Performance Characteristics Evaluation for Cooperative Communication

ANKIT JAI SHANKAR PAL

DEPARTMENT OF ELECTRICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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Ankit Jai Shankar Pal

(Roll No – 211EE1325)

Under the Guidance of

Dr. (Prof.) Susmita Das

Department of Electrical Engineering

National Institute of Technology, Rourkela

Rourkela-769008, Odisha, INDIA

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Rourkela

CERTIFICATE

This is to certify that the thesis entitled **"Performance Characteristics evaluation for Cooperative Communication"** submitted by **Mr. Ankit Jai Shankar Pal**, in partial fulfilment of the requirements for the award of Master of Technology (Regular) in Electrical Engineering, with specialization of **'Electronic Systems and Communication'** at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter presented in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Dr. (Prof.) Susmita Das
Department of Electrical Engineering
National Institute of Technology
Rourkela-769008

Date:

Place: NIT Rourkela

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ABSTRACT

Wireless channels suffer severely from the effect of multi-path and fading. To mitigate these effects of fading and, cooperative diversity protocols are used. In cooperative diversity, two or more users share their antennas to create a virtual MIMO system. Hence in cooperative communication several single antenna relays assist the transmission between a source and a destination.

In this work, cooperative communication protocols such as amplify and forward and decode and forward are simulated for relaying. The received signals at the destination are combined using various diversity combination protocols such as Maximal Ratio Combining (MRC) and Fixed Ratio Combining (FRC). For the performance study of cooperative communication protocol in wireless network, the symbol error rate (SER), outage probability and channel capacity are simulated for single relay and multiple relay in a flat fading Rayleigh channel..

In addition to this, for a 3 node cooperative communication containing a source , a relay and a destination the impact of relay location is studied for 3 different location of relay i.e. relay placed closer to the source, closer to the destination and at the midway between the source and the destination. When the relay is located in the middle of source and destination, it gives the best system performance. When the relay is located closer to the source, the quality of source-relay link is good, and the relay can decode the received information. On the other hand, when the relay node is located close to the destination, the system performance degrades. Through simulation results, it is shown the positive role that the relay plays, as it improves significantly the performance of the system and leads to lower SER and lower outage probability..

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LIST OF ABBREVIATIONS

Abbreviations	Description
AF	Amplify and Forward
APAF	All Power Amplify and Forward
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
DF	Decode and Forward
CRC	Cyclic Redundancy Check
EGC	Equal Gain Combining
FEC	Forward Error Correcting Code
FRC	Fixed Ratio Combining
MRC	Maximum Ratio Combining
M-QAM	M-ary Quadrature Amplitude Modulation
OPAF	Optimum Power Amplify and Forward
QPSK	Quadrature Phase Shift Keying
SNRC	Signal to Noise Ratio Combining
SER	Symbol Error Rate

Chapter 1

INTRODUCTION

1.1 Overview

Cooperative communications is a new way of communication that draws from the ideas of using the broadcast nature of the wireless channel to make communicating nodes help each other, of implementing the communication process in a distribution fashion and of gaining the same advantages as those found in MIMO systems. This results in a set of new tools that improve communication capacity, speed, and performance. It also reduce power consumption and hence improve battery life and extend network lifetime; increase the throughput and stability region for multiple access schemes; expand the transmission coverage area; and provide cooperation tradeoff beyond source–channel coding for multimedia communications [1].

To increase the data rates while also maintaining high reliability (lower probability of error) of the data sent over the communication link is the main objective of any mode of communication. However, in wireless communication networks, the channel suffers from unwanted yet inevitable effects (e.g. shadowing, pathloss, multipath fading etc.) which make it difficult to communicate reliably over the channel. . To reduce such effects diversity can be used to transmit the different samples of the same signal over different independent channels. In this thesis, diversity is realized by using a third station acting as a relay.

Various diversities of the wireless channels are used as potential solutions to mitigate some of these channel impairments. Spatial diversity is used to mitigate the deleterious effects of fading via transmitting the signals from different locations, thereby allowing independently faded versions of the signal at the receiver. The multiple input multiple output (MIMO) system was proposed to generate spatial diversity by equipping the wireless device with multiple antennas. However many wireless devices are limited by size and hardware complexity to one antenna and MIMO is not realizable in these cases. Cooperative communications provides an alternative solution for this problem via enabling single antenna wireless devices in a multi-user environment to share their antennas and generate a virtual multi-antenna transmitter in order to achieve spatial diversity. The broadcast nature of the wireless channel is exploited in cooperative communications. The wireless devices which ’overhear’ the transmission between two entities meant to forward the overheard information and provide another independently faded version of the information at the receiver. Thus, each device in the network transmits its own information as well as cooperates in delivering the information originating from other devices.

In this thesis, combinations of several diversity relaying protocols and different combining methods are examined to see their effects on the performance. The transmission protocols used in this thesis are *Amplify and Forward* and *Decode and Forward.*

Basically two types of combining protocols are examined which differs in the knowledge of the channel quality they need to work. One combination that achieves a good performance is then used to see the effect on the performance depending on the location of the relay.

1.2 Motivation

Cooperative communications presents various challenges to researchers along with the plethora of advantages. The major concern for the realization of cooperative communication is the relay functionality. This problem has received large attention of researchers, and significant progress has been made in this area. Another major concern in cooperative communication is the sharing of network resources (potential relays) among users and to investigate resource allocation schemes. While many important results have been obtained in this field, several issues remain unexplored. The optimal relay assignment in the wireless communication network is one area that demands attention. Further, which criterion for optimality should be considered is another important issue.

1.3 Objectives

The main objectives of this thesis are:

1. To study various protocols of cooperative diversity such as amplify and forward (AF) and decode and forward (DF).
2. To calculate symbol error rate (SER)for single relay and multi relay Amplify and Forward (AF) protocol in Rayleigh and Rician fading channel
3. To calculate the symbol error rate for single relay Decode and Forward (DF) protocol in Rayleigh fading channel.
4. To calculate the outage probability for single relay AF and DF protocol.
5. To calculate the channel capacity for single relay and multi relay AF.
6. To examine the effect of relay location on the system performance.

1.4 Literature Survey

Cooperative diversity can mitigate the effect of fading via providing spatial diversity. Spatial diversity can be used to reduce the transmission power and hence the battery life can be extended by using cooperative diversity. Cooperative diversity can also be used to increase the coverage area (e.g., cellular networks) as was investigated in [2] For decode and forward if no MRC is deployed then the optimum location is midway between the source and the destination, but if MRC is used then the optimum location is towards the source as derived in [2].. A distributed relay assignment algorithm was also given in [2]. It also addresses the problem of relay–source assignment. The optimum locations of relay for decode and forward and amplify and forward have also been proposed by the author.

Simon, Marvin K et al., in [3] presented a unified approach to evaluating the error rate performance of digital communication system over fading channels. The classical relay channel was introduced by Van der Meulen [4] models a three terminal communication channel. The relay channel is a channel with one transmitter, one receiver and a number of nodes acting as relay to improve the system performance. In [5,6], the capacities of the Gaussian relay channel are evaluated and also lower bound on the channel capacities are derived..

Sendonaris, A et al in [7] describes the user cooperation strategy while part ii [8] focuses on performance and implementation issues.

In [9], Laneman et al. proposed different cooperative diversity protocols and analyzed the system performance in terms of outage behavior. The terms amplify-and-forward and decode-and-forward were first introduced in [9]. Sadek, A.K et al. in [10] derives the average symbol error probability for amplify and forward method and also addresses the best location of relay. For amplify and forward, the best location for the relay is midway between the source and the destination [10]. An outage analysis was provided under a random spatial distribution for the users, and an approximate expression for the outage probability was derived. Anghel, Paul A. et al. in [11] presented an exact average symbol error rate analysis for the distributed spatial diversity wireless system with K amplifying relays in a Rayleigh-fading environment to illustrate the advantage that the distributed diversity system has in overcoming the severe penalty in signal-to-noise ratio caused by Rayleigh fading.

Yuan, Runping, et al. in [12] presented the asymptotic symbol error rate and outage probability expressions at medium and high SNR regions, and the optimal power allocation scheme between the source and opportunistic relay is also proposed to minimize the outage probability. The outage probability of the single relay amplify and forward network was obtained by considering the high SNR behavior of the outage probability based on cumulative distributed function (CDF) of certain exponential random variables. Various cooperation protocols were also proposed for wireless networks in order to combat the severe effect of fading. Zhao, Yi et al. presented an asymptotic analysis of SER for selection amplify and forward system [17,18] and compared it with the conventional all participate scheme. Seddik, Karim G., et al. derived the outage probability of multi node amplify and forward system with N nodes helping the source in forwarding the information. Sadek et al. in [21] derived the closed form SER for PSK and QAM signals.

There are various proposed protocols in literature for the selection of best relay among a collection of available relays. In [28], authors proposed to choose the best relay based on its geographical location.

1.5 Thesis Organization

The thesis is organized as follows:

Chapter 1: Introduction

Chapter 1 consists of objectives, motivation behind the project work and literature survey. This chapter gives brief idea about the cooperative communication systems.

Chapter 2: **Cooperative Communication system- An overview**

This chapter explains the basics of cooperative communication. It also explains various cooperative diversity strategies such as amplify and forward and decode and forward. At the receiver side, the combination techniques used are maximum ratio combining (MRC), equal gain combining (EGC), fixed ratio combining (FRC).

Chapter 3: System Model

This chapter describes the system model and explains the arrangement of diversity system used in the system. The mathematical expression for SER, outage, channel capacity and relay location are derived in this section.

Chapter 4: Results and Discussion

In this chapter we present the results of our simulation. The simulation is carried out in MATLAB and the transmitted power is P_t =1 W and relay and source power are 0.5 W each. The noise power is calculated for different values of SNR values. Results are compared with theoretical results for BPSK modulation with AWGN and Rayleigh fading channels. We also analyze the impact of relay location on the system performance.

Chapter 2

COOPERATIVE DIVERSITY PROTOCOLS

2.1 Introduction

In this chapter, we discuss various types of cooperative diversity protocols. Consider a simple cooperative model as depicted in Figure 3.1, where the source transmits with power P_1 and the relay transmits with power P_2.

- In broadcast phase, a source sends its message to its destination, and the message is also received by the relay at the same time.
- In cooperation phase, the relay help the source by forwarding or retransmitting the message received during broadcast phase to the destination.

