ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTING
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Performance Analysis of Cooperative Relay Protocols over Fading Channels

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A Thesis Submitted to ASTU in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Electrical Engineering

[Communication Engineering]

February 10, 2017

Adama, Ethiopia

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Declaration

I declare that this thesis is my original work, it has not been previously submitted to this University or to any other University for a degree or other qualification, and all sources of materials used for the thesis have been fully referenced.

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Abstract

Recently, the cellular mobile networks become fast growing to give services with high data rate transmission and more reliable networks. One proven solution for improving the reliability of a wireless channel is to use cooperative relay. It is most efficient technique to combat the fading effect induced by multipath signal propagation.

The main objective of this thesis is to investigate the performance relaying protocols over Rayleigh and Nakagami-m fading channels. The Detect and Forward (DeF), Amplify and Forward (AF) and Estimate and Forward (EF) protocols has been used at the relay system. In this thesis, two- hop relay network with one source(S), one relay and one destination (D) is considered. It is implemented under three relay placement topologies, i.e., equilateral, isosceles and linear topologies. To combine the signals from source and relay the maximum likelihood (ML) is implemented as detector. The metric used for measure the performance of relaying protocols is expressed in terms of Bit error rate (BER) versus signal to noise ratio (SNR) and BER versus normalized distance between source and relay(d_{sr}) by using Matlab software.

According to simulation results, the cooperative relaying techniques have better performance than point-to-point transmission. However, overall results the EF relay network performs better in terms of BER compared with DeF and AF relay networks. The EF relay protocol hits BER value of 10^{-3} at SNR value of 13dB, 12dB and 6dB under equilateral, isosceles and linear topologies respectively. Therefore, linear topology has better system performance, than equilateral and isosceles topologies.

Key words: Cooperative relay, fading channels, The Detect and Forward, Amplify and Forward and Estimate and Forward protocols, maximum likelihood, Bit error rate.

Acknowledgement

First, I would like to give thanks to my loving and caring Allah for giving me the opportunity to study my Master's Degree (Msc), for giving me the strength to overcome all challenges and for always being there with me to give me hope. I would also like to extend my deepest thanks to my advisor Dr.sultan Feisso for inspiring me to work on this area from the start. His ideas and guidance had a vast contribution.

I wish to my warm thanks to my parents, Sheik Jemal, brothers and sisters, for their love and countless prayers , making me believe in myself, always encouraged me in every aspect of life and their throughout support. Especially I am grateful to my brother Mohammed Sheik Jemal and his wife Fatimah Kader for offering me the financial support for my Masters Degree study and always encouraged me in every aspect of life. This thesis would not have been possible without their countless sacrifices so I would like to express special thanks for Mohammed and Fatimah again.

Finally, I would like to express my gratitude to Hasna Kadir and Adera Ababu, for their moral support and motivation guided me through my study. My sincere thanks also go to Dr. M. V. Raghuvandra for giving me his time to share idea, forward comments for me.

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List of Abbreviations

Abbreviations	Description
AF	Amplify-and-Forward
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary phase-shift keying
BS	Base Station
CDF	Cumulative Distribution Function
C-MRC	Cooperative Maximum Ratio Combining
CSI	Channel State Information
DeF	Detected-and-Forward
DF	Decode and Forward
EF	Estimate-and-Forward
FSK	Frequency Shift Keying
GSC	Generalized Selection Combining
LOS	Line-of-Sight
MAP	Maximum Posterior probability
MGF	Moment Generating Function
MIMO	Multiple-Input Multiple-Output
ML	Maximum Likelihood
MMSE	Minimum Mean Squared Error
MRC	Maximum Ratio Combining
MS	Mobile Stations
MSK	Minimum Shift Keying
NLOS	No line of Sight
OP	Outage Probability
PDF	Probability Density Function
PSK	Phase-Shift Keying
QAM	Quadrate Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
QOS	Quality of Service

RD	Relay to Destination
RS	Relay Station
SD	Source to Destination
SER	Symbol Error Ratio
SNR	Signal to Noise Ratio
SR	Source to Relay
TDMA	Time Division Multiple Accesses
3G	Third Generation
4G	Fourth Generation

Chapter 1

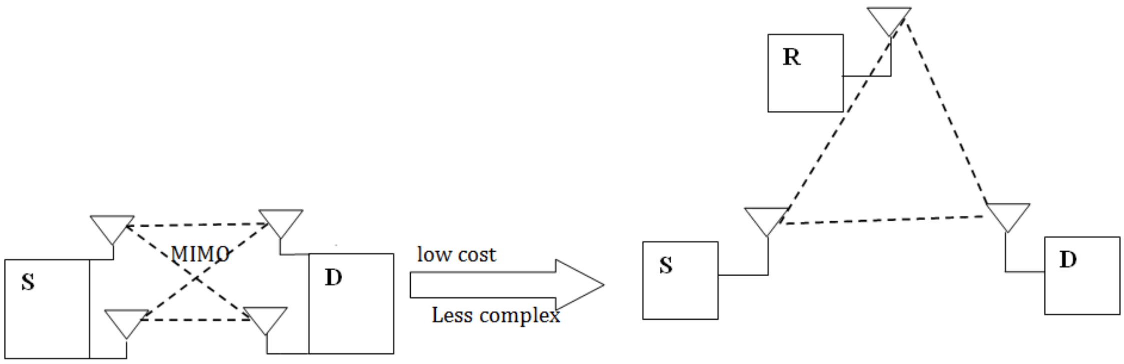
Introduction

1.1 Background

Nowadays, wireless systems become fast growing schemes for communication systems over wired system. Wired communication also has comparative advantage that it is fixed and reliable while the wireless channels are random and unreliable. In the fact that a wireless communication has broadcast characteristics in nature and can be affecting by environmental factors such as a mountain, building, etc. Based on these natural factors, fading and interference are two major problems of wireless transmission that make it complex and unreliable [31, 32]. The small-scale effect of multi-path and the large-scale effects of pathloss and shadowing cause fluctuation and attenuation of the channel powers that critically degrade reliability of wireless signals. Unlike the wireline communication, which the transmission channels can be considered free of interference, the wireless communication is affected to interference which caused by other neighboring cells.

These challenging problems of wireless channel transmission can be minimized by different techniques such as by increasing to transmit power, bandwidth, Multiple-input multiple-output (MIMO) antenna systems and cooperative diversity etc. However, increasing power or bandwidth techniques have less efficient to achieve higher data rate. As transmit power increasing a risk of interference from neighboring cells also increasing and the bandwidth is scarce and expensive radio resources.

Multiple-input multiple-output (MIMO) antenna systems are an efficient solution to overcome these wireless channel problems by providing significant improvement in data rates and reliability over traditional wireless system. The main difference between traditional wireless systems and MIMO systems is only number of antenna they used in system. Traditional wireless systems are using one transmitting and one receiving antenna and MIMO systems use multiple antennas at transmitter and receiver. All antennas used in MIMO system operating in the same frequency and the same time to providing the multiplex and diversity gains. However, MIMO systems are infeasible at the mobile stations due to cost or hardware limitations for installing multiple antennas. Therefore, the advantageous of MIMO systems only for cellular base stations (BS) [33, 34]. To overcome such challenges, a cooperative communication has been introduced. Cooperative diversity is the most efficient technique to mitigate the fading effect of wireless channels in wireless network achieved through cooperative relaying [35].The key idea in a cooperative communication are that the relay node overhears the source's signal due to broadcast nature of wireless medium and sends the information to the destination as shown in Fig.1.1b. In this communication scheme, the Source (S) can broadcast the signal in two paths that are direct and relayed paths. When the source directly communicates with the destination (D) without help of relay(R) nodes, it called the direct path whereas the relayed path is the communication path to help of a relay node. The transmitted signals through the direct and the relayed paths are combined at the destination to provide spatial diversity. Spatial diversity is a powerful technique to combat the fading effect of the wireless channel [36]. Therefore, cooperative communication system exploits the advantages of MIMO communications systems like diversity without using physical antenna arrays of lower cost and better performance [37, 38]. The main purpose of cooperative communication schemes is to increase the effective quality of service of communication network. This performance can be measured in terms of bit-error-rate (BER) or outage probability (OP) that measure the quality of the communication process to fading based on the SNR at physical layer [34].



a. Traditional MIMO b. Cooperative MIMO

Figure 1.1: Traditional MIMO System versus cooperative MIMO System.

There are some fundamental characteristics that distinguish cooperative communication from the conventional and MIMO systems.

Cooperative MIMO: The main advantage of cooperative communication is that it attained spatial diversity in a distributed fashion that avoids the requirement to installing more than one antenna at the mobile terminals [38].

Low cost: Technically the cost of network is decreasing in terms of using less number of equipments. In cooperative communication network each nodes are having single antenna terminal and created virtual antenna arrays. Therefore, it has much cost efficient compare to traditional MIMO systems due to reducing the requirements of more antennas [34].

Complexity: Cooperative systems have less complexity than traditional MIMO systems when system use dedicated relay nodes. However, there are still some complexities existed when the mobile station act as a relay node it required some power full a computational component to handle a complex routing algorithm [39].

Security: User's cooperative diversity needed suitable security measures due to the user information is passing through another user's mobile.

Reduce propagation loss: In cooperative communication, by using relay node the direct distance between source and destination is divided into short distances that help in reducing propagation losses, decreasing transmission power and interference [40].

1.2 Problem Statement

Recently, the demand for multimedia services in new generation of mobile cellular networks such as third generation (3G) and fourth generation (4G) are rapidly growing. However, providing services with high data rate transmission can be limited by several factors, which imposed multipath fading channels. Therefore, a main challenge to designing a wireless communication system is how to obtain higher data rate with reliable communication. To overcome this problem, cooperative-relaying protocols is proposed as a powerful technique to improve the reliability of the network as well as improve coverage especially for users at the cell edge or other deep faded regions within the cell.

1.3 Objectives of the Thesis

1.3.1 General Objective

The main objective of this thesis is to investigate the performance of relaying protocols over various fading channels.

1.3.2 Specific Objectives

The specific objectives to be carried out in this thesis are:

- Design relaying protocols for wireless communication system that able to provide suitable bit-error-rate (BER) performance with BPSK modulation.
- Investigate the comparative advantage of amplify-and-forward (AF), detect-and-forward (DeF), and estimate-and-forward (EF) cooperative relay protocols.
- Investigate the advantage of Nakagami-m fading channel over Rayleigh fading channel.
- Investigate the comparative advantage of different relay topologies such as equilateral, isosceles and linear relaying topologies.
- Investigate the optimal relay placement between source and destination.

1.4 Methodology

The following methods will use to achieve the objectives of the research:

Literature Review: Including Reading books, research papers and other information available through the internet those related to the topic.

Modeling: Includes the relay model, the modulation scheme, choosing the channel models and the formulating mathematical expression of relaying protocols.

Simulation: Simulating the modeled system with the assumed parameters using Matlab software for the direct scheme and the cooperative scheme networks of the fading channels.

1.5 Related Works

In recent years to increase the link reliability and coverage of cellular mobile network without expending additional bandwidth and transmit power, cooperative systems have been got attraction in a wide research. Some of the researches proposed to the area of cooperative diversity systems that related to this work are briefly reviewed below.

The first idea about three-terminal communication channels had been introduced in [1]. This three-terminal communication channels to represent the fundamental scheme for cooperative communication. After that, the performance of relay networks has been analyzed according to different protocols and parameters, including communication theoretic analysis and information theoretical analysis. The communication theoretic analysis is related to the performance in terms of reliability with the aid of certain modulation and coding techniques, where as information theoretic analysis is concern with capacity of the relay channel .The first study for the channel capacity of relay networks over non-faded channels in [2]. After this study, the capacity of relay networks over Rayleigh fading channels have been investigated in [3–5]. Different relaying protocols have been proposed to process the received signal at the relay. The performances of amplify -and-forward (AF) and decode-and-forward (DF) relay protocols have been investigated in terms of bite error rate (BER), diversity , capacity and outage probability over different fading channels in [6–18].

The main characteristics of AF and DF based on their relay function is that relay amplifies the received original signal and forwards to the destination and the relay decodes the received original signal and forwards after re-encoding respectively. The relay function of an estimate-and-forward (EF) protocol is defined as estimation function to make hard and soft detection, to transmit detectable information to the destination. An idea of EF relay network first proposed in [2]. Many studies have been investigated in [17, 19–22] based on the advantage of EF in comparison with DF relay network.

In these studies, the performance of an EF protocol higher in the same gain as the DF relays network means EF has lower BER at low SNRs. In [23] an EF relay network has been studied for minimizing the error probability by using the Lambert-W method as relay function. In this study, the direct link between the source and the destination did not consider. This function is non-analytical and it needs approximations or table look up. Then in [24], the minimum mean squared error (MMSE) method was proposed as relay function and optimal for BPSK modulation in a two-hop relay network.

In cooperative communication system, the destination required detectors to combine all the incoming signals from direct and relaying paths and detecting the correct transmitted message signals to error to get the diversity gain. Many of the research papers in cooperative cooperation had implemented the maximum ratio combining (MRC) technique at the destination to combine all the coming signals from source and relays. In [25], a comprehensive analysis has been done on the practical maximum-ratio-combining (MRC) technique applied to both AF and DF. In this study, MRC technique is the maximum likelihood (ML) detector for AF relay protocol. However, this does not hold for the DF relays protocols. After that in [26], cooperative-MRC (C-MRC) is introduced. This method of detection is similar to the ML method, but this work shows that the computational complexity of this method is less and the network can reach to a maximum diversity of this method.

In [27], the performance analysis of decode-and- forward (DF) protocol is presented with receiving generalized selection combining (GSC) with cognitive relaying in Nakagami fading channel. In this study analytical expression of the probability density function (PDF), the cumulative distribution function (CDF), and the moment generating function (MGF) of the end-to end signal to noise ratios (SNR) of the system was derived. Those expressions used for maximum likelihood (ML) detection at the destination. In addition, the average symbol error rates (SER), the outage probability (OP), and the average end-to-end SNR obtained from these expressions. In [28], the error performance of relay protocols with the binary phase shift keying (BPSK) analyzed by using the ML algorithm at the destination. In [29], the performance of AF relay network has been investigated under equilateral, isosceles and linear relay topologies. In this study show that, linear network topology has the best system performance than isosceles triangle topology and equilateral triangle topology. In [30], the performance of an EF relay network with AF and DeF relay protocol has been investigated over Rayleigh fading channel. It was shown that the EF relay network has better performance than AF and DeF relay networks.

Therefore, argue with this thesis is that, in practical investigation, the channel fading coefficient should be considered as a random variable rather than constant.

1.6 Contributions

The main contributions to this thesis are outlining as follows:

- In previous studies, many works have been done on performance of DeF, AF and EF relay protocol over Rayleigh fading channel. In [30], the performances of relay protocols are investigated over Rayleigh fading channel as fading coefficient as constant. Therefore, the scope of this thesis is to extend the study of the EF protocol over Nakagami-m fading channel in real environmental wireless communication.

- In previous studies, the comparative advantage of equilateral, isosceles and linear relay topologies has been investigated only with AF relay protocol in [29]. In this thesis work, the two-hop relay networks with single relay in different relay topologies with different relay protocols are investigated.
- The comparison performance of proposed relay protocols in this thesis are analyzed with each other in terms of Bit-error-rate (BER) versus SNR to see better performance under the Rayleigh and Nakagami-m fading channels.

1.7 Outline of the Thesis

After the background information about this work is described, the remaining chapters organized as follows. Chapter 2 discusses the overview of wireless fading channel and types of fading channel. Chapter 3 introduces system models of relay networks with their relay function. Chapter 4 discusses about simulation results. Finally, in Chapter 5, includes the thesis conclusion and recommendations for future works.

Chapter 2

Wireless Channel Modeling

2.1 Introduction

In wireless communication, the signals propagate from the transmitter to receiver passing through free space. During this propagation time, the signals have to go through reflection, diffraction and scattering due to the surrounding structures between transmitter and receiver shown in Fig.2.1. For these reasons, the signals received at the destination are not the same as the transmitted signals. Generally, in cellular systems, due to the height of the cellular antenna is smaller than the surrounding structures, the line-of-sight (LOS) communication between the transmitter and the receiver is mostly not possible. Therefore, signals arrive at the receiver through different paths and different time delays, which give rise to multipath communication.

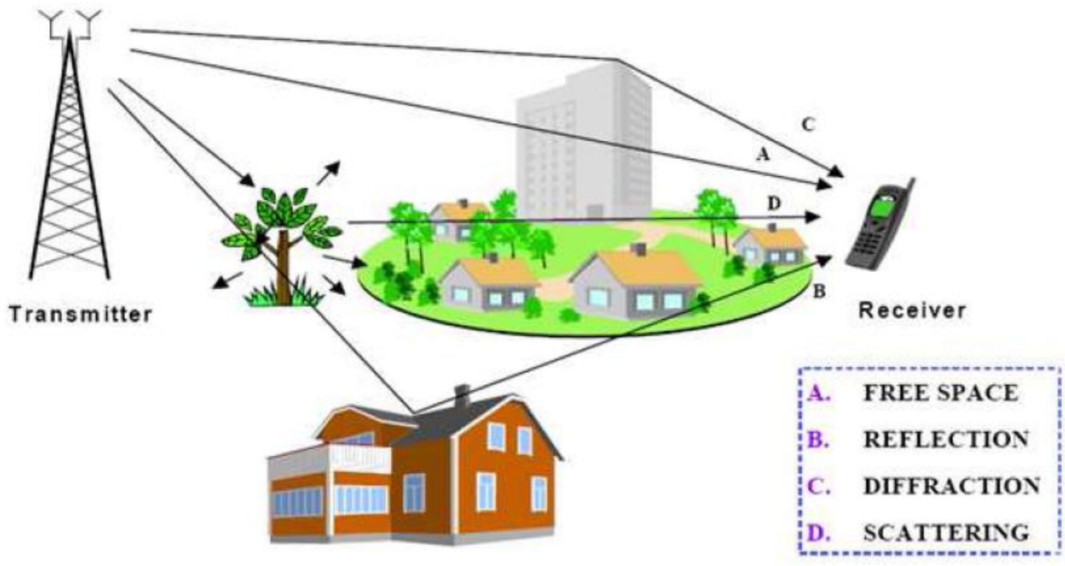


Figure 2.1: Propagation mechanism.

2.2 Wireless Channel Impairments

In a wireless communication system, the medium between a transmitter and receiver is air or not electrical conductor like wired system. Due to this reason for transmission, the quality of signals may affect by different channel conditions that introduce as follows:

2.2.1 Pathloss

When the signal propagates through channel, the attenuation takes place based on the distance between the transmitter and receiver. This attenuation is called pathloss. As the distance between the transmitter and receiver increases, the strength of the signal becomes weaker. To this problem, the repeaters and amplifiers are used. The degradation of signal strength due to pathloss relative to distance is defined as the ratio to the transmitted power (P_t) and the received power (P_r). Mathematically, which is represented by [41].

$$P_L = \frac{P_t}{P_r} \tag{2.1}$$

where P_L is representing pathloss, P_t represent transmitted power and P_r is the received power.

