Palestine Polytechnic University

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College of Engineering and Technology
Electrical and Computer Engineering Department
Communication and Electronics Engineering

Bachelor Thesis

Graduation Project

Performance Analysis of Fixed Gain Amplify and Forward Based Cooperative Diversity in MIMO Relay Channels

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Hebron – Palestine

2011-2012

جامعة بوليتكنك فلسطين

الخليل – فلسطين

كلية الهندسة والتكنولوجيا

دائرة الهندسة الكهربائية والحاسوب

اسم المشروع:

Performance Analysis of Fixed Gain Amplify and Forward Based Cooperative Diversity in MIMO Relay Channels

أسماء الطلاب :

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بناءً على نظام كلية الهندسة والتكنولوجيا وإشراف ومتابعة المشرف المباشر على المشروع ومتابعة أعضاء اللجنة الممتحنة تم تقديم هذا المشروع إلى دائرة الهندسة الكهربائية والحاسوب وذلك استكمالاً لمتطلبات درجة البكالوريوس في تخصص هندسة الاتصالات والإلكترونيات

توقيع المشرف

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11/6/2012

توقيع اللجنة الممتحنة

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11/6/2012

توقيع رئيس الدائرة

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الإهداء

إلى الذين خضبت دماءهم تراب فلسطين الطهور ....

إلى شهداء فلسطين الميامين ....

إلى الذين صنعوا من صمودهم قصة كفاح وتحدي للسجّان ......

إلى الأسرى الصامدين خلف القضبان............................

إلى شعب فلسطين المرابط على أرض الإسراء والمعراج وفي الشتات ....

إلى أمتنا العربية والإسلامية ....

إلى آباءنا وأمهاتنا وأخوتنا وأخواتنا وأهلونا وأقاربنا ....

إلى أصدقاءنا وأحباءنا و كل من لهُ فضل علينا...............................

إليكم جميعا نهدي هذا العمل المتواضع الذي نسأل فيه رضى الله عز وجل وأن يوفقنا لما يحب ويرضى ....

والله ولي التوفيق

فريق المشروع

Acknowledgement

We would like to express our thanks and gratitude to ALLAH who granted us the ability to complete this project successfully.

We wish to express our special thanks and gratitude to Eng.Ahmad Qudaimat for a valuable help, encouragement, supervision through working on our project.

We want to thank all instructors in Communication and Electronics Engineering Department in Palestine Polytechnic University specifically, to Dr.Ghandi Manasra, Dr.Murad Abu Sbaih, Dr. Osama Ata for their support which was really good.

We also would like to thank our parents, brothers, sisters, and friends for their support, and encouragement.

Our love to all

Project Team

Abstract

This project aims to develop multiple-input multiple-output (MIMO) system to enhance the performance of wireless communications system. Cooperative communications is a new paradigm shift for the 4th generation wireless system that will guarantee high data rates to all users in the network, its anticipated that will be the key technology aspect in 5th generation wireless networks.

This project aims to simulate and analyze four schemes of cooperative communications. They implemented based on amplify-and-forward (AF) relaying protocol under uncorrelated flat fading Rayleigh channel. The first scheme contains source (S), relay (R) and destination (D). Each node equipped with single antennas (AF 1×1×1 SISO Relaying System). The other schemes are AF 2×2×2 MIMO relaying system, AF 4×4×4 MIMO relaying system and AF 8×8×8 MIMO relaying system. Orthogonal space-time block coding (OSTBC) and maximal ratio combining (MRC) at the destination are used for all MIMO relaying systems. Also assumes that the channel status information (CSI) is perfectly known at the relay and the destination.

The project implements four schemes of AF Cooperative communications system by using MATLAB simulation. The project studies the probability of error (BER) performance and channel capacity performance of these schemes. It makes a comparison between the cooperative communications system schemes and the conventional systems in terms of BER and capacity performance.

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List of Abbreviations

Abbreviation	Connotation
MIMO	Multiple-Input Multiple-Output
SNR	Signal-to-Noise Ratio
BER	Bit Error Rate
3G	Third Generation of cellular system
4G	Fourth Generation of cellular system
WLAN	Wireless Local Area Network
STC	Space-Time Coding
CSI	Channel Status Information
S	Source
R	Relay
D	Destination
N	Number of relays
MGF	Moment Generating Function
DPSK	Differential Phase Shift Keying
M_s	Number of source antennas

$\mathbf{M_d}$	Number of destination antennas
$\mathbf{M_r}$	Number of relay antennas
DF	Decode-and-Forward
AF	Amplify-and-Forward
SEP	Symbol Error Probability
M-QAM	M-array-Quadrature Amplitude Modulation
TDMA	Time Division Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing
MIMO-OFDM	Multiple-Input Multiple-Output Orthogonal Frequency Division Multiplexing
DMT	Diversity Multiplexing Tradeoff
DSTBC	Distributed Space Time Block Code
PEP	Pairwise Error Performance
Ad-hoc	Advanced developers hands on conference
MRC	Maximal Ratio Combining
BPSK	Binary Phase Shift Keying
STBC	Space-Time Block Coding
PDF	Probability Density Function
PC'S	Personal Computers
$\mathbf{P_r}$	Received Power
$\mathbf{P_t}$	Transmitted Power
$\mathbf{G_t}$	Power gain of transmit antenna

G_r	Power gain of receive antenna
λ_c	Wave length
P(r)	Probability density function
A	Peak amplitude of the dominant signal
K	Ratio between the deterministic signal power and the variance of the multipath
PL	Path Loss
dB	Decibel Scale
M_t	Number of transmit antennas
M_r	Number of receive antennas
SISO	Single-Input Single-Output
SIMO	Single-Input Multiple-Output
MISO	Multiple-Input Single-Output
Y(t)	Received signal
S(t)	Transmit signal
σ	The root mean square of the received voltage signal before envelope detection
σ^2	The time-average power of the received signal before envelope detection
d	Range separation
h (t, t)	Time varying channel impulse response
g(t)	The pulse shaping filter
p(t, t)	Propagation channel

*	Convolution operator
AWGN	Additive White Gaussian Noise
C	The capacity of the channel
$Y_i\ (t)$	The received signal at the ith received antenna
λ_i	The ith eigen values
H	Channel matrix
$\|\|\mathbf{H}\|\|_\mathrm{F}^2$	The squared Frobenius norm of H
LOS	Line Of Sight
ST	Space-Time
RF	Radio Frequency
Tx	Transmitter
Rx	Receiver
t	Channel impulse response duration
SVD	Singular Value Decomposition
Y[k]	The received signal vector with dimension $M_r \times 1$
s[k]	Transmit signal vector with dimension $M_t \times 1$
n[k]	The noise vector
r	Rank of the channel
G_d	Diversity Gain
P_e	Probability of error
G_m	Multiplexing Gain
R	Code Rate

f_c	The carrier frequency
A_c	Amplitude of the sinusoidal carrier
E_b	Energy per bit
T_b	Bit time
S_{bpsk}	Transmitted BPSK signal
m(t)	Binary data signal
Θ_{ch}	Phase shift corresponding to time delay in the channel
P_b	Bit error probability
N_0	Noise power
d_{min}	Minimum Euclidian Distance
$\overline{p}_s$	Averaged probability of error
$p_s(\gamma)$	Symbol error probability
$\sigma^{2}{}_{n}$	Power spectral density of noise
$\overline{\gamma}_s$	Average SNR per symbol
Q(.)	Queue function
$\overline{p}_b$	Average probability of error
$\overline{\gamma}\ _b$	Average SNR per bit
f_d	Fading rate
$\overline{\gamma}\Sigma$	Average SNR of the combined output
$\overline{\gamma}$	Average SNR
θ_i	The phase of the incoming signal
r	Envelope of the combined output

N_{tot}	Total noise
$\gamma\Sigma$	The output SNR of the combiner
M	Number of branches (diversity order)
DeF	Demodulate-and-Forward
$2\sigma^2$	The main of the signal power
PSD	Power Spectral Density
DSSS	Direct Sequence Spread Spectrum
SC	Selection Combining
EGC	Equal Gain Combining
CF	Compress-and-Forward
a_i	The weight of the ith branch
WZC	WynerZiv Coding
ACK	Acknowledgment
NACK	Negative Acknowledgment
QoS	Quality of Service
SM	Spatial Multiplexing
M_s	Number of source antennas
M_r	Number of relay antennas
M_d	Number of destination antennas
X_s	Symbol vector
$X_s[m]$	The symbol transmitted on the m-th antenna

$\mathbf{R}$	The rate of a space-time block code
$\mathbf{K}$	Number of symbols the encoder takes as its input
$\mathbf{P}$	Number of space-time coded symbols transmitted from each antenna
η	The spectral efficiency of the space-time block code
$Y_r[m]$	The received signal at the relay
$y_d{}^{(1)}$	The received signal at the destination in phase 1
P_s	Transmission power of the source
$H_{s,r}$	The channel matrix of the source–relay link
$H_{s,d}$	The channel matrix of the source–destination link
W_r	Additive White Gaussian Noise at the relay
$w_d^{(1)}$	Additive White Gaussian Noise at the destination in phase 1
R_s	Covariance matrix of the source symbol vector
X_r	Symbol vector generated from relay
P_r	Relay power
$y_d^{(2)}$	The received signal at the destination in phase 2
$H_{r,d}$	The channel matrix of relay- destination link
$w_d^{(2)}$	Additive White Gaussian Noise at the destination in phase 2
$\mathbf{I}$	Identity matrix
$\mathbf{F}$	$M_r \times M_r$ Pre-coding Matrix
$\widetilde{w}_d^{(2)}$	The effective noise at the destination in phase 2
$R_{\widetilde{w}}$	Covariance matrix of the effective noise

$\sigma^2{}_r$	Power spectral density of the noise between source and relay
$\sigma^2{}_d$	Power spectral density of the noise between source and destination and between the relay to destination
PDF	Probability Density Function
T_c	Channel coherence time
PLL	Phase Locked Loop
MLE	Maximum–Likelihood Estimation
ML	Maximum Likelihood
$y_d{}^{(1)}[m]$	The received signal at the destination in phase 1
$y_d{}^{(2)}[m]$	The received signal at the destination in phase 2
$X_r[m]$	The normalized relay transmit vector
M	The number of transmitted symbols /antennas
$h_{s,r}$	The channel coefficient between source and relay
$h_{s,d}$	The channel coefficient between source and destination
$h_{r,d}$	The channel coefficient between relay and destination
$W_r[m]$	Additive White Gaussian Noise at the relay
$W_d{}^{(1)}[m]$	Additive White Gaussian Noise at the destination in phase 1
$W_d{}^{(2)}[m]$	Additive White Gaussian Noise at the destination in phase 2
$\lvert h_{s,r}\rvert^2$	Instantaneous channel gain between source and relay
$\lvert h_{r,d}\rvert^2$	Instantaneous channel gain between relay and destination
$\lvert h_{s,d}\rvert^2$	Instantaneous channel gain between source and destination
$\gamma_{s,r}$	Effective signal-to-noise ratio between source and relay

$\gamma_{r,d}$	Effective signal-to-noise ratio between relay and destination
$\gamma_{s,d}$	Effective signal-to-noise ratio between source and destination
P_{out}	The outage probability
CN	Circular Normal Distribution
$\eta^2_{s,r}$	Channel gain between source and relay
$\eta^2_{r,d}$	Channel gain between relay and destination
$\eta^2_{s,d}$	Channel gain between source and destination
$\bar{\gamma}_{s,r}$	Average effective signal-to-noise ratio between source and relay
$\bar{\gamma}_{r,d}$	Average effective signal-to-noise ratio between relay and destination
$\bar{\gamma}_{s,d}$	Average effective signal-to-noise ratio between source and destination
K_1	The first order modified Bessel function of the second kind
CDF	Cumulative Distribution Function
$\tilde{y}_d$	Output signal at the destination with diversity combining (MRC)
$h^*_{s,d}$	Channel coefficient conjugate between source and destination with diversity combining
$h^*_{s,r}$	Channel coefficient conjugate between source and relay with diversity combining
$h^*_{r,d}$	Channel coefficient conjugate between relay and destination with diversity combining
σ^2_w	Variance of Additive White Gaussian Noise
G_f	Fixed gain for relay
T	Transpose of the channel Matrix
E_s	Energy of the symbol

$(.)^H$	Hermetian of the channel Matrix
W	Effective noise with covariance matrix
M	Maximum diversity order (number of branching)
DSP	Digital Signal Processing
X	Transmission matrix
S-R	Source- Relay
R-D	Relay-Destination
M	Distinct sequences of symbols
n_T	Parallel signal sequences of length p according to the transmission matrix X
r_b	Bit rate
r_s	Symbol rate
B	Bandwidth
h_t	Effective height of transmit antenna
h_r	Effective height of receive antenna
P^L	The probability that the instantaneous SNR is below the same critical threshold on all L diversity branches.
p	The number of transmitted periods required to transmit the space time coded symbols through the multiple transmit antennas
X_1,x_2	Modulated symbols
det	The determinant of the matrix
$\gamma_{BasicAF,1}$	The received SNR at the destination in phase 1
$C_{BasicAF,1}$	The capacity at the destination in phase 1
E_b/N_0	Signal to noise ratio

Xs	Symbol block
tr	Matrix trace
$\sigma_{s,d}^2$	Variance of the channel between source and destination
$\sigma_{s,r}^2$	Variance of the channel between source and relay
$\sigma_{r,d}^2$	Variance of the channel between relay and destination
P	Total transmitted power
N_0^2	Noise variance

CHAPTER

1

Introduction

1.1 Overview

1.2 Importance of the Project

1.3 Project Objectives

1.4 Literature Review

1.5 Time Planning

1.6 Cost Estimation

Introduction

1.1 Overview

Wireless communications, are one of the fastest growing fields in the engineering world. It provides a wide area to search, develop, simulate and design any topics or roots related to wireless communications systems.

Wireless communication system have many limitations such as, limited spectrum available, channel environments, fading problem that resulted from multipath, more over interference and noise that affect the system performance. In multi path environments different copies of the same signal may reach at the destination with different attenuations (fading coefficients), with different delays due to scattering, reflections, refractions, diffractions of the transmitted signals. It's important for the benefit of these copies in order to achieve best quality, and good capacity. As a result a MIMO system which use multiple antennas at the transmitter and at the receiver utilize this fading environment to achieve better performance than conventional wireless communication system that uses single antennas for transmission and another one for reception.

Researchers develop a new technology which is called spatial diversity that uses multiple antennas to transmit the same symbol to provide high signal-to-noise ratio (SNR) and cause to improve the reception, and enhance the data rate. Researchers almost dynamically search about how to develop MIMO system to enhance the performance of wireless systems based on data rate and BER. Due to request of people and their continuous need to benefit from the wireless technologies effectively, i.e. make a video call in cellular system 3G, 4G networks, and other cellular applications that need high data rate to work properly.

The new system design that improved the wireless communications system performance to achieve people desires combines the cooperative diversity model with MIMO model to achieve good performance that we implement in this project.

1.2 The Importance of The Project

Nowadays, multi hop wireless communications systems are able to provide a potential for broader, and more efficient coverage in bent pipe satellites, and microwave links, as well as modern ad–hoc, cellular, WLAN, and hybrid wireless networks.(1)

Multiple antennas at transmitter and receiver introduce spatial degrees of freedom into a wireless communications system and this yield to boost link capacity or enhances link reliability of MIMO communication system. With spatial multiplexing, we can increase the data rate without additional cost of bandwidth or power by transmitting data streams simultaneously over spatial sub-channels which are available in a rich scattering environments. Future wireless communication environments are highly resource-constrained, offering a limited and tightly regulated spectrum. It is expected that future wireless broadband communication systems will operate beyond 5 GHZ, i.e., WLANS at 17 GHZ. (2)

The energy supply of wireless terminals is usually very limited and must be properly conserved to gain the longest operational time possible. A promising approach to overcome such limitations is the use of multiple antennas both to transmit and receive information, also known as multiple-input multiple-output (MIMO) systems, which can provide a diversity gain as well as a multiplexing gain at no extra bandwidth or power consumption.(3)

Relays are commonly used in wireless networks to improve the performance, although the fundamental capacity limits of relay channels have yet to be fully characterized, even for simple system. (5)

Cooperative diversity has recently become a subject of significant interest in wireless communications as it realizes the performance of MIMO systems through multiple relays instead of having multiple transmit or receive antennas at the source and destination. MIMO relay system is quite useful for communication across multiple base stations in large communication networks. Furthermore, MIMO relay techniques are also feasible in the ad-hoc networking as the mobile station can support up to two antennas. In the process the relay combines the symbols received at the antennas and without decoding, waits for a few time slots depending on the size of the space-time coding (STC) and then transmit the combined symbols by using STC with channel status information (CSI) based gain.(6)

In a cooperative diversity network, users cooperate to transmit each other's messages; to some extent nodes therefore collectively act as an antenna array and create a virtual or distributed multiple-input multiple-output (MIMO) system. One of the gains in a true MIMO system is a multiplexing gain in the high signal-to-noise ratio (SNR) regime, an extra factor in front of the log in the capacity expression. It is shown that cooperative diversity gives no such multiplexing gain, but it does give a high SNR additive gain. The benefits include an increased capacity-roughly proportional to the minimum of the number of receive and transmit antennas, a robustness to fading and shadowing. (8)

In wireless environment, the fading effects and channel variation often degrade signal transmission and increase bit error rate. Diversity techniques have been widely used to suppress channel variation. (9)

Since the growth of wireless communications technologies, the main interest is how to increase that data rate (capacity) or the speed of transmission of the system and how to reduce the probability of error to enhance the quality and to develop a new application based wireless communications system with high data rate.

In order to achieve a good performance that utilizes the system hardware and environment, we simulate a system that mitigate or overcome some of the wireless communications limitations. Which is fixed gain AF MIMO relaying system.

1.3 Project Objectives

In this project there are four main objectives:

1) Studying and perform deep analysis for cooperative diversity based on amplify-and-forward (AF) relaying protocol under uncorrelated flat fading Rayleigh channel.
2) Implementing four schemes of Cooperative diversity system by using MATLAB simulation.
3) Studying the BER and capacity performance of these cooperative schemes.
4) Comparing the performance of conventional systems with the performance of cooperative systems in terms of capacity and BER.

1.4 Literature Review

The authors present efficient performance bounds for multi hop wireless communication systems with non-regenerative fixed gain relay operating over non-identical generalized fading channels, and provide the end-to-end SNR formulation, and provide an upper bounded by using the well-known inequality between harmonic and geometric mean of positive random variables. Modulate a closed form for end-to-end SNR for Rayleigh, Nakagami-m, and Rice fading channels. Furthermore expressed the outage performance and the average error probability for coherent, and non-coherent modulation scheme by using the moment generating function (MGF) approach. The system model in this paper is a multi-hop wireless communication system is considered, operating over independent, but not necessarily i.e. fading channels.(1)

This paper studies the impact of multiple amplifies-and-forward relays on the capacity of wireless MIMO channels. Furthermore it determines the compound (over two time slots) channel matrix of the relay assisted MIMO channel for wireless networks with one source (destination pair equipped with multiple antennas) and several single antenna amplify-and-forward. It also derive the asymptotic Eigen values of the compound channel matrix by letting the number of transmit and receive antennas go to infinity. Moreover, it determines the asymptotic ergodic capacity of the amplify-and- forward transmission scheme for Rayleigh and Rice fading channels.(2)

This paper propose a new amplify-and-forward cooperative spatial multiplexing scheme in which the transmitter (source), equipped with single antenna, forms virtual antenna array from collection of distributed single-antenna wireless terminals, and broad cast identical signal to those terminals (relays). Each relay amplifies-and-forwards different portion of the received signal at a reduced data rate to the receiver (destination). The receiver is equipped with multiple antennas, nulls and cancels the interference from different relays in order of SNR, and detects the original signal transmitted from the source. The combination of transmitter, relays and receiver forms a virtual MIMO system in single antenna wireless terminals environment. (3)

Instead of multiple antennas at the mobile user, antenna sharing among various users leads to improvement in the system performance. This paper makes a derivation of BER for dual hop cooperative network employing non–regenerative relays for MIMO Relay channel experiencing Rayleigh fading. Also the paper discussed the application of MRC on the source-relay (S-R) link and space time coding (STC) on the relay-destination (R-D) link for a MIMO relay channel individually as well as jointly in the MRC-STC scheme. The team work consider the system model as follows: the source (S), relay (R) and the destination (D) may now support multiple antennas. There are *N* relays in the system. The source has M_s transmit antennas, the rth relay has M_r antennas that are used for reception on the S-R link and transmission on the R-D link, and the destination has M_d receive antennas. All transmissions are on orthogonal channels use binary phase shift keying (BPSK). (6)

The basic idea of cooperative diversity is that several nodes, each with one antenna, form a kind of coalition to cooperatively act as a large transmit or receive array. When terminals cooperate as a transmit array, they first exchange messages and then cooperatively transmit those messages as a multi antenna broadcast transmitter; similarly for receive cooperation. The channel therefore shares characteristics with the MIMO channel, such as diversity. Cooperative diversity for wireless networks was first investigated by Sedonaris et al. for cellular networks and by Laneman et al. for ad-hoc networks. (8)

MIMO systems are proposed to employ multiple transmitting and receiving antennas for signal transmission. The BER decreases due to the diversity gain and the increase in degree of freedom for signal detection. To achieve spatial diversity without multiple antenna equipment's, cooperative network has been proposed to achieve virtual MIMO systems with single antenna devices. In cooperative networks, the transmitting nodes use neighbor nodes as relays to obtain spatial diversity gain. The required mean uplink signal-to-noise ratio (SNR) of cooperative methods is significantly less than that of non-cooperative transmission. (9)

The study shows a result which is MIMO cooperative diversity offers a 3.4 dB increase in spectral efficiency at 5% outage, with no additional cost incurred in transmit time, power or bandwidth. The teamwork consider a fading relay channel where the total transmit power used is constrained to be equal to that of the standard single-hop channel. The relay channel used operates in what is termed as MIMO cooperative diversity mode, where the source transmits to both relay and destination terminals in the first instance. Both the source and relay then transmit to the destination in the second instance. Initially the cooperative diversity framework is introduced to consider system constraints so a direct and fair comparison with the single-hop case can be made. (10)

The team work study the Performance analysis of cooperative multiple-input multiple-output (MIMO) relaying system with a single relay. The MIMO scheme is based on Alamouti space-time block coding (STBC) over flat fading Rayleigh channel. The source node, equipped with two transmit antennas, simply broadcasts each STBC code to the relay and the destination nodes. Then, the relay node, equipped with multiple antennas, amplifies-and-forwards (AF) the received STBC codes. Finally, the destination node uses maximum ratio combining (MRC) and exploits the diversity gain obtained through the direct and the indirect links simultaneously. Lower bounds of the symbol error probability (SEP) and the outage probability are derived by using the moment generating function (MGF) of the total signal-to-noise ratio (SNR) for a particular signal of M-ary-quadrature-amplitude modulation (M-QAM). (11)

The authors analyze diversity performance of scalar fixed gain amplify-and-forward (AF) cooperation in multiple-input multiple-output (MIMO) relay channels with multiple source antennas, multiple relay antennas, and multiple destination antennas. They derive the exact symbol error probability (SEP) for maximum likelihood (ML) decoding of orthogonal space-time block codes with M-ary phase-shift keying modulation over such channels. Also they characterize the effect of MIMO cooperative diversity on SEP behavior in a high signal-to-noise ratio. (12)

The authors study the performance of existing cooperative protocols in the two-ring scattering model. The two source nodes and two destination nodes form a 2×2 virtual MIMO cooperative system. The time division multiple access (TDMA) scheme is proposed with half duplex mode. They reached to the cooperative diversity brings performance improvement in correlated channel, even with the keyhole MIMO channel. And, cooperative strategy reduces the spatial correlation of each path, increases the capacity of the correlated channels and enhances the overall performance of virtual MIMO system by high quality of cooperative inter-user channel. (13)

The team work analyzed the system performance of MIMO-Relaying MIMO in different wireless channels. Relay networks achieve high performance by utilizing cooperation between nodes which can classified as multi-hop networks and cooperative MIMO relaying networks. As an important part of "spatial diversity" systems, cooperative diversity involving multi hop data relays is a solution to improve propagation performance, expanding coverage and enhancing system capacity in such wireless environments. In the third part mobile devices use and acting as relays to help the main transmission link for improving the performance such as bit error rate (BER), data rate and coverage. (14)

The authors studied the Distributed space-time linear dispersion codes that are proposed for the cooperative strategies amplify-and-forward (AF) and decode-and-forward (DF) by assuming that no channel state knowledge at the transmitter. The work's team consider different configurations regarding the number of antennas at the relay and the destination nodes. Cooperation among users at the physical layer level is studied for the downlink for a cellular network. (15)

The team work study the performance of a multiple-relay system with fixed-gain amplify-and-forward (AF) relaying in Nakagami-m fading channels. To reduce the complexity at the relays, the fixed-gain relaying scheme has been proposed, which maintains the long-term average transmit power at each relay. With K relays and when the maximal ratio combining (MRC) is used at the destination, they obtained the average symbol error probability (SEP). (16)

The authors consider multiple-input multiple-output (MIMO) orthogonal frequency division multiplexing (OFDM) amplify-and-forward relay channels. They analyze the maximum achievable diversity of the coded beam forming scheme in MIMO-OFDM relaying systems. For systems with multiple source, multiple relay and multiple destination antennas with proper code design. (17)

Cooperative diversity refers to user cooperative diversity because the terminals share their antenna and other resources to create a virtual array through distributed transmission and signal processing. In the relays , there is fixed relaying protocols in which the relay either amplifies what it receives, or fully decodes, re-encodes and retransmits the source message. These options called amplify-and-forward and decode-and-forward respectively. (19)

Transmission over wireless channels suffers from random fluctuations in signal level known as fading and from co-channel interference. To solve this problem, we use diversity to mitigate fading. There is a new way of realizing spatial diversity in this new technology, multiple terminals in a network cooperate to form a virtual antenna array realizing special diversity in distributed fashion. The uplink capacity can be increased by cooperative diversity. (20)

Diversity-Multiplexing Tradeoff (DMT) in MIMO relay Channels is a tool to characterize the fundamental limits of a communication system in fading environment and the fundamental tradeoff between the reliability and the number of degrees of freedom which measured by the special multiplexing gain, which is the rate of increase in transmission rate with SNR. In DMT, the links are assumed to be quasi-static, frequency non selective fading and there is no direct link between source and destination. The channel status information (CSI) is available only at the receiving end of each transmission. (21)

Performances of distributed space-time block code (DSTBC) in cooperative MIMO are analyzed and compared with general cooperative diversity protocols. The increase of cooperative nodes, DSTBC could obtain both spatial diversity gain and coding gain. In addition, higher order modulation with the increased number of relays could also enhance the BER performance in multi-relay cooperative MIMO network. In cooperative MIMO, outage performance and Pair wise Error Performance (PEP) are the basic index for system robustness. (22)

This paper discusses space-time signal design for a simple amplify-and-forward relay channel, code design criteria for the relay case that consists of the traditional rank and determinant criteria as well as appropriate power control rules and the potential benefit of relay-assisted communication over direct communication depending strongly on the channel conditions. Finally, it presents a switching criterion based on which the source terminal may opt to forego relay-assisted communication and communicate with the destination terminal directly. (23)

This project simulates and studies the BER and capacity performance for four schemes of cooperative diversity system which consists of source (S), relay (R) and destination (D). Each node is equipped with M_s, M_r and M_d antennas, respectively. In the first scheme each node equipped with single antennas while the second, third and fourth schemes are equipped with two, four and eight antennas, respectively. These schemes are implemented based on fixed gain amplify-and-forward (AF) relaying protocol. Furthermore, this project makes a comparison between the performance of conventional systems with the performance of cooperative diversity systems in terms of capacity and BER.

The project system design is different to last works in terms of using relay with multiple antennas and using fixed gain amplify-and-forward relaying scheme, i.e., the relay just receives the different copies, due to multipath channel, and amplifies-and-forwards them to the destination. It assumes the same power on each antenna. It also assume that the transmitted signal affected by three random flat fading Rayleigh channels, where the channel is not varying during time separation. In all schemes using BPSK modulation and use MRC at the destination in order to combine the two signal phases to enhance the total system SNR. And to assume each node obey half duplex constraint, .i.e., the node can't transmit and receive simultaneously. And it assumes that the channel status information (CSI) is perfectly known in both relay and destination. In all AF MIMO relaying systems OSTBC are used.

1.5 Time Planning

The project plan follows the time schedule, which includes the related tasks of study and system analysis. The time plan is for the first and second semesters:

Table 1.1: Time planning for first semester

Tasks Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Choose a project idea	🟦	🟦														
Collect information about the project		🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Writing project proposal			🟦	🟦	🟦											
Requirements analysis					🟦	🟦	🟦	🟦								
System design								🟦	🟦	🟦	🟦	🟦	🟦			
Documentations						🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	

Table 1.2: Time planning for second semester

Tasks \ Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Learning MATLAB simulation	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦								
Writing project software			🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			
Analyses the simulation result				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			
Plot explanation curves							🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		
Make a conclusions							🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Documentations					🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Project delivery															🟦	

1.6 Cost Estimation

Table 1.3: Cost estimation for software components

Software Component	Required Number	Price ($)
Microsoft windows 7	4	600
Microsoft office 2010	4	600
MATLAB software R2011b	4	600

Table 1.4: Cost estimation for hardware components

Hardware Component	Price ($)
4 PC's	3600

CHAPTER

2

Theoretical Background

Theoretical Background

2.1 The Wireless Channel

A signal propagating through the wireless channel arrives at the destination along multi different paths which arise from scattering (deviation of waves from a straight trajectory as passing through the channel), reflection (wave propagating in one medium impinges upon another medium having different electrical properties, so the wave is partially reflected and partially transmitted) and diffraction (occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities) of radiated energy by objects in the environment. The power of the signal drops off due to three effects; path loss (is a measure of attenuation based only on the distance to the transmitter), macroscopic fading and microscopic fading. The first which is the mean propagation loss is a range dependent, in microcellular environments comes from inverse square law power loss and received signal power is given by:

$$P_r = P_t\left(\frac{\lambda_c}{4\pi d}\right)^2 G_t G_r \ldots\ldots\ldots\ldots (2.1)$$

Where P_t and P_r are the transmitted and received powers respectively , λ_c is the wavelength, G_t and G_r are the power gains of transmit and receive antennas respectively, and d is the range separation. In cellular environments the received power can be approximated by:

$$P_r = P_t\left(\frac{h_t h_r}{d^2}\right)^2 G_t G_r \ldots\ldots\ldots\ldots (2.2)$$

Where h_t, h_r are the effective heights of transmit and receive antennas respectively, with assumption that $d^2 >> h_t h_r$, so the effective path loss follows an inverse fourth power low. In real environments the path loss exponent varies from 2.5 to 6. Also there are several path loss models such as Okumura and Hate models.(25)

2.2 Limitations Facing Wireless Communication Systems

The major problems that the wireless communications suffer are mainly the limited spectrum available, propagation channel environment, fading, path loss, interference and noise. Since the signal may reach the destination from multipath at the receiver side producing many copies of the signal with different attenuations and with different delays.

The multipath environment causes the fading problem in the channel resulted from scattering, reflections, refractions and diffractions.

Despite the fact that, multipath arrival of a signal was harmful to the conventional communication system that uses one transmitter and one receiver, multi antenna systems has benefited from this multipath propagation phenomena to enhance the system capacity, coverage, and quality. But for now the available bandwidth will be the most limiting factor that faces wireless communication system, thus, all recent research related to wireless field focus on how to efficiently use the bandwidth.(25)

2.3 Fading Models

In wireless communications, fading is deviation of the attenuation that a carrier modulated telecommunication signal experiences over certain propagation media. The fading may vary with time, geographical position or radio frequency.

The presence of reflectors in the environment surrounding a transmitter and receiver create multiple paths that a transmitted signal can travel. As a result, the receiver sees the superposition of multiple copies of the transmitted signal, each traveling a different path. Each signal copy will experience differences in attenuation, delay and phase shift while travelling from the source to the receiver. This can result in either constructive or destructive interference, amplifying or attenuating the signal power seen at the receiver. Strong destructive interference is frequently referred to as a deep fade and may result in temporary failure of communication due to a severe drop in the channel signal to noise ratio.

Fading channel models are often used to model the effects of electromagnetic transmission of information over the air in cellular networks and broadcast communication. Mathematically, fading is usually modeled as a time varying random change in the amplitude and phase of the transmitted signal.

There are two main types of fading, small scale fading and large scale fading:

- **Small Scale Fading** (rapid fluctuations in the signals envelope) characteristic of radio propagation resulting from the presence of the reflectors and scatters that cause multiple versions of the transmitted signal to arrive at the receiver, each distorted in amplitude, phase and angle of arrival.

Small scale fading has the following forms; Slow fading, Fast fading, Flat fading, and Frequency selective fading.

- **Large Scale Fading** (slow fluctuations in the signals envelope) is explained by the gradual loss of received signal power (since it propagates in all directions) with transmitter receiver separation distance.

Several fading models have been developed, here are the most used

1) **Rayleigh Fading:** Is a statistical model for the effect of a propagation environment on a radio signal, such as that used by wireless devices. Rayleigh fading models assume that the magnitude of a signal that has passed through a communication channel will vary randomly, or fade, according to a Rayleigh distribution. Rayleigh fading is most applicable when there is no dominant propagation along a line of sight between the transmitter and receiver.

The Rayleigh distribution has a probability density function given by:

$$P(r) = \begin{cases} \frac{r}{\sigma^2}\exp\left(-\frac{r^2}{2\sigma^2}\right) & 0 \leq r < \infty \\ 0 & r < 0 \end{cases} \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (2.3)$$

Where σ is the root mean square (rms) of the received voltage signal before envelope detection, and σ^2 is the time average power of the received signal before envelope detection. (25)

2) **Rician Fading:** Whenever there is a dominant stationary signal component present, such as a line of site propagation path, the small scale fading envelope is Rician. In such a situation, random multipath components arriving at different path are superimposed on a stationary dominant signal. The Rician distribution degenerates to a Rayleigh distribution when the dominant component fades away.

   The Rician distribution is given by:

$$P(r) = \begin{cases} \frac{r}{\sigma^2}\left(\frac{A_r}{\sigma^2}\right) e^{-\frac{(r^2+A^2)}{2\sigma^2}} I_0, & A \geq 0, r \geq 0 \\ 0 & r < 0 \end{cases} \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (2.4)$$

   Where the parameter (A) denotes the peak amplitude of the dominant signal. The Rician distribution is often described of a parameter K which is defined as the ratio between the deterministic signal power and the variance of the multipath. (27)

2.4 Space Time Channel Mode

The space-time channel is a channel that use multiple antennas at the transmitter and/or receiver in a wireless system. The typical space-time (ST) wireless system consist of M_t transmit antennas and M_r receive antennas.

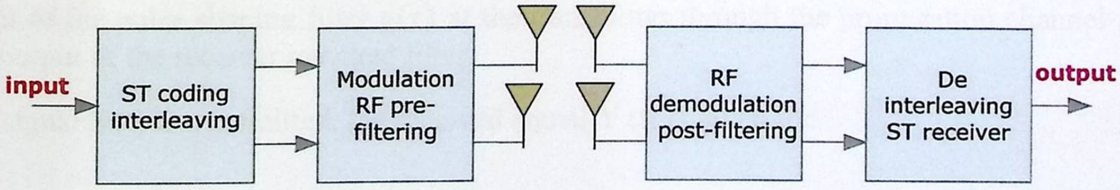


Figure 2.1: schemes of a ST wireless communication system

The input data bits enter a ST coding block that add parity bits for protection against noise and also capture diversity from space and possibly frequency or time dimensions in a fading environment. After coding, the bits (or words) are interleaved a cross space, time, and frequency and mapped to data symbols.

The signals pass through the radio channel where they are attenuated and undergo fading in multiple dimensions before they arrive at the M_r receive antennas. Additive thermal noise in the M_r parallel RF chains at the receiver corrupts the received signal. The mixture of signal plus noise is matched-filtered and sampled to produce M_r output streams. These streams are them ST de-interleaved and ST decoded to produce the output data bits.

The difference between a ST communication system and a conventional system comes from the use of multiple antennas, ST encoding or interleaving, ST pre-filtering and post filtering and ST decoding or de-interleaving. (28)

There are many ST channel models including SISO, SIMO, MISO, and MIMO.

2.4.1 SISO Channel

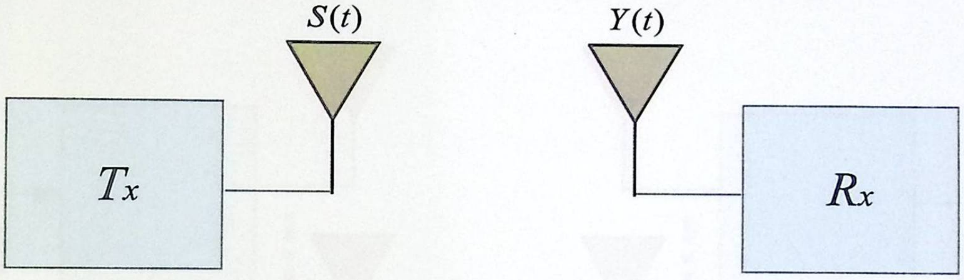


Figure 2.2. single-input single-output system

SISO refer to single-input single-output; is a radio channel where we have one antenna in the transmitter and one antenna in the receiver. There is no diversity and no additional processing required. The advantage of SISO system is its simplicity. However, the SISO channel is limited in its performance, interference and fading will impact the system performance more than a MIMO system that using some kind of diversity and spatial multiplexing.

Let us consider $h(\tau, t)$ be the time varying channel impulse response that comes from the input of the pulse shaping filter $g(\tau)$ at the transmitter through the propagation channel $p(\tau, t)$, to the output of the receiver matched filter.

If a signal S (t) is transmitted, the received signal Y (t) is given by:

$$Y(t) = \int_0^{\tau} h(\tau, t) S(t-\tau) d\tau = h(\tau, t) * S(t) + \eta(t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.5)$$

Where:

$h(t, t)$, $S(t)$, $Y(t)$ are complex envelopes of a narrow band signal, $\eta(t)$ additive white Gaussian noise and * denotes the convolution operator and assumed a casual channel impulse response of duration t total.

If we assumed SISO system in AWGN channel. The spectral efficiency is expressed as:

$$C = \log_2(1 + \text{SNR})(\text{bps/Hz}) \quad (2.6)$$

Where SNR is the average signal-to-noise ratio at the receiver.

To improve the performance of SISO system, engineers traditionally used several techniques to combat multi path, such as diversity which will explained briefly in the next sections.(28),(29), (30)

2.4.2 MIMO Wireless Communication

2.4.2.1 MIMO Concept

A MIMO is referring to multiple-input multiple-output. The basic concept of MIMO is the use of multiple antennas at the transmitter and receiver in wireless system.