The received signal at the destination $y_{s,d}$ and the relay $y_{s,r}$ can be written as [1]:

$$y_{s,d} = \sqrt{P} h_{s,d} x + \eta_{s,d} \quad (2.1.1)$$

$$y_{s,r} = \sqrt{P} h_{s,r} x + \eta_{s,r} \quad (2.1.2)$$

In which P is the total power transmitted at the source, x is the transmitted information symbol, and $\eta_{s,r}$ and $\eta_{s,d}$ are additive white Gaussian noise. The channel coefficients are given by $h_{s,r}$ and $h_{s,d}$ for the source to relay and source to destination link respectively. The channel coefficients are modeled as zero mean, complex Gaussian random variables with variances $\delta^2_{\mathrm{s,r}}$ and $\delta^2_{\mathrm{s,d}}$ respectively [1]. The noise terms are modeled as zero mean, complex Gaussian random variables with variance N_0.

The received signal at the destination from the relay is [1]

$$y_{r,d} = \frac{\sqrt{P_2}}{\sqrt{P_1 \left| h_{s,r} \right|^2 + \aleph_0}} h_{r,d} y_{s,r} + \eta_{r,d} \quad (2.1.3)$$

2.2 Cooperative Transmission Protocol

The cooperative transmission protocols used at the relay are amplify and forward (AF), decode and forward (DF), compress and forward and coded cooperation. The most commonly used strategies are AF and DF.

2.2.1 Amplify and Forward

In this case the relay forwards the information received from the sender during broadcast phase and it amplifies and retransmit the signal to its destination during the cooperation phase. In doing so, noise also get amplified, which is the major drawback of this method. This method is used when the time delay caused by decoding and re encoding is to be minimized.

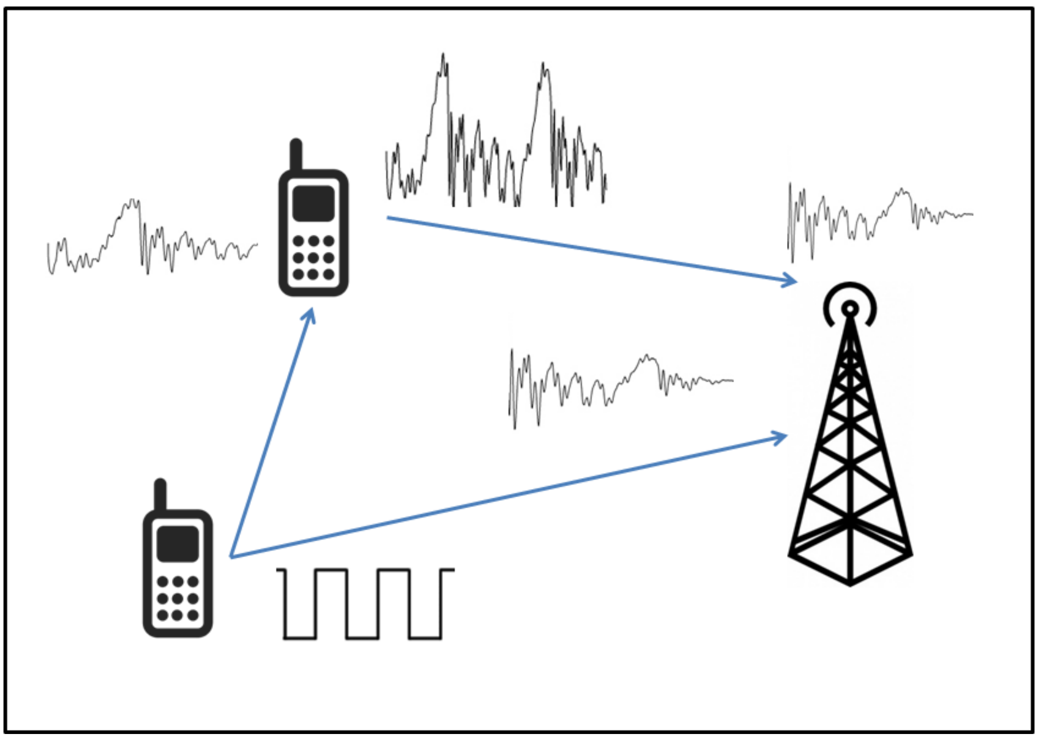

Figure-2.1 Amplify and Forward [29]

The received signal at the relay is given by [1]:

$$y_{s,r} = \sqrt{P}h_{s,r}x + \eta_{s,r} \tag{2.2.1}$$

Similarly signal received at the receiver through direct communication ($y_{s,d}$) is given by:

$$y_{s,d} = \sqrt{P} h_{s,d} x + \eta_{s,d}$$

(2.2.2)

The relay has to send the signal at the same power level at which it received the signal; hence the relay has to use a gain of

$$\beta_r = \frac{\sqrt{P}}{\sqrt{P \left| h_{s,r} \right|^2 + N_0}}$$

(2.2.3)

Thus signal received at the destination is [1]

$$y_{r,d} = \frac{\sqrt{P}}{\sqrt{P \left| h_{s,r} \right|^2 + N_0}} h_{r,d} y_{s,r} + \eta_{r,d}$$

(2.2.4)

$$y_{r,d} = \frac{\sqrt{P}}{\sqrt{P \left| h_{s,r} \right|^2 + N_0}} h_{r,d} \sqrt{P} h_{s,r} x + \eta'_{r,d}$$

(2.2.5)

Where equivalent noise is given as:

$$\eta'_{r,d} = \frac{\sqrt{P}}{\sqrt{P \left| h_{s,r} \right|^2 + N_0}} h_{r,d} \eta_{s,r} + \eta_{r,d}$$

(2.2.6)

2.2.2 Decode and Forward

In this scheme, the relay decodes the information received from the source during the broadcast phase before forwarding it to its destination. After successfully decoding the received signal, the relay re-encodes the signal and forwards it to the destination [1]. So there is no amplified noise in the received signal. The received information at the receiver via relay can be expressed as:

$$y_{r,d} = x.h_{r,d} + \eta_{r,d}$$

(2.2.7)

The decode and forward method can be implemented in two ways. One is when the relay can completely decode the message, but this requires a lot of time. If there is an error correcting code in the source message, then the received bit errors can be corrected at the relay station.

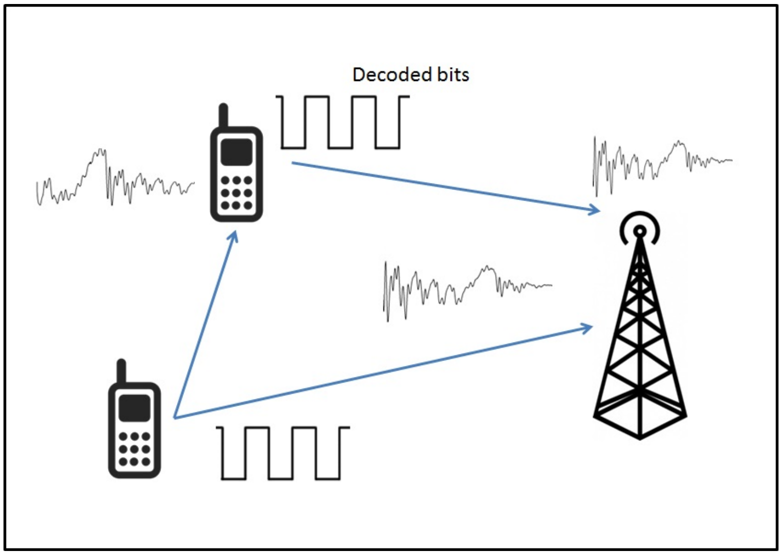

Fig-2.2 Decode and Forward [29]

But it is not possible to always completely decode the source message, since this requires a lot of computing time and the additional delay caused might be unacceptable. In such a case, the source message is just decoded and re-encoded symbol by symbol. So no error correcting code can be applied.

2.2.3 Compress and Forward

Compress and forward differs from amplify/decode and forward method in a way that while in the later the relay transmits a copy of the received message, in compress and forward, the relay transmits a compressed and quantized form of the received signal.

The quantization and compression process at the relay node is a process of source encoding i.e., representing each received message as a sequence of symbols. At the destination node, the received sequence of bits is decoded thereby obtaining the estimate of the compressed and quantized message. The decoding process is done by mapping the received bits into a set of values that estimate the transmitted message.

2.2.4 Coded Cooperation

Coded cooperation integrates cooperation into channel coding. In both the decode and forward and amplify and forward, the relay repeats the bits sent by the source. In coded cooperation, the relay sends incremental redundancy. Hence the resulting signal at the receiver is a code word with larger redundancy.

The redundancy is introduced in the code word to increase the chance of recovering the original information if error occurs during the transmission process. In some code words, the redundancy is introduced in such a way that it is very difficult to separate the information and redundancy without fully decoding, while in many other codes the redundancy can be added or removed from the code word in a simple manner. These second types of codes are used in coded cooperation.

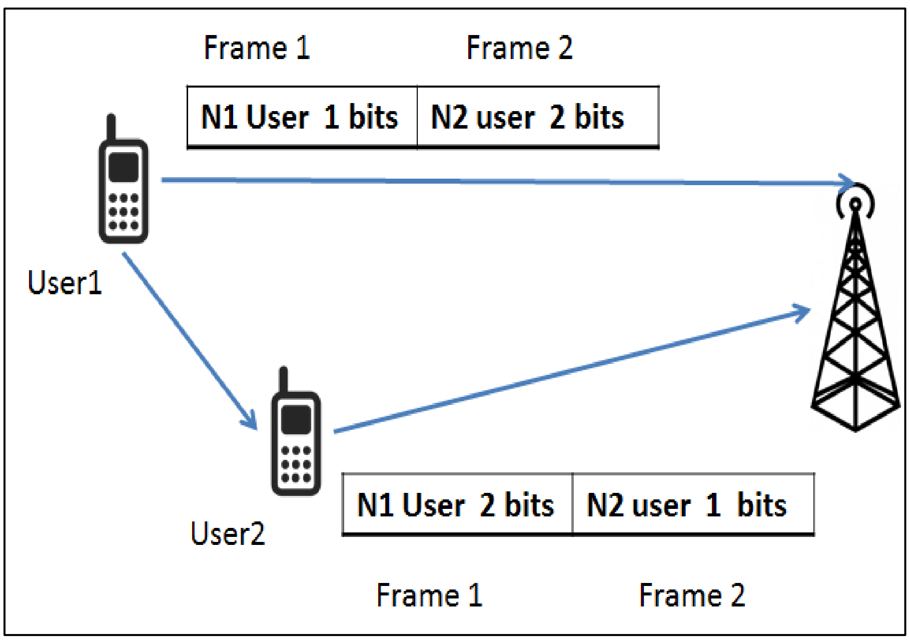

Figure-2.3.1 Coded cooperation [29]

