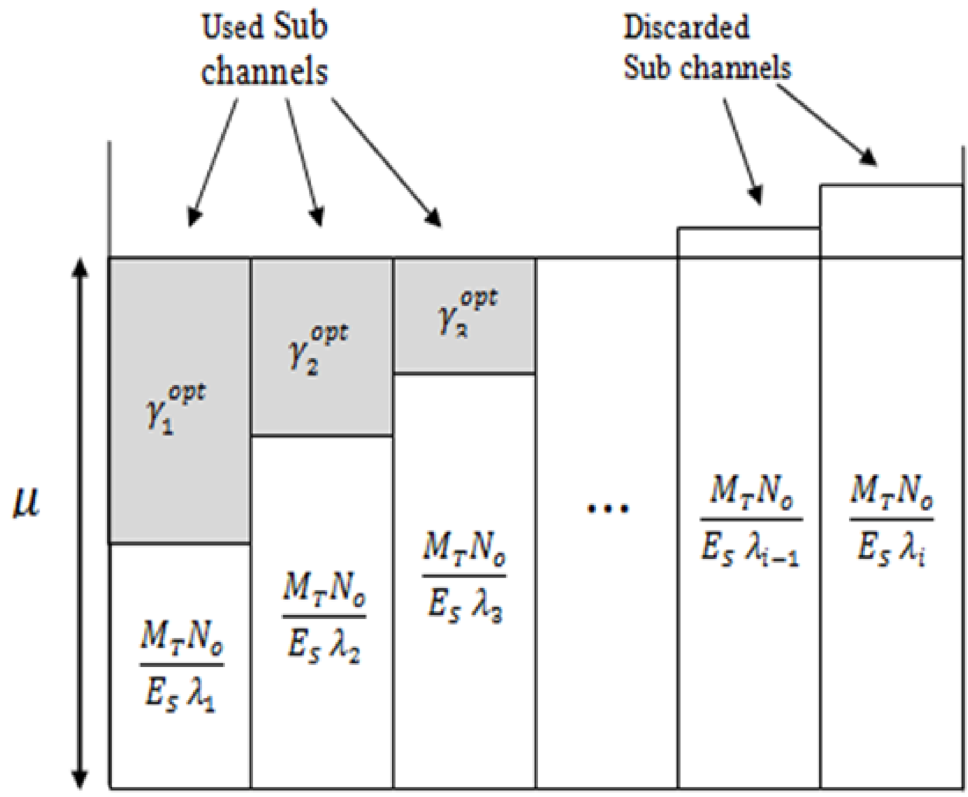


Figure 3.8. Principle of Water-Filling (WF) algorithm

3.9 MIMO –OFDM Systems

For next years , broadband wireless systems must supply huge magnitudes of data rate and more enhanced performance over channels which may be time selective and frequency-selective. The MIMO and OFDM have the ability to meet this stringent requirement since MIMO can improve the bandwidth and the diversity and OFDM can reduce the adverse effects because of multipath fading.

MIMO OFDM can be used to send data in wireless communications so as to treat with frequency selective channel effect. The OFDM signal on each subcarrier can overcome narrowband fading, therefore, OFDM can transform frequency-selective fading channels into parallel flat ones. Then by combining MIMO and OFDM technology together, MIMO algorithms can be applied in broadband transmission [16,17].

A MIMO OFDM system transmits data modulated by OFDM from multiple antennas simultaneously. At the receiver, after OFDM demodulation, the signal are recovered by decoding each the sub-channels from all the transmit antennas [55].
MIMO OFDM will permit service suppliers to apply a Broadband Wireless Access (BWA) system which has Non-Line-of-Sight (NLOS) feature. MIMO-OFDM takes benefits of the multipath features of channels using base station antennas without LOS. By MIMO-OFDM emerging ,this technique can provide flexibility and big throughput. In a multiuser application in which users may communicate with a central station (base station or access point), this technique is more favor since it supplies extra chance to be used because of huge number of users. In Figure 3.8, the main scheme of MIMO OFDM is demonstrated. In this figure, the signals are modulated by OFDM modulator, then they are transmitted by MIMO system, finally, the signals are recovered by the OFDM demodulator.

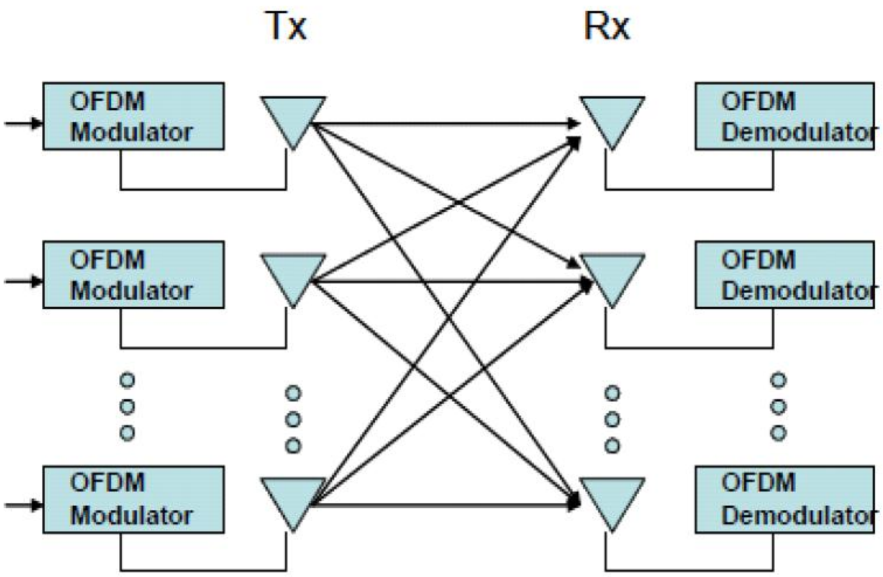


Figure 3.9. MIMO OFDM Structure.

3.10 MIMO-OFDM Channel Model

Let a MIMO-OFDM system with N subcarriers adopted over a MIMO channel with L ISI taps. Consider the fading parameters are spatially not related to each other, and that they remain fixed through single OFDM symbol. The sent signal over M_T sending antenna as may be stood for $N \times M_T$ matrix, $\boldsymbol{X_{OFDM}}$ whose $(n, i)th$ element is the symbolsent at subcarrier $n$on sending antenna $i, Xi(n)$.We consider that there is restricted power over the MIMO-OFDM word to act as :

$$\sum_{n=0}^{N-1} \sum_{i=1}^{M_T} E[|X_i(n)|^2] = N \qquad (73)$$

The sender will do the IFFT of the columns of the code word matrix X_{OFDM}, inserts CP, and sends the equivalent sequence. The CP function is to transform the circular convolution to linear convolution as shown below. Moreover, it is possible to use for synchronization purpose. clearly, there is some overhead included within CP , but the length of the ISI is generally smaller than the OFDM word, by the way the needed overhead is small. At the jthreceive antenna, after taking the FFT and excluding CP, the output signal for the n^{th} subcarrier is as follows :

$$y_j(n) = \sqrt{\rho} \sum_{i=1}^{M_T} X_i(n)\, H_{i,j}(n) + n_i(n) \qquad (74)$$

where the resulting channel coefficient from the ith to the jth antenna for the n^{th} subcarrier is written as:

$$H_{i,j}(n) = \sum_{l=0}^{L-1} h_{i,j}^{(l)} \, e^{-j2\pi nl/T} \tag{75}$$

Denoting the channel coefficients for the $(i, j)th$ antenna pair by

$$H_{i,j} = \left[H_{i,j}(0) H_{i,j}(1) \; \ldots . H_{i,j}(N-1) \right] \tag{76}$$

That is, the vector of *L* independent fading coefficient (for the *L* distinct paths of ISI links).Since our of independent random variables from the *L* (*N* generally greater than *N*) derived from the *N* equivalent channel coefficients, it is obvious that in equivalent channel fading coefficient for various sub carriers is different and dependent. Channel gain matrix (in the frequency domain) of the most up ranking ISI represents number of taps *L*, but it is integer allow-rank matrices. For example ,quasi-static fading channel coefficient is the same (time frame), for full inter leaving fading, they are mutually independent. Obviously, the channel looks the same mathematical model, but for different reasons, but the dependence fading coefficients are here inter-symbol interference[58] .

3.11 The Proposed Block Diagram of MIMO-OFDM

The adopted block diagram of MIMO-OFDM as new proposed model is presented in Figure 3.10. The system consists of several transceivers transmit and receive for STBC model . In general, n_t sending antennas and n_r receiving antennas system has been assumed for the proposed MIMO-OFDM system. For practical purposes, it is generally to represent the channel as frequency flat channel where the system bandwidth is less than the reciprocal delay spread of the channel; therefore broadband operation of the system delay spread is quite small, the frequency may also be considered flat.

After digital modulation (i.e M-ary PSK) ,The incoming data stream is arranged into the word size for transmission preparation, e.g. 2 bits/word for QPSK, and shifted into a parallel format. Then, parallel sent data is assigned to a carrier for the transmission of each data word.

In communication theory, the concept of cyclic prefix (CP)is the prefix of a symbol, with repeating of end. By the way , Cyclic prefix has two purposes:

- As a guard interval, which reduce the inter-symbol interference for the previous symbol.
- As the end of repeated symbol, it allows the linear convolution of a frequency-selective multipath channel to be defined as circular convolution, which can be transformed to the frequency domain using a discrete Fourier transform. This method is possible for channel estimation and equalization.

The cyclic prefix (CP) is assumed to be longer than the channel delay spread.

The OFDM signal for each antenna is obtained by using Inverse Fast Fourier Transform (IFFT) . The OFDM symbol can be expressed as:

$$x(n) = \frac{1}{N}\sum_{m=0}^{N-1} X\,(m) e^{j\frac{2mn\pi}{N}} \qquad (77)$$

The discrete OFDM signal can be detected by Fast Fourier Transform (FFT) after removing CP and parallel to serial conversion processes. The demodulated symbol stream is determined by:

$$y(m) = \sum_{n=0}^{N-1} y\,(n)\, e^{-j\frac{2mn\pi}{N}}\;\; G(m) \qquad (78)$$

where, G(*m*) is related to the FFT of the samples of g(*n*), which is the Additive White Gaussian Noise (AWGN) introduced in the channel.

Channel estimator for adopted MIMO-OFDM is used to send a trial sequence from one or more antennas at a time when the other transmit antennas are not active using pilot structures.

