

STUDY AND ANALYSIS OF TWO-WAY AF RELAYING BASED COOPERATIVE DIVERSITY SYSTEM

A Thesis Submitted in Fulfillment of the Requirement for the Award of the Degree of

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Submitted By

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DECLARATION


I, Manpreet Kaur hereby declare that the work presented in this thesis entitled "Study and Analysis of Two-Way AF Relaying Based Cooperative Diversity System" in partial fulfillment of the requirement for the award of degree of Master of Engineering submitted at Electronics and Communication Engineering Department, Thapar University, Patiala is an authentic record of work carried out under supervision of Dr. Hem Dutt Joshi (Assistant Professor), Electronics and Communication Engineering Department, Thapar University from January 2017 to July 2017. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

Date: 10 August 2017


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It is certified that the above statement made by the candidate is correct to the best of my knowledge and belief.

Date: 10 August 2017


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ABSTRACT

In wireless communication system, the presence of electromagnetic waves cause multipath propagation of wireless signals and results in variation of received signal strength as a function of transceiver location, transceiver motion and frequency. These variations produce wireless channel variations, known as fading. Different diversity techniques are used to mitigate and exploit multipath fading to improve the performance of wireless communication system.

One such technique is cooperative diversity which reduces variation in signal attenuation which in turn controls interference and fading. The key concept of this method is to send multiple copies of the signal and then adding them at the receiver and the receiver decodes the information received from different nodes which act as virtual antennas, this increases the signal to noise ratio of the system. Cooperative diversity prevents the size limitations and gives spatial diversity in wireless applications like ad hoc, cellular and sensor networks.

In conventional cooperative diversity networks, this uses half-duplex fashion in which sending one information symbol from the source to destination terminal needs two channels. This result in a loss in spectral efficiency, to improve this two way relaying is proposed. In this technique in first phase the multiple access (MA) phase, two source nodes simultaneously transmit their information to relay and then the second phase the broadcast (BC) phase, in which relay broadcasts the received signal to the two source nodes.

Two way amplify and forward (AF) relaying has been a promising technique in future wireless communication because it has a capability to achieve high coverage and spectral efficiency for half duplexer lay systems. It provides large coverage area, high spectral efficiency and high data rate even in hostile environments and lands.

The objective of this dissertation is to present a holistic study and analysis of the performance of a two way amplify and forward cooperative communication system under different fading channel conditions. The performance evaluation is done by analysing different mathematical expressions and analytical as well as Monte Carlo simulation are done to achieve performance curves for different modulation schemes over a range of signal-to-noise ratios for various values of fading parameter.

CHAPTER-1

INTRODUCTION

1.1 OVERVIEW

The demand of wireless communication system increases day by day, due to mobile internet, users are increasing at rapid pace. It is required to provide internet services to large number of users at very high data rate. The major hindrance to provide high data rate is multipath fading. Due to multipath propagation, fading occurs and it degrades the quality of signal at receiver. Lot of techniques have been proposed in the literature by many learned researcher to combat the effect of multipath fading. One of these techniques are diversity techniques [1]. Diversity is technique of transmitting multiple copies of the same signal through independent channels [2]. Cooperative relaying has been proposed to form virtual antenna arrays to provide reduced power consumption and network coverage extension [3]. In conventional one-way communication system, when data is transmitted from source to destination via a relay, it takes two relay channels and four time slots. This cause loss in spectral efficiency, to reduce this effect we use two-way relaying which uses only two time slots [4]. In two-way transmission will take place in two phases: MA phase and BC phase. In first time slot in multiple access phase, both sources simultaneously transmit their message signals to relay then in second time slot in broadcast phase, the relay broadcasts the received signal to the two source nodes [5].

MPSK modulation scheme is preferred because of its constant envelop features and high spectral efficiency. MPSK is used for cellular mobile applications, deep space probes, optical wireless devices and satellite etc. [6]. The amplify and forward (AF) relaying is more practical than decode and forward (DF) as it is less complex as for this data processing is simple so burden on relay is less, especially for the case of heterogeneous communications [4]. The work on AF scheme with the two-way relaying has been done by many researchers due to its considerable interest. We have used CDF approach in this paper as it improves SNR of the system by a considerable amount.

Many research works have been done in which ASER performance of different modulation schemes by using various standard approaches over different fading channels is calculated. ASER is calculated for AF TWRN over independent and non-identically distributed (i.n.i.d) Nakagami-m fading for M-ary PSK (MPSK) modulation scheme by using moment generating function (MGF) based approach in [5]. The ASER expressions of L-branch MRC receiver is calculated for one-way communication system over η - μ and κ - μ fading channels for RQAM, DE-QPSK and $\pi/4$ QPSK modulation schemes by using probability density

function (PDF)-based approach in [7]. Exact expression for ASER for AF TWRN over independent and non-identically distributed Nakagami-m fading for RQAM, 32-cross QAM, DE-QPSK and $\pi/4$ -QPSK modulation by using cumulative distribution function (CDF)-based approach in [8].

That's why we have considered M-ary phase shift keying (MPSK) modulation scheme in amplify and forward two-way relaying network over i.n.i.d. Nakagami-m channels by using cumulative distribution function (CDF)-based approach.

1.2 WIRELESS COMMUNICATION

In wireless communication there is multipath propagation environment, in which there are multiple paths between transmitter and receiver, these multiple paths are due to the obstacles present between transmitter and receiver. These obstacles are scatters and reflectors like trees, cars and buildings. These obstacles can be stationary or moving objects or big or small. Two types of paths are present in multipath propagation first is, line of sight (LOS) path that is direct path and second is, non-line of sight path (NLOS) that is indirect path. These indirect signals are reflected, diffracted, scattered and refracted signals. There are different waves which travel different distance and have different paths and each wave that comes through a different distance is subject to attenuation (different delays and different phase). Now due to different delays and different paths there will interference, now the interference can be constructive or destructive. If interference is constructive then power of signal will increase and if it is destructive then power of signal will decrease [9]

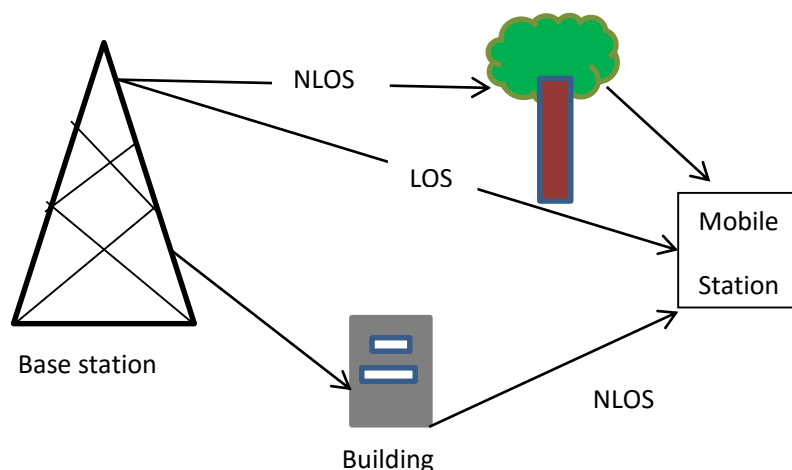


Figure 1.1 Wireless communication system [9]

A range of powers is received at the receiver, based on the random behaviour of the multipath component in the channel. Signal power varies with time and this variation in the signal power is known as fading. The poor performance of a wireless communication system is not due to the receiver noise. The poor performance of a wireless communication system is because of the deep fade and that deep fade is resulting from the destructive interference arising from the multipath propagation. The performance (probability of error) of a wireless communication system can be severely reduced by fading [9].

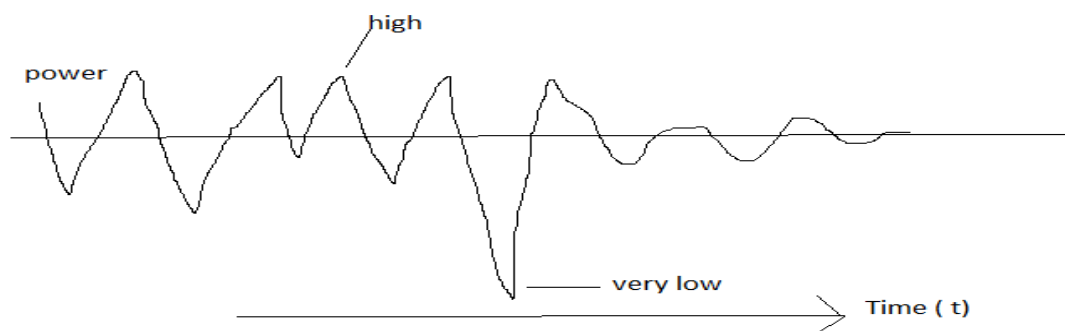


Figure 1.2 Plot of signal power versus time [9]

1.2.1 Parameters of Fading Channels

- 1) Multipath spread T_m informs us about the maximum delay between paths of significant power in the channel.
- 2) Coherence Bandwidth B_C is the maximum frequency for which the signals are still considered to be correlated or it measures the separation in frequency after which two signals will experience uncorrelated fading.
- 3) Coherence Time T_C is defined as the time duration, beyond which two signal samples separated longer than T_C can usually be considered independent of each other.
- 4) Doppler Spread B_d is a factor which gives us the maximum range of Doppler shifts [10].

1.2.2 Types of Fading Channels

According to different parameters given above fading channels can be categorized as follows:

- 1) Frequency non-selective fading- In this type of fading coherence bandwidth B_C of the channel is greater than the bandwidth of the signal B , therefore all frequency components present in the signal will experience the same fading that is magnitude of fading will be same.

$$B_C > B$$

- 2) Frequency selective fading- In this type of fading the coherence bandwidth B_C of the channel is smaller than the bandwidth of the signal B , therefore different frequency components of the signal experience uncorrelated fading that is different fading.

$$B_C < B$$

- 3) Slow fading- In this type of fading when the symbol duration T is smaller than T_C , this is known as slow fading, slow fading channels are usually modelled as time invariant channels for different symbol intervals.

$$T_C > T$$

- 4) Fast fading- Fast fading is when the impulse response of channel varies more faster than the changes in the characteristics of the given transmitted signal, the type of fading encountered by the transmitted signal is fast fading.

$$T_C < T$$

The two ways of categorization give rise to four types of channel:

- Frequency non-selective slow fading
- Frequency selective slow fading
- Frequency non-selective fast fading
- Frequency selective fast fading [10]

1.3 DIVERSITY

The poor performance of wireless communication system is due to fading, now diversity can be employed to improved performance of wireless communication system through controlling or combating fading. Diversity is a technique to combine several copies of the same message received over different channels. As there are multiple copies of the same signal even if one or two links are in a deep fade or error then receiver automatically picks the other copy which is undistorted, the rest of the links carry the information so it is possible to receive the proper signal at the receiver [9].