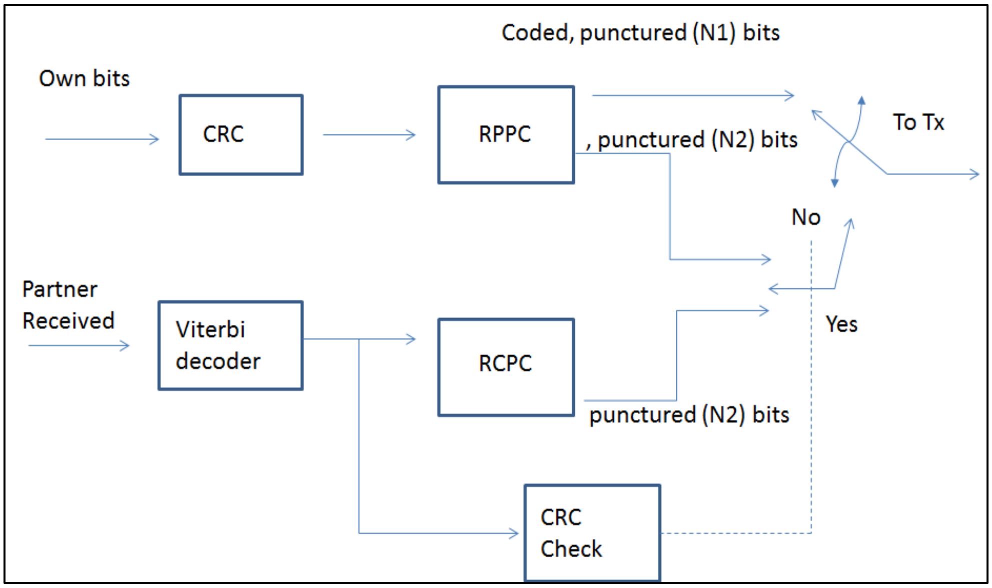

Figure-2.3.2 Coded Cooperation block diagram [29]

In coded cooperation, a code word is sent in two parts, each using different path or channel [2]. The main steps in coded cooperation strategy are as follows:

1. A block of N_I information symbols enters a cyclic redundancy check (CRC) encoder at the source node.
2. Result of step 1 enters a forward error correcting (FEC) code encoder resulting in a rate of $R_1 = N_1/N_I$.
3. The resulting codeword is then transmitted to a destination node and also is overheard by the relay.
4. After receiving the source transmission, the relay decodes both the FEC and CRC codes.
5. If CRC does not reveal any error, the resulting N_I information symbols at the relay are fed into a CRC encoder.
6. The output of the CRC encoder is then processed through an FEC encoder, resulting in a codeword of $N > N_I$. Now the channel encoding rate at the relay node is $R = N_1/N_I < R_1$.
7. Thus the overall codeword generated as a result of the above steps is a codeword containing $N_2 = N - N_1$ extra parity symbols, which are separated from the rest of the symbols.

8. During the second phase, the extra N_2 symbols are sent by the relay to the destination.
9. N_2 symbols from the relay are combined with the N_1 node from the source node, at the destination to reconstitute the codeword with N symbols and rate R.
10. The codeword is then decoded.
11. The original message will be recovered if the FEC code was able to correct all the errors introduced during communication.

2.3 Combining Type

Since there are more than one incoming transmissions, hence all the incoming information has to be combined at the receiver side before they can be compared.

2.3.1 Equal Ratio Combining (ERC)

This is the easiest way of combining the signals, in which all the received signals are just added up.

$$y_d[n] = y_{s,d}[n] + y_{r,d}[n] \tag{2.3.1}$$

$y_{s,d}[n]$ denotes the received signal from the sender and $y_{r,d}[n]$ denotes one from the relay.

2.3.2 Fixed Ratio Combining (FRC)

In fixed ratio combining (FRC), instead of just adding up the incoming signals, they are weighted with a constant ratio, which will not change a lot during the whole communication process, thus giving a much better performance than the ERC. The ratio represents the average channel characteristics over a period of time and hence does not take into effect the temporary influence due to fading or other parameters. The FRC can be expressed as [31]:

$$y_d[n] = \sum_{i=1}^{K} d_{i,d} . y_{i,d}[n] \tag{2.3.2}$$

For a single relay case it simplifies to

$$y_d[n] = d_{s,d} . y_{s,d}[n] + d_{s,r,d} . y_{r,d}[n]$$

(2.3.3)

where, $d_{s,d}$ denotes the weight of the direct link and $d_{s,r,d}$ denotes the one of the multi-hop link. The best ratio is approximated by using different possible values and using that ratio to compare with the other combining techniques.

2.3.3 Signal to Noise Ratio Combining (SNRC)

This gives a much better performance by intelligently weighting the incoming signals. Here SNR is used to weight the received signals. SNRC can be expressed as [31]:

$$y_d[n] = \sum_{i=1}^{K} SNR_i . y_{i,d}[n]$$

(2.3.4)

Using single relay, the above equation can be minimized as:

$$y_d[n] = SNR_{s,d} . y_{s,d}[n] + SNR_{s,r,d} . y_{r,d}[n]$$

(2.3.5)

$SNR_{s,d}$ denotes the SNR of the direct link and $SNR_{s,r,d}$ the one over the whole multi hop channel.

An additional sequence needs to be sent to estimate the channel quality. For AF protocol, a known symbol sequence can be sent in every block to estimate the SNR. Thus, sending an additional sequence, results in the certain loss of the bandwidth.

2.3.4 Maximum Ratio Combining (MRC)

The maximum ratio combining technique achieves the best possible performance by multiplying each received signal with its corresponding conjugated channel gain. This assumes that the channel state information (CSI) is available at the receiver side [31].

$$y_d[n] = \sum_{i=1}^{K} h_{i,d}^* . y_{i,d}[n]$$

(2.3.6)

Using one relay system, the above equation can be written as

$$y_d[n] = h_{i,d}^* . y_{s,d}[n] + h_{i,d}^* . y_{r,d}[n]$$

(2.3.7)

Chapter 3

SYSTEM MODEL

In this chapter, we consider single relay as well as multi relay cooperative communication in wireless network. Our aim is to theoretically analyze the symbol error rate (SER), outage probability, channel capacity and the impact of relay locations on the system performance in case of both single relay as well as multi relay for AF and DF both.

3.1 System Model

A cooperative communication strategy with two phrases is considered for wireless communication networks [1]. There are two phases in cooperation i.e., broadcast phase and cooperation phase .Here we consider a two user cooperation scheme in which the user 1 sends the information to its destination in broadcast phase, and user 2 also receives the information. User 2 forwards the information in cooperation phase. Similarly, when user 2 sends its information to its destination in broadcast phase, user 1 receives the information and forwards it to the destination of user 2 in cooperation phase. Due to symmetry of the two users, we may consider only the performance of user 1.

The source broadcasts its information to both the destination and the relay in broadcast phase. The received signals $y_{s,d}$ and $y_{s,r}$ at the destination and relay [1] respectively can be given as

$$y_{s,d} = (\sqrt{P_1})h_{s,d}x + \eta_{s,d} \quad (3.1.1)$$

$$y_{s,r} = (\sqrt{P_1})h_{r,d}x + \eta_{r,d} \quad (3.1.2)$$

where P_1 is the transmitted power at the source, x is the transmitted information symbol, and $\eta_{s,d}$ and $\eta_{r,d}$ are the additive noise. In the above two equations $h_{s,d}$ and $h_{r,d}$ are the channel coefficients from the source to the destination and the relay respectively. Channel coefficients are modeled as zero-mean, complex, Gaussian random variables with variances as $\delta^2_{s,d}$ and $\delta^2_{s,r}$ respectively. The noise terms $\eta_{s,d}$ and $\eta_{r,d}$ are modeled as zero-mean, complex Gaussian random variables with variance N_0.

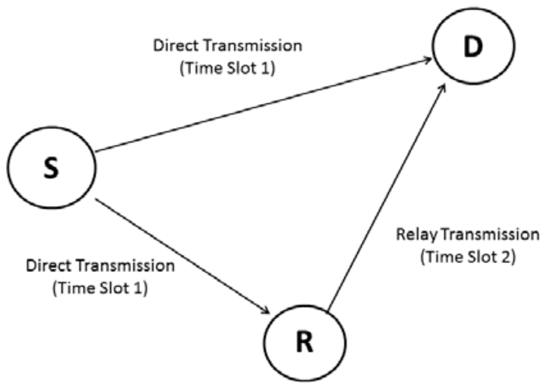

Figure 3.1 A simplified cooperation model [1]

3.1.1 Decode and Forward (DF) Protocol

If the relay is able to decode the transmitted symbol correctly in cooperation phase, then for DF protocol, the relay forwards the decoded symbol with power P_2 to the destination, otherwise it remains idle. The received signal in cooperation phase is given as [1]

$$y_{r,d} = \sqrt{\overline{P_2}} h_{r,d} x + \eta_{r,d} \tag{3.1.3}$$

If the relay decodes the transmitted symbol correctly then $\overline{P_2} = P_2$ otherwise $\overline{P_2} = 0$. In (3.1.3), $h_{r,d}$ is the channel coefficients from the relay to the destination and is modeled as zero-mean, complex, Gaussian random variables with variances as $\delta^2_{r,d}$. The noise term $_{r,d}$ is modeled as zero-mean, complex Gaussian random variables [1] with variance N_0 .