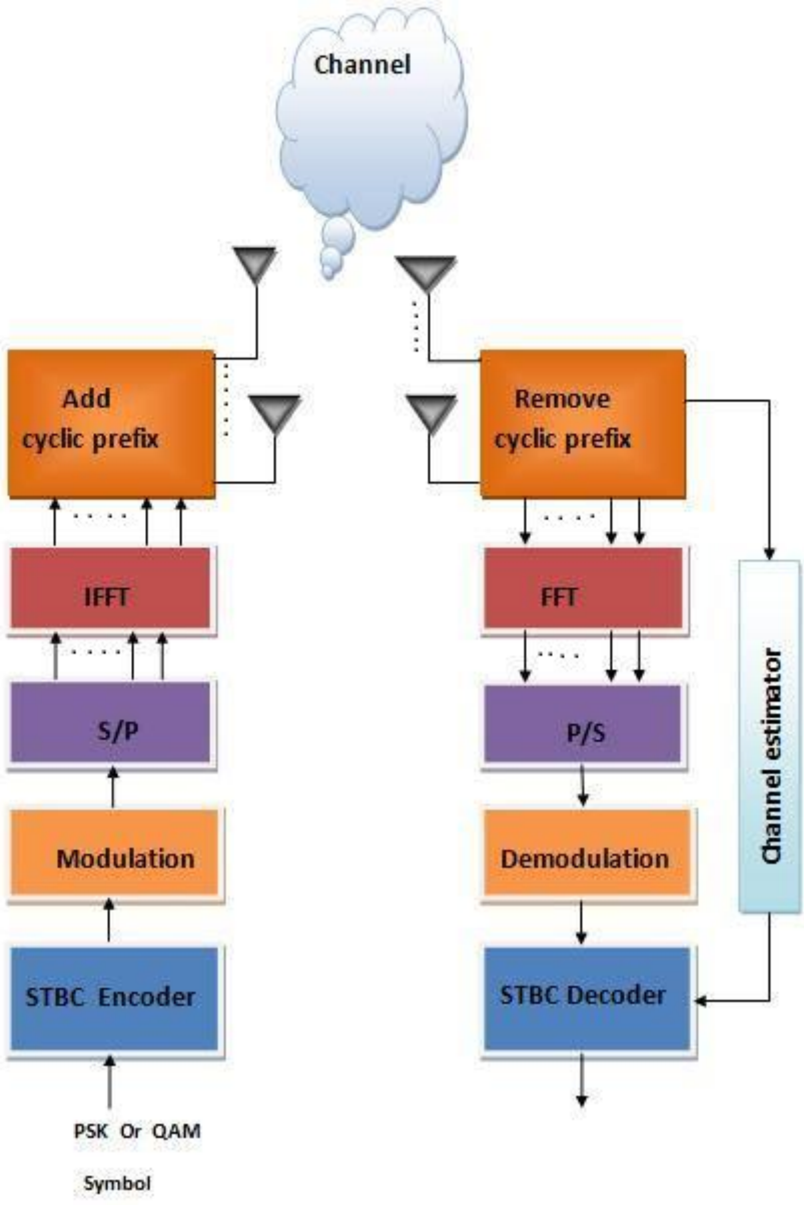


Figure 3.10. Proposed MIMO-OFDM Transceiver

3.12 MIMO-OFDM Channel Order

Ina wireless communication system, the channel order results by two or more paths in order to reach radio signals to the receiving antenna. Multipath causes many issues of pipeline atmosphere, the ionosphere reflections and refractions, reflections from water and ground objects such as mountains and buildings [45].

The impact of the channel order may have a long and destructive interference, and phase shift of the signal. Harmful interference generates fading.Through a variety of paths ,the signal amplitudes will be reached ,this phenomenon has Ray Leigh distribution and it called Rayleigh fading. There is a component (often, but not required ,line of sight component) dictates Rice distribution supplies a more exact model, which is called the Rice fading[59].

During Fax and television transmission, multipath causes jitter and ghosting, is looked as a faded image duplicate main image on the right.Transmission occurs when the ghost image leaps on mountain or other large objects, but also through a short, direct route, reaching the antenna and receiver picked up two signals via delay.

Digital radio communication, channel path may generate errors that affect communication quality. These errors are due to ISI. Equalizer is usually applied to correct for ISI .Alternatively, techniques such as OFDM, MIMO - OFDM may be used.

Mathematically ,the expressions of the channel paths can be explained using impulse response criteria used for studying linear systems. Suppose you want to send just one, ideal Dirac pulse of electromagnetic power at time 0, i.e.

$$x(t) = \delta(t) \qquad (79)$$

At the receiving end, the plurality of electromagnetic paths in the presence of one or more pulses will be received (in this case, we assume the channel has unlimited bandwidth, so the pulse shape is not modified it),and each will reach at various times.

In fact, since the electromagnetic signal has the same speed of light, because each path has a geometry may differ in length, while the others have also different air travel time (taking into account, in free-space the light requires 3.33 microseconds to cross1 km distance). Thus, the received signal will be expressed by:

$$\mathrm{y(t)} = h(t) = \sum_{n=0}^{N-1} \rho_n \, \delta(t - \tau_n) \; e^{j\emptyset_n} \tag{80}$$

Where N stands for received impulses number which is the same number of electromagnetic paths, and it can be huge number,τ_n is the time delay generatedn^{th} impulse, and $\rho_n e^{j\emptyset_n}$ is the complex magnitude and phase of received pulse, Consequently $\mathrm{y(t)}$ also stands for the impulse response function $h(t)$ of the output multipath model .In general, in the presence of a change with time under conditions of geometrical reflection, impulse response is time varying, we have

$$\tau_n = \tau_n(t) \tag{81}$$

$$\rho_n = \rho_n(t) \tag{82}$$

$$\emptyset_n = \emptyset_n(t) \tag{83}$$

In many cases, only one parameter is used to indicate multipath conditions severity: it is called multipath time, T_M,which is defined as the existing first and the last received time delay between pulses

$$T_M = \tau_{N-1} - \tau_0 \qquad (84)$$

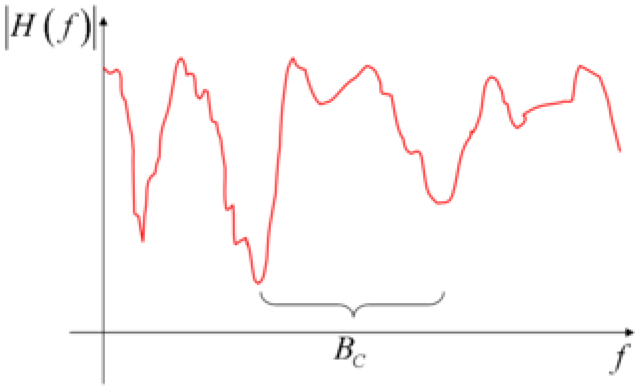


Figure 3.11. The Multipath Channel Transfer Function Response

Practically , the multipath time is calculated by assuming last pulse as first pulse that permits to receive certain amount transmit power of, for example, 99% consideration.

A linear time-invariant system which is aimed to be maintained also to be characterized in multipath phenomena channel transfer function *H(f)* and it is defined as :

$$H(f) = \beth(h(t)) = \int_{-\infty}^{+\infty} h(t)e^{-j2\pi ft}dt = \sum_{n=0}^{N-1} \rho_n e^{j\emptyset_n} e^{-j2\pi f\tau_n} \qquad (85)$$

It is easy to remember that a Dirac pulse Fourier transform is a complex exponential function, and also it is stood for a linear system of each Eigen -function. By the way, the last term on the right of the last equation can be determined simply . The resulting channel transmission characteristics has usual appearance, it can be shown that, on average, the path in two valleys respectively or two successive peaks distance (in Hz), where multipath inversely proportional to time. This is known as coherent bandwidth and it can be written as[44,60]

$$Bc \approx \frac{1}{T_M} \qquad (86)$$

3.13 Challenges in MIMO-OFDM

We have concentrated on MIMO - OFDM advantages that help us deal with the broadband wireless communication channel frequency selectivity. Obviously, avoiding costly equalization algorithm, implemented in a reasonable complexity which is used in modern digital signal processing technology and it is highly desirable. There is also difficulties in the use of OFDM, especially, the MIMO - OFDM. In this section, we will not be fully involved in difficulties, but we will focus some of the issues . MIMO - OFDM symbol is usually long (the same data transfer rate , N times over a single carrier).In practical system , even if fading is slow , there may be some more than one OFDM word for each channel variation . This may undermine the orthogonal subcarriers at receiving end and may lead to inter-channel interference , which reduces system performance. In addition , the possible frequency offset performance will worsen if it is not handled properly. Another potential problem is the large peak power to average power ratio for sent signal as a result of a *PAPR* as well as increased number of sinusoidal signals having different frequencies . Large *PAPR*, inexpensively made , may produce some distortion into sent signal from non-linear amplifier. Many methods help to reduce *PAPR* which is really necessary and indicated in [58] **.**

CHAPTER 4
DESIGN AND SIMULATION RESULTS OF MIMO-OFDM SYSTEM

4.1 Introduction

OFDM is modulation method can be adopted to restrict frequency selective fading due to multipath and narrow band interference. In OFDM ,the full transmission bandwidth is divided into orthogonal subcarriers where wideband signal is arranged to narrowband orthogonal signals , modulated by QAM or PSK techniques. The symbol duration is determined longer by inserting a cyclic prefix (CP) to each symbol. Since CP is longer than the channel delay spread ,OFDM does not undergo from inter-symbol interference (ISI) problems. Another usefulness of OFDM is that it effectively eliminate equalization complexity by activating equalization in the frequency domain. OFDM, implemented with IFFT at the transmitter and FFT at the receiver, makes the wideband signal, affected by frequency selective fading, into N narrowband flat fading signals thus the equalization can be performed in the frequency domain by a scalar division carrier-wise with the subcarrier related channel coefficients . From Table 4.1 , OFDM parameters are used to simulate OFDM model indicated in Figure 2.7. The simulated result of Figure 2.7. is presented as shown in Figure 4.1 .

Table 4.1: OFDM Simulation Parameters.