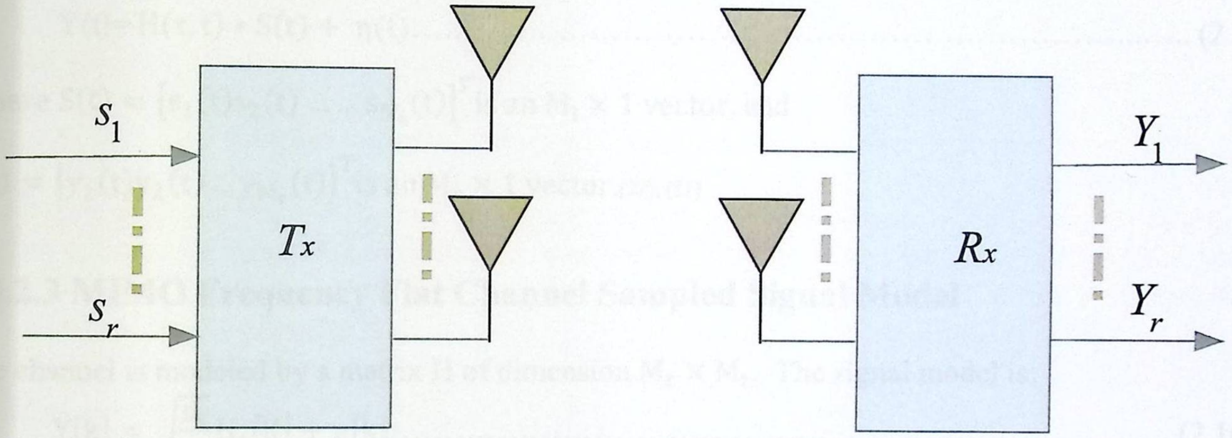


Figure 2.3. multiple-input multiple-output system

The multiple antennas can be used to increase data rates through multiplexing or to improve the performance through diversity. Multiplexing is obtained by exploiting the structure of the channel gain matrix to obtain independent signaling paths that can be used to send independent data.

The cost of the performance enhancements obtained through MIMO techniques is the added cost of deploying multiple antennas, the space and power requirements of these extra antennas (especially on small handheld units), and the added complexity required for multi-dimensional signal processing.

2.4.2.2 MIMO Channel

Consider a MIMO system with M_t transmit antennas and M_r receive antennas. Denoting the impulse response between the jth (j=1,2,……., M_t) transmit antenna and the ith ((i=1,2,……., M_r) receive antenna by $h_{i,j}(\tau, t)$,the MIMO channel is given by:

$$H(\tau,t) = \begin{bmatrix} h_{1,1}(\tau,t) & h_{1,2}(\tau,t) & h_{1,M_t}(\tau,t) \\ \vdots & \ddots & \vdots \\ h_{M_r,1}(\tau,t) & \dots & h_{M_r,M_t}(\tau,t) \end{bmatrix} \dots\dots\dots\dots\dots \text{(2.7)}$$

The vector $[h_{1,j}(\tau,t)[h_{2,j}(\tau,t)$............ $h[h_{M_r,j}(\tau,t)]^T$ is the channel induced by the jth transmit antenna. Across the receive antenna array. Furthermore, given that the signal $S_j(t)$ is launched from the jth transmit antenna, the received signal at the ith received antenna.

$Y_i(t)$ is given by:

$$Y_i(t) = \sum_{j=1}^{Mt} h_{i,j}(\tau,t) * S_j(t) + \eta_i(t), \ i = 1,2, \dots, M_r \dots\dots\dots \text{(2.8)}$$

The input- output relation for the MIMO channel can be expressed as:

$$Y(t) = H(\tau,t) * S(t) + \eta(t) \dots\dots\dots\dots\dots \text{(2.9)}$$

Where $S(t) = [s_1(t)s_2(t) \dots\dots s_{M_t}(t)]^T$ is an $M_t \times 1$ vector, and

$y(t) = [y_1(t)y_2(t) \dots y_{M_r}(t)]^T$ is an $M_r \times 1$ vector.(28), (31)

2.4.2.3 MIMO Frequency Flat Channel Sampled Signal Model

The channel is modeled by a matrix H of dimension $M_r \times M_t$. The signal model is:

$$Y[k] = \sqrt{\frac{E_s}{M_t}} H_s[K] + n[k] \dots\dots\dots\dots\dots \text{(2.10)}$$

Where Y[k] is the received signal vector with dimension $M_r \times 1$, S[k] is the transmit signal vector with dimension $M_t \times 1$ and n[k] is the noise vector with variance N_0 in each dimension. Since the output at any instant of time is independent of inputs at previous time, we can drop the time index k for simplicity and express input-output relation as:

$$Y = \sqrt{\frac{E_s}{M_t}} H_s + n \dots\dots\dots\dots\dots \text{(2.11)}$$

2.4.2.4 Capacity of The Frequency Flat Deterministic MIMO Channel

In general the capacity of wireless channel is the basic measure of performance which request the maximum rate of communication for which arbitrary small error probability can be achieved.(28), (29)

Assume the channel has a bandwidth of 1 Hz and is frequency flat over this band and the channel is unknown to the transmitter. Then the capacity of MIMO channel is given by:

$$C = \log_2\left(\det\left(I_{M_r} + \frac{E_s}{M_t N_0} HH^H\right)\right) \text{ bps/Hz} \qquad (2.12)$$

2.4.2.5 The Benefits of MIMO Technology

There are many benefits of MIMO technology that help achieve such significant performance gains such that:

1) **Array Gain**

Array gain refers to the increase in the SNR that result from a coherent combining affected of the wireless signals at the receiver. Array gain improves resistance to noise, thereby improving the coverage and the range of a wireless communication network. Array gain exploitation requires channel knowledge at the transmitter.

2) **Spatial Diversity Gain**

Spatial diversity gain mitigates fading and is realized by providing the receiver with multiple copies (independent) of the transmitted signal in space, frequency, or time. The diversity order which refer to the number of copies if the copies increased as a result decrease the effect of fading or combat the fading because the receiver combines the independently faded versions of the same signal so the resultance signal reduced amplitude variability hence improving the quality (improving SNR), and reliability of reception.

3) Spatial multiplexing gain

MIMO system offers a linear increase in data rate (capacity) through spatial multiplexing, i.e., using MIMO you can transmit or receive from multiple independent data streams simultaneously within the same bandwidth and with no additional power expenditure. This is only possible in MIMO channel under rich scattering environment. The spatial multiplexing gain increases capacity of a wireless network.

In practical wireless communication system there is a tradeoff between the diversity gain and the spatial multiplexing gain because the diversity benefit assumes that the data rate is held constant and BER decreases as SNR increases, while multiplexing assumes the BER is held constant and data rate increases with SNR, by use of increasingly bandwidth efficient modulation and coding schemes.

4) Interference Reduction

Co-channel interference a rises due to frequency reuse in wireless communication channel or when multiple users sharing time and frequency resources. Interference can be mitigated in MIMO channel by exploiting the spatial dimension to increase the separation between users so allows using of aggressive reuse factors and improves network capacity.

In general we must note that it may not be possible to exploit simultaneously all the benefits of MIMO due to conflicting demand on the spatial degrees of freedom. However, using some combination of the benefits a cross a wireless network will improve capacity, coverage, quality, and reliability.(28),(31),(32),(33)

2.5 Binary Phase Shift keying (BPSK)

In binary phase shift keying (BPSK), the phase of a constant amplitude carrier signal is switched between two values a according to the two possible signals m_1 and m_2, corresponding to binary 1, and 0, respectively. Normally, the two phases are separated by 180 degree. If the sinusoidal carrier has an amplitude A_c and energy per bit:

$$E_b = \frac{1}{2}A_c^2T_b \qquad (2.13)$$

Where T_b is the bit time.

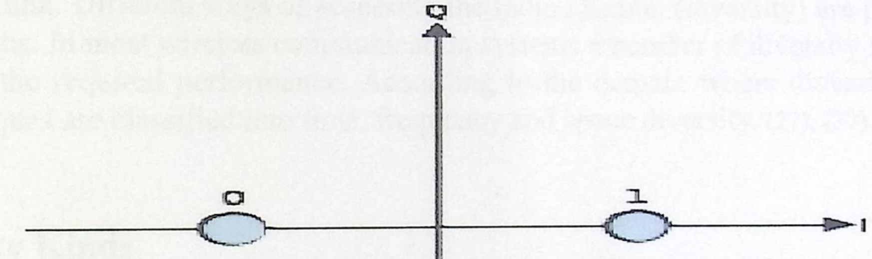


Figure 2.4: Constellation Diagram Example for BPSK.

Then the transmitted BPSK signal are:

$$S_{bpsk}(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t + \theta_c)\,; \quad 0 \le t \le T_b \text{ (binary 1)} \qquad (2.14)$$

$$S_{bpsk}(t) = -\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t + \theta_c); \quad 0 \le t \le T_b \text{ (binary 0)} \qquad (2.15)$$

BPSK uses coherent demodulation, which requires that information about the phase and frequency of the carrier be available at the receiver.(31), (34)

2.6 Diversity

2.6.1 Principle of Diversity

In wireless mobile communications, diversity techniques are widely used to reduce effects of multipath fading and improve the reliability of transmission without increasing the transmitted power or sacrificing the bandwidth.

The principle of diversity is to provide the receiver with multiple versions of the same transmitted signal. Each of these versions is defined as a diversity branch. If these versions are affected by independent fading conditions, the probability that all branches are in a fade at the same time reduces dramatically. To understand the mechanism, let p denote the probability that the instantaneous signal-to-noise ratio is below a critical threshold on each diversity branch. Then with independently faded branches, p^L is the probability that the instantaneous signal-to-noise ratio is below the same critical threshold on all L diversity branches.

Continuously selecting the path with the best signal quality will result in an improved communication link. Different ways of accessing the radio channel (diversity) are possible to obtain uncorrelated paths. In most wireless communication systems a number of diversity methods are used in order to get the required performance. According to the domain where diversity is introduced, diversity techniques are classified into time, frequency and space diversity. (27), (37),(40)

2.6.2 Diversity Kinds

2.6.2.1 Time Diversity

Time diversity can be achieved by transmitting identical messages in different time slots, which results in uncorrelated fading signals at the receiver. The required time separation is at least the coherence time of the channel, or the reciprocal of the fading rate $1/f_d$. The coherence time is a statistical measure of the period of time over which the channel fading process is correlated.

The time separation between the replicas of the transmitted signals is provided by time interleaving to obtain independent fades at the input of the decoder. Since time interleaving results in decoding delays, this technique is usually effective for fast fading environments where the coherence time of the channel is small. For slow fading channels, a large interleave can lead to a significant delay which is intolerable for delay sensitive applications such as voice transmission.

Clearly time diversity can’t be used for stationary applications, since the channel coherence time is infinite and thus fading is highly correlated over time. For example, when a mobile radio station is stationary, time diversity cannot help to reduce fades.

Time diversity does not require increased transmit power, but it does decrease the data rate since data is repeated in the diversity time slots rather than sending new data in these time slots. Due to the redundancy introduced in the time domain, there is a loss in bandwidth efficiency.

2.6.2.2 Frequency Diversity

In frequency diversity, a number of different frequencies are used to transmit the same message. The frequencies need to be separated enough to ensure independent fading associated with each frequency. The frequency separation of the order of several times the channel coherence bandwidth will guarantee that the fading statistics for different frequencies are essentially uncorrelated. The coherence bandwidth is different for different propagation environments.

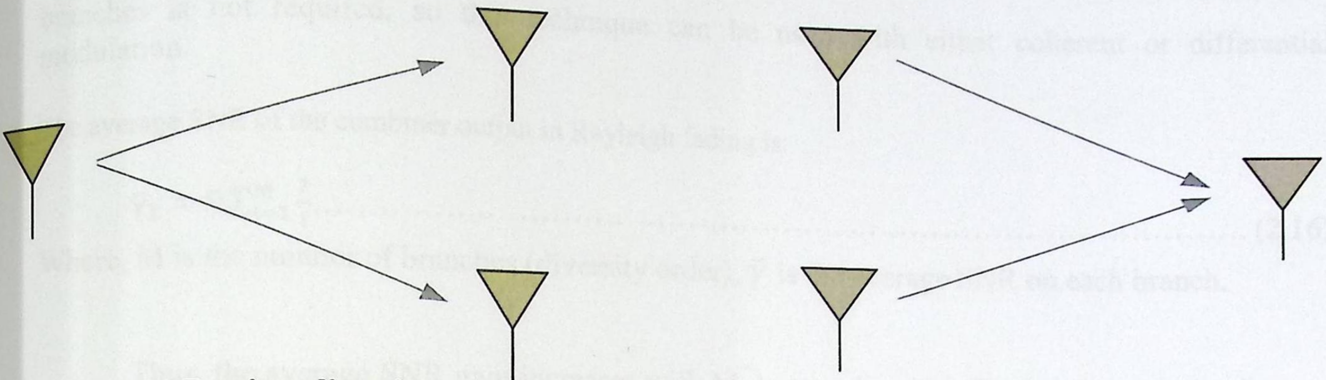
In mobile communications, the replicas of the transmitted signals are usually provided to the receiver in the form of redundancy in the frequency domain introduced by spread spectrum such as direct sequence spread spectrum (DSSS), multicarrier modulation and frequency hopping. Spread spectrum techniques are effective when the coherence bandwidth of the channel is small. However, when the coherence bandwidth of the channel is larger than the spreading bandwidth, the multipath delay spread will be small relative to the symbol period. In this case, spread spectrum is ineffective to provide frequency diversity. Like time diversity, frequency diversity induces a loss in bandwidth efficiency due to a redundancy introduced in the frequency domain. This technique requires additional transmit power to send the signal over multiple frequency bands.

2.6.2.3 Space Diversity

Space diversity has been a popular technique in wireless microwave communications. Space diversity is also called antenna diversity. It is typically implemented using multiple antennas or antenna arrays arranged together in space for transmission and/or reception.

The multiple antennas are separated physically by a proper distance so that the individual signals are uncorrelated. A disadvantage of space diversity is the increased volume needed to contain multiple antennas. The attractiveness of this diversity implementation is its simplicity.

The separation requirements vary with antenna height, propagation environment and frequency. Typically a separation of a few wavelengths is enough to obtain correlated signals. In space diversity, the replicas of the transmitted signals are usually provided to the receiver in the form of redundancy in the space domain. Unlike time and frequency diversity, space diversity does not induce any loss in bandwidth efficiency. This property is very attractive for high data rate wireless communications. Polarization diversity and angle diversity are two examples of space diversity. (27), (31), (37),(39)



(a) Receiver diversity

(b) Transmit diversity

Figure 2.5: Receiver Diversity (SIMO) and Transmit Diversity (MISO).

2.6.3 Diversity Combining Methods

In general, the performance of communication systems with diversity techniques depends on how multiple signal replicas are combined at the receiver to increase the overall received SNR. Therefore, diversity schemes can also be classified according to the type of combining methods employed at the receiver.

According to the implementation complexity and the level of channel state information required by the combining method at the receiver, there are main types of combining techniques, including selection combining (SC), equal gain combining (EGC) and maximal ratio combining (MRC). Diversity combining that takes place at radio frequency (RF) is called pre-detection combining, while diversity combining that takes place at baseband is called post-detection combining. In many cases there is no difference in performance, at least in an ideal sense. The maximum diversity order of a system with M antennas is M, and when the diversity order equals M the system is said to achieve full diversity order. The diversity order indicates how the slope of the average probability of error as a function of average SNR changes with diversity.

2.6.3.1 Selection Combining

Selection combining (SC) is a simple diversity combining method. The diversity combiner selects the signal with the largest instantaneous signal to noise ratio (SNR) at every symbol interval as the output, so that the output SNR is equal to that of the best incoming signal. In practice, the signal with the highest sum of the signal and noise power (S + N) is usually used, since it is difficult to measure the SNR.

Since only one branch is used at a time, SC often requires just one receiver that is switched into the active antenna branch. However, a dedicated receiver on each antenna branch may be needed for systems that transmit continuously in order to simultaneously and continuously monitor SNR on each branch. With SC the path output from the combiner has an SNR equal to the maximum SNR of all the branches. Moreover, since only one branch output is used, co-phasing of multiple branches is not required, so this technique can be used with either coherent or differential modulation.

The average SNR of the combiner output in Rayleigh fading is:

$$\bar{\gamma}_{\Sigma} = \bar{\gamma} \sum_{i=1}^{M} \frac{1}{i} \qquad (2.16)$$

Where, M is the number of branches (diversity order), $\bar{\gamma}$ is the average SNR on each branch.

Thus, the average SNR gain increases with M, but not linearly. The biggest gain is obtained by going from no diversity to two-branch diversity. Increasing the number of diversity branches from two to three will give much less gain than going from one to two.

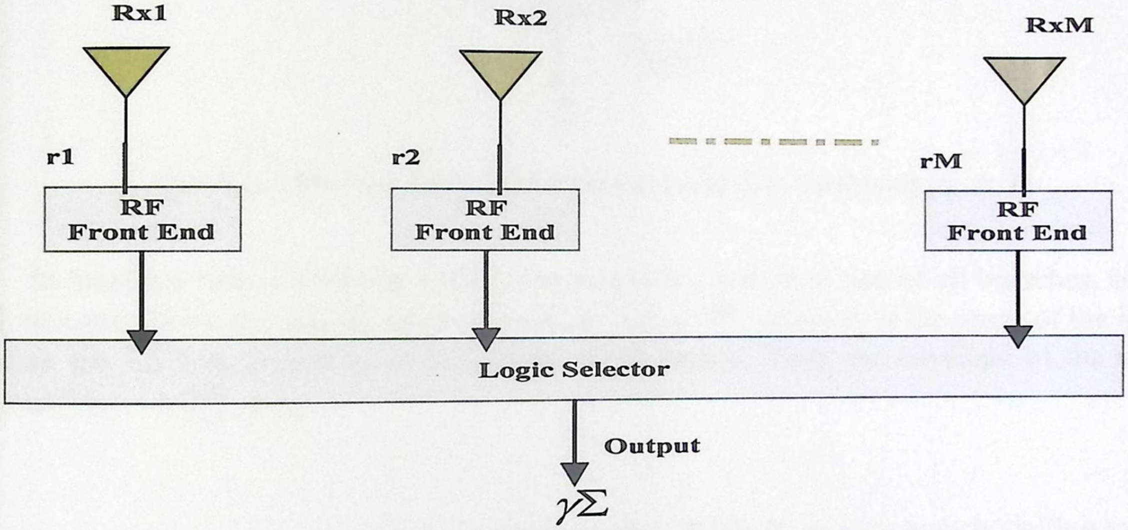


Figure 2.6: Selection Combining Method

2.6.3.2 Maximal Ratio Combining

In this method first proposed by Kahn, the signals from all of the M branches are weighted according to their individual signal voltage to noise power ratios and then summed. The individual signals must be co-phased before being summed (unlike selection diversity) which generally requires an individual receiver and phasing circuit for each antenna element.

Maximal ratio combining produces an output SNR equal to the sum of the individual SNRs. Thus, it has the advantage of producing an output with an acceptable SNR even when none of the individual signals are themselves acceptable. This technique gives the best statistical reduction of fading of any known linear diversity combiner. Modern digital signal processing (DSP) techniques and digital receivers are now making this optimal form of practical diversity.

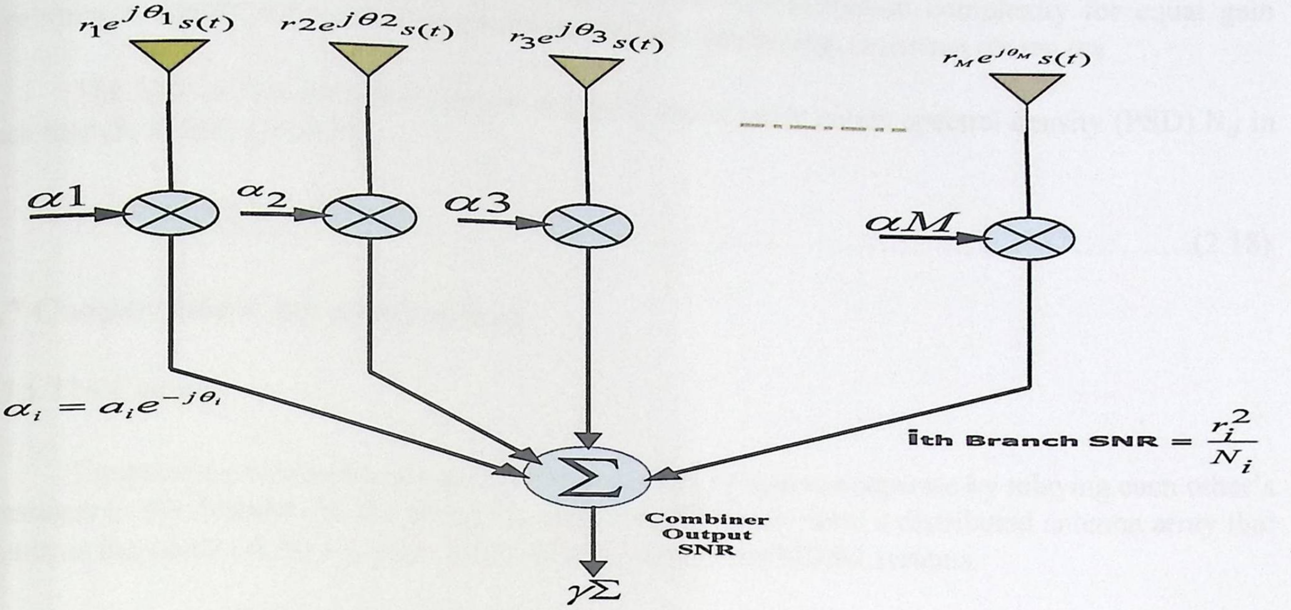


Figure 2.7: Maximal Ratio Combining and Equal-Gain Combining ($a_i = 1$)

In maximal ratio combining (MRC) the output is a weighted sum of all branches, so the α_is are all nonzero. Since the signals are co-phased, $\alpha_i = a_ie^{-j\theta i}$, where θ_i is the phase of the incoming signal on the ith branch and a_i is the weight of ith branch. Thus, the envelope of the combiner output will be $\mathrm{r} = \sum_{\mathrm{i=0}}^{\mathrm{M}} \mathrm{a_i\,r_i}$.

Assuming the same noise power spectral density (PSD) N_0 in each branch yields a total noise PSD $\mathrm{N_{tot}}$ at the combiner output of $N_{tot} = \sum_{\mathrm{i=0}}^{\mathrm{M}} a_i{}^2 N_0$. Thus, the output SNR of the combiner is:

$$\gamma_\Sigma = \frac{\mathrm{r_i}^2}{\mathrm{N_{tot}}} = \frac{1}{N_0}\frac{\left(\sum_{\mathrm{i=0}}^{\mathrm{M}} a_ir_i\right)^2}{\sum_{\mathrm{i=0}}^{\mathrm{M}} a_i{}^2} \qquad (2.17)$$

The goal is to choose the a_i to maximize γ_Σ. Then $\bar{\gamma}_\Sigma = M\bar{\gamma}$. Where, M is number of branches (diversity order) and $\bar{\gamma}$ is average SNR on each branch.

2.6.3.3 Equal Gain Combining

MRC requires knowledge of the time varying SNR on each branch, which can be very difficult to measure. A simpler technique is equal-gain combining, which co-phases the signals on each branch and then combines them with equal weighting, $\alpha_i = e^{-j\theta i}$. Where, $a_i = 1$ for all branches.

Equal gain combining is a sub optimal but simple linear combining method. It does not require estimation of the fading amplitude for each individual branch. Instead, the receiver sets the amplitudes of the weighting factors to be unity. The implementation complexity for equal gain combining is significantly less than the maximum ratio combining. (31),(35) (36), (37), (39), (40)

The SNR of the combiner output, assuming equal noise power spectral density (PSD) N_0 in each branch, is then given by:

$$\gamma_\Sigma = \frac{1}{N_0 M}\left(\sum_{i=0}^{M} r_i\right)^2 \ldots\ldots(2.18)$$

2.7 Cooperative Communications

2.7.1 The Concept

Cooperative communications, allow users in the system to cooperate by relaying each other's messages to the destination. By doing so, users can effectively form a distributed antenna array that emulates the spatial diversity gains achievable by centralized MIMO systems.

Due to multipath fading, the signal-to-noise ratios (SNRs) at the destination may vary rapidly over time, causing communication outage whenever one of the user's SNRs falls below the required level. However, if the two users can cooperate by relaying each other's messages to the destination, communication outage will occur only when both users simultaneously experience poor channels, thereby improving the transmission reliability.(26)

2.7.2 The Benefits of Cooperative Diversity

Cooperative communications is a new communication paradigm which generates independent paths between the user and the base station by introducing a relay channel. Hence, cooperative communications is a new paradigm shift for the 4th generation wireless system that will guarantee high data rates to all users in the network, and it anticipated that will be the key technology aspect in 5th generation wireless networks. In terms of research, cooperative communications can be seen as related to research in relay channel and MIMO systems. (41)

2.7.3 The Relays

2.7.3.1 The Concept

The relay channel can be thought of as an auxiliary channel to the direct channel between the source and destination. Since the relay node is usually several wavelengths distant from the source, the relay channel is guaranteed to fade independently from the direct channel, which introduces a full rank MIMO channel between the source and the destination.

In the cooperative communications setup, there are a-priori few constraints to different nodes receiving useful energy that has been emitted by another transmitting node. The new paradigm in user cooperation is that, by implementing the appropriate signal processing algorithms at the nodes, multiple terminals can process the transmissions overheard from other nodes and be made to collaborate by relaying information for each other.

The relayed information is subsequently combined at a destination node so as to create spatial diversity. This creates a network that can be regarded as a system implementing a distributed multiple antenna where collaborating nodes create diverse signal paths for each other.

2.7.3.2 Cooperative Relaying Schemes

There are some basic cooperative relaying techniques such as:

1) **Decode-and-forward Relaying (DF)**

Decode-and-forward (DF) relaying schemes refer to cases where the relay explicitly decodes the message transmitted by the source and forwards a newly generated signal to the destination. These schemes are also known as regenerative relaying schemes, which have been widely adopted in the literature, including those employed in conventional multi-hop networks.

There are three variants of DF relaying schemes:

a- The basic DF relaying scheme (Basic DF)

b- The selection DF relaying scheme (Selection DF)

c- The demodulate-and-forward (DeF) relaying scheme.

2) **Amplify-and-Forward Relaying(AF)**

In amplify-and-forward (AF) relaying schemes, the relay amplifies the analog signal received from the source and forwards it to the destination (without explicitly decoding or demodulating the messages or symbols) as shown in figure 2.8.

These schemes are also referred to as non-regenerative relaying schemes. Here, relays need not have knowledge of the encoding or modulation schemes employed at the source. Moreover, in addition to its low complexity, AF schemes are also desirable when the quality of the source-relay (S-R) link is not sufficient to guarantee reliable decoding at the relay. In this case, amplifying the analog signal preserves soft information that can be further exploited at the destination.

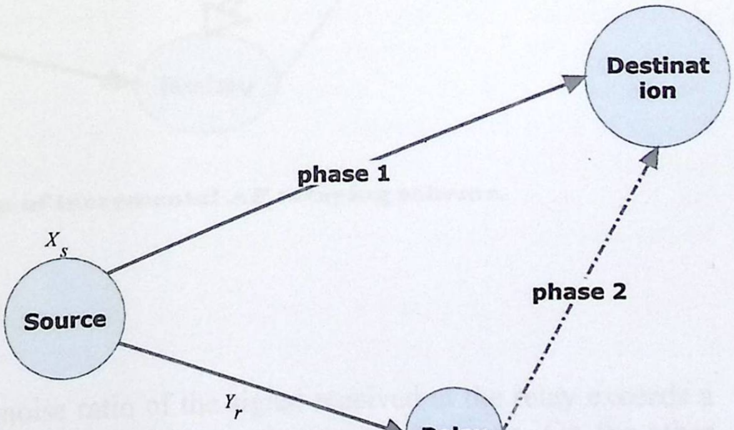


Figure 2.8. Illustration of amplify-and-forward (AF) relaying scheme.

We describe two variants of AF relaying schemes:

a- The basic AF relaying scheme with and without diversity combining at the destination. This is the main idea of our project and will be explained in chapter 3.

b- Incremental AF Relaying Scheme

The basic AF relaying scheme is able to achieve full diversity when signals received in both Phase 1 and Phase 2 are combined for detection at the destination. However, the relaying schemes (including the DF schemes) may not be bandwidth efficient, compared to direct transmission, since the same codeword is transmitted twice over the entire cooperative transmission period.

To improve upon this, as illustrated in figure (2.9), where the Phase 2 of the cooperative transmission is utilized only when the source transmission fails in Phase 1. This leads to higher bandwidth efficiency, since the second transmission phase is not always required, and can be achieved with a simple feedback mechanism at the destination.

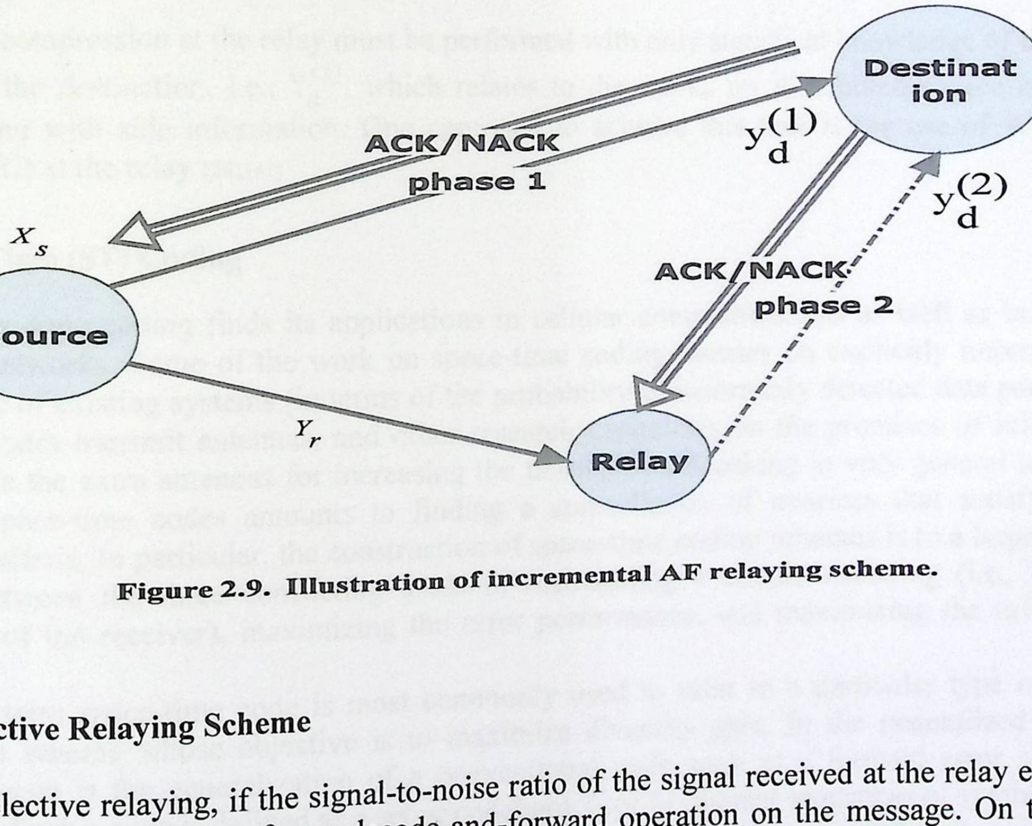


Figure 2.9. Illustration of incremental AF relaying scheme.

3) Selective Relaying Scheme

In selective relaying, if the signal-to-noise ratio of the signal received at the relay exceeds a certain threshold, the relay performs decode-and-forward operation on the message. On the other hand, if the channel between the source and the relay has severe fading such that the signal-to-noise ratio is below the threshold, the relay idles. Moreover, if the source knows that the destination does not decode correctly, then the source may repeat to transmit the information to the destination or the relay may help forward information, which is termed as incremental relaying. In this case, a feedback channel from the destination to the source and the relay is necessary.

4) Compress-and-Forward Relaying Schemes

Compress-and-forward (CF) relaying schemes refer to cases where the relay forwards quantized, estimated, or compressed versions of its observation to the destination. In contrast to DF the relay in CF schemes need not decode perfectly the source message but need only to extract, from its observation, the information that is most relevant to the decoding at the destination. The amount of information extracted and forwarded to the destination depends on the capacity of the relay-destination (R-D) link.

In fact, it has been shown that CF can outperform DF when the relay is farther from the source (i.e., decoding is less reliable at the relay) and is closer to the destination (i.e., more information can be conveyed to the destination through the R-D channel). Moreover, CF also provides a more general form of compression compared to the simple scaling done in AF.

The CF relaying scheme also takes on two phases of transmission. In Phase 1, the source transmits a message to both the relay and the destination, where the received signals are denoted by Y_r and $Y_d^{(1)}$, respectively; in Phase 2, the relay compresses Y_r or extracts from Y_r the information that is most useful for the decoding at the destination.

The compression at the relay must be performed with only statistical knowledge of the signal received at the destination, i.e., $Y_d^{(1)}$, which relates to the works on distributed source coding or source coding with side information. One approach to achieve this task is the use of Wyner-Ziv coding (WZC) at the relay. (26),(41)

2.8 Space-Time (ST) Coding

Space-time coding finds its applications in cellular communications as well as in wireless local area networks. Some of the work on space-time coding focuses on explicitly improving the performance of existing systems (in terms of the probability of incorrectly detected data packets) by employing extra transmit antennas, and other research capitalizes on the promises of information theory to use the extra antennas for increasing the throughput. Speaking in very general terms, the design of space-time codes amounts to finding a constellation of matrices that satisfy certain optimality criteria. In particular, the construction of space-time coding schemes is to a large extent a trade-off between the three conflicting goals of maintaining a simple decoding (i.e., limit the complexity of the receiver), maximizing the error performance, and maximizing the information rate.

The term space-time code is most commonly used to refer to a particular type of MIMO transmission scheme whose objective is to maximize diversity gain. In the generalized sense, a space-time code is the generalization of a conventional code such as a forward error correcting (FEC) code. Such a code is defined as a set or codebook C of M distinct sequences of symbols, often binary but in wireless communication often drawn from a complex constellation representing modulated signals. For a space-time code these symbols become length n_T complex vectors, whose elements represent the modulated signals transmitted on each transmit antenna. We will call these vector symbols space time symbols, to distinguish them from the modulation symbols transmitted on each antenna, which are the elements of the vectors. The code sequences become arrays or matrices of complex modulation symbols.

2.8.1 Alamouti Space Time Code

The Alamouti scheme is historically the first space-time block code to provide full transmit diversity for systems with two transmit antennas. It is worthwhile to mention that delay diversity schemes can also achieve a full diversity, but they introduce interference between symbols and complex detectors are required at the receiver. In this section, we present Alamouti's transmit diversity technique, including encoding and decoding algorithms and its performance.

$$[X_1 \quad X_2] \rightarrow \begin{bmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \end{bmatrix}$$

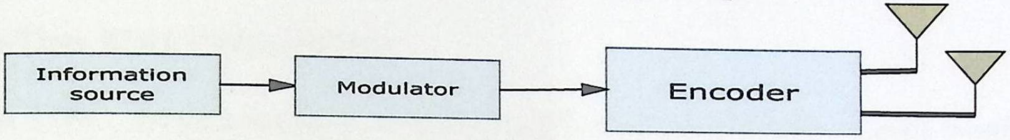


Figure 2.10: Alamouti space-time Encoder

Figure (2.10) shows the block diagram of the Alamouti space-time encoder. Let us assume that an *M*-ary modulation scheme is used. In the Alamouti space-time encoder, each group of m information bits is first modulated, where $m = \log_2 M$. Then, the encoder takes a block of two modulated symbols x_1 and x_2. In each encoding operation and maps them to the transmit antennas according to a code matrix given by:

$$X = \begin{bmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \end{bmatrix} \quad \text{...(2.19)}$$

The encoder outputs are transmitted in two consecutive transmission periods from two transmit antennas. During the first transmission period, two signals x_1 and x_2 are transmitted simultaneously from antenna one and antenna two, respectively. In the second transmission period, signal $-x_2^*$ is transmitted from transmit antenna one and signal x_1^* from transmit antenna two, where x_1^* is the complex conjugate of x_1. It is clear that, the encoding is done in both the space and time domains. Let us denote the transmit sequence from antennas one and two by x^1 and x^2, respectively.

$$x^1 = [X_1 \quad -X_2^*] \quad \text{...(2.20)}$$

$$x^2 = [X_2 \quad X_1^*] \quad \text{...(2.21)}$$

The key feature of the Alamouti scheme is that the transmit sequences from the two transmit antennas are orthogonal, since the inner product of the sequences x^1 and x^2 is zero, (i.e., $x^1 . x^2 = x_1 x_2^* - x_2^* x_1 = 0$).

The code matrix has the following property:

$$X.X^H = \begin{bmatrix} |x_1|^2+|x_2|^2 & 0 \\ 0 & |x_1|^2+|x_2|^2 \end{bmatrix} = (|x_1|^2 + |x_2|^2)I_2 \ldots\ldots\ldots\ldots (2.22)$$

Where I_2 is a 2 × 2 identity matrix.

The Alamouti scheme achieves the full diversity with a very simple maximum likelihood decoding algorithm. The key feature of the scheme is orthogonality between the sequences generated by the two transmit antennas. This scheme was generalized to an arbitrary number of transmit antennas by applying the theory of orthogonal designs. (27)

2.8.2 Space-Time Block Codes (STBC)

In an STBC, the data stream to be transmitted is encoded in blocks, or code words C, which are distributed among M antennas and across t time slots. Despite the name, an STBC can be considered as a modulation scheme for multiple antennas that provides full diversity and very low complexity encoding and decoding but, in general, cannot provide coding gains. The simpler block codes were envisioned by Alamouti and later by Tarokh et al.

Figure (2.11) shows an encoder structure for space-time block codes. In general, a space-time block code is defined by an $n_T \times p$ transmission matrix X. Here n_T represents the number of transmit antennas and p represents the number of time periods for transmission of one block of coded symbols.

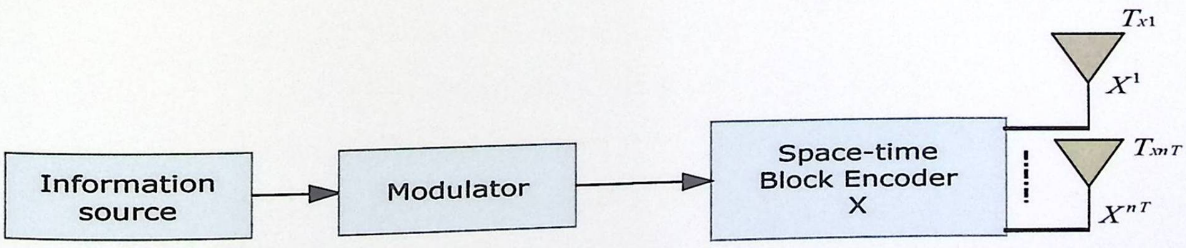


Figure 2.11: Encoder for STBC

Let us assume that the signal constellation consists of 2m points. At each encoding operation, a block of km information bits are mapped into the signal constellation to select k modulated signals $X_1, X_2, \ldots, X_k$, where each group of m bits selects a constellation signal. The k modulated signals are encoded by a space time block encoder to generate n_T parallel signal sequences of length p according to the transmission matrix X. These sequences are transmitted through n_T transmit antennas simultaneously in p time periods.

In the space-time block code, the number of symbols the encoder takes as its input in each encoding operation is k. The number of transmission periods required to transmit the space-time coded symbols through the multiple transmit antennas is p. In other words, there are p space-time symbols transmitted from each antennas for each block of k input symbols.

The rate of a space-time block code is defined as the ratio between the number of symbols the encoder takes as its input and the number of space-time coded symbols transmitted from each antenna. It is given by R = k/p.

The spectral efficiency of the space-time block code is given by:

$$\eta = \frac{r_b}{B} = \frac{r_s m R}{r_s} = \frac{km}{p} \ldots\ldots \quad (2.23)$$

Where r_b and r_s are the bit and symbol rate, respectively, and B is the bandwidth. (27), (28)

CHAPTER

3

System Design

System Design

3.1 Introduction

In this chapter, we explain our systems that are fixed gain amplify-and-forward (AF) SISO relaying system, and fixed gain amplify-and-Forward (AF) MIMO relaying system. We discuss the general system design and do analysis design for our systems in details. We explain the detailed block diagram for each scheme, that describe the subsystems block diagram for both scheme, and explain the overall system flow chart for both schemes.