The path loss is usually represented in decibels by:

$$\mathrm{P_L(dB)} = 10\log_{10}\left(\frac{P_t}{P_r}\right) \tag{2.2}$$

The Friis free space model is only a valid predictor for P_r for values of d, which are in the far field of the transmitting antenna. The far-field or Fraun-hofer region of a transmitting antenna is defined as the region beyond the far-field distance (d_f). The far-field distance is related to the largest linear dimension of the transmitter antenna aperture and the carrier wavelength, λ. Mathematically, in [32] as follow represent the faun-hofer distance.

$$d_f = \frac{2D^2}{\lambda} \tag{2.3}$$

where D is the largest physical linear dimension of antenna. Additionally in the far field region,d_f must satisfy $d_f \gg D$ and $d_f \gg \lambda$.

The free space power received by a receiver antenna, which is separated from a radiating transmitter antenna by a distance d, is represented by the Friis free formula as shown bellow.

$$P_r(d) = \frac{P_t\ \lambda^2}{(4\pi)^2 d^2} \tag{2.4}$$

where $P_r(d)$ is the received power which a function of the distance between transmitter and receiver, d is the separation distance between transmitter and receiver in meters and λ is the wavelength in meter.

Additionally, it is clear that Eq. (2.4) does not hold for d=0. For this reason, pathloss model environment use a close in distance, d_o as a known received power reference point as shown in Fig.2.2 [42].

The received power $P_r(d)$ at any distance given by as follow:

$$P_r(\mathrm{d}) = P_r(d_o)\left(\frac{d_o}{d}\right)^{\alpha}\ ;\ \ d \geq d_o\ \geq \mathrm{d_f} \tag{2.5}$$

where α is called the path loss exponent.

The value of $P_r(d_o)$ can be predicted from Eq. (2.4). The reference distance shown from Fig.2.2 must be chosen such that it lies in the far-field region, that is $d_o \geq \mathrm{d_f}$. Therefore, d_o is chosen to be smaller than any practical distance used in the mobile communication system. The refrence distance d_o for practical systems in the 1-2GHz region is typically chosen to be 1m in indoor environments and 100m or 1000m in outdoor environments.

In cellular mobile systems, P_r is not fixed it may change by many orders of magnitude over a typical coverage area of several square kilometers. Due to variation of received power levels dBm or dBW units often express it. The Eq. (2.5) can be represented in units of dBm or dBW as follow:

$$P_r(\mathrm{d})\mathrm{dBm} = 10\log\left[\frac{P_r(d_o)}{0.001\mathrm{W}}\right] + 10\alpha\log\left(\frac{d_o}{d}\right);\ \ d \geq d_o\ \geq d_f \tag{2.6}$$

where $P_r(d_o)$ is in units of watts.

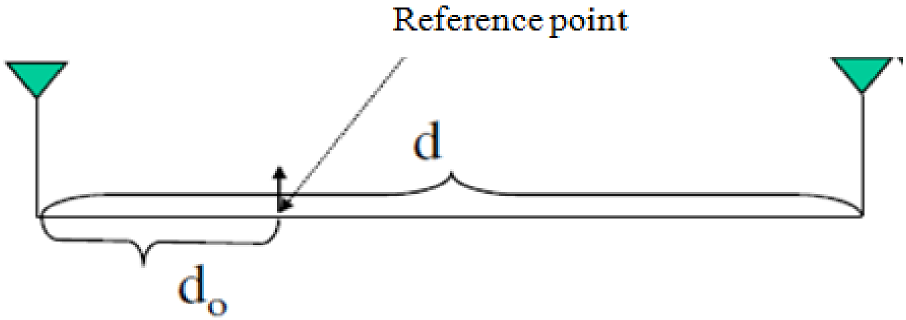


Figure 2.2: Pathloss model.

Table 2.1: Typical values of path loss exponent for different environment.

Environments	**Path Loss exponent, α**
Free Space	2
Urban Area	2.7 to 4
Suburban Area	3 to 5
Indoor (line-of-sight)	1.6 to 1.8

2.2.2 Noise

Noise is the unwanted signal in communication system superposed on a wanted signal, which tends to unclear the signal at receiver. There are various forms of noise in communication system these are thermal noise, inter-modulation, cross -talk, impulse noise and white noise etc. [43].

2.2.3 Fading

Fading is defined as the distortion of signal over a certain propagation media. In wireless communication, the fading is occurred due to multipath propagation. A signal that propagates from the transmitter to the receiver through multiple paths is called multipath propagation. There are different factors that cause multipath propagation these are atmospheric ducts, ionosphere reflection and refraction, and reflection from terrestrial objects, such as mountains and buildings as shown in Fig.2.1.The effects of multipath propagation include the variations on signal amplitude, phase and angle. This distortion of signals caused by multipath is known as a multipath fading. The variations in transmitted signal in wireless communication are classified according to fading scale. Therefore, depend on the scale of the fading occurred in transmitted signal a fading can be classified as the Large-scale fading and Small scale fading [44].

Large-Scale Fading:

Large-scale fading is the result of signal attenuation due to the travel of the signals over long distances from the overall path between the transmitter and the receiver. Long-term variation in the mean signal level is called large-scale fading [45]. Large-scale fading is also known as shadowing when the mobile station (MS) moves into the shadow of taller objects such as buildings and hills and also known as path loss.

Small-scale fading:

The Small-scale fading is used to describe the rapid fluctuation of the amplitude of radio signal over short periods or travel distance. This type of fading occurs due to local obstacles such building, trees etc. in general the fading can be fast or slow. The fast fading happens when many rapid fluctuations occur during a short period or signal transmission. The reason for this fading is coming from the propagation of the signal inside an environment, which contains objects such as buildings, and trees that cause signals to be scattered. The slow fading, may be caused by shadowing effects of objects such as buildings and trees for slow moving mobiles or objects. In a slow fading, the channel coefficients are constant during a frame period but they are changing independently from frame to frame. In this thesis, Rayleigh and nakagami-m fading models are used to describe phenomenon of small-scale fading.

2.3 Communication Channel Model

The performance of any communication system is eventually determined by the medium or channel between transmitter and receiver. To design communication system all factors that affect the propagation signals are must be considered [43]. Some typical communication channels models are introduced as follows.

2.3.1 Additive White Gaussian Noise (AWGN) Model

In an ideal wireless communication channel, the receiver perfectly decoded input signal without any noise. This mean the bit error probability of such a channel is zero. However, in the real world the receiver always add noise to the transmitted signal. AWGN is adding white Gaussian noise to the signal propagating through it as shown in Fig.2.3.The mathematically the received signal can be represented as follow.

$$r(t) = s(t) + n(t) \tag{2.7}$$

where, $r(t)$ is the output of the AWGN channel with input $s(t)$ and white Gaussian noise $n(t)$.

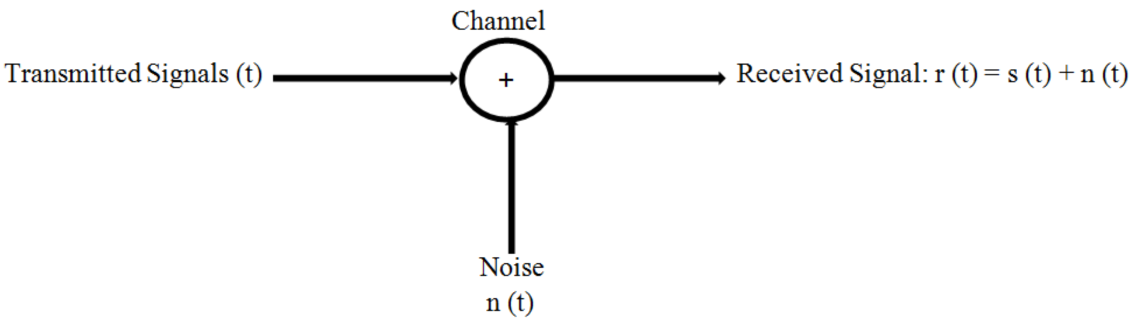


Figure 2.3: Signal in AWGN Channel.

The Gaussian probability distribution function of random variable, r is given by

$$f(r) = \frac{1}{\sqrt{2\pi\sigma^2}} \; e^{\frac{-(r-\mu)^2}{2\sigma^2}} \tag{2.8}$$

where r is a random variable with Gaussian distribution, mean (μ) and σ^2 is variance .

AWGN is present in any communication channel, but alongside fading distortions considered more practical in the approach. The following sections explain about the fading channels considered in the system.

2.3.2 Rayleigh Fading Channel

As stated in introduction sections, when a radio wave is propagated through communication channels, there are different factors that affect its propagation between the transmitter and the receiver. Rayleigh fading is one of statistical models for estimating the effect of propagation environment on a radio signal. This channel model is usually used in case of multipath propagation between the transmitter and receiver but no line of sight (LOS). It is the most useful model in case when there are many objects between the transmitter and the receiver and the signal scatters before reaching the receiver. When the number of propagation path is large, central limit theorem applies and $h(t)$ can be modeled as a complex Gaussian process.

In this case, the channel coefficient denote $h = re^{j\emptyset}$ and it can be written as

$$h = h_I + jh_Q \tag{2.9}$$

where $h_I and\ h_Q$ represent the in-phase and the quadrature phase components, respectively.

The PDF of the random variables r and $\emptyset$, obtained through the transformations.
Based on the general transformation the PDF of r and $\emptyset$ random variables written as

$$f(\mathrm{r}, \emptyset) = \frac{r}{2\pi\sigma^2}\ exp\left(-\frac{\mathrm{r}^2}{2\sigma^2}\right), r \geq 0, 0\ \leq\ \emptyset\ \leq \frac{\pi}{2} \quad (2.10)$$

The marginal PDF of each both random variables $(\mathrm{r}, \emptyset)$ can be derived as follows:

$$f(r) = \int_0^{\frac{\pi}{2}} f(r, \emptyset\,)\, d\emptyset = \frac{r}{2\pi\sigma^2}\ exp\left(-\frac{\mathrm{r}^2}{2\sigma^2}\right), r \geq 0 \quad (2.11)$$

$$f(\emptyset) = \int_0^{\infty} f(r, \emptyset\,)\, dr = \frac{1}{2\pi}\ , 0\ \leq\ \emptyset\ \leq \frac{\pi}{2} \quad (2.12$$

This result shows that the magnitude of the channel coefficients is a random variable with a Rayleigh distribution and the phase angle $\emptyset$ is uniformly distributed on $[0, \frac{\pi}{2}]$. Because the magnitude of the channel coefficients follow a Rayleigh distribution, this model is commonly called a Rayleigh fading model.

2.3.3 Nakagami-m Fading Channel

Nakagami distribution has the ability to describe both Rayleigh and Rician distributions [46]. Rayleigh distribution failed to estimate the channel behavior over long distances and high frequencies but Nakagami-*m* distribution often used to model a wide range of fading environments. It provides the best fit to the mobile communication channel data and other deep space communication.

A special case of the Nakagami distribution is the Rayleigh distribution, which arises from the situation of multipath transmission with no line of sight (NLOS), i.e., when all of the received power stems from scattered components. Nakagami-m distribution does not assume line-of-sight conditions, but use a parametric gamma distribution based density function to describe the experimental data and get approximately distribution, so it is more universality.

Nakagami-m fading is one of fading model for estimating the effect of propagation environment on radio signal. It states that when a signal passes through a communication channel its amplitude will fade randomly according to nakagami-m distribution. In this case, the channel coefficient denote $h = re^{j\emptyset}$ where the angle $\emptyset$ is uniformly distributed on [0, 2π]. The variable r and $\emptyset$ are assumed to be mutually independent. The PDF of Nakagami distribution is

$$f(\mathrm{r}) = \frac{2\,(m)^m r^{2m-1}}{\Gamma(\mathrm{m})\Omega^{\mathrm{m}}}\ \exp\left(-\frac{\mathrm{mr}^2}{\Omega}\right), \mathrm{r} \geq 0 \tag{2.13}$$

where m is Nakagami fading parameter or shape factor that described the fading degree of propagation fields due to scattering and multipath interference process and Γ (m) is the gamma function [47]. When m is approached to infinity ($m \to \infty$) Nakagami fading channel becomes a non-fading channel.

Ω is the channel power gain it can be represented as

$$\Omega = \mathrm{E}\{\mathrm{r}^2\} \tag{2.14}$$

Rayleigh is the special cases of Nakagami distribution when m=1, become one-sided Gaussian distribution when m=0.5 and r is denoted amplitude of nakagami-m fading.

2.4 Modulation Schemes

Modulation is the process of varying one or more properties of a high-frequency periodic waveform called the carrier signal, with a modulating signal, which typically contains information to transmit. In general, it involves translating a baseband signal to a modulated signal. The base band signal means source signal whereas modulated signal is a signal at a higher frequency (the carrier frequency, fc). At receiver, the original signal recovers through a process called demodulation. This thesis work stand for digital transmission and hence digital modulation is used.

There are different digital modulation techniques such as Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), Frequency Shift Keying (FSK), Minimum Shift Keying (MSK) and Quadrate Amplitude Modulation (QAM). Each of them performs differently in the presence of noise. In particular, higher order modulation schemes that are able to carry higher data rates are not as robust in the presence of noise. Lower order modulation schemes offer lower data rates but are more robust in highest presence of noise. This means lower order modulation schemes the highest noise or distortion in demodulation to give the incorrect results. In [48], Performance of BPSK, QPSK and 16 QAM with and without using OFDM over different fading channels has been investigated. As result shows, the BPSK has an overall better performance as compared to QPSK and 16-QAM techniques. That means lower order of modulation techniques is better to use in communication system if spectral efficiency is not considered or taken in an account.

In this thesis, Binary Phase Key Shifting (BPSK) is assumed as modulation technique. It is a modulation scheme where in zeros and ones are used in modulating a given data (audio, video, any kind of waves etc...) into the many bits and bytes of data and transmitted which is later demodulate on the receiver end as shown in Fig.2.4. In Phase Key Shifting (PSK), the phase of a carrier is changed according to the modulating waveform, which is a digital signal. BPSK is the simple modulation in PSKs scheme using two phases and the transmitted signal is a sinusoid of fixed amplitude. It has one fixed a phase when the data is at one level and when the data is at the other level which separated by phase of 180^{o}. In BPSK, the binary digits '1' and '0' may be represented as analog levels $+\sqrt{E_b}$ and $-\sqrt{E_b}$ respectively.

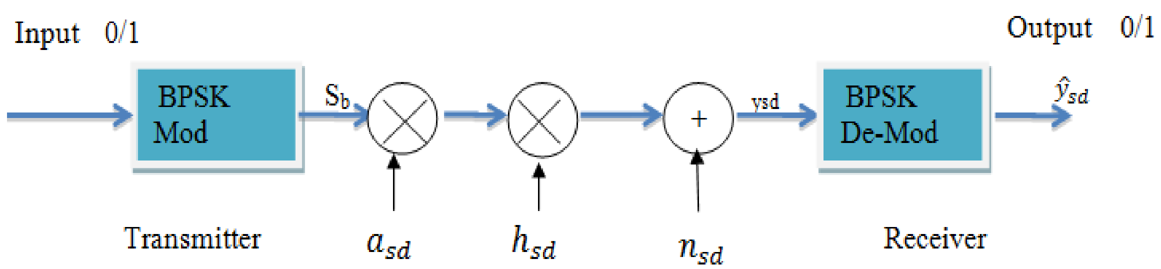


Figure 2.4: BPSK Transmitter and Receiver Block Diagram.

The general BPSK equation could be written as follows in [43]:

$$S_b(t) = \sqrt{\frac{2E_b}{T_b}}\cos\big(2\pi f_c t + \pi(1-n)\big)\,;\text{for n} = 0{,}1 \tag{2.15}$$

An Eq. (2.15) gives two phases 0 and π and in the specific form, Binary data often transmitted with the following signals:

$$S_0(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t + \pi) = -\sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t)\text{ ; for binary “0”} \tag{2.16}$$

$$S_1(t) = \sqrt{\frac{2E_b}{T_b}}\cos(2\pi f_c t)\text{ ; for binary “1”} \tag{2.17}$$

where f_c is the carrier frequency, E_b *is* Energy per bit, T_b is Bit duration, S_b is Symbol of bit b.

The received signal of point-to-point communication can be written as follows:

$$y_{sd} = h_{sd}\ e^{-j\emptyset} \times a_{sd} \times S_b + \mathrm{n}_{sd} \tag{2.18}$$

where $h_{sd}, \emptyset, a_{sd}\ and\ n_{sd}$ are fading coefficient, phase angle, pathloss and noise respectively.

The channel impulse response of a multipath fading channel is modeled as follow:

$$h_{sd} = \left|h_{sd}e^{j\emptyset}\right| = \sqrt{h_{sd}^2(\cos\emptyset^2 - (j\sin\emptyset)^2)} \tag{2.19}$$

Hence, by using Eq. (2.19) and trigonometric identity in Eq. (2.18) it can be reduced as:

$$y_{sd} = h_{sd}\ a_{sd} \times S_b + \mathrm{n}_{sd} \tag{2.20}$$

In this study, BPSK modulation is used as modulation technique due to this only real part is considered. In addition, through all documentation based on Eq. (2.19) all channel coefficients are writing in terms of magnitude rather than writing amplitude and phase separately. Finally, the receiver detects the received signal symbol-by-symbol. For a BPSK modulated signal, one bit is used to represent one symbol that is detected as:

$$\hat{y}_{sd} = \begin{cases} +1, & \text{for real } (y_{sd}) \geq 0 \\ -1, & \text{for real } (y_{sd}) < 0 \end{cases} \tag{2.21}$$

The transmitted input signal goes through both phase and amplitude variations. The phase of the signal can be corrected by having proper feedback of the channel conditions. The receiver only detects the signal based on received signal strength. Clearly, the receiver has full knowledge of channel condition based on perfect channel estimation information. As the real and imaginary part of the channel impulse response represent the amplitude and phase, the average value of the real part of the symbol received have been used for detection as from Eq.(2.21) for direct link transmission. The consequence this thesis works to increasing the reliability of wireless communication channel by using different relay protocols.

2.5 Mitigating Techniques of Fading Channels

In this Section, diversity techniques are introduced to avoid losing the data due to deep fading channels. Diversity is powerful communication technique to improve the reliability of message signals by using two or more communication channels with different characteristic This technique does not eliminate errors completely but it minimize the error rate. There are several diversity techniques have been identified which include the following:

2.5.1 Space Diversity

In this diversity scheme, the signal is transmitted or received over different propagation paths to improve reliability of message signal. As shown in Fig.2.5, the space diversity is achieved by using two or more antennas at transceiver it called antenna diversity. Using multiple transmitter antennas called transmit diversity whereas using multiple receiver antennas is called receive diversity. Thus, using multiple antennas offers a receiver to received different copies of the same signal, if one antenna can receive a sufficient signal then another one will experience faded signal. The receiver will choose the signal from the antenna with the best possible result. The separation spaces between antennas at a transmitter or a receiver is at least half of the wavelengths or more to make the received signals uncorrelated.