Number of bits per OFDM symbol	52
Number of symbols	10000
Number of Subcarrier	64
FFT sampling frequency	20 MHz
Subcarrier spacing	312.5kHz
Constellation	2 PSK
Cyclic Prefix	0.8 μs

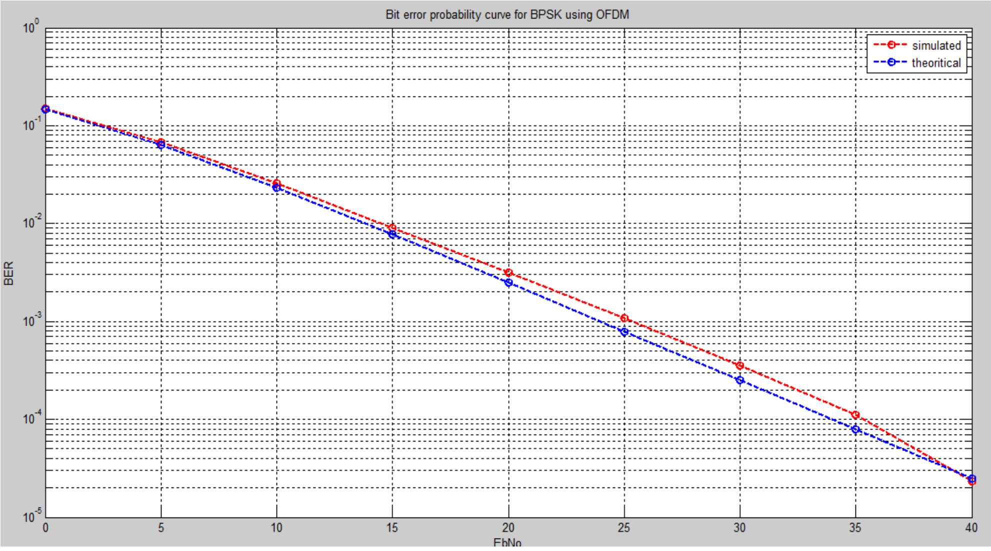


Figure 4.1. BER Plot for BPSK with OFDM Modulation

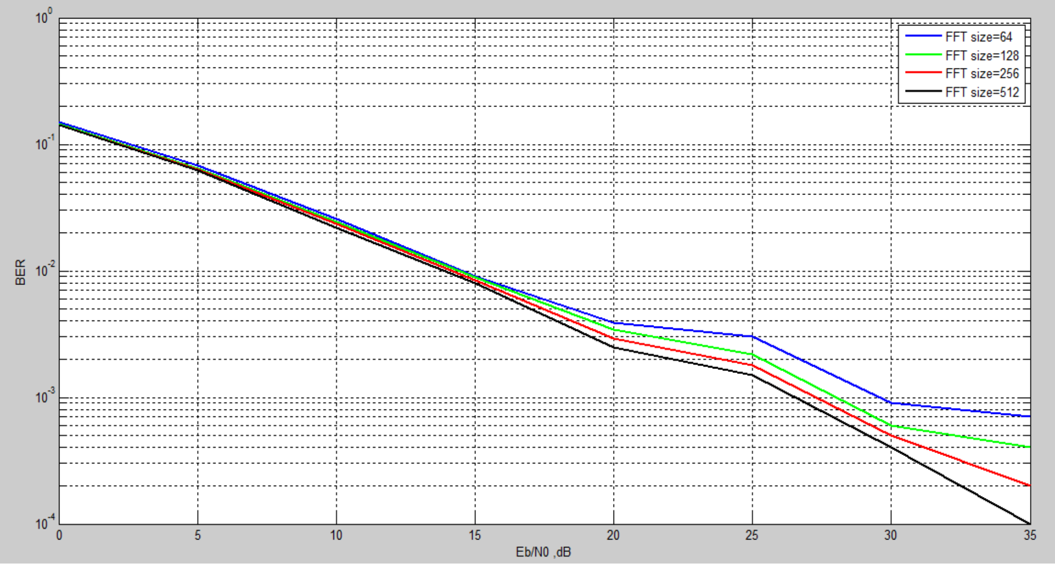


Figure 4.2. OFDM Bit Error Rate for Different FFT Sizes

Figure 4.2 shows BER performance with various FFT sizes. It can observed from this figure as FFT size increases ,BER decreases due to increasing of narrow band subcarrier that reduces multi path delay improves more the quality of modulation and demodulation.

Considering different plans, the transmitter and receiver use multiple antennas to improve the communication system coverage and performance. By the way, the promising multi-antenna technology today happens to be multiple-input multiple-output (MIMO) systems using multiple antennas at the transmitter and receiver ends . BER for 2PSK modulation for 2x2 Alamouti STBC is shown in Figure 4.3.

In this figure single input single output (SISO) with 1x1 antenna exhibits the BER of 0.01208 while maximum ratio combining (MRC) with 1x2 antenna and Almouti scheme (transmit diversity) with 2x2 antennas offer the BER of 0.001606 and 1.1e-005 respectively. So, the Almouti scheme with 2x2 antennas gives the best performance as compared to MRC case due to effective diversity of 4^{th} order based on dual receive antenna over two symbols .

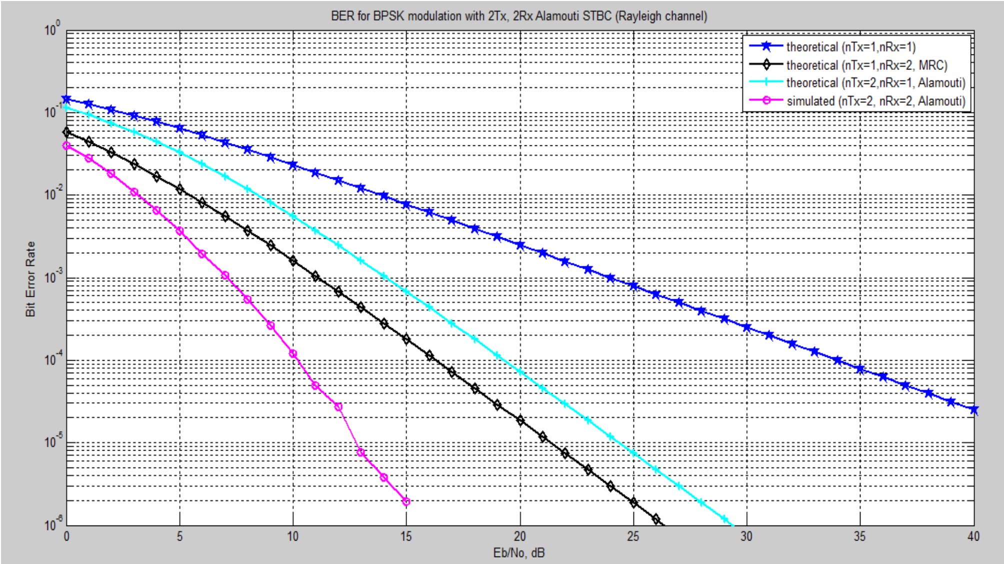


Figure 4.3. BER Curves for 2PSK in Rayleigh Channel for (2x2) Antenna Configuration

MIMO wireless communication indicate transmissions over wireless channels formed by multiple antennas at transmitter and receiver sides . The main advantages of employing multiple antennas are more enhanced performance obtained through diversity and the greater data rate through spatial multiplexing .

MIMO scheme can be performed in various ways, if the advantage of MIMO diversity is used to cop the fading then the same signals must be sent through different MIMO antennas, and at the receive end, the different antennas will receive the same signals moved through diversity links. If MIMO scheme is used for increasing capacity then different streams of data must be sent simultaneously through the different MIMO antennas without the automatic-repeat request .

Emerging OFDM with MIMO technique improve spectral efficiency to reach to throughput of 1 Gbit/sec and more, and enhances link reliability .MIMO technique to be sufficient theoretically, the antenna spacing must be half the wavelength at least of the sent signal, however, in some recent research this issue has been solved and some modern broadband mobile phones support more than one antenna. Efficient model of MIMO-OFDM system is relied on the Fast Fourier Transform (FFT) and MIMO encoding, such as Alamouti Space Time Block coding (STBC), and Golden Space-Time Trellis Code (Golden STTC) .

The MIMO-OFDM systems have a great effect to meet up the rigorous requirement for enhancing the transmit diversity and mitigation due to side effects of multipath fading. With the advancement of various time and frequency-selective channel coding techniques, the MIMO-OFDM can activate more reliable and stable transmission in grim wireless environment .

4.2 MIMO-OFDM System Model of IEEE802.16 Using PSK and QAM Constellations

In MIMO systems, Alamouti scheme has been implemented widely. The transmit diversity idea given by Alamouti was the space time block coding (STBC).The implementation of block diagram of MIMO-OFDM that combines OFDM with MIMO systems is with the help of STBC encoder and decoder at the transmit and receive ends .

The steps of Matlab simulation for computing BER for different M-ary PSK using STBC techniques are as following:

1. Generation of M-ary PSK and QAM symbols.
2. Choosing antenna configurations.
3. Assuming a transmission sequence has been used, For example $\{X_1, X_2, X_3, \ldots.\}$.Normally, X_1 will be sent in the first time slot, X_2 in the second time slot, X_3 and so on .
4. Encode these sequences using STBC encoder as in section 3.4.1.2 of chapter three.
5. M-ary PSK or QAM Modulation and then serial in parallel out data bits conversion.
6. use IFFT in OFDM to convert the signal from frequency domain to time domain.

   the idea in OFDM generation, the transmitter accepts a stream of data and converts them to symbols using modulation technique, for example QPSK. Then add cyclic prefix (CP) to retain sinusoids properties in multipath channels.
7. Calculate channel matrix, transmission matrix and received signal per receiver antenna.

8. Remove CP and FFT to handle the incoming signals from multiple receive chains separately.
9. Parallel to serial conversion and demodulate received signals.
10. Decode demodulated signals using STBC decoder as in section 3.4.1.3
11. Counting the number of bit errors.
12. Repeat the same for multiple values of Eb/N0.
13. Plot the bit error rate versus EB/N0 using semilogy command.

Data encoding is performed by a channel code and the encoded data is divided into plurality of data streams simultaneously transmitted using a plurality of transmit antennas . The received signal at each receive antenna is a linear superposition of the different transmitted signals.

This sections aims to analyze the effect of antenna array length on transmitting and receiving sides on the behavior of proposed MIMO-OFDM system as in Figure 3.10 using Matlab simulator. The performance analysis will give insight into the impact of important and optimal number of transmitter and receiver antennas with lowest bit error rate and different PSK constellations. In this chapter, a comparative study of BER performance of the system with different number of transceiver antennas with OFDM are analyzed and simulated considering different PSK modulation modes. The simulation parameters are chosen for MIMO-OFDM of Figure 3.10 as shown in Table 4.2.

Table 4.2: Important Simulation Parameters

Number of bits per OFDM symbol	10
Number of symbols	10000
FFT size	50
Constellation	16-PSK,32-PSK,64 PSK,128PSK
Antenna configurations	1x2,1x4,2x1,2x2, 3x1,3x4, 4x1, 4x4

BER responses with respect to Eb/N0 (bit energy to noise power spectral density) for different PSK levels over Rayleigh channel have been depicted in Figures (4.4,4.5,4.6 and 4.7). It shows as the number of transmit and receive antennas are increased, the BER keeps on decreasing and provide better BER performance due to spatial diversity.

It is worth pointing that SIMO antenna configurations (1x2 and 1x4) have better BER responses as compared with (2x1 and 4x1) MISO antenna configurations . This is because the series of the information received from the active channel leads to antenna diversity order of 4 and 8 ,where diversity order is twice the number of receive antennas . Although there is more complexity in receiver sides. With number of symbols = 10000 (transmitted), BER can be only measured down to 10^{-3} reliably .It is necessary to indicate that if the number of symbols increases the output exponential responses for BER will be smoother and more clear. The optimal BER can be observed in (4 x 4) transceiver configuration for all PSK modes.