As shown in above figure if L1 and L3 are in deep fade then we can receive proper signals through L2 and L4. Now as we have more than one path to select from the available multiple

paths, now both the SNRs instantaneous and average SNR (signal to noise ratio) at the receiver will get better [9].

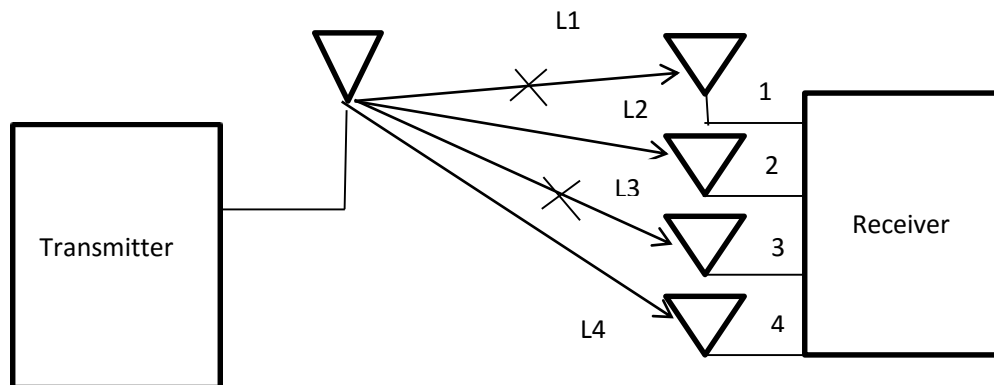


Figure 1.3 Receiving multiple copies of signal using diversity [9]

1.3.1 Types of Diversity

There are different types of diversities given as Space diversity, Frequency diversity, Time diversity and Polarization diversity.

1.3.1.1 *Space Diversity*

In space diversity N antennas are used to get N copies of the transmitted signal at the receiver. The space between the antennas should be such that distinct copies of received signal should experience independent or different fading. At the transmission end no extra additional work is required as needed in temporal diversity and frequency diversity and no additional transmission time or bandwidth is required. Spatial diversity reduces time selective fading and frequency selective fading. Its applications can be limited by physical constraints [10]. In frequency diversity for transmitting information numbers of carrier frequencies are used. Basic concept for this is that if the frequencies components separated by more than the coherent bandwidth B_c of the channel will not undergo same fading.

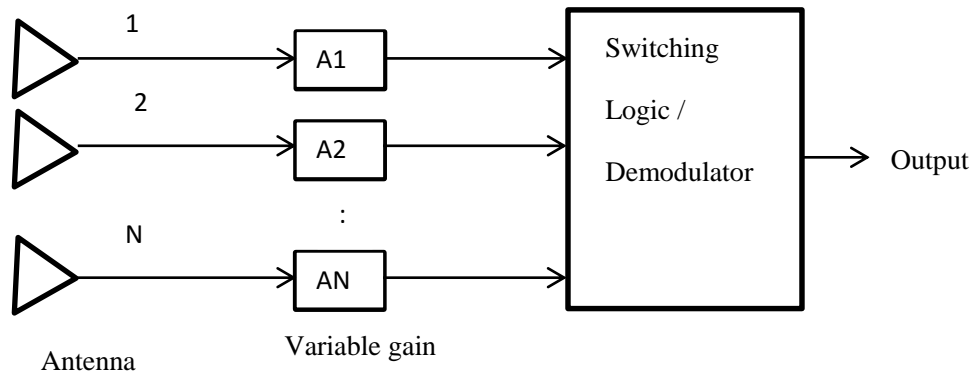


Figure 1.4 Simple block diagram for space diversity [11]

1.3.1.2 Frequency Diversity

If channels are mutually uncorrelated, then the probability of concurrent fading can be given by the multiplication of individual fading probabilities. It is usually used in microwave line-of-sight (LOS) links. Practically, 1: M protection switching is used in which one frequency is minimally idle and is available to provide frequency diversity switching from any one of the M other carriers (frequencies) which are used on the same channel and independent traffic is carried by each carrier. When diversity is required, the suitable traffic is shifted to the backup frequency as required [11].

1.3.1.3 Time Diversity

In this type of diversity information is transmitted at time spacing's which is larger than coherence time T_c of channel, so that various copies of the signal will be received at the receiver with independent or different fading. RAKE receiver for spread spectrum (SS) code division multiple access (CDMA) is used for the implementation of this diversity [11].

1.3.1.4 Polarization Diversity

In polarization diversity, information is carried by magnetic and electric fields of signal which are then adjusted and then these signals are used to transmit the same information, this is known as orthogonal polarization. By using antennas with different polarization (vertical and horizontal) multiple versions of same signal are transmitted and received. Since the different reflections divide the power almost equally to vertical and horizontal polarizations, thus the corresponding average received power is same for either polarized antenna. The

scattering angle (θ) for each polarization will be different, so it is unlikely that signals on the two distinctly polarized antennas will be faded simultaneously.

1.3.2 Diversity Combining Methods

Diversity is combining multiple copies of signal transmitted, where each experience independent fading, to improve the power at the receiver. There are different types of combining techniques, which are analysed below.

1.3.2.1 Selective Combining Technique

Let there be N independent Rayleigh channels at a receiver and each Rayleigh channel is known as diversity branch. Now, assume that the average SNR for each branch is same which is expressed as:

$$\text{SNR} = \frac{E_b}{N_0} \overline{\alpha^2} \quad (1.1)$$

If γ_i is instantaneous SNR for each branch, then pdf of γ_i is given by

$$P(\gamma_i) = \frac{1}{\gamma_m} e^{-\frac{\gamma_i}{\gamma_m}} \quad \gamma_i \geq 0 \quad (1.2)$$

Where, each branch has γ_m mean SNR. The probability of single branch having signal to noise ratio (SNR) less than some threshold γ_{th} is

$$\begin{aligned} \Pr[\gamma_i \leq \gamma_{th}] &= \int_0^{\gamma_{th}} P(\gamma_i) d\gamma_i \\ &= \int_0^{\gamma_{th}} \frac{1}{\gamma_m} e^{-\frac{\gamma_i}{\gamma_m}} d\gamma_i \\ \Pr[\gamma_i \leq \gamma_{th}] &= 1 - e^{-\frac{\gamma_{th}}{\gamma_m}} \end{aligned} \quad (1.3)$$

Now, the probability for the case when all N independent branches will receive signals which all are simultaneously less than specific SNR threshold γ_{th} is

$$\Pr[\gamma_1, \dots, \gamma_N \leq \gamma_{th}] = \left(1 - e^{-\gamma_{th}/\gamma_m}\right)^N = P_N(\gamma_{th}) \quad (1.4)$$

$P_M(\gamma_{th})$ in (1.4) is the probability of all branches failing to achieve signal to noise ratio equal to threshold value ($SNR = \gamma_{th}$). If a single branch achieves signal to noise ratio greater than threshold value ($SNR > \gamma_{th}$) then the probability of $SNR > \gamma_{th}$ for one or more than one branches can be expressed as

$$\Pr[\gamma_i > \gamma_{th}] = 1 - P_N(\gamma_{th}) = 1 - \left(1 - e^{-\gamma_{th}/\gamma_m}\right)^N \quad (1.5)$$

Equation (1.5) gives the probability when SNR exceeds a threshold value when selection diversity is utilized.

To evaluate the average signal-to-noise ratio (SNR) of the received signal, first probability density function of the fading channel is calculated. For selection diversity, to calculate the average SNR first the derivative of $P_N(\gamma_{th})$ is calculated. As given in the following steps

$$P_N(\gamma_{th}) = \frac{d}{d\gamma_{th}} P_N(\gamma_{th}) = \frac{N}{\gamma_m} \left(1 - e^{-\gamma_{th}/\gamma_m}\right)^{N-1} e^{-\gamma_{th}/\gamma_m} \quad (1.6)$$

Then, the mean signal to noise ratio, $\bar{\gamma}$ may be given by

$$\bar{\gamma} = \int_0^{\gamma} \gamma_{th} P_M(\gamma_{th}) d\gamma = \gamma_m \int_0^{\gamma} Nr(1 - e^{-r})^{N-1} e^{-r} dx \quad (1.7)$$

where, $r = \gamma/\gamma_m$.

The above expression (1.7) is calculated to give the average SNR improvement offered by selection diversity

$$\frac{\bar{\gamma}}{\gamma_m} = \sum_{L=1}^N \frac{1}{L} \quad (1.8)$$

From equation (1.8) it can be analysed that the average signal to noise ratio in the selected branch using selection diversity increases in a natural manner, because it is always above specified threshold [11].

1.3.2.2 Switch and Stay Connected Combining Technique

Scanning diversity is same as selection diversity except the difference that in this method best of N signals is not used always, instead of that the signals are scanned in a fixed sequence until one signal is found to be greater than the threshold which is already predetermined. Now this one selected signal is received until it drops below that predetermined threshold and then scanning process starts again. The fading statistics are inferior as compared to other techniques of combining but the benefit is that it is easy to apply because only one receiver is needed. Simple block diagram of this technique is given in figure 1.5 [11].

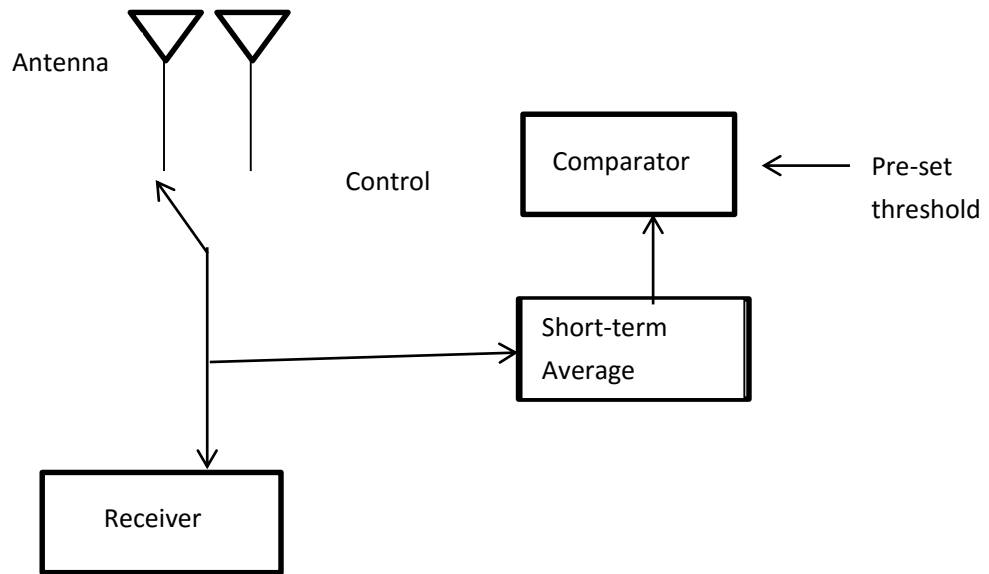


Figure 1.5 Basic block diagram of scanning diversity [11]

1.3.2.3 Maximal Ratio Combining Technique

In maximal ratio combining (MRC) technique, resultant signal at the output will be calculated as the weighted sum of the signal on all the diversity branches. In an N-branch MRC technique, the gain A_l for each branch is non-zero where $1 \leq l \leq N$. The signals on the different diversity branches are co-phased, therefore, for the l^{th} branch, $A_l = A_i e^{j\theta_l}$, where θ_l is the signal phase on the l^{th} branch [12]. Therefore, the envelope of the output at the combiner is $r = \sum_{l=1}^N A_l r_l$.