3.1.2 Amplify and Forward (AF) protocol

For an AF protocol, during the cooperation phase, the relay amplifies the received signal and forwards it to the destination with transmitted power P_2. The signal received at the destination in cooperation phase is

$$y_{r,d} = \frac{\sqrt{P_2}}{\sqrt{P_1 |h_{s,r}|^2 + N_0}} h_{r,d} y_{s,r} + \eta_{r,d} \tag{3.1.4}$$

Where $h_{r,d}$ is the channel coefficients from the relay to the destination and $\eta_{r,d}$ is the noise term, both modeled with the same statistics as in (3.1.3)

From equation (3.1.2) $y_{r,d}$ can be given as [1]

$$y_{r,d} = \frac{\sqrt{P_1 P_2}}{\sqrt{P_1 |h_{s,r}|^2 + N_0}} h_{r,d} h_{s,r} y_{s,r} + \eta'_{r,d} \tag{3.1.5}$$

where

$$\eta'_{r,d} = \frac{\sqrt{P_2}}{\sqrt{P_1 |h_{s,r}|^2 + N_0}} h_{r,d} \eta_{s,r} + \eta_{r,d} \tag{3.1.6}$$

Assuming $\eta_{s,d}$ and $\eta_{r,d}$ as independent, the variance of equivalent noise is a zero mean, complex Gaussian random variable with variance [1]

$$\left(\frac{P_2 |h_{r,d}|^2}{P_1 |h_{s,r}|^2 + N_0} + 1 \right) N_0$$

In both the protocols, AF and DF, the channel coefficients $h_{s,d}$, $h_{r,d}$ and $h_{s,r}$ are assumed to be known at the receiver side, but not at the transmitter side. The destination combines the signal received from the source in Phase 1 and the signal received from the relay in Phase 2, and detects the transmitted symbols by using maximum-ratio combining (MRC). The total transmitted power P is given by $P_1 + P_2 = P$

3.2 ANALYSIS OF DF PROTOCOL

3.2.1 SER analysis for DF protocol

Having the knowledge of $h_{s,d}$ and $h_{r,d}$ the channel coefficients between source and destination and between relay and destination respectively, the destination detects the transmitted symbol by combining the received signal $y_{s,d}$ from the source and $y_{r,d}$ from the relay. After applying MRC, the combined signal is given as [1]:

$$y = a_1 y_{s,d} + a_2 y_{r,d} \tag{3.2.1}$$

where a_1 and a_2 are factors which are determined such that the SNR of the MRC output is maximized [1]

$$a_1 = \frac{\sqrt{P_1} h^*_{s,d}}{N_0}, a_2 = \frac{\sqrt{P_2} h^*_{r,d}}{N_0} \tag{3.2.2}$$

Assuming that the transmitted symbol x in (3.1.1) and (3.1.2) has average energy 1, hence the SNR of the MRC output is [1]

$$\gamma = \frac{P_1 \left|h_{s,d}\right|^2 + \overline{P_2} \left|h_{r,d}\right|^2}{N_0} \tag{3.2.3}$$

SER formulations for an uncoded system with M-PSK modulation [1] are given by [1]

$$\varphi_{PSK}(\rho) \triangleq \frac{1}{\pi} \int_0^{(M-1)\pi/M} \exp\left(-\frac{b_{PSK}\rho}{\sin^2\theta}\right) d\theta \tag{3.2.4}$$

In which ρ is SNR [1] and

$$b_{PSK} = \sin^2(\pi / \mathrm{M}), \mathrm{k} = 1 - (1/\sqrt{M}),$$

(3.2.5)

and $\mathrm{Q(u)} = (1/\sqrt{2\pi})\int_0^\infty \exp(-\mathrm{t}^2/2)dt$ is the Gaussian Q-function [1]. Therefore, if for M-PSK modulation in DF cooperation system, the conditional SER of the system with channel coefficients $h_{s,d}$, $h_{r,d}$ and $h_{s,r}$ can be written as [1]:

$$P_{PSK}^{h_{s,d},h_{s,r},h_{r,d}} = \varphi_{PSK}(\rho)$$

(3.2.6)

We have assumed that if the relay correctly decodes the transmitted symbol *x*, then the relay forwards the decoded symbol to the destination with power P_2 i.e., $\overline{P_2} = P_2$; otherwise the relay does not send i.e., . $\overline{P_2} = 0$. For an M-PSK symbol, the chance of correct decoding is $1 - \varphi_{PSK}\left(P_1 |h_{s,r}|^2 \big/ N_0 \right)$ and the chance of incorrect decoding is $\varphi_{PSK}\left(P_1 |h_{s,r}|^2 \big/ N_0 \right)$.

SER of the DF cooperation system with M-PSK modulation, taking into account two scenarios $\widetilde{P_2} = 0$ and $\widetilde{P_2} = P_2$ is given as [1]:

$$P_{PSK} = F_1\left(1 + \frac{b_{PSK} P_1 \delta_{s,d}^2}{N_0 \sin^2\theta}\right) F_1\left(1 + \frac{b_{PSK} P_1 \delta_{\mathrm{s,r}}^2}{N_0 \sin^2\theta}\right) + F_1\left(\left(1 + \frac{b_{PSK} P_1 \delta_{s,d}^2}{N_0 \sin^2\theta}\right)\left(1 + \frac{b_{PSK} P_1 \delta_{\mathrm{r,d}}^2}{N_0 \sin^2\theta}\right)\right) \times \left[1 - F_1\left(1 + \frac{b_{PSK} P_1 \delta_{\mathrm{s,r}}^2}{N_0 \sin^2\theta}\right)\right]$$

(3.2.7)

where

$$F_1(\mathrm{x}(\theta)) = \frac{1}{\pi}\int_0^{(\mathrm{M}-1)\pi/\mathrm{M}} \frac{1}{x(\theta)} d\theta$$

(3.2.8)

$$F_2(\mathrm{x}(\theta)) = \frac{4K}{\pi}\int_0^{\pi/2}\frac{1}{x(\theta)}d\theta - \frac{4K^2}{\pi}\int_0^{\pi/4}\frac{1}{x(\theta)}d\theta \tag{3.2.9}$$

3.2.2 SER upper bound and asymptotic approximation [1]

Since the closed form SER formulations derived above are very complex and it is difficult to get an insight into the system performance from these. Hence SER upper bound and SER approximation are useful in evaluating the asymptotic performance of DF cooperation scheme.

Theorem 3.2.1 *The SER of DF cooperation systems with M-PSK or M-QAM modulation can be upper bounded as [1]*

$$P_s \le \frac{3\mathrm{N}_0^2}{16}\cdot\frac{4bP_1\delta_{s,\mathrm{r}}^2 + 3\mathrm{b}\,P_2\delta_{r,d}^2 + 7\,\mathrm{N}_0}{(\mathrm{N}_0 + bP_1\delta_{s,\mathrm{d}}^2)(\mathrm{N}_0 + bP_1\delta_{s,\mathrm{r}}^2)(\mathrm{N}_0 + bP_1\delta_{r,d}^2)} \tag{3.2.10}$$

b=b_{PSK} for M-PSK signals.

Theorem *3.2.2 If all the channel links $h_{s,d}$, $h_{r,d}$ and $h_{s,r}$ are available i.e., $\delta_{s,\mathrm{d}}^2 \ne 0, \delta_{s,\mathrm{r}}^2 \ne 0, \delta_{\mathrm{r,d}}^2 \ne 0$, then when $\frac{P_1}{N_0}$ and $\frac{P_2}{N_0}$ go to infinity, then the SER of the DF system with M-PSK or M-QAM modulation can be tightly approximated as [1]:*

$$P_s \approx \frac{N_0^2}{b^2}\cdot\frac{1}{P_1\delta_{s,\mathrm{d}}^2}\left(\frac{A^2}{P_1\delta_{s,\mathrm{r}}^2} + \frac{B}{P_2\delta_{\mathrm{r,d}}^2}\right) \tag{3.2.11}$$

Where A and B are specified as:

For M-PSK signals, b=b_{PSK}

$$A = \frac{3}{8} + \frac{\sin\frac{\pi}{2}}{4\pi}$$

$$B = \frac{9}{32} + \frac{\sin\frac{\pi}{2}}{4\pi} - \frac{\sin\pi}{32\pi}$$

For QPSK M = 4, hence

$$A = \frac{3}{8} + \frac{\sin\frac{\pi}{2}}{4\pi}$$

$$B = \frac{9}{32} + \frac{\sin\frac{\pi}{2}}{4\pi} - \frac{\sin\pi}{32\pi}$$

Putting these values in (3.2.11) ,

$$P_s \le \frac{3N_0^2}{16} \cdot \frac{4bP_1\delta_{s,r}^2 + 3bP_2\delta_{r,d}^2 + 7N_0}{(N_0 + bP_1\delta_{s,d}^2)(N_0 + bP_1\delta_{s,r}^2)(N_0 + bP_1\delta_{r,d}^2)}$$

(3.2.12)

3.2.3 Outage Probability analysis for DF protocol

The mutual information for decode and forward transmission in terms of channel fading coefficients can be given as [1]:

$$I_{DF} = \frac{1}{2}\min\left\{\log(1+\Gamma|h_{s,r}|^2, \log(1+\Gamma|h_{s,d}|^2 + \Gamma|h_{r,d}|^2\right\}$$

(3.2.13)

min operator here ensures that the relay only transmits if decoded correctly, thus the performance of DF cooperation protocol is limited by the weakest link [1] between the source-destination and the source-relay. The outage probability of DF relaying scheme is given as $P_r[I_{DF} < R]$. The outage event is equivalent to [1]

$$\min\left\{|h_{s,r}|^2, |h_{s,d}|^2 + |h_{r,d}|^2\right\} < \left(\frac{2^{2R}-1}{\Gamma}\right)$$

(3.2.14)

The outage probability can be written as [1]:

$$P_r[I_{DF} < R] = P_r\left\{|h_{s,r}|^2 < \frac{2^{2R}-1}{\Gamma}\right\} + P_r\left\{|h_{s,r}|^2 > \frac{2^{2R}-1}{\Gamma}\right\} P_r\left\{|h_{s,d}|^2 + |h_{r,d}|^2 < \frac{2^{2R}-1}{\Gamma}\right\}$$

(3.2.15)

Averaging over the channel conditions, the outage probability for decode and forward at high SNR regions is given by the following equation [1]

$$P_r\left[I_{DF} < R\right] \approx \frac{1}{\sigma_{s,r}^2}\frac{2^{2R}-1}{\Gamma} \tag{3.2.16}$$

3.3 ANALYSIS OF AF PROTOCOL

3.3.1 SER Analysis for AF Protocol

In AF cooperation sytem, the relay amplifies the received signal but the noise also gets amplified. The equivalent noise at the destination in broadcast phase is a zero mean, complex Gaussian random variable with variance as [1]

$$\left(\frac{P_2\left|h_{r,d}\right|^2}{P_1\left|h_{s,r}\right|^2+N_0}+1\right)N_0$$