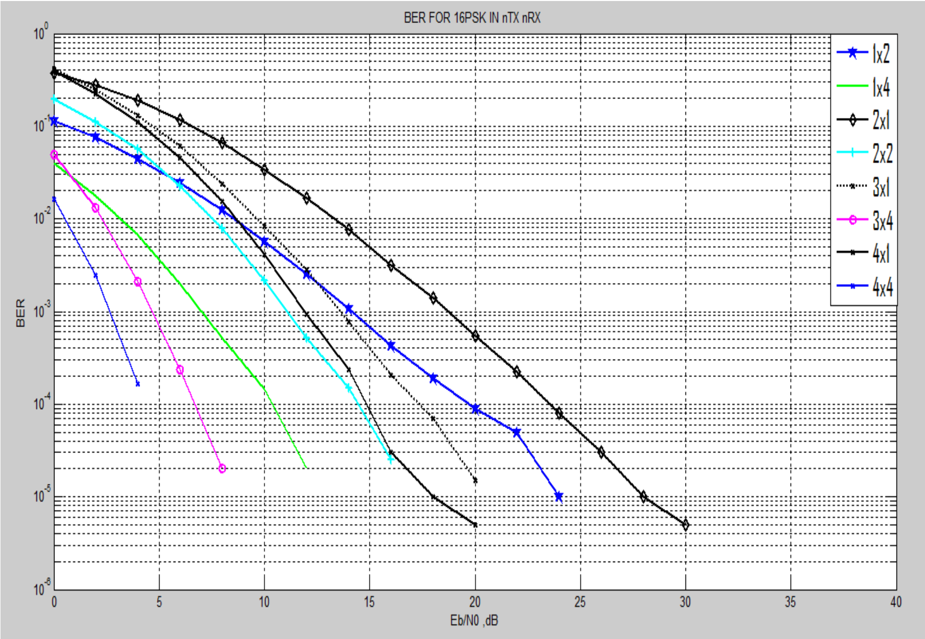


Figure 4.4. Simulated BER Curves of 16 PSK MIMO-OFDM System with Different Antenna Configurations

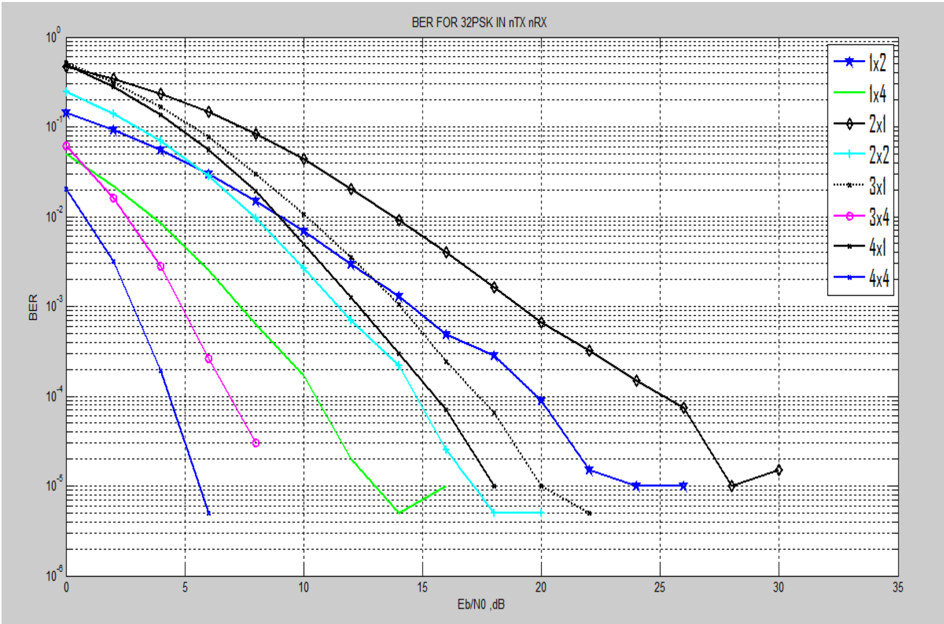


Figure 4.5. Simulated BER Curves of 32 PSK MIMO-OFDM System with Different Antenna Configurations

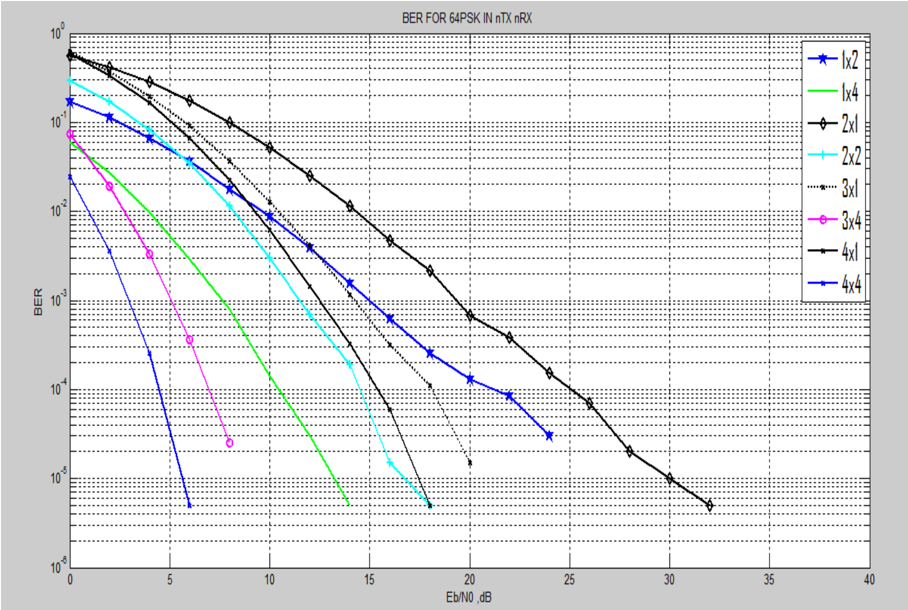


Figure 4.6. Simulated BER Curves of 64PSK MIMO-OFDM System with Different Antenna Configurations

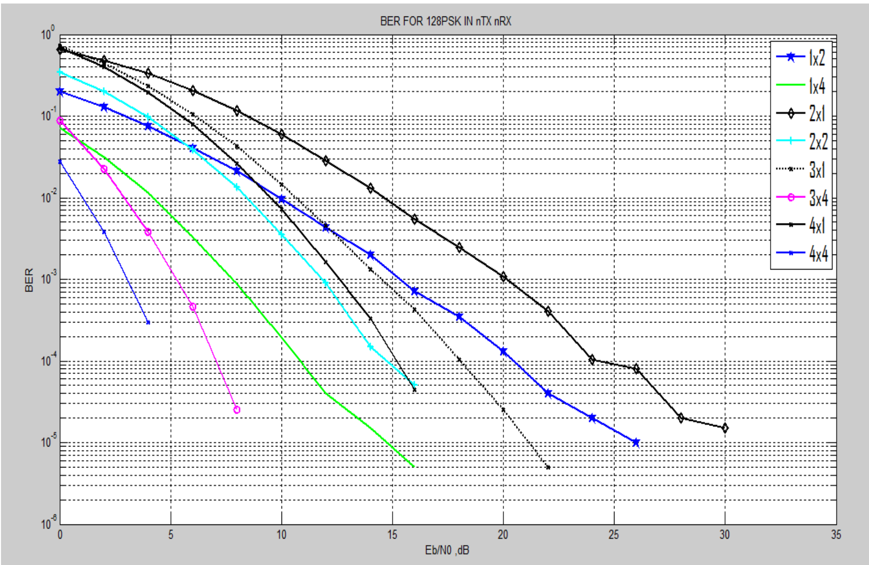


Figure 4.7. Simulated BER Curves of 128PSK MIMO-OFDM System with Different Antenna Configurations

Figures (4.8,4.9) show the bit error rate performance using 16QAM and 64QAM respectively with different antenna transceivers configurations (2x1,1x2,2x2,2x4 and 4x4).Those figures show as the number of transmitter and receiver antennas increases, the BER remains on decreasing because of spatial diversity and provide better BER behavior .

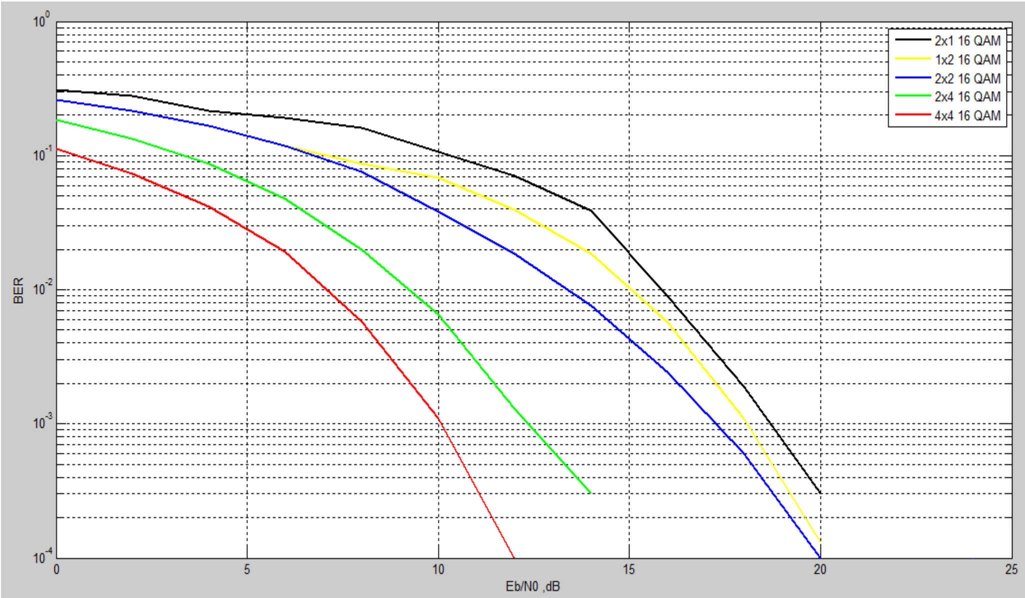


Figure 4.8. Simulated BER Curves of 16QAM MIMO-OFDM System with Different Antenna Configurations

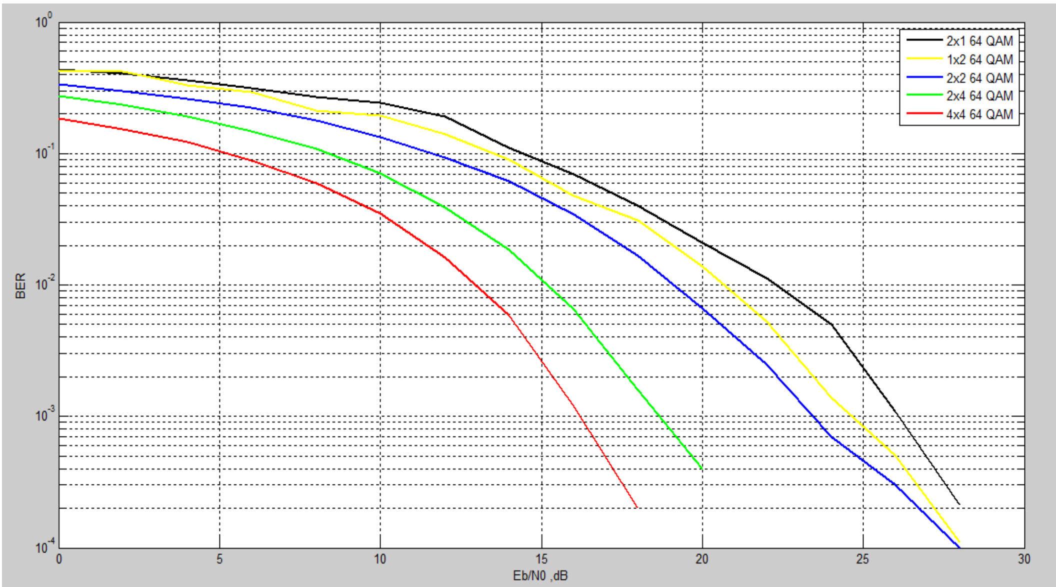


Figure 4.9. Simulated BER Curves of 64 QAM MIMO-OFDM System with Different Antenna Configurations