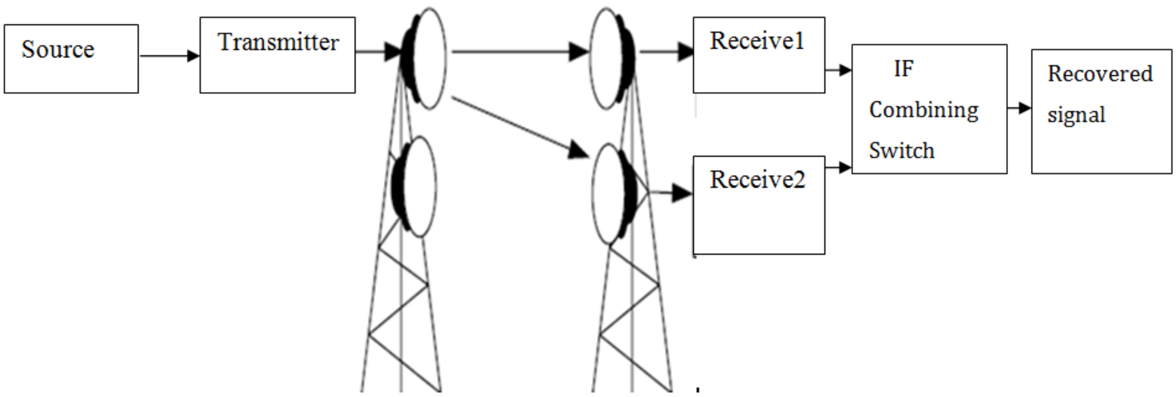


Figure 2.5: Space Diversity.

2.5.2 Time Diversity

In this diversity scheme, the transmission is achieved by sending multiple copies of the same signal at different time slots. At receiver, multiple repetitions of the signals are received with independent fading conditions [49].

2.5.3 Frequency Diversity

In this frequency diversity scheme, the information signal transmits by using more than one carrier frequency, which means different frequency channel [43]. As shown in Fig.2.6, the receiver receives various copies of signals with different frequency and selects the best possible result. The basic idea behind this diversity scheme is one antenna can process the function of different antennas. Due to this, one transmitter can be assumed as transmitter1 and transmitter2 to transmit the same message with two different frequencies and at receiver side the same idea also used. Therefore, the channel frequency 1 and the channel frequency 2 also called transmitter 1 and transmitter 2 at transmitter side respectively. and recever1 and receiver 2 at receiver side respectively.

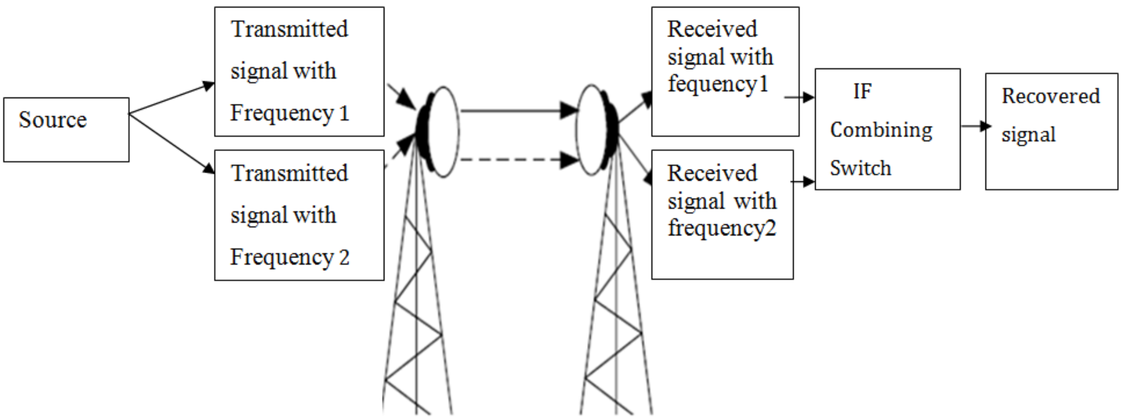


Figure 2.6: Frequency Diversity.

2.5.4 Cooperative Diversity

In this diversity scheme, a relay is used for the improvement in the transmission. The transmitter transmits the signal to the relay (relay path) and destination (direct path) at the same time as shown in Fig.1.1 b. Then the signal at relay is retransmitted to the destination.

At the destination, the signals from the relay path and the direct path combines to provide receive diversity. Therefore, it is assumed as a diversity scheme for this study to mitigate the fading problems.

Chapter 3

Cooperative Relay Networks

3.1 Introduction

As described in literature review, the cooperative relay communication is one proven solution to provide the reliability of wireless channels in multipath fading environment by using relay nodes. This chapter introduces a relay station with its advantages, two- hop of relay network, general system model of relay network, Signal Detection model at destination and relay transmission topology. Then after described general relay network and its system model, the particular relay network of cooperative relay protocols (AF, DeF and EF) with their relay functions is describing extensively.

3.2 Relay Station

A relay station (RS) is a node, which assists the transmission of data between the source and the destination as shown in Fig.3.1 in a cellular network [50]. Relay nodes apply several protocols on the received signal and forward it to the destination. Single or multiple relays can be placed between the nodes. They are relying on wireless transmission to communicate with the Base station (BS) and need additional power but still they are cheaper than installing a BS due to their limited functionality. Deploying relays in cellular networks had the following advantages [38]:

Low transmit power: A relay node in cooperative communication it requires less transmits power in cell.

System coverage: Deploying relays nodes in wireless communication network can really increase system coverage for high data rates in macro-cells. Installing a relay node helps to improve performance for mobile stations (MS) that are on the edge of the cell (dead spots of the cell) and are fading areas behind the building or in the metro stations.

Transmit and receive diversity: in some cases, relays can provide the concept of diversity over fading channels to the MSs. It that creates virtual antenna arrays this means a single handset turns into MIMO system [39].

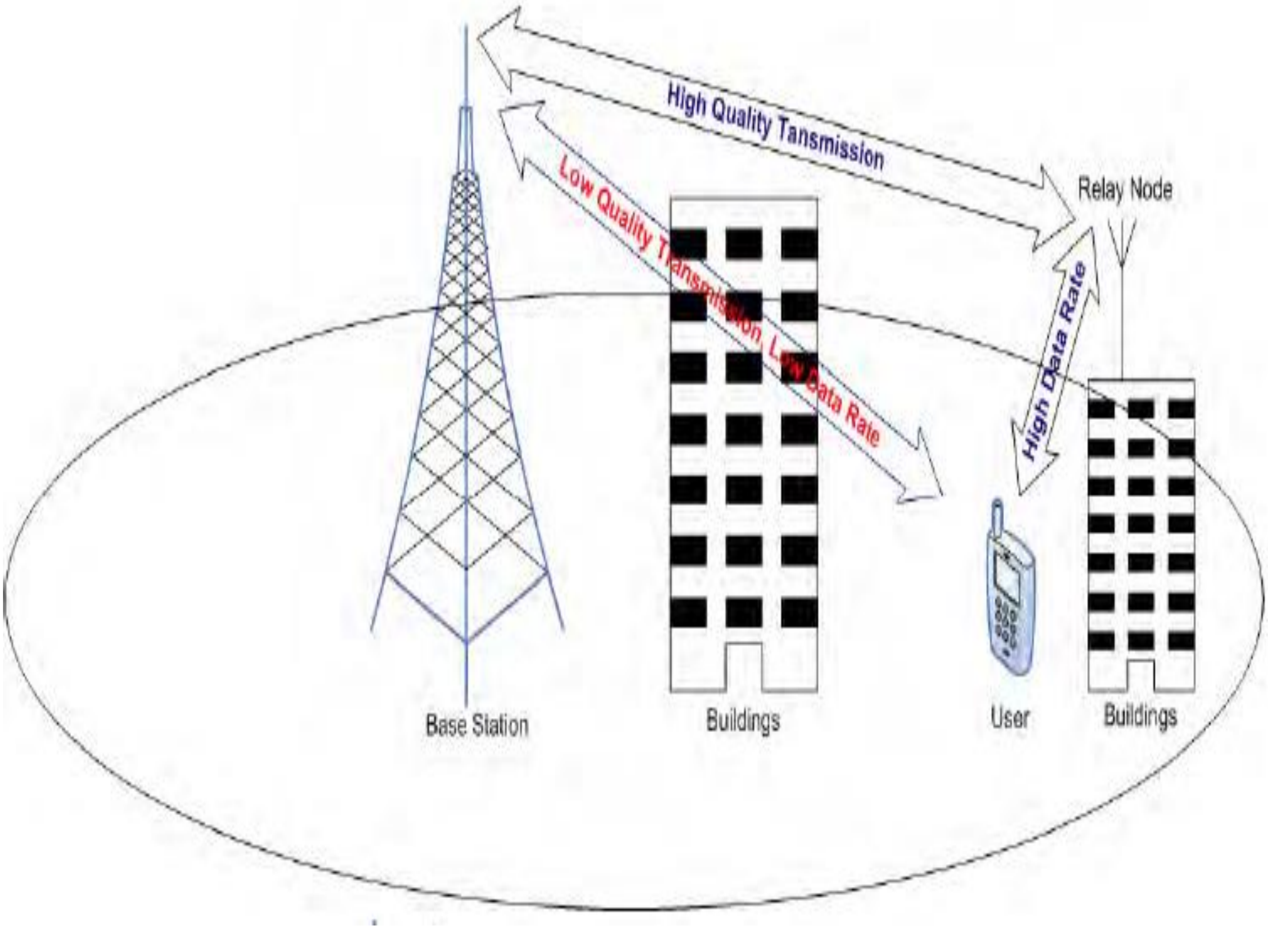


Figure 3.1: Relay deployment in fading environment.

3.3 Two-Hop Relay Network

In cooperative communication network when a single relay or multiple relays are placed in parallel between the source and the destination it is called a two-hop relay network. In two-hop relay network, the source broadcast the data to all relay then the relays received data transmitted from source adds some processing and forward to destination. A vast proportion of the research on cooperative communications has been dedicated to study the 3-node model. According to the facts, it is possible to have “N” number of relays contributing to the diversity reception. However, in this thesis, two-hop relay network considered with one source(S), one destination (D) and one relays over fading channels as shown in Fig.3.2.

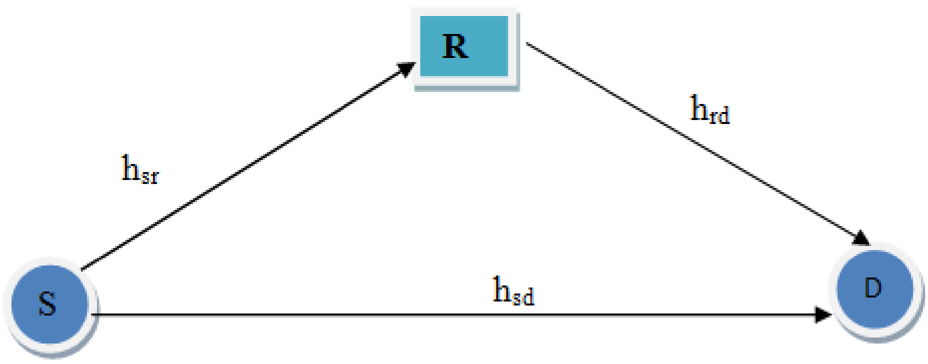


Figure 3.2: Two –hop relay network.

3.4 System Model and Description

In this Section, The general system model of cooperative relay network is implemented as shown in Fig.3.3. For this model, all nodes means source (S), Relay (R) and destination (D) have one antenna. The transmission mode of relay network is a half-duplex mode and it cannot receive and transmit simultaneously. Orthogonal cooperative protocol assumed with time division multiple accesses (TDMA) where the signal is transmitted in two time slots. During the first time slot, the source broadcasts the symbol to the relay and the destination at the same time as shown in Fig.3.4a. The received symbols y_{sr} and y_{sd} at a relay node and a destination node respectively, can be written as

$$y_{sr} = \sqrt{P_s d_{sr}^{-\alpha}} x_s h_{sr} + n_{sr} \tag{3.1}$$

$$y_{sd} = \sqrt{P_s d_{sd}^{-\alpha}} x_s h_{sd} + n_{sd} \tag{3.2}$$

where x_s is the symbol sent by source, d_{sd} is distance between source destination, d_{sr} is distance between source and relay, α is pathloss exponent, P_s is the transmitted power at the source node. h_{sr} and h_{sd} are the channels fading coefficients from S to R and from S to D respectively. n_{sd} and n_{sr} are additive white Gaussian noises (AWGN) from source to the destination and from source to relay respectively.

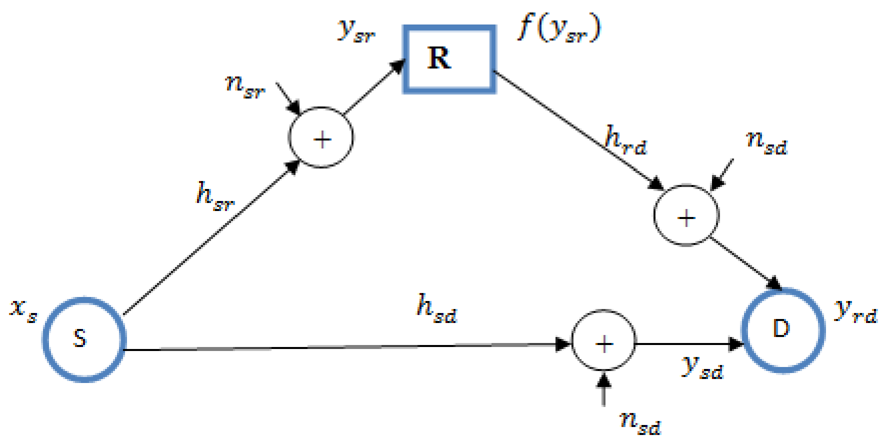


Figure 3.3: System model with signal notation and noise.

a) First time slot. b) Second time slot

Figure 3.4: Orthogonal cooperative protocol sharing two time slots.

In the second time slot, due to the channel is orthogonal only the relay transmits the signal to destination, as shown in Fig 3.4 b. The received symbols at the destination (y_{rd}) can be written as

$$y_{rd} = \sqrt{P_r d_{rd}^{-\alpha}} f(y_{sr}) h_{rd} + n_{rd} \tag{3.3}$$

where $f(y_{sr})$ is the relay function, also known as the signal processing at the relay after transmitted to the destination, h_{rd} is the channel fading coefficient (channel gain) from R to

D and n_{rd} is additive white Gaussian noise (AWGN). The term d_{rd} is representing the distance between relay and destination.

3.5 Signal Detection Schemes and Detector at Destination

In this Section, three main schemes are introduced to detect the signal transmitted from the source node at the destination node. These are the direct scheme, the non-cooperative scheme and the cooperative scheme. In all schemes, the destination node uses the relayed signal except the direct scheme [51].

3.5.1 Direct Scheme

In this scheme, the destination only detects the transmitted signal from the source node by using the direct path signal received on the first phase of the transmission. The transmitted signal from the relay node not involves. The detect signal received at the destination from the source node is written as in Eq. (3.1).

3.5.2 Non-Cooperative Scheme

In this scheme, the destination detects the signal received from the relay node in the second phase. One advantage of this scheme is to boosting of signal power. The signal received at the destination from the relayed node is written as in Eq. (3.3).

3.5.3 Cooperative Scheme

In this scheme, the destination node combines the signals received from the source and the relay nodes to achieve diversity by using combining techniques. In this thesis, to model the received signal at the destination a cooperative scheme is proposed by using the Maximum-likelihood detector. The ML detector is one of diversity combining techniques, which combine the received signals from the source and the relay node that results in the diversity advantage used to make optimum decision in the form of a maximum a posterior probability (MAP) detector [30].

$$\hat{x}_d = max\{P(x_s \backslash y_{sd}, y_{rd})\} \tag{3.4}$$

where $\hat{x}_d$ is denoting the symbol resulted from the decision made at the destination node.

By Using the Bayes' rule [52], the posterior probabilities can be calculated as

$$\hat{x}_d = \max_{x_s}\left\{\frac{P(x_s, y_{sd}, y_{rd})}{P(y_{sd}, y_{rd})}\right\} \tag{3.5}$$

The probability of input signal and output signal pair

$$P(x_s, y_{sd}, y_{rd}) = P(x_s)P(y_{sd}, y_{rd}\backslash x_s) \tag{3.6}$$

Substitute Eq. (3.6) into Eq. (3.5) yield

$$\hat{x}_d = \max_{x_s}\left\{\frac{P(x_s)P(y_{sd}, y_{rd}\backslash x_s)}{P(y_{sd}, y_{rd})}\right\} \tag{3.7}$$

where $P(x_s)$ is Priori probability of particular input x_s will be transmitted.

The Eq. (3.7) can be written as

$$\hat{x}_d = \max_{x_s}\left\{\frac{P(x_s)P(y_{sd}\backslash x_s)P(y_{rid}\backslash x_s)}{P(y_{sd}, y_{rd})}\right\} \tag{3.8}$$

The term $P(y_{sd}, y_{rd})$ is independent of x_s, it does not affect the result of the detector and for BPSK modulation, symbols are equal likely, therefore $P(x_s)$ for each symbol is equal and it not affected the result of the detector. Thus, Eq. (3.8) can be rewritten as

$$\hat{x}_d = \max_{x_s}\{P(y_{sd}\backslash x_s)\ P(y_{rd}\backslash x_s)\} \tag{3.9}$$

The detector given in Eq. (3.9) is the well-known maximum likelihood (ML). The MAP and ML detectors are the same for this system, mainly because equally likely symbols are used for transmission.

For BPSK modulation the detector given in Eq. (3.9) becomes comparison between two probability values of each transmitted signals from the source and the relay is an independent and identically distributed (i.i.d) sample.

$$P(y_{sd}\backslash x_s = +1)\ P(y_{rd}\backslash x_s = +1) \underset{-1}{\overset{+1}{\gtrless}} P(y_{sd}\backslash x_s = -1)\ P(y_{rd}\backslash x_s = -1) \tag{3.10}$$

where $P_{sd\backslash x_s=+1}(.)$ and $P_{sd\backslash x_s=-1}(.)$ refers the probability density function(PDF) of received signals of the $S \rightarrow D$ path at the destination when $x_s = +1$ or $x_s = -1$ is transmitted from the source respectively and $P_{rd\backslash x_s=+1}(.)$ and $P_{rd\backslash x_s=-1}(.)$ give the PDF of the received signals of the $R \rightarrow D$ path at the destination when $x_s = +1$ or $x_s = -1$ is transmitted from the source respectively.

The conditional density function of y_{sd} given the source symbol x_s in Gaussian noise is

$$P(y_{sd} \backslash x_s = \pm 1) = \frac{1}{\sqrt{2\pi\sigma_{sd}^2}} \; exp\left[\frac{-\left(y_{sd} - \sqrt{P_s d_{sd}^{-\alpha}} h_{sd} x_s\right)^2}{2\sigma_{sd}^2}\right] \tag{3.11}$$

By applying, the natural logarithm and introducing the conditional probability density function of y_{sd} in Eq. (3.10) simplify as

$$\frac{\sqrt{P_s d_{sd}^{-\alpha}} h_{sd} y_{sd}}{\sigma^2{}_{sd}} \underset{-1}{\overset{+1}{\gtrless}} \ln(P(y_{rd} \backslash x_s = -1)) - \ln(P(y_{rd} \backslash x_s = +1)) \tag{3.12}$$

All type of relay protocols depends on their particular relay function, to drive the probability density function (PDF) $P(y_{rd} \backslash x_s)$. The density of the received signal at the destination from the source y_{sd} is not affected by the change in the relay function. Thus, the conditional probability density function of y_{rd} plays an important role in defining the decision rule for the destination.