Thus, having the knowledge of the channel coefficients $h_{s,d}$, $h_{r,d}$,$h_{s,r}$,the output of the MRC detector at the destination can be written as:

$$y = a_1 y_{s,d} + a_2 y_{r,d}$$

where $a_1 = \frac{\sqrt{P_1}h^*_{s,d}}{N_0}$ and $a_2 = \frac{\sqrt{\frac{P_1P_2}{P_1\left|h_{s,r}\right|^2+N_0}}h^*_{s,d}h^*_{r,d}}{\left(\frac{P_2\left|h_{r,d}\right|^2}{P_1\left|h_{s,r}\right|^2+N_0}+1\right)N_0}$

the instantaneous SNR of the MRC output is $\gamma = \gamma_1 + \gamma_2$ where $\gamma_1 = P_1\left|h_{s,d}\right|^2 / N_0$

and

$$\gamma_2 = \frac{\frac{P_1 P_2}{P_1|h_{s,r}|^2 + N_0}|h_{s,r}|^2 |h_{r,d}|^2}{\left(\frac{P_2|h_{r,d}|^2}{P_1|h_{s,r}|^2 + N_0} + 1\right) N_0} \tag{3.3.1}$$

$$= \frac{1}{N_0} \frac{P_1 P_2 |h_{s,r}|^2 |h_{r,d}|^2}{P_1|h_{s,r}|^2 + P_2|h_{r,d}|^2 + N_0} \tag{3.3.2}$$

Tight upper bound on the instantaneous SNR γ_2 can be given as [1]

$$\gamma_2 \le \overline{\gamma_2} \triangleq \frac{1}{N_0} \frac{P_1 P_2 |h_{s,r}|^2 |h_{r,d}|^2}{P_1|h_{s,r}|^2 + P_2|h_{r,d}|^2} \tag{3.3.3}$$

The above equation is a harmonic mean of two random variables $P_1|h_{s,r}|^2 / N_0$ and $P_2|h_{r,d}|^2 / N_0$. Approximating the SNR as $\gamma \approx \gamma_1 + \overline{\gamma_2}$, the conditional SER of AF cooperation system with M-PSK can be given as [1]

$$P_{PSK}^{h_{s,d},h_{s,r},h_{r,d}} \approx \frac{1}{\pi} \int_0^{(M-1)\pi/M} \exp\left(-\frac{b_{PSK}(\gamma_1 + \overline{\gamma_2})}{\sin^2\theta}\right) d\theta \tag{3.3.4}$$

where $b_{PSK} = \sin^2\left(\frac{\pi}{M}\right)$,

3.3.2 Asymptotically approximation

Since the closed form SER formulations derived above are very complex and it is difficult to get an insight into the system performance from these. Hence SER approximation is useful in evaluating the asymptotic performance of AF cooperation scheme.

Theorem 3.3.1 *If all the channel links $h_{s,d}$, $h_{r,d}$ and $h_{s,r}$ are available i.e.,* $\delta_{s,d}^2 \neq 0, \delta_{s,r}^2 \neq 0, \delta_{r,d}^2 \neq 0$, *then when* $\frac{P_1}{N_0}$ *and* $\frac{P_2}{N_0}$ *go to infinity, then the SER of the AF sytem with M-PSK or M-QAM modulation can be tightly approximated as [1]*

$$P_s \approx \frac{B\aleph_0^2}{b^2} \cdot \frac{1}{P_1\delta_{s,d}^2}\left(\frac{1}{P_1\delta_{s,r}^2} + \frac{1}{P_2\delta_{r,d}^2}\right) \tag{3.3.5}$$

Where b and B are specified as:

For M-PSK signals, $b=b_{PSK}$ and

$$B = \frac{3(M-1)}{8M} + \frac{\sin\frac{2\pi}{M}}{4\pi} - \frac{\sin\frac{4\pi}{M}}{32\pi} \tag{3.3.6}$$

3.3.3 Outage probability analysis for AF relaying

The instantaneous mutual information as a function of the fading coefficients for amplify and forward is given by [1]

$$I_{AF} = \frac{1}{2}\log(1+\gamma_1+\gamma_2) \tag{3.3.7}$$

Putting the values of γ_1 and γ_2, the mutual information can be written as [1]

$$I_{AF} = \frac{1}{2}\log(1+\Gamma\left|h_{s,d}\right|^2 + f\left(\Gamma\left|h_{s,r}\right|^2, \Gamma\left|h_{r,d}\right|^2\right) \tag{3.3.8}$$

where $f(x,y) \triangleq \frac{xy}{x+y+1}$

The outage probability is obtained by averaging over the exponential channel gain distribution [1], as follows

$$P_R\left[I_{AF} < R\right] = E_{h_{s,d},h_{r,d},h_{s,r}}\left[\frac{1}{2}\log(1+\Gamma\left|h_{s,d}\right|^2 + f\left(\Gamma\left|h_{s,r}\right|^2, \Gamma\left|h_{r,d}\right|^2\right) < R\right] \tag{3.3.9}$$

At high SNR regions, the outage probability is given by:

$$P_R\left[I_{AF} < R\right] \approx \left(\frac{\sigma_{s,r}^2 + \sigma_{r,d}^2}{2\sigma_{s,d}^2\left(\sigma_{s,r}^2\sigma_{r,d}^2\right)}\right)\left(\frac{2^{2R}-1}{\Gamma}\right)^{-2} \tag{3.3.10}$$

The outage expression for AF cooperation decays as Γ^{-2}, which means that the AF protocol achieves diversity 2.

3.3.4 Channel capacity for AF

The ergodic channel capacity for an AF can be calculated assuming that the channel state information is available at the receiver [1].

$$\overline{\gamma_{s,d}} = \left(P_t\left|h_{s,d}\right|^2 \big/ N_0\right) = \left(\frac{P_t\delta_{s,d}^2 d_{s,d}^{-4}}{N_0}\right) = \frac{1}{2}\gamma\delta_{s,d}^2 d_{s,d}^{-4} \tag{3.3.11}$$

$$\overline{\gamma_{s,r_i}} = \left(P_t\left|h_{s,r_i}\right|^2 \big/ N_0\right) = \left(\frac{P_t\delta_{s,r_i}^2 d_{s,r_i}^{-4}}{N_0}\right) = \frac{1}{2}\gamma\delta_{s,r_i}^2 d_{s,r_i}^{-4} \tag{3.3.12}$$

$$\overline{\gamma_{r_i,d}} = \left(P_t\left|h_{r_i,d}\right|^2 \big/ N_0\right) = \left(\frac{P_t\delta_{r_i,d}^2 d_{r_i,d}^{-4}}{N_0}\right) = \frac{1}{2}\gamma\delta_{r_i,d}^2 d_{r_i,d}^{-4} \tag{3.3.13}$$

$$\overline{\gamma_{s,r_i,d}} = \sum_{i=1}^{M}\frac{\overline{\gamma_{s,r_i}}\,\overline{\gamma_{r_i,d}}}{1+\overline{\gamma_{r_i,d}}+\overline{\gamma_{r_i,d}}} \tag{3.3.14}$$

For M relays, the ergodic channel capacity is given by [1]

$$C = \frac{1}{M+1}\log 2\left(1+\overline{\gamma_{s,d}}+\overline{\gamma_{s,r_i,d}}\right) \tag{3.3.15}$$

$$C = \frac{1}{M+1}\log 2\left(1+\frac{1}{2}\delta_{s,d}^2 d_{s,d}^{-4} + \sum_{i=1}^{M}\frac{\gamma\delta_{s,r_i}^2 d_{s,r_i}^{-4}\delta_{r_i,d}^2 d_{r_i,d}^{-4}}{\frac{2}{\gamma}+\delta_{r_i,d}^2 d_{r_i,d}^{-4}+\delta_{s,r_i}^2 d_{s,r_i}^{-4}}\right) \tag{3.3.16}$$

3.3.5 Best location of relay

There are two phases of operation:

A. *Broadcast phase*

The data is broadcasted by the source to the destination and to the relays. The received complex baseband signal at the destination and i_{th} relay is given by

$$y_{\mathrm{s},d} = \sqrt{P_t} h_{\mathrm{s},d} x + \eta_{\mathrm{s},d} \tag{3.3.17}$$

$$y_{\mathrm{s,d}} = \sqrt{P_t} h_{\mathrm{s,d}} x + \eta_{\mathrm{s,d}} \tag{3.3.18}$$

$$y_{\mathrm{s,r}_i} = \sqrt{P_t} h_{\mathrm{s,r}_i} x + \eta_{\mathrm{s,r}_i} \tag{3.3.19}$$

$$h_{s,d} = l_{s,d} . a_{s,d} \tag{3.3.20}$$

$$h_{\mathrm{r}_i,d} = l_{\mathrm{r}_i,d} . a_{\mathrm{r}_i,d} \tag{3.3.21}$$

Where $a_{s,d}$ and $P_R\left[I_{AF} < R\right] \approx \left(\frac{\sigma_{\mathrm{s,r}}^2 + \sigma_{\mathrm{r},d}^2}{2\sigma_{s,d}^2\left(\sigma_{\mathrm{s,r}}^2 \sigma_{\mathrm{r},d}^2\right)}\right)\left(\frac{2^{2R}-1}{\Gamma}\right)^{-2}$ are modeled as zero mean, complex Gaussian random variable with variance as $\delta_{\mathrm{s,d}}^2$ and $\delta_{\mathrm{r}_i,\mathrm{d}}^2$ respectively. The path loss $l_{s,d}$ is proportional to $d_{s,d}^{-4}$, where $d_{s,d}$ is the distance of source node from the destination node. The path loss l_{s,r_i} is proportional to d_{s,r_i}^{-4}, where d_{s,r_i} is the distance between the source node and the *i*th relay node.

B. *Cooperation phase*

In this phase each relay acts as a cooperative agent by helping the source i.e., by amplifying the source signal and retransmitting to the destination.

$$y_{r_i,d} = \frac{\sqrt{P_i}}{\sqrt{P_0\left|h_{s,r_i}\right|^2 + N_0}} h_{r_i,d}\, y_{s,r_i} + \eta_{r_i,d} \tag{3.3.22}$$

Where $h_{r_i,d}$ is the channel coefficients of the i^{th} relay to the destination node given as

$h_{\mathrm{r}_i,d} = l_{\mathrm{r}_i,d} . a_{\mathrm{r}_i,d}$

$a_{r_i,d}$ can be modeled as zero mean, complex Gaussian random variable with variance as $\delta^2_{r_i,d}$. The pathloss $l_{r_i,d}$ is proportional to $d^{-4}_{r_i,d}$, where $d_{r_i,d}$ is the distance from the i[th] relay to the destination.

Assuming all the relay nodes are located at the same position and the transmitted power is also same for each relay. The distance between source-relay, source-destination and relay-destination is given by d_{s,r_i}, $d_{s,d}$ and $d_{r_i,d}$ respectively.