Figures (4.10,4.11) present bit error rate comparisons with QAM and PSK modulations using constellation orders of 16 and 64 for selected antenna transceivers configurations (2x1,1x2,2x2,2x4 and 4x4).It is clear from those graphs that MIMO-OFDM using 16QAM and 64QAM exhibit more BER as compared 16PSK and 64PSK.This is because QAM represent the message by amplitude which offers more error rate as compared to PSK modulation that represents the message signal by phases that provides lower error rate values. The comparison for simulated bit error rate values with respect to different antenna schemes and selected digital modulations at Eb / N0 =8 dB . It should be noted that the new proposed MIMO-OFDM model as in Figure 3.10 has higher data rate and lower bit error rate as compared to [16] and [17] .

Table 4.3: Simulated bit error rate magnitudes at Eb / N0 =8 dB

n_t X n_r / BER	2 x 1	1 x 2	2 x 2	2 x 4	4 x 4
BER using 16 PSK	0.0084	0.0007	0.0075	0.0005	0.0001
BER using 64 PSK	0.0135	0.0015	0.0112	0.0011	0.0005
BER using 16 QAM	0.1601	0.0863	0.0763	0.0199	0.0058
BER using 64 QAM	0.2712	0.2112	0.1771	0.1085	0.0596

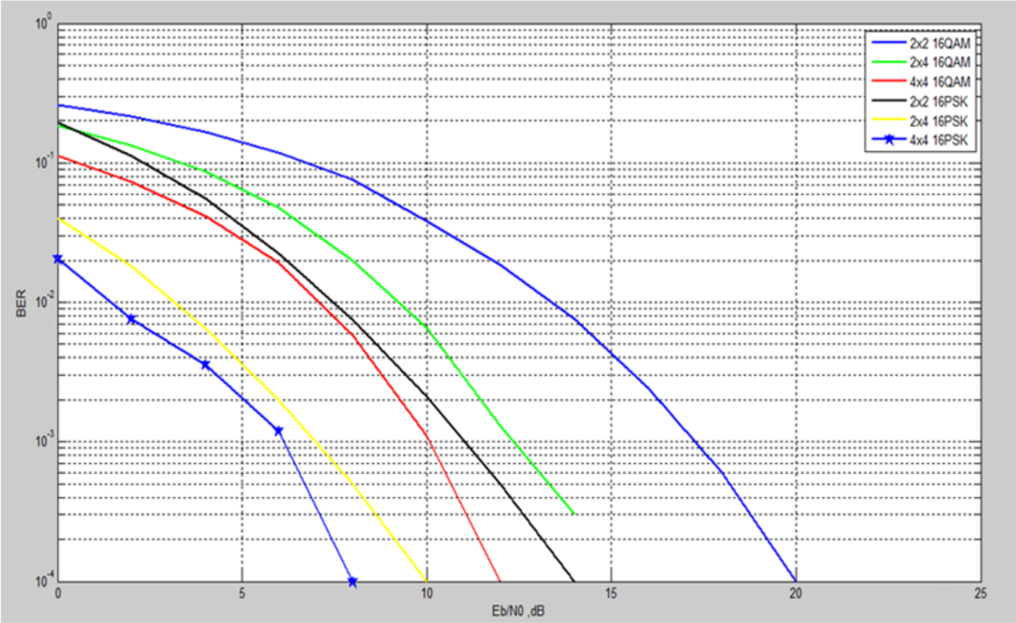


Figure 4.10. BER Performance of MIMO OFDM System with Different Antenna Configuration at 16QAM and 16PSK Cases

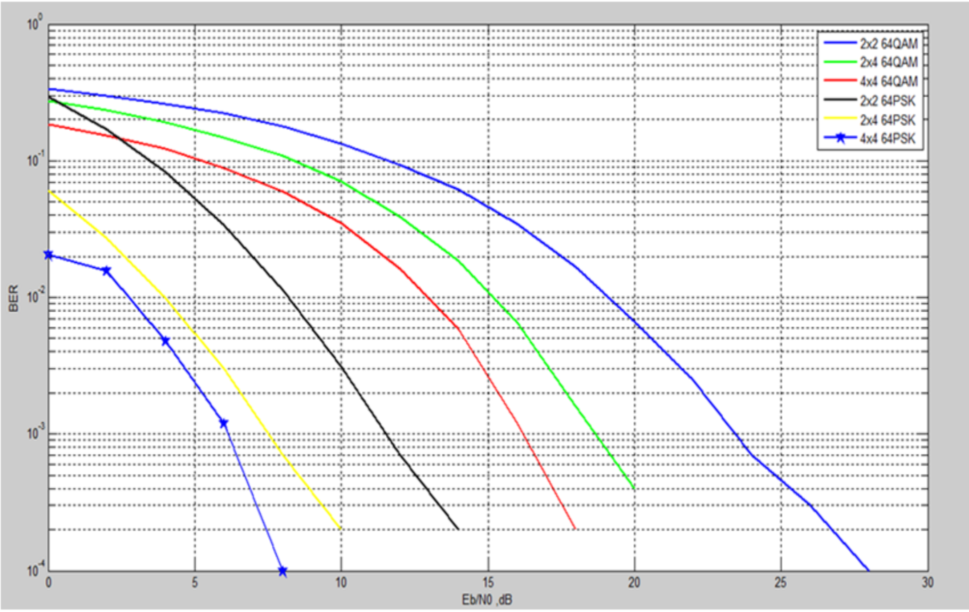


Figure 4.11. BER Performance of MIMO OFDM System with Different Antenna Configuration at 64QAM and 64PSK Cases

4.3 Effect of Channel Order on the Performance of MIMO-OFDM System Using (2 x 2) Antenna Configurations

MATLAB simulations have been conducted to investigate the effect of channel order (Number of channel paths) on the performance of the adopted MIMO-OFDM system using (2 x 2) transceiver antennas. The Data frame length is 50 bits while FFT size and CP are 64 and 16 respectively. AWGN noise is used. The BER behavior of our suggested MIMO-OFDM system is under consideration for different channel length (L) .All transmitted signals are modulated with M-ary PSK consideration .

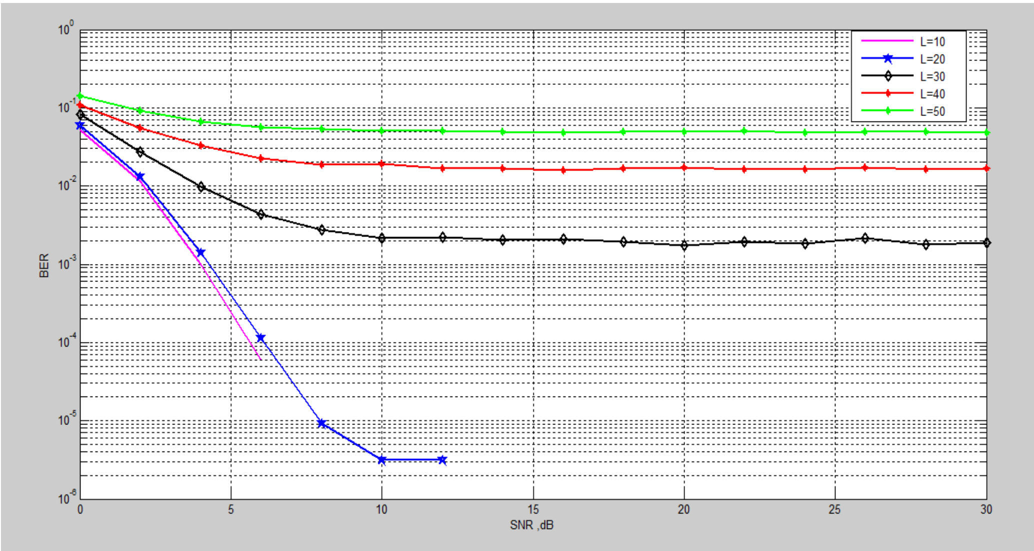


Figure 4.12. Plot between BER and SNR for MIMO OFDM System with L=10 ,20,30,40 and 50

From Figure 4.12 , observed that the BER increases when the channel order increases from 10 to 50. It demonstrates that the channel orders have proportional effect with SNR on the proposed MIMO OFDM scheme. An obvious steady state point can be seen in the cases of L =30,40 and 50. It is worth pointing that BER nearly reached to steady state value around 0.001953 at L=30 within higher SNR values whereas it is settled at 0.01648 and 0.0501 respectively during setting channel lengths ,L=40 and 50 respectively.

Figures (4.13,4.18) show the bit error rate responses with respect to different number of paths (L) at M =2,4,8 ,16,32 and 64.

From simulation graphs ,it can be noted that as the number of M increases, the error probability also increases over Rayleigh channel. It is seen that higher-order modulations offer greater error-rates , although they deliver a larger raw data-rate. Increasing L will increase the SNR clearly as from those figures .