3. 6 Cooperative relaying protocols

Cooperative communication network can be classified depending on type of relay protocols. Cooperative relaying transmission protocol describes how a relay can process the transmitted signal from the source. In this section, three types of relay protocols are considered. These are amplify-and-forward (AF), detect-and-forward (DeF) and estimate-and forward (EF).

3.6.1 Amplify-and-Forward

In AF relay protocol, the relay node amplifies the received signal from the source then transmits an amplified signal to the destination as shown in Fig.3.5. In this process, the noise is also amplified with received signals.

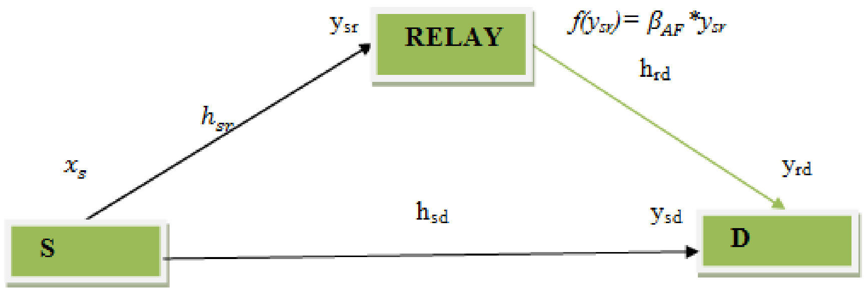


Figure 3.5: Amplify and Forward relay network.

The AF relay function is amplification of received signal y_{sr} at the relay by a relay amplifier gain (β). Mathematically given by

$$f_{AF}(y_{sr}) = x_r = \beta_{AF} \times y_{sr} \quad (3.13)$$

where β_{AF} is a relay amplifier gain.

The relay function is the type of a signal processing the relay is applying to the received signal from the source (y_{sr}). The output of this relay processing is described what the relay is really going to send to the destination. A relay amplifier gain (β_{AF}) is derived as follows in [8]:

First, the Input-Output relation at the relay node expressed as follows.

- Input from the source: $y_{sr} = \sqrt{P_s d_{sr}^{-\alpha}} x_s h_{sr} + n_{sr}$
- Output to destination(AF relays function): $x_r = \beta_{AF} \times y_{sr}$

$$P_r = E[|\, x_r|^2] = E[|\beta_{AF} \times y_{sr}|^2] = (\beta_{AF})^2 \times E[|\, y_{sr}|^2] \quad (3.14)$$

where P_r is the received relay power .

Now

$$\beta_{AF} = \sqrt{\frac{P_r}{E[\,|\, y_{sr}|^2]}} \quad (3.15)$$

By substituting Eq. (3.1) into Eq. (3.15)

$$\beta_{AF} = \sqrt{\frac{P_r}{E\left\{\left|\sqrt{P_s d_{sr}^{-\alpha}} x_s h_{sr} + n_{sr}\right|^2\right\}}} \quad (3.16)$$

$$= \sqrt{\frac{P_r}{E(|h_{sr}|^2)d_{sr}^{-\alpha}P_s + \sigma_{sr}^2}} \quad (3.17)$$

$$= \sqrt{\frac{P_r}{N_o + E|h_{si}|^2 P_s d_{sr}^{-\alpha}}} \quad (3.18)$$

where, N_o is the noise power.

In the second hop of AF, relay network the output of the received signal at a relay node is transmitted to the destination. Therefore, the received signal at the destination from the relay is given by:

$$y_{rd} = \sqrt{P_r d_{rd}^{-\alpha}} h_{rd}(\beta_{AF} y_{sr}) + n_{rd} \quad (3.19)$$

By substituting Eq. (3.1) at place of y_{sr} the Eq. (3.19) rewrite as follows:

$$y_{rd} = \sqrt{P_r d_{rd}^{-\alpha}} h_{rd} \beta_{AF} \left(h_{sr} x_s \sqrt{P_s} + n_{sr}\right) + n_{rd} \quad (3.20)$$

$$= \sqrt{P_r P_s d_{sr}^{-\alpha} d_{rd}^{-\alpha}} \beta_{AF} h_{sr} h_{rd} x_s + \sqrt{P_r d_{rd}^{-\alpha}} \beta_{AF} h_{rd} n_{sr} + n_{rd} \quad (3.21)$$

The Eq. (3.21) can be simplified as

$$y_{rd} = \sqrt{P_r P_s d_{sr}^{-\alpha} d_{rd}^{-\alpha}} \beta_{AF} h_{sr} h_{rd} x_s + n \quad (3.22)$$

where, n=$\sqrt{P_r d_{rd}^{-\alpha}} \beta_{AF} h_{rd} n_{sr} + n_{rd}$ is equivalent noise.

After all signals are received at the destination, it uses the following detection rule for maximum likelihood detection to get back the original signal. The conditional density function of y_{rd} given the source symbol x_s in Gaussian noise is

$$P(y_{rd} \backslash x_s = \pm 1) = \frac{1}{\sqrt{2\pi\left({\beta_{AF}}^2 {h^2}_{rd} P_r d_{rd}^{-\alpha} {\sigma^2}_{sr} + {\sigma^2}_{rd}\right)}} \times$$

$$\exp\left[\frac{-\left(y_{rd} - \sqrt{P_r P_s d_{sr}^{-\alpha} d_{rd}^{-\alpha}} \beta_{AF} h_{sr} h_{rd} x_s\right)^2}{2\left({\beta_{AF}}^2 {h^2}_{rd} P_r d_{rd}^{-\alpha} {\sigma^2}_{sr} + {\sigma^2}_{rd}\right)}\right] \quad (3.23)$$

By using ML detector Eq. (3.12), the decision process of AF relay protocol is described as follows

$$\frac{\sqrt{P_s d_{sd}^{-\alpha}} h_{sd} y_{sd}}{\sigma^2{}_{sd}} \underset{-1}{\overset{+1}{\gtrless}} \ln \left(\frac{\exp\left[\frac{-\left(y_{rd} + \sqrt{P_r P_s d_{sr}^{-\alpha} d_{rd}^{-\alpha}} \beta_{AF} h_{sr} h_{rd}\right)^2}{2\left(\beta_{AF}{}^2 h^2{}_{rd} d_{rd}^{-\alpha} P_r\ \sigma^2{}_{sr} + \sigma^2{}_{rd}\right)} \right]}{\exp\left[\frac{-\left(y_{rd} - \sqrt{P_r P_s d_{sr}^{-\alpha} d_{rd}^{-\alpha}} \beta_{AF} h_{sr} h_{rd}\right)^2}{2\left(\beta_{AF}{}^2 h^2{}_{rd} d_{rd}^{-\alpha} P_r \sigma^2{}_{sr} + \sigma^2{}_{rd}\right)} \right]} \right) \tag{3.24}$$

By simplification Eq. (3.24) is reduced to Eq. (3.25)

$$\frac{\sqrt{P_s d_{sd}^{-\alpha}} h_{sd} y_{sd}}{\sigma^2{}_{sd}} + \frac{y_{rd} \beta_{AF} h_{sr} h_{rd} \sqrt{P_r P_s d_{sr}^{-\alpha} d_{rd}^{-\alpha}}}{\beta_{AF}{}^2 h^2{}_{rd} P_r d_{rd}^{-\alpha} \sigma^2{}_{sr} + \sigma^2{}_{rd}} \underset{-1}{\overset{+1}{\gtrless}} 0 \tag{3.25}$$

3.6.2 Detect- and- Forward

In this relay protocol, a relay attempts to detect the transmitted data from source and then retransmits the detected data to the destination only if the message transmitted from the source gets detect properly at the relay as shown in Fig.3.6. This protocol only detects and forward does not add any additional information to the signal. Generally, a DeF relay network needs to know source-destination and relay-destination channel state information (CSI), but AF relay network just needs to know channel state information of the source to relay link. This difference causes a better performance for the AF relay network than the DeF relay network. However, this not always true the performance of relay protocols are depended by the quality of the channels and more precisely by the position of relay node.

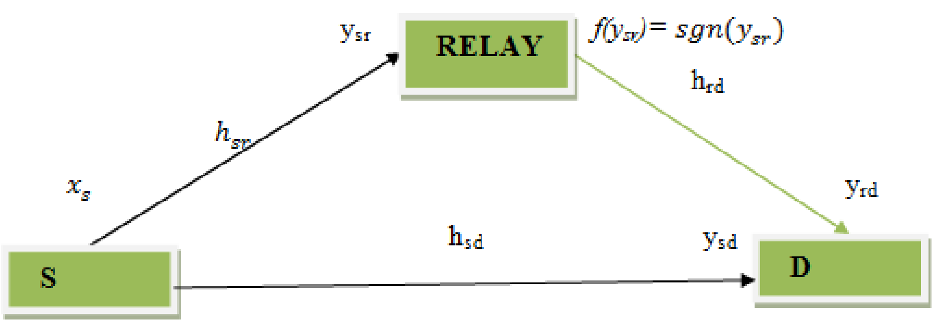


Figure 3.6: Detect and Forward relay network.

In this thesis, the uncoded modulation is proposed so to this case decode and forward protocol is known as detect and forward protocol. The relay function of DeF is defined as the signum function of received signals from the source. Mathematically DeF relay function is written as:

$$f_{DeF}(y_{sr}) = \text{ sgn } (y_{sr}) = \begin{cases} +1, y_{sr} > 0 \\ 0 \, , y_{sr} = 0 \\ -1 \, , y_{sr} < 0 \end{cases} \tag{3.26}$$

where sgn is signum function [53].

The DeF relay function depends only on the received signal y_{sr}, and does not need any information about the quality of the S-R channel. In the second hop, the received signal at the destination from the relay node is given by:

$$y_{rd} = \sqrt{P_r d_{rd}^{-\alpha}} h_{rd} f_{DeF}(y_{sr}) + n_{rd} \tag{3.27}$$

By substituting Eq. (3.26) at place of $f_{DeF}(y_{sr})$ the Eq. (3.27) rewrite as follows:

$$y_{rd} = \sqrt{P_r d_{rd}^{-\alpha}} h_{rd} \text{sgn } (y_{sr}) + n_{rd} \tag{3.28}$$

The process of deriving decision rule of this protocol is the same AF relay protocol.

$$\frac{\sqrt{P_s d_{sd}^{\alpha-}} h_{sd} y_{sd}}{\sigma^2{}_{sd}} + \frac{\sqrt{P_r d_{rd}^{-\alpha}} h_{rd} y_{rd}}{\sigma^2{}_{rd}} \underset{-1}{\overset{+1}{\gtrless}} 0 \tag{3.29}$$

3.6.3 Estimate-and-Forward

In estimate-and-forward (EF) protocol received signals at the relay estimated by using estimation method as shown in Fig.3.7. In [30], BPSK modulation is used with MMSE estimation, a hyperbolic tangent can be used as the estimation function of the relay. In this thesis, MMSE estimation method is used as EF relay function.

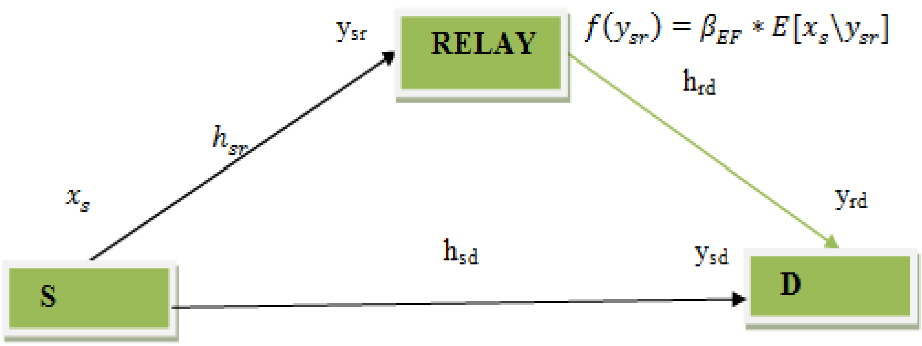


Figure 3.7: Estimate and Forward relay network.

Based on the general definition the MMSE estimation, an EF relay function is defined as the conditional expectation of the source sent symbol x_s given the received signal (y_{sr}) at the relay. Mathematically given by:

$$x_{MMSE} = f_{EF}(y_{sr}) = \beta_{EF} \times E[x_s \backslash\ y_{sr}] \tag{3.30}$$

By definition of discrete expectation formula the above can rewrite as

$$f_{EF}(y_{sr}) = \beta_{EF} \sum_{x_s} x_s\ p(x_s \backslash y_{sr}) \tag{3.31}$$

By applying Bayes', rule [52]

$$f_{EF}(y_{sr}) = \beta_{EF} \sum_{x_s} \frac{x_s\ P(y_{sr}, x_s)}{P(y_{sr})} = \beta_{EF} \sum_{x_s} \frac{x_s\ P(x_s)P(y_{sr} \backslash x_s)}{P(y_{sr})} \tag{3.32}$$

$$f_{EF}(y_{sr}) = \beta_{EF} \frac{\sum_{xs} x_s\ P(x_s)P(y_{sr} \backslash x_s)}{\sum_{xs}\ P(x_s)P(y_{sr} \backslash x_s)} \tag{3.33}$$

The conditional density function of y_{sr} given the source symbol x_s in Gaussian noise is

$$P(y_{sr} \backslash x_s) = \frac{1}{\sqrt{2\pi\sigma_{sr}^2}} \exp\left[\frac{-\left(y_{sr} - \sqrt{P_s d_{sr}^{-\alpha}} h_{sr} x_s\ \right)^2}{2\sigma_{sr}^2}\right] \tag{3.34}$$

By introducing, the conditional probability density function of y_{sr} in Eq. (3.33), EF relay function can be expanded as follows

$$f_{EF}(y_{sr}) = \beta_{\mathrm{EF}} \frac{\sum_{x_s} \frac{1}{\sqrt{2\pi\sigma_{sr}^2}} x_s\, P(x_s)\, \exp\left[\frac{-\left(y_{sr} - \sqrt{P_s d_{sr}^{-\alpha}} h_{sr} x_s\right)^2}{2\sigma_{sr}^2}\right]}{\sum_{x_s} \frac{1}{\sqrt{2\pi\sigma_{sr}^2}}\, P(x_s)\, \exp\left[\frac{-\left(y_{sr} - \sqrt{P_s d_{sr}^{-\alpha}} h_{sr} x_s\right)^2}{2\sigma_{sr}^2}\right]} \quad (3.35)$$

where, $\frac{1}{\sqrt{2\pi\sigma_{sr}^2}}$ can be simplify from the numerator and the denominator as follow.

$$f_{EF}(y_{sr}) = \beta_{\mathrm{EF}} \frac{\sum_{x_s} x_s\, P(x_s)\, \exp\left[\frac{-\left(y_{sr} - \sqrt{P_s d_{sr}^{-\alpha}} h_{sr} x_s\right)^2}{2\sigma_{sr}^2}\right]}{\sum_{xs}\, P(x_s)\, \exp\left[\frac{-\left(y_{sr} - \sqrt{P_s d_{sr}^{-\alpha}} h_{sr} x_s\right)^2}{2\sigma_{sr}^2}\right]} \quad (3.36)$$

By using BPSK modulation technique the relay function of EF described in Eq. (3.36) can be derived as follows:

$$f_{EF}(y_{sr}) = \beta_{\mathrm{EF}} \frac{\exp\left(\frac{-y_{sr}^2 + 2y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr} - h_{sr}^2 P_s d_{sr}^{-\alpha}}{2\sigma_{sr}^2}\right) - \exp\left(\frac{-y_{sr}^2 - 2y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr} - h_{sr}^2 P_s d_{sr}^{-\alpha}}{2\sigma_{sr}^2}\right)}{\exp\left(\frac{-y_{sr}^2 + 2y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr} - h_{sr}^2 P_s d_{sr}^{-\alpha}}{2\sigma_{sr}^2}\right) + \exp\left(\frac{-y_{sr}^2 - 2y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr} - h_{sr}^2 P_s d_{sr}^{-\alpha}}{2\sigma_{sr}^2}\right)} \quad (3.37)$$

Rewrite Eq. (3.37) as follows

$$f_{EF}(y_{sr}) = \beta_{\mathrm{EF}} \frac{\exp\left(\frac{-y_{sr}^2}{2\sigma_{sr}^2}\right) \exp\left(\frac{-h_{sr}^2 P_s d_{sr}^{-\alpha}}{2\sigma_{sr}^2}\right) \left\{\exp\left(\frac{2\, y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr}}{2\sigma_{sr}^2}\right) - \exp\left(\frac{-2y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr}}{2\sigma_{sr}^2}\right)\right\}}{\exp\left(\frac{-y_{sr}^2}{2\sigma_{sr}^2}\right) \exp\left(\frac{-h_{sr}^2 P_s d_{sr}^{-\alpha}}{2\sigma_{sr}^2}\right) \left\{\exp\left(\frac{2\, y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr}}{2\sigma_{sr}^2}\right) + \exp\left(\frac{-2y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr}}{2\sigma_{sr}^2}\right)\right\}} \quad (3.38)$$

Simplify $\exp\left(\frac{-y_{sr}^2}{2\sigma_{sr}^2}\right) \exp\left(\frac{-h_{sr}^2 P_s d_{sr}^{-\alpha}}{2\sigma_{sr}^2}\right)$ from the numerator and the denominator Eq. (3.38) becomes:

$$f_{EF}(y_{sr}) = \beta_{\mathrm{EF}} \times \frac{\exp\left(\frac{2\, y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr}}{2\sigma_{sr}^2}\right) - \exp\left(\frac{-2y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr}}{2\sigma_{sr}^2}\right)}{\exp\left(\frac{2\, y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr}}{2\sigma_{sr}^2}\right) + \exp\left(\frac{-2y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr}}{2\sigma_{sr}^2}\right)} \quad (3.39)$$

Hyperbolic identities are used to simplify Eq. (3.39) as in [54].

$$f(y_{sr}) = \beta_{\mathrm{EF}} \frac{\sinh\left(\frac{y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr}}{\sigma_{sr}^2}\right)}{\mathrm{Cosh}\left(\frac{2\, y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr}}{\sigma_{sr}^2}\right)} = \beta_{\mathrm{EF}} \tanh\left(\frac{y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr}}{\sigma_{sr}^2}\right) \tag{3.40}$$

where β_{EF} is the average gain for the EF relay protocol.