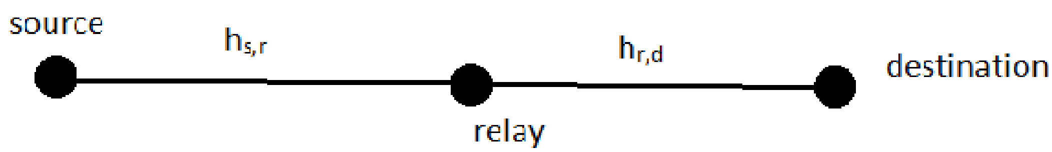

Figure 3.2 Best relay location [30]

Assuming $d_{s,d}$ is a fixed value and $d_{s,r_i} = d_{s,r} = p.d_{s,d}$. For 0<p<1,

$d_{r_i,d} = d_{r,d} = (1-p).d_{s,d}$

The best location of relay is given by [30]

$$P_s \approx \frac{4B}{\gamma d^{-4}_{s,d}} \prod_{i=1}^{3} \left(\frac{1}{\gamma p^{-4} d^{-4}_{s,d}} + \frac{1}{\gamma (1-p)^{-4} d^{-4}_{s,d}} \right) \tag{3.3.23}$$

Taking the second derivative of the above equation w.r.t 'd', we get [30]

$$\approx \frac{4B}{\gamma d^{-4}_{s,d}} \left[12p^2 + 12(1-\mathrm{p})^2 \right] \tag{3.2.24}$$

The result comes out to be (16>0), hence the minimum value exists. Now take the first derivative w.r.t. 'd' and equate to zero.

$$\approx \frac{4B}{\gamma d^{-8}_{s,d}} \left[4p^3 - 4(1-\mathrm{p})^3 \right] \tag{3.3.24}$$

The root satisfying the constraint $p \in (0,1)$ is 0.5

Chapter 4

RESULTS AND DISCUSSION

Simulations have been performed using the MATLAB software. The channel coefficients have been calculated using random samples of the Rayleigh distribution. Path loss has been incorporated using the path loss exponent as $\alpha = 2$. The transmitted power P_t =1 W and relay and source power are 0.5 W each. The noise power is calculated for different values of SNR values.

The Fig 4.1 provides SER analysis of amplify and forward cooperative protocol using QPSK modulation. Results are compared with theoretical results for QPSK modulation with AWGN and Rayleigh fading channels.

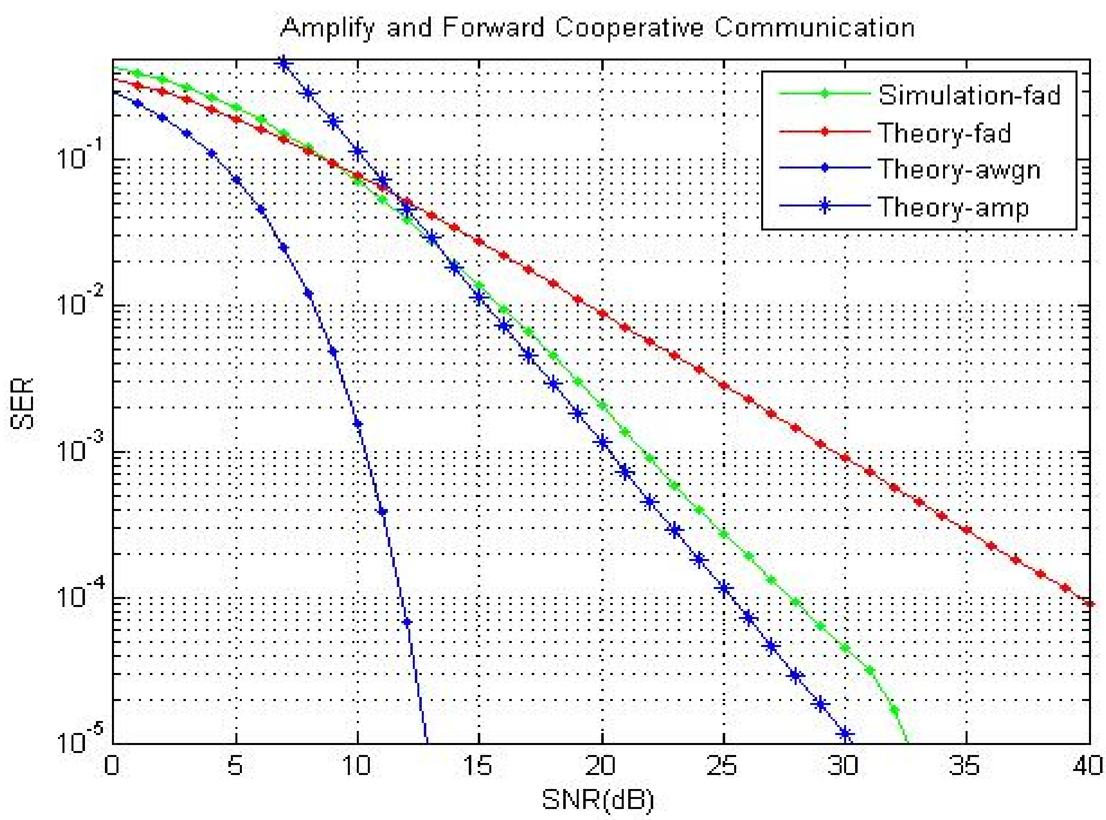

Figure 4.1: Symbol Error Rate v/s SNR for AF

It can be seen in Fig 4.1that the simulation result closely follows the theoretical values in the Low SNR region but they don’t follow in High SNR regions. The slope of the curve is almost the same in High SNR regions in comparison with that obtained using theoretical SER for Amplify and Forward method.

Outage Probability

The outage occurs when the channel link quality falls below a certain threshold level. The threshold level can SNR, BER or

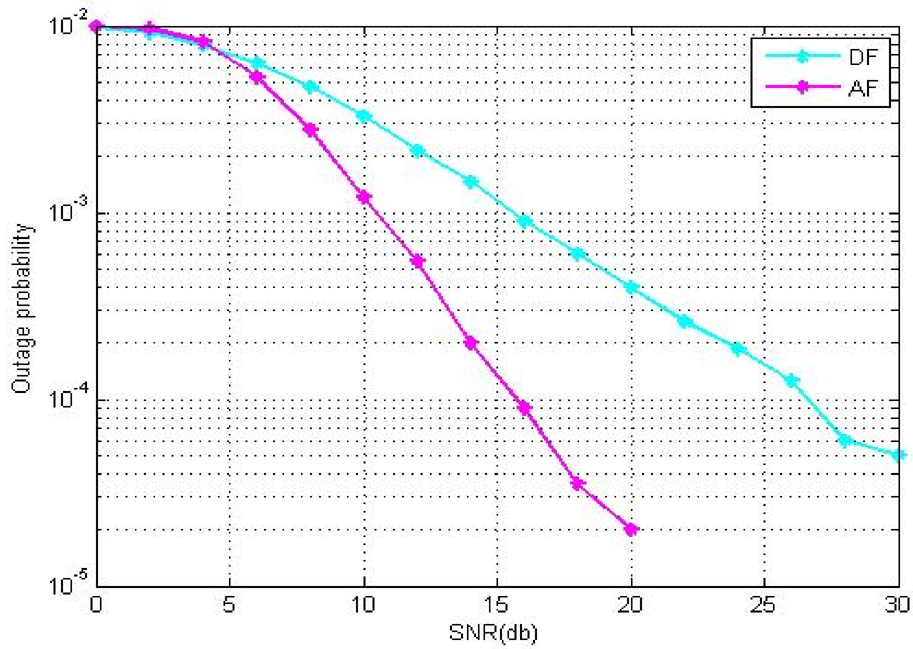

Figure 4.2: Outage Probability for AF and DF

Fig 4.2 shows the simulated results for QPSK modulation in the symmetric network with 3 relays. From the figure it is clear that the curves for the Opportunistic AF (OAF) and the All Power AF (APAF) protocols have the same slope in the high SNR regions with the same fading parameters, indicating that they achieve the same diversity order. Under the overall power constraints, the OAF protocol always outperform the APAF protocol under the same conditions. This is due to the fact that the opportunistic relaying provides a power gain by giving priority to the overall relay- power transmission of a single opportunistic relay, whereas idle relays only choose to cooperatively listen and devote the selection diversity capability. Figure 3 shows the outage probability of amplify and forward method.

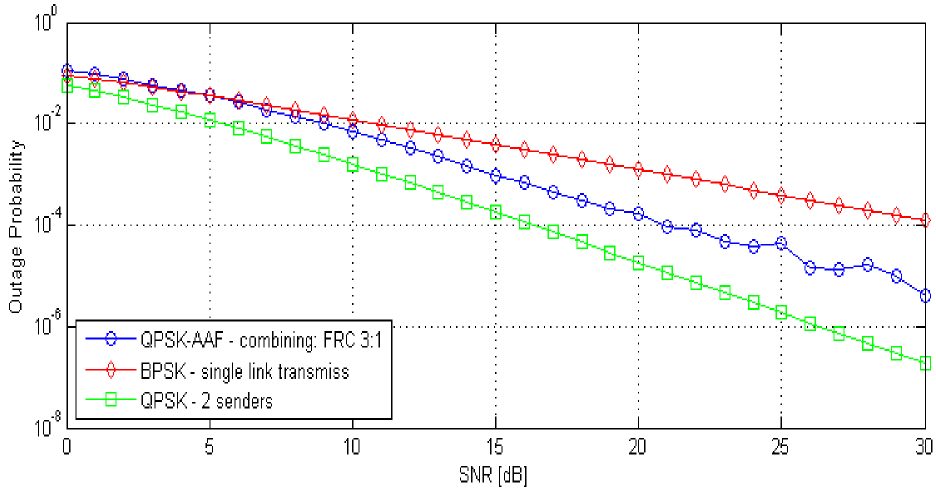

Figure 4.3 Outage Probability using FRC 3:1

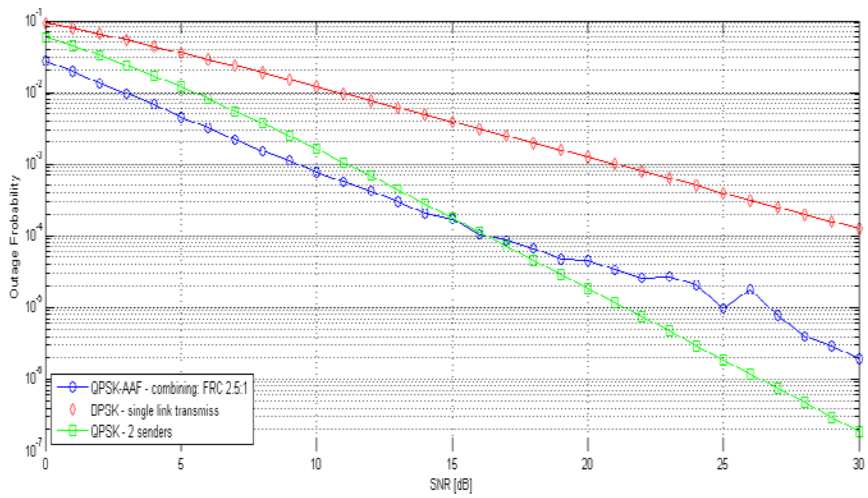

Figure 4.4 Outage Probability using FRC 2.5:1

In Figure 4.3 and Figure 4.4, AAF technique is used for different weights in case of FRC. From the figure 4.4 and 4.5 it is clear that AAF performs better with FRC = 3.