The SNR at the output of the maximal ratio combiner is given by the sum of the SNRs at each branch. The performance of maximal ratio combination is much improved than the selection combining scheme. For higher values of signal to

noise ratio, the diversity order for MRC will be equals N, it can be said that a full diversity order is achieved by MRC [12].

The system model for the MRC technique is given in figure 1.6. N-receivers are present at destination, each receiver have one receiving antenna. All the SNRs from each receiver is co-phased and then summed to generate a resultant output, which is then demodulated with the help of detector.

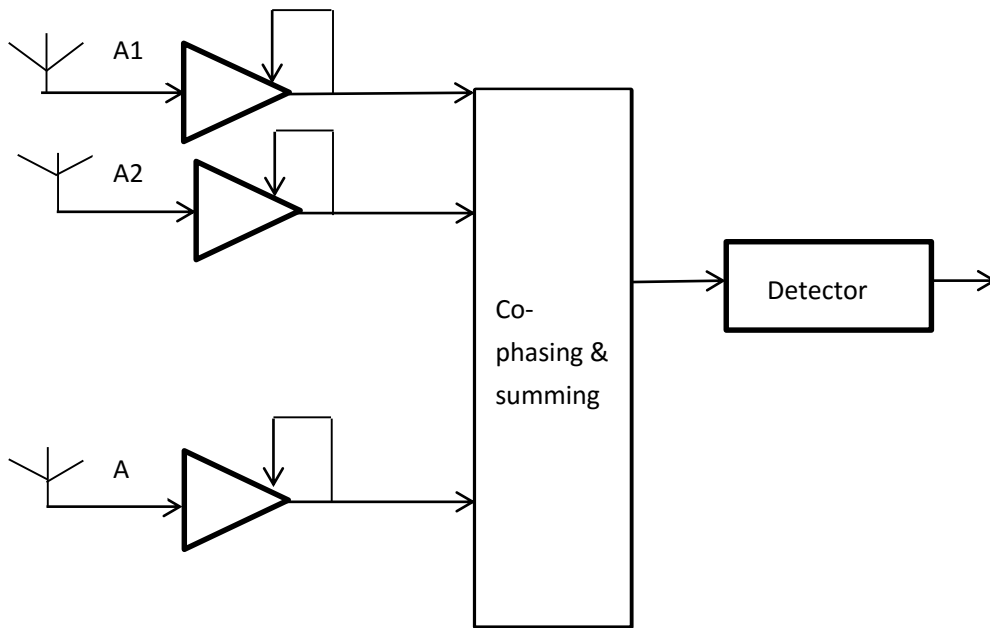


Figure 1.6 Maximal Ratio Diversity Combining [11]

1.3.2.4 Equal Gain Combining Technique

In equal gain combining (EGC) scheme, for generating the output signals on each diversity branch are co-phased and summed with identical weighting that is $A_i = e^{-\theta_i}$. Equal gain combining is simple in comparison to maximal ratio

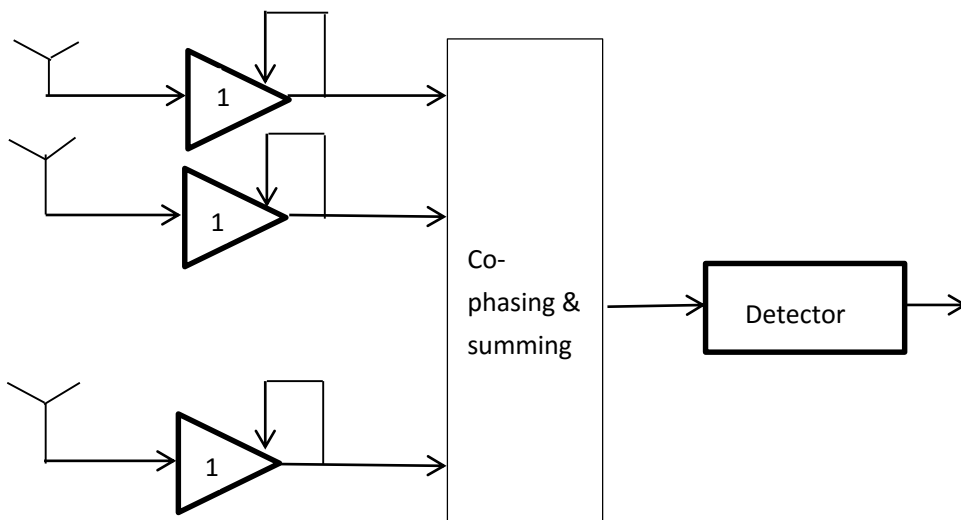


Figure 1.7 Equal gain combining technique [11]

combining, as the values of the SNR (varying with time) for each branch is not required for EGC which is difficult to compute. Performance of EGC and MRC is almost equal [12].

1.4 COOPERATIVE DIVERSITY

Recently cooperative wireless communications is used widely because of the fact that these methods can enhance system performance and can have higher system capacity, higher network resilience, smaller packet loss rate and much less power consumption. In this technology relay nodes cooperate with the direct nodes to send data to receiver node so this is known as cooperative diversity [13]. These networks give the combination of RF power requirements power saving with the spatial diversity. It is used for ad-hoc wireless communications systems and the high data-rate coverage required in future cellular. This technology has two main advantages first is the use of spatial diversity to mitigate fading and second is the low transmit [14].

1.4.1 Multiple Input Multiple Output System

MIMO systems have multiple antennas at the transmitter and receiver. There is single transmitter with multiple antennas and single receiver with multiple antennas, as there are multiple antennas MIMO system can be employed for diversity gain. MIMO system can increase data rate by transmitting several information streams in parallel, this is known as spatial multiplexing [15].

For explaining the system model let us consider a MIMO system with M_t transmit and M_r receive antennas. We can express this system at discrete time n by $M_r \times M_t$ complex channel matrix $H(n)$. It provides better quality of service (QoS), lower bit-error rate (BER) and lower transmitter power [15].

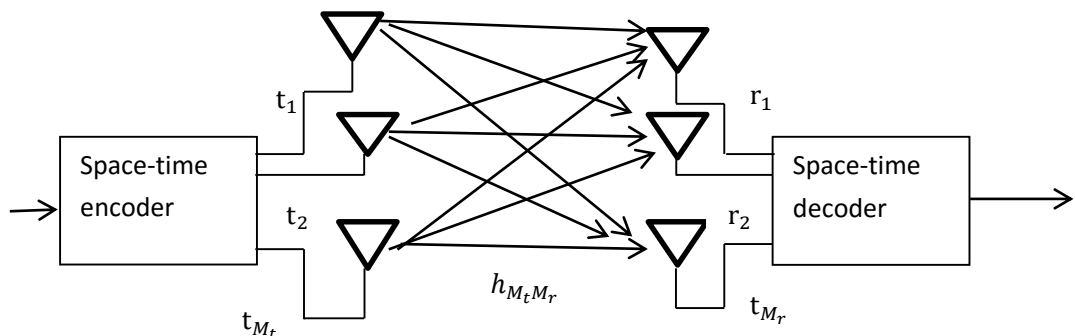


Figure 1.8 MIMO system model [15]

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_{M_r} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{M_t1} \\ h_{21} & h_{22} & h_{M_t2} \\ \vdots & \vdots & \vdots \\ h_{M_r1} & h_{M_r2} & h_{M_rM_t} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_t \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_r \end{bmatrix}$$

(1.9)

$$\bar{y} = H\bar{x} + \bar{n}$$

\bar{y} = M_r dimensional receive vector

$H = M_r \times M_t$ channel matrix

\bar{x} = M_t dimensional transmit vector

\bar{n} = M_r dimensional receive vector

Because of limitations in size, cost, hardware and inability in use of multiple antennas at source MIMO system may not be practical. Thus, cooperative communication systems can be used as a substitute to MIMO systems as these can give the same advantages as MIMO systems but in a virtual way [16].

1.4.2 Cooperative Diversity System Model

The communication system model shown in above figure shows that the source S first mobile subscriber is communicating data to the destination D, while at the same time the relay station second mobile subscriber R is also over hearing the transmission. The source sends the original message signal to the destination and the relay station

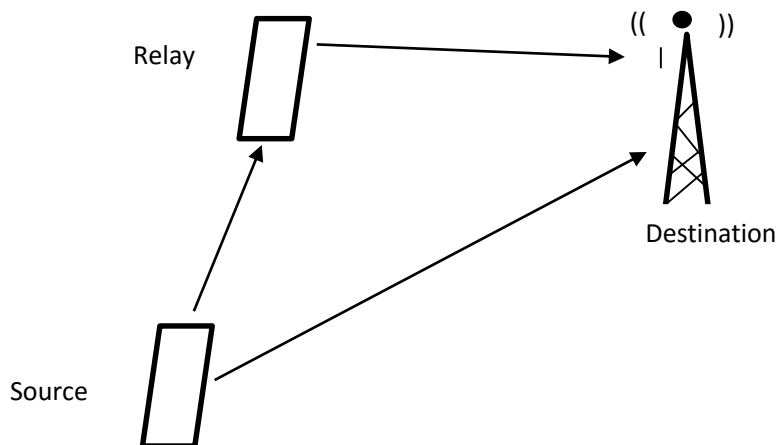


Figure 1.9 Cooperative Diversity Model [17]

also process signal based on a particular cooperative signalling protocol and forward the same message to the destination D, where both of the signals are then combined at the receiver. As both the versions of the signals one directly sent by source and other sent by relay are transmitted using independent paths, resulting in spatial diversity [17].

In cooperative communication systems, each user transmits its own information and act as a cooperative agent (as relay) for the other users. Three channel links are present in the model. The relay forwards the message transmitted by the source and acts as an inter-user channel. The channel links between the three users, relays and the destination are statistically independent fading channels. Because there are statistically independent fading channel paths, spatial diversity is obtained in a virtual manner [17].