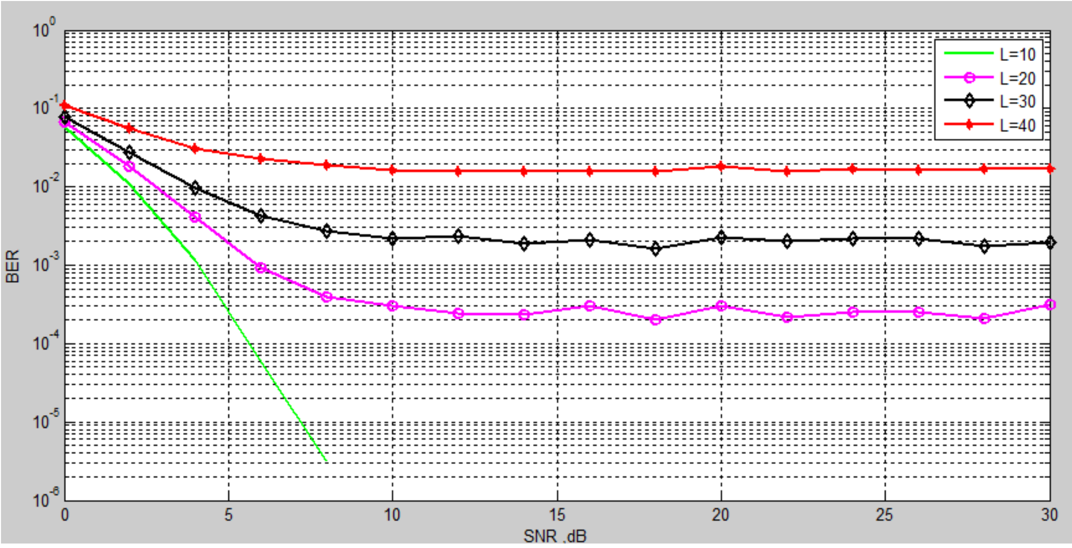


Figure 4.13. Simulated BER Curves of MIMO OFDM System with M =2

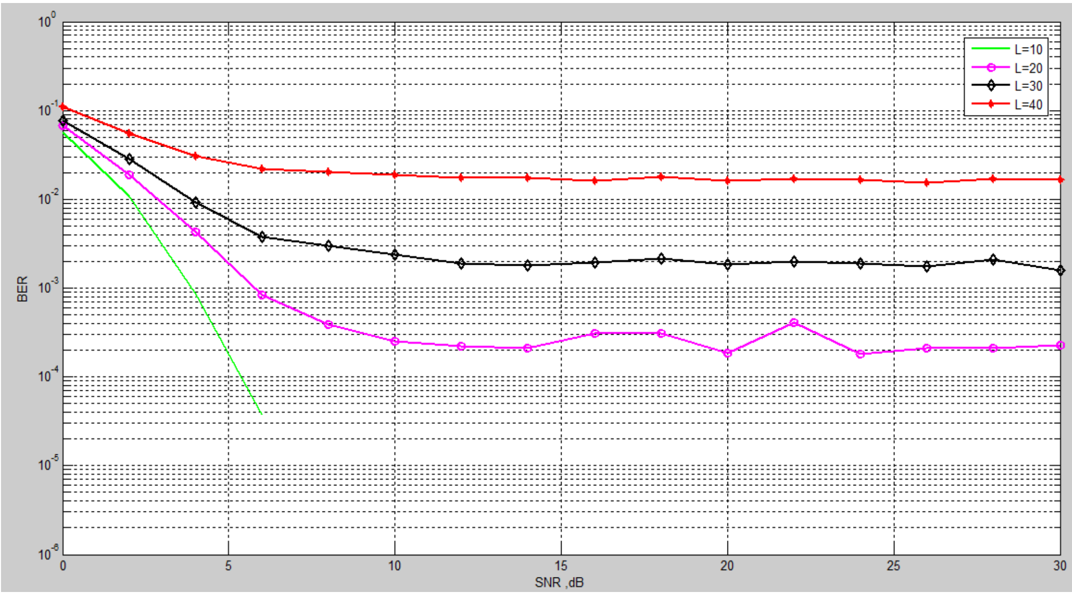


Figure 4.14. Simulated BER Curves of MIMO OFDM System with M =4

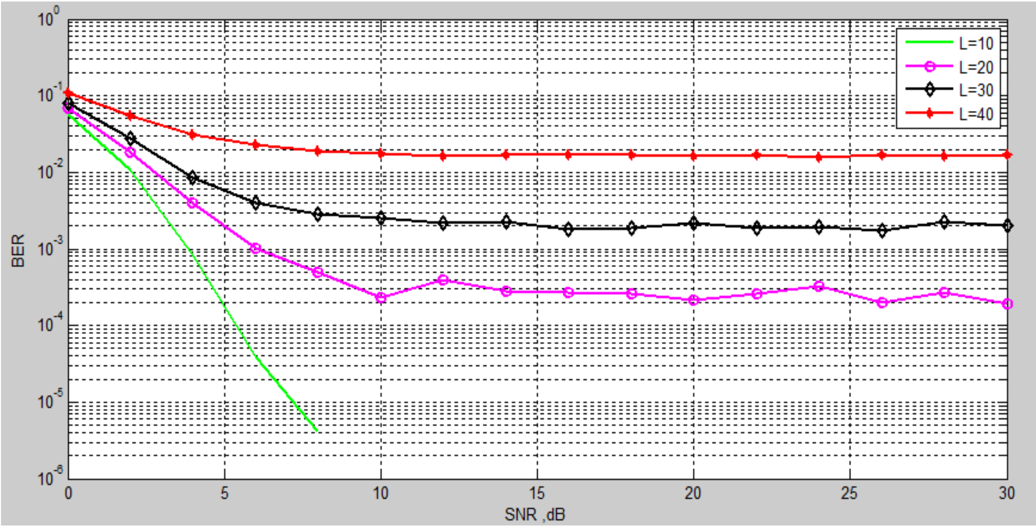


Figure 4.15. Simulated BER curves of MIMO OFDM System with M =8

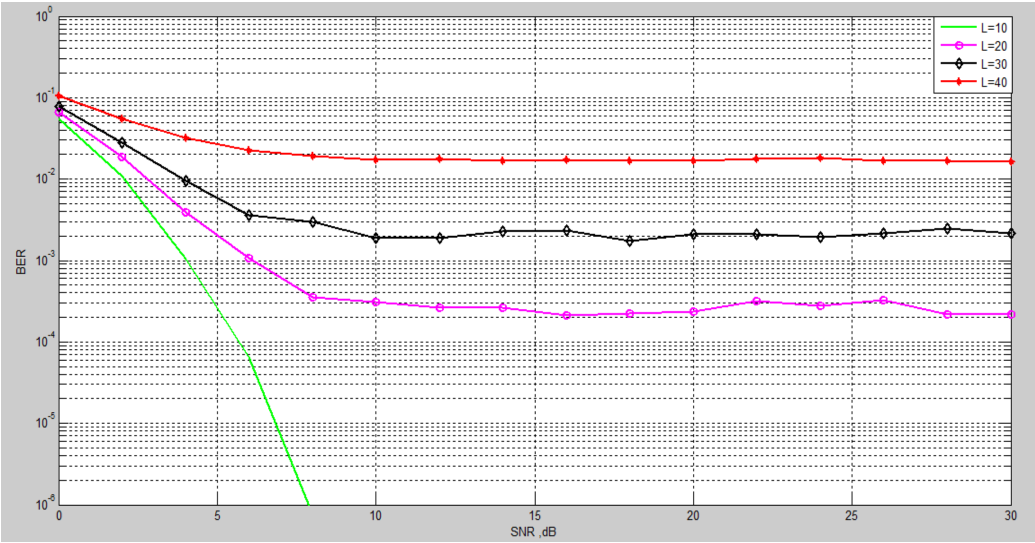


Figure 4.16. Simulated BER Curves of MIMO OFDM System with M =16

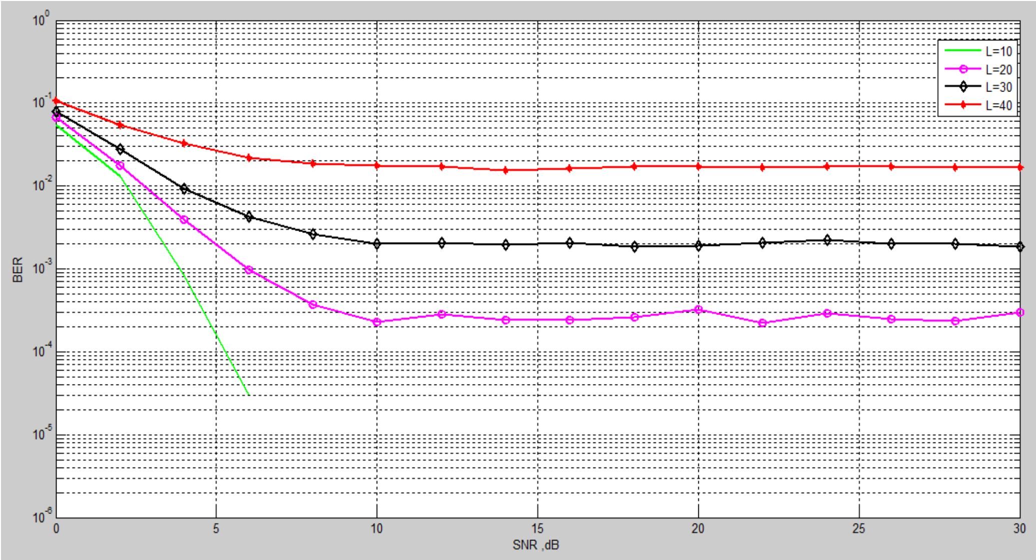


Figure 4.17. Simulated BER Curves of MIMO OFDM System with M =32

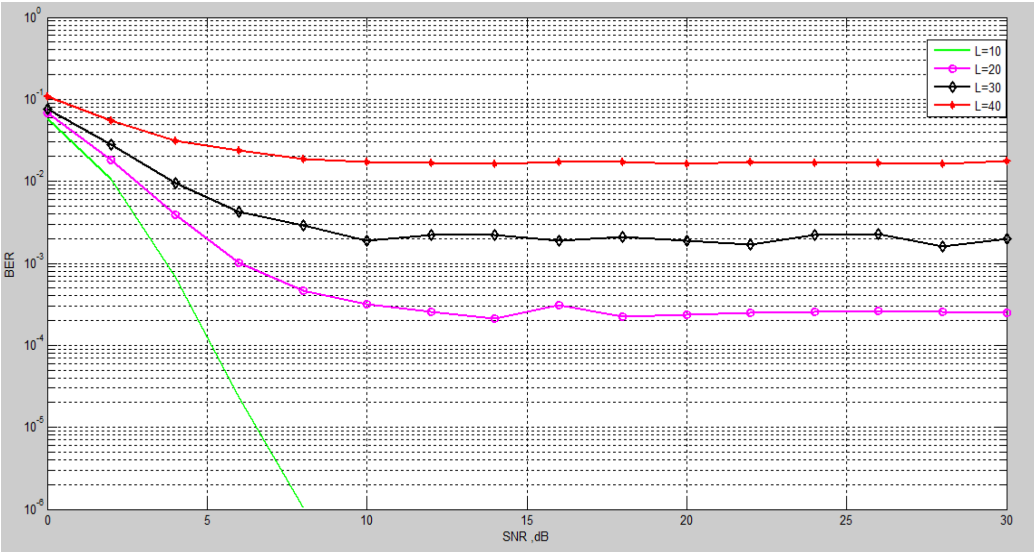


Figure 4.18. Simulated BER Curves of MIMO OFDM System with M =64

Figures. (4.19- 4.21) specify the bit error rate performance curves for each L (15,30,45,60) using different values of FFT length (64,128,256) . It can be seen from these figures that increasing of FFT length improves MIMO OFDM performance and decreases bit error rate. This is because of increasing of OFDM subcarriers that enhances modulating and demodulating signals within sender and receiver stages and hence reducing the bit error rate values of adopted system. Namely ,larger FFT size reduces sub-carrier spacing yielding protection against multi-path delay spread