<u>Impact of relay location:</u>

The following curves show the impact of relay location on the SER performance. 3 cases of relay location are considered i.e., relay close to the destination, close to the source and at the midway between the source and the destination.

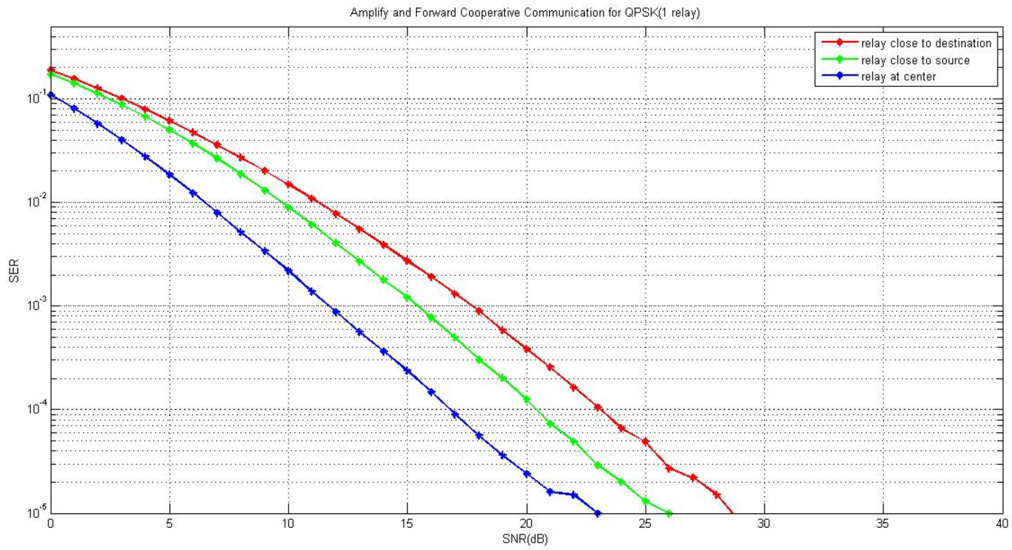

Figure 4.5 SER versus SNR for different relay location in case of single relay for Rayleigh fading channel.

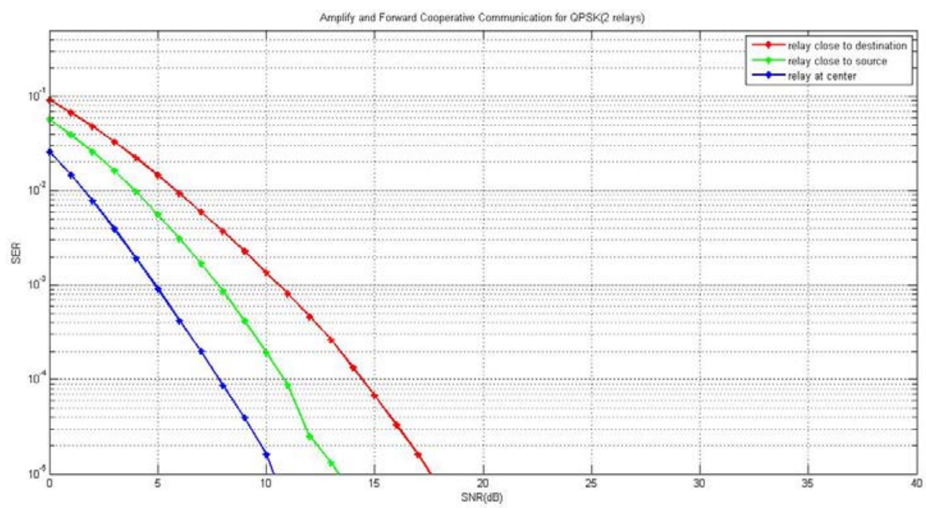

Figure 4.6 SER versus SNR for different relay location in case of 2 relay for Rayleigh fading channel.

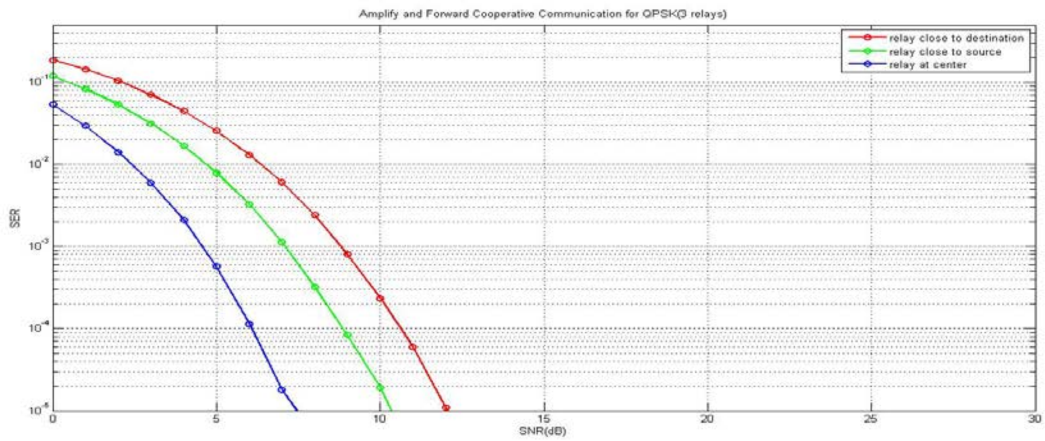

Figure 4.7 SER versus SNR for different relay location in case of 3 relay for Rayleigh fading channel.

Thus from fig-4.5, fig-4.6 and fig-4.7, it is clear that the SER performance of the system using multiple relays improves significantly over the system using only single relay. For all the three cases, the best performance is achieved when the relay is located closer to the destination.

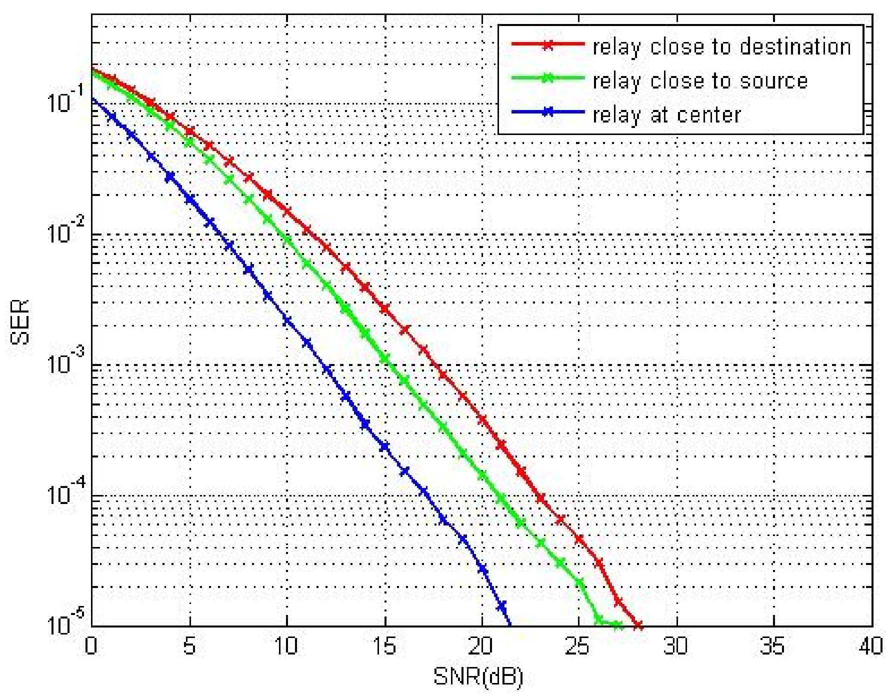

Figure 4.8 SER versus SNR for different relay location in case of single relay for Rician fading channel.

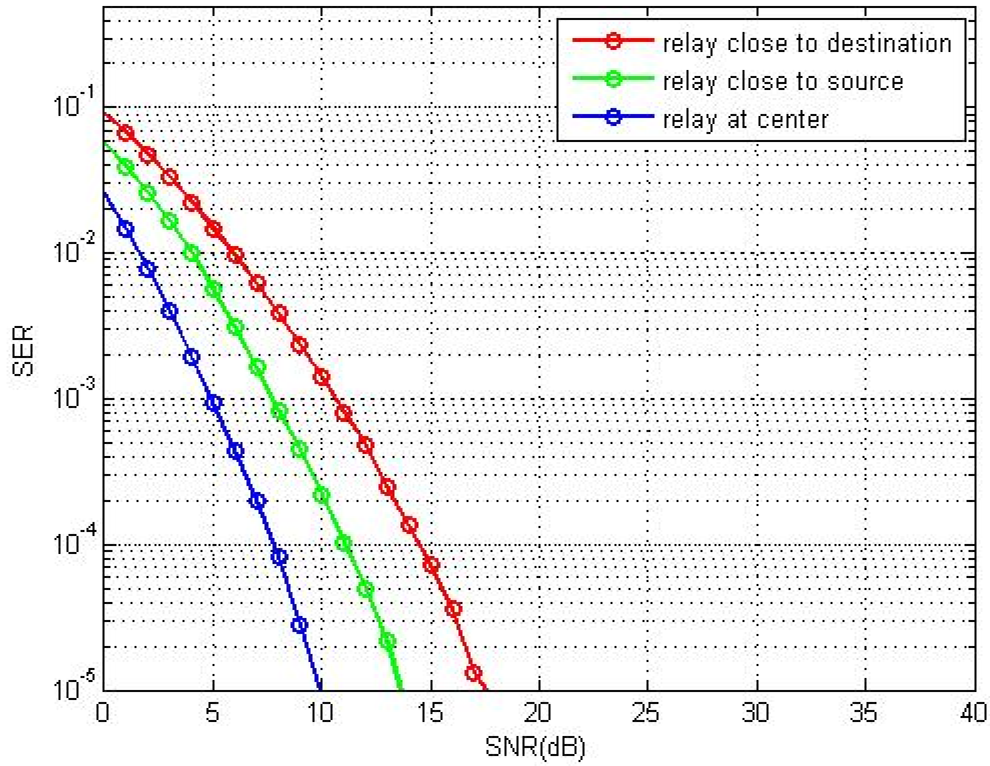

Figure 4.9 SER versus SNR for different relay location in case of 2 relay for Rician fading channel.