1.5 COOPERATIVE RELAYING PROTOCOLS

Cooperative transmission relaying protocols tells us about how the received information is processed at the relay node that is second mobile subscriber (one behaving as cooperative agent), before forwarding it to the destination. There are two ways in which signals can be processed - Amplify and Forward (AF) and the Decode and Forward (DF).

1.5.1 Amplify and Forward

The signal received at the relay station from the source is a noisy form of source signal. Amplify and Forward technique amplifies the signal which is received by the relay station before transmitting it to the destination. The figure below shows the transmission of the signal from source to the destination using the AF relaying method [17].

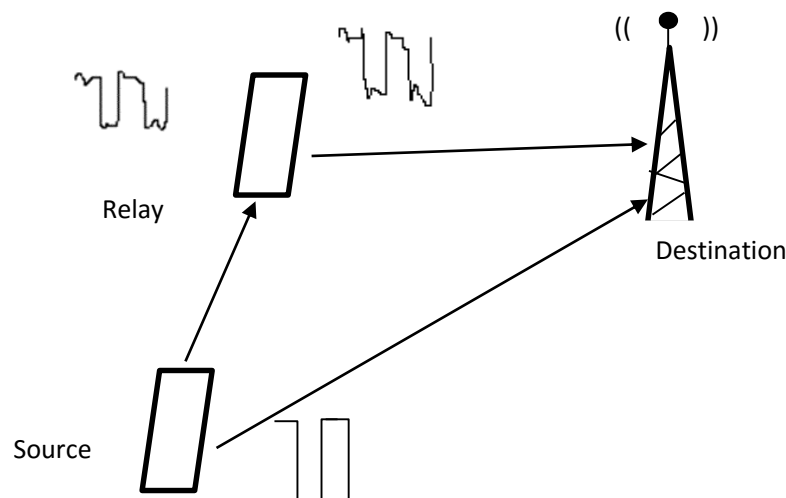


Figure 1.10 Amplify and forward Relaying Protocol [17]

The basic working of AF relaying is in two time periods, in first time period source transmits original signal to relay station and the destination. According to the system model which we have considered above, signal received by the relay station in first time period is given as

$$y_{sr} = \sqrt{E_s} h_{sr} x + n_{sr} \quad (1.10)$$

where h_{sr} is the channel gain coefficient between S - R link, E_s is the average energy / symbol, x is the transmitted signal from the source and n_{sr} represents the complex zero mean additive white Gaussian noise (AWGN) process at the relay R. In the same time periods, signal received by the destination is expressed as in [18]

$$y_{sd} = \sqrt{E_s} h_{sd} x + n_{sd} \quad (1.11)$$

where h_{sd} is the channel gain coefficient of S - D link and n_{sd} represents the complex zero mean additive white Gaussian noise (AWGN) process at the destination D. In second time period of cooperation, the received signal from the source is amplified by relay R in the first time period, and transmit it to the destination. The received signal at the destination is denoted as in [18]

$$y_{rd} = G \sqrt{E_s} h_{rd} x + n_{rd} \quad (1.12)$$

where $G = \frac{1}{\sqrt{E_{sr}|h_{rd}|^2 + N_o}}$ is the scaling factor at relay R and N_o denotes the noise variance. h_{rd} is the channel gain coefficient for R - D link and n_{rd} is the complex additive white Gaussian noise (AWGN) at destination. At the end of the second time-slot, the destination processes the copies of signal received directly as well as from the relays in the network [18].

1.5.2 Decode and Forward

The Decode and Forward (DF) method is the idea of a conventional relay. In this protocol, the relay station detects the source information, decodes it and then transmits it to the receiver. To aid the received bit errors to be corrected at the relay station, a

method such as error correcting code can be used at the relay station. The basic idea of decode and forward relaying is given in Figure 9.

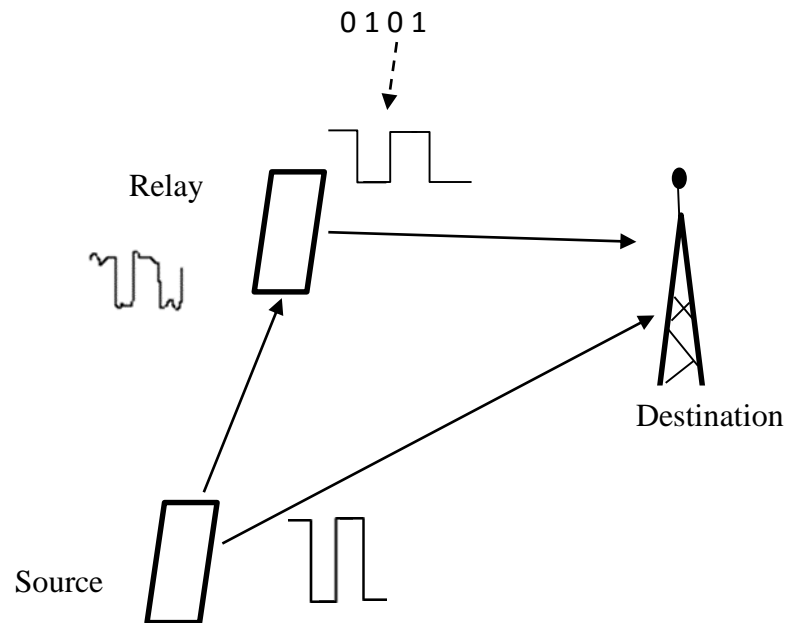


Figure 1.11 Decode and forward relaying protocol [17]

The basic working of DF relaying is in two time periods, in first time period source transmits original information signal to relay station and the destination. After this, relay successfully decode the message signal, re-encode the received message signal and the message is ready to be transmitted to the destination. At the end of the second time slot, the destination decodes the message [17].

1.6 ADVANTAGES AND DISADVANTAGES OF COOPERATIVE DIVERSITY

1.6.1 Advantages

- 1) Many wireless network applications like ad hoc, cellular and sensor networks prevent the use of multiple antennas due to limitations like cost and size of the terminals, cooperative diversity prevents the size limitations and gives spatial diversity by permitting the terminals to relay in parallel and thus making possible to share multiple antennas belonging to various terminals [19].
- 2) In cooperative diversity, cooperative relaying systems considers the original signal copy transmitted by the source node and utilizes useful side information that simple relaying systems discard as noise.

- 3) By using cooperative diversity either increased data rates can be achieved at the same transmit power P_T level are achieved or decreased transmit power P_T at the same data rate are achieved [20].
- 4) It increases battery life of the mobiles and cell coverage is also increased in a cellular system [20].

1.6.2 Disadvantages

- 1) Implementation of cooperative diversity increases complexity in the system as in this data has to be encrypted before transmission because of security purposes [20].

CHAPTER - 2

LITERATURE SURVEY

This chapter presents the review of research works that has been done by various researchers in the field of cooperative diversity. These works are basically on the analysis of the performance of different type of cooperative diversity systems over various fading channel with different type of modulation schemes. The review are as follows

- **D. Dixit and P. R. Sahu** in [21] investigated the performance of communication system having L-branch maximal ratio combining (MRC) over k - μ and η - μ fading channels. The author derived approximate expression of average symbol error rate (ASER) for quadrature amplitude modulation (QAM) scheme. The author has also given the method to evaluate the performance of coherent, differentially encoded quadri-phase shift-keying (DE-QPSK) and $\pi/4$ -QPSK modulation schemes.

$$P_{\alpha_{k-\mu}}(\alpha_1) = \frac{2\mu(1+k)\frac{\mu+1}{2}\alpha_1^2}{K\frac{\mu-1}{2}e^{\mu k}\Omega_1^{\frac{\mu+1}{2}}} e^{-\frac{\mu(K+1)}{\Omega_1}\alpha_1^2} \times I_{\mu-1}\left(2\mu\sqrt{\frac{K(K+1)}{\Omega_1}}\alpha_1\right) \quad (2.1)$$

ASER for rectangular QAM for k - μ fading channel can be expressed as

$$P_s(e) = P\left[\frac{1}{6}Y\left(\frac{a^2}{2}\right) + \frac{1}{2}Y\left(\frac{2a^2}{3}\right)\right] + q\left[\frac{1}{6}Y\left(\frac{b^2}{2}\right) + \frac{1}{2}Y\left(\frac{2b^2}{3}\right)\right] \\ - pq\left[\frac{1}{36}Y\left(\frac{a^2 + b^2}{2}\right) + \frac{1}{12}Y\left(\frac{3a^2 + 4b^2}{6}\right) + \frac{1}{12}Y\left(\frac{4a^2 + 3b^2}{6}\right) + \frac{1}{4}Y\left(\frac{2a^2 + 2b^2}{3}\right)\right] \quad (2.2)$$

In (2.2) highly accurate ASER formula for L-branch maximal ratio combining receiver for rectangular QAM scheme are presented for η - μ and K - μ channels [21].

- **D. Dixit and P. R. Sahu** in [22] analysed performance for independent and non-identically (i.n.i.) distributed Nakagami-m fading channels of communication model having L-branch selection combining (SC) receiver. With the help of cumulative distribution function based approach, the author derived exact closed form expression for average symbol error rate (ASER) for rectangular quadrature amplitude modulation

(RQAM) scheme. Mathematically, ASER for a digital modulation scheme can be computed as

$$P_{\text{ASER}}(e) = - \int_0^{\infty} P'_s(e|\gamma_t) F_{\gamma_t}(\gamma_t) d\gamma \quad (2.3)$$

$$P_{\text{ASER}}^{\text{RQAM}}(e|\gamma_t) = 2pQ(a_0\sqrt{\gamma_t}) + 2qQ(b_0\sqrt{\gamma_t}) - 4pqQ(a_0\sqrt{\gamma_t})Q(b_0\sqrt{\gamma_t}) \quad (2.4)$$

$$\text{where, } M = M_I * M_Q, p = 1 - \frac{1}{M_I}, q = 1 - \frac{1}{M_Q}, a_0 = \sqrt{\frac{6}{(M_I^2 - 1) + (M_Q^2 - 1)\beta^2}}$$

$$b_0 = \beta a_0$$

$$\begin{aligned} P_{\text{ASER}}^{\text{RQAM}}(e) = & R_{m,K} \left\{ \left[a_0 p (1 - q) \Gamma\left(\frac{\Delta_K(0.5)}{\sqrt{2\pi}}\right) \times [\overline{m}_K + \right. \right. \\ & 0.5 a_0^2]^{-\Delta_K(0.5)} F_A^{(K)}(\Delta_K(0.5); \{1\}_{1:K}; \{m_j + 1\}_{j=1}^K; \{\Delta_j(a_0, 0)\}_{j=1}^K) + \left. \left[b_0 (1 - \right. \right. \\ & p) q \Gamma\left(\frac{\Delta_K(0.5)}{\sqrt{2\pi}}\right) \times [\overline{m}_K + 0.5 b_0^2]^{-\Delta_K(0.5)} F_A^{(K)}(\Delta_K(0.5); \{1\}_{1:K}; \{m_j + \right. \\ & 1\}_{j=1}^K; \{\Delta_j(0, b_0)\}_{j=1}^K) + \left. \left[a_0 b_0 p q \Gamma\left(\frac{\Delta_K(1)}{\pi}\right) \times [\overline{m}_K + 0.5(a_0^2 + \right. \right. \\ & b_0^2)]^{-\Delta_K(1)} F_A^{(K+1)}(\Delta_K(1); \{1\}_{1:K}; 1.5, \{m_j + 1\}_{j=1}^K; \alpha_K(a_0, b_0), \{\Delta_j(0, b_0)\}_{j=1}^K) + \\ & \left. \left[a_0 b_0 p q \Gamma\left(\frac{\Delta_K(1)}{\pi}\right) \times [\overline{m}_K + 0.5(a_0^2 + \right. \right. \\ & b_0^2)]^{-\Delta_K(1)} F_A^{(K+1)}(\Delta_K(1); \{1\}_{1:K+1}; 1.5, \{m_j + 1\}_{j=1}^K; \alpha_K(a_0, b_0), \{\Delta_j(0, b_0)\}_{j=1}^K) \right. \end{aligned} \quad (2.5)$$

Further, for $\pi/4$ -QPSK and differentially encoded quadri-phase shift-keying (DE-QPSK) modulation schemes exact closed-form average SER expressions have been presented [22].