3.2 Analysis Design

3.2.1 Amplify-and-Forward (AF) Relaying System

In amplify-and-forward (AF) relaying schemes, the relay amplifies the analog signal received from the source and forwards it to the destination (without explicitly decoding or demodulating the messages or symbols). Figure 3.1 illustrates the AF relaying scheme.

These schemes are also referred to as non-regenerative relaying schemes. Here, relays need not have knowledge of the encoding or modulation schemes employed at the source. Moreover, in addition to its low complexity, AF schemes are also desirable when the quality of the source-relay (S-R) link is not sufficient to guarantee reliable decoding at the relay. In this case, amplifying the analog signal preserves soft information that can be further exploited at the destination. (26)

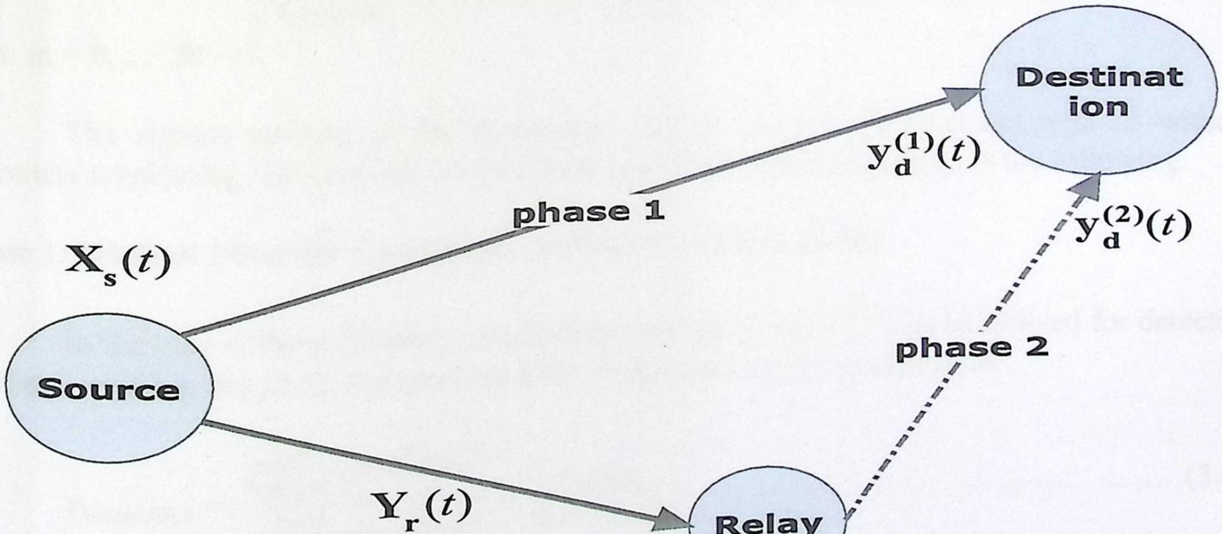


Figure 3.1. Illustration of amplify-and-forward (AF) relaying scheme.

3.2.1.1 Fixed Gain Amplify-and-Forward (AF) SISO Relaying System

In the basic AF relaying scheme, the relay forwards a scaled version of the received signal to the destination, regardless of the source-relay (S-R) link quality. Specifically, in Phase1 the source transmits the symbol block $X_s = [X_s[0], \ldots, X_s[M-1]]$ to both the relay and the destination, where the received signals are given by:

$$y_r[m] = h_{s,r}\sqrt{P_s}X_s[m] + W_r[m] \tag{3.1}$$

$$y_d^{(1)}[m] = h_{s,d}\sqrt{P_s}X_s[m] + W_d^{(1)}[m] \tag{3.2}$$

Form = 0, . . .,M − 1.

In Phase 2, the relay first scales the received signal in (3.1) to yield a normalized transmit vector X_r with $\mathbb{E}[|X_r[m]|^2] = 1$, for all m. If only the mean of the channel gain $\eta_{s,r}^2$ is known, the relay can multiply the received signal $y_r[m]$ by a fixed gain:

$$G_f = \frac{1}{\sqrt{E[|y_r[m]|^2]}} = \frac{1}{\sqrt{P_s\eta_{s,r}^2 + \sigma_r^2}} \tag{3.3}$$

$$X_r[m] = G_f y_r[m] = \frac{\sqrt{P_s}}{\sqrt{P_s\eta_{s,r}^2 + \sigma_r^2}} h_{s,r}X_s[m] + \frac{1}{\sqrt{P_s\eta_{s,r}^2 + \sigma_r^2}} w_r[m] \tag{3.4}$$

Where the constraint $E[|x_r[m]|^2] = 1$ is satisfied. This is referred to the fixed-gain AF relaying scheme. Then, with power P_r, the relay forwards the signal X_r to the destination, where the received signal can be expressed as:

$$\begin{aligned} y_d^{(2)}[m] &= \sqrt{P_r}\, h_{r,d}X_r[m] + W_d^{(2)}[m] \\ &= \sqrt{\frac{P_sP_r}{P_s\eta_{s,r}^2 + \sigma_r^2}} h_{s,r}h_{r,d}X_s[m] + \sqrt{\frac{P_r}{P_s\eta_{s,r}^2 + \sigma_r^2}} h_{r,d}w_r[m] + W_d^{(2)}[m] \end{aligned} \tag{3.5}$$

For m = 0, . . .,M − 1.

The signals arriving at the destination can be utilized for detection with or without diversity combining. The performance of these two cases will be discussed in the following:

Case 1: Without Diversity Combining (without direct link (S-D))

In the case without diversity combining, only the signal $y_d^{(2)}$ will be utilized for detection at the destination. By (3.5), the received SNR in this case can be computed as:

$$\gamma_{BasicAF,1} = \frac{\frac{P_sP_r}{P_s\eta_{s,r}^2 + \sigma_r^2}|h_{s,r}|^2|h_{r,d}|^2}{\frac{P_r\sigma_r^2}{P_s\eta_{s,r}^2 + \sigma_r^2}|h_{r,d}|^2 + \sigma_d^2} = \frac{\gamma_{s,r}\gamma_{r,d}}{\bar{\gamma}_{s,r} + \gamma_{r,d} + 1} \tag{3.6}$$

Where $\bar{\gamma}_{s,r} = P_s\eta_{s,r}^2/\sigma_r^2$, $\gamma_{r,d} = P_r|h_{r,d}|^2/\sigma_d^2$ and $\gamma_{s,r} = P_s|h_{s,r}|^2/\sigma_r^2$.

Thus the maximum achieved end to end capacity is given by:

$$C_{BasicAF,I}(\gamma_{s,r}, \gamma_{r,d}) = \frac{1}{2}\log_2\left(1 + \frac{\gamma_{s,r}\gamma_{r,d}}{\bar{\gamma}_{s,r} + \gamma_{r,d} + 1}\right) \tag{3.7}$$

Case 2: With Diversity Combining (with direct link (S-D))

In the case of diversity combining, the signals received in Phases 1 and 2, i.e.(3.2) and (3.5), can be optimally combined at the destination using MRC to obtain the output signal:

$$\widetilde{Y}_{d}^{(1)} = \frac{\sqrt{P_s} h_{s,d}^{*}}{\sigma_d^2} y_d^{(1)} + \frac{\sqrt{\frac{P_s P_r}{P_s \eta_{s,r}^2 + \sigma_r^2}} h_{s,r}^{*} h_{r,d}^{*}}{\frac{P_r}{P_s \eta_{s,r}^2 + \sigma_r^2} |h_{r,d}|^2 \sigma_r^2 + \sigma_d^2} y_d^{(2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.8)$$

The effective SNR at the output of the MRC is given by:

$$\gamma_{BasicAF,2} = \frac{P_s |h_{s,d}|^2}{\sigma_r^2} + \frac{(P_s |h_{s,r}|^2 / \sigma_r^2).(P_r |h_{r,d}|^2 / \sigma_d^2)}{(P_s \eta_{s,r}^2 / \sigma_r^2) + (P_r |h_{r,d}|^2 / \sigma_d^2) + 1} = \gamma_{s,d} + \frac{\gamma_{s,r}\gamma_{r,d}}{\gamma_{s,r} + \gamma_{r,d} + 1} \ldots\ldots\ldots\ldots(3.9)$$

The maximum achievable end-to-end transmission rate for the basic AF relaying scheme with diversity combining is thus given by:

$$C_{BasicAF,I}(\gamma_{s,r}, \gamma_{r,d}, \gamma_{s,d}) = \frac{1}{2}\log_2\left(1 + \gamma_{s,d} + \frac{\gamma_{s,r}\gamma_{r,d}}{\gamma_{s,r} + \gamma_{r,d} + 1}\right) \ldots\ldots\ldots\ldots\ldots\ldots(3.10)$$

As a note, the term of direct link doesn't mean line of sight link; there is a multipath wireless channel between source and destination.

Theorem 3.1:

If all channel links $h_{s,d}$, $h_{s,r}$ and $h_{r,d}$ are available, i.e., the variances of channels are $\sigma_{s,d}^2 \neq 0$, $\sigma_{s,r}^2 \neq 0$ and $\sigma_{r,d}^2 \neq 0$, then when $\frac{P_s}{N_o}$ and $\frac{P_r}{N_o}$ go to infinity, the SER of AF cooperation system with M-PSK modulation can be tightly approximated as:

$$P_{es} \approx \frac{B N_o^{2}}{b^2} \frac{1}{P_s \sigma_{s,d}^2} \left(\frac{1}{P_s \sigma_{s,r}^2} + \frac{1}{P_r \sigma_{r,d}^2} \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.11)$$

Where $b = \sin^2\left(\frac{\pi}{M}\right)$, $B = \frac{3(M-1)}{8M} + \frac{\sin^2(\frac{2\pi}{M})}{4\pi} - \frac{\sin^2(\frac{4\pi}{M})}{32\pi}$ and N_o^{2} is noise variance.

For a fixed total transmitted power, total transmitted power $P_s + P_r = P$, we need to optimize P_s and P_r such that the asymptotically tight SER approximation in (3.11) is minimized.

Theorem 3.2:

For sufficiently high SNR, the optimum power allocation for AF cooperation systems with M-PSK modulation is:

$$P_s = \frac{\sqrt{\sigma_{s,r}^2 + \sqrt{\sigma_{s,r}^2 + 8\,\sigma_{r,d}^2}}}{3\sqrt{\sigma_{s,r}^2 + \sqrt{\sigma_{s,r}^2 + 8\,\sigma_{r,d}^2}}} P \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.12)$$

$$P_r = \frac{2\sqrt{\sigma_{s,r}^2}}{3\sqrt{\sigma_{s,r}^2}+\sqrt{\sigma_{s,r}^2+8\,\sigma_{r,d}^2}}\,P \quad \text{……(3.13)}$$

From Theorem 3.2, we observe that the optimum power allocation for AF cooperation system is not modulation dependent. This is due to the fact that, in AF cooperation systems, the relay amplifies the received signal and forwards it to the destination regardless of what kind of received signal it is. We note that the asymptotic optimum power allocation scheme does not depend on the channel link between source and destination, but instead depends only on the channel that links between source and relay and between relay and destination.

We can see from Theorem 3.2 that the optimum ratio of transmitted power P_s at the source over the total power P is less than 1 and larger than 1/2, while the optimum ratio of power P_r used at the relay over the total power P is larger than 0 and less than 1/2. In general, the equal power strategy is not optimum. For example, if $\sigma_{s,r}^2 = \sigma_{r,d}^2$, then the optimum power allocation is $P_s = \frac{P}{3}$ and $P_r = \frac{P}{3}$.(41)

3.2.1.2 Fixed gain Amplify-and-Forward (AF) MIMO Relaying System

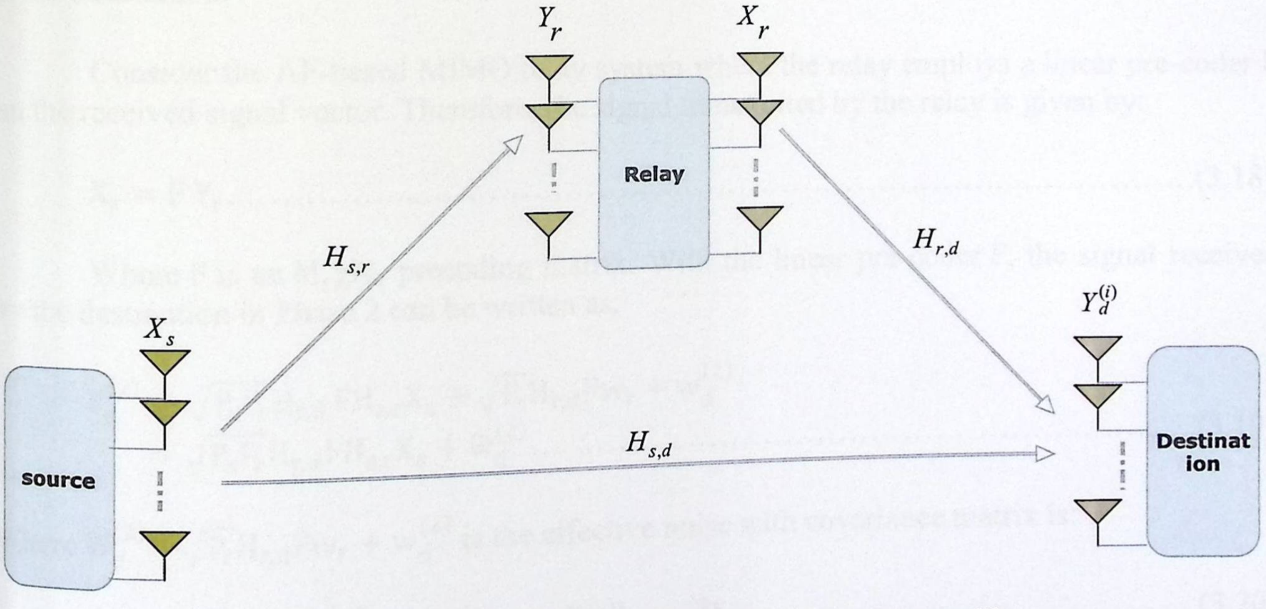


Figure. 3.2: Model of a MIMO Cooperative Diversity System with multiple antennas at source, relay, and destination.

Consider a cooperative system that consists of source, relay and destination, each node equipped with M_s, M_r, and M_d antennas, respectively, as shown in figure 3.2. Similarly, we assume that the relay obey half-duplex constraint and the cooperation takes on two phases of transmission. In Phase 1, the source transmits a symbol vector $X_s = [X_s[1], \ldots, X_s[M]]^T$ to the relay and the destination, where $X_s[m]$ is the symbol transmitted on the m-th antenna. The signals received at the relay and the destination are given by:

$$Y_r = \sqrt{P_s}H_{s,r}X_s + w_r \text{ .... } (3.14)$$

$$Y_d{}^{(1)} = \sqrt{P_s}H_{s,d}X_s + w_d^{(1)} \text{ .... } (3.15)$$

respectively, where P_s is the transmission power of the source, $H_{s,r}$, $H_{s,d}$ are $M_r \chi \; M_s$ and $M_d\chi M_s$channel matrices of the S-R and the sours-destination (S-D) links and $w_r \sim CN(0_{M_r}, \sigma_r^2 \, I_{M_r,M_r})$,$w_d^{(1)} \sim CN(0_{M_d}, \sigma_d^2 I_{M_d\chi M_d})$ are the AWGN at the relay and the destination, respectively.

Moreover, assume that the source symbol vector is zero mean circularly symmetric complex Gaussian and the covariance matrix of the source symbol vector is given by:

$$R_s \triangleq E[x_s x_s^H] = \frac{1}{M_s} I_{M_s\chi M_s} \text{ .... } (3.16)$$

In Phase 2, the relay generates an $M_r \times 1$ symbol vector X_r with $E[x_r^H x_r]$=1 according to the specific cooperation scheme and forwards the signal to the destination with power P_r. Where the signal vector X_r is a linear transformation of Y_r. The signal received at the destination in Phase 2 is given by:

$$Y_d^{(2)} = \sqrt{P_r}H_{r,d}X_r + w_d^{(2)} \text{ .... } (3.17)$$

Where $H_{r,d}$ is an $M_d\chi M_r$ channel matrix, and $w_d^{(2)} \sim CN(0_{M_d}, \sigma_d^2 I_{M_d\chi M_d})$, is the AWGN at the destination.

Consider the AF-based MIMO relay system where the relay employs a linear pre-coder F on the received signal vector. Therefore, the signal transmitted by the relay is given by:

$$X_r = F\,Y_r \text{ .... } (3.18)$$

Where F is an $M_r\chi M_r$ precoding matrix. With the linear pre-coder F, the signal received by the destination in Phase 2 can be written as:

$$\begin{aligned} Y_d^{(2)} &= \sqrt{P_s P_r}H_{r,d}\,FH_{s,r}X_s + \sqrt{P_r}H_{r,d}Fw_r + w_d^{(2)} \\ &= \sqrt{P_s P_r}H_{r,d}FH_{s,r}X_s + \widetilde{w}_d^{(2)} \text{ .... } (3.19) \end{aligned}$$

Where $\widetilde{w}_d^{(2)} = \sqrt{P_r}H_{r,d}Fw_r + w_d^{(2)}$ is the effective noise with covariance matrix is:

$$R_{\widetilde{w}} \triangleq E\left[\widetilde{w}_d^{(2)}\widetilde{w}_d^{(2)H}\right] = P_r\sigma_r^2 H_{r,d}FF^H H_{r,d}^H + \sigma_d^2 I_{M_d} \text{ .... } (3.20)$$

Case 1: Without Source-Destination Link

Let us first consider the case where the destination is located beyond the transmission range of the source and, thus, only the signals received in Phase 2, i.e., $Y_d^{(2)}$, is utilized for detection at the destination. Given the instantaneous knowledge of both $H_{s,r}$ and $H_{r,d}$, the capacity of the AF MIMO relay channel is given by:

$$C = \frac{1}{2}\log_2\left(I_{M_s} + \frac{P_s P_r}{M_s} H_{s,r}^H F^H H_{r,d}^H R_{\widetilde{w}}^{-1} H_{r,d} F H_{s,r}\right) \ldots\ldots (3.21)$$

And, then, the channel capacity is given by:

$$C = \frac{1}{2}\log_2\left(\frac{\det\left(I_{M_r} + \left(I_{M_r} + \frac{P_s}{M_s\sigma_r^2} H_{s,r} H_{s,r}^H\right)\frac{P_r\sigma_r^2}{\sigma_d^2} F^H H_{r,d}^H H_{r,d} F\right)}{\det\left(I_{M_r} + \frac{P_r\sigma_r^2}{\sigma_d^2} F^H H_{r,d}^H H_{r,d} F\right)}\right) \ldots\ldots (3.22)$$

In the equal gain scheme, the signals received at the relay antennas are all amplified by a common weighting factor is:

$$F = 1/\sqrt{\mathrm{tr}(\sigma_r^2 I_{M_r} + (P_s/M_s) H_{s,r} H_{s,r}^H)} \ldots\ldots (3.23)$$

Case 2: With Source-Destination Link

When the destination is within the transmission range of the source, the channel capacity and, thus, the relay pre-coder design must take into consideration the signal received at the destination on the source-relay (S-D) link. By combining the signals received at the destination in both phases, we obtain:

$$Y_d \triangleq \begin{bmatrix} Y_d^{(1)} \\ Y_d^{(2)} \end{bmatrix} = \sqrt{P_s}\begin{bmatrix} H_{s,d} \\ \sqrt{P_r} H_{r,d} F H_{s,r} \end{bmatrix} X_s + \begin{bmatrix} I & 0 & 0 \\ 0 & \sqrt{P_r} H_{r,d} F & I \end{bmatrix}\begin{bmatrix} w_d^{(1)} \\ w_r \\ w_d^{(2)} \end{bmatrix}$$

$$\triangleq \sqrt{P_s} H\, X_s + w \ldots\ldots (3.24)$$

Where $H = \begin{bmatrix} H_{s,d} \\ \sqrt{P_r} H_{r,d} F H_{s,r} \end{bmatrix}$ is the effective channel between the source and the destination, and

$w = \begin{bmatrix} I & 0 & 0 \\ 0 & \sqrt{P_r} H_{r,d} F & I \end{bmatrix}\begin{bmatrix} w_d^{(1)} \\ w_r \\ w_d^{(2)} \end{bmatrix}$ is the effective noise with covariance matrix

$$R_w = \begin{bmatrix} \sigma_d^2 I_{M_d} & 0 \\ 0 & P_r\sigma_r^2 H_{r,d} F F^H H_{r,d}^H + \sigma_d^2 I_{M_d} \end{bmatrix} \ldots\ldots (3.25)$$

Given $H_{s,r}$, $H_{r,d}$ and $H_{s,d}$, the channel capacity can be computed as:

$$C = \frac{1}{2}\log_2\left(\det\left(I_{M_s} + \frac{P_s}{M_s} H^H R_w^{-1} H\right)\right) = \frac{1}{2}\log_2\left(\det\left(I_{2M_d} + \frac{P_s}{M_s} H H^H R_w^{-1}\right)\right) \ldots\ldots (3.26)$$

The channel capacity can be further written as:

$$C=\frac{1}{2}\log_2\det\left(I_{M_d}+\frac{P_s}{M_s\sigma_d^2}H_{s,d}H_{s,d}^H\right)$$
$$+\frac{1}{2}\log_2\left(I_{M_d}+\frac{P_sP_r}{M_s}H_{r,d}FH_{s,r}\left(I_{M_s}+\frac{P_s}{M_s\sigma_d^2}H_{s,d}^HH_{s,d}\right)^{-1}\times\right.$$
$$\left.H_{s,r}^HF^HH_{r,d}^H\left(P_r\sigma_r^2H_{r,d}FF^HH_{r,d}^H+\sigma_d^2I_{M_d}\right)^{-1}\right)\ldots\ldots\ldots\ldots(3.27)$$

The channel capacity can be upper bounded by:

$$C=\frac{1}{2}\log_2\det\left(I_{M_d}+\frac{P_s}{M_s\sigma_d^2}H_{s,d}H_{s,d}^H\right)+$$
$$\frac{1}{2}\log_2\det\left(I_{M_d}+\frac{P_sP_r}{M_s}H_{r,d}FH_{s,r}H_{s,r}^HF^HH_{r,d}^H\times\left(P_r\sigma_r^2H_{r,d}FF^HH_{r,d}^H+\sigma_d^2I_{M_d}\right)^{-1}\right)\ldots\ldots(3.28)$$

The channel capacity is lower bounded by:

$$C=\frac{1}{2}\log_2\det\left(I_{M_d}+\frac{P_sP_r}{M_s}H_{r,d}FH_{s,r}H_{s,r}^HF^HH_{r,d}^H\times\left(P_r\sigma_r^2H_{r,d}FF^HH_{r,d}^H+\sigma_d^2I_{M_d}\right)^{-1}\right)\ldots\ldots(3.29)$$

3.3 General System Design

Our idea in this project is to use additional component, relay, between the source and the destination, the outage benefits from relay on communication system are mentioned in chapter two. The relay acts as transceiver, receive the modulated symbol from the source and make some signal processing on the received symbols, then forward the processed symbols to the destination. The relay may equipped with multiple antennas that use for receive and transmit symbols. Actually this called cooperative by relay (i.e. cooperate to reach the symbols / messages to the destination).

3.3.1 Fixed Gain Amplify-and-Forward (AF) SISO Relaying System

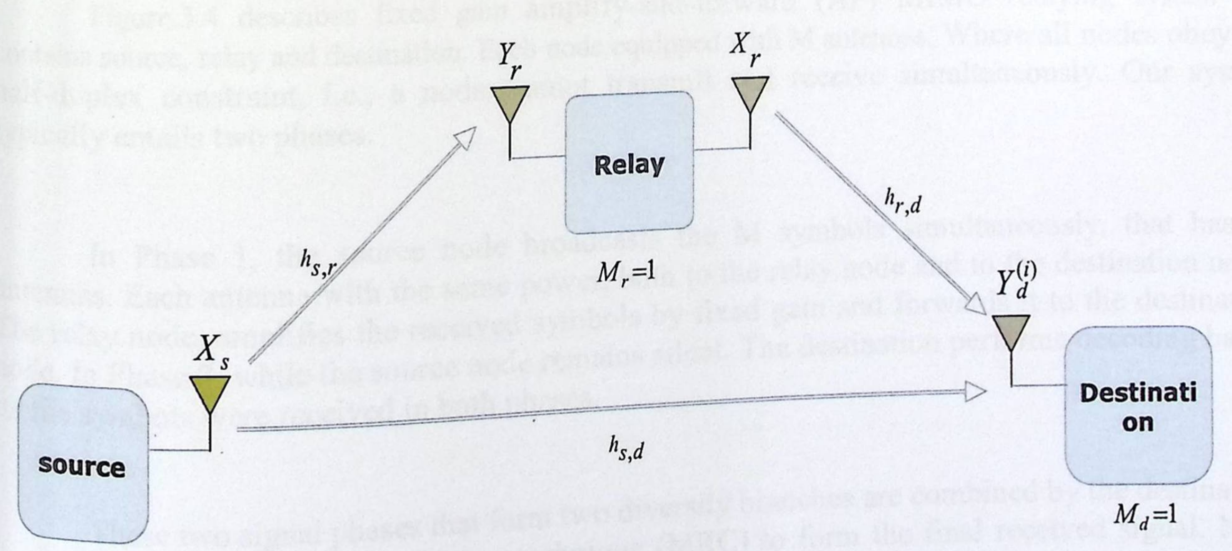


Figure. 3.3 First System Model of a SISO Cooperative Diversity System with single antenna at source, relay, and destination.

We describe a fixed gain amplify-and-forward SISO relaying system in figure.3.3, that contains source, relay and destination. Each node is equipped with single antenna where all nodes obey half-duplex constraint, i.e., a node cannot transmit and receive simultaneously. Our system typically entails two phases.

In Phase 1, the source node broadcasts one symbol to the relay node and to the destination node. The relay node, amplifies the received symbol by fixed gain and forwards it to the destination node. In Phase 2, while the source node remains silent. The destination performs decoding based on the symbols that received in both phases. These two signal phases from two diversity branches are combined by the destination node using maximal ratio combining technique (MRC) to form the final received signal.

3.3.2 Fixed Gain Amplify-and-Forward (AF) MIMO Relaying System

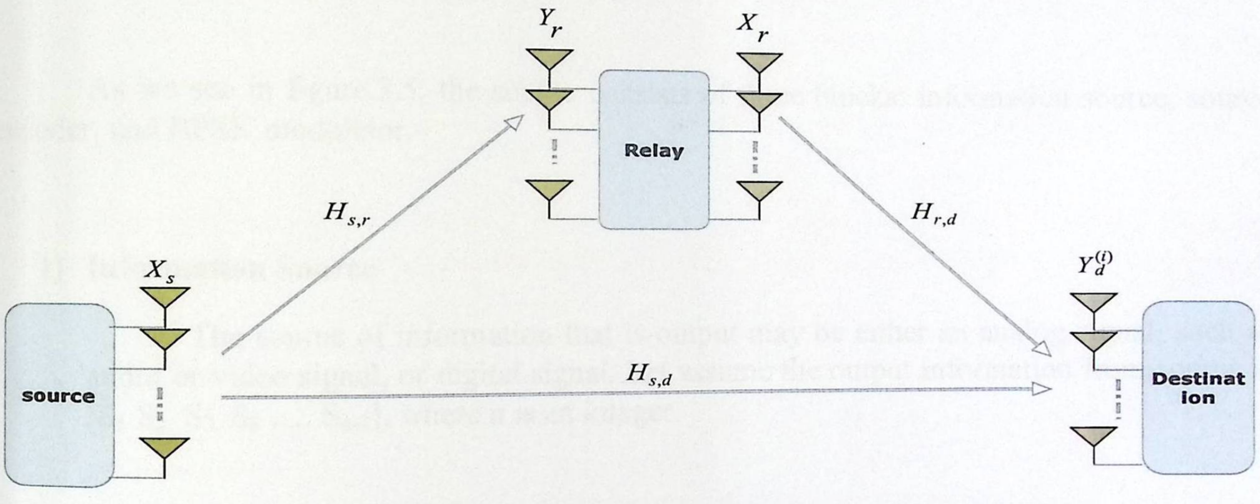


Figure. 3.4 Second System Model of a MIMO Cooperative Diversity System with multiple antennas at source, relay, and destination.

Figure.3.4 describes fixed gain amplify-and-forward (AF) MIMO relaying system that contains source, relay and destination. Each node equipped with M antennas. Where all nodes obey the half-duplex constraint, i.e., a node cannot transmit and receive simultaneously. Our system typically entails two phases.

In Phase 1, the source node broadcasts the M symbols simultaneously, that has M antennas. Each antenna with the same power, both to the relay node and to the destination node. The relay node, amplifies the received symbols by fixed gain and forwards it to the destination node. In Phase 2, while the source node remains silent. The destination performs decoding based on the symbols were received in both phases.

These two signal phases that form two diversity branches are combined by the destination node using maximal ratio combining technique (MRC) to form the final received signal. Note that we have three different wireless channels, and each symbol will be affected by a random Rayleigh channels with additive white Gaussian noise (AWGN).

3.4 Detailed System Design

3.4.1 Detailed Block Diagrams

3.4.1.1 Detailed Block Diagrams for Fixed Gain (AF) SISO relaying System

3.4.1.1.1 The Source Block Diagram

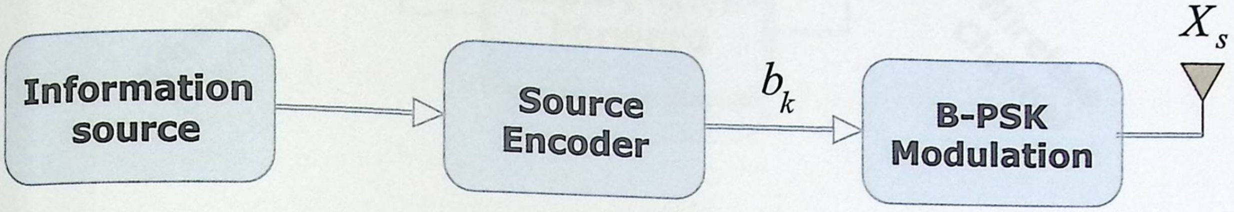


Figure. 3.5 Source Block Diagram

As we see in figure.3.5, the source consists of three blocks: information source, source encoder, and BPSK modulator.

1) **Information Source**

The source of information that is output may be either an analog signal, such as audio or video signal, or digital signal. Let assume the output information from source is $[S_1\ S_2\ S_3\ S_4 \ldots S_{n-1}]$, where n is an integer.

2) **Source Encoder**

The second stage of the source converts the information source messages as a function of S into a binary sequence b_k.,i.e., the resulted bits are either zeros and ones.

3) **B-PSK Modulator**

The BPSK modulator maps the binary information sequence b_k into a BPSK signals waveforms. In binary phase shift keying (BPSK), the phase of a constant amplitude carrier signal is switched between two values according to the two possible signals m_1 and m_2, corresponding to binary 1 and 0, respectively. Then the modulated signals transmit to both the relay and the destination simultaneously.

3.4.1.1.2 The Relay Block Diagram

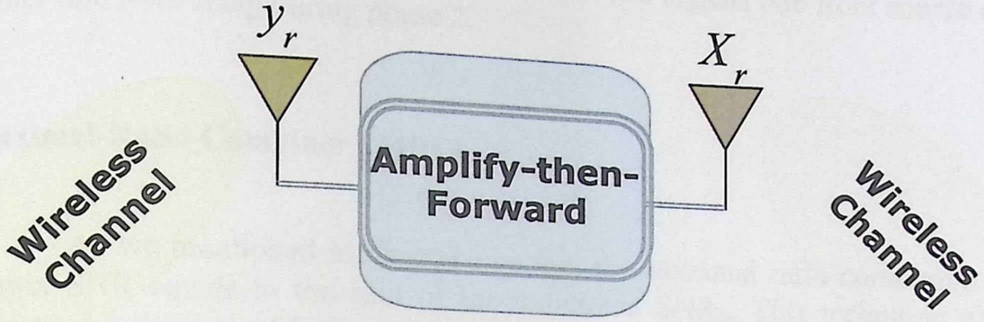


Figure. 3.6 Relay Block Diagram

In figure.3.6, the relay receive the symbols that transmitted from the source and affected by the channel between source and relay (multiply by channel coefficient) with AWGN in the phase 1 (y_r). Then the relay forward the amplified symbols (X_r), that affected by relay-destination channel, to the destination in phase 2 and also these symbols will be affected by another AWGN.

The relay transmitted symbol is not more than amplified version from the received symbols during phase 1. But the drawback of this method, that is amplifying the received symbol with its noise that comes from wireless channel.

3.4.1.1.3 Wireless Channel

We assume that the wireless channel is small scale fading and typically flat fading channel follows Rayleigh probability density function (PDF), where the channel is not varying during time separation, or in other words the time separation between symbol block is greater or equal the channel coherence time (T_c) in order to achieve independency at the receiver for MRC. During our project we assume that the relay and destination know the characteristics of each channel.

3.4.1.1.4 The Destination Block Diagram

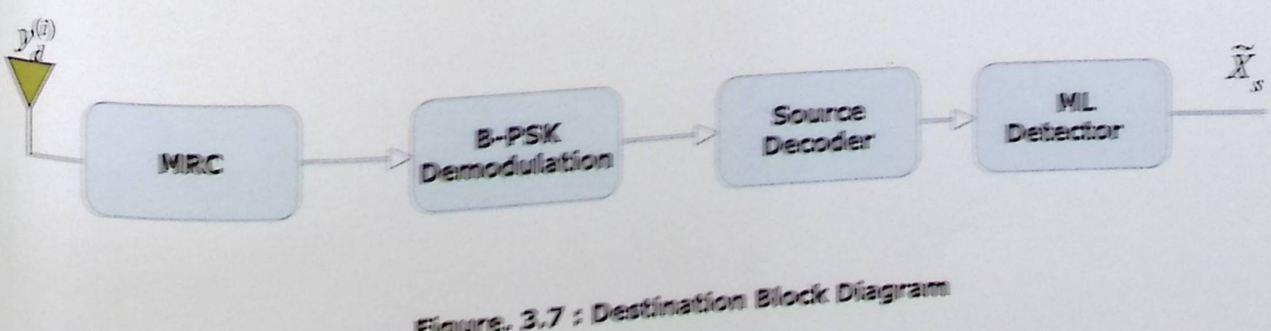


Figure. 3.7 : Destination Block Diagram

In the figure.3.7, we assume that the destination block diagram contains four blocks, MRC combiner, BPSK demodulator, source decoder, and ML detector.

Since two phases, the destination node receive two signals one from source during phase 1 and another one from relay during phase 2.

1) Maximal-Ratio-Combiner (MRC)

As we mentioned in chapter two that the Maximal ratio combining produces an output SNR equals to the sum of the individual SNRs. This technique gives the best statistical reduction of fading of any known linear diversity combiner. In this stage the MRC combined the signals that received in phase 1 and phase 2, $y_d^{(1)}$ and $y_d^{(2)}$, respectively. In other words, it sums the two phases SNR .

2) BPSK-Demodulator

Demodulate the combined signals, to recover the original symbols.

3) Source Decoder

A decoder is a device which does the reverse operation of an encoder so that the original information can be retrieved. In our system design the decoder de-maps the binary information sequence $b_k$from a BPSK demodulated signals waveforms.

4) ML Detector

We use ML detection for calculate the probability of error and determine the accuracy of our system by comparing the transmitted binary information by the demodulating-decoding one.

3.4.1.2 Detailed Block Diagrams for Fixed Gain (AF) MIMO Relaying System

3.4.1.2.1 The Source Block Diagram

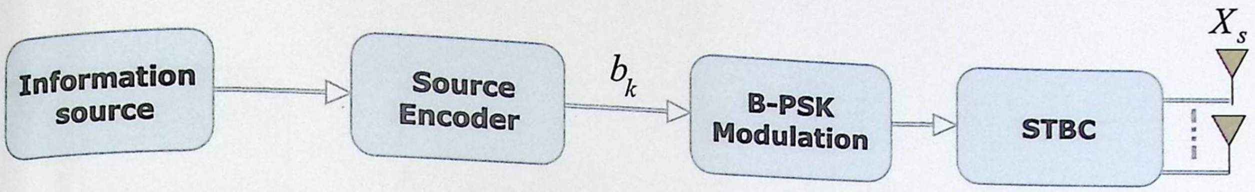


Figure. 3.8 Source Block Diagram

As we see in figure.3.8, the source contains four blocks, information source, source encoder, and BPSK modulator and space time block (STBC) encoder.

The first three blocks, do the same functions that previously explained in figure 3.5.

Space-Time Block (STBC) Encoder

In this stage the source forms the symbols block, i.e., $X_S = [X_S[1], \ldots, X_S[M_S]]^T$, where M_S is the number of source antennas, and $X_S[m]$ is the symbol transmitted on the m-th antenna. So the size of each block is determined by the number of source antennas or the dimension of the system.

3.4.1.2.2 The Relay Block Diagram

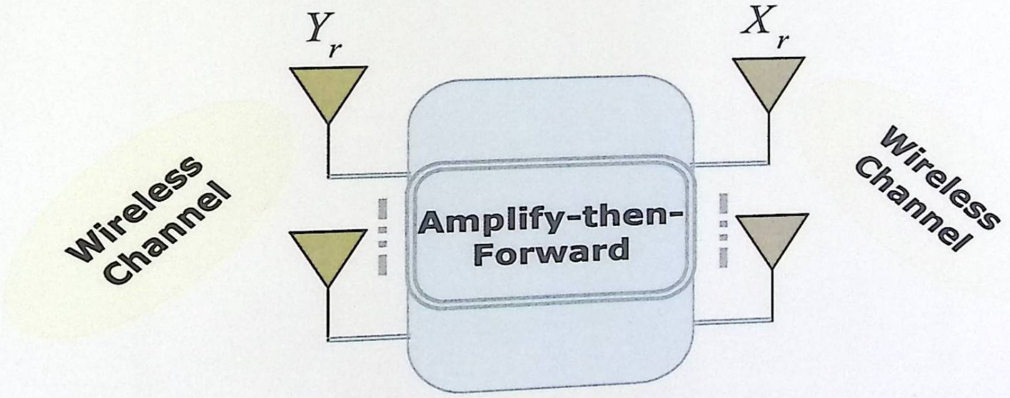


Figure. 3.9 Relay Block Diagram

As previously explained in figure.3.6 of AF SISO relaying system. In AF MIMO relaying system do the same thing, but the difference is the number of antennas on the relay.

3.4.1.2.3 Wireless Channel

There is no difference in our assumptions for the channels, this means that the same thing we assume in AF SISO relaying system is taken in AF MIMO relaying system.