Therefore, the average transmit power (P_r) at the relay and β_{EF} can be derived similar as in AF.

$$P_r = E[|\beta_{EF} \times E[x_s \backslash y_{sr}]|^2] = (\beta_{EF})^2 \times E[|E[x_s \backslash y_{sr}]|^2] \tag{3.41}$$

$$\beta_{EF} = \sqrt{\frac{\mathrm{P_r}}{\mathrm{E}\ [|\ E\ [x_s \backslash\ y_{sr}]|^2]}} = \sqrt{\frac{P_r}{\mathrm{E}\{|\tanh\left(\frac{y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr}}{\sigma_{sr}^2}\right)|^2\}}} \tag{3.42}$$

In the second hop for EF relay network received signals at the destination from the relay node is given by:

$$y_{rd} = \sqrt{P_r d_{rd}^{-\alpha}} h_{rd} f_{EF}(y_{sr}) + n_{rd} \tag{3.43}$$

By substituting Eq. (3.41) at place of $f_{EF}(y_{sr})$ in (3.44), rewrite as follows

$$y_{rd} = \sqrt{P_r d_{rd}^{-\alpha}} h_{rd}\, \beta_{\mathrm{EF}} \tanh\left(\frac{y_{sr}\sqrt{P_s d_{sr}^{-\alpha}} h_{sr}}{\sigma_{sr}^2}\right) + n_{rd} \tag{3.44}$$

3.7 Relay Positioning

In this Section, three basic categories of relay network topologies will be considering for analyzing the performance of relaying protocols. These will include the equilateral triangle, the isosceles triangle and the linear topologies.

3.7.1 Equilateral Triangle Topology

Here, the source, relay and receiver are placed in a triangular topology with equal distance between them as shown in Fig.3.8.

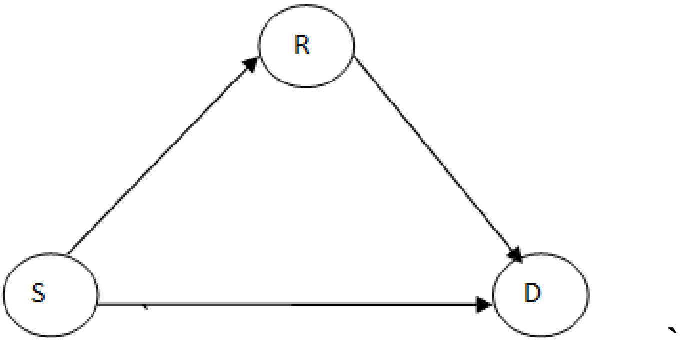


Figure 3.8: Equilateral Triangle Topology

3.7.2 Isosceles Triangle Topology

Under this topology the distance from source to the destination (d_{sd}) and distance from relay to destination (d_{rd}) both are equal as shown Fig.3.9.

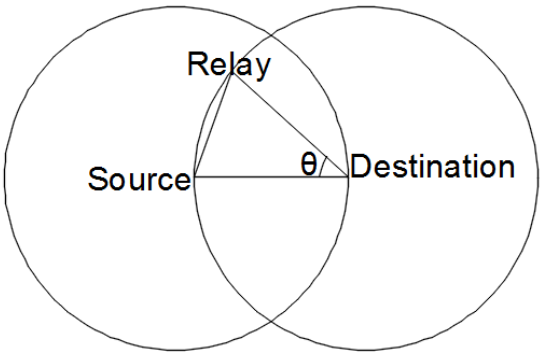


Figure 3.9: Isosceles triangle topology

when d_{sd}=d_{rd}=d

$$d_{sr} = d\sqrt{2(1 - cos\theta)}, \qquad \theta \in \left[-\frac{\pi}{3}, 0\right) \cup \left(0, \frac{\pi}{3}\right] \tag{3.45}$$

Because of the symmetry of the topology, $\theta \in \left[\frac{\pi}{3}, 0\right)$ and when $\theta = \frac{\pi}{3}$ the isosceles triangle topology becomes the equilateral triangle topology. where θ is the angle between d_{sd} and d_{rd}.

3.7.3 Linear Topology

In this topology, the source, relay and destination are placed linearly on the same axis. Under this topology, the path attenuation is considering. The propagation path loss increases based on distance between nodes. The pathloss of each link follows an exponential-decay model. If the distance between the source and destination is equal to d_{sd}, the channel mean power of the source-to-destination link is $\Omega_{sd} \propto \mathrm{d}_{\mathrm{sd}}^{-\alpha}$, where α is the pathloss exponent correspond to a typical non line-of-sight propagation. Then, $\Omega_{sr} = \in^{-\alpha} \Omega_{sd}$ and $\Omega_{rd} = (1 - \in)^{-\alpha}\Omega_{sd}$. Where Ω_{sr} and Ω_{rd} are the channel mean powers of the source-to-relay and relay-to-destination links, respectively. The scalar value ∈ stands for the ratio of the distance from source to relay and the distance from source to the destination$\left(\frac{d_{sr}}{d_{sd}}\right)$. Under this section, two separate scenarios will be considered based on the position where a relay node is placed.

Relay Close to Source:

Here the relay is positioned close to the signal source as shown in Fig.3.10.

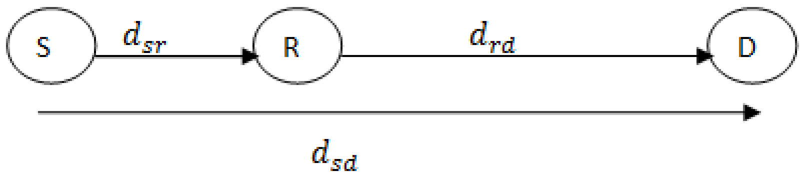


Figure 3.10: Linear Placement topology when a relay close to source

Relay Close to Receiver:

Here the relay is positioned close to the receiver as shown in Fig.3.11.

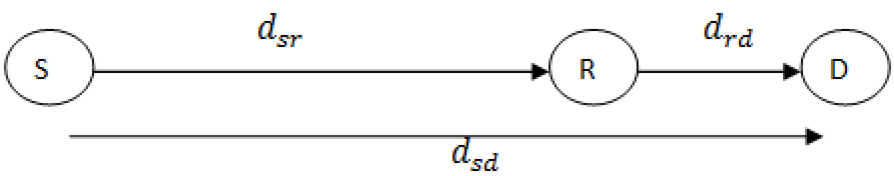


Figure 3.11: Linear Placement topology when a relay close to destination

3.8 Performance measures

The system performance measurement is essential for any wireless system in order to estimate the quality of the signal with reliability before implementation. Depending on the system design and the environment where the system is going to be used, the performance of the system will vary. There are many ways of measuring the performance of a wireless link such as Bit error rate (BER) and outage probability (P_{out}). In this thesis, the measurement parameter that used to measures the performance of the relay system is the Bit Error Rate (BER) versus different parameters. The bit error rate (BER) and the signal to noise ratio (SNR) parameters are defining as follows.

3.8.1 Bit Error Rate (BER)

BER is an important parameter to measure the performance of any communication systems. The BER is calculated from the number of bits received in error divided by the number of bits transmitted or it is defined as probability of bits error, which received bits in error. Mathematically it can be defined as

$$\mathrm{BER} = \frac{\mathrm{n}}{\mathrm{N}} \tag{3.46}$$

where n is total numbers of bit error and N is total number of transmitted bits.

In wireless communication system, the minimum and maximum possibilities of bit error rate (BER) or probability of bit error (P_e) is 0 and 0.5 respectively ($0 \leq P_e \leq 0.5$). BER is a unit less performance measure, often expressed as a percentage of bits that have errors due to noise, interference, distortion. Therefore, as the BER increases the reliability of the communication system is becoming less. This means the communication system more reliable when the probability of bit error (P_e) approaches to zero.

3.8.2 Signal to Noise Ratio (SNR)

Signal-to-Noise-Ratio (SNR) is defined as the ratio of the received signal power (P_r) to the noise power (P_n) or SNR is a term used to compare power of the received signal to noise power. Mathematically it can be defined as

$$\mathrm{SNR} = \frac{\mathrm{P_r}}{\mathrm{P_n}} \tag{3.47}$$

If SNR is more than one, then it shows that P_r is stronger than the noise power(P_n). Hence, SNR could also state in decibels (dB) as:

$$\mathrm{SNR}_{dB} = 10 \log_{10}\left(\frac{P_r}{P_n}\right) \tag{3.48}$$

Chapter 4

Simulation Results and Discussions

4.1 Introduction

In this chapter, the simulation results are presented to investigate the performance of relay networks described in previous chapter and compare them with no relay node system. The evaluations of this performance were carried out using a code developed in MATLAB software with BPSK modulation scheme. For convenience, this chapter is divided into five Sections. In the first Section, the effect of fading on the performance of wireless system is simulated by assuming no relay node between source and destination. In the second Section, it is assumed that source, relay and destination nodes are placed in an equilateral triangle topology. In this topology the distance between nodes are equal. In the third Section, it is assumed that source, relay and destination nodes are placed in an isosceles triangle topology. This topology has two equal distances these are the distance between source to the destination (d_{sd}) and relay to destination (d_{rd}). The pathloss is considered in this topology. In the fourth Section, it is assumed that the source, relay and destination nodes are placed in linear topology by using relay moving between source and destination. In the fifth Section the optimal relay position are investing by using linear topology. Generally, in the last four Sections, the performance of three different relay protocols are compared over Rayleigh and Nakagami-m fading channels with Additive white Gaussian Noise. These are amplify- and-forward (AF), detect- and- forward (DeF) and estimate- and -forward (EF) cooperative relay protocols.

Generally, the performances of relay protocols are simulated based on their sequences operation introduced in Appendix A. In addition, for these protocols implementation three complexes white Gaussian noises with three independent Rayleigh and Nakagami-m channel models were considered. The bit error rate (BER) versus SNR and distance from source to relay (d_{sr}) are parameters used as metric for performance measurements. The basic parameters uses for simulations are listed in the Table 4.1.

Table 4.1: Basic Simulation Parameters.

No.	Parameters	Value
1	Number of bits (N)	10^6
2	Signal to noise ratio (SNR)	0-25 dB
3	Relay power(Pr)	26.98 dBm
4	Source power (Ps)	26.98 dBm
5	Performance Metrics	BER
6	Modulation Scheme	BPSK
7	Noise	AWGN
8	Channel used	Rayleigh and Nakagami-m
9	Shape parameter ,m and Controlling spread, Ω	m=1,1.5 and Ω=1
10	Types of relay Relaying protocols	AF, DeF and EF
11	Types of relay topologies	Equilateral, isosceles and linear
12	Number of Relay	1
13	Software	Matlab
14	version	R2013a

4.2 Performance comparison of the system without the relay with no fading and fading channel

The aim of this Section is to introduce the effect of fading on system performance in terms of BER versus SNR. The simulation results started by assuming no relay node between source and destination. The channel between source and destination considered as non-faded channel and faded channel. An Additive white Gaussian noise channel (AWGN) is considered as a non-faded channel model whereas Rayleigh and Nakagami-m fading channels are considered as faded channel models. According to result from Fig.4.1, it is observed that the signal quality is much worse under fading environment. For example, the BPSK signal in AWGN is

10dB better than the BPSK signal in the Rayleigh fading channel to hit BER value of 10^{-2}. This means it needs a 10dB less signals energy. It is 6dB better than the BPSK signal in Nakagami-m fading channel to hit BER of 10^{-2}. These differences grow as SNR values increasing, to hit the BER value of 10^{-3} AWGN is 16dB better than the Rayleigh fading channel and 10dB better than Nakagami-m fading channel. To mitigate this fading problem the different cooperative relay protocols have been used in this study to provide the advantage of diversity as shown in following sections.

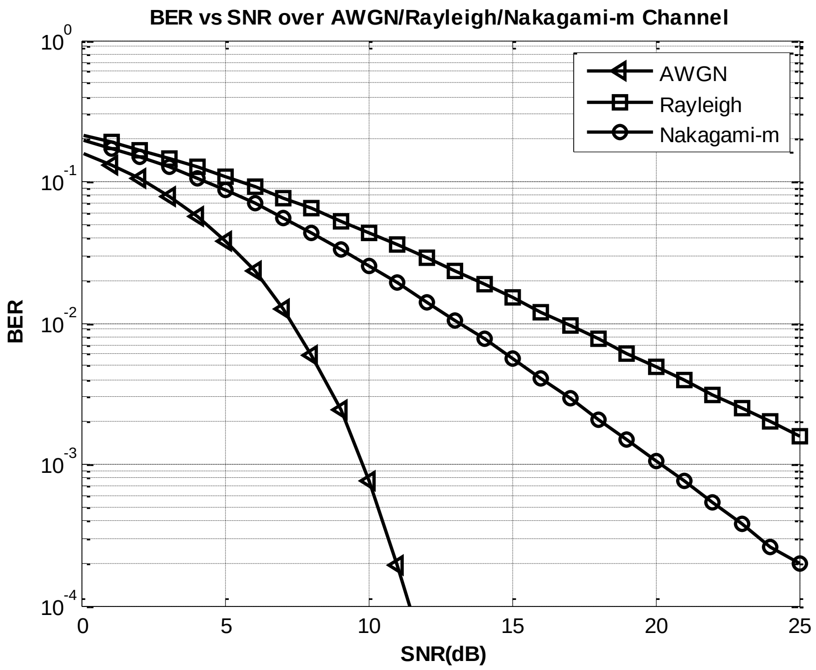


Figure 4.1: BER versus SNR for System without relay node over AWGN channel, Rayleigh and Nakagami-m fading channels.

4.3 Performance of relay protocols with equilateral triangle topology

In this Section, the simulation results are obtained with equilateral triangle topology. In this topology, a relay node placed at one of the edges of the equilateral triangle with the source and destination nodes are placed on the other edges as shown in Fig.3.8. The distance between all nodes is normalized to unity due to this the path loss on each channel practically the same. The results are simulated by using Rayleigh and Nakagami-m fading channels due to these two plots are there under this Section. Fig.4.2 and Fig.4.3 illustrates the comparison performance of AF, DeF and EF relay protocols over Rayleigh and Nakagami-m fading channels. According to the results from these plots, all relay protocols have better BER for a given SNR when compared to the direct link transmission.

As shown in Fig.4.2 and Table 4.2, to achieve a BER value of about 10^{-3} the EF relay protocol provides 5.5dB and 0.5dB gains relative to the DeF and AF respectively for the Rayleigh fading channel.

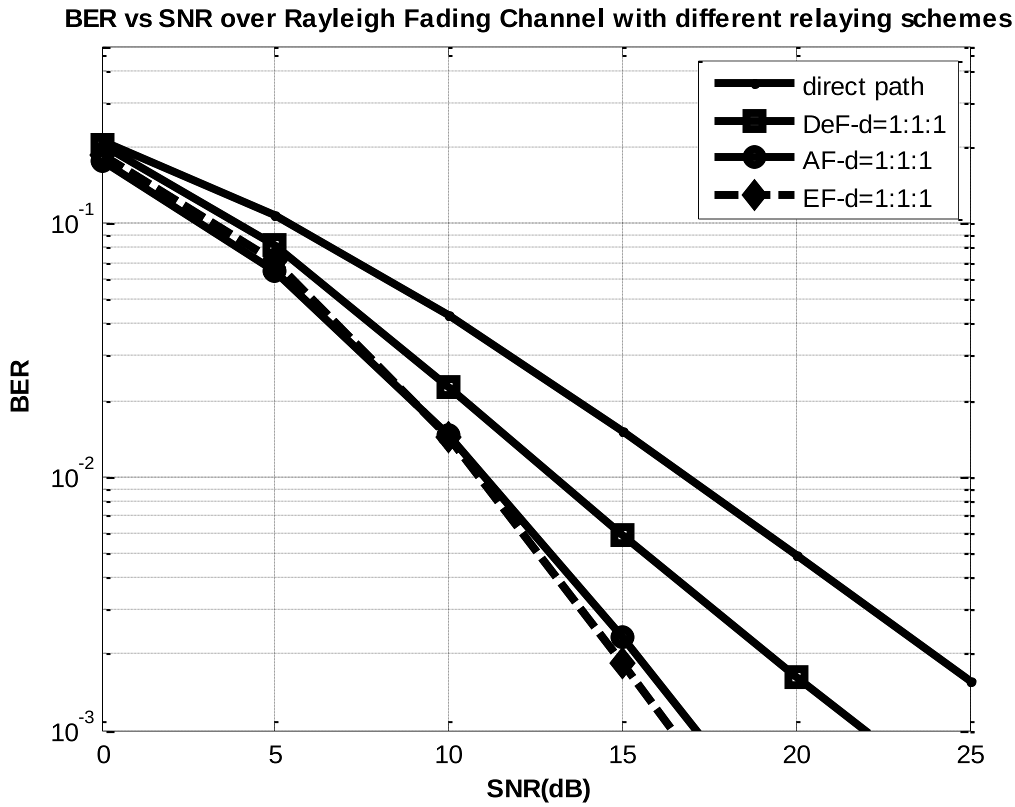


Figure 4.2: BER versus SNR for various relay protocols with path distance ratio 1.0:1.0:1.0 [S-D: S-R: R-D] over Rayleigh fading channel.

For the Nakagami fading channel to achieve a BER value of about 10^{-3} the EF relay protocol provides 3dB and 1dB gains relative to the DeF and AF respectively as shown in Fig.4.3 and Table 4.2. Therefore, as shown from both simulation graphs the EF relay network has better gain than AF and DeF relay networks. Moreover, the performances also more improve when nakagami-m fading channel used instead of Rayleigh fading channel.

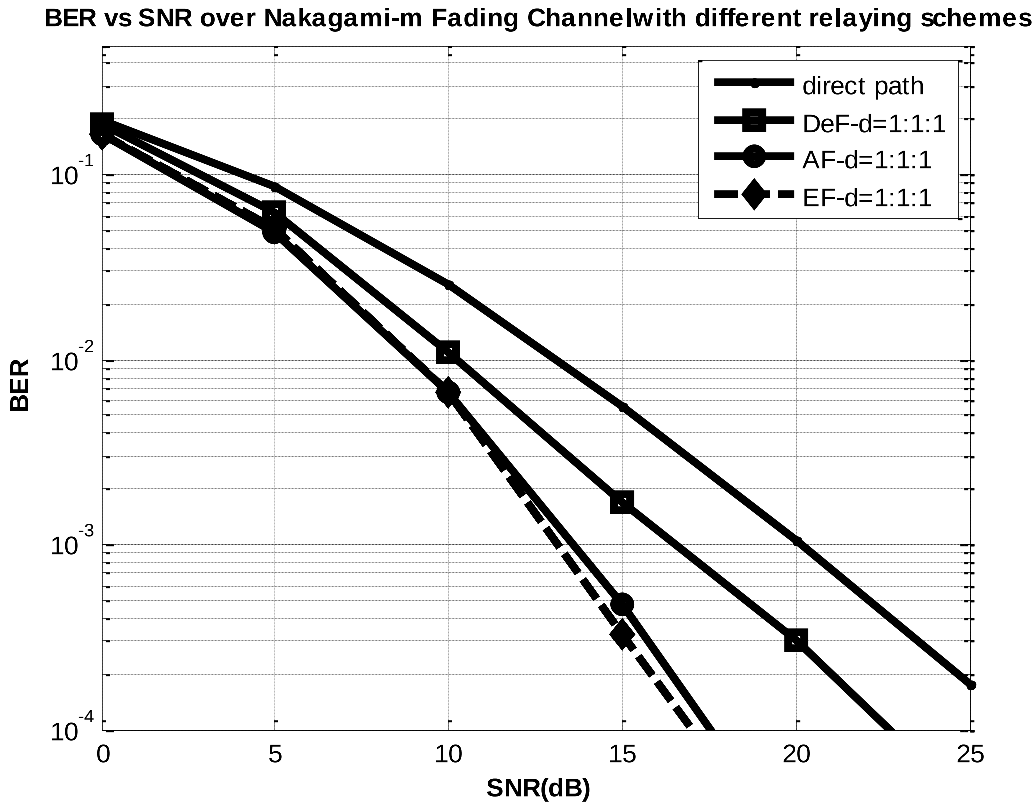


Figure 4.3: BER versus SNR for various relay protocols with path distance ratio 1.0:1.0:1.0 [S-D: S-R: R-D] over Nakagami-m fading channel.