- **Andrew Sendonaris** *et al.* in [20] introduces the concept of cooperative diversity to remove the limitations of mobile user's data rate and (QOS) quality of service which they undergo due to extreme variations in signal attenuation. The author suggested a new form of spatial diversity called as cooperative diversity, in which cooperation of mobile users is used to achieve diversity gain. The author shows that cooperation not only increases capacity for two of the users but also provide more powerful system in

which data rates are less effected by variations in channel but at the same time it is also mentioned that inter channel noise will be noisy. The throughput for this system is given by

$$\eta = (1 - u)C_{\text{BSC}} \left(Q \left(\sqrt{\frac{\text{SNR}}{1-u}} \right) \right) \quad (2.6)$$

Binary phase shift keying modulation is used by transmitter and it decides not to transmit during fraction u of its L symbol period. $C_{\text{BSC}}(p)$ is the capacity of BSC with probability p , SNR will be nominal SNR and $Q(\cdot)$ is complementary cumulative distribution function. The author analysed by the results that cooperation results in considerable gains over a non-cooperative strategy [20].

- **Andrew Sendonaris** *et al.* in [23] discusses practical issues related to implementation of cooperative diversity. The author provides performance analysis for conventional and high rate CDMA system and investigated different receiver designs. The case for cooperation strategy is discussed when the channel state information (CSI) at the transmitters is relaxed. The overall throughput for user 1 is thus given by

$$\eta_1^\alpha = E_{\{K_{ij}^{lg}\}} \left[\eta_1^\alpha \left(\{K_{ij}^{lg}\} \right) \right] \quad (2.7)$$

The analogous expression holds for user 2 and is given by

$$\eta_2^\alpha = E_{\{K_{ij}^{lg}\}} \left[\eta_2^\alpha \left(\{K_{ij}^{lg}\} \right) \right] \quad (2.8)$$

The achievable rate region is given by the set of all $(\eta_1^\alpha, \eta_2^\alpha)$ pairs, where $\alpha = [0, 1]$. The whole study shows that in all scenarios cooperation is more advantageous than non-cooperation system as it provides increased throughput and cell coverage and it decreases sensitivity to channel variations [23].

- **J. Nicholas Laneman** *et al.* in [24] proposed a protocol to reduce fading present in wireless networks due to multipath propagation which is an energy-efficient cooperative diversity protocol. The considered techniques utilize space diversity accessible at distributed antennas through coordinated transmission. The author suggests that mainly these techniques have application in peer-to-peer and ad-hoc wireless networks with radios use single antenna. The author compares two protocols

amplify and forward (AF) and decode and forward (DF) with direct and transmit diversity bound and gives outage probability for large rate normalized SNR for all the protocols. Now for direct outage probability is given by

$$P_{\text{out}} = [\rho_{\text{norm}}]^{-1} \quad (2.9)$$

For amplify and forward (AF) and hybrid decode and forward protocol P_{out} is same and is given by

$$P_{\text{out}} = \left[\left(\frac{2^{2R}-1}{2^{4R}-1} \right) \rho_{\text{norm}} \right]^{-2} \quad (2.10)$$

For transmit diversity bound P_{out} is given as

$$P_{\text{out}} = \left[\left(\frac{1}{\sqrt{2}} \right) \rho_{\text{norm}} \right]^{-2} \quad (2.11)$$

ρ_{norm} is the large rate normalized SNR. The protocols save energy and therefore provide advantages like longer network lifetime, improves capacity of network and reduces battery drain [24].

- **J. Ping and S. H. Ting** in [25] investigated and compared two usual protocols given as one-way AF relaying and two-way amplify-and forward (AF) relaying for Rayleigh flat fading channel. Generally it is believed from both the relaying systems two-way amplify-and forward half-duplex relaying is always better than its one-way half-duplex relaying. The author found that this is not true when we consider total power constraint and the signal to noise ratio. The author also derived signal to noise ratio threshold, under which the performance of one-way AF relaying actually surpass two-way AF relaying. The author presents rate of one-way AF relaying and sum-rate of two-way AF relaying without a fair power constraint $P_2 = P = P_1$ is as follows

$$R_1^{\text{AF}} = \frac{1}{2} \log_2 \left(1 + \frac{h_1^2 \gamma_1 \gamma_2 P}{h_1^2 \gamma_2 \sigma^2 + \sigma^2} \right) \quad (2.12)$$

$$R_2^{\text{AF}} = \frac{1}{2} \log_2 \left(1 + \frac{h_2^2 \gamma_1 \gamma_2 P}{h_2^2 \gamma_2 \sigma^2 + \sigma^2} \right) \left(1 + \frac{h_2^2 \gamma_1 \gamma_2 P}{h_2^2 \gamma_1 \sigma^2 + \sigma^2} \right) \quad (2.13)$$

where h_1 and h_2 are the power normalization factors. The rate of one-way AF and two-way AF relaying with fair power constraint $3P_2 = 2P_1 = P_T$ is given as

$$R_1^{\text{AF}} = \frac{1}{2} \log_2 \left(1 + \frac{\check{h}_1^2 \gamma_1 \gamma_2 P_T / 2}{\check{h}_1^2 \gamma_2 \sigma^2 + \sigma^2} \right) \quad (2.14)$$

$$R_2^{\text{AF}} = \frac{1}{2} \log_2 \left(1 + \frac{\check{h}_2^2 \gamma_1 \gamma_2 P_T / 3}{\check{h}_2^2 \gamma_2 \sigma^2 + \sigma^2} \right) \left(1 + \frac{\check{h}_2^2 \gamma_1 \gamma_2 P_T / 3}{\check{h}_2^2 \gamma_1 \sigma^2 + \sigma^2} \right) \quad (2.15)$$

The author shows with the help of simulation results the two-way relaying might not preferred over one-way relaying for applications with limited power operating at low signal to noise ratio. The author concludes that if we consider the case with fair power constraint (the case when both relaying methods have equal total power) two-way AF relaying only surpass one way AF relaying when the signal to noise ratio is greater than a certain threshold [25].

- **Nagendra Kumar and Vimal Bhatia** in [26] given the performance of amplify-and-forward cooperative diversity communication network over Weibull fading channel with best-relay selection. The author calculated the expression for moment generating function (MGF) of the signal-to-noise ratio at the destination in terms of the Meijer's G-function.

$$\begin{aligned} M_{\gamma_t}(s) &= \left[\left(\frac{\beta_{sd}}{\bar{\gamma}_{sd}} \right)^{m_{sd}} (2\pi)^{\frac{1-m_{sd}}{2}} (m_{sd})^{m_{sd}+\frac{1}{2}} (s)^{-m_{sd}} \right] \\ &\times \left[2m_i \left(\frac{\beta_i}{\bar{\gamma}_i} \right)^{m_i} \sum_{v=1}^N \binom{N}{v} v(-1)^{v-1} (2\pi)^{\frac{1-m_i}{2}} (m_i)^{m_i+\frac{1}{2}} (s)^{-m_i} \right] \\ &\times G_{1,m_{sd}}^{m_{sd},1} \left(\frac{s^{m_{sd}}}{(m_{sd})^{m_{sd}} \left(\frac{\beta_{sd}}{\bar{\gamma}_{sd}} \right)^{m_{sd}}} \middle| 1, 1 + \frac{1}{m_{sd}}, \dots, 1 + \frac{(m_{sd}-1)}{m_{sd}} \right) \\ &\times G_{1,m_i}^{m_i,1} \left(\frac{s^{m_i}}{(m_i)^{m_i} \left(\frac{\beta_{sd}}{\bar{\gamma}_{sd}} \right)^{m_i}} \middle| 1, 1 + \frac{1}{m_i}, \dots, 1 + \frac{(m_i-1)}{m_i} \right) \end{aligned} \quad (2.16)$$

With this calculated MGF, the author evaluated the expression of outage probability and average symbol error rate (ASER) for multiple relays over independent and identical distributed Weibull fading channels and the obtained expression is given in [26]

$$P_s(e) = \frac{4}{\pi} \left(1 - \frac{1}{\sqrt{M}}\right) \int_0^{\pi/2} M_{\gamma_t} \left(\frac{g_{\text{QAM}}}{\sin^2 \theta}\right) d\theta - \frac{4}{\pi} \left(1 - \frac{1}{\sqrt{M}}\right)^2 \int_0^{\pi/4} M_{\gamma_t} \left(\frac{g_{\text{QAM}}}{\sin^2 \theta}\right) d\theta \quad (2.17)$$