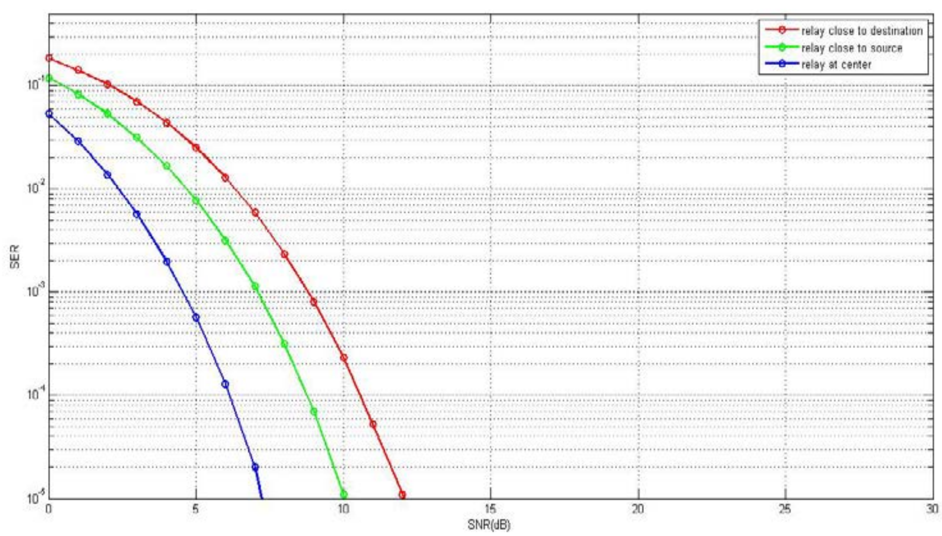

Figure 4.10 SER versus SNR for different relay location in case of 3 relay for Rician fading channel.

Figure 4.8, figure 4.9 and figure 4.10 shoes the SNR versus SNR plots for single relay and multiple relay amplify and forward in Rician fading channel for 3 different locations i.e., relay close to source, relay close to destination and relay located in between the source and the destination. The results clearly show that the multiple relay AF protocol performs better as compared to single relay.

Channel capacity :

Channel capacity for single relay and multiple relay is calculated over a range of SNR values. Channel capacity against source to relay distance is calculated for both single relay as well as multiple relays.

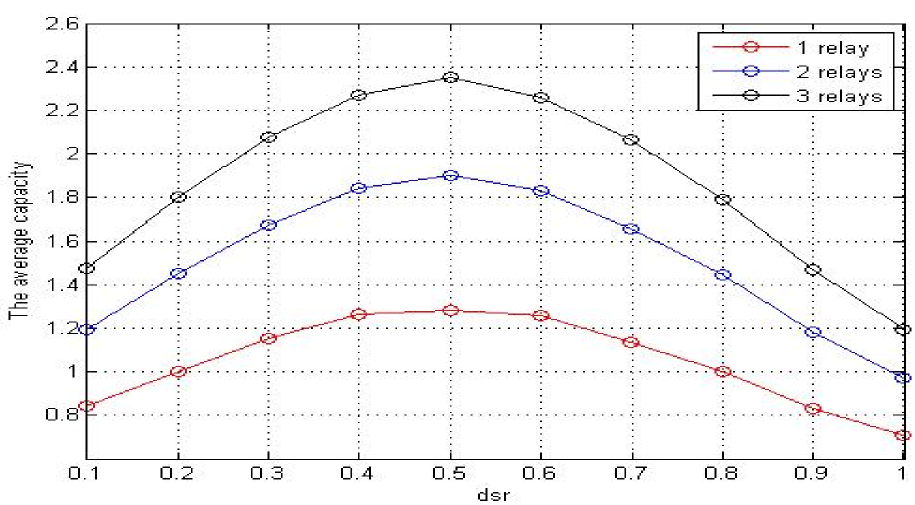

Figure-4.11 Channel capacity versus source to relay distance.

From figure 4.11, the channel capacity is maximum when source to relay distance is around 0.5 i.e., relay is located in between the source and the destination. Channel capacity comes out to be maximum for 3 relay case.

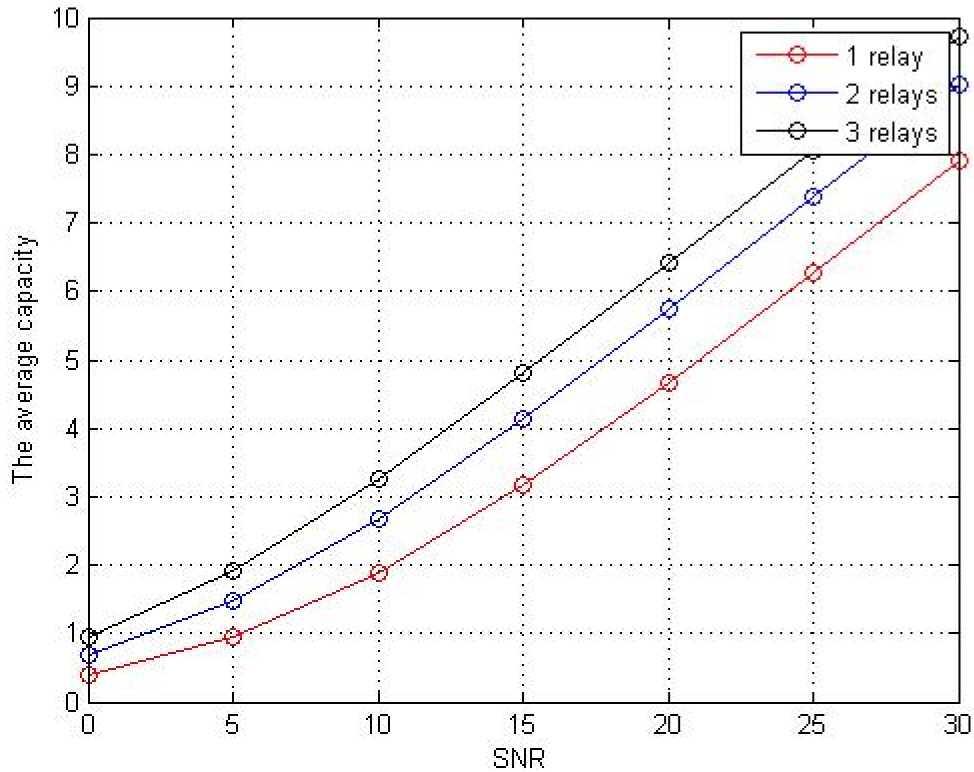

Figure-4.12 Channel capacity versus Signal to Noise Ratio.

From the fig-4.12, it is clear that the average channel capacity increases as the SNR increases.

SER calculation for Decode and Forward

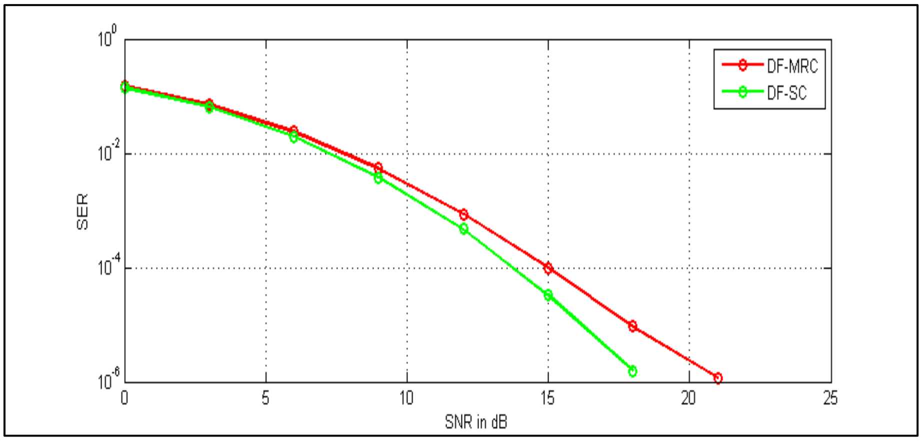

Figure 4.13: Symbol Error Rate calculation for Decode and Forward

Fig-4.13 shows the symbol error rate calculation for single relay decode and forward method in Rayleigh fading channel. The maximum ratio combining and selective combining protocols are compared in the study. It is clear from the figure that for the same value of SNR, the MRC protocol gives more SER as compared to Selective combining.

From the above results it is clear that the use of relays always results in better performance i.e., SER and outage probability reduces and the channel capacity increases. The relay location plays a major role in the system performance. From the results obtained, it is clear that when relay is located close to the sender, SER is low. This is because when the relay is located closer to the sender, the channel link quality is good and the chances of incorrectly detecting the symbol is also very less.

Chapter 5

CONCLUSIONS AND SCOPE OF FUTURE WORK

The possible benefits of a wireless transmission using cooperative diversity to increase the performance i.e., lower the symbol error rate (SER) and reduce the outage probability. The diversity is realized by building an ad-hoc network using a third station as a relay. The data is sent directly from the base to the destination or via the relay station. Such a system has been simulated to see the performance of different diversity protocols and various combining methods.

The performances of amplify and forward and decode and forward, the two basic signal relaying protocols have been analyzed for a three terminal cooperative system in Rayleigh fading environment. The SER analysis for AF for single relay as well as multiple relays has been done in Rayleigh and Rician fading environments. The outage probability for AF and DF has been simulated for single relay in Rayleigh fading environment.

From the simulation results, it is observed that the performance of a system improves while using relays in between the source and the destination. This is due to the fact that the wireless network suffers from various deleterious effects like multi-path fading, pathloss etc which is mitigated by using a third station acting as a relay. Hence the information is sent over different paths to the destination, and at the receiver side, the signals from all the sources are combined using different combination protocols.

The channel capacity for single relay and multiple relay AF protocol is simulated over a range of SNR values. For a 3 relay system the channel capacity is improved over the system employing 2 relay or a single relay.

The location of the relay is crucial to the system performance. The performance achieved when the relay is at equal distance from the sender and the destination or slightly closer to the source is better as compared to when the relay is near the destination. In general the relay should not be too far from the line between the two stations.

As a scope of future work the hybrid method employing both the decode and forward and the amplify and forward can be implemented for single as well as multiple relays.

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