3.4.1.2.4 The Destination Block Diagram

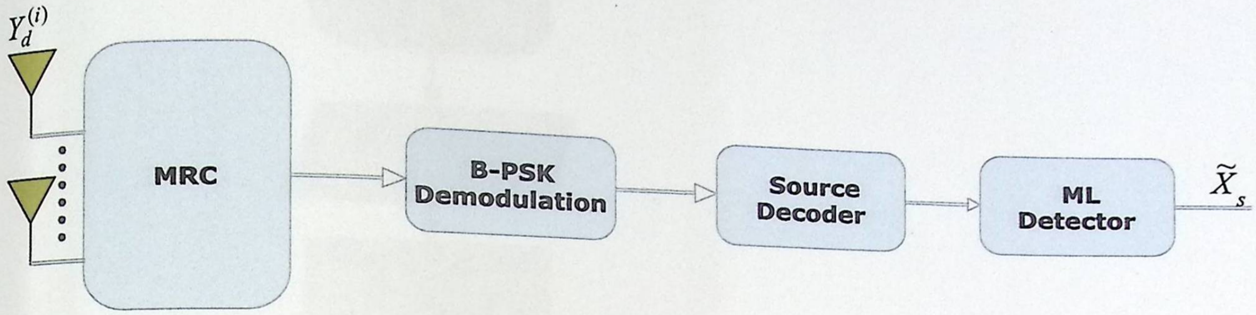


Figure. 3.10 Destination Block Diagram

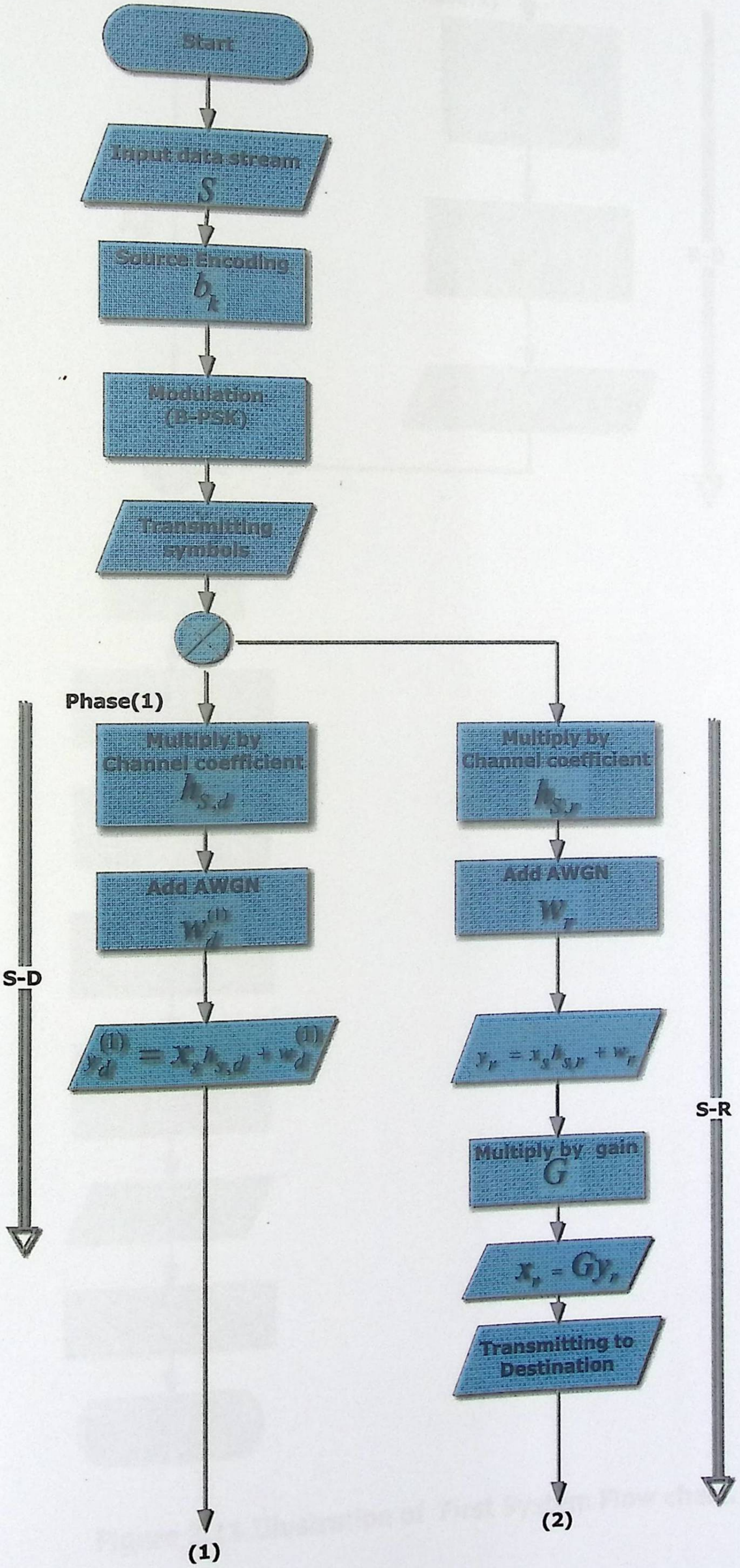
In the figure.3.10. We assume that the destination block diagram contains four blocks, MRC combiner, BPSK demodulator, source decoder, and ML detector.

Since two phases, the destination node receive M signals in two phases, from source during phase 1 and from relay during phase 2.

As explained in AF SISO relaying system for destination block diagram, the same thing happens in AF MIMO relaying system, but with more complexity in processing because the number of antennas increased.

3.4.2 Systems Flow Charts

3.4.2.1 Flow Chart for Fixed Gain AF SISO Relaying System



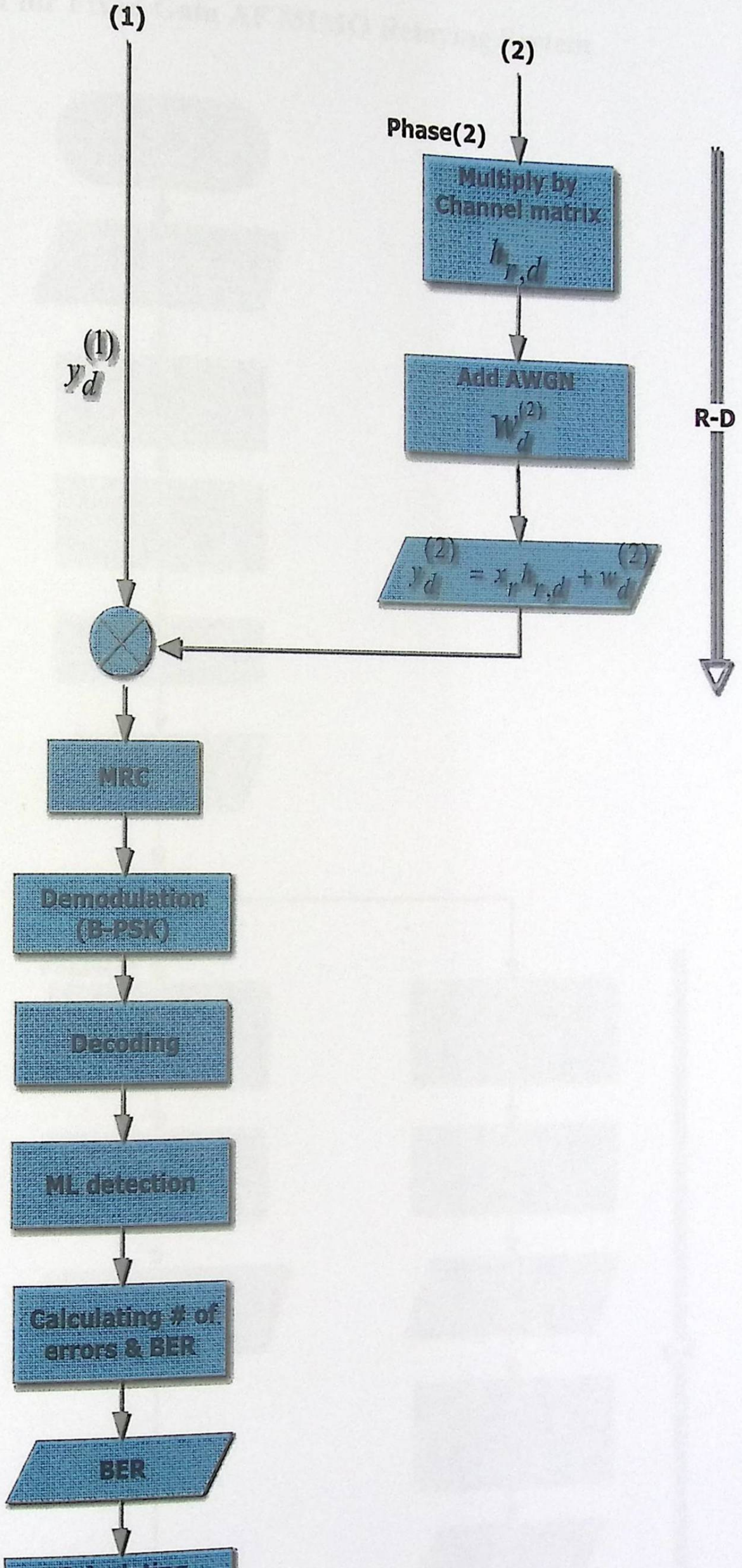
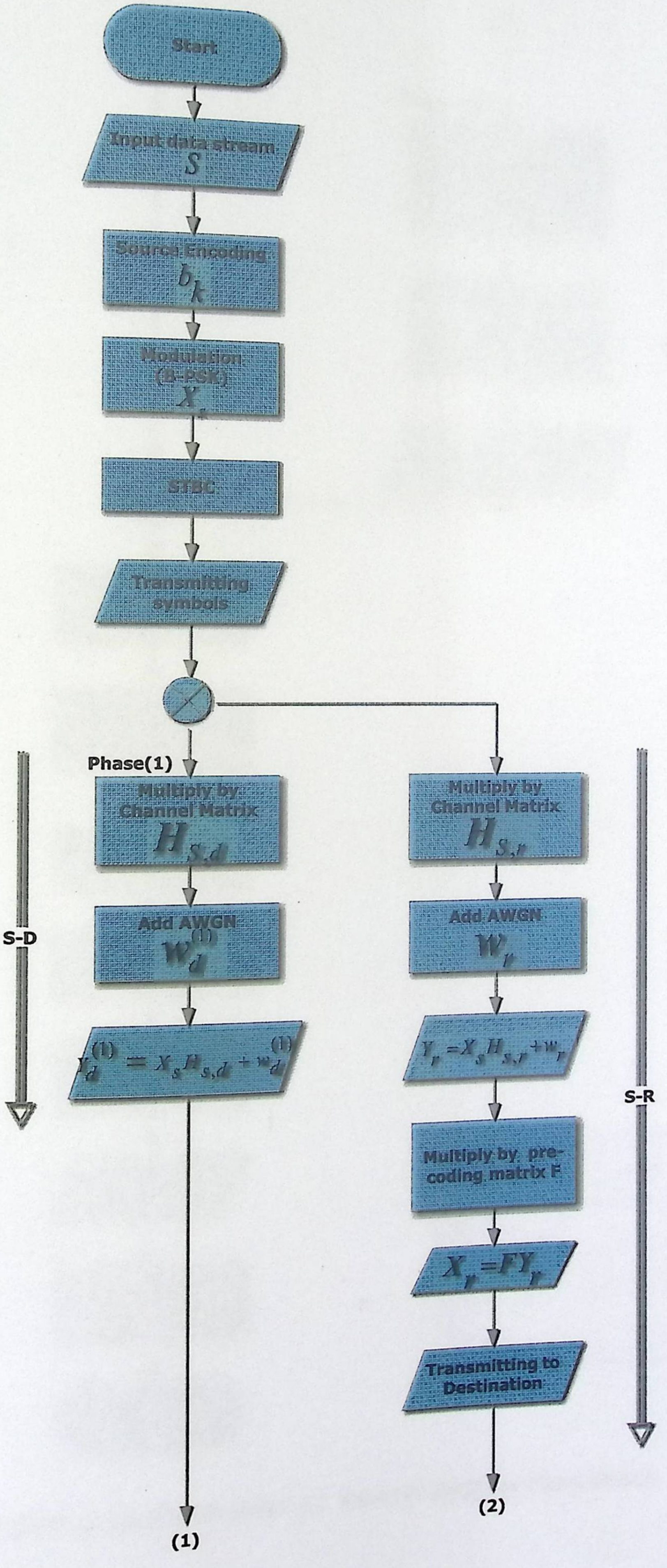


Figure 3.11 Illustration of First System Flow chart.

3.4.2.2 Flow Chart for Fixed Gain AF MIMO Relaying System



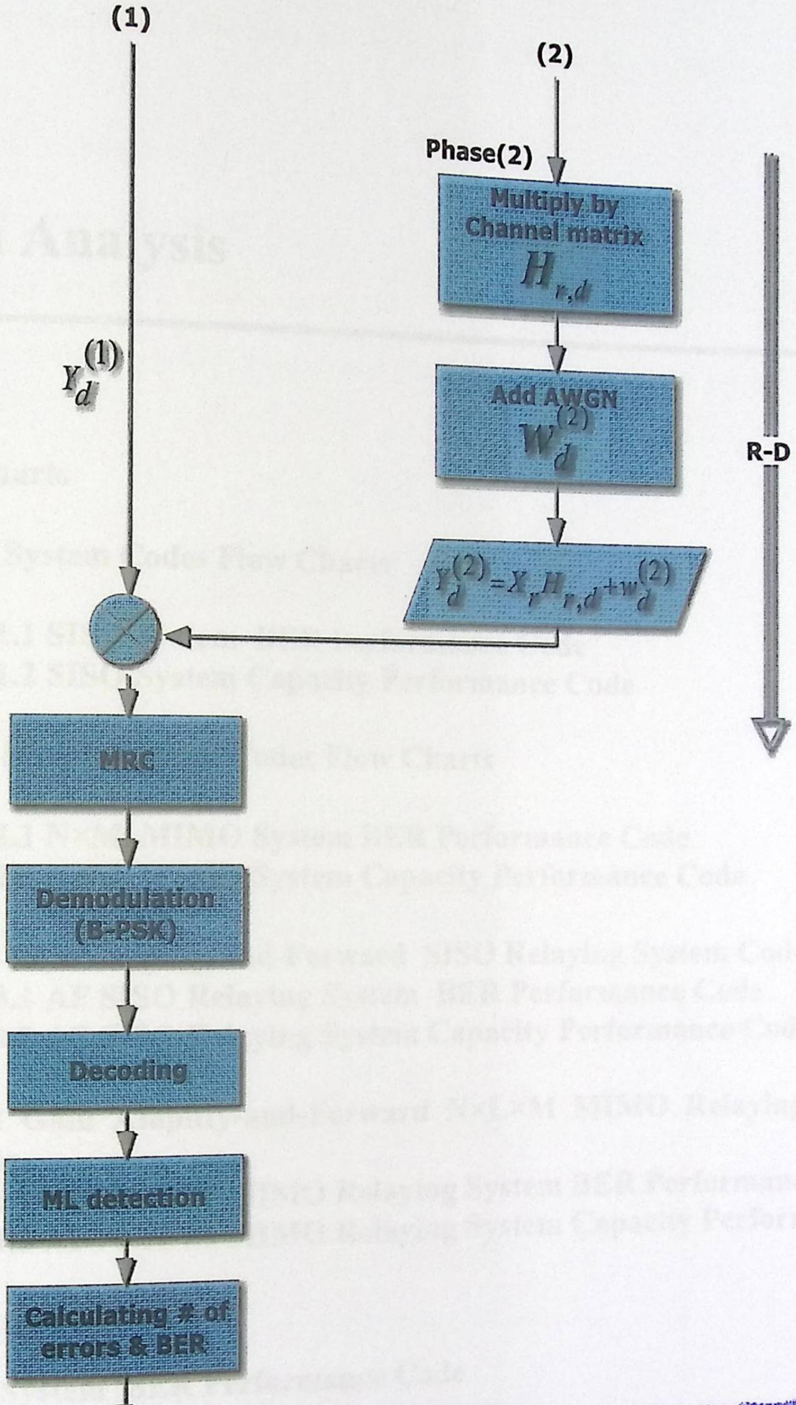


Figure 3.12 Illustration of Second System Flow chart.

CHAPTER

4

Simulation Analysis

4.1 Introduction

4.2 Codes Flow Charts

- **4.2.1 SISO System Codes Flow Charts**
  - **4.2.1.1 SISO System BER Performance Code**
  - **4.2.1.2 SISO System Capacity Performance Code**
- **4.2.2 N×M MIMO System Codes Flow Charts**
  - **4.2.2.1 N×M MIMO System BER Performance Code**
  - **4.2.2.2 N×M MIMO System Capacity Performance Code**
- **4.2.3 Fixed Gain Amplify-and-Forward SISO Relaying System Codes Flow Charts**
  - **4.2.3.1 AF SISO Relaying System BER Performance Code**
  - **4.2.3.2 AF SISO Relaying System Capacity Performance Code**
- **4.2.4 Fixed Gain Amplify-and-Forward N×L×M MIMO Relaying System Codes Flow Charts**
  - **4.2.4.1 AF N×L×M MIMO Relaying System BER Performance Code**
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4.3 Codes Main Stages

- **4.3.1 SISO System BER Performance Code**
- **4.3.2 SISO System Capacity Code**
- **4.3.3 N×M MIMO System BER Performance Code**
- **4.3.4 N×M MIMO System Capacity Code**
- **4.3.5 AF SISO Relaying System BER Performance Code**
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- **4.3.7AF N×L×M MIMO Relaying System BER Performance Code**
- **4.3.8AF N×L×M MIMO Relaying System Capacity Performance Code**

4.4 Constructing MIMO System and AF MIMO Relaying System for Diversity

4.5 Simulation Setup

4.1 Introduction

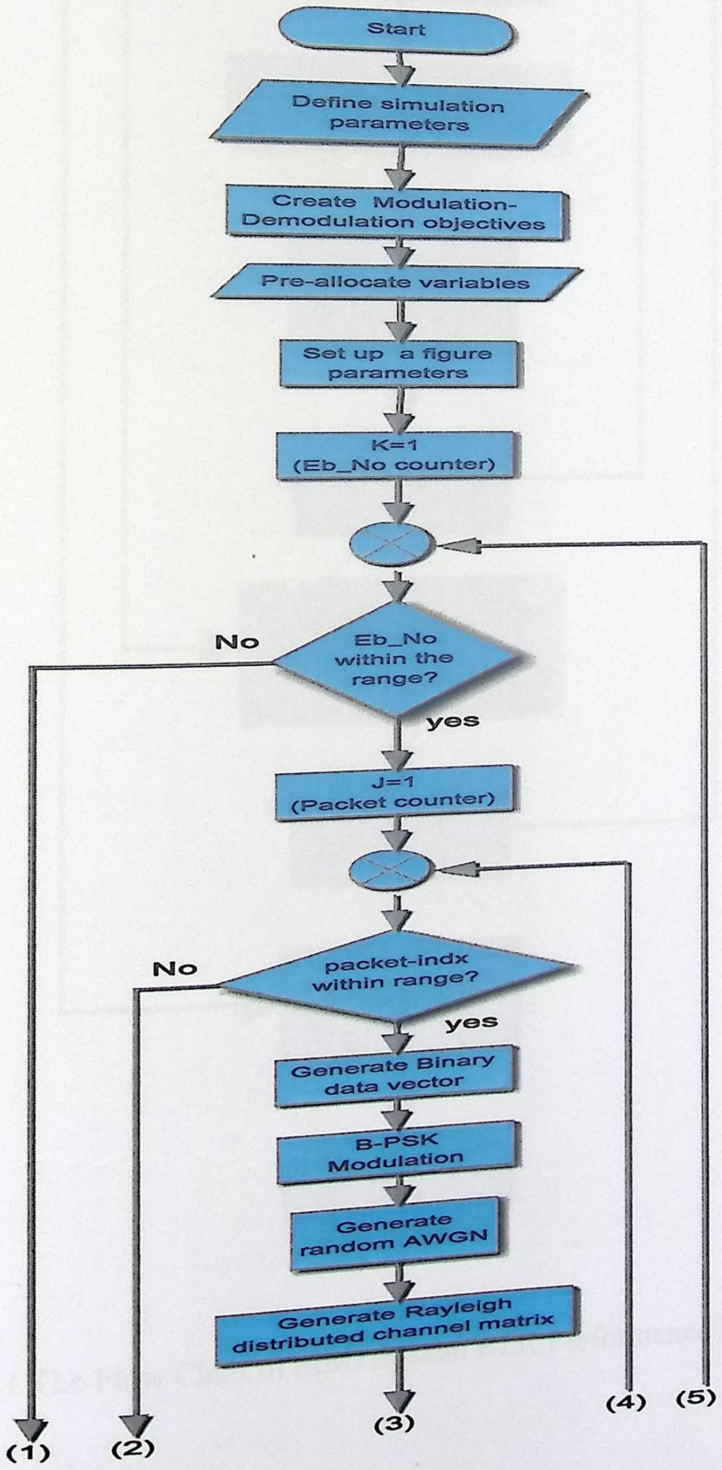
In this chapter, we introduce flow charts for all MATLAB Codes then describe the mean stages for each one.

4.2 Codes Flow Charts

4.2.1 SISO System Codes Flow Charts

4.2.1.1 SISO System BER Performance Code

The flow chart of single-input single-output (SISO) system BER performance code under flat fading Rayleigh channel.



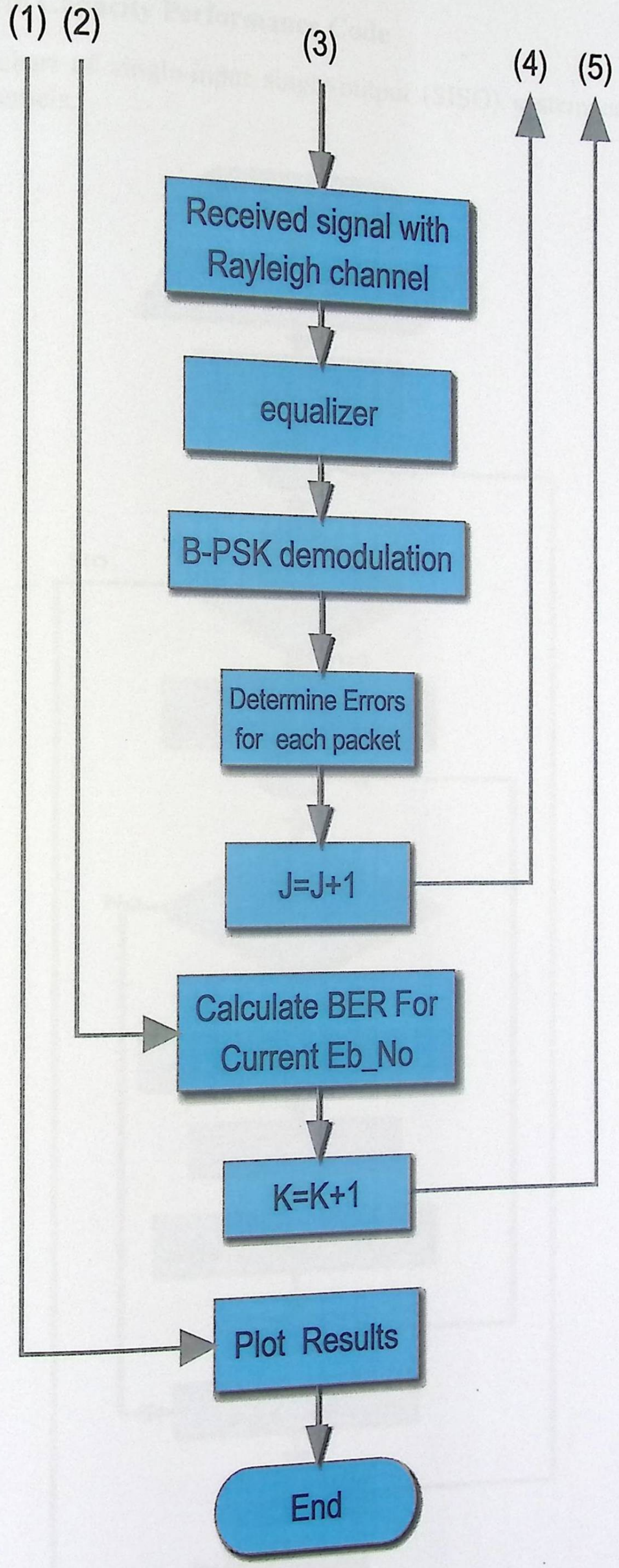


Figure 4.1 The Flow Chart of SISO System BER Performance MATLAB Code

4.2.1.2 SISO System Capacity Performance Code

The flow chart of single-input single-output (SISO) system capacity code under flat fading Rayleigh channels.

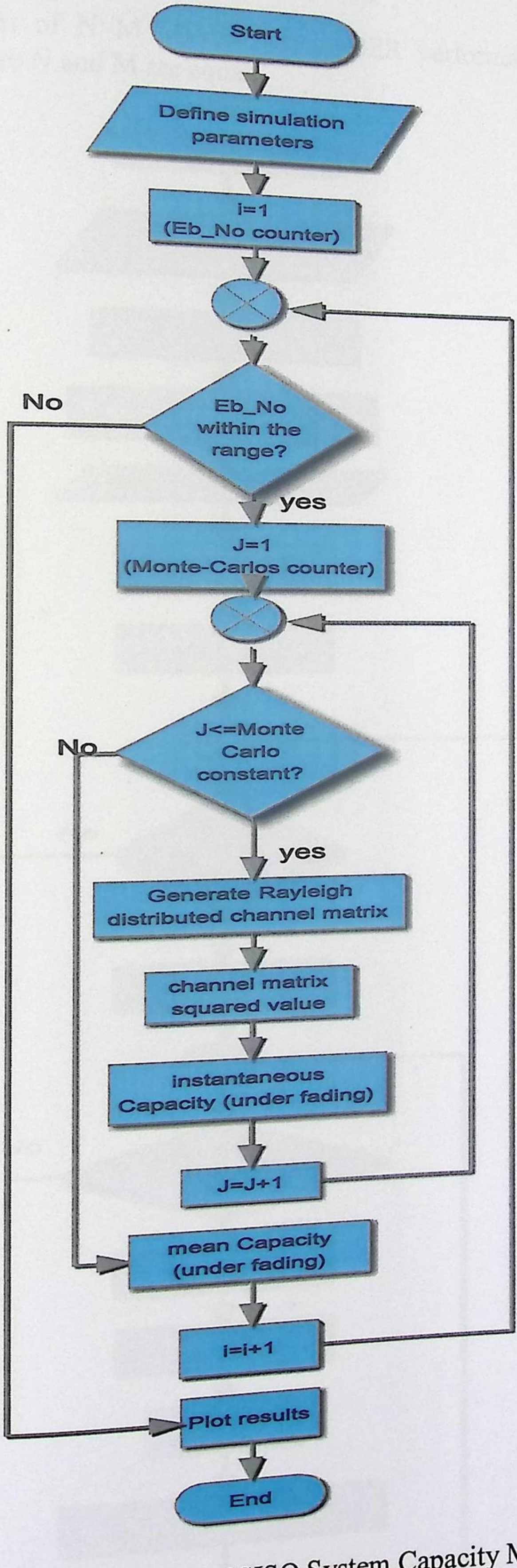
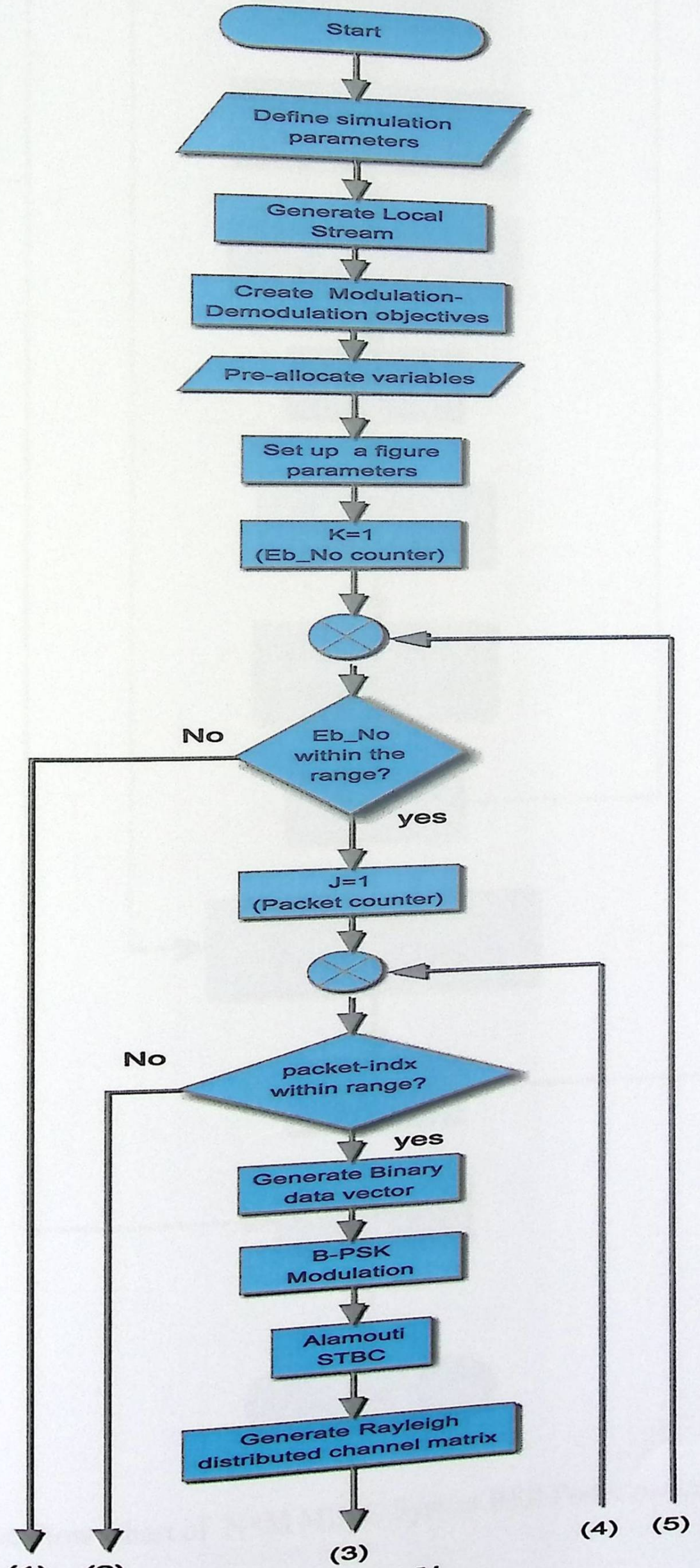


Figure 4.2 The Flow Chart of SISO System Capacity MATLB Code

4.2.2 N×M MIMO System Codes Flow Charts

4.2.2.1 N×M MIMO System BER Performance Code

The flow chart of N×M MIMO system BER performance code under flat fading Rayleigh channel. Where N and M are equal.



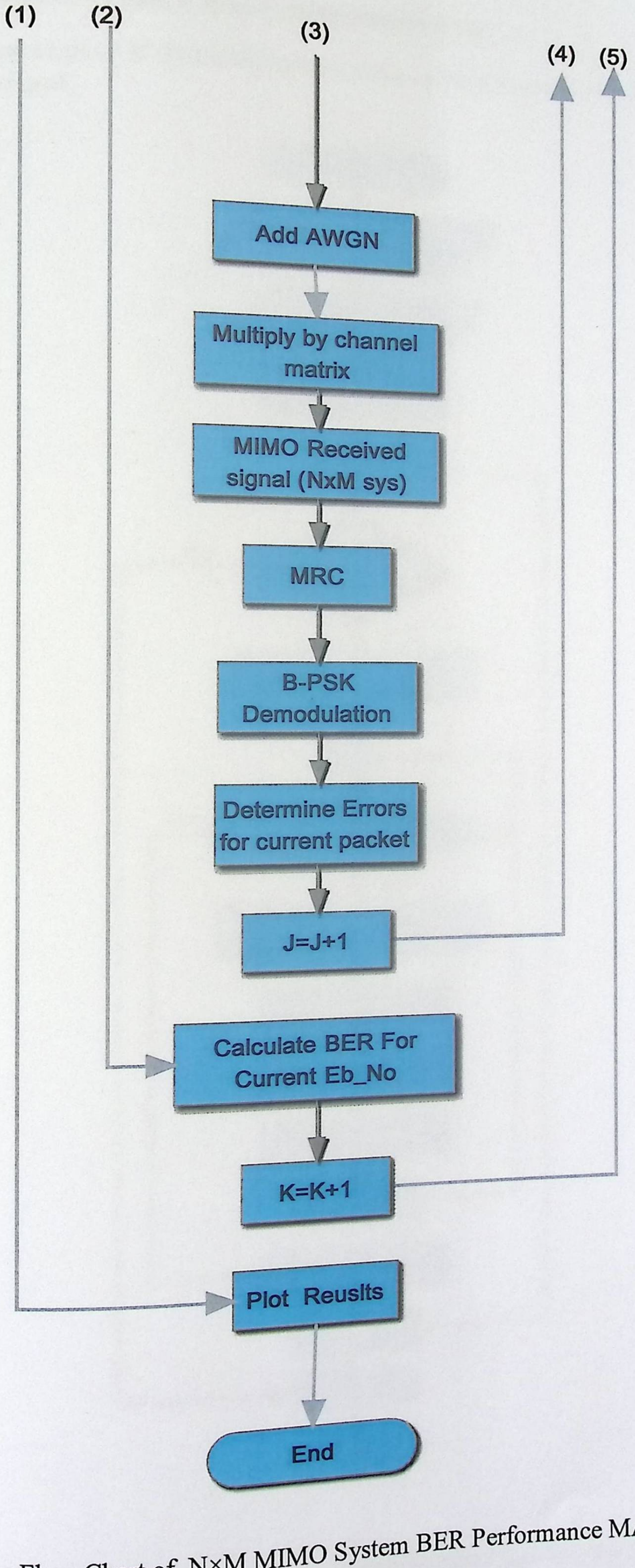


Figure 4.3 The Flow Chart of N×M MIMO System BER Performance MATLAB Code

4.2.2.2 N×M MIMO System Capacity Performance Code

The flow chart of N×M MIMO system capacity code under flat fading Rayleigh channel. Where N and M are qual.

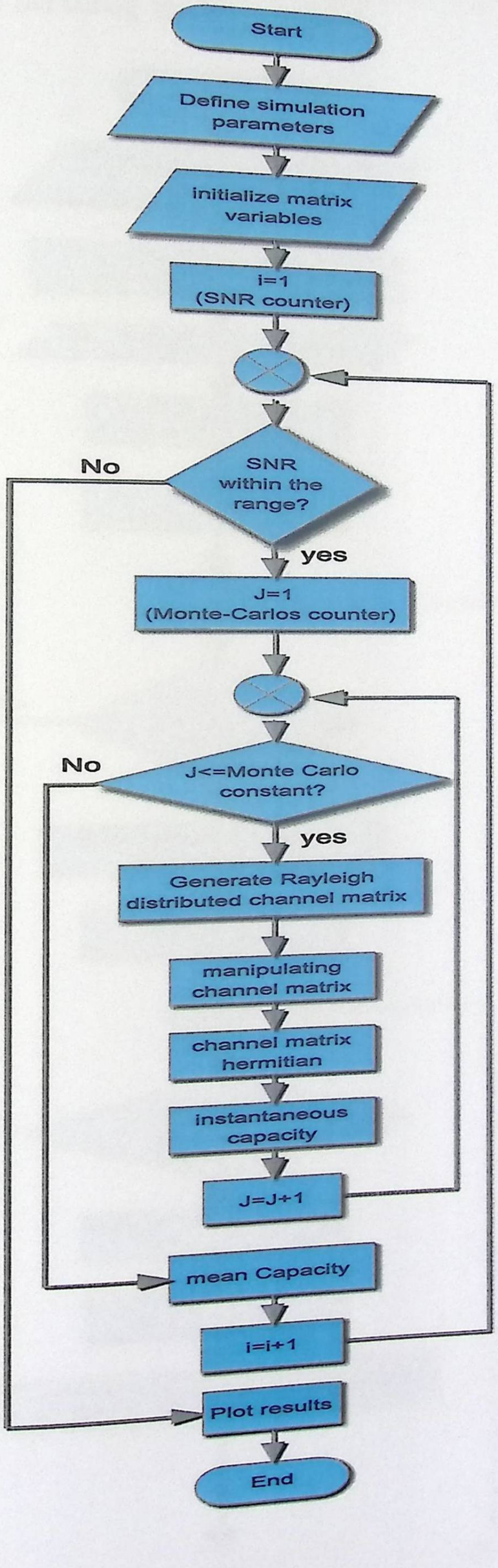
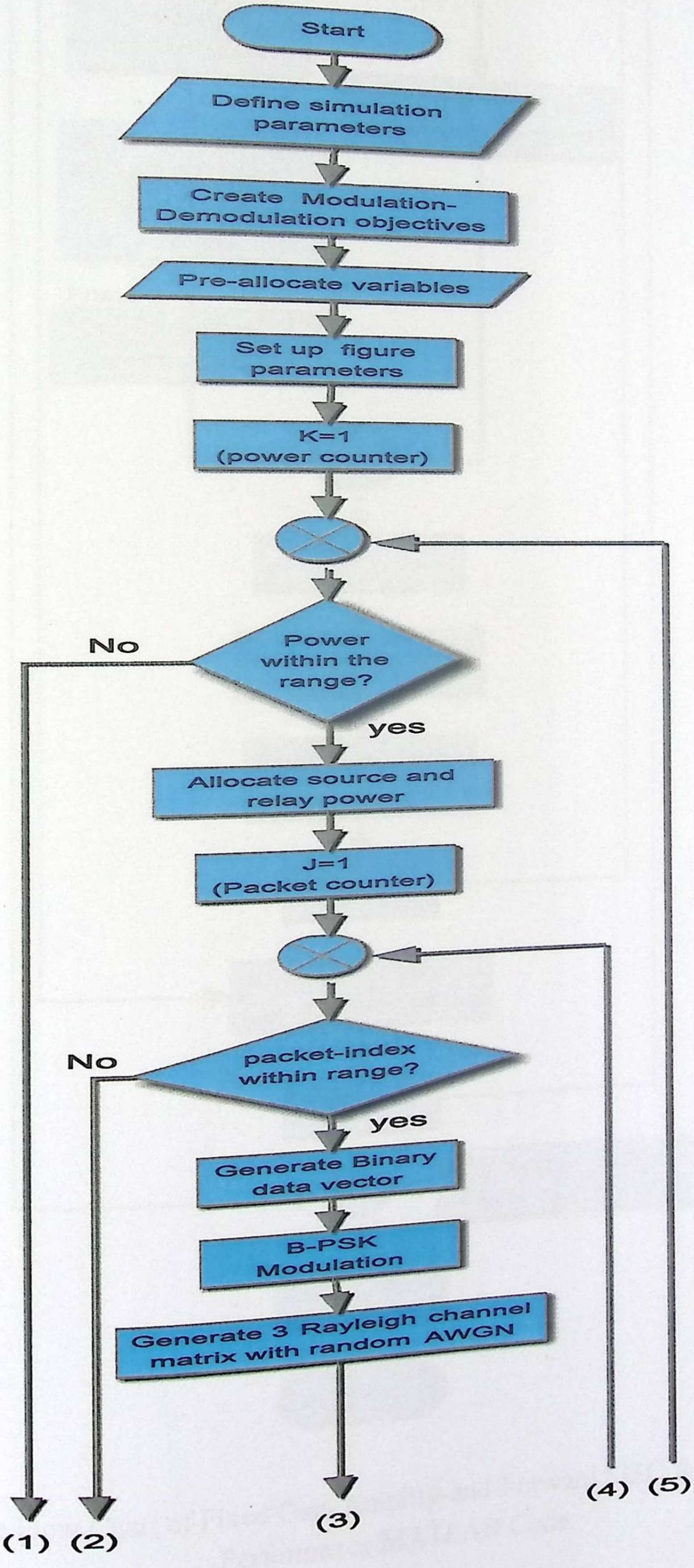


Figure 4.4 The Flow Chart of N×M MIMO System Capacity MATLAB Code

.2.3 Fixed Gain Amplify-and-Forward SISO Relaying System Codes Flow Charts

.2.3.1 AF SISO Relaying System BER Performance Code

The flow chart of fixed gain amplify-and-forward (AF) SISO relaying system BER erformance code under flat fading Rayleigh channel.