Table 4.2: Compression of relaying protocols at a BER value of 10^{-3} for equilateral topology over fading channels.

Relaying protocols	**SNR values for each protocol at fixed BER**	
	For Rayleigh	**For Nakagami-m**
DeF	22dB	16dB
AF	17dB	14dB
EF	16.5dB	13dB

4.4 Performance of relay protocols with isosceles triangle topology

In this Section, the simulation results are obtained with isosceles triangle topology. In this topology, a relay node placed at one of the edges of the isosceles triangle with the source and destination nodes are placed on the other edges as shown in Fig.3.9. Under this topology, the distance from source to the destination (d_{sd}) and the distance from relay to the destination (d_{rd}) are normalized to unity. The distance between source and relay (d_{sr}) is equal to 0.76 unit distance ratio it is calculated based on Eq. (3.45) with $\theta = 45°$. The results are simulated by using Rayleigh and Nakagami-m fading channels due to these two plots are there under this Section. Fig.4.4 and Fig.4.5 illustrates the comparison performance of AF, DeF and EF relay protocols over Rayleigh and Nakagami-m fading channels with isosceles topology. The result from Fig.4.4 and Fig.4.5 shows that for given SNR, the performances of all relaying protocol better than direct link transmission. For instance to achieve a BER value of 10^{-2} the required SNR values for DeF, AF and EF protocols are about 5.5dB, 5.5dB and 6dB better when compared to the direct path transmission respectively. In addition, under nakagami-m fading channel to achieve a BER value of 10^{-2} the required SNR values for DeF, AF and EF protocols are about 5dB, 5dB and 6dB better when compared to the direct path transmission respectively.

To achieve a BER value of about 10^{-3} the EF relay protocol provide 3 dB and 1dB gains relative to the DeF and AF respectively, for the Rayleigh fading channel as shown in Fig.4.4 and Table 4.3.

For the Nakagami fading channel as shown in Fig.4.5 and Table 4.3 to achieve a BER value of about 10^{-3} the EF relay protocol provides 1dB and 1 dB gains relative to the DeF and AF respectively. Hence, as shown from both simulation graphs the EF relay network has better performance than AF and DeF relay networks. In addition, the performances also more improves when nakagami-m fading channel used instead of Rayleigh fading channel.

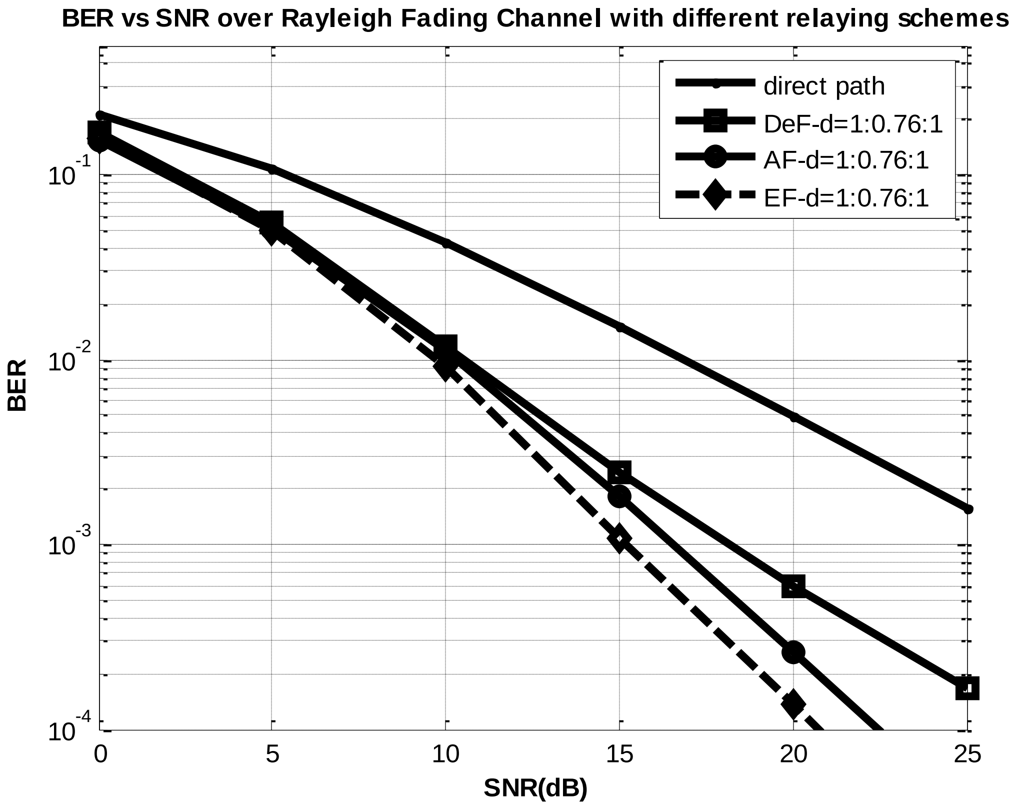


Figure 4.4: BER versus SNR for various relay protocols with path distance ratio 1.0:0.76:1.0 [S-D: S-R: R-D] over Rayleigh fading channel.

Table 4.3: Compression of relaying protocols at a BER value of 10^{-3} for isosceles over fading channels.

Relaying protocols	**SNR values for each protocol at fixed BER**	
	For Rayleigh	**For Nakagami-m**
DeF	18dB	13dB
AF	16dB	13dB
EF	15dB	12dB

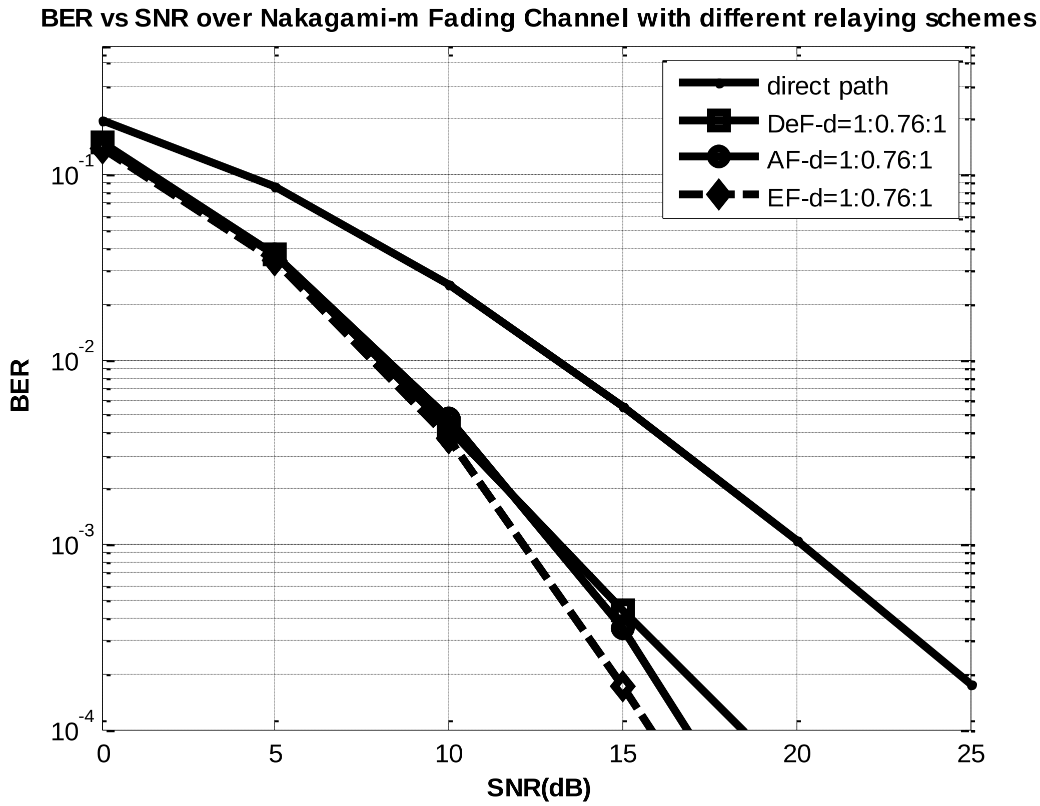


Figure 4.5: BER versus SNR for various relay protocols with path distance ratio 1.0:0.76:1.0 [S-D: S-R: R-D] over Nakagami-m fading channel.

4.5 Performance of relay protocol with linear placement topology

In earlier sections, systems are modeled and simulated by using an equilateral triangle and isosceles triangle topologies with single relay at fixed position. Now the performances of relay networks are analyzed using linear placement topology with variable position of relay. In linear topology, the relay is placed at different positions between the source and destination as shown in Fig.3.11 and Fig.3.12. The BER performances of the all-relaying protocols have been evaluated in the following subsection sections.

4.5.1 Relay close to source

Under this subsection, the aim is to investigate the performance of DeF, AF and EF relay protocols when a relay node closes to source as shown in Fig.3.11. The distance from source to the destination (d_{sd}) is normalized to unity. The distance between source and relay (d_{sr}) and relay to destination are equal to 0.25 and 0.75 unit distance ratios respectively. The results are simulated by using Rayleigh and Nakagami-m fading channels as shown bellow.

Fig. 4.6 and Fig.4.7 show that all the relaying protocols have better a BER value for a given SNR when compared to the direct link transmission.

For the Rayleigh fading channel to achieve a BER value of about 10^{-3} the EF relay protocol provides 1 dB and 2 dB gains relative to the DeF and AF respectively, as shown in Fig.4.6 and Table 4.4.

Under the Nakagami-m fading channel to achieve a BER value of about 10^{-3} the EF relay protocol provides1dB and 1 dB gains relative to the DeF and AF respectively, as shown in Fig.4.7 and Table 4.4.

Table 4.4: Compression of relaying protocols at a BER value of 10^{-3} when relay close to source over fading channels.

Relaying protocols	**SNR values for each protocol at fixed BER**	
	For Rayleigh	**For Nakagami-m**
DeF	10.5dB	7dB
AF	12dB	8dB
EF	9dB	6dB

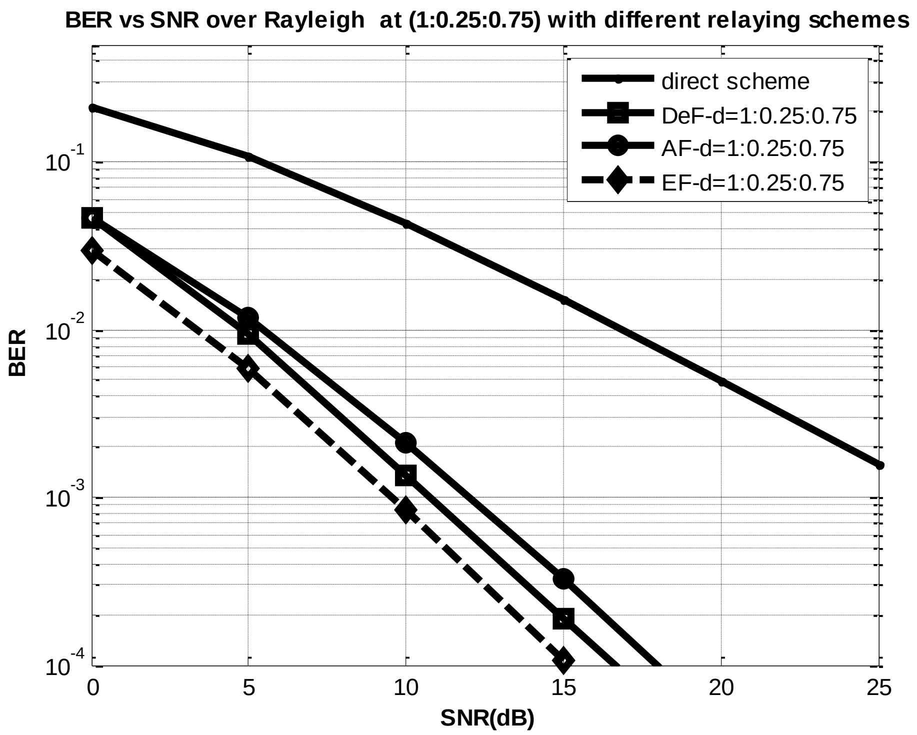


Figure 4.6: BER versus SNR for various relay protocols when relay node close to source at Path distances are in the ratio 1.0:0.25:0.75 over Rayleigh fading channel.

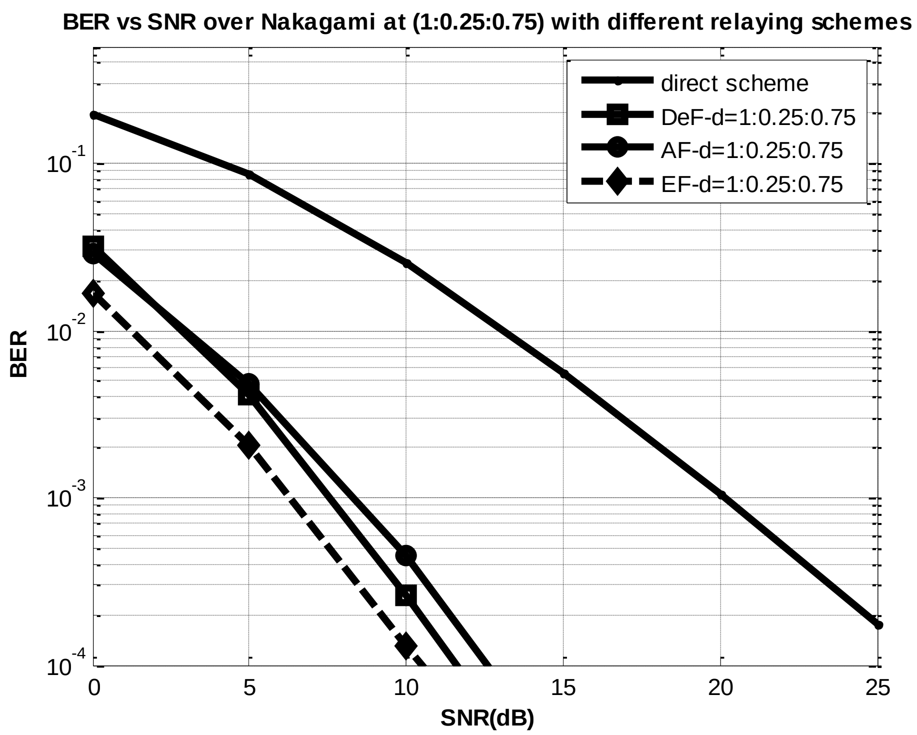


Figure 4.7: BER versus SNR for various relay protocols when relay node close to source in path distance ratio 1.0:0.25:0.75 over Nakagami-m fading channel.

4.5.2 Relay close to destination

Under this subsection, the aim is to investigate the performance of DeF, AF and EF relay protocols when a relay node closes to destination as shown in Fig.3.12. The distance from source to the destination (d_{sd}) is normalized to unity. The distance between source and relay (d_{sr}) and relay to destination are equal to 0.75 and 0.25 unit distance ratios respectively. The results are simulated by using Rayleigh and Nakagami-m fading channels as shown bellow. According to Fig.4.8 and Fig.4.9, shows that all the relaying protocols have better a BER value for a given SNR when compared to the direct link transmission. For instance to achieve a BER value of 10^{-2} the required SNR values for DeF, AF and EF protocols are about 4dB, 8dB and 8dB better when compared to the direct path transmission respectively. In addition, under nakagami-m fading channel to achieve a BER value of 10^{-2} the required SNR values for DeF, AF and EF protocols are about 5dB, 7dB and 7dB better when compared to the direct path transmission respectively.

For the Rayleigh fading channel as shown in Fig.4.8 and Table 4.5 to achieve a BER value about of 10^{-3} the EF and AF relay protocols provides 7 dB gain relative to the DeF relay protocol. Whereas under the Nakagami-m fading channel as shown in Fig.4.9 and Table 4.5 to achieve a BER value of about 10^{-3} the EF and AF relay protocols provides 3 dB gain relative to the DeF relay protocol. Generally, when relay closer to the destination; the path distance between the source and the relay becomes higher, it causes more attenuation losses. Therefore, the performances of all relay protocols show poor performance as compared to the results the when relay is placed close to the source.

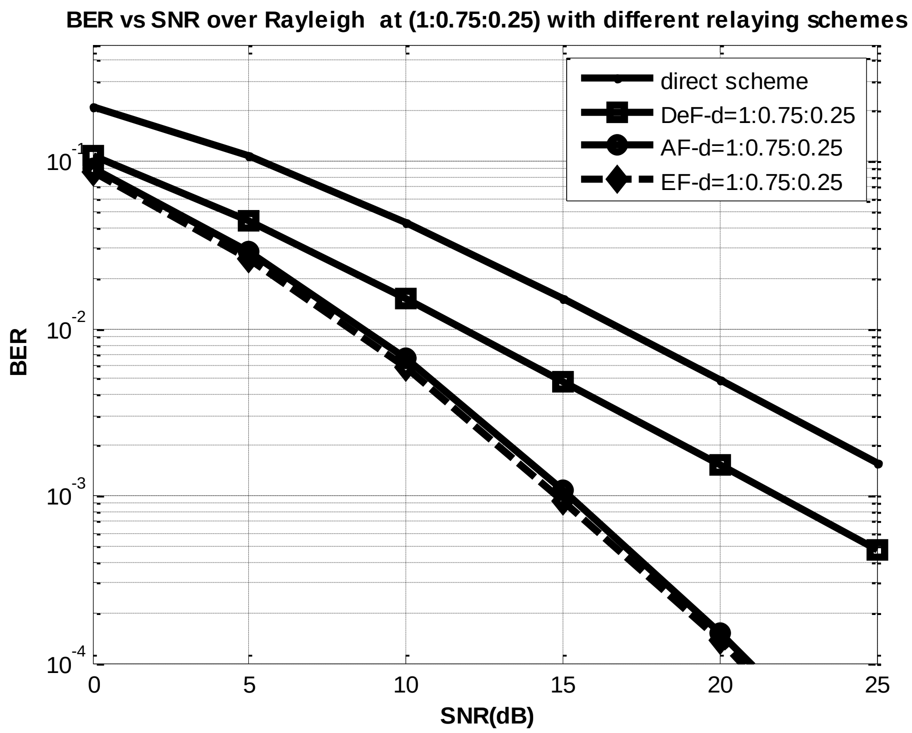


Figure 4.8: BER versus SNR for various relay protocols when relay node close to destination at path distances ratio 1.0:0.75:0.25 over Rayleigh fading channel.