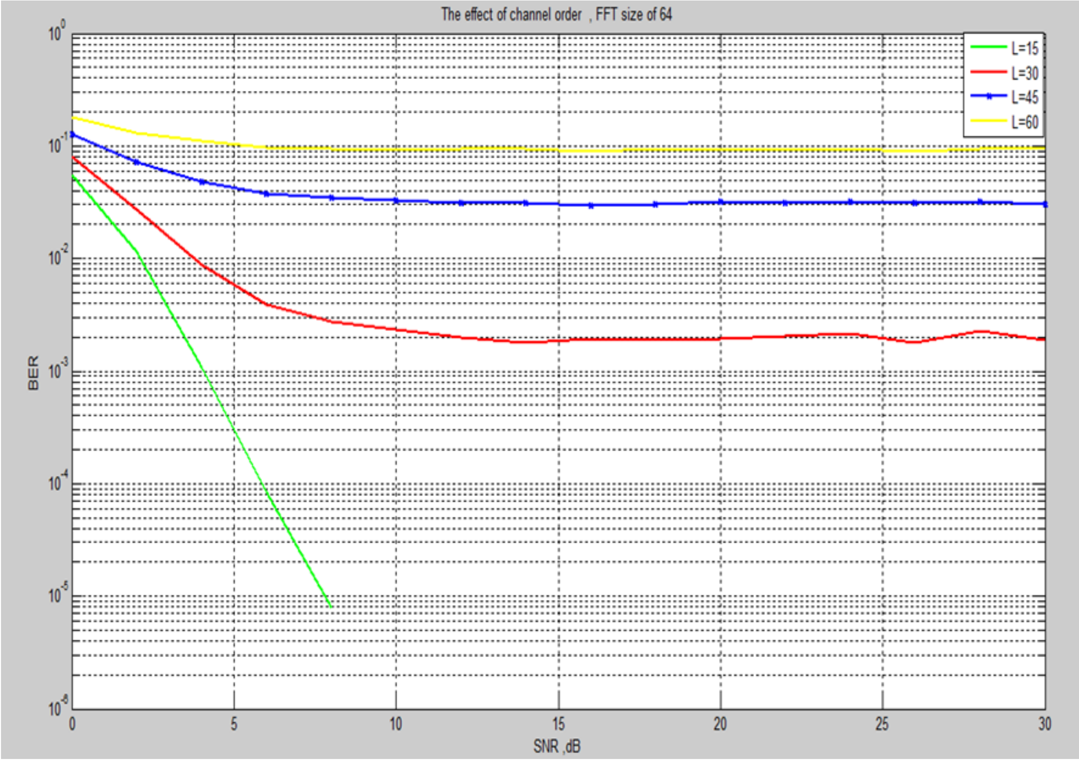


Figure 4.19. Simulated BER Curves of MIMO OFDM System with FFT length =64

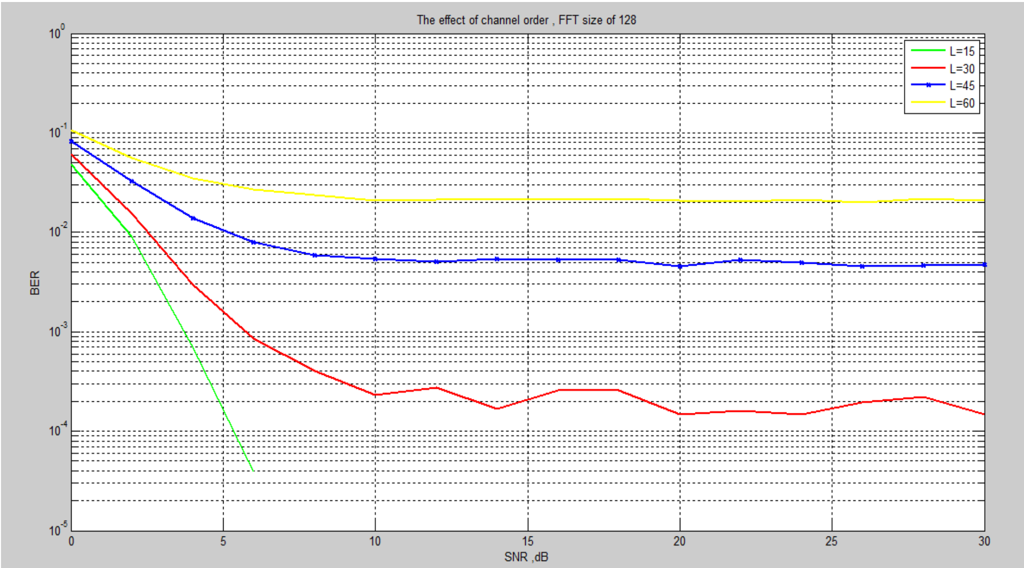


Figure 4.20. Simulated BER Curves of MIMO OFDM System with FFT length =128

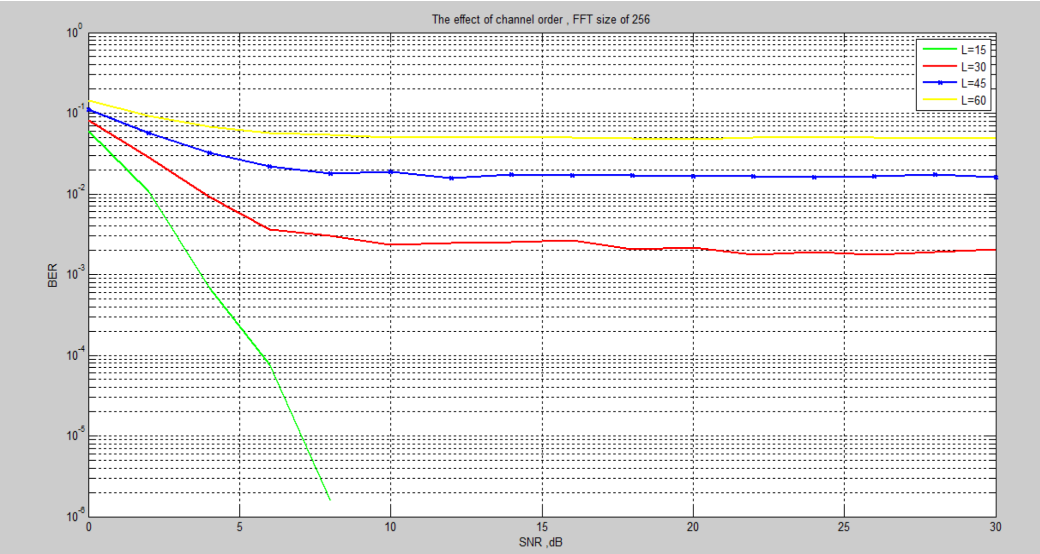


Figure 4.21. Simulated BER Curves of MIMO OFDM System with FFT length =256

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

5.1 Conclusions

In this dissertation, a new suggested MIMO-OFDM model in different phase shift keying (PSK) modulation levels and for different antenna configurations is reported. The performance of MIMO OFDM system is analyzed with simulation under Rayleigh fading channel. MIMO-OFDM system can use higher modulation levels to implement high data capacity.

The goal of using higher number of antennas at transmit / receive sides is to increase the space diversity, which decreases bit error rate at given Eb/N0 unlike lower orders of Antenna configurations. It is found effectively the diversity order increases as number of receiving antenna increases regardless the number of transmitting antennas , also the lowest BER can be obtained at highest number of transmitting and receiving antenna configurations .

It is worth pointing that bit error rate value increases as PSK or QAM modulation order increases for same transceiver antenna configurations. Also ,the simulation results showed that QAM MIMO-OFDM offers higher bit error rate values as compared with PSK MIMO-OFDM in similar specifications of constellations order and antenna configurations.

The behavior of proposed MIMO-OFDM model at different channel orders and for various FFT lengths is reported. The properties of this model is analyzed under Rayleigh fading channel. The used MIMO-OFDM model can be fulfilled using higher FFT size to perform better performance.The reason of using higher FFT size is to raise the OFDM subcarriers, that will further decrease bit error rate with respect to SNR values rather than to lowest FFT size . Also It was found the BER increases when the channel order increases due to increasing of multi path channel fading.

5.2 Suggestions for Future Work

Using plurality of antennas at transmitter and receiver sides of a wireless link using (MIMO) technology has been used to get highest possible data bit rates as far as possible. OFDM effectively lessen receiver complexity in modern wireless broadband communication systems. The combination of MIMO technique with (OFDM-MIMO) sounds to be an good solving process for next generation of promising communication systems. Some of the suggestion that can be recommended on this issue can be summarized as a follows :

I. Relating the work presented in this thesis, further research work has to be achieved to find the possiblity of designing MIMO-OFDM with higher STBC antenna configuration such as (5 x 5 or 6 x 6 ,…..etc).

II. Combing space time frequency blocks codes (STFBC) with adopted MIMO-OFDM design can increase channel capacity and data rates without increasing the bandwidth or input power.

III. Using pilot signal insertion and cyclic prefix together in all future design of MIMO-OFDM structures can increase the synchronization and prevent inter carrier interferences (ICI) and inter symbol interference (ISI) .

REFERENCES

[1] **SHOKOUH,J.A. (2008)**, Receives of Antenna Selection for Noise-Limited/Interference MIMO Channels, Ph.D. Thesis, University of Waterloo, Canada.

[2] **RIEDIGER,M. L. (2006)**, Techniques for Noncoherent Space-Time Communications, Ph.D. Thesis, University of Manitoba.

[3] **PARK ,Y., ADACHI, F.** (2007) , Enhanced Radio Access Technologies for Next Generation Mobile Communication, Springer, The Netherlands.

[4] **KIM ,M. (2004),** Hardware Implementation of Signal Processing in Smart Antenna Systems for High Speed Wireless Communication, Ph.D. Thesis, Yokohama National University.

[5] **ARSHAD, K. (2002)**, Channel Estimation in OFDM Systems, M.Sc. Thesis, King Fahd University.

[6] **NGUYEN, V. K. (2003)**, Signal Processing Techniques for Wireless Communication Systems, Ph.D. Thesis, University of Adelaide.

[7] **RINTAMAKI,M. (2005)**,Adaptive Power Control in CDMA Cellular Communication Systems.

[8] **HICKS,C.D.(2006)**, Performance Analysis of MIMO Linear Precoders/Decoders, M.Sc. Thesis, University of Cincinnati.

[9] **ALAMOUTI ,S. M.**(1998), A Simple Transmit Diversity Technique For Wireless Communications, IEEE Journal on Selected Areas in Communications, vol.16, pp. 1451- 1458.

[10] **KALLIOLA, K.(2002)**,Experimental Analysis of Multidimensional Radio Channels, Ph.D. Thesis, Helsinki University of Technology Radio Laboratory Publications.

[11] **A. H., AL-HASSAN(2004)**,Design and Implementation of Software Radio Receiver Over Mobile Channel, M.Sc. Thesis, Al-Nahrain University.