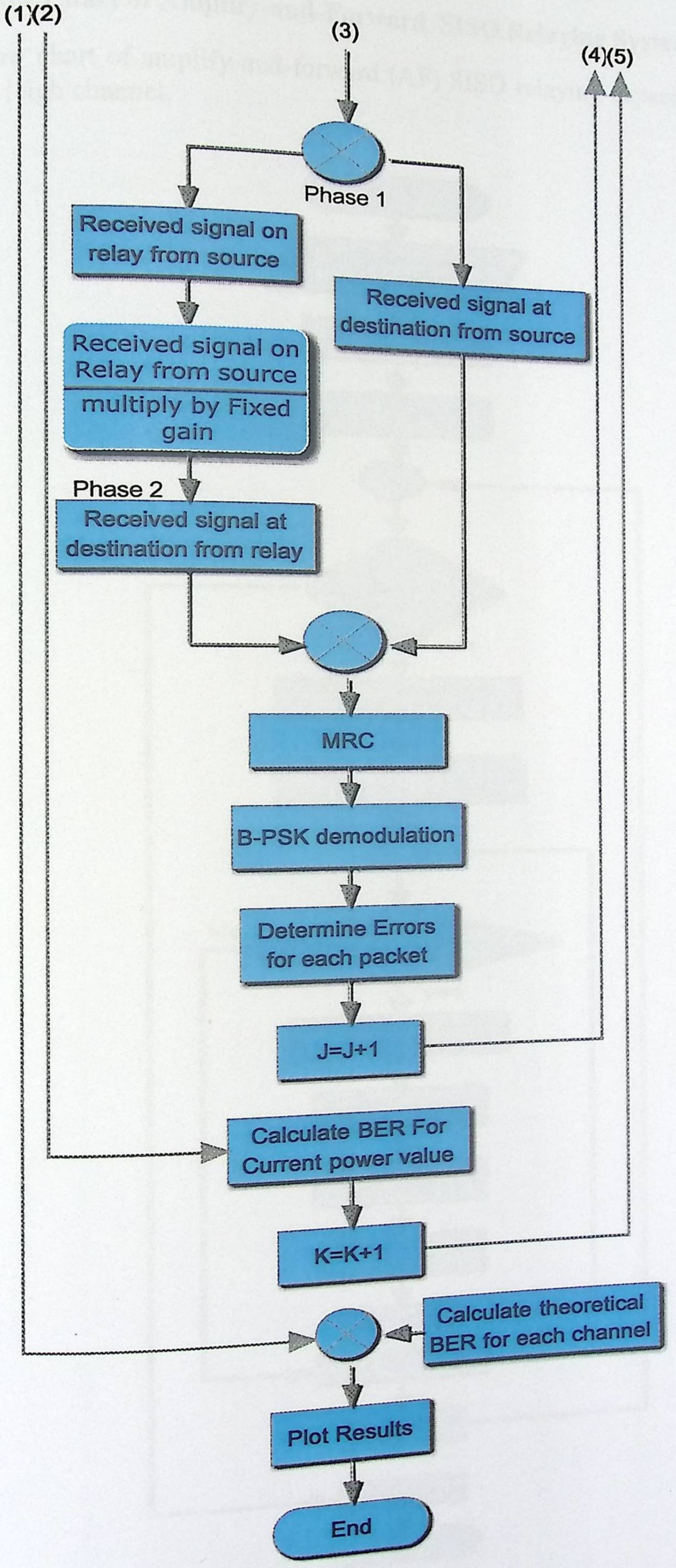


Figure 4.5 The Flow Chart of Fixed Gain Amplify-and-Forward SISO Relaying System BER Performance MATLAB Code

.2.3.2 The Flow Chart of Amplify-and-Forward SISO Relaying System Capacity Code

The flow chart of amplify-and-forward (AF) SISO relaying capacity system code under lat fading Rayleigh channel.

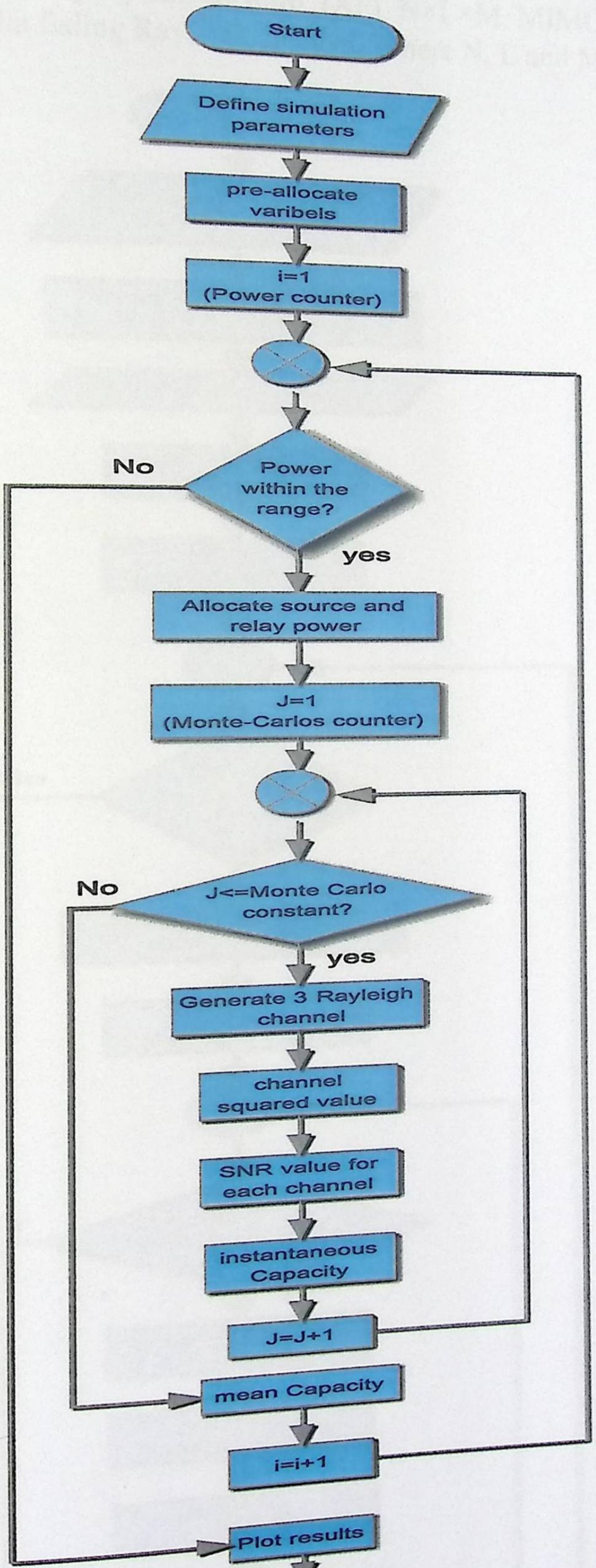
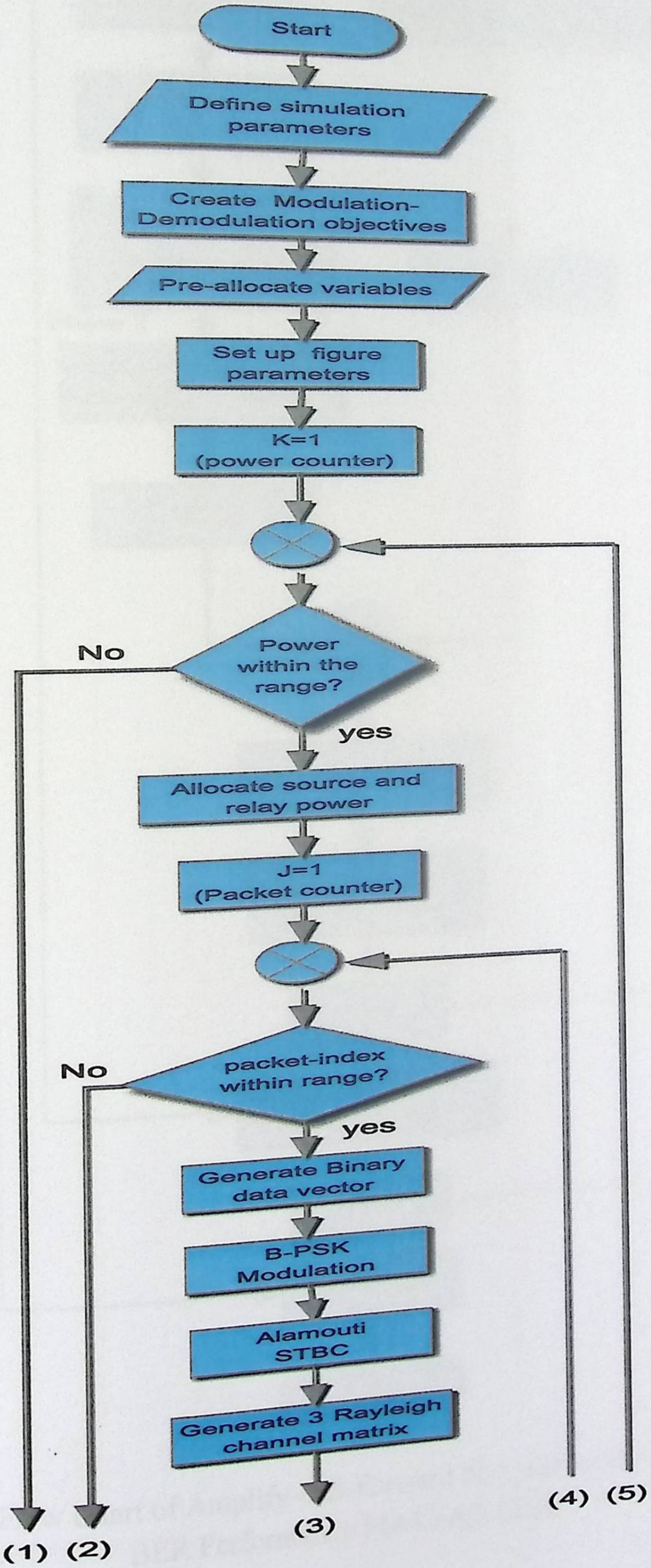


Figure 4.6 The Flow Chart of Fixed Gain Amplify-and-Forward SISO Relaying System Capacity Performance MATLAB Code

.2.4 Fixed Gain Amplify-and-Forward N×L×M MIMO Relaying System Codes Flow Charts

.2.4.1 AF N×L×M MIMO Relaying System BER Performance Code

The flow chart of amplify-and-forward (AF) N×L×M MIMO relaying system BER erformance code under flat fading Rayleigh channel. Where N, L and M are equal.



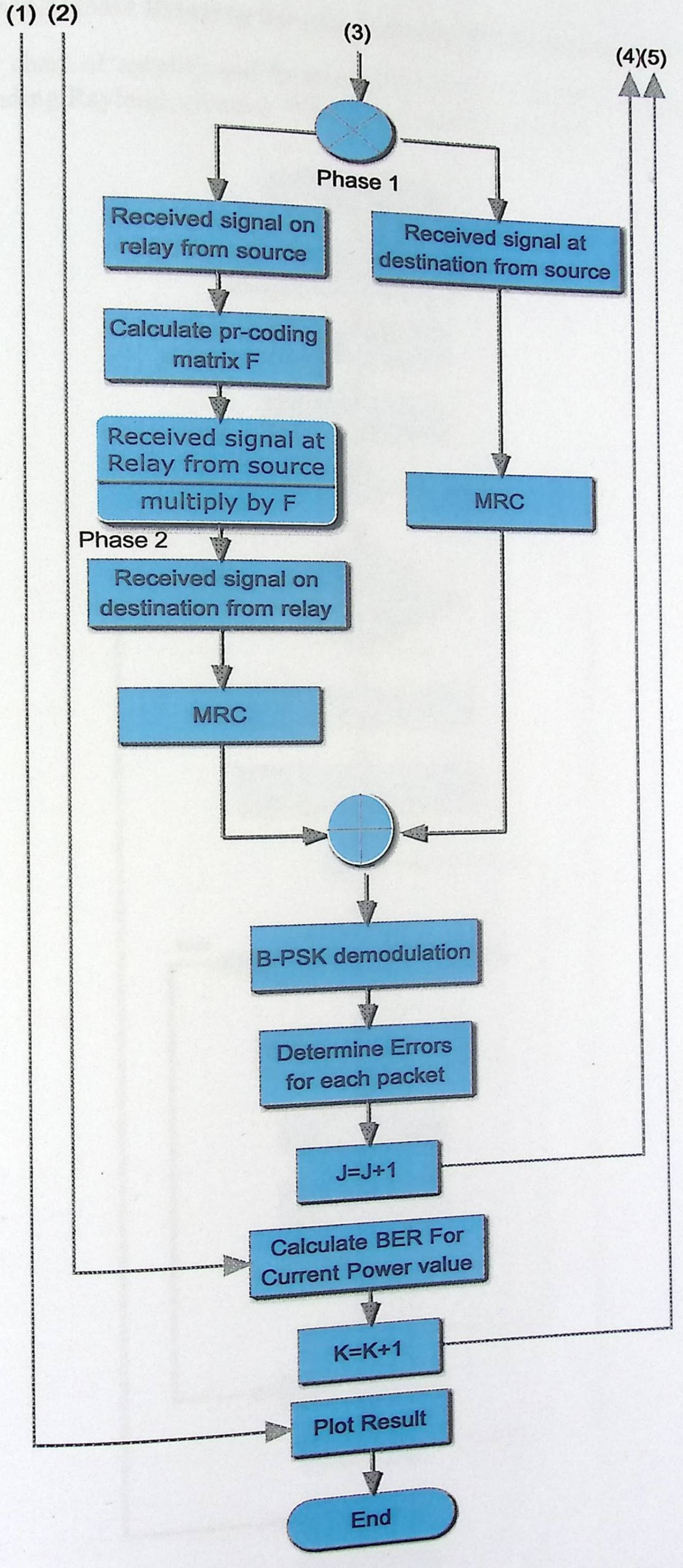


Figure 4.7 The Flow Chart of Amplify-and-Forward N×L×M MIMO Relaying System BER Performance MATLAB Code

.2.4.2 AF N×L×M MIMO Relaying System Capacity Performance Code

The flow chart of amplify-and-forward (AF) N×L×M MIMO relaying system capacity ode under flat fading Rayleigh channel. Where N, L and M are equal.

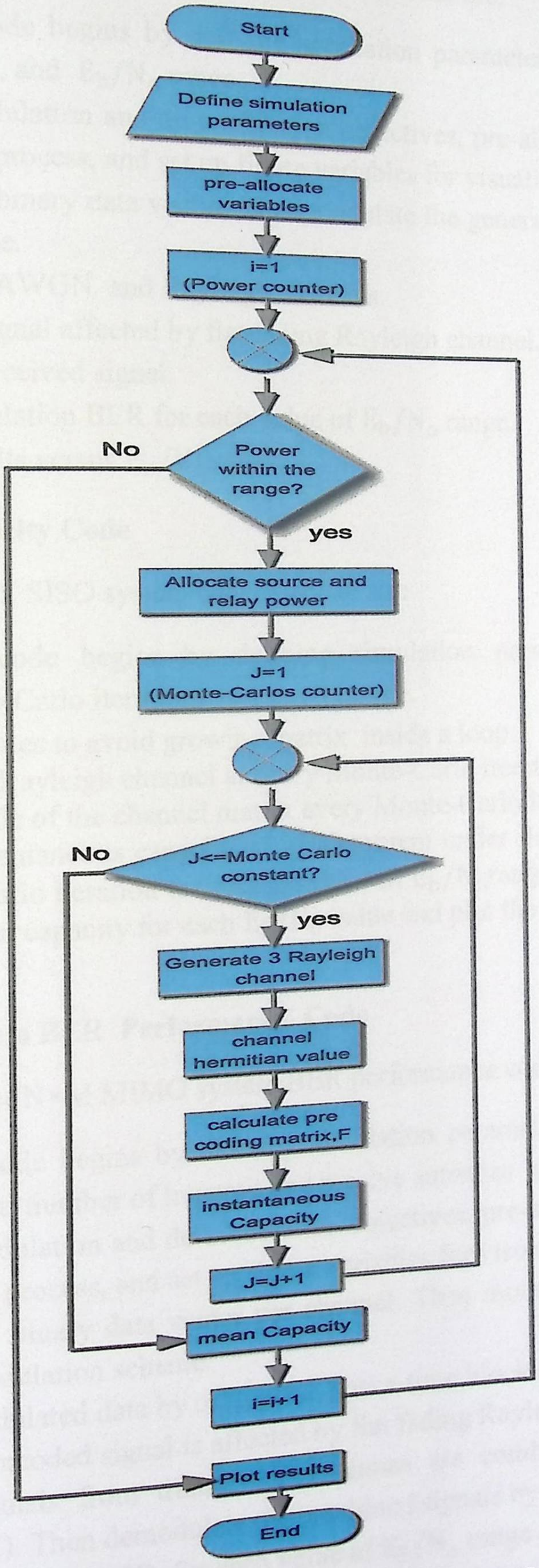


Figure 4.8 The Flow Chart of Fixed Gain Amplify-and-Forward N×L×M MIMO Relaying System Capacity Performance MATLAB Code

.3 Codes Main Stages

.3.1 SISO System BER Performance Code

The main stages of SISO system BER performance code are:

1. The MATLAB code begins by defining simulation parameters such as packet length, number of packets, and E_b/N_o range.
2. Create BPSK modulation and de-modulation objectives, pre-allocate variables for speed up the simulation process, and set up figure variables for visualizing the BER results.
3. Generate random binary data vector. Then modulate the generated data by using BPSK modulation scheme.
4. Generate random AWGN and Rayleigh channels.
5. The transmitted signal affected by flat fading Rayleigh channel.
6. Demodulate the received signal.
7. Calculate the simulation BER for each value of E_b/N_o range.
8. Plot the BER results versus E_b/N_orange.

.3.2 SISO System Capacity Code

The main stages of SISO system capacity code are:

1. The MATLAB code begins by defining simulation parameters such as channel bandwidth, Monte-Carlo iterations and E_b/N_orange.
2. Pre-allocate variables to avoid growing matrix inside a loop.
3. Generate random Rayleigh channel at every Monte-Carlo iteration.
4. Take the magnitude of the channel matrix every Monte-Carlo iteration.
5. Calculate the instantaneous capacity of SISO system under flat fading Rayleigh channel at every Monte-Carlo iteration for specific value of E_b/N_orange.
6. Calculate the mean capacity for each E_b/N_o value and plot the results.

.3.3 N×M MIMO System BER Performance Code

The main stages of N×M MIMO system BER performance code are:

1. The MATLAB code begins by defining simulation parameters such as packet length, number of packets, number of transmit and receive antennas and E_b/N_o range.
2. Create BPSK modulation and de-modulation objectives, pre-allocate variables for speed up the simulation process, and set up figure variables for visualizing the BER results.
3. Generate random binary data vector per channel. Then modulate the generated data by using B-PSK modulation scheme.
4. Encoding the modulated data by orthogonal space-time block coding (OSTBC) encoder.
5. The transmitted encoded signal is affected by flat fading Rayleigh channel.
6. The received signals from transmitted antennas are combined using maximal ratio combining (MRC). Then demodulate the combined signals by BPSK demodulator.
7. Calculate the simulation BER for each value of E_b/N_o range and Plot the BER results.

3.4 N×M MIMO System Capacity Code

The main stages of N×M MIMO system capacity code are:

1. The MATLAB code begins by defining simulation parameters such as channel bandwidth, Monte-Carlo iterations, number of transmit and receive antennas and E_b/N_o range.
2. Matrix initializations to avoid matrix growing inside loop.
3. Generate complex channel matrix every Monte-Carlo iteration.
4. Take the Hermitian of channel matrix.
5. Calculate the instantaneous capacity at every Monte-Carlo iteration.
6. Calculate the mean capacity for every E_b/N_o value and plot the result

3.5 Amplify-and-Forward SISO Relaying System BER Performance Code

The main stages of amplify-and-forward SISO relaying system BER performance code re:

1. The MATLAB code begins by defining simulation parameters such as packet length, number of packets and power range.
2. Create BPSK modulation and de-modulation objectives.
3. Pre-allocate variables for speed up the simulation process and set up figure variables for visualizing the BER results.
4. Allocate power for both source and relay at each value of power range.
5. Generate random binary data vector per channel. Then modulate the generated data by using BPSK modulation scheme.
6. Generate three random AWGN and three random Rayleigh channels.
7. In phase 1, the source transmits the modulated signal to the destination and relay, simultaneously.
8. The received signal at the relay is amplified by fixed gain, then forwarded to the destination in phase 2 at each power range value.
9. Combined the two signals from two phases using MRC. Then demodulate the combined signal by BPSK demodulator.
10. Calculate the simulated BER for each value of power range.
11. Plot the BER results versus E_b/N_o.

.3.6 Amplify-and-Forward SISO Relaying System Capacity Performance Code

The main stages of amplify-and-forward SISO relaying system capacity code are:

1. The MATLAB code begins by defining simulation parameters such as channel bandwidth, power range, channel variances, and Monte–Carlo iterations.
2. Pre-allocate variables to avoid growing matrix inside loop.
3. Generate three random Rayleigh channels and calculate the magnitude of each channel at every Monte-Carlo iteration.
4. Calculate SNR for each channel at every Monte-Carlo iteration.
5. Calculate the instantaneous capacity of AF SISO relaying system under flat fading Rayleigh channel at every Monte–Carlo iteration.
6. Calculate the mean capacity for each E_b/N_o value and plot the results.

.3.7 Amplify-and-Forward N×L×MMIMO Relaying System BER Performance Code

The main stages of amplify-and-forward N×L×M MIMO relaying system BER performance code are:

1. The MATLAB code begins by defining simulation parameters such as packet length, number of packets, number of each node antennas, and power range.
2. Create BPSK modulation and de-modulation objectives.
3. Pre-allocate variables for speed up the simulation process, and set up figure variables for visualizing the BER results.
4. Allocate power for both source and relay at each value of power range.
5. Generate random binary data vector per channel. Then modulate the generated data by using BPSK modulation scheme. Then encode the modulated signals using orthogonal space-time block coding (OSTBC).
6. Generate three random Rayleigh channels with AWGN.
7. In phase 1, the source transmit the modulated signals vector to the destination and relay, simultaneously.
8. The received signal vector at the relay is amplified by pre-coding matrix . Then forwarded to the destination in phase 2 at each power range value.
9. Combined the received signal vector from source, in phase 1 using MRC Then combined the received signal vector from relay, in phase 2 using MRC. Demodulate the combined signal by BPSK demodulator.
10. Calculate the simulation BER for each value of power range.
11. Plot the BER results versus E_b/N_o.

4.3.8 Amplify-and-Forward N×L×M MIMO Relaying System Capacity Performance Code

The main stages of amplify-and-forward N×L×M MIMO relaying system capacity code are:

1. The MATLAB code begins by defining simulation parameters such as channel bandwidth, power range , channel variances, Monte–Carlo iterations and number of each node antennas.
2. Pre-allocate variables to avoid growing matrix inside loop.
3. Generate three random Rayleigh channels and take the Hermitian of each channel at every Monte-Carlo iteration.
4. Calculate pre-coding matrix at every Monte-Carlo iteration.
5. Calculate the instantaneous capacity at every Monte–Carlo iteration.
6. Calculate the mean capacity for each E_b/N_o range and plot the results.

4.4 Constructing MIMO System and AF MIMO Relaying System for Diversity

This project simulates fixed gain AF MIMO relaying system using flat fading Rayleigh channel through means of space-time block coding (STBC), which constructed from known orthogonal designs, achieving full diversity, and are easily decodable by maximum likelihood decoding via linear processing at the receiver. Assumed that the channel is unknown for the source and perfectly known at the relay and destination for all systems.

In all MIMO systems and AF MIMO relaying systems we use orthogonal space time block coding (OSTBC) which is employable when multiple transmitter antennas are used i.e. in 2×2 MIMO system, AF 2×2×2 MIMO relaying system, we use full rate Alamouti STBC, while we use half rate OSTBC in 4×4 MIMO system, AF 4×4×4 MIMO relaying system, 8×8 MIMO system, and AF 8×8×8 MIMO relaying system.

The following matrices in which the columns represent the symbol period (time slot) and the rows represent the antennas (space) are used to generate the STBC. These matrices are considered as the main part in building MIMO system and AF MIMO relaying system codes which are used to simulate the performance of different cases.

a. Two-transmit two-receive antenna diversity (full rate G_2):

$$S = G_{2-\text{Alamouti}} = \begin{bmatrix} S_1 & -S_2^{*} \\ S_2 & S_1^{*} \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

b. Four-transmit four- receive antenna diversity (Half rate S):

$$G_{4-\text{transmitters}} = \begin{bmatrix} S_1 & -S_2 & -S_3 & -S_4 \\ S_2 & S_1 & S_4 & -S_3 \\ S_3 & -S_4 & S_1 & S_2 \\ S_4 & S_3 & -S_2 & S_1 \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.2)$$

$$S = [G_4\,,\quad G_4{}^{*}]\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.3)$$

c. Eight-transmit eight-receive antenna diversity (Half rate S):

$$G_{8-\text{transmitters}} = \begin{bmatrix} S_1 & -S_2 & -S_3 & -S_4 & -S_5 & -S_6 & -S_7 & -S_8 \\ S_2 & S_1 & S_4 & -S_3 & S_6 & -S_5 & -S_8 & S_7 \\ S_3 & -S_4 & S_1 & S_2 & -S_7 & -S_8 & S_5 & S_6 \\ S_4 & S_3 & -S_2 & S_1 & -S_8 & S_7 & -S_6 & S_5 \\ S_5 & -S_6 & S_7 & S_8 & S_1 & S_2 & -S_3 & -S_4 \\ S_6 & S_5 & S_8 & -S_7 & -S_2 & S_1 & S_4 & -S_3 \\ S_7 & S_8 & -S_5 & S_6 & S_3 & -S_4 & S_1 & -S_2 \\ S_8 & -S_7 & -S_6 & -S_5 & S_4 & S_3 & S_2 & S_1 \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots(4.4)$$

$$S = [G_8\,,\quad G_8{}^{*}]\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.5)$$

The MIMO output is given by:

$$Y = H^{T} x\, S + N \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.6)$$

Where :

S: it is the input data matrix formulated as OSTBC.

N: it is Zero Mean Circularly Symmetric Complex Gaussian Noise matrix.

H: it is an independent and identical distributed (i.i.d) complex matrix consists of frequency flat fading Rayleigh channels represents the channel response between transmit and receive antennas.(27),(28),(43),(44).

4.5 Simulation setup

The simulation covers an end-to-end conventional SISO system, N×M MIMO system, fixed gain AF SISO relaying system and fixed gain AF N×L×M MIMO relaying system where N, L and M are equal. Such that N equal 2,4 and 8. Giving that the channel state information (CSI) is unknown at the source and perfectly known at both the relay and destination.

In 2×2 MIMO system and AF 2×2×2 MIMO relaying system, the modulated symbols ransmitted in 2 time slots using full rate Alamouti STBC. In 4×4 MIMO system and AF 4×4×4 MIMO relaying system, the modulated symbols transmitted in 8 time slots using half rate OSTBC. In 8×8 MIMO system and AF 8×8×8 MIMO relaying system, the modulated symbols ransmitted in 16 time slots using half rate OSTBC. By considered that STBC is used to encode he transmitted symbols; transmitting different symbols through different antennas and different ime slots as follows

The first column of S will be transmitted through the N antenna array elements at the source during the first symbol period, then the symbol of column two of S will be transmitted from the N antenna array elements during the following symbol period, and this process continues until all columns are transmitted. Monte-Carlo simulation methods are used to make realizations for channel when the capacity simulated.

CHAPTER

5

Simulation Results

.1 Introduction

.2 Comparison between SISO, 2×2 MIMO, 4×4 MIMO and 8×8 MIMO Systems under Flat Fading Rayleigh Channel

- **5.2.1 Comparison between SISO, 2×2 MIMO, 4×4 MIMO and 8×8 MIMO Systems in terms of BER Performance**
- **5.2.2 Comparison between SISO, 2×2 MIMO, 4×4 MIMO and 8×8 MIMO Systems in terms of Capacity Performance**

.3 Simulation Results for Fixed Gain AF SISO Relaying System under Flat Fading Rayleigh Channel

- **5.3.1 Fixed Gain AF SISO Relaying System BER Performance**
    - **5.3.1.1 Fixed Gain AF SISO Relaying System with Direct Link using Optimal Power Allocation**
    - **5.3.1.2 Comparison between Fixed Gain AF SISO Relaying System with Direct Link using Optimal and Equal Power Allocation**
    - **5.3.1.3 Comparison between SISO System, 2×2 MIMO System and Fixed Gain AF SISO Relaying System with and without Direct Link using Optimal Power Allocation**
- **5.3.2 Fixed Gain AF SISO Relaying System Capacity Performance**
    - **5.3.2.1 Comparison between Fixed Gain AF SISO Relaying System with Direct Link using Optimal and Equal Power Allocation**
    - **5.3.2.2 Comparison between SISO System, 2×2 MIMO System and Fixed Gain AF SISO Relaying System with and without Direct Link using Optimal Power Allocation**

.4 Simulation Results for Fixed Gain AF 2×2×2 MIMO Relaying System under Flat Fading Rayleigh Channel

5.6.2 Fixed Gain AF 8×8×8 MIMO Relaying System Capacity Performance

5.6.2.1 Comparison between Fixed Gain AF 8×8×8 MIMO Relaying System with Direct Link using Optimal and Equal Power Allocation

5.6.2.2 Comparison between 8×8 MIMO System and Fixed Gain AF 8×8×8 MIMO Relaying System with and without Direct Link using Optimal Power Allocation

5.7 Comparison between Fixed Gain AF SISO, AF 2×2×2 MIMO, AF 4×4×4 MIMO and AF 8×8×8 MIMO Relaying Systems under Flat Fading Rayleigh Channel

5.7.1 Comparison between Fixed Gain AF SISO, AF 2×2×2 MIMO, AF 4×4×4 MIMO and AF 8×8×8 MIMO Relaying Systems in terms of BER Performance

5.7.2 Comparison between Fixed Gain AF SISO, AF 2×2×2 MIMO, AF 4×4×4 MIMO and AF 8×8×8 MIMO Relaying Systems in terms of Capacity Performance

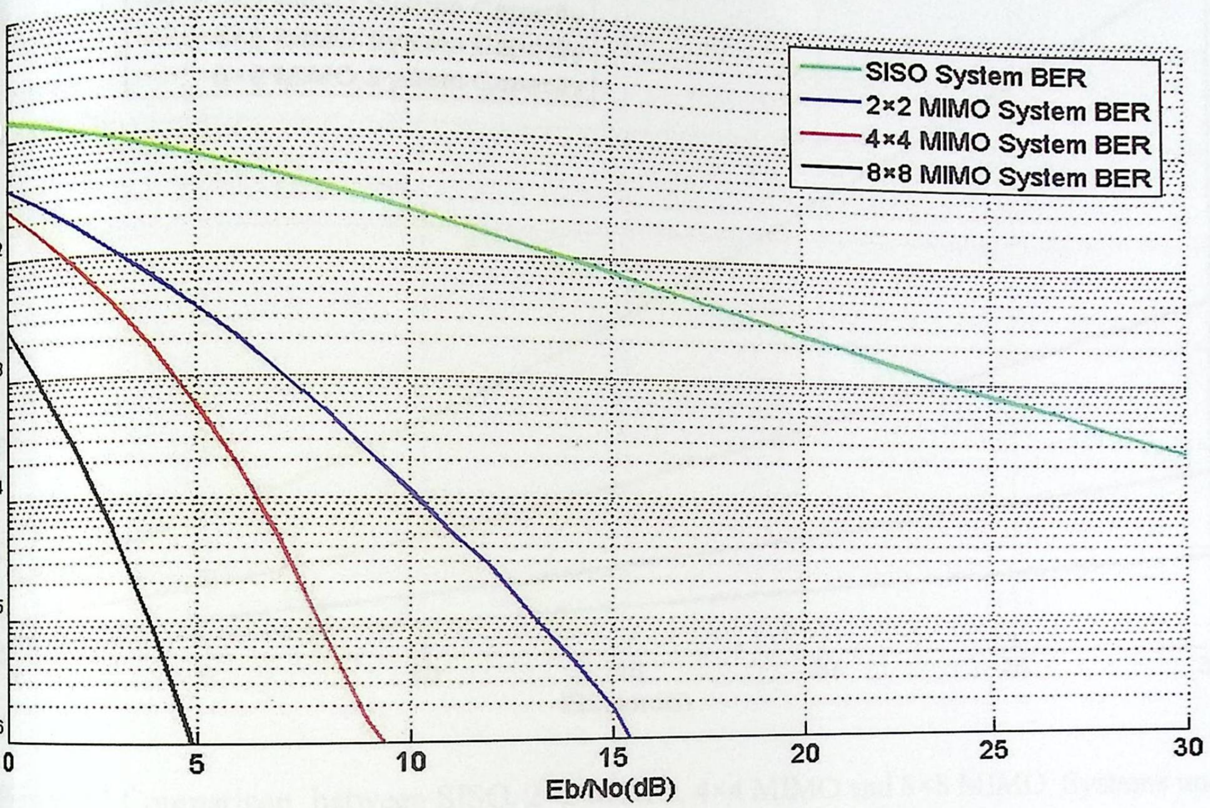
5.1 Introduction

This project use MATLAB to simulate the BER and capacity performance of fixed gain AF SISO relaying system with and without direct link, fixed gain AF 2×2×2 MIMO relaying ystem with and without direct link, fixed gain AF 4×4×4 MIMO relaying system with and without direct link, and fixed gain AF 8×8×8 MIMO relaying system with and without direct ink under flat fading Rayleigh channel.

The project also simulate the BER and capacity performance of SISO system, 2×2 MIMO system, 4×4 MIMO system, and 8×8 MIMO system under flat fading Rayleigh channel. To make a comparison between the BER and capacity performance of conventional systems with he BER and capacity performance of AF relaying systems at the same conditions.

.2 Comparison between SISO, 2×2 MIMO, 4×4 MIMO and 8×8 MIMO Systems under Flat Fading Rayleigh Channel

.2.1 Comparison between SISO, 2×2 MIMO, 4×4 MIMO and 8×8 MIMO Systems in erms of BER Performance



igure 5.1 Comparison between SISO, 2×2 MIMO, 4×4 MIMO and 8×8 MIMO Systems under Flat Fading Rayleigh Channel in terms of BER Performance

In this case, we assume that the number of transmitted symbols are 4,000,000 and the E_b/N_o range is [0:1:30] dB. The figure show a comparison between SISO, 2×2 MIMO, 4×4 MIMO and 8×8 MIMO systems under flat fading Rayleigh channel in terms of BER performance.

We notice that, the BER performance of 8×8 MIMO system is better one followed by 4×4 MIMO system, 2×2 MIMO system and SISO system, respectively, i.e., at E_b/N_o equal 3 dB, the BER of 8×8 MIMO system is equal 5.55×10^{-5}, while the BER of 4×4 MIMO system, 2×2 MIMO system and SISO system equal 4.073×10^{-3}, 1.107×10^{-2}, and 9.194×10^{-2}, respectively. There is approximately 4 dB difference between the BER of 4×4 MIMO system and 8×8 MIMO system. So using 8×8 MIMO system reduce the power consumption and can achieve good BER performance at low E_b/N_o.

As a result, when E_b/N_o increases, the BER decreases accordingly in all systems. The BER performance of MIMO systems is much better than the BER performance of SISO system. As the number of antennas increases, the BER performance of MIMO system increases accordingly but this increasing is limited to a certain number of antennas. So the BER performance of wireless communication systems become more better when using MIMO systems. This result matches the results in (47).