➤ **D. Dixit and P. R. Sahu** in [27] investigated an expression for (ASER) average symbol error rate for rectangular (QAM) quadrature amplitude modulation with best-relay selection for Amplify and Forward (AF) cooperative systems for Rayleigh channel. The ASER for the RQAM scheme can be calculated by

$$P_s(e) = \int_0^\infty P_s(e|\bar{\gamma}_o) f_{\bar{\gamma}}(\bar{\gamma}_o) d\bar{\gamma}_o \quad (2.18)$$

where $f_{\bar{\gamma}}(\bar{\gamma}_o)$ is probability density function of $\bar{\gamma}_o$ and $P_s(e|\bar{\gamma}_o)$ is the conditional SER for the rectangular QAM modulation and is represented by

$$P_s(e|\bar{\gamma}_o) = 2pQ(a\sqrt{\bar{\gamma}_o}) + 2qQ(b\sqrt{\bar{\gamma}_o}) - 4pqQ(a\sqrt{\bar{\gamma}_o}) Q(b\sqrt{\bar{\gamma}_o}) \quad (2.19)$$

where, $M = M_I * M_Q$, $p = 1 - \frac{1}{M_I}$, $q = 1 - \frac{1}{M_Q}$, $a = \sqrt{\frac{6}{(M_I^2 - 1) + (M_Q^2 - 1)\beta^2}}$,
 $b = \beta a$

the ASER expression is given by

$$P_s(e) = \sum_{v=1}^N \binom{N}{v} \frac{(-1)^{v-1}}{(1-2v)} \left[2p \left\{ J_1 \left(\frac{a^2 \bar{\gamma}_o}{4v} \right) - 2v J_1 \left(\frac{a^2 \bar{\gamma}_o}{2} \right) \right\} \right. \\
+ 2q \left\{ J_1 \left(\frac{b^2 \bar{\gamma}_o}{4v} \right) - 2v J_1 \left(\frac{b^2 \bar{\gamma}_o}{2} \right) \right\} \\
- 2pq \left\{ J_2 \left(a, b, \frac{a^2 \bar{\gamma}_o}{4v} \right) + J_3 \left(a, b, \frac{b^2 \bar{\gamma}_o}{4v} \right) - 2v J_2 \left(a, b, \frac{a^2 \bar{\gamma}_o}{4v} \right) \right. \\
\left. \left. - 2v J_3 \left(a, b, \frac{b^2 \bar{\gamma}_o}{4v} \right) \right\} \right] \quad (2.20)$$

The obtained result is suitable for small number of relays, this is shown by comparison of numeral values of the evaluated lower bound. The author plotted ASER results and studied the effect of different parameters on the ASER [27].

- **Minhwan Choi** *et al.* in [28] investigated closed-form formulas for average symbol error rate (ASER) over independent and identically distributed (i.i.d.) Rayleigh channels for M-ary phase shift keying (M-PSK) and M-ary quadrature amplitude modulation (M-QAM) modulation scheme for amplify-and-forward (AF) cooperative system with a relay selection. The author also explains about probability density function (PDF), cumulative density function (CDF), and moment generating function (MGF) for the end-to-end signal-to-noise ratio (SNR). The average SER can be calculated by using

$$P_s(e) = \int_0^{\infty} P_s(e|\bar{\gamma}_0) f_{\gamma_{\text{up}}}(\bar{\gamma}_0) d\bar{\gamma}_0 \quad (2.21)$$

ASER for MPSK is given by the author as

$$P_S^{\text{PSK}} = \frac{N! \Gamma\left(1 + \frac{\bar{\gamma}_0 g_{\text{PSK}}}{2}\right)}{4\pi(1 + \bar{\gamma}_0 g_{\text{PSK}}) \Gamma\left(1 + N + \frac{\bar{\gamma}_0 g_{\text{PSK}}}{2}\right)} \times \left[\pi + \sin\left(\frac{2\pi}{M}\right) + 2\sin^{-1}\left(\cos\left(\frac{\pi}{M}\right)\right) \right] \quad (2.22)$$

ASER for MQAM is given by the author as

$$P_S^{\text{QAM}} = \frac{N! (\sqrt{M} - 1)(2\sqrt{M} + \pi - 2) \Gamma\left(1 + \frac{0.75\bar{\gamma}_0}{M-1}\right)}{\pi M \left(1 + \frac{1.5\bar{\gamma}_0}{M-1}\right) \Gamma\left(1 + N + \frac{0.75\bar{\gamma}_0}{M-1}\right)} \quad (2.23)$$

By going through numerical results obtained we noticed the improvement of diversity gain with different number of relays. We can see that analytical results evaluated by the author are similar to the Monte-Carlo results for wide range of SNR, so author efficiently evaluated the various advantages of relay selection in the cooperative systems [28].

- **Jing Yang and Pingzhi Fan** *et al.* in [29] presented the performance analysis for independently but not necessarily identically distributed (i.n.i.d.) Nakagami- m fading channels for two-way amplify-and-forward (AF) relaying networks with integer and integer plus one-half values of fading parameter m . The author calculated closed-form expressions for probability density function (PDF), cumulative distribution function (CDF), and moment generating function (MGF) for the signal to-noise ratio (SNR).

$$F_{\gamma_{T_i}} = 1 - \frac{2m_i^{m_i} e^{-b_i \gamma} (m_j - 1)!}{\bar{\gamma}_i^{m_i} \Gamma(m_i) \Gamma(m_j)} \sum_{v=0}^{m_i-1} \sum_{r=0}^{m_j-1} \sum_{k=0}^r \frac{1}{r!} \binom{r}{k} \binom{m_i-1}{v} \left(\frac{m_i}{\bar{\gamma}_i}\right)^{-\frac{\sigma_i+1}{2}} \left(\frac{2m_j}{\bar{\gamma}_j}\right)^{r+\frac{\sigma_i+1}{2}} \gamma^{\delta_i} K_{\sigma_i+1}(a\gamma). \quad (2.24)$$

$$\text{where } \delta_i = m_i + r, \sigma_i = v + k, b_i = \frac{m_i}{\bar{\gamma}_i} + \frac{2m_j}{\bar{\gamma}_j},$$

$$a = 2 \sqrt{2m_i m_j / \bar{\gamma}_i \bar{\gamma}_j}$$

Using these expressions, the author presented performance analysis of two-way amplify and forward relaying system by evaluating the average symbol error rate (SER), outage probability, and average sum-rate. For that MGF is calculated and is given by

$$\varphi_{\gamma_{T_i}}(s) = -\frac{2m_i^{m_i} (m_j - 1)!}{\bar{\gamma}_i^{m_i} \Gamma(m_i) \Gamma(m_j)} \sum_{v=0}^{m_i-1} \sum_{r=0}^{m_j-1} \sum_{k=0}^r \frac{1}{r!} \binom{r}{k} \binom{m_i-1}{v} \left(\frac{m_i}{\bar{\gamma}_i}\right)^{-\frac{\sigma_i+1}{2}} \left(\frac{2m_j}{\bar{\gamma}_j}\right)^{r+\frac{\sigma_i+1}{2}} [b_i s_1 + (\delta_i - (\sigma_i + 1)) s_2 + a s_3] \quad (2.25)$$

With help of this MGF average SER is calculated and is given by

$$P_s^{T_i} = \frac{1}{\pi} \int_0^{(\pi - \frac{\pi}{M})} \varphi_{\gamma_{T_i}}\left(\frac{g}{\sin^2 \theta}\right) d\theta \quad (2.26)$$

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

Simulations are done to verify theoretical analysis. Basically the results are evaluated for QPSK modulation [29].

- **Nagendra Kumar and Vimal Bhatia** in [8] presented performance analysis of a two-way amplify-and-forward relaying network for general order rectangular quadrature amplitude modulation (RQAM) scheme by deriving exact closed-form expression of average symbol error rate (ASER) over independent and non-identically

distributed(i.n.i) Nakagami-m fading channels with integer values of fading parameter (m) by using cumulative distribution function-based approach.

$$P_{\text{ASER}}(e) = - \int_0^{\infty} P'_s(e|\Delta) F_{\Delta}(\Delta) d\Delta \quad (2.27)$$

$$P_{\text{ASER}}^{\text{RQAM}}(e|\Delta) = 2pQ(a_o\sqrt{\Delta}) + 2qQ(b_o\sqrt{\Delta}) - 4pqQ(a_o\sqrt{\Delta}) Q(b_o\sqrt{\Delta}) \quad (2.28)$$

$$\text{where } M = M_I * M_Q, p = 1 - \frac{1}{M_I}, q = 1 - \frac{1}{M_Q}, a_o = \sqrt{\frac{6}{(M_I^2 - 1) + (M_Q^2 - 1)\beta^2}}$$

$$b_o = \beta a_o$$

CDF for two way nakagami-m fading channel will be given by

$$F_{\Delta T_i} = 1 - \frac{2m_i^{m_i} e^{-b_i\Delta} (m_j - 1)!}{\bar{\gamma}_i^{m_i} \Gamma(m_i) \Gamma(m_j)} \sum_{v=0}^{m_i-1} \sum_{r=0}^{m_j-1} \sum_{k=0}^r \frac{1}{r!} \binom{r}{k} \binom{m_i - 1}{v} \left(\frac{m_i}{\bar{\gamma}_i}\right)^{-\frac{\sigma_i+1}{2}} \left(\frac{2m_j}{\bar{\Delta}_j}\right)^{r+\frac{\sigma_i+1}{2}} \Delta^{\delta_i} K_{\sigma_i+1}(a\Delta). \quad (2.29)$$

now putting all the above values the expression of ASER for RQAM is evaluated

$$\begin{aligned} P_{\text{ASER}}^{\text{RQAM}}(e) &= p + q - 2pq \\ &+ \frac{2a_o b_o pq}{\pi(a_o^2 + b_o^2)} \left[F_1 \left(1, 1; 1.5; \frac{a_o^2}{(a_o^2 + b_o^2)} \right) + F_1 \left(1, 1; 1.5; \frac{b_o^2}{(a_o^2 + b_o^2)} \right) \right] \\ &- N_o \left\{ \frac{a_o p(1-q)}{\sqrt{2\pi}} \theta(0, b_o, 0) + \frac{b_o q(1-p)}{\sqrt{2\pi}} \theta(b_o, 0, 0) \right. \\ &+ \frac{a_o b_o pq}{\pi} \left[\sum_{z=0}^{\infty} \nabla \left(z, \frac{a_o^2}{2} \right) \theta \left(a_o, b_o, z + \frac{1}{2} \right) \right. \\ &\left. \left. + \sum_{v=0}^{\infty} \nabla \left(v, \frac{a_o^2}{2} \right) \theta \left(a_o, b_o, v + \frac{1}{2} \right) \right] \right\} \quad (2.30) \end{aligned}$$

$$N_o = \frac{2m_i^{m_i} e^{-b_i\Delta} (m_j - 1)!}{\bar{\gamma}_i^{m_i} \Gamma(m_i) \Gamma(m_j)} \sum_{v=0}^{m_i-1} \sum_{r=0}^{m_j-1} \sum_{k=0}^r \frac{1}{r!} \binom{r}{k} \binom{m_i - 1}{v} \left(\frac{m_i}{\bar{\gamma}_i}\right)^{-\frac{\sigma_i+1}{2}}$$

$$\left(\frac{2m_j}{\bar{\gamma}_j}\right)^{r+\frac{\sigma_j+1}{2}} \quad (2.31)$$

Further, the author calculated exact closed-form expressions of ASER for differentially encoded quadri-phase shift-keying (DE-QPSK), $\pi/4$ -QPSK modulation and 32-cross QAM modulation schemes. For high signal-to-noise ratio asymptotic expression of ASER for RQAM scheme is also given. Monte Carlo simulations are done to check the correctness of derived expression and to compare the numerical results [8].