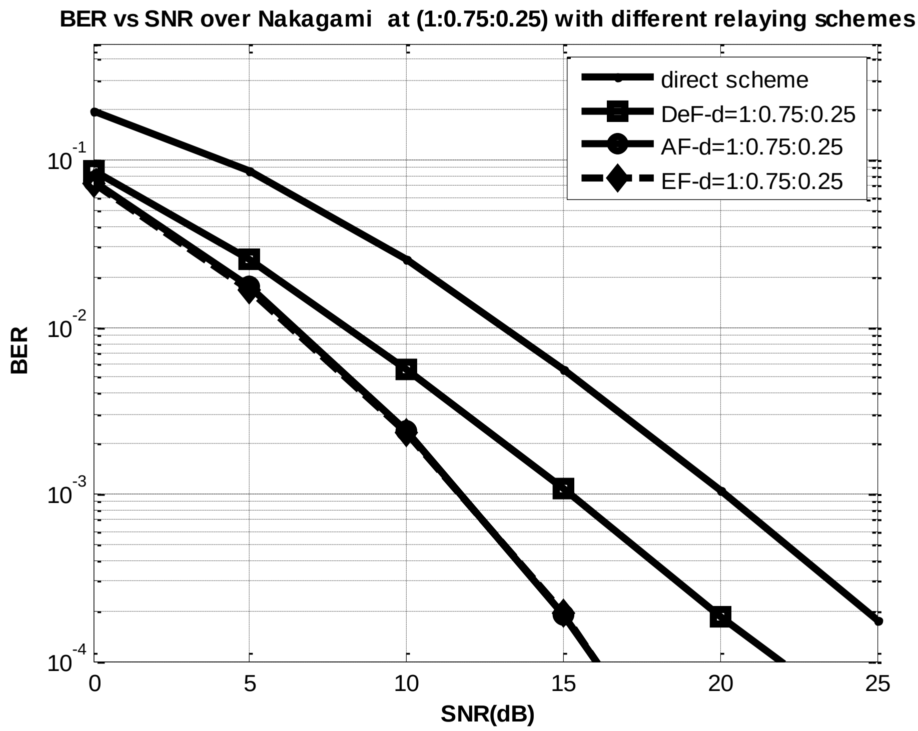


Figure 4.9: BER versus SNR for various relay protocols when relay node close to destination at path distances in the ratio 1.0:0.75:0.25 over Nakagami-m

Table 4.5: Compression of relaying protocols at a BER value of 10^{-3} when relay close to destination over fading channels.

Relaying protocols	**SNR values for each protocol at fixed BER**	
	For Rayleigh	**For Nakagami-m**
DeF	22dB	15dB
AF	15dB	12dB
EF	15dB	12dB

4.6 Optimal Relay Position

The aim this Section, to investigate the optimal relay position of DeF, AF and EF relaying protocols to minimize bite error rate probability over Rayleigh and Nakagami-m fading channel. The simulations are performed by using BER versus the distance between source and relay (d_{sr}). The black line denoted as no relay node between source and destination, represents the BER obtained for the direct path, when no cooperation is applied.

The optimal relay position of DeF relay protocol is occurred when $d_{sr} \leq 0.4$. For AF and EF relay networks, the optimal relay positions are occurred when $d_{sr} \leq 0.5$ and $d_{sr} \leq 0.4$ respectively as shown from Fig.4.10 and Fig.4.11. The optimal position of relay protocols under Rayleigh fading channel is the same as Nakagami fading channel. However, the BER performances of both simulation plots are not same. For instance, under Rayleigh fading channel at distance 0.4 a BER value of the EF relay protocol is about 1.35×10^{-2}. Whereas under Nakagami fading channel at distance 0.4 a BER value of the EF relay protocol is about 4.3×10^{-3}. Generally, the performances of all relay protocols are increased to their balance position. After their balance position a BER value of all protocols are decreasing as shown from Fig.4.10 and Fig.4.11.

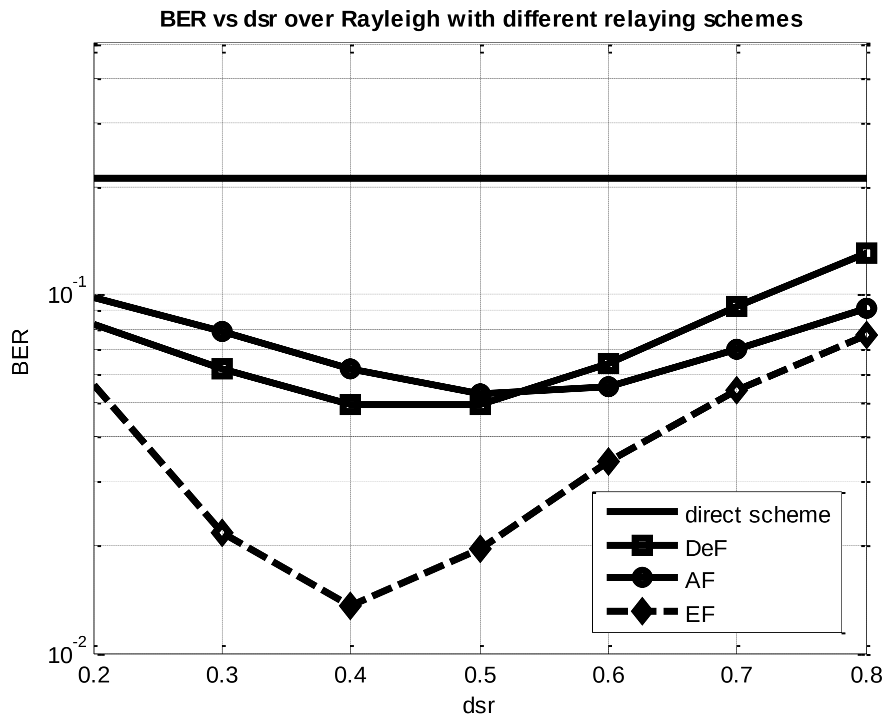


Figure 4.10: BER versus dsr over Rayleigh fading channel.

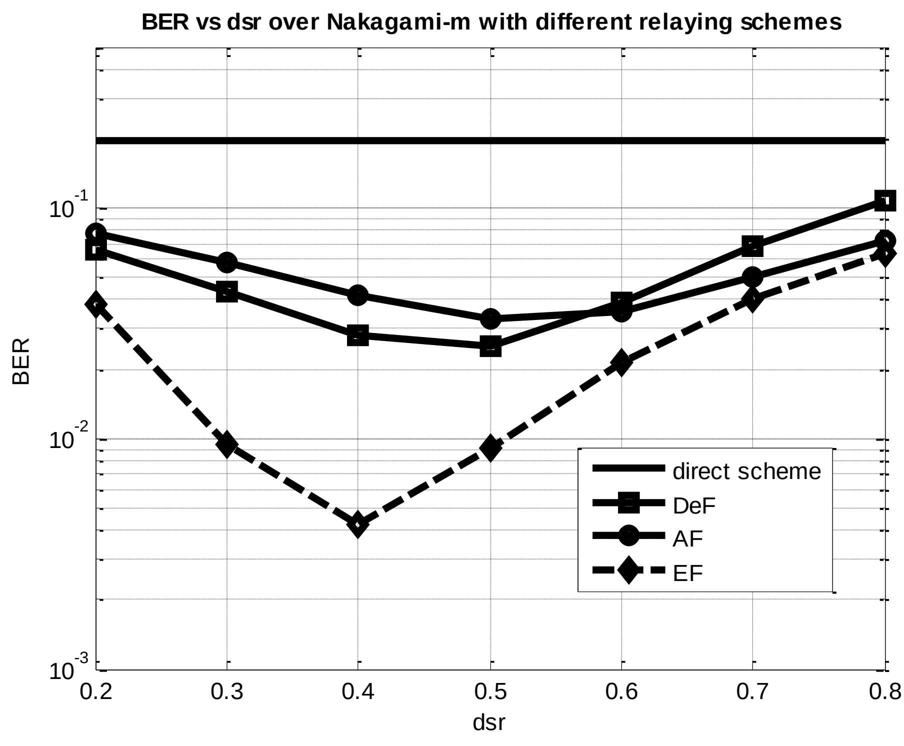


Figure 4.11: BER versus dsr over Nakagami-m fading channel

Chapter 5

Conclusions and Recommendation for Future Works

5.1 Conclusions

In this thesis, the performance of cooperative relay protocols over fading channels was investigated. This investigation has shown the potential benefits of wireless transmission using a relay node rather than direct transmission to achieve improved performance in terms of signal quality.

The BER performances of DeF, AF and EF relay protocols were compared by using equilateral, isosceles and linear placement topologies. They are also compared to direct link communication. According to results have been done in chapter four; all protocols have better performance than direct link transmission. As result shows, nakagami-m fading channel has better performances than Rayleigh fading channel over all topologies. This is occurred because of the consumed power in Nakagami-*m* with m>1 is less than in Rayleigh.

The comparative performances of DeF, AF and EF are concluded under nakagami fading channel as follows. The DeF protocol hits BER value of 10^{-3} at SNR values of 16dB, 13dB and 7dB under equilateral, isosceles and linear topologies respectively. The AF protocol hits BER value of 10^{-3} at SNR values of 14dB, 13dB and 8dB under equilateral, isosceles and linear topologies respectively. The EF relay protocol hits BER value of 10^{-3} at SNR values of 13dB, 12dB and 6dB under equilateral, isosceles and linear topologies respectively. Therefore, as results shows that overall the EF protocol has shown a better performance than the DeF and AF protocols whatever relay topologies were used. In all the BER performances of a linear topology has better than equilateral and isosceles topologies. Therefore, in order to get the better BER performance, the use of cooperative relay positioning is a better choice. As shown from Fig 4.10 and Fig 4.11 the relay protocol performance highly depends on the relay position. The best BER performance of the DeF, AF and EF relay networks happens when the relays are located close to the source i.e. $0.2 \leq d_{sr} \leq 0.4$, $0.2 \leq d_{sr} \leq 0.5$ and $0.2 \leq d_{sr} \leq 0.4$ respectively.

5.2 Recommendations for Future Works

- In this thesis, only the bit error rate (BER) was considered for simulation over Rayleigh and Nakagami-m fading channels. The performance of the systems can be measured by other parameter such as outage probability (OP) or energy efficiency over Rician and Weibull fading channel.
- For all networks, only one source one relay and one destination have been assumed. Many numbers of sources with multiple relays can be implemented to evaluate the overall system performance.
- Only BPSK modulation technique assumed in this work. Other modulation schemes can also be used to investigate the system performance.

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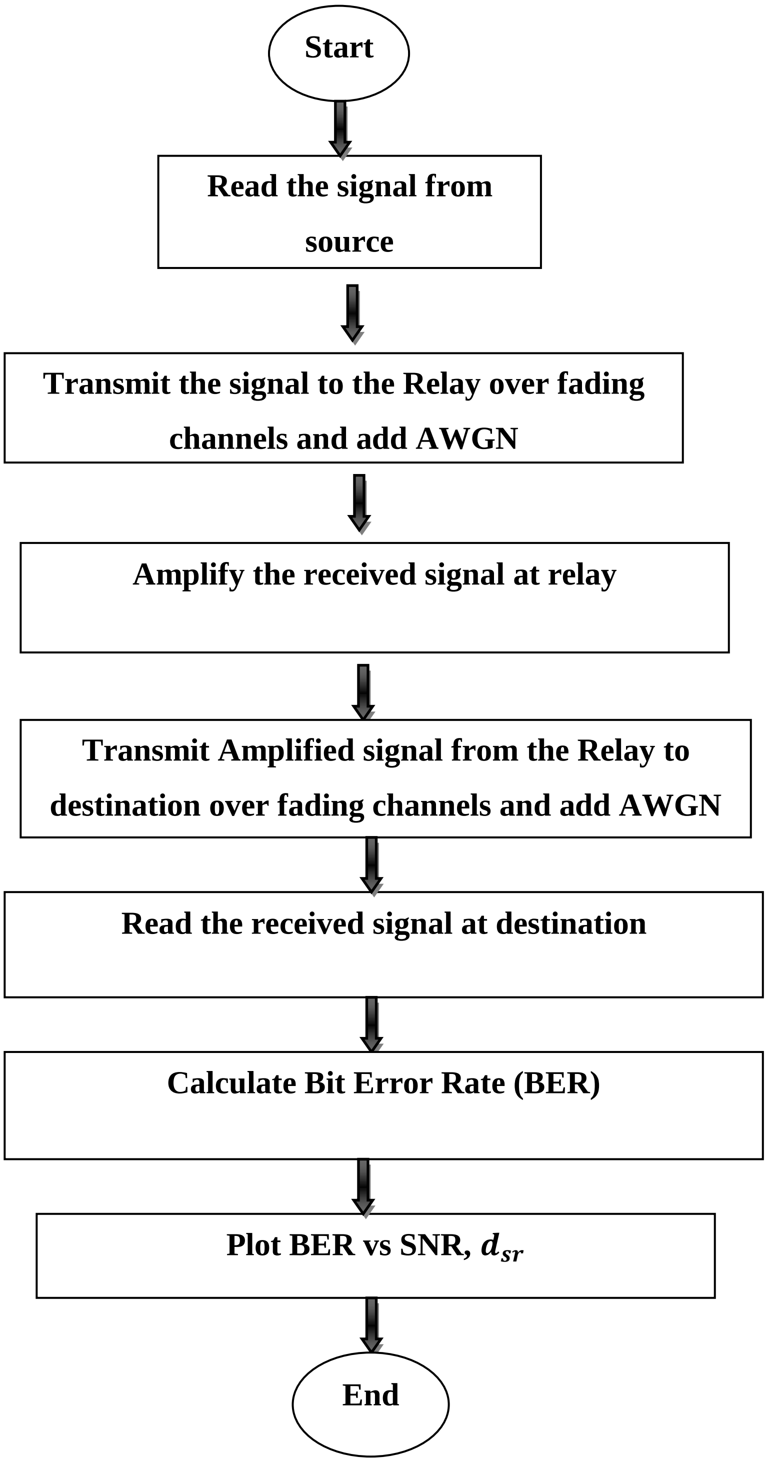
Appendix A

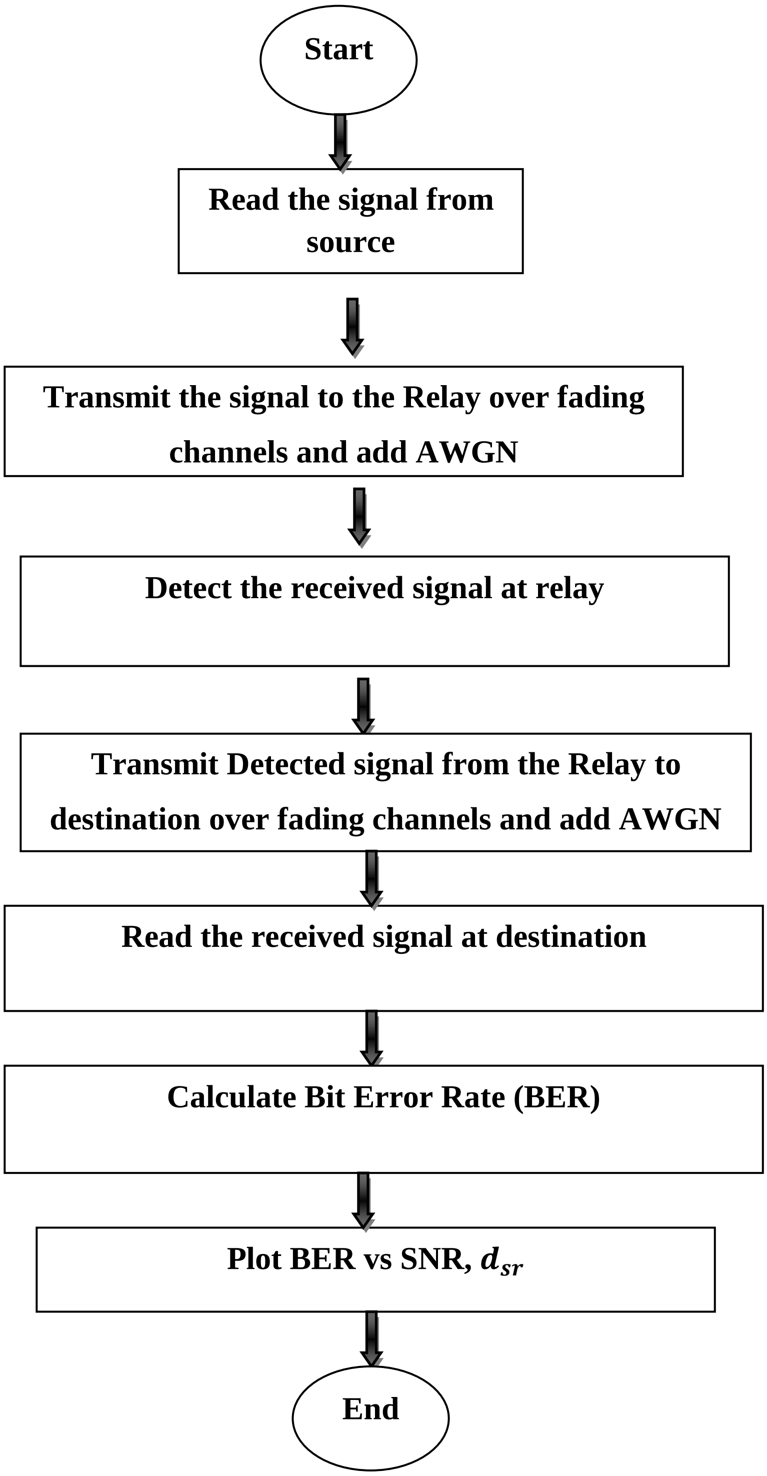
Flowcharts of the Relying Protocols Algorithms