5.2.2 Comparison between SISO, 2×2 MIMO, 4×4 MIMO and 8×8 MIMO Systems in terms of Capacity Performance

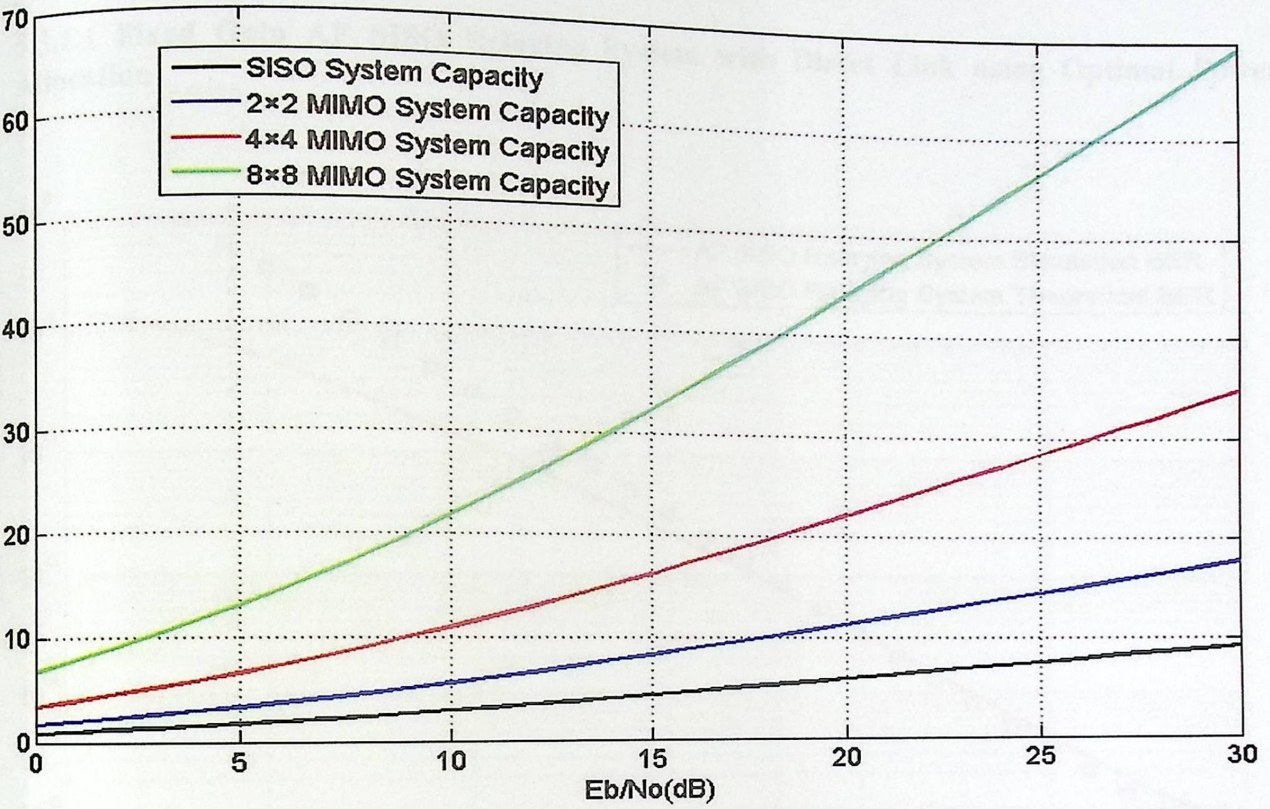


Figure 5.2 Comparison between SISO, 2×2 MIMO, 4×4 MIMO and 8×8 MIMO Systems under Flat Fading Rayleigh Channel in terms of Capacity Performance

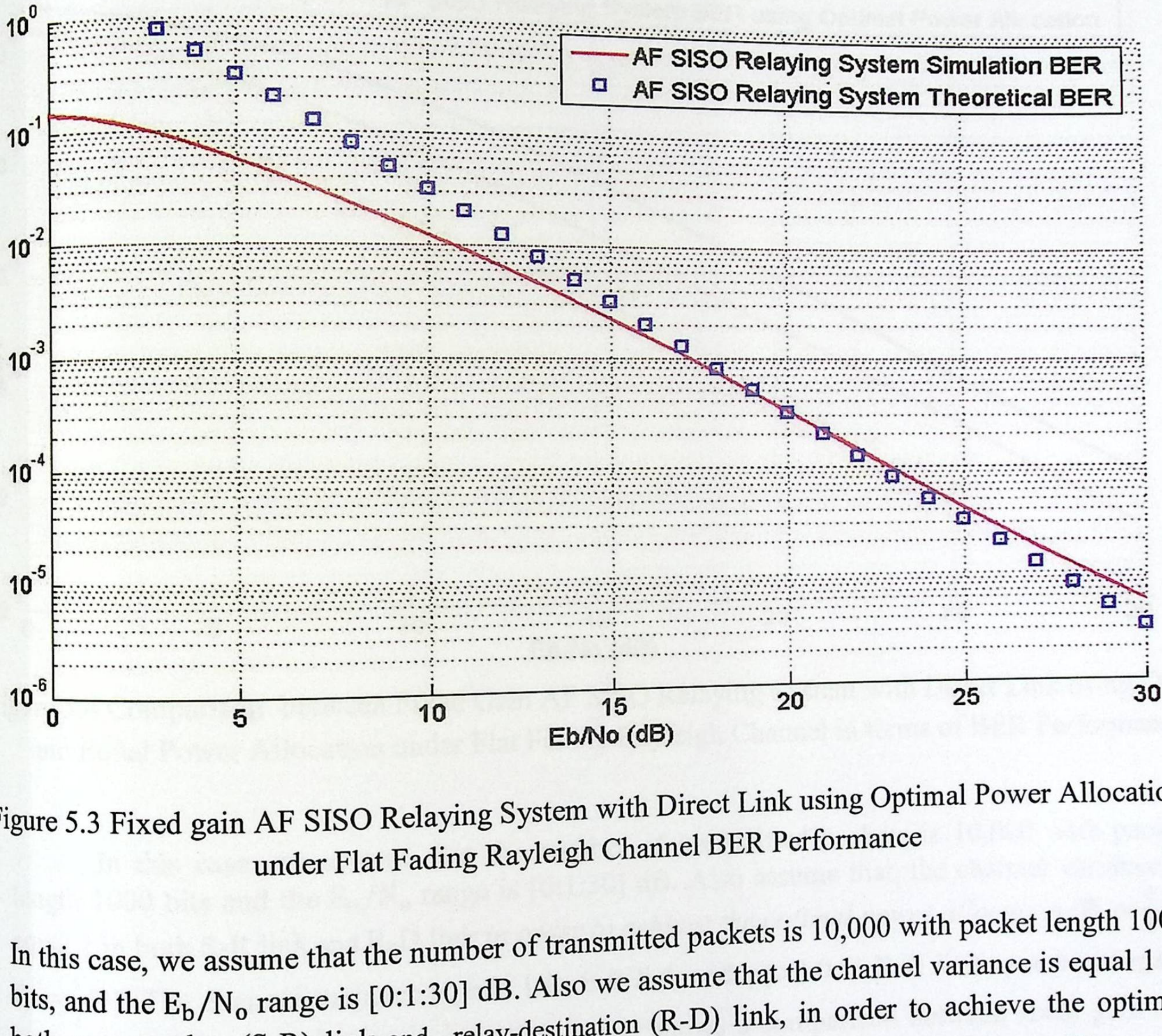
In this case, we assume that the E_b/N_o range is [0:1:30] dB and the number of Monte-Carlo iterations is 10,000. The figure show a comparison between SISO, 2×2 MIMO, 4×4 MIMO and 8×8 MIMO systems under flat fading Rayleigh channel in terms of capacity performance. As we notice, the mean capacity of 8×8 MIMO system is greater one followed by 4×4 MIMO system, 2×2 MIMO system and SISO system, respectively, i.e., at E_b/N_o equal 30 dB, the mean capacity of 8×8 MIMO system is equal 69.2 bits/s/Hz, while the mean capacity of 4×4 MIMO system, 2×2 MIMO system and SISO system are equal 34.86 bits/s/Hz, 17.73 bits/s/Hz, and 9.159 bits/s/Hz, respectively. It's clear that, the mean capacity of 2×2 MIMO system is approximately twice or less than the mean capacity of SISO system. The mean capacity of 4×4 MIMO system is approximately twice or less than the mean capacity of 2×2 MIMO system. The mean capacity of 8×8 MIMO system is approximately twice or less than the mean capacity of 4×4 MIMO system at specific value of E_b/N_o.

As a result, when E_b/N_o increases, the mean capacity increases accordingly in all systems. As the number of system antennas increases, the channel mean capacity increases accordingly so the capacity performance of wireless communication systems become more better. This result matches the results in (45).

5.3 Simulation Results for Fixed Gain AF SISO Relaying System under Flat Fading Rayleigh Channel

5.3.1 Fixed Gain AF SISO Relaying System BER Performance

5.3.1.1 Fixed Gain AF SISO Relaying System with Direct Link using Optimal Power Allocation



igure 5.3 Fixed gain AF SISO Relaying System with Direct Link using Optimal Power Allocation under Flat Fading Rayleigh Channel BER Performance

In this case, we assume that the number of transmitted packets is 10,000 with packet length 1000 bits, and the E_b/N_o range is [0:1:30] dB. Also we assume that the channel variance is equal 1 in both source-relay (S-R) link and relay-destination (R-D) link, in order to achieve the optimal power allocation ($P_s = \frac{2}{3}$ P, $P_r = \frac{1}{3}P$). The figure show the relationship between BER versus E_b/N_o in dB for fixed gain AF SISO relaying system with direct link using optimal power allocation under flat fading Rayleigh channel. As we notice, the simulated BER of AF SISO relaying system started at 1.467×10^{-1} when E_b/N_o equals 0 dB. And achieved BER equal 5.472×10^{-6} when E_b/N_o equals 30 dB.

As a result, when the E_b/N_o increases, the BER decreases accordingly, i.e., the BER equals 2.275×10^{-3} at E_b/N_o equal 15 dB, while the BER is equal 4.085×10^{-5} at E_b/N_o equal 25 dB. *Moreover, the simulation BER result matches the theoretical BER result except for*

5.3 Simulation Results for Fixed Gain AF SISO Relaying System under Flat Fading Rayleigh Channel

5.3.1 Fixed Gain AF SISO Relaying System BER Performance

5.3.1.1 Fixed Gain AF SISO Relaying System with Direct Link using Optimal Power Allocation

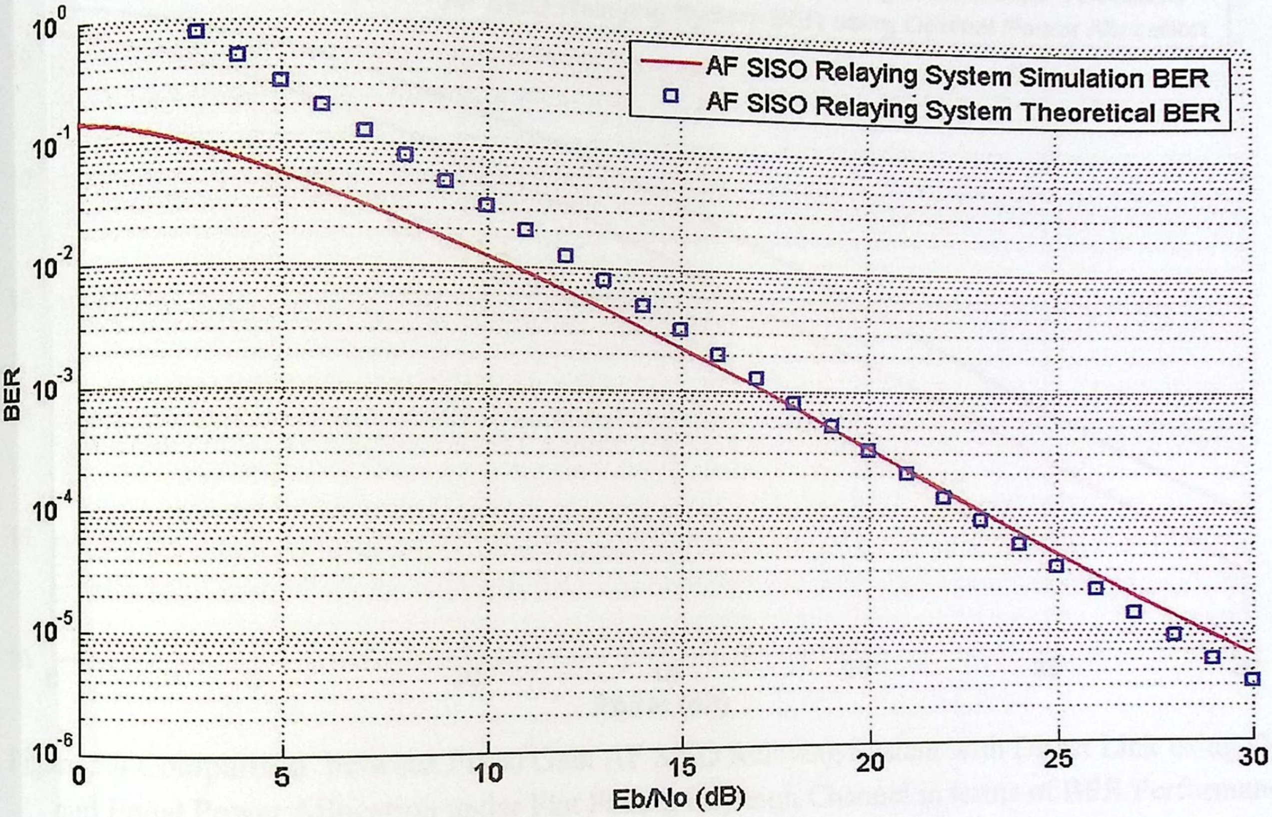


Figure 5.3 Fixed gain AF SISO Relaying System with Direct Link using Optimal Power Allocation under Flat Fading Rayleigh Channel BER Performance

In this case, we assume that the number of transmitted packets is 10,000 with packet length 1000 bits, and the E_b/N_o range is [0:1:30] dB. Also we assume that the channel variance is equal 1 in both source-relay (S-R) link and relay-destination (R-D) link, in order to achieve the optimal power allocation ($P_s = \frac{2}{3}$ P, $P_r = \frac{1}{3}$P). The figure show the relationship between BER versus E_b/N_o in dB for fixed gain AF SISO relaying system with direct link using optimal power allocation under flat fading Rayleigh channel. As we notice, the simulated BER of AF SISO relaying system started at 1.467×10^{-1} when E_b/N_o equals 0 dB. And achieved BER equal 5.472×10^{-6} when E_b/N_o equals 30 dB.

As a result, when the E_b/N_o increases, the BER decreases accordingly, i.e., the BER equals 2.275×10^{-3} at E_b/N_o equal 15 dB, while the BER is equal 4.085×10^{-5} at E_b/N_o equal 25 dB. *Moreover, the simulation BER result matches the theoretical BER result except for* *a small difference due to approximation of the theoretical equation.* This result matches the results in (41).

5.3.1.2 Comparison between Fixed Gain AF SISO Relaying System with Direct Link using Optimal and Equal Power Allocation

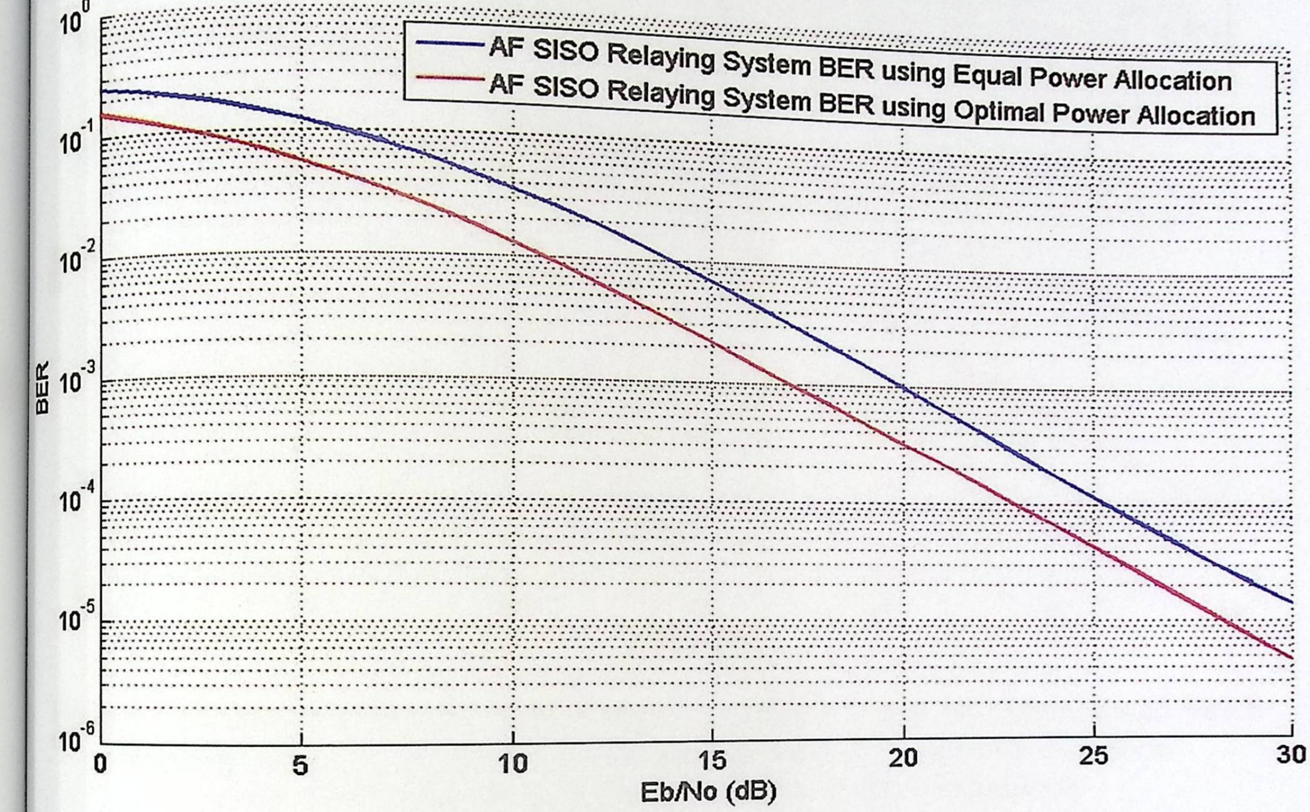


Figure 5.4 Comparison between Fixed Gain AF SISO Relaying System with Direct Link using Optimal and Equal Power Allocation under Flat Fading Rayleigh Channel in terms of BER Performance

In this case, we assume that the number of transmitted packets is 10,000 with packet length 1000 bits and the E_b/N_o range is [0:1:30] dB. Also assume that, the channel variance is equal 1 in both S-R link and R-D link *in order to achieve the optimal power allocation* ($P_s = \frac{2}{3}$ P, $P_r = \frac{1}{3}P$). The channel variance equals 1 in S-R link and equal 0 in R-D link *to achieve equal power allocation* ($P_s = \frac{1}{2}$ P, $P_r = \frac{1}{2}$ P). The figure shows a comparison between fixed gain AF SISO relaying system with direct link using optimal and equal power allocation under flat fading Rayleigh channel in terms of BER performance.

As the figure shows, the BER performance of fixed gain AF SISO relaying system with direct link using optimal power allocation is better than the BER performance of fixed gain AF SISO relaying system with direct link using equal power allocation, i.e., at E_b/N_o equal 15 dB, the BER of fixed gain AF SISO relaying system using optimal power allocation equals 2.159×10^{-3} while the BER using equal power allocation equals 6.985×10^{-3}. We notice that, after E_b/N_o equal 10 dB, the dB difference between the two systems BER is approximately constant and equals 3 dB.

a small difference due to approximation of the theoretical equation. This result matches results in [illegible].

5.3.1.2 Comparison between Fixed Gain AF SISO Relaying System with Direct Link using Optimal and Equal Power Allocation

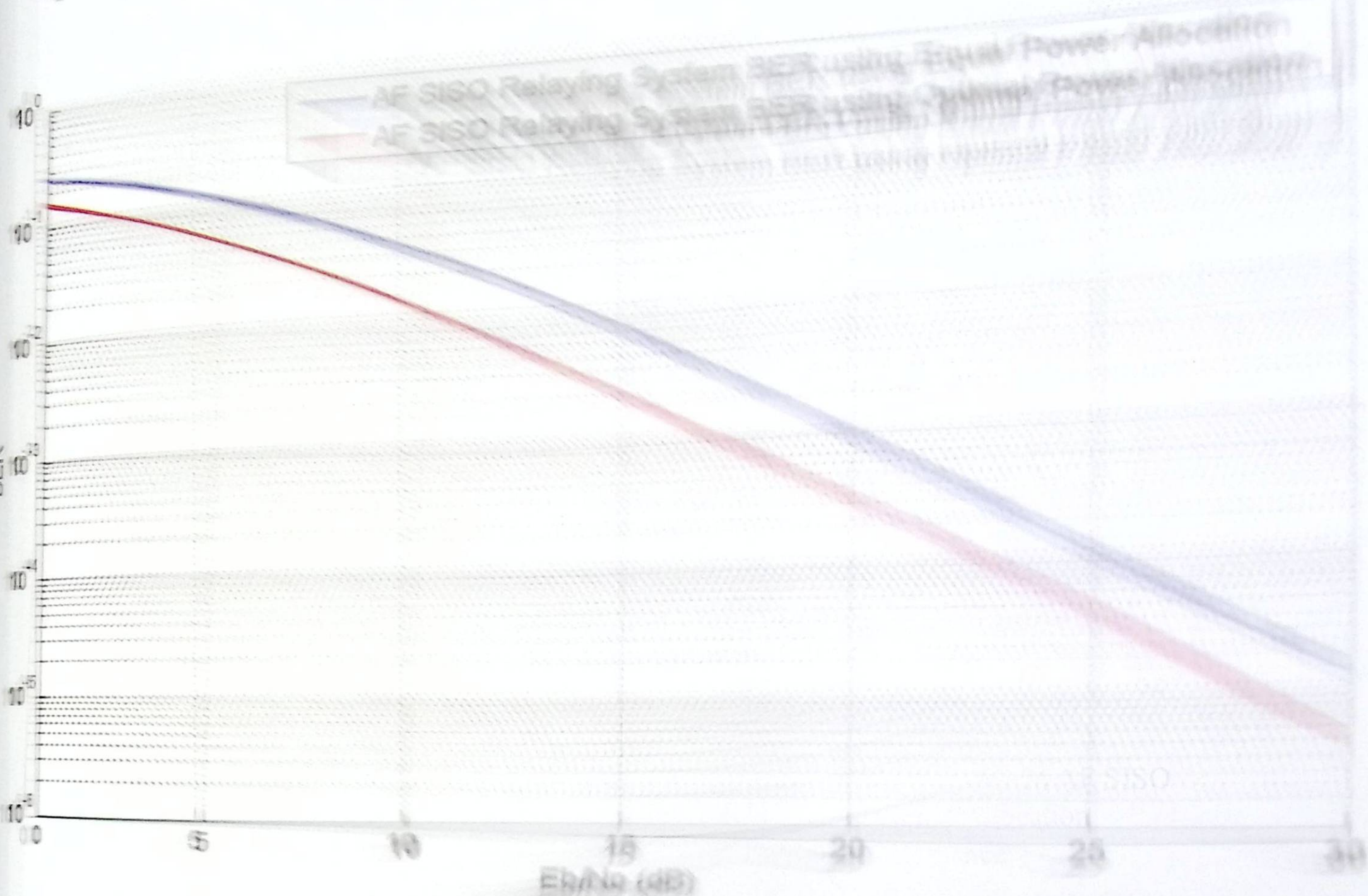


Figure 5.4 Comparison between Fixed Gain AF SISO Relaying System with Direct Link using Optimal and Equal Power Allocation under Flat Fading Rayleigh Channel in terms of BER Performance

In this case, we assume that the number of transmitted packets is 10,000 with packet length 1000 bits and the E_b/N_0 range is [0:1:30] dB. Also assume the channel variance is equal 1 in both S-R link and R-D link in order to achieve the optimal power allocation ($P_s = \frac{2}{3}P$, $P_r = \frac{1}{3}P$). The channel variance equals 1 in S-R link [illegible] power allocation ($P_s = \frac{1}{2}P$, $P_r = \frac{1}{2}P$). The figure shows a comparison between fixed gain AF SISO relaying system with direct link using optimal and equal power allocation under flat fading Rayleigh channel in terms of BER performance.

As the figure shows, the BER [illegible] link using optimal power allocation [illegible] relaying system [illegible] BER of fixed gain AF SISO [illegible] while the BER [illegible]

5.3.1.3 Comparison between SISO System, 2×2 MIMO System and Fixed Gain AF SISO Relaying System with and without Direct Link using Optimal Power Allocation

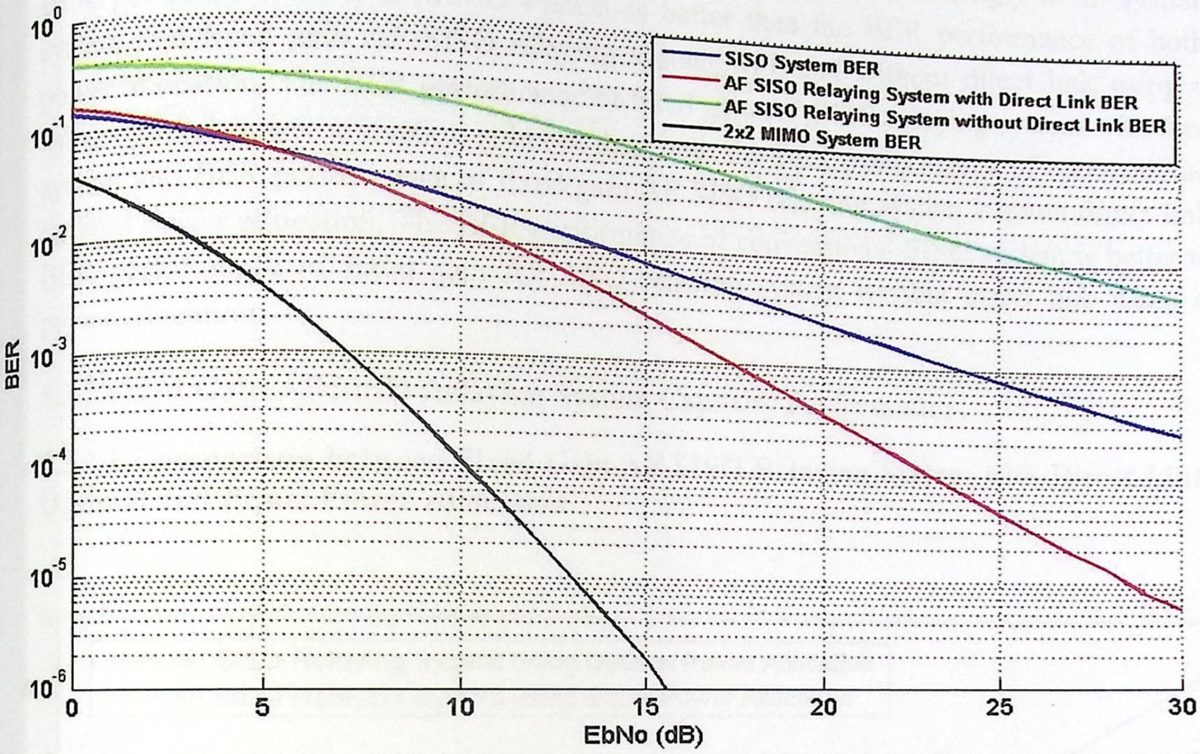


Figure 5.5 Comparison between SISO System, 2×2 MIMO System and Fixed Gain AF SISO Relaying System with and without Direct Link using Optimal Power Allocation under Flat Fading Rayleigh Channel in terms of BER Performance

In this case, we assume that the number of transmitted packets is 10,000 with packet length 4000 bits and the E_b/N_o range is [0:1:30] dB. The figure shows a comparison between the SISO system, 2×2 MIMO system and fixed gain AF SISO relaying system with and without direct link using optimal power allocation under flat fading Rayleigh channel in terms of BER performance. We notice that the BER performance of 2×2 MIMO system is better than the BER performance of both conventional SISO system and fixed gain AF SISO relaying system with and without direct link using optimal power allocation, i.e., at E_b/N_o equals 15 dB, the BER of 2×2 MIMO system equals 1.8×10^{-6}, while the BER of SISO system, fixed gain AF SISO relaying system with and without direct link using optimal power allocation equal 7.708×10^{-3}, 2.593×10^{-3}, and 8.046×10^{-2}, respectively. So the BER performance of 2×2 MIMO system is better one.

As the figure shows, the BER performance of fixed gain AF SISO relaying system without direct link using optimal power allocation is worse than the BER performance of conventional SISO system, i.e., at E_b/N_o equal 15 dB, the BER of conventional SISO system is less than the BER of fixed gain AF SISO relaying system without direct link due to the signal affected by two cascaded channel (S-R channel and R-D channel). The BER performance of fixed gain AF SISO relaying system with direct link using optimal power allocation is better than the BER performance of conventional SISO system, i.e., at E_b/N_o equal 15 dB due to the diversity of two links at the destination.

As a result, when E_b/N_o increases, the BER decreases accordingly in all systems. The BER performance of 2×2 MIMO system is better than the BER performance of both SISO system and fixed gain AF SISO relaying system with and without direct link using optimal power allocation. The BER performance of fixed gain AF SISO relaying system with direct link using optimal power allocation is better than both the BER performance of conventional SISO system and BER performance of fixed gain AF SISO relaying system without direct link using optimal power allocation. The BER performance of conventional SISO system is better than the BER performance of fixed gain AF SISO relaying system without direct link using optimal power allocation.

5.3.2 Fixed Gain AF SISO Relaying System Capacity Performance

5.3.2.1 Comparison between Fixed Gain AF SISO Relaying System with Direct Link using Optimal and Equal Power Allocation

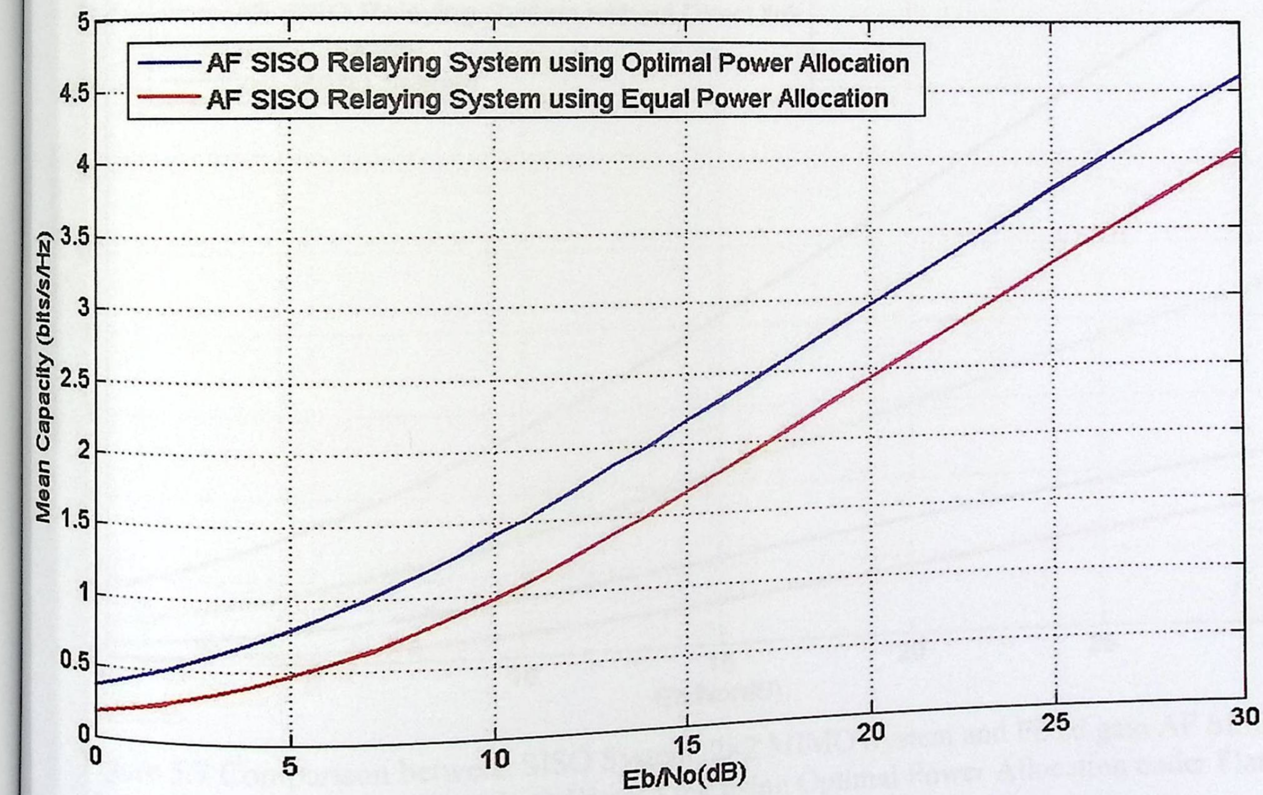


Figure 5.6 Comparison between Fixed Gain AF SISO Relaying using Optimal and Equal Power Allocation under Flat Fading Rayleigh Channel in terms of Capacity Performance

In this case, we assume that the E_b/N_o range is [0:1:30] dB and the number of Monte-Carlo iterations are 10,000. The figure shows a comparison between fixed gain AF SISO relaying system with direct link using optimal and equal power allocation under flat fading Rayleigh channel in terms of the capacity performance. As the figure shows, the capacity performance of fixed gain AF SISO relaying system with direct link using optimal power allocation is better than the capacity performance of fixed gain AF SISO relaying system with direct link using equal power allocation, i.e., at E_b/N_o equal 30 dB, the mean capacity of fixed gain AF SISO relaying system using optimal power allocation is equal 4.604 bits/s/Hz, while the mean capacity using equal power allocation equals 4.061 bits/s/Hz. So the mean capacity of fixed gain AF SISO relaying system using optimal power allocation is greater than the mean capacity using equal power allocation. We notice that after E_b/N_o equal 10 dB, the dB difference between the two systems mean capacity is approximately constant and equals 3 dB.

As a result, using optimal power allocation in fixed gain AF SISO relaying system increases the amount of mean capacity due to allocating more power in direct link (S-D) that assists the destination to decode correctly, so it decreases the amount of losing bits in decoding. So the performance of fixed gain AF SISO relaying system becomes more better.

5.3.2.2 Comparison between SISO System, 2×2 MIMO System and Fixed Gain AF SISO Relaying System with and without Direct Link using Optimal Power Allocation

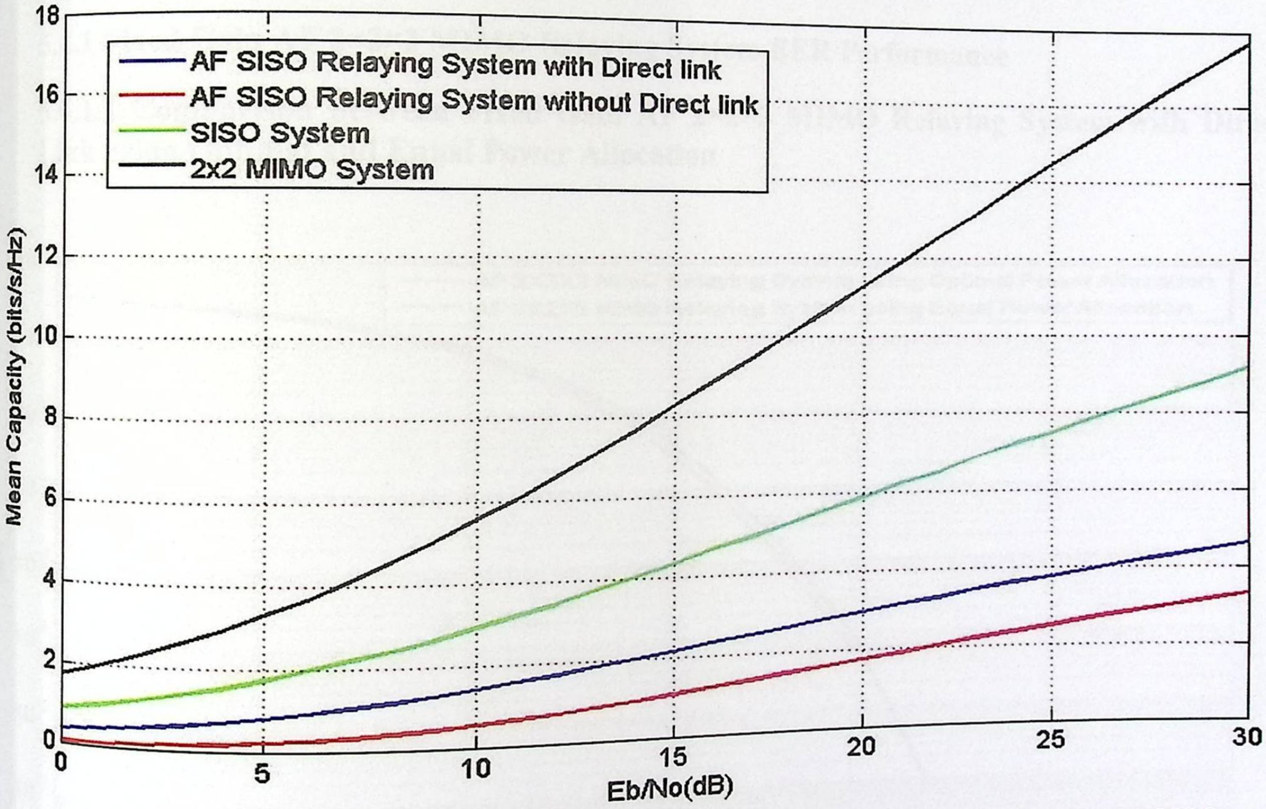


Figure 5.7 Comparison between SISO System, 2×2 MIMO System and Fixed gain AF SISO Relaying System with and without Direct Link using Optimal Power Allocation under Flat Fading Rayleigh Channel in terms of Capacity Performance

In this case, we assume that the E_b/N_o range is [0:1:30] dB and the number of Monte-Carlo iterations is 10,000. The figure shows a comparison between SISO system, 2×2 MIMO system and fixed gain AF SISO relaying system with and without direct link using optimal power allocation under flat fading Rayleigh channel in terms of capacity performance. As we notice, the mean capacity of 2×2 MIMO system is greater one followed by SISO system, fixed gain AF SISO relaying system with and without direct link, respectively, i.e., at E_b/N_o equal 22 dB, the mean capacity of 2×2 MIMO system equals 12.56 bits/s/Hz. While, the mean capacity of SISO system, fixed gain AF SISO relaying system with and without direct link equal 6.842

bits/s/Hz, 3.259 bits/s/Hz and 2.027 bits/s/Hz, respectively. We notice that after E_b/N_o equal 10 dB, the dB difference between fixed gain AF SISO relaying system with and without direct link using optimal power allocation mean capacities is approximately constant and equals 7 dB.

As a result, when E_b/N_o increases, the capacity increases accordingly in all systems. The capacity performance of 2×2 MIMO system is better than the capacity performance of both SISO system and fixed gain AF SISO relaying system with and without direct link using optimal power allocation. Also the capacity performance of SISO system is better than the capacity performance of both AF SISO relaying system with and without direct link using optimal power allocation due to the assumption that the source is remain silent during relay transmit symbols, and half of the channel resources are allocated to the relay for transmission.

The capacity performance of fixed gain AF SISO relaying system with direct link is better than the capacity performance of fixed gain AF SISO relaying system without direct link due to the direct link (S-D) that decreases the amount of losing bits in decoding.

5.4 Simulation Results for Fixed Gain AF 2×2×2 MIMO Relaying System under Flat Fading Rayleigh Channel

5.4.1 Fixed Gain AF 2×2×2 MIMO Relaying System BER Performance

5.4.1.1 Comparison between Fixed Gain AF 2×2×2 MIMO Relaying System with Direct Link using Optimal and Equal Power Allocation

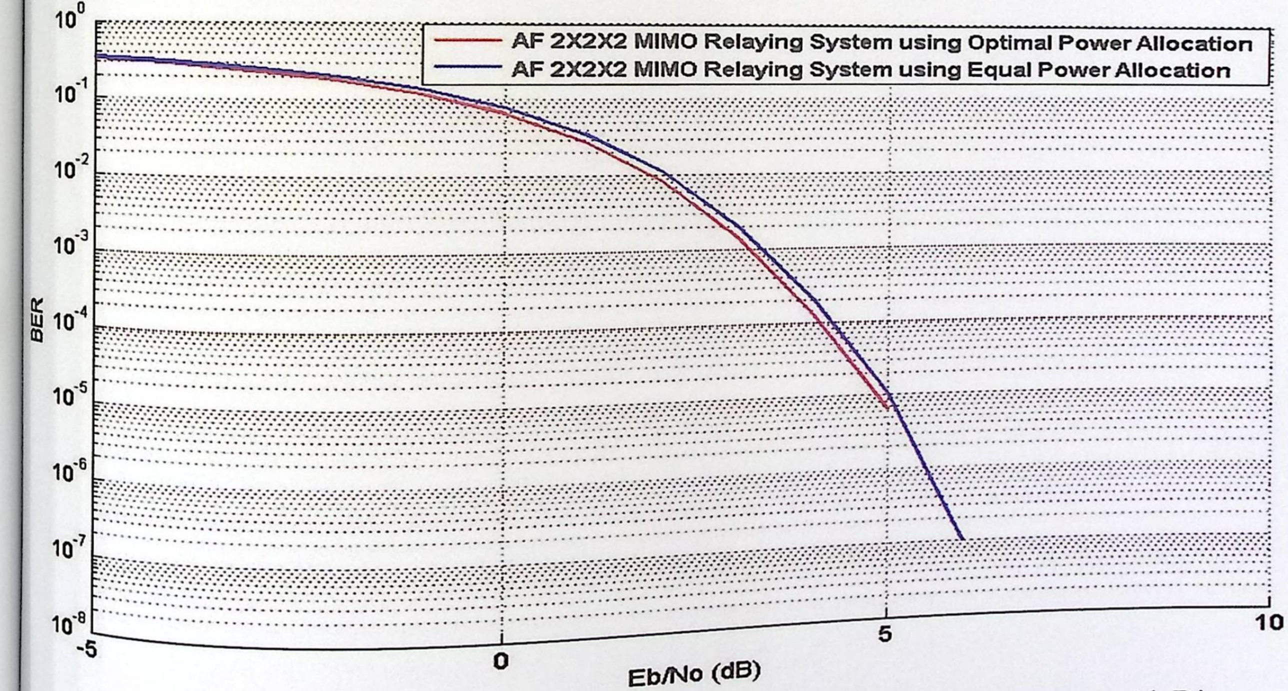


Figure 5.8 Comparison between Fixed gain AF 2×2×2 MIMO Relaying System with Direct Link using Optimal and Equal Power Allocation under Flat Fading Rayleigh Channel in terms of BER Performance

In this case, we assume that the number of transmitted packets is 10,000 with packet length 1000 bits and the E_b/N_o range is [-5:1:10] dB. Also we assume that, the channel variance equals 1 in both S-R link and R-D link, in order to achieve optimal power allocation ($P_s = \frac{2}{3}P$, $P_r = \frac{1}{3}P$). The channel variance equals 1 in S-R channel and equal 0 in R-D channel to achieve equal power allocation ($P_s = \frac{1}{2}$ P, $P_r = \frac{1}{2}$P). The figure shows a comparison between fixed gain AF 2×2×2 MIMO relaying system with direct link using optimal and equal power allocation under flat fading Rayleigh channel in terms of BER performance.