[12] **KRISHNAMURTHY**, **S.H. (2005)**, Fundamental Limits and Joint Design of Wireless Systems with Vector Antennas, Ph.D. Thesis, North Carolina State University.

[13] **MCKAY, R. (2006)**, Random Matrix Theory Analysis of Multiple Antenna Communication Systems, Ph.D. Thesis, University of Sydney, Australia.

[14] **TRUNG, D. Q., PRAYONGPUN N., RAOOF K.**(2008), Antenna Selection for MIMO Systems in Correlated Channels with Diversity Technique, The 4th IEEE international conference on Wireless Communication, Networking and Mobile Computing, Dalian, China,.

[15] **LOZANO A., JINDAL N.(2009)**, Transmit Diversity v. Spatial Multiplexing in Modern MIMO Systems, University of Minnesota, Minneapolis, MN55455, USA.

[16] **JAYAKUMARI, J.**(2010), MIMO-OFDM for 4G Wireless Systems, International Journal of Engineering Science and Technology, Vol. 2(7), 2886-2889.

[17] **BHATNAGAR, P.,et.al**(2011) ,Enhancement of OFDM System Performance with MIMO technique, International Journal of Computer Technology and Electronics Engineering (IJCTEE),Vol.1,Issue3.

[18] **SREEKANTH N. , GIRIPRASAD M.N.**(2012),BER Analysis of MMSE Equalization and ML Decoding by Using MIMO-OFDM-STBC Techniques, International Journal of Engineering Research & Technology (IJERT), Vol. 1 Issue 4.

[19] **YANG**, **T. S. (2004)**, Performance Analysis of Adaptive Transmission Aided by Long Range Channel Prediction for Realistic Single and Multi-Carrier Mobile Radio Channels, Doctor of Philosophy thesis, Dept. of Electrical Engineering, North Carolina State University.

[20] **SHEN ,Y. , MARTINEZ ,E.**(2006),Channel Estimation in OFDM System , Freescale Semiconductor, www.freescale.com.

[21] **AHMAD R.S. BAHAI, BURTON R. SALTZEBERG,MOSTAFA ERGEN (2004)**, Multi-Carrier Digital Communications Theory and Applications of OFDM Second Edition, Created in the United States of America, Bosten .

[22] **GAUR ,S. (2003)**, Analysis of Advanced Diversity Receivers for Fading Channels , Msc. thesis in Electrical Engineering , Virginia Polytechnic Institute and State University, U.S.A.

[23] **SARI H., KARAM G., JEANCLAUDLE I.**(1994), Frequency-domain equalization of mobile radio and terrestrial broadcast channels , Proc. in IEEE Global Telecommunications Conference, GLOBECOM '94. Communications: The Global Bridge, vol. 1, pp. 1-5.

[24] **CHRISTOPHER E., KHAN M. A., WANG X., SAMARABANDUAND J.**(2011) , Adaptive modulation for OFDM system with varying speed receiver , Proc. in IEEE 24th Canadian Conference on Electrical and Computer Engineering(CCECE), pp. 000892-000895.

[25] **THAHNABALASINGHAM ,T. (2006)**, Resource Allocation in OFDM Cellular Networks, Doctor of Philosophy thesis, Department of Electrical and Electronic Engineering, University of Melebourne, Australia.

[26] **EYCEŐZ**, **T. (2001)**, Deterministic Modeling and Long Range Prediction of Fast Fading Channels with Applications to Mobile Radio Systems, Ph.D. thesis in Electrical Engineering, North Carolina State University, U.S.A.

[27] **YANG ,Y. (2003)**, Frequency-Domain Equalization for Space-Time Block Coded Transmissions over Frequency-Selective Fading Channels, Msc. thesis in Electrical and Computer Engineering National University of Singapore.

[28] **HADI ,W. A. H. (2006)**, Enhancement of DWT-OFDM-CDMA System Using Turbo Coding, Doctor of Philosophy thesis, Department of Electrical & Electronic Engineering, University of Technology, Iraq.

[29] **SkLAR, B.**(1997), Rayleigh Fading Channels in Mobile Digital Communication Systems Part II: Mitigation , IEEE Trans. on Communications, vol. 35, no.7, pp. 102-109.

[30] **SkLAR, B.**(1997) ,Rayleigh Fading Channels in Mobile Digital Communication Systems Part I: Characterization , IEEE Trans. on Communications, vol. 35, no.7, pp. 90-100.

[31] **WANG J., QIANG Y., ZHANG B. , Li D.**(2003), Comparison of Statistical Properties between an Improved Jakes' Model and the Classical One , in Proc.14th IEEE Int. Symp. on Persona1,lndoor and Mobile Radio Communication (PIMRC 2003), vol. 1, pp.380-384.

[32] **FALCONER D. D., ARIYAVISITAKUL S. L.**(2002), Broadband Wireless Using Single Carrier and Frequency Domain Equalization , in Proc.5th IEEE Int. Symp. on Wireless Personal Multimedia Communications, vol. 1, pp.27-36.

[33] **FRANK T. , KLEIN A. , COSTA E. , SCHULZ E.**(2005), Low Complexity Equalization with and without Decision Feedback and its Application to IFDMA ,in Proc.5th IEEE Int. Symp. On Personal, Indoor and Mobile Radio Communications(PIMRC.2005), vol. 2, pp.1219-1223.

[34] **HARA S.,PRASAD R.(2003)**, Multicarrier Techniques for 4G Mobile Communications, The Artech House Universal Personal Communications Series, Boston· London.

[35] **OYERINDE ,O. O. (2010)**, Channel Estimation for SISO and MIMO OFDM Communication Systems , Doctor of Philosophy in Electrical, Electronic and Computer Engineering, University of KwaZulu-Natal, Durban, South Africa, .

[36] **CHEUNG**, **B. P. (2002)**, Simulation of Adaptive Array Algorithms for OFDM and Adaptive Vector OFDM Systems , M.Sc thesis, Dept. of Electrical Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

[37] **PROAKIS, J. G.** (2000) , Digital Communications . McGraw-Hill Series in Electrical and Computer Engineering, fourth edition .

[38] **LAWREY**, **E. P. (2001)**, Adaptive Techniques for Multiuser OFDM, Ph.D. thesis in Electrical and Computer Engineering, James Cook University, Christchurch.

[39] **K¨UHU, V.**(2006), Wireless Communications over MIMO Channels. John Wile & Sons Ltd .

[40] **LIU H.Y. , LEE C.Y.**(2006), A Low-Complexity Synchronizer for OFDM-Based UWB System ,IEEE Tran. on Circuits and Systems-II: Express Briefs, Vol. 53, No. 11, pp 1296-1273,.

[41] **ARSHAD ,K. (2002)**,Channel Estimation in OFDM System", M.Sc thesis, Dept. of Electrical Engineering, College of Engineering, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.

[42] **HARA S. , PRARAD R.**(1999), Design and Performance of Multicarrier CDMA System in Frequency-Selective Rayleigh Fading Channels , IEEE Trans. on vehicular technology, vol. 48, no. 5, pp. 1584-1595.

[43] http://www.ece.ualberta.ca/~hcdc/mimohistory.html, visited on June 2013.

[44] **SOO CHOO YONG, KIM JAEKWON, YONG WON, KANG CHUNG-GU**(2010) , MIMO-OFDM Wireless Communications with MATLAB ,Singapore, John Wiley &Sons(Asia).

[45] **BIGLIERI E., CALDERBANK R., CONSTANTINIDES A., GOLDSMITH A., PAULRAJ A., POORH. V.**(2007), MIMO Wireless Communications, Cambridge University Press, USA.

[46] **JANKIRAMAN ,M.**(2004), Space-Time Codes and MIMO Systems, Artech House, Boston, London.

[47] **VUCETIC B., YUAN J.(2003)**, Space-Time Coding, John Wiley & Sons Ltd.

[48] **KALLIOLA K. (2002)**, Experimental Analysis of Multidimensional Radio Channels, Ph.D. Thesis, Helsinki University of Technology Radio Laboratory Publications.

[49] **NEUBAUER A., FREUDENBERGER J., KUHN V.**(2007), Coding Theory - Algorithms, Architectures, and Applications, John Wiley & Sons ,Ltd.

[50] **BANASER ,H. H. (2007)**, High Performance WLAN Using Smart Antenna, M.Sc. Thesis, University of Waterloo, Waterloo, Ontario, Canada.

[51] **KING P.R. (2007)**, Modelling and Measurement of the Land Mobile Satellite MIMO Radio Propagation Channel, Ph.D. Thesis, University of Surrey.

[52] **ZOOGHBY E.(2005)**, Smart Antenna Engineering, Artech House, Artech House, Boston, London.

[53] **POLLOCK ,T. S. (2003)**, On Limits of Multi-Antenna Wireless Communications in Spatially Selective Channels, Ph.D. Thesis, The Australian National University.

[54] **HUNG ,J. (2005)**, A Matlab/Octave Simulation Environment for SDR with application to OFDM and MIMO, M.Sc. Thesis, Stockholm.

[55] **SAMPATH H., TALWAR S., TELLADO J., ERCEG V., PAULRAJ A**.(2002), A fourth-generation MIMO-OFDM broadband wireless system: design, performance, and field trial results , IEEE Communications Magazine, vol. 40, no. 9, pp. 143–149.

[56] **ALAMOUTI S.M.**(1988) , Simple Transmit Diversity Technique for Wireless Communications, IEEE Journal on Select Areas in Communications, vol16 pp 1451-1458.

[57] **TAROKH V., SESHADRI N. , CALDERBANK A. R.**(1998), Space Time Codes for High Data Rate Wireless Communication: Performance Criterion and Code Construction, IEEE Transactions on Information Theory, Vol. 44, Issue 2, pp 744-765.

[58] **TOLGA M. DUMAN, ALI GHRAYEB** (2007), Coding for MIMO Communication Systems , John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester.

[59] **TANG XIAOYI, ALOUINI MOHAMED-SLIM, GOLDSMITH ANDREA J.** (1999), Effect of Channel Estimation Error on M-QAM BER Performance in Rayleigh Fading , IEEE TRANSACTIONS. ON COMMUNICATIONS, VOL. 47, NO. 12.

[60] **JING XIAO** (2010) , Analysis of OFDM MIMO, MSc thesis , Faculty of San Diego State University.

APPENDIX

CIRRICULUM VITE

PERSONAL INFORMATION

Surname, Name: Hammadi, Yousif.

Nationality: Iraqi (IQ)

Date and Place of Birth: 10 February 1988 , Diyala

Marital Status: Single

Phone: +9647901130895

Email: yousif_com88@yahoo.com

EDUCATION

Degree	Institution	Year of Graduation
MSc.	Çankaya Univ. Electronic and Communication engineering	2013
BSc.	DiyalaUniv. Communication Engineering	2011
High School	AL Kalss for boys	2006

FOREIGN LANGUAGES

Advanced English

HOBBIES

Reading of social books , Learning languages, Movies, Motor Sports.