RESEARCH GAPS

- 1) Performance analysis of two-way amplify and forward relaying network is given with CDF approach for rectangular quadrature amplitude modulation (RQAM) scheme over Nakagami-m channel but it is not given for M-ary phase shift keying (MPSK) modulation scheme.
- 2) From the literature survey we can see that the performance of two-way amplify and forward relaying network is given by calculating ASER with MGF approach for M-ary phase shift keying (MPSK) modulation scheme but it is not calculated for rectangular quadrature amplitude modulation (RQAM) scheme.

CHAPTER-3

MATHEMATICAL ANALYSIS

3.1 PERFORMANCE ANALYSIS OF WIRELESS COMMUNICATION SYSTEMS

As discussed in the section below for the performance analysis purpose of wireless system we derive expressions for the PDF (probability density function) of γ_t (output signal to noise ratio). The ASER can be obtained by averaging the probability density function (PDF) of the output signal to noise ratio and the conditional symbol error rate (SER) for additive white Gaussian (AWGN) channel. Average SER is calculated for various fading channels and modulation schemes.

Average Signal-to-Noise Ratio

The word average represents here statistical averaging over the probability distribution function of the fading. Mathematically it can be represented as, if γ_t denotes a random variable called as instantaneous SNR at the receiver output, which includes

$$\bar{\gamma}_t = \int_0^{\infty} \gamma_t p_{\gamma_t}(\gamma_t) d\gamma_t \quad (3.1)$$

Equation (3.1) is the average signal to noise ratio, where $p_{\gamma_t}(\gamma_t)$ denotes the probability density function (PDF) of γ_t , the moment generating function (MGF) associated with γ_t , namely is given in [30]

$$M_{\gamma}(s) = \int_0^{\infty} P_{\gamma_t}(\gamma_t) e^{s\gamma_t} d\gamma_t \quad (3.2)$$

Outage probability

This probability represents the probability that the output SNR, γ falls under a certain specified threshold γ_{th} . Mathematically it is represented as,

$$P_{out} = \int_0^{\gamma_{th}} p_{\gamma_t}(\gamma_t) d\gamma_t \quad (3.3)$$

Where $P_{\gamma_t}(\gamma_t)$ is the cumulative distribution function (CDF) of γ_t , evaluated at $\gamma_t = \gamma_{th}$. As the PDF and the CDF have following relation, given by $p_{\gamma_t}(\gamma_t) = dP_{\gamma_t}(\gamma_t)/d\gamma_t$ [30].

Average Bit Error Probability

The general formula for calculating average BEP can be given as

$$P_b(E) = \int_0^{\infty} P_b(E|\gamma_t) P_{\gamma_t}(\gamma_t) d\gamma_t \quad (3.4)$$

Consider that the conditional BEP can be expressed as

$$P_b(E) = C_1 \exp(-a_1 \gamma_t) \quad (3.5)$$

Now taking into account the case for differentially coherent detection of phase-shift keying (PSK)

$$P_b(E) = \int_0^{\infty} C_1 \exp(-a_1 \gamma_t) P_{\gamma_t}(\gamma_t) d\gamma_t \quad (3.6)$$

$$P_b(E) = C_1 M_{\gamma_t}(-a_1) \quad (3.7)$$

Where again $M_{\gamma_t}(s)$ is the MGF which depends only upon the model of the fading channel considered [30].

3.2 SYSTEM MODEL OF AVERAGE SYMBOL ERROR RATE OF ONE WAY RELAYING

In the above figure we consider a cooperative diversity system for flat Rayleigh fading channels, in which there is a source S, destination D and N relays. The propagation among source and destination consist of two paths, one direct path from source to destination, given as $S \rightarrow D$ link and N indirect paths that is, N indirect amplify and forward two hop relay channels, given as $S \rightarrow R_n \rightarrow D$ links (where $1 \leq n \leq N$). We assume that the CSI (channel state information) is known at the receiver terminal. One antenna as transmitter and one antenna as receiver are present at S and D respectively. In the above figure we consider a cooperative diversity system for flat Rayleigh fading channels, in which there is a source S, destination D and N relays. The propagation among source and destination consist of two paths, one direct path from source to destination, given as $S \rightarrow D$ link and N indirect paths that is, N indirect amplify and forward two hop relay channels,

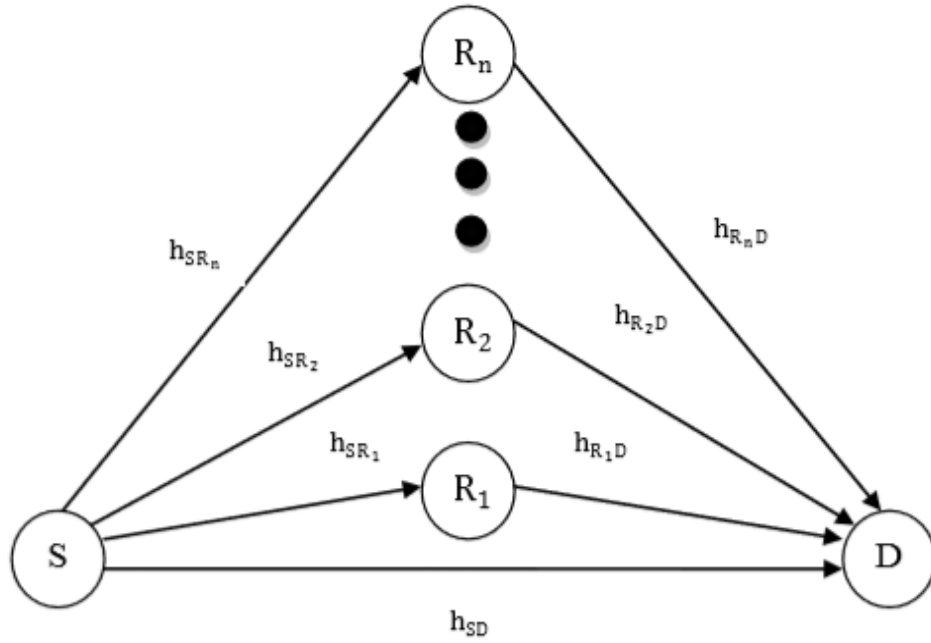


Figure 3.1 System model for one-way model of cooperative diversity [31]

given as $S \rightarrow R_n \rightarrow D$ links (where $1 \leq n \leq N$). We assume that the CSI (channel state information) is known at the receiver terminal. One antenna as transmitter and one antenna as receiver are present at S and D respectively. Relays contain one receive and one transmit antenna each. For relay selection best relay algorithm is used in which it selects the best relay such that $b = \arg \max_{n \in R} \{\gamma_n\}$, where (where $1 \leq R \leq N$) and $\gamma_n = \min(\gamma_{SR_n}, \gamma_{R_nD})$ is upper bound instantaneous SNR of $S \rightarrow R_n \rightarrow D$ link for relay R_n . Total SNR γ_t at the destination with best relay can be expressed as

$$\gamma_t \leq \gamma_{SD} + \max_{n \in R} \{\min(\gamma_{SR_n}, \gamma_{R_nD})\} \quad (3.8)$$

Where, instantaneous SNR for the link $S \rightarrow R_n$ is given by

$$\gamma_{SR_n} = |h_{SR_n}|^2 E_o / N_o \quad (3.9)$$

h_{SR_n} , is the channel gain for $S \rightarrow R_n$ link. (Rayleigh distributed)

Instantaneous SNR for the link $R_n \rightarrow D$ is given by

$$\gamma_{R_nD} = |h_{R_nD}|^2 E_o / N_o \quad (3.10)$$

h_{R_nD} , is the channel gain for $R_n \rightarrow D$ link.

Instantaneous SNR for the link $S \rightarrow D$ is given by

$$\gamma_{SD} = |h_{SD}|^2 E_o / N_o \quad (3.11)$$

h_{SD} , is the channel gain for $S \rightarrow D$ link. Where, E_o is average energy/symbol and N_o is the variance of AWG noise [18].

3.2.1 Derivation of Average Symbol Error Rate

Generally the ASER for RQAM modulation scheme can be calculated by

$$P_s(e) = \int_0^\infty P_a(e|\gamma_t) f_\gamma(\gamma_t) d\gamma_t \quad (3.12)$$

where $f_\gamma(\gamma_t)$ is probability density function of γ_t which is represented by (3.8) and $P_s(e|\gamma_t)$ is the conditional SER for the rectangular QAM modulation with $M=M_I \times M_Q$ and is represented by

$$P_a(e|\gamma_t) = 2pQ(a_o\sqrt{\gamma_t}) + 2qQ(b_o\sqrt{\gamma_t}) - 4pqQ(a_o\sqrt{\gamma_t}) Q(b_o\sqrt{\gamma_t}) \quad (3.13)$$

Where gaussian Q function $Q(x)$ is represented as

$$Q(x) = \left(\frac{1}{2\pi}\right) \int_x^\infty e^{-t^2/2} dt \quad (3.14)$$

p and q are modulation parameter given as

$$p = 1 - \frac{1}{M_I} \text{ and } q = 1 - \frac{1}{M_Q} \quad (3.15)$$

respectively, a is also modulation parameter given by

$$a_o = \sqrt{\frac{6}{(M_I^2 - 1) + (M_Q^2 - 1)\beta^2}} \quad (3.16)$$

$b_o = \beta a_o$ and $\beta = dQ/dI$, where dQ is decisions distance for the quadrature -phase and dI is decisions distance for the in-phase component. Also, the average in-phase component

signal energy is $(M_I^2 - 1)/(M_Q^2 - 1)$ times the average energy for the quadrature-phase component signal.