This appendix summarize the operations of AF, DeF and EF relay protocols

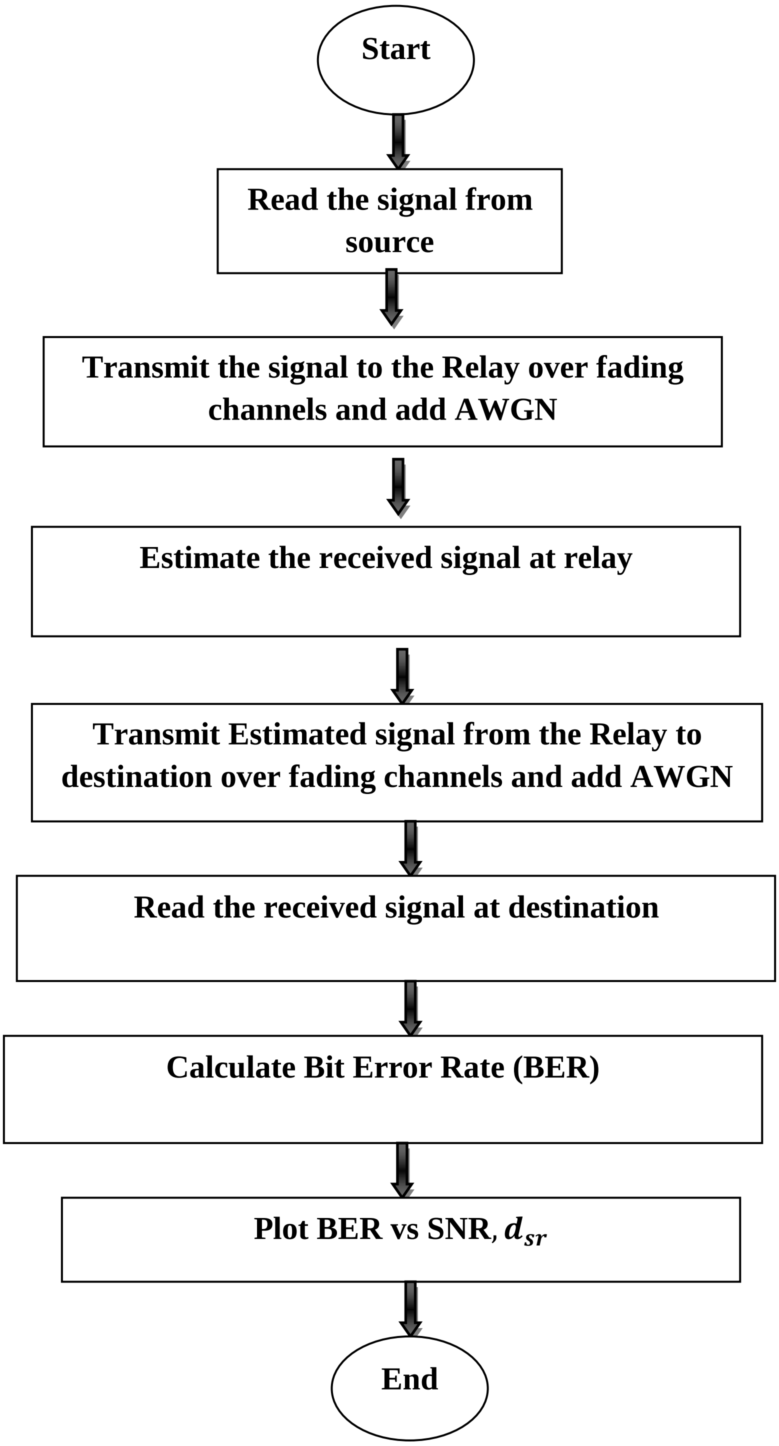
A.1 Amplify- and - Forward relying



A.2 Detect- and- Forward relying



A.3 Estimate and forward relying



Appendix B

Partially Matlab code simulations

This appendix lists partial MATLAB codes used in this work

B.1 Matlacode for equilateral topology for comparisons of relay protocols

```
clear all
clc
N=10^6;% Number of bits
rand('state',100); % initializing the rand()function
randn('state',200); % initializing the randn() function
Ps=0.5;% Transmitted power of source
Pr=0.5;% Transmitted power of relay
SNRdB=0:25; % Transmitted power of source in dB
snrLin=10.^(0.1.*SNRdB);% Linear value snr
omega=1;
m =1 and 1.5; % number fading  parameter
n=4;%path loss exponent
b=rand(1,N)>0.5; % Generate 0s and 1s  with equal probability
xs=2.*b-1;% BPSK modulation 0 -> -1; 1 -> 1
% nErr=zeros(1,length(SNRdB))
nErr DeF=zeros(1,length(SNRdB));
nErr_AF=zeros(1,length(SNRdB));
nErr_AF=zeros(1,length(SNRdB));
%% Channel gains
hsd=(sqrt(gamrnd(m,omega./m,1,N))); % Channel coefficients for Source-destination node
Hsd=sum((abs(hsd)))./N;%Average channel gain for Source-destination node
hsr=(sqrt(gamrnd (m,omega./m,1,N ))) ;% Channel coefficients for Source-relay node
Hsr=sum((abs(hsr)))./N;%Average channel gain for Source-relay node
hrd=(sqrt(gamrnd(m,omega./ m, 1 , N ) )) ;% Channel coefficients for relay-destination node
Hrd=sum((abs(hrd)))./N;%Average channel gain for relay-destination node
```

```
%% AWGN
nsd=(1/(sqrt(2))).*(randn(1,N)+1i.*randn(1,N)); %AWGN for at Destination  for source-Destination node
nsr=(1/(sqrt(2))).*(randn(1,N)+1i.*randn(1,N));%AWGN for at Relay for Source-Relay node
nrd=(1/(sqrt(2))).*(randn(1,N)+1i.*randn(1,N));%AWGN for at Destination  for Relay-Destination node
%% Matlab Code For BER Simulation without relay
for ii = 1:length(SNRdB)
   No(ii)=1./snrLin(ii);           % Noise power
ysd=(hsd.*xs).*sqrt(Ps)+sqrt(No(ii)).*nsd;% the received signal in the direct path (from source to destination).
bHat = real(ysd)>0;% receiver - hard decision decoding
nErr(ii) = size(find(b- bHat),2);% counting the errors
end
Ber = nErr/N% simulated ber
%plot simulation result with a solid line and  use a point as the marker codes
semilogy (SNRdB,Ber,'r .- ','linewidth',3,'MarkerSize', 6);
 hold on
%% Matlab code for Detect and Forward (DeF)
for ii=1:length(SNRdB)
   No(ii)=1./snrLin(ii);           % Noise power
   sd=sqrt(No(ii));
% The received signal at destination from source to destination.
  ysd=(hsd.*xs).*sqrt(Ps)+nsd.*sqrt(No(ii));
% The received signal at relay from source to relay.
ysr=(hsr.*xs).*sqrt(Ps)+nsr.*sqrt(No(ii));
nErr_DeF(ii)=size(find(bHat-b),2);
end
% simulation result
DF_BER=nErr_DeF./N
%plot simulation result with a solid line and  use a square as the marker codes
semilogy(SNRdB,DF_BER,'m s-','linewidth',3,'MarkerSize', 6);
hold on
```

```
%% AF
for ii=1:length(SNRdB)
 No(ii)=1./snrLin(ii);            % Noise power
 sd=sqrt(No(ii));
 % The received signal at destination from source to destination.
ysd=(hsd.*xs).*sqrt(Ps)+nsd.*sqrt(No(ii));
% The received signal at relay from source to relay.
ysr=(hsr.*xs).*sqrt(Ps)+nsr.*sqrt(No(ii));
%  GAIN at relay
Beta1=sqrt(Pr./((Ps.*Hsr.^2)+No(ii)));
% Amplification of ysr by gain at relay
yAmp = Beta1.*ysr;
% The received signal at destination from relay to destination.
yrd=(hrd.*yAmp)+nrd.*sqrt(No(ii));
% Exact the number of errors between b and bHat
 nErr_AF(ii)=size(find(bHat-b),2) ;
end
% simulation result
AF_BER=nErr_AF./N
%plot simulation result with a solid line and  use a circle as the marker codes
semilogy(SNRdB,AF_BER,'b o-','linewidth',3,'MarkerSize', 6);
hold on
%% EF matlb code
for ii=1:length(SNRdB)
     No(ii)=1./snrLin(ii);            % Noise power
  % The received signal at destination from source to destination.
ysd=(hsd.*xs).*sqrt(Ps)+nsd.*sqrt(No(ii));
% The received signal at relay from source to relay.
ysr=(hsr.*xs).*sqrt(Ps)+nsr.*sqrt(No(ii));
%  GAIN at relay
Beta2=sqrt(Pr./mean(abs(tanh((ysr.*hsr.*sqrt(Ps)./sd))).^2));
% Amplification of ysr
BAmp = Beta2.*tanh(ysr.*hsr.*sqrt(Ps)./sd);
```

```
% The received signal at destination from relay to destination.
yrd=(hrd.*BAmp)+nrd.*sqrt(No(ii));
% simulation result
EF_BER=nErr_EF./N
%plot simulation result with a solid line and  use a diamond as the marker codes
semilogy(SNRdB,EF_BER,'g d-','linewidth',3,'MarkerSize', 6);
end
grid on
hold on
% create axis labels and a title
xlabel('\bf SNR(dB)');
ylabel('\bf BER');
axis([0 25 10^-3 0.5]);
 title('\bf BER vs SNR over Rayleigh  and  Nakagami-m Fading Channel')
   % create a legend
 legend('direct path','DeF-d=1:1:1','AF-d=1:1:1','EF-d=1:1:1')
```

B.2 Matlacode for isosceles topology for comparisons of relay protocols

```
clear all
clc
dsd=1;% distance between source and destination
drd=1;% distance between relay and destination
dsr=0.76;% distance between source and relay
%% Matlab code for Detect and Forward (DeF)
for ii=1:length(SNRdB)
    No(ii)=1./snrLin(ii);           % Noise power
    sd=sqrt(No(ii));
% The received signal at destination from source to destination.
   ysd=(hsd.*xs).*sqrt(Ps*dsd^-n)+nsd.*sqrt(No(ii));
% The received signal at relay from source to relay.
ysr=(hsr.*xs).*sqrt(Ps*dsr^-n)+nsr.*sqrt(No(ii));
```

```
%The output received signal at relay
y=sign(ysr);
% The received signal at destination from relay to destination.
yrd=(hrd.*y).*sqrt(Pr*drd.^-n)+nrd.*sqrt(No(ii));
% Exact the number of errors between b and bHat
nErr_DeF(ii)=size(find(bHat-b),2);
end
% simulation result
DF_BER=nErr_DeF./N
%plot simulation result with a solid line and  use a square as the marker codes
semilogy(SNRdB,DF_BER,'m s-','linewidth',3,'MarkerSize', 6);
hold on
%% AF
for ii=1:length(SNRdB)
 No(ii)=1./snrLin(ii);           % Noise power
 % The received signal at destination from source to destination.
sd=sqrt(No(ii));
ysd=(hsd.*xs).*sqrt(Ps*dsd^-n)+nsd.*sqrt(No(ii));
% The received signal at relay from source to relay.
ysr=(hsr.*xs).*sqrt(Ps.*dsr^-n)+nsr.*sqrt(No(ii));
% AMPLIFICATION GAIN
Beta1=sqrt(Pr./((Ps.*Hsr.^2.*dsr^-n)+No(ii)));
% Amplification of ysr
yAmp = Beta1.*ysr;
% The received signal at destination from relay to destination.
yrd=(hrd.*yAmp).*sqrt(drd.^-n)+nrd.*sqrt(No(ii));
% Exact the number of errors between b and bHat
 nErr_AF(ii)=size(find(bHat-b),2) ;
end
% simulation result
AF_BER=nErr_AF./N
%plot simulation result with a solid line and  use a circle as the marker codes
semilogy(SNRdB,AF_BER,'b o-','linewidth',3,'MarkerSize', 6);
```

```
hold on
%% EF matlb code
for ii=1:length(SNRdB)
     No(ii)=1./snrLin(ii);            % Noise power
  % The received signal at destination from source to destination.
ysd=(hsd.*xs).*sqrt(Ps.*dsd^-n)+nsd.*sqrt(No(ii));
% The received signal at relay from source to relay.
ysr=(hsr.*xs).*sqrt(Ps.*dsr^-n)+nsr.*sqrt(No(ii));
% AMPLIFICATION GAIN
Beta2=sqrt(Pr./mean(abs(tanh((ysr.*hsr.*sqrt(Ps.*dsr^-n)./sd))).^2));
% Amplification of ysr
BAmp = Beta2.*tanh(ysr.*hsr.*sqrt(Ps.*dsr^-n)./sd);
% The received signal at destination from relay to destination.
yrd=(hrd.*BAmp).*sqrt(drd.^-n)+nrd.*sqrt(No(ii));
 % Exact the number of errors between b and bHat
nErr_AF (ii) =size (find (bHat-b), 2);
end
% simulation result
EF_BER=nErr_EF./N
%plot simulation result with a solid line and  use a diamond as the marker codes
semilogy(SNRdB,EF_BER,'g d-','linewidth',3,'MarkerSize', 6);
grid on
hold on
% create axis labels and a title
xlabel('\bf SNR(dB)');
ylabel('\bf BER');
  axis([0 25 10^-4 0.5]);
 title('\bf BER vs SNR over Rayleigh and Nakagami-m Fading Channel')
   % create a legend
 legend('direct path','DeF-d=1:0.76:1','AF-d=1:0.76:1','EF-d=1:0.76:1')
```

B.3 Matlacode for linear topology for comparisons of relay protocols

```
clear all
clc
dsd=1;
dsr=0.25;
drd=0.75;
n=4;
%% Matlab code for Detect and Forward (DeF)
for ii=1:length(SNRdB)
    No(ii)=1./(snrLin(ii));
    sd =sqrt(1./(snrLin(ii)));           % Noise power
% The received signal at destination from source to destination.
   ysd=(hsd.*xs).*sqrt(Ps)+nsd.*sd;
% The received signal at relay from source to relay.
ysr=(hsr.*xs).*sqrt(Ps.*(dsr.^-n))+nsr.*sd;
%The output received signal at relay
y=sign(ysr);
% The received signal at destination from relay to destination.
yrd=(hrd.*y).*(Pr.*drd.^-n)+nrd.*sd;
end
% simulation result
DeF_BER=nErr_DeF./N
%plot simulation result with a solid line and  use a square as the marker codes
Semilogy (SNRdB,DeF_BER,'m s-','linewidth',3,'MarkerSize', 6);
hold on
%% AF
for ii=1:length(SNRdB)
 No(ii)=1./(snrLin(ii));
    sd =sqrt(1./(snrLin(ii)));
 % The received signal at destination from source to destination.
ysd=(hsd.*xs).*sqrt(Ps).*(dsd)+nsd.*sd;
% The received signal at relay from source to relay.
ysr=(hsr.*xs).*sqrt(Ps.*(dsr.^-n))+nsr.*sd;
```

```
% AMPLIFICATION GAIN
Beta1=sqrt(Pr./((Ps.*Hsr.^2.*dsr.^-n)+No(ii)));
% Amplification of ysr
yAmp = Beta1.*ysr;
% The received signal at destination from relay to destination.
yrd=(hrd.*yAmp).*(drd.^-n)+nrd.*sd;
% Exact the number of errors between b and bHat
 nErr_AF(ii)=size(find(bHat-b),2) ;
end
% simulation result
AF_BER=nErr_AF./N;
%plot simulation result with a solid line and  use a circle as the marker codes
semilogy(SNRdB,AF_BER,'b o-','linewidth',3,'MarkerSize', 6);
hold on
%% EF matlb code
for ii=1:length(SNRdB)
  sd =sqrt(1./(snrLin(ii)));             % Noise power
  % The received signal at destination from source to destination.
ysd=(hsd.*xs).*sqrt(Ps)+nsd.*sd;
% The received signal at relay from source to relay.
ysr=(hsr.*xs).*sqrt(Ps.*(dsr.^-n))+nsr.*sd;
% AMPLIFICATION GAIN
Beta2=sqrt(Pr./mean(abs((tanh((ysr.*hsr.*sqrt(Ps.*dsr.^-n)./sd)))).^2));
% Amplification of ysr
BAmp = Beta2.*tanh(ysr.*hsr.*sqrt(Ps.*dsr.^-n)./(sd));
% The received signal at destination from relay to destination.
yrd=(hrd.*BAmp).*(drd.^-n)+nrd.*sd;
bHat=real(yEF)>0;
 % Exact the number of errors between b and bHat
nErr_EF(ii)=size(find(bHat-b),2);
end
% simulation result
EF_BER=nErr_EF./N;
%plot simulation result with a solid line and  use a diamond as the marker codes
```

```
semilogy(SNRdB,EF_BER,'g d-','linewidth',3,'MarkerSize', 6);
grid on
% create axis labels and a title
xlabel('\bf SNR(dB)');
ylabel('\bf BER');
axis([0 25 10^-4 0.5])
 title('\bf BER vs SNR over Rayleigh  at (1:0.25:0.75)'  )
   % create a legend
legend('direct scheme','DeF-d=1:0.25:0.75','AF-d=1:0.25:0.75','EF-d=1:0.25:0.75')
```

B.4 Matlacode of optimal relay position for various relay protocols

```
clc
dsr=0.2:0.1:0.8;% Relay position from source

% Matlab Code For BER Simulation without relay over nakagami-m fading-m channel

for ii = 1:length(dsr) ;
% Noise addition
ysd=(hsd.*xs).*sqrt(Ps)+nsd;% the received signal in the direct path.
% receiver - hard decision decoding
bHat = real(ysd)>0;
% counting the errors
nErr(ii) = size(find(b- bHat),2);
end
 Ber = nErr/N % simulated ber
 semilogy(dsr,Ber,'k','linewidth',3,'MarkerSize', 6);
 hold on
%% DF
for ii=1:length(dsr)
ysd=sqrt(Ps).*xs.*hsr+nsd;% the received signal in the direct path.
ysr=sqrt(Ps.*(dsr(ii)).^-n).*hsr.*xs+nsr;% the received signal in the first hop.
y=sign(ysr);
```

```
yrd=(y).*sqrt(Pr*((1-dsr(ii))).^-n).*hrd +nrd;% the received signal in second hop.
bHat=real(yDF)>0;% The estimated bit sequence
nErr(ii)=size(find(b-bHat),2); % Exact the number of errors between b and bHat
end
BER=nErr./N;  % Average BER
semilogy(dsr,BER,'r s-','linewidth',3,'MarkerSize', 6);
 hold on
%% AF
for ii=1:length(dsr)
ysd=sqrt(Ps).*xs.*hsd+nsd;% the received signal in the direct path.
 % AMPLIFICATION GAIN
Beta1=sqrt(Pr./(Ps.*dsr(ii).^(-n)+1));
% the received signal in the first hop.
 ysr=sqrt(Ps./dsr(ii).^n).*hsr.*xs+nsr;
 % Amplification of ysr
yAmp = Beta1.*ysr;
% the received signal in second hop.
yrd=sqrt((1-dsr(ii)).^-n).*hrd.*yAmp+nrd;
nErr(ii)=size(find(bHat-b),2) ;% Exact the number of errors between b and bHat
end
BER=nErr./N; % Average BER
semilogy(dsr,BER,'b o-','linewidth',3,'MarkerSize', 6);
hold on
%% EF matlb code
for ii=1:length(dsr)
   ysd=sqrt(Ps).*hsd.*xs+nsd; % the received signal in the direct path.
ysr=sqrt(Ps./dsr(ii).^n).*hsr.*xs+nsr; % the received signal in the first hop.

% AMPLIFICATION GAIN
  Beta2 = sqrt(Pr.*(1-dsr(ii)).^-n./mean((abs(tanh((ysr.*hsr.*dsr(ii).^-n)))).^2));
BAmp = Beta2.*tanh(ysr.*hsr.*sqrt(Ps.*dsr(ii).^-n));
yrd=(BAmp).*sqrt((1-dsr(ii)).^-n).*hrd+nrd;
end
BER=nErr./N ;% Average BER
```

```
semilogy(dsr,BER,'g d-','linewidth',3,'MarkerSize', 6);
 grid on
xlabel('dsr');
ylabel('BER');
axis([0.2 0.8 10^-2 0.5]);
 % create a title
  title('\bf BER vs dsr over Rayleigh'  )
    % create a legend
legend('direct scheme','DeF','AF','EF')
```