As the figure shows, the BER performance of fixed gain AF 2×2×2 MIMO relaying system using optimal power allocation is better than the BER performance of fixed gain AF 2×2×2 MIMO relaying system using equal power allocation, i.e., at E_b/N_o equal 3 dB, the BER of fixed gain AF 2×2×2 MIMO relaying system using optimal power allocation equals 1.408×10^{-3}, while the BER of fixed gain AF 2×2×2 MIMO relaying system using equal power allocation equals 1.968×10^{-3}. Also after E_b/N_o equal 2 dB, the dB difference between two systems BER is approximately constant.

As a result, when E_b/N_o increases, the BER decreases accordingly in all systems. The BER performance of fixed gain AF 2×2×2 MIMO relaying system using optimal power allocation decreases the amount of BER rather than using equal power allocation. So when using optimal power allocation, the performance of fixed gain AF 2×2×2 MIMO relaying system becomes more efficient.

5.4.1.2 Comparison between Fixed Gain AF SISO Relaying System, 2×2 MIMO System and Fixed Gain AF 2×2×2 MIMO Relaying System with and without Direct Link using Optimal Power Allocation

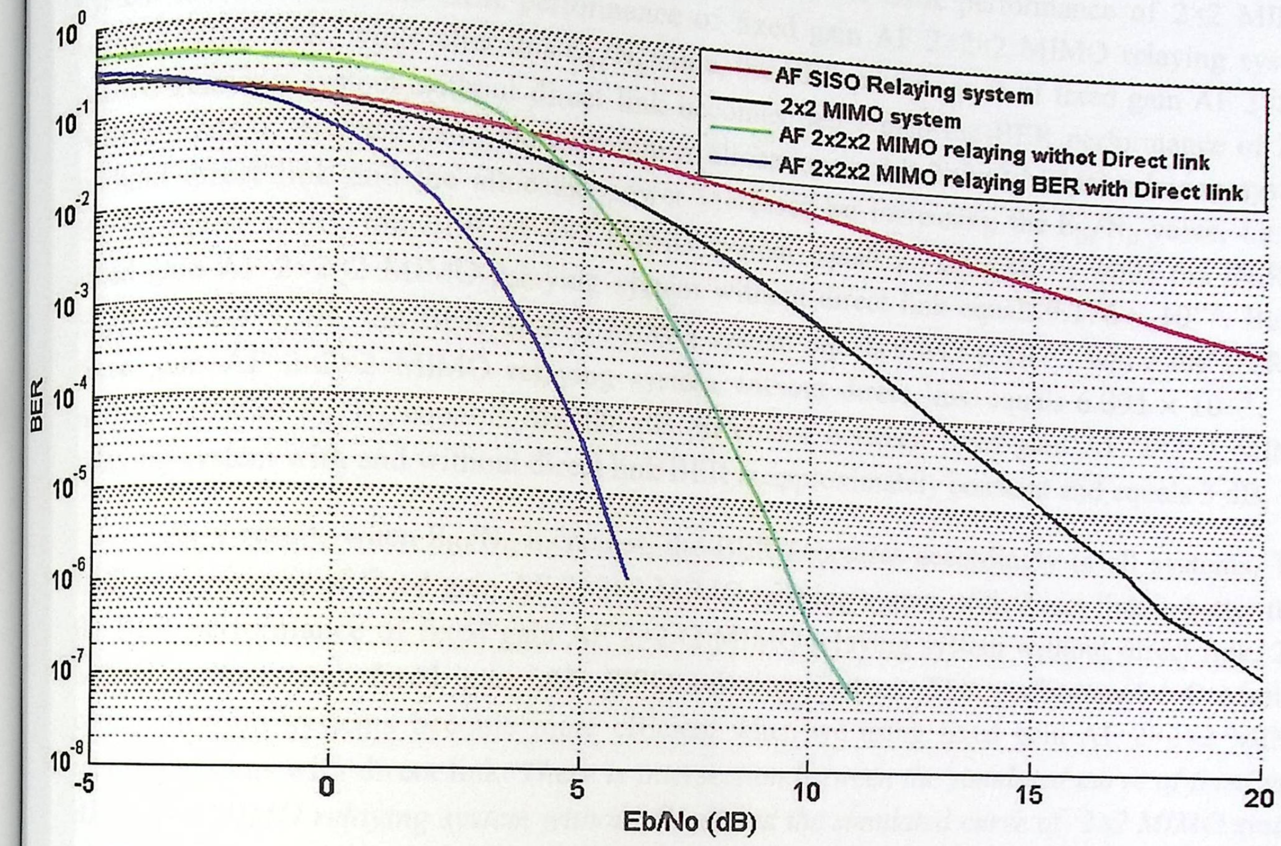


Figure 5.9 Comparison between Fixed Gain AF SISO Relaying System, 2×2 MIMO System and Fixed Gain AF 2×2×2 MIMO Relaying System with and without Direct Link using Optimal Power Allocation under Flat Fading Rayleigh Channel in terms of BER Performance

In this case, we assume that the number of transmitted packets are 2000 with packet length 1000 bits and the E_b/N_0 range is [0:1:20] dB. The figure shows a comparison between fixed gain AF SISO relaying system, 2×2 MIMO system and fixed gain AF 2×2×2 MIMO relaying system with and without direct link using optimal power allocation under flat fading Rayleigh channel in terms of BER performance.

As the figure shows, the BER performance of fixed gain AF 2×2×2 MIMO relaying system with direct link is better than the BER performance of all other systems, i.e., 2×2 MIMO system, fixed gain AF 2×2×2 MIMO relaying system without direct link and fixed gain AF SISO relaying system. As we notice, at low E_b/N_0 values, i.e., less or equal to 5 dB, the BER of fixed gain AF SISO relaying system is less than the BER of fixed gain AF 2×2×2 MIMO relaying system without direct link. While after this E_b/N_0 value, the BER of fixed gain AF 2×2×2 MIMO relaying system without direct link becomes less than the BER of fixed gain AF SISO relaying system, i.e., at E_b/N_0 equal 2 dB, the BER of fixed gain AF SISO relaying system equals 1.072×10^{-1}, while the BER of fixed gain AF 2×2×2 MIMO relaying system without direct link equals 2.103×10^{-1}. But at E_b/N_0 equal 10 dB, the BER of fixed gain AF SISO relaying system equals 1.725×10^{-2}, while the BER of fixed gain AF 2×2×2 MIMO relaying system without direct link equals 4×10^{-7}.

As we notice, before E_b/N_o equals 4.603 dB, the BER performance of 2×2 MIMO system is better than the BER performance of fixed gain AF 2×2×2 MIMO relaying system without direct link, while after this E_b/N_ovalue, the BER performance of fixed gain AF 2×2×2 MIMO relaying system without direct link becomes better than the BER performance of 2×2 MIMO system, because using optimal power allocation in AF 2×2×2 MIMO relaying system without direct link and the allocated power increases by increasing the E_b/N_o value, i.e., at E_b/N_o equals 5 dB, the BER of 2×2 MIMO system equals 2.729×10^{-2}, while the BER of fixed gain AF 2×2×2 MIMO relaying system without direct link equals 9.176×10^{-2}. But at E_b/N_o equals 7 dB, the BER of 2×2 MIMO system equals 9.643×10^{-3}, while the BER of fixed gain AF 2×2×2 MIMO relaying system without direct link equals 6.891×10^{-4}. We notice that after E_b/N_o equal 5 dB, the dB difference between fixed gain AF 2×2×2 MIMO relaying system with and without direct link BER is approximately constant and equals 3 dB.

As a result, when E_b/N_o increases, the BER decreases accordingly in all systems. The BER performance of fixed gain AF 2×2×2 MIMO relaying system with direct link is better than the BER performance of fixed gain AF 2×2×2 MIMO relaying system without direct link, 2×2 MIMO system and fixed gain AF SISO relaying system. The performance of wireless communication systems become more efficient when we using fixed gain AF 2×2×2 MIMO relaying system with direct link. *There is intersection between the simulated curve of fixed gain AF 2×2×2 MIMO relaying system without direct and the simulated curve of 2×2 MIMO system due to using optimal power allocation in fixed gain AF 2×2×2 MIMO relaying system.*

5.4.2 Fixed Gain AF 2×2×2 MIMO Relaying System Capacity Performance

5.4.2.1 Comparison between Fixed Gain AF 2×2×2 MIMO Relaying System with Direct Link using Optimal and Equal Power Allocation

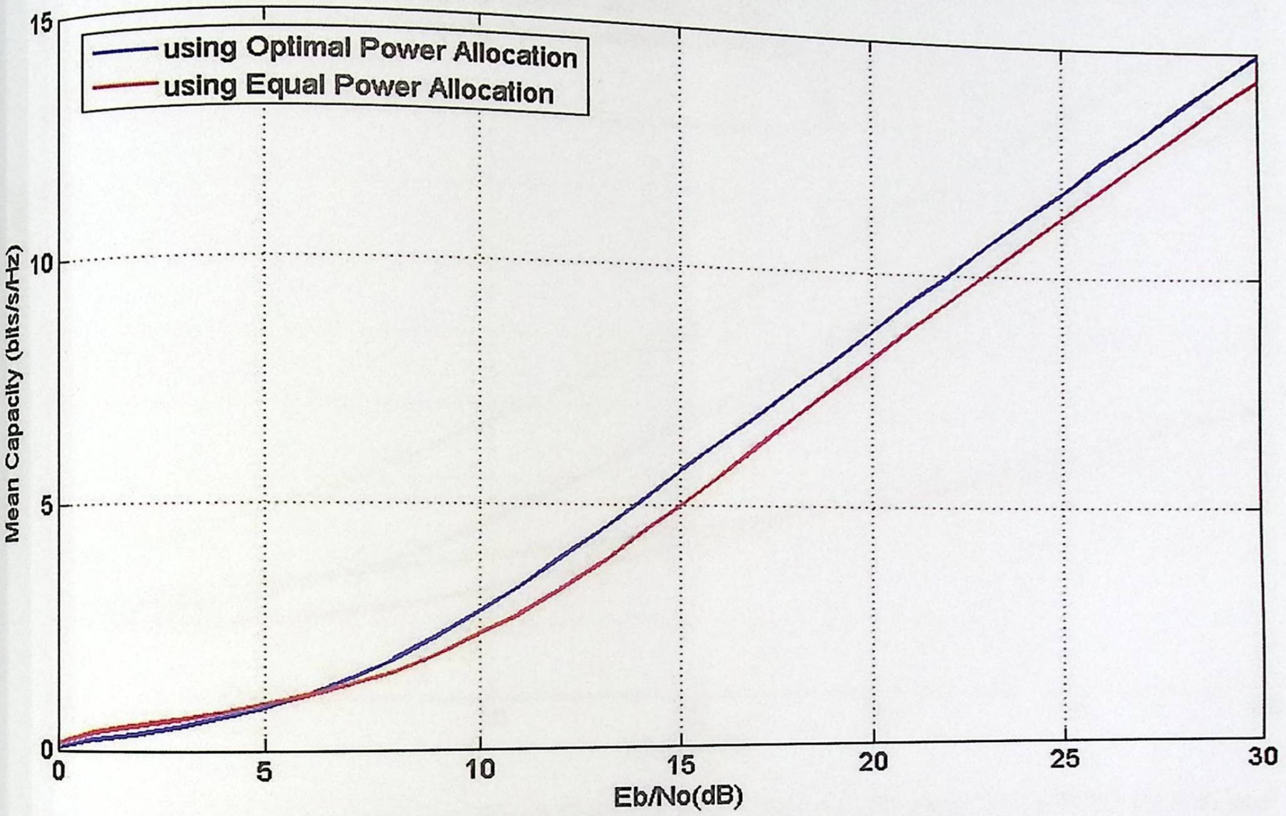


Figure 5.10 Comparison between Fixed gain AF 2×2×2 MIMO Relaying System using Optimal and Equal Power Allocation under Flat Fading Rayleigh Channel in terms of Capacity Performance

In this case, we assume that the E_b/N_o range is [0:1:30] dB and the number of Monte-Carlo iterations are 10,000. The figure shows a comparison between fixed gain AF 2×2×2 MIMO relaying system with direct link using optimal and equal power allocation under flat fading Rayleigh channel in terms of capacity performance. As the figure show, the mean capacity of fixed gain AF 2×2×2 MIMO relaying system using optimal power allocation is greater than the mean capacity of fixed gain AF 2×2×2 MIMO relaying system using equal power allocation, i.e., at E_b/N_o equals 15 dB and 30 dB, the mean capacity of fixed gain AF 2×2×2 MIMO relaying system using optimal power allocation equals 5.715 bits/s/Hz and 14.9 bits/s/Hz, respectively. While the mean capacity of fixed gain AF 2×2×2 MIMO relaying system using equal power allocation equals 4.985 bits/s/Hz and 14.36 bits/s/Hz, respectively. Also after E_b/N_o equals 15dB, the dB difference between the two systems mean capacity is approximately constant and equals 1dB.

As a result, when E_b/N_o increases, the mean capacity increases accordingly in both systems. The capacity performance of fixed gain AF 2×2×2 MIMO relaying system with direct link using optimal power allocation is better than the capacity performance of fixed gain AF 2×2×2 MIMO relaying system with direct link using equal power allocation.

5.4.2.2 Comparison between Fixed Gain AF SISO Relaying System, 2×2 MIMO System and Fixed Gain AF 2×2×2 MIMO Relaying System with and without Direct Link using Optimal Power Allocation

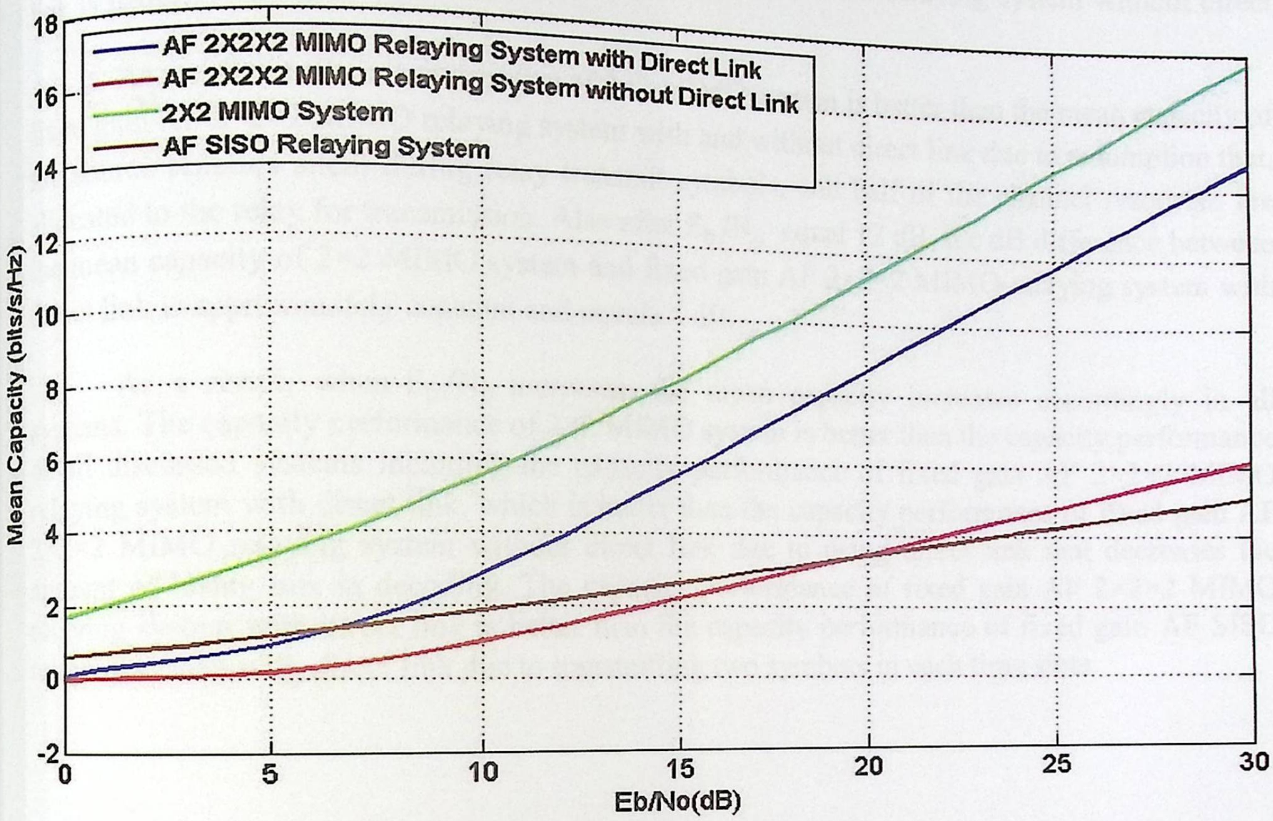


Figure 5.11 Comparison between Fixed Gain AF SISO Relaying System, 2×2 MIMO system and Fixed Gain AF 2×2×2 MIMO Relaying System with and without Direct Link using Optimal Power Allocation under Flat Fading Rayleigh Channel in terms of Capacity Performance

In this case, we assume that the E_b/N_o range is [0:1:30] dB and the number of Monte-Carlo iterations is 10,000. The figure show a comparison between 2×2 MIMO system, fixed gain AF SISO relaying system with direct link using optimal power allocation and fixed gain AF 2×2×2 MIMO relaying system with and without direct link using optimal power allocation under flat fading Rayleigh channel in terms of capacity performance.

As the figure shows, the mean capacity of 2×2 MIMO system is greater than the mean capacity of both fixed gain AF SISO relaying system with direct link using optimal power and fixed gain AF 2×2×2 MIMO relaying system with and without direct link using optimal power allocation, i.e., at E_b/N_o equals 10 dB and 30 dB, the mean capacity of 2×2 MIMO system equals 5.535 bits/s/Hz, 17.72 bits/s/Hz, respectively. While the mean capacity of fixed gain AF 2×2×2 MIMO relaying system with direct link equals 2.849 bits/s/Hz and 14.77 bits/s/Hz, respectively. The mean capacity of fixed gain AF 2×2×2 MIMO relaying system without direct link are equal 1.002 bits/s/Hz and 6 bits/s/Hz, respectively, and the mean capacity of fixed gain AF SISO relaying system equals 1.855 bits/s/Hz and 5.11 bits/s/Hz, respectively. So the mean capacity of fixed gain AF 2×2×2 MIMO relaying system with direct link is greater than the mean capacity of fixed gain AF 2×2×2 MIMO relaying system without direct link. When E_b/N_o less than 20 dB, the mean capacity of fixed gain AF SISO relaying system is better than the mean capacity of fixed gain AF 2×2×2 MIMO relaying system without direct link. When E_b/N_o greater than 20 dB, the capacity of fixed gain AF 2×2×2 MIMO relaying system without direct link is better.

As we notice, the mean capacity of 2×2 MIMO system is better than the mean capacity of fixed gain AF 2×2×2 MIMO relaying system with and without direct link due to assumption that, the source remains silent during relay transmit symbols, and half of the channel resources are allocated to the relay for transmission. Also after E_b/N_o equal 12 dB, the dB difference between the mean capacity of 2×2 MIMO system and fixed gain AF 2×2×2 MIMO relaying system with direct link is approximately constant and equals 4 dB.

As a result, when E_b/N_o increases, the mean capacity increases accordingly in all systems. The capacity performance of 2×2 MIMO system is better than the capacity performance of all discussed systems including the capacity performance of fixed gain AF 2×2×2 MIMO relaying system with direct link, which is better than the capacity performance of fixed gain AF 2×2×2 MIMO relaying system without direct link due to using direct link that decreases the amount of losing bits in decoding. The capacity performance of fixed gain AF 2×2×2 MIMO relaying system with direct link is better than the capacity performance of fixed gain AF SISO relaying system with direct link due to transmitting two symbols in each time slots.

5.5 Simulation Results for Fixed Gain AF 4×4×4 MIMO Relaying System under Flat Fading Rayleigh Channel

5.5.1 Fixed Gain AF 4×4×4 MIMO Relaying System BER Performance

5.6.1.1 Comparison between Fixed Gain AF 4×4×4 MIMO Relaying System with Direct Link using Optimal and Equal Power Allocation

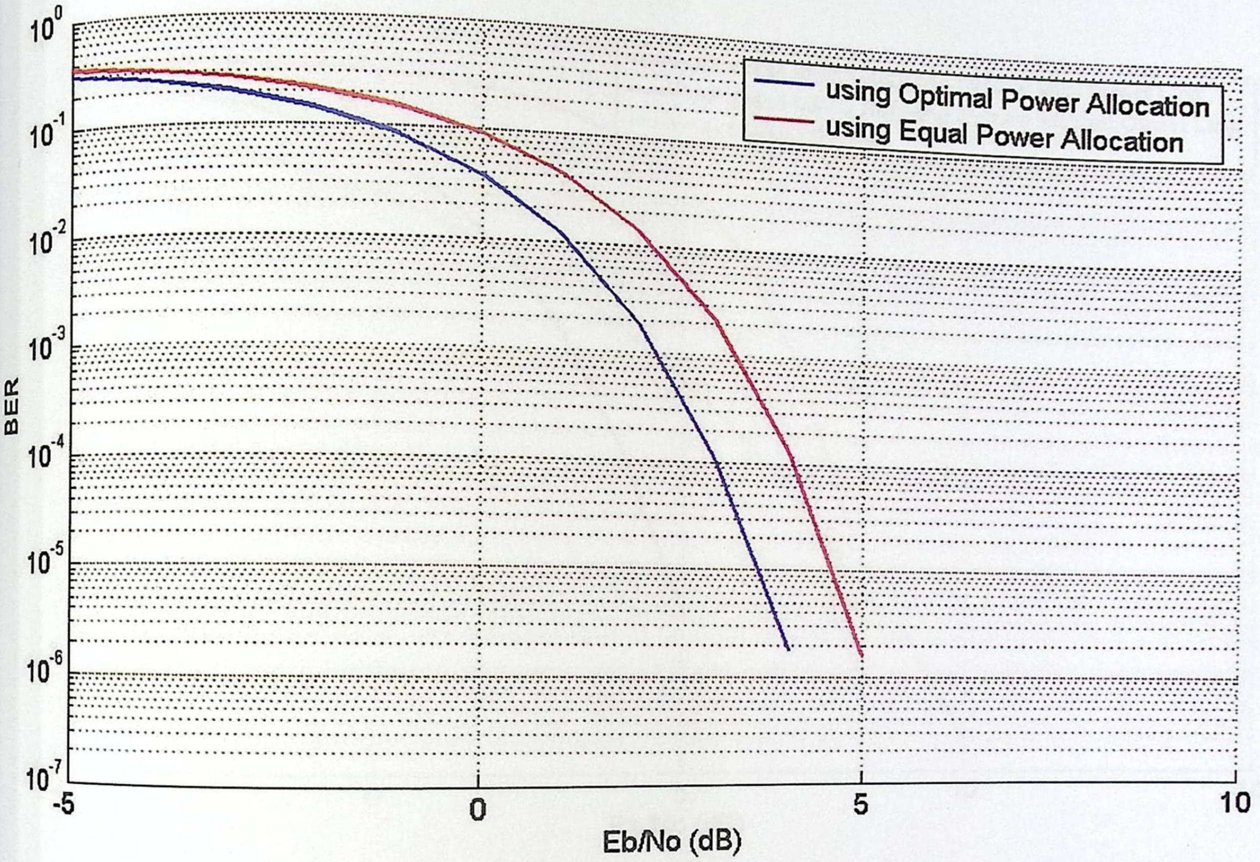


Figure 5.12 Comparison between Fixed Gain AF 4×4×4 MIMO Relaying System with Direct Link using Optimal and Equal Power Allocation under Flat Fading Rayleigh Channel in terms of BER Performance

In this case, we assume that the number of transmitted packets is 10,000 with packet length 1000 bits and the E_b/N_o range is [-5:1:10] dB. The figure show a comparison between fixed gain AF 4×4×4 MIMO relaying system with direct link using optimal and equal power allocation under flat fading Rayleigh channel in terms of BER performance. As the figure show, the BER performance of fixed gain AF 4×4×4 MIMO relaying system using optimal power allocation is better than using equal power allocation, i.e., at E_b/N_o equal 1 dB and 3 dB, the BER of fixed gain AF 4×4×4 MIMO relaying system using optimal power allocation are equal 1.166×10^{-2} and 1.084×10^{-4}, respectively, and the BER of fixed gain AF 4×4×4 MIMO relaying system using equal power allocation equals 4.292×10^{-2} and 2.04×10^{-3}, respectively. Also after E_b/N_o equals 2 dB, the dB difference between two systems BER is approximately constant and equal 1 dB. To achieve BER equals 1.084×10^{-4} for fixed gain AF 4×4×4 MIMO relaying system using optimal and equal power allocation, we need 3 dB and 4.042 dB, respectively.

As a result, when E_b/N_o increases, the BER decreases accordingly in all systems. The BER performance of fixed gain AF 4×4×4 MIMO relaying system using optimal power allocation decreasing the amount of BER rather than using equal power allocation due to that the power allocates in S-D link is more than the power allocates in R-D link, this decreases the probability of error in decoding. So the performance of fixed gain AF 4×4×4 MIMO relaying system become more efficient when using optimal power allocation.

5.6.1.2 Comparison between 4×4 MIMO System and Fixed Gain AF 4×4×4 MIMO Relaying System with and without Direct Link using Optimal Power Allocation

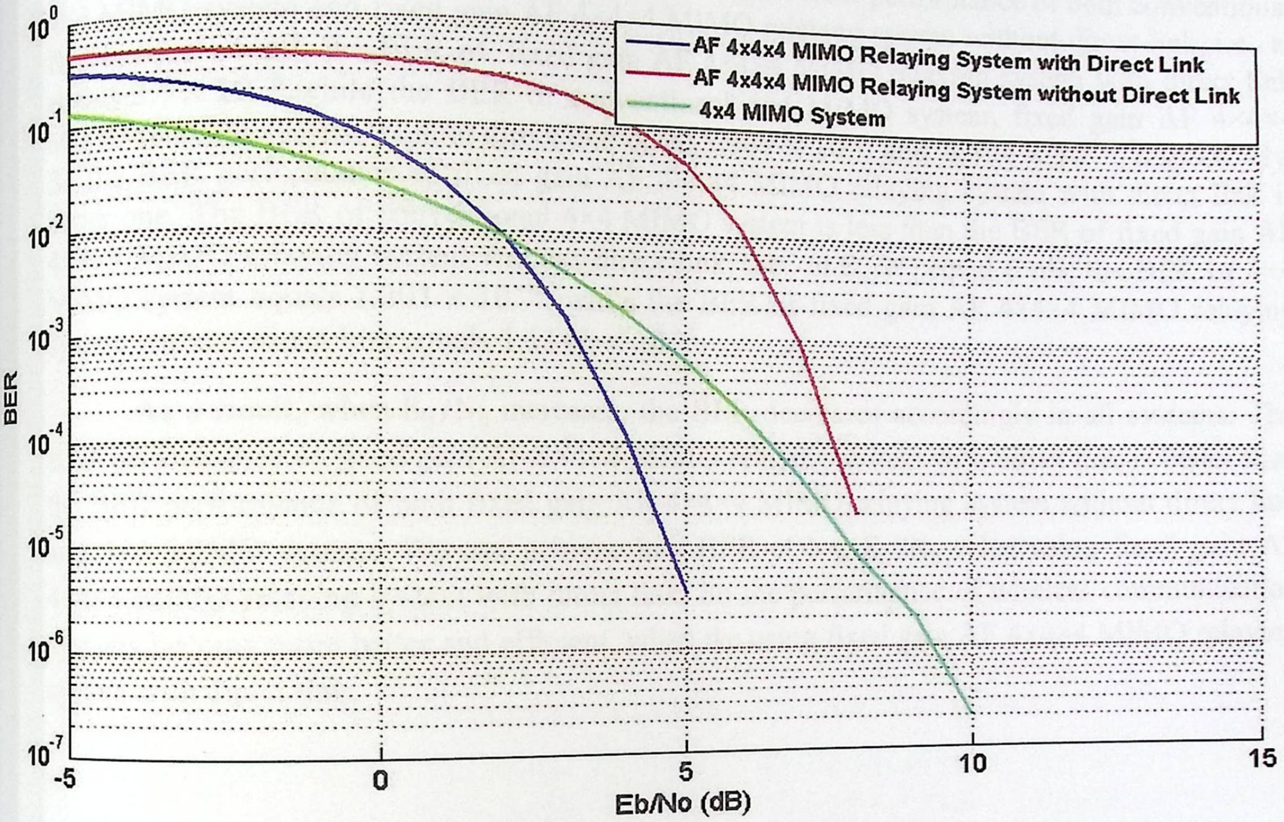


Figure 5.13 Comparison between 4×4 MIMO System and Fixed Gain AF 4×4×4 MIMO Relaying system with and without Direct Link using Optimal Power Allocation under Flat Fading Rayleigh Channel in terms of BER Performance

In this case, we assume the number of transmitted packets is 200 with packet length 10,000 bits and the E_b/N_o range is [-5:1:15] dB. The figure show a comparison between 4×4 MIMO system and fixed gain AF 4×4×4 MIMO relaying system with and without direct link using optimal power allocation under flat fading Rayleigh channel in terms of BER performance. It's clear that, after E_b/N_o equals 3 dB, the dB difference between fixed gain AF 4×4×4 MIMO relaying system with and without direct link BER is approximately constant and equals 4 dB.

As the figure shows, before E_b/N_o equal 2 dB, the BER performance of 4×4 MIMO system is better than the BER performance of fixed gain AF 4×4×4 MIMO relaying system with direct link, while after this E_b/N_ovalue, the BER performance of fixed gain AF 4×4×4 MIMO relaying system with direct link becomes better than the BER performance of 4×4 MIMO system, due to the using of optimal power allocation in AF 4×4×4 MIMO relaying system without direct link and the value of the allocated power increases by increasing the E_b/N_ovalue, i.e., at E_b/N_o equals 0 dB, the BER of 4×4 MIMO system equals 2.695×10^{-2}, while the BER of fixed gain AF 4×4×4 MIMO relaying system with direct link equals 6.609×10^{-2}. But at E_b/N_0 equal 5 dB, the BER of 4×4 MIMO system is equal 5.969×10^{-4}, while the BER of fixed gain AF 4×4×4 MIMO relaying system with direct link equals 3.4×10^{-6}. This mean achieve low BER at low E_b/N_0 value using fixed gain AF 4×4×4 MIMO relaying system with direct link .

As we notice, after the E_b/N_0 equal 2 dB, the BER performance of fixed gain AF 4×4×4 MIMO relaying system with direct link is better than the BER performance of both conventional 4×4 MIMO system and fixed gain AF 4×4×4 MIMO relaying system without direct link, i.e., at E_b/N_0 equals 5 dB, the BER of fixed gain AF 4×4×4 MIMO relaying system with direct link equals 3.4×10^{-6},while the BER of conventional 4×4 MIMO system, fixed gain AF 4×4×4 MIMO relaying system without direct link equal 5.969×10^{-4} and 4.994×10^{-2}, respectively. So the BER performance of fixed gain AF 4×4×4 MIMO relaying system with direct link is better one. The BER of conventional 4×4 MIMO system is less than the BER of fixed gain AF 4×4×4 MIMO relaying system without direct link, .i.e., at E_b/N_0 equal 6 dB, the BER of 4×4 MIMO system equals 1.801×10^{-4}, while the BER of fixed gain AF 4×4×4 MIMO relaying system without direct link equals 1.1146×10^{-2}.

As a result, when E_b/N_0 increases, the BER decreases accordingly in all systems. The BER performance of fixed gain AF 4×4×4 MIMO relaying system with direct link is better than the BER performance of both fixed gain AF 4×4×4 MIMO relaying system without direct link and 4×4 MIMO system. We can achieve low BER at low E_b/N_0 value using fixed gain AF 4×4×4 MIMO relaying system with direct link. So the performance of wireless communication systems become more better and efficient, when we using fixed gain AF 4×4×4 MIMO relaying system with direct link.

5.5.2 Fixed Gain AF 4×4×4 MIMO Relaying System Capacity Performance

5.5.2.1 Comparison between Fixed Gain AF 4×4×4 MIMO Relaying System with Direct Link using Optimal and Equal Power Allocation

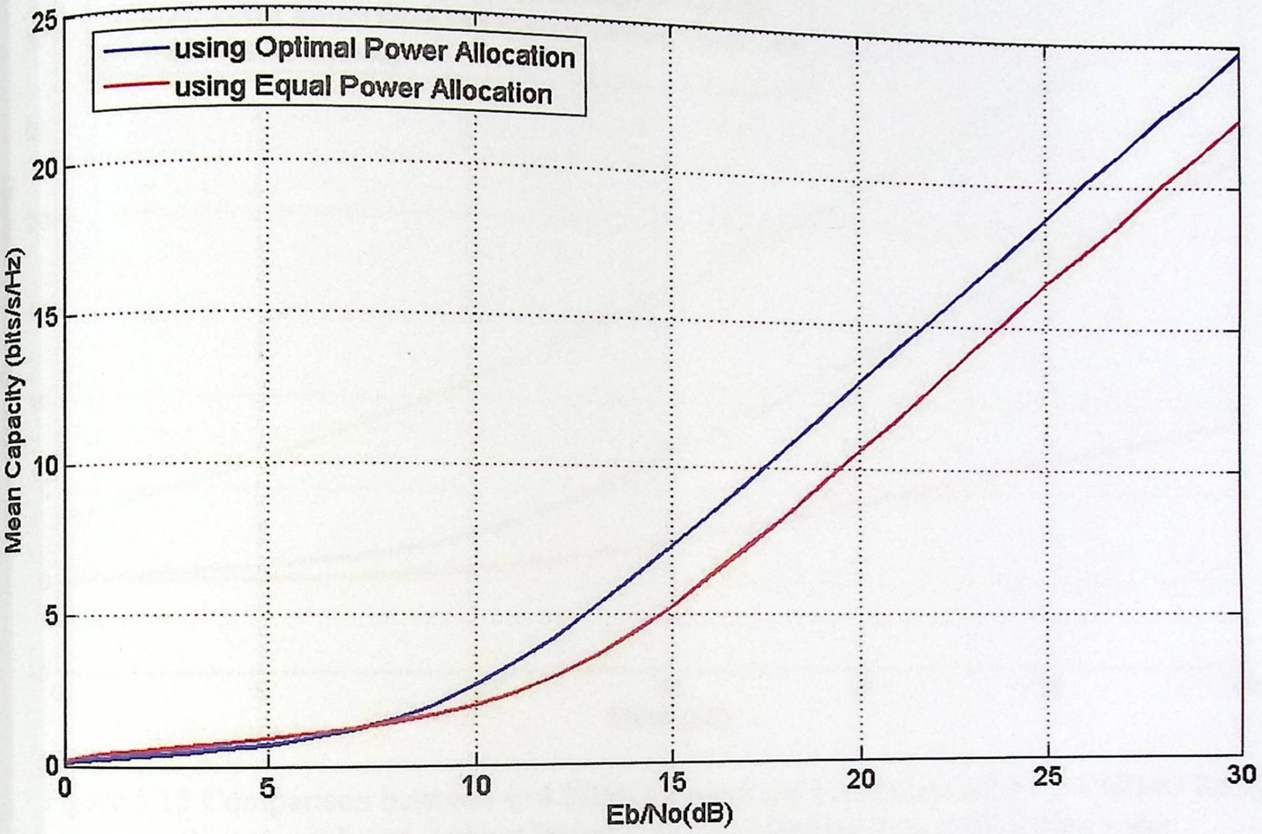


Figure 5.14 Comparison between Fixed Gain AF 4×4×4 MIMO Relaying System using Optimal and Equal Power Allocation under Flat Fading Rayleigh Channel in terms of Capacity Performance

In this case, we assume that the E_b/N_o range is [0:1:30] dB and the number of Monte-Carlo iterations is 10,000. The figure show a comparison between fixed gain AF 4×4×4 MIMO relaying system with direct link using optimal and equal power allocation under flat fading Rayleigh channel in terms of capacity performance. As the figure show, the mean capacity of fixed gain AF 4×4×4 MIMO relaying system using optimal power allocation is greater than the mean capacity of fixed gain AF 4×4×4 MIMO relaying system using equal power allocation, i.e., at E_b/N_o equals 15 dB and 30 dB, the mean capacity of fixed gain AF 4×4×4 MIMO relaying system using optimal power allocation equals 7.287 bits/s/Hz and 24.74 bits/s/Hz, respectively, while the mean capacity of fixed gain AF 4×4×4 MIMO relaying system using equal power allocation equals 5.216 bits/s/Hz and 22.36 bits/s/Hz, respectively. Also after E_b/N_o equals 15 dB, the dB difference between the two systems mean capacity is approximately constant and equals 2 dB.

As a result, when E_b/N_o increases, the mean capacity increases accordingly in both systems. The capacity performance of fixed gain AF 4×4×4 MIMO relaying system with direct link using optimal power allocation is better than the capacity performance of fixed gain AF 4×4×4 MIMO relaying system with direct link using equal power allocation.

5.5.2.2 Comparison between 4x4 MIMO System and Fixed Gain AF 4x4x4 MIMO Relaying System with and without Direct Link using Optimal Power Allocation

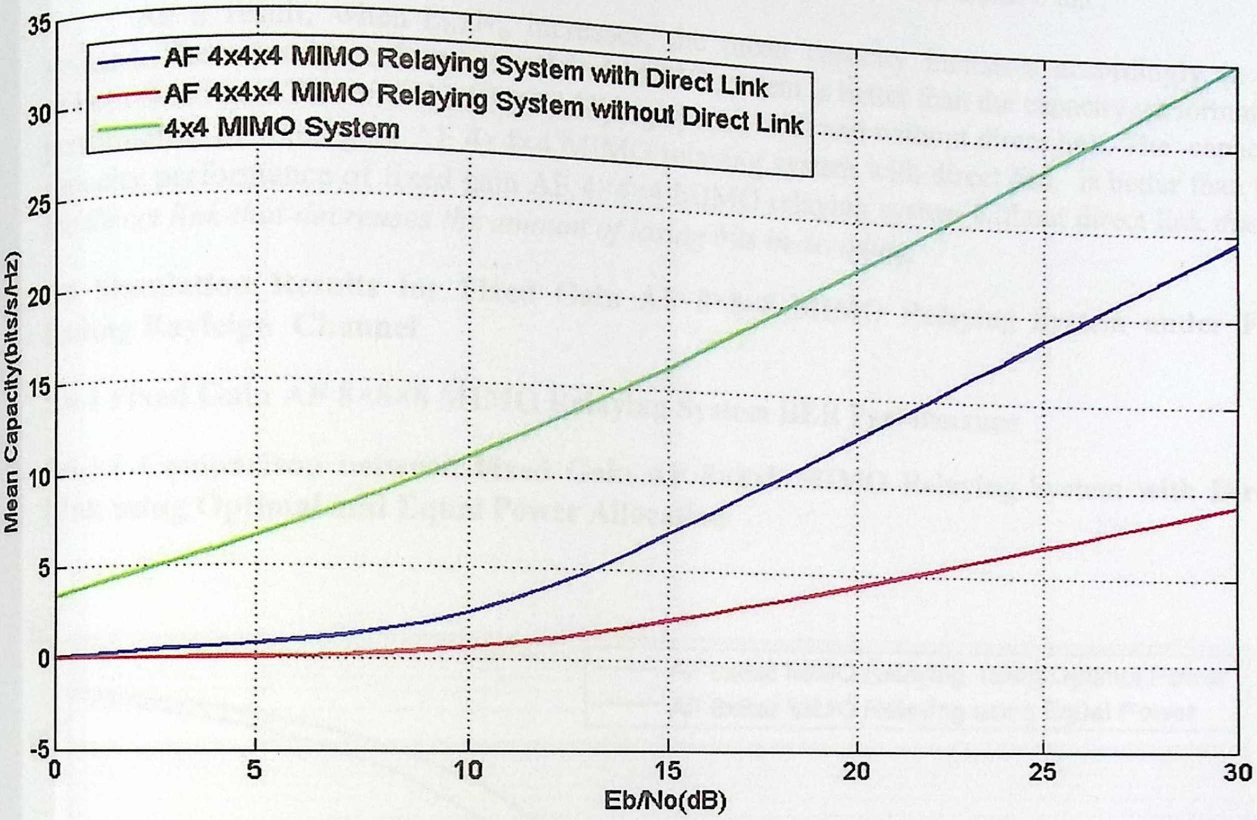


Figure 5.15 Comparison between 4×4 MIMO System and Fixed Gain AF 4×4×4 MIMO Relaying System with and without Direct Link using Optimal Power Allocation under Flat Fading Rayleigh Channel in terms of Capacity Performance

In this case, we assume that the E_b/N_o range is [0:1:30] dB and the number of Monte-Carlo iterations is 10,000. The figure show a comparison between 4×4 MIMO system and fixed gain AF 4×4×4 MIMO relaying system with and without direct link using optimal power allocation under flat fading Rayleigh channel in terms of capacity performance.

As the figure show, the mean capacity of 4×4 MIMO system is greater than the mean capacity of both fixed gain AF 4×4×4 MIMO relaying system with and without direct link using optimal power allocation, i.e., at E_b/N_o equals 15 dB and 30 dB, the mean capacity of 4×4 MIMO system equals 16.2 bits/s/Hz and 34.92 bits/s/Hz, respectively, while the mean capacity of fixed gain AF 4×4×4 MIMO relaying system with direct link equals 7.022 bits/s/Hz and 24.48 bits/s/Hz, respectively, and the mean capacity of fixed gain AF 4×4×4 MIMO relaying system without direct link equals 2.195 bits/s/Hz and 9.193 bits/s/Hz, respectively. So the mean capacity of fixed gain AF 4×4×4 MIMO relaying system with direct link is greater than the mean capacity of fixed gain AF 4×4×4 MIMO relaying system without direct link.

As we notice, the capacity performance of 4×4 MIMO system is better than the capacity performance of both fixed gain AF 4×4×4 MIMO relaying system with and without direct link *due to assumption that the source remains silent during relay transmit symbols, and half of the* *channel resources are allocated to the relay for transmission.* Also after E_b/N_o equals 10 dB, the dB difference between the mean capacity of 4×4 MIMO system and fixed gain AF 4×4×4 MIMO relaying system with direct link is approximately constant and equal 8 dB .

As a result, when E_b/N_o increases, the mean capacity increases accordingly in all systems. The capacity performance of 4×4 MIMO system is better than the capacity performance of both fixed gain AF 4×4×4 MIMO relaying system with and without direct link. The capacity performance of fixed gain AF 4×4×4 MIMO relaying system with direct link is better than the capacity performance of fixed gain AF 4×4×4 MIMO relaying system without direct link *due to the direct link that decreases the amount of losing bits in decoding.*

5.6 Simulation Results for Fixed Gain AF 8×8×8 MIMO Relaying System under Flat Fading Rayleigh Channel

5.6.1 Fixed Gain AF 8×8×8 MIMO Relaying System BER Performance

5.6.1.1 Comparison between Fixed Gain AF 8×8×8 MIMO Relaying System with Direct Link using Optimal and Equal Power Allocation

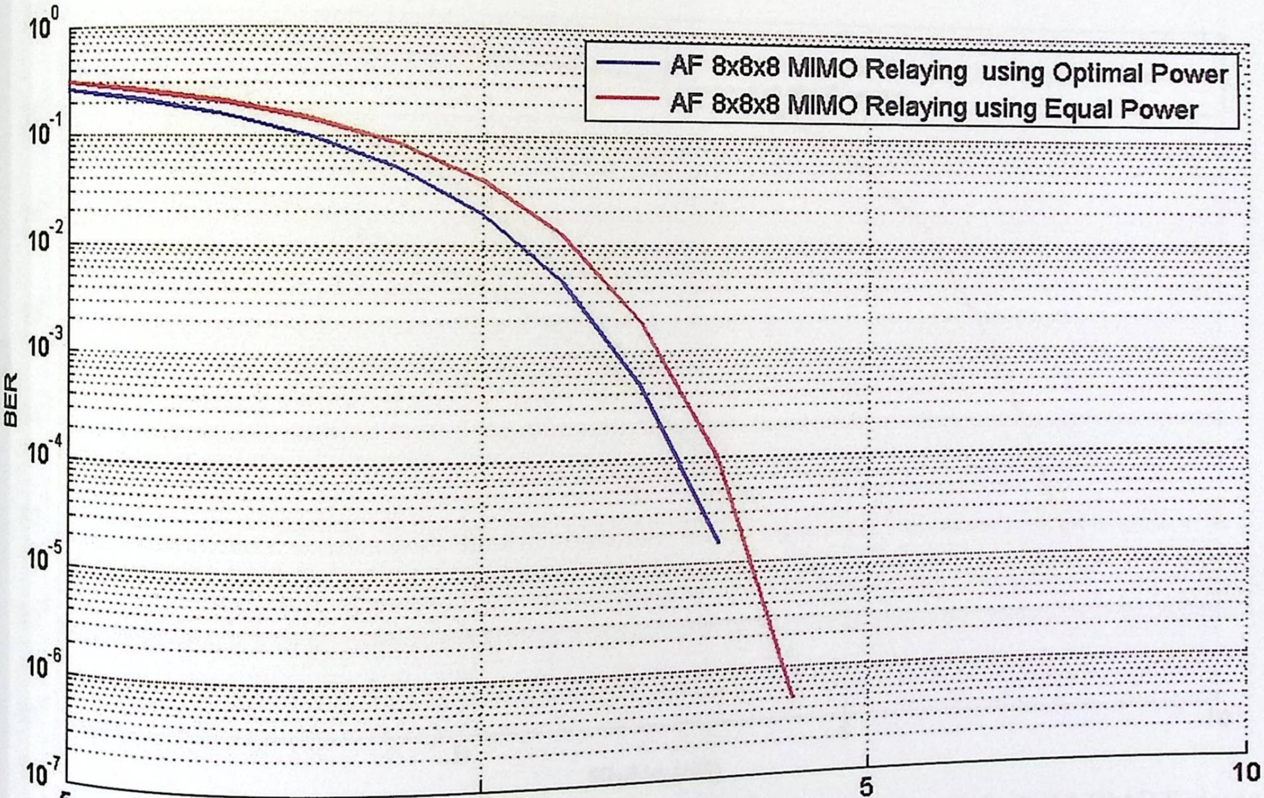


Figure 5.16 Comparison between Fixed Gain AF 8×8×8 MIMO Relaying System with Direct Link using Optimal and Equal Power Allocation under Flat Fading Rayleigh Channel in terms of BER Performance

In this case, we assume that the number of transmitted packets are 10,000 with packet length 1000 bits and the E_b/N_o range is [-5:1:10] dB. The figure shows a comparison between fixed gain AF 8×8×8 MIMO relaying system with direct link using optimal and equal power allocation under flat fading Rayleigh channel in terms of BER performance. As the figure show, the BER performance of fixed gain AF 8×8×8 MIMO relaying system using optimal power allocation is better than the BER performance of fixed gain AF 8×8×8 MIMO relaying system using equal power allocation, i.e., at E_b/N_o equal 2 dB, the BER of fixed gain AF 8×8×8 MIMO relaying system using optimal power allocation equals 4.645×10^{-4}, while the BER of fixed gain AF 8×8×8 MIMO relaying system using equal power allocation equals 1.857×10^{-3}. Also after E_b/N_o equals 0 dB, the dB difference between two systems BER is approximately constant and equal 1 dB.

As a result, when E_b/N_o increases, the BER decreases accordingly in all systems. The BER performance of fixed gain AF 8×8×8 MIMO relaying system using optimal power allocation decreases the amount of BER rather than using equal power allocation. So when using optimal power allocation, the performance of fixed gain AF 8×8×8 MIMO relaying system become more efficient.

5.6.1.2 Comparison between 8×8 MIMO System and Fixed Gain AF 8×8×8 MIMO Relaying System with and without Direct Link using Optimal Power Allocation

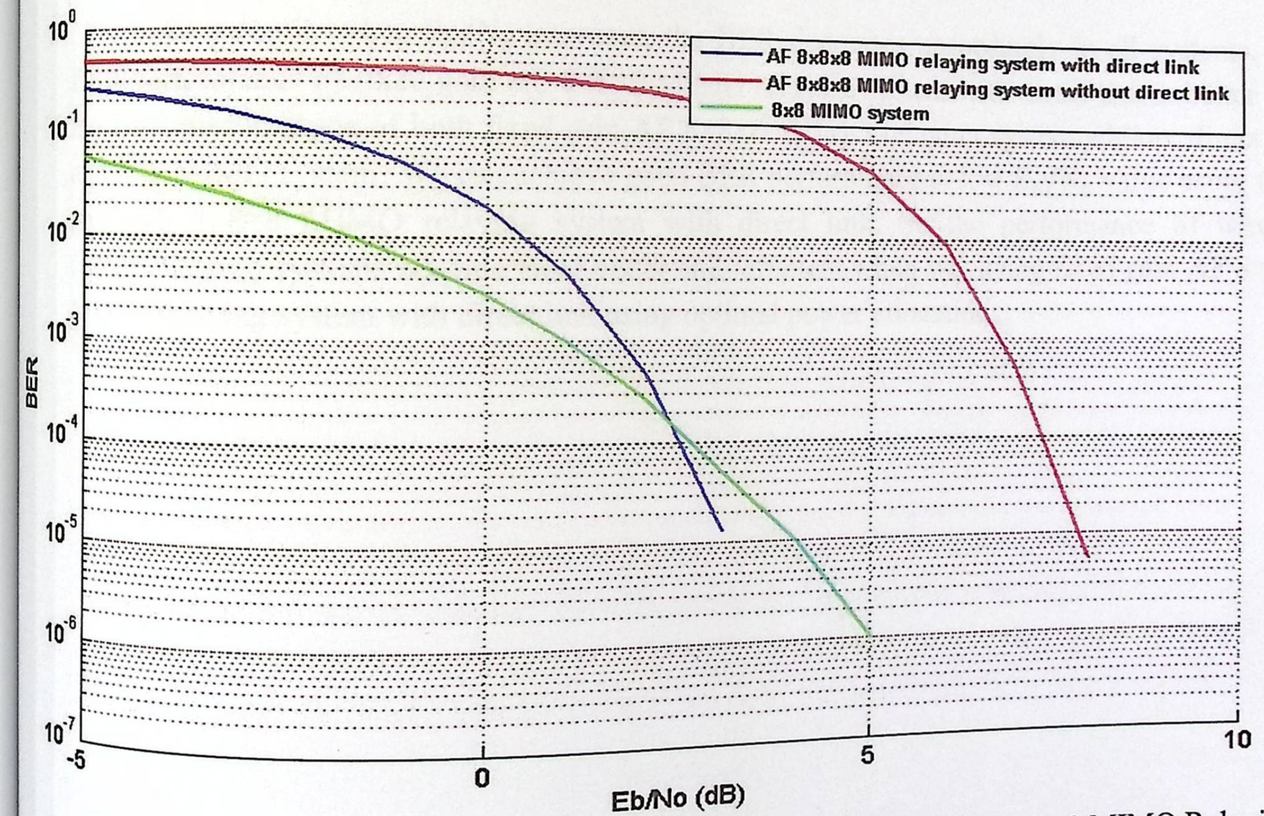


Figure 5.17 Comparison between 8×8 MIMO System and Fixed Gain AF 8×8×8 MIMO Relaying System with and without Direct Link using Optimal Power Allocation under Flat Fading Rayleigh Channel in terms of BER Performance

In this case, we assume that the number of transmitted packets is 200 packets with packet length 10,000 bits and the E_b/N_o range is [-5:1:10] dB. The figure show a comparison between 8×8 MIMO system and fixed gain AF 8×8×8MIMO relaying system with and without direct link using optimal power allocation under flat fading Rayleigh channel in terms of BER performance.

As the figure shows, before E_b/N_o equals 2.288 dB, the BER performance of 8×8 MIMO system is better than the BER performance of fixed gain AF 8×8×8 MIMO relaying system with direct link, i.e., at E_b/N_o equals 0 dB, the BER of 8×8 MIMO system equals 2.681×10^{-3}, while the BER of fixed gain AF 8×8×8 MIMO relaying system with direct link equals 1.903×10^{-2}.

As we notice, after the E_b/N_o equals 2.288 dB, the BER performance of fixed gain AF 8×8×8 MIMO relaying system with direct link is better than the BER performance of both conventional 8×8 MIMO system and fixed gain AF 8×8×8 MIMO relaying system without direct link, i.e., at E_b/N_o equals 3 dB, the BER of fixed gain AF 8×8×8 MIMO relaying system with direct link is equals 1.3×10^{-5}, while the BER of conventional 8×8 MIMO system, fixed gain AF 8×8×8 MIMO relaying system without direct link equal 4.9×10^{-5} and 1.9×10^{-1}, respectively. So the BER of fixed gain AF 8×8×8 MIMO relaying system with direct link is the minimum. The BER of conventional 8×8 MIMO system is less than the BER of fixed gain AF 8×8×8 MIMO relaying system without direct link.

As a result, when E_b/N_o increases, the BER decreases accordingly in all systems. The BER performance of fixed gain AF 8×8×8 MIMO relaying system with direct link is better than the BER performance of both fixed gain AF 8×8×8 MIMO relaying system without direct link and 8×8 MIMO system. We can achieve good BER performance at low E_b/N_o value using fixed gain AF 8×8×8 MIMO relaying system with direct link. So the performance of wireless communication systems become more better and efficient when we using fixed gain AF 8×8×8 MIMO relaying system with direct link using optimal power allocation.

5.6.2 Fixed Gain AF 8x8x8 MIMO Relaying System Capacity Performance

5.6.2.1 Comparison between Fixed Gain AF 8×8×8 MIMO Relaying System with Direct Link using Optimal and Equal Power Allocation

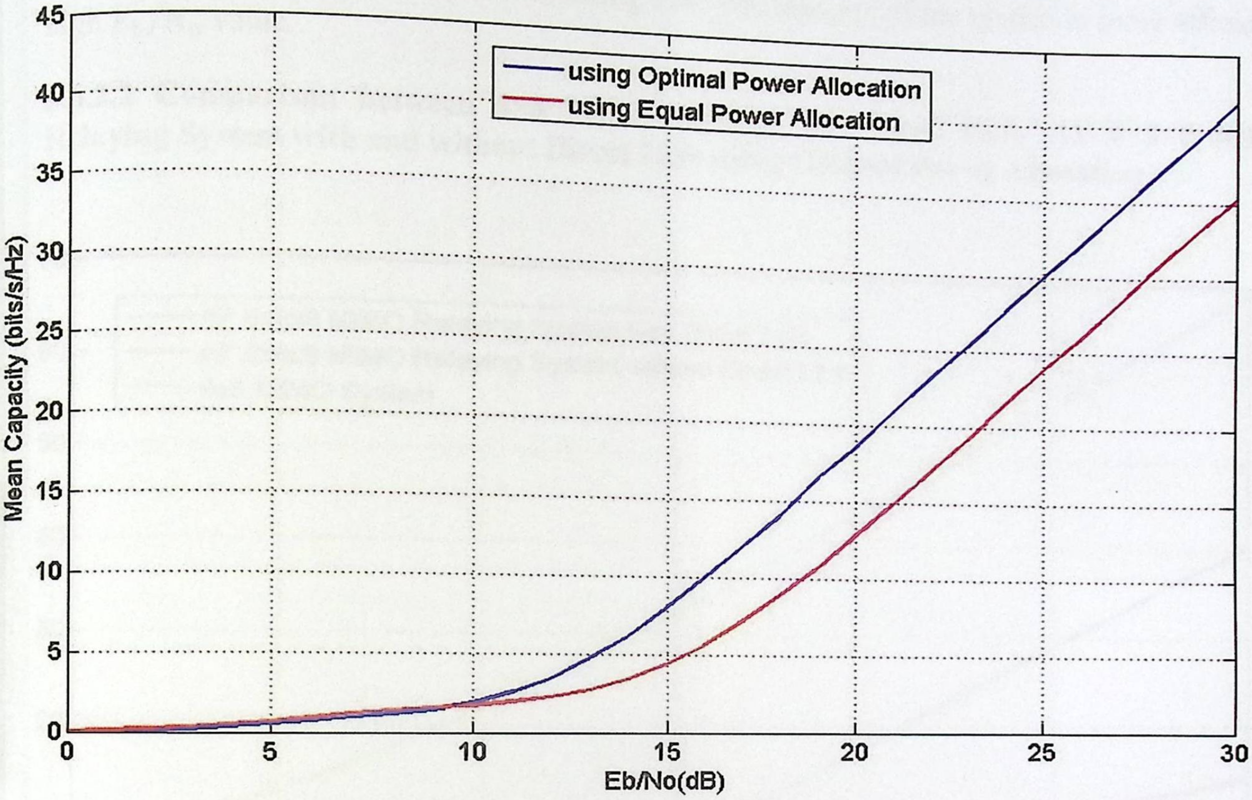


Figure 5.18 Comparison between Fixed Gain AF 8×8×8 MIMO Relaying System with Direct Link using Optimal and Equal Power Allocation under Flat Fading Rayleigh Channel in terms of Capacity Performance

In this case, we assume that the E_b/N_o range is [0:1:30] dB and the number of Monte-Carlo iterations are 10,000. The figure show a comparison between fixed gain AF 8×8×8 MIMO relaying system with direct link using optimal and equal power allocation under flat fading Rayleigh channel in terms of capacity performance. As the figure shows, the mean capacity of fixed gain AF 8×8×8 MIMO relaying system using optimal power allocation is greater than the mean capacity of fixed gain AF 8×8×8 MIMO relaying system using equal power allocation, i.e., at E_b/N_o equals 15 dB and 30 dB, the mean capacity of fixed gain AF 8×8×8 MIMO relaying system using optimal power allocation equals 8.008 bits/s/Hz and 41.69 bits/s/Hz, respectively, while the mean capacity of fixed gain AF 8×8×8 MIMO relaying system using equal power allocation equals 4.385 bits/s/Hz and 35.35 bits/s/Hz, respectively. Also after E_b/N_o equals 21 dB, the dB difference between the two system mean capacities of is approximately constant and equals 2.71dB.

As a result, when E_b/N_o increases, the capacity increases accordingly in all systems. The capacity performance of fixed gain AF 8×8×8 MIMO relaying system with direct link using optimal power allocation is better than using equal power allocation due to the power allocation in S-D link is more than the power allocation in R-D link, this increases the probability of correct decoding, so decreases the amount of losing bits. The capacity of the system is more efficient at high E_b/N_o value.

5.6.2.2 Comparison between 8×8 MIMO System and Fixed Gain AF 8×8×8 MIMO Relaying System with and without Direct Link using Optimal Power Allocation

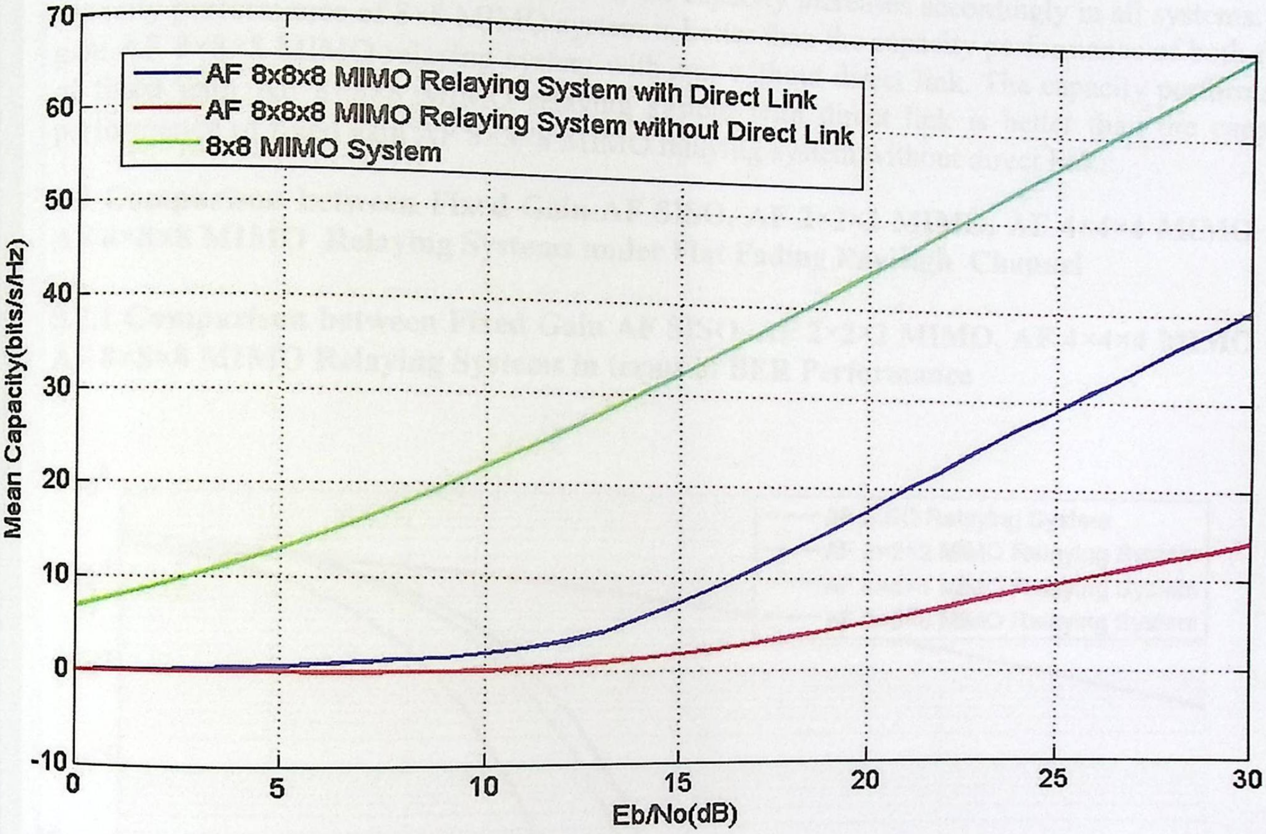


Figure 5.19 Comparison between 8×8 MIMO System and Fixed Gain AF 8×8×8 MIMO Relaying System with and without Direct Link using Optimal Power Allocation under Flat Fading Rayleigh Channel in terms of Capacity Performance

In this case, we assume the that E_b/N_o range is [0:1:30] dB and the number of Monte-Carlo iterations is 10,000. The figure shows a comparison between 8×8 MIMO system and AF 8×8×8 MIMO relaying system with and without direct link using optimal power allocation under flat fading Rayleigh channel in terms of capacity performance.

As the figure show, the mean capacity of 8×8 MIMO system is greater than the mean capacity of fixed gain AF 8×8×8 MIMO relaying system with and without direct link, i.e., at E_b/N_o equals 15 dB and 30 dB, the mean capacity of 8×8 MIMO system equals 32.31 bits/s/Hz and 69.29 bits/s/Hz, respectively, while the mean capacity of fixed gain AF 8×8×8 MIMO relaying system with direct link equals 7.32 bits/s/Hz and 40.52 bits/s/Hz, respectively, and the mean capacity of fixed gain AF 8×8×8 MIMO relaying system without direct link equals 1.744 bits/s/Hz and 14.19 bits/s/Hz, respectively.

As we notice, the mean capacity of 8×8 MIMO system is greater than the mean capacity of both fixed gain AF 8×8×8 MIMO relaying system with and without direct link due to assumption that the source remains silent during relay transmits symbols, and half of the channel resources are allocated to the relay for transmission. Also, after E_b/N_o equals 17 dB, the dB difference between the mean capacity of 8×8 MIMO system and fixed gain AF 8×8×8 MIMO relaying system with direct link is approximately constant and equals 11.971dB.

As a result, when E_b/N_o increases, the capacity increases accordingly in all systems. The capacity performance of 8×8 MIMO system is better than the capacity performance of both fixed gain AF 8×8×8 MIMO relaying system with and without direct link. The capacity performance of fixed gain AF 8×8×8 MIMO relaying system with direct link is better than the capacity performance of fixed gain AF 8×8×8 MIMO relaying system without direct link.

5.7 Comparison between Fixed Gain AF SISO, AF 2×2×2 MIMO, AF 4×4×4 MIMO and AF 8×8×8 MIMO Relaying Systems under Flat Fading Rayleigh Channel

5.7.1 Comparison between Fixed Gain AF SISO, AF 2×2×2 MIMO, AF 4×4×4 MIMO and AF 8×8×8 MIMO Relaying Systems in terms of BER Performance

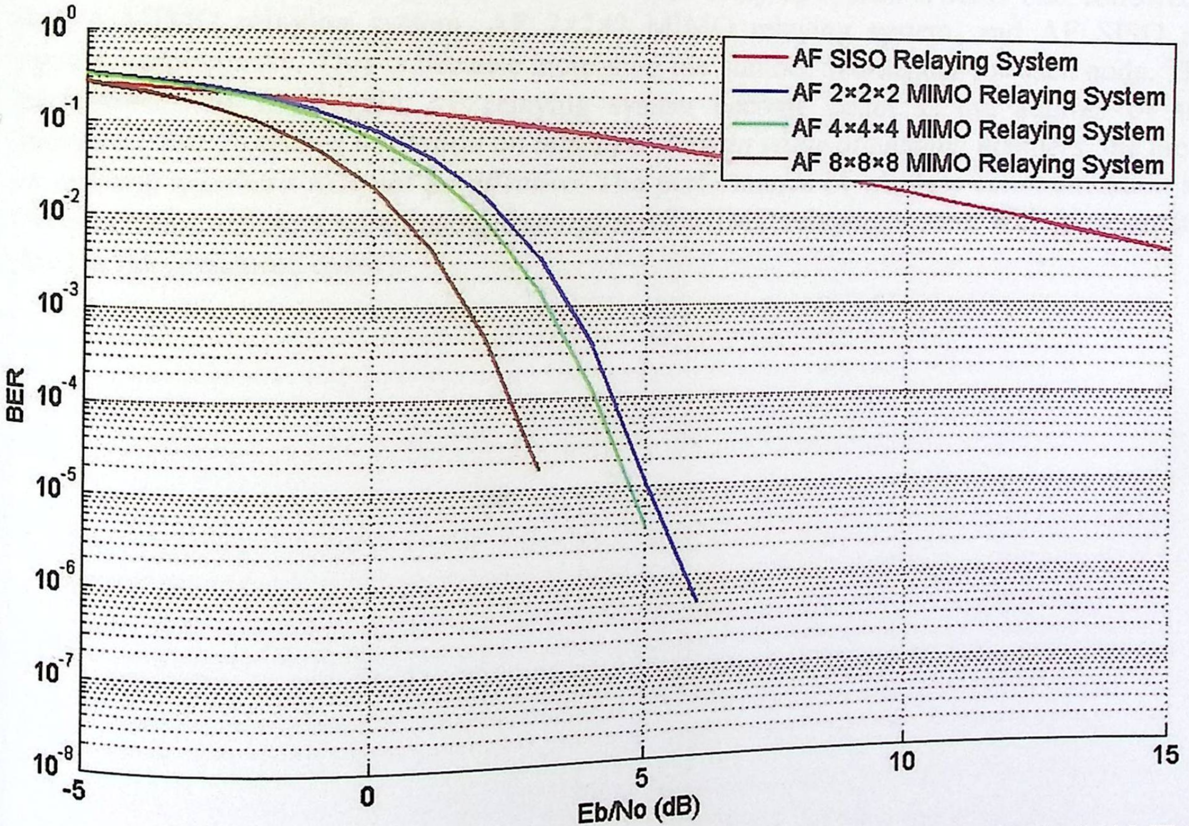


Figure 5.20 Comparison between Fixed Gain AF SISO, AF 2×2×2 MIMO, AF 4×4×4 MIMO and AF 8×8×8 MIMO Relaying Systems using Optimal Power Allocation under Flat Fading Rayleigh Channel in terms of BER Performance

In this case, we assume that the number of transmitted packets is 10,000 with packet length 4000 bits and the E_b/N_o range is [-5:1:15] dB. The figure shows a comparison between fixed gain AF SISO relaying system, AF 2×2×2 MIMO relaying system, AF 4×4×4 MIMO relaying system, and AF 8×8×8 MIMO relaying system using optimal power allocation under flat fading Rayleigh channel in terms of BER performance.

As the figure shows, the BER performance of fixed gain AF 8×8×8 MIMO relaying system is better one followed by AF 4×4×4 MIMO relaying system, AF 2×2×2 MIMO relaying system, and AF SISO relaying system, respectively, i.e., at E_b/N_o equals 1 dB and 3 dB, the BER performance of fixed gain AF 8×8×8 MIMO relaying system equals 4.273×10^{-3} and 1.65×10^{-5}, respectively, the BER performance of fixed gain AF 4×4×4 MIMO relaying system equals 2.87×10^{-2} and 1.393×10^{-3}, respectively, the BER performance of fixed gain AF 2×2×2 MIMO relaying system equals 4.156×10^{-2} and 3.344×10^{-3}, respectively, and the BER performance of fixed gain AF SISO relaying system equals $1.269 \times 10^{-1}$and 8.933×10^{-2}, respectively.

To achieve BER equals 1.065×10^{-4} for AF 8×8×8 MIMO relaying system, AF 4×4×4 MIMO relaying system and AF 2×2×2 MIMO relaying we need 2.439 dB, 4.021 dB and 4.349 dB, respectively.

As a result, when E_b/N_o increases, the BER decreases accordingly in all systems. The BER performance of fixed gain AF 8×8×8 MIMO relaying system is better one, followed by AF 4×4×4 MIMO relaying system, AF 2×2×2 MIMO relaying system, and AF SISO relaying system, respectively. This is because increasing the number of antennas for each node. The BER performance of fixed gain AF relaying system become better as the number of antennas increases. *But there is a limitation on this, after certain value of antenna numbers, the increasing in antenna numbers will not be effective.* The performance of wireless communication systems become more efficient when using fixed gain AF MIMO relaying system with more antennas (at least in the presented cases).

5.7.2 Comparison between Fixed Gain AF SISO, AF 2×2×2 MIMO, AF 4×4×4 MIMO and AF 8×8×8 MIMO Relaying Systems in terms of Capacity Performance

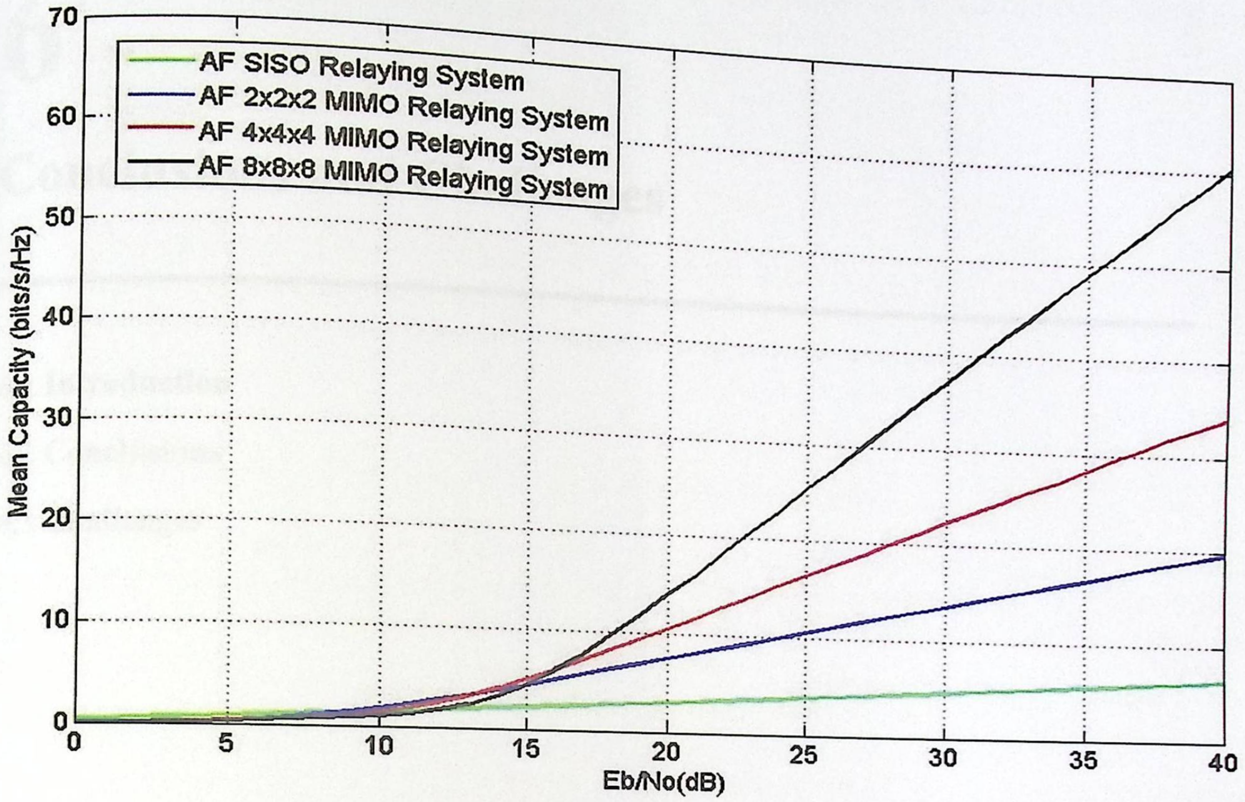


Figure 5.21 Comparison between Fixed Gain AF SISO, AF 2×2×2 MIMO, AF 4×4×4 MIMO and AF 8×8×8 MIMO Relaying Systems using Optimal Power Allocation under Flat Fading Rayleigh Channel in terms of Capacity Performance

In this case, we assume that the E_b/N_o range is [0:1:40] dB and the number of Monte-Carlo iterations is 10,000. The figure shows a comparison between fixed gain AF SISO relaying system, AF 2×2×2 MIMO relaying system, AF 4×4×4 AF MIMO relaying system, and AF 8×8×8 MIMO relaying system under flat fading Rayleigh channel in terms of capacity performance. As we notice, the mean capacity of AF 8×8×8 MIMO relaying system is greater one followed by AF 4×4×4 MIMO relaying system, AF 2×2×2 MIMO relaying system, and AF SISO relaying system, respectively, i.e., at E_b/N_o equals 20 dB and 40 dB, the mean capacity of AF 8×8×8 MIMO relaying system equals 14.07 bits/s/Hz and 60.45 bits/s/Hz, respectively. The mean capacity of AF 4×4×4 AF MIMO relaying system equals 10.45 bits/s/Hz, 34.07 bits/s/Hz, respectively. The mean capacity of AF 2×2×2 MIMO relaying system equals 7.485 bits/s/Hz and 19.74 bits/s/Hz, respectively, and the mean capacity of AF SISO relaying system equals 2.968 bits/s/Hz and 6.251 bits/s/Hz, respectively.

As a result, when E_b/N_o increases the mean capacity increases accordingly in all systems. The capacity performance of AF 8×8×8 MIMO relaying system is better one followed by AF 4×4×4 MIMO relaying system, AF 2×2×2 MIMO relaying system, and AF SISO relaying system, respectively. As the number of system antennas increases, the channel mean capacity increases accordingly. So The capacity performance of AF relaying system becomes more better and more efficient at high E_b/N_o.

CHAPTER

6

Conclusions and Challenges

6.1 Introduction

6.2 Conclusions

6.3 Challenges

6.1 Introduction

In this chapter, we introduce the project conclusions that are noticed from the simulation results and the challenges that are faced during the project.

6.2 Conclusions

The objective of this project is to study the BER and Capacity Performance of fixed gain AF SISO relaying system and fixed gain AF N×L×M MIMO relaying system where N, L and M are equal. Such that N equal 2,4 and 8. And makes a comparison with the performances of the conventional systems.

The following points present the main results of the project

1. The BER performance of fixed gain AF SISO relaying system with direct link using optimal power allocation is better than the BER performance of both conventional SISO system and fixed gain AF SISO relaying system without direct link using optimal power allocation.
2. The BER performance of conventional SISO system is better than the BER performance of fixed gain AF SISO relaying system without direct link using optimal power allocation. *By using fixed gain AF SISO relaying system without direct link, the signal affected by two cascaded channel and no diversity is used.*
3. The capacity performance of SISO system is better than the capacity performance of both AF SISO relaying system with and without direct link using optimal power allocation *due to assumption that the source is remain silent during relay transmit symbols, half of the channel resources are allocated to the relay for transmission.*
4. The capacity performance of all studied conventional N×M MIMO system is better than the capacity performance of all studied fixed gain AF N×L×M MIMO relaying system with and without direct link using optimal power allocation. *This is due to assumption that the source is remain silent during relay transmit symbols, which mean half of the channel resources are allocated to the relay for transmission.*
5. The BER and capacity performance of all studied fixed gain AF N×L×M MIMO relaying systems using optimal power allocation is better than using equal power allocation. *This is due to allocate more power in direct link that assist the destination to decode correctly. So decrease the amount of losing bits in decoding.*
6. The BER and capacity performance of all studied fixed gain AF N×L×M relaying systems with direct link using optimal power allocation is better than fixed gain AF N×L×M relaying systems without direct link using optimal power allocation. *This is due to the direct link that decreases the amount of losing bits in decoding. So decreases the the BER.*

7. The BER performance of all studied fixed gain AF N×L×M MIMO relaying systems with direct link using optimal power allocation is better than the BER performance of conventional N×M MIMO system. This is due to two branches diversity that are resulted from direct link and the assistanced link from relay. *This decreases the amount of losing bits in decoding and thereby decreases the BER.*

8. The BER performance of all studied conventional N×M MIMO system is better than the BER performance of all studied fixed gain AF N×L×M MIMO relaying system without direct link using optimal power allocation, this is due to the signal that is affected by two cascaded channel and the relay amplify the signal with its noise using fixed gain AF N×L×M MIMO relaying system without direct link. But after a certain value of E_b/N_o, there is inversion in the generated simulation curves and this is *due to using optimal power allocation that is increasing as* E_b/N_o *increases.*

9. There is a roughly constant dB difference between BER and capacity performance using optimal power allocation and equal power allocation in all discussed AF relaying systems.

6.3 Challenges

During the project, we faced some of challenges such that

1. The lack of references that cover the simulation results about the project, in order to compare the project results with the previous results.

2. Finding the suitable OSTBC matrix which takes a lot of time to find and manipulate it in the code.

3. The simulation speed was very low for some systems especially higher order MIMO and AF MIMO relaying systems.

4. The complexity of receiver designs especially; in the design of MRC combiner for AF MIMO relaying systems.

5. We faced difficulties in understanding the papers and references about the project topic.

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