Substitute the expression (4.87) in the (4.86), and rearranging, we get

$$P_s(e) = 2p \int_0^\infty Q(a_o\sqrt{\gamma_t})f_\gamma(\gamma_t)d\gamma_t + 2q \int_0^\infty Q(b_o\sqrt{\gamma_t})f_\gamma(\gamma_t)d\gamma_t - 4pq \int_0^\infty Q(a_o\sqrt{\gamma_t})Q(b_o\sqrt{\gamma_t})f_\gamma(\gamma_t)d\gamma_t \quad (3.17)$$

The product of the two Gaussian Q functions is given as

$$Q(p) Q(q) = \frac{1}{2\pi} \int_0^{\pi/2 - \arctan(q/p)} \exp\left(-\frac{p^2}{2\sin^2\theta}\right) d\theta + \frac{1}{2\pi} \int_0^{\pi/2 - \arctan(q/p)} \exp\left(-\frac{p^2}{2\sin^2\theta}\right) d\theta \quad (3.18)$$

Using the expression in (4.93) and (4.94) in (4.92), $P_s(e)$ is expressed as

$$P_s(e) = 2pI_1 + 2qI_2 - 4pqI_3 \quad (3.19)$$

where,

$$I_1 = \frac{1}{\pi} \int_0^{\pi/2} M_{\gamma_t} \left(\frac{a_o^2}{2\sin^2\theta} \right) d\theta \quad (3.20)$$

$$I_2 = \frac{1}{\pi} \int_0^{\pi/2} M_{\gamma_t} \left(\frac{b_o^2}{2\sin^2\theta} \right) d\theta \quad (3.21)$$

$$I_3 = \frac{1}{2\pi} \int_0^{\pi/2 - \arctan(b_o/a_o)} M_{\gamma_t} \left(\frac{a_o^2}{2\sin^2\theta} \right) d\theta + \frac{1}{2\pi} \int_0^{\arctan(b_o/a_o)} M_{\gamma_t} \left(\frac{b_o^2}{2\sin^2\theta} \right) d\theta \quad (3.22)$$

where, M_{γ_t} is moment generating function (MGF) of the SNR γ_t [27]

For the independent and the identical (i.i.d) relay channel links, M_{γ_t} MGF is represented by

$$M_{\gamma_t} = \sum_{v=1}^N \binom{N}{v} \frac{v(-1)^{v-1}}{(v + \bar{\gamma}_{CS})(1 + \bar{\gamma}_{SDS})} \quad (3.23)$$

where, $\bar{\gamma}_{SD} = \bar{\gamma}_o = \frac{E_o}{N_o}$ and $\bar{\gamma}_C = \frac{\bar{\gamma}_{SR_n}\bar{\gamma}_{R_nD}}{\bar{\gamma}_{SR_n} + \bar{\gamma}_{R_nD}}$

To calculate the exact value of the expression given in (3.19), the integrals I_1 , I_2 and I_3 are calculated as given in appendix in [27].

Substitute the solutions of I_1 , I_2 and I_3 in (4.95), the expression for the average ASER is given by [24], the ASER expression is given by

$$P_s(e) = \sum_{v=1}^N \binom{N}{v} \frac{(-1)^{v-1}}{(1-2v)} \left[2p \left\{ J_1 \left(\frac{a^2 \bar{\gamma}_o}{4v} \right) - 2v J_1 \left(\frac{a^2 \bar{\gamma}_o}{2} \right) \right\} + 2q \left\{ J_1 \left(\frac{b^2 \bar{\gamma}_o}{4v} \right) - 2v J_1 \left(\frac{b^2 \bar{\gamma}_o}{2} \right) \right\} - 2pq \left\{ J_2 \left(a, b, \frac{a^2 \bar{\gamma}_o}{4v} \right) + J_3 \left(a, b, \frac{b^2 \bar{\gamma}_o}{4v} \right) - 2v J_2 \left(a, b, \frac{a^2 \bar{\gamma}_o}{4v} \right) - 2v J_3 \left(a, b, \frac{b^2 \bar{\gamma}_o}{4v} \right) \right\} \right] \quad (3.24)$$

where, $J_1(\cdot)$, $J_2(\cdot, \cdot, \cdot)$ and $J_3(\cdot, \cdot, \cdot)$ are given in the [27].

3.3 SYSTEM MODEL OF AVERAGE SYMBOL ERROR RATE OF TWO WAY RELAYING

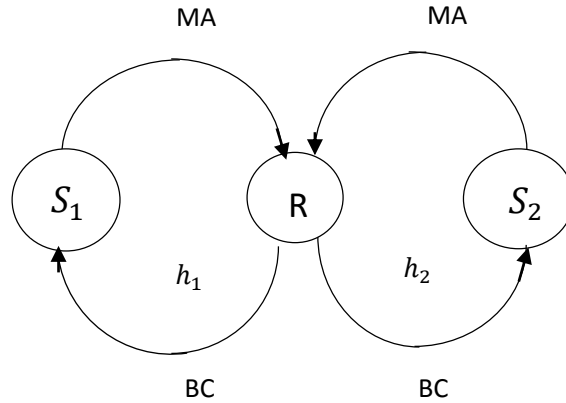


Figure 3.2 System model for two-way model of cooperative diversity [29]

In the figure shown above system model for two way relaying system model is given, which is working over i.n.i.d. Nakagami- m fading channels. T_1 and T_2 two source nodes want to interchange information with each other with the help of AF relay node R. Transmission will take place in two phases: multiple access and broadcast phase. In multiple access phase, T_1 and T_2 transmit their message signals simultaneously to R. In the broadcast phase, received message signal is normalized by R depending on its transmit power constraint and then this normalized signal is broadcasted to T_1 and T_2 . For simplicity, we consider equal transmit power P_s at T_1 , T_2 and R and equal variance N_o for the AWG noise on all the three nodes. To

avoid self-interference assume that T1 and T2 have knowledge of the channel coefficients. Here h_1 and h_2 are respective channel coefficients which are mutually independent for $T_1 \rightarrow R$ and $T_2 \rightarrow R$ links; these are modelled as random variables having nakagami-m distribution. Consider that channels have identical channel gains for $T_i \rightarrow R$ and $R \rightarrow T_i$ (where $i = 1, 2$) links [29]. Now instantaneous SNR of node T_i in the broadcast phase (BC), γ_{T_i} is given by

$$\gamma_{T_i} = \frac{\gamma_i \gamma_j}{2\gamma_i + \gamma_j} \quad (3.25)$$

Where $\gamma_i = P_s |h_i|^2 / N_o$ and $\gamma_j = P_s |h_j|^2 / N_o$ are the respective instantaneous SNRs for

$T_i \rightarrow R$ and $R \rightarrow T_i$ links, such that $i, j=1, 2$ and $i \neq j$. Here $\gamma_0 = P_s / N_o$ is average transmit SNR and $\Omega_i = E\{h_i^2\}, \Omega_j = E\{h_j^2\}$ are variances of h_i and h_j respectively ($E\{\cdot\}$ = statistical average operator). Now as h_i is modelled as nakagami-m random variable, so γ_i instantaneous SNR is a random variable (gamma distributed) with probability distribution function given by

$$f_{\gamma_i}(\gamma) = \frac{m_i^{m_i}}{\bar{\gamma}_i \Gamma(m_i)} \gamma^{m_i-1} e^{-\frac{m_i \gamma}{\bar{\gamma}_i}} \quad (3.26)$$

$\Gamma(\cdot)$ is the gamma function, m_i is nakagami fading parameter and $\bar{\gamma}_i = \Omega_i \gamma_0$ is average signal to noise ratio of the $T_i \rightarrow R$ link and its CDF can be expressed as

$$F_{\gamma_i}(\gamma) = 1 - \frac{\Gamma(m_i, (\frac{m_i}{\bar{\gamma}_i})\gamma)}{\Gamma(m_i)} \quad (3.27)$$

$\Gamma(\cdot, \cdot)$ is the incomplete gamma function [29].

3.3.1 Performance of Two-Way Amplify and Forward Relaying Network

3.3.1.1 MGF Approach

When m (fading parameter) is integer, CDF of γ_{T_i} is expressed as

$$F_{\gamma_{T_i}}(\gamma) = 1 - \frac{2m_i^{m_i} e^{-b_i \gamma} (m_j - 1)!}{\bar{\gamma}_i^{m_i} \Gamma(m_i) \Gamma(m_j)} \sum_{v=0}^{m_i-1} \sum_{r=0}^{m_j-1} \sum_{k=0}^r \frac{1}{r!} \binom{r}{k} \binom{m_i-1}{v} \left(\frac{m_i}{\bar{\gamma}_i}\right)^{-\frac{\sigma_i+1}{2}} \left(\frac{2m_j}{\bar{\gamma}_j}\right)^{r+\frac{\sigma_i+1}{2}} \gamma^{\delta_i} K_{\sigma_i+1}(a_i \gamma). \quad (3.28)$$

where

$$\delta_i = m_i + r, \sigma_i = v + k \quad (3.29)$$

and

$$b_i = \frac{m_i}{\bar{\gamma}_i} + \frac{2m_j}{\bar{\gamma}_j}, \quad (3.30)$$

$$a_i = 2\sqrt{2m_i m_j / \bar{\gamma}_i \bar{\gamma}_j} \quad (3.31)$$

and $K_\nu(\cdot)$ is the fifth order modified Bessel function of second kind. For the performance analysis of the two-way AF relaying network the average SER is calculated and analysed. In MGF approach to calculate ASER, first PDF $f_{\gamma_{T_i}}(\gamma)$ and MGF $M_{\gamma_{T_i}}(s)$ will be calculated. We know that $M_{\gamma_{T_i}}(s) = E_{\gamma_{T_i}}\{\exp(-s\gamma)\}$. Now, to calculate $f_{\gamma_{T_i}}(\gamma)$ the first derivative of (3.28) with respect to γ will be taken, which is as given in [29]

$$f_{\gamma_{T_i}}(\gamma) = -\frac{2m_i^{m_i}(m_j-1)!}{\bar{\gamma}_i^{m_i}\Gamma(m_i)\Gamma(m_j)} \sum_{v=0}^{m_i-1} \sum_{r=0}^{m_j-1} \sum_{k=0}^r \frac{1}{r!} \binom{r}{k} \binom{m_i-1}{v} \left(\frac{m_i}{\bar{\gamma}_i}\right)^{-\frac{\sigma_i+1}{2}} \left(\frac{2m_j}{\bar{\gamma}_j}\right)^{r+\frac{\sigma_i+1}{2}} [N_1'(\gamma)N_2(\gamma) + N_1(\gamma)N_2'(\gamma)]. \quad (3.32)$$

As we know the relationship between $f_{\gamma_{T_i}}(\gamma)$ and $M_{\gamma_{T_i}}(s)$, by using that $M_{\gamma_{T_i}}(s)$ can be calculated as

$$M_{\gamma_{T_i}}(s) = -\frac{2m_i^{m_i}(m_j-1)!}{\bar{\gamma}_i^{m_i}\Gamma(m_i)\Gamma(m_j)} \sum_{v=0}^{m_i-1} \sum_{r=0}^{m_j-1} \sum_{k=0}^r \frac{1}{r!} \binom{r}{k} \binom{m_i-1}{v} \left(\frac{m_i}{\bar{\gamma}_i}\right)^{-\frac{\sigma_i+1}{2}} \left(\frac{2m_j}{\bar{\gamma}_j}\right)^{r+\frac{\sigma_i+1}{2}} \int_0^\infty [N_1'(\gamma)N_2(\gamma) + N_1(\gamma)N_2'(\gamma)] e^{-s\gamma} d\gamma \quad (3.33)$$

Where $N_1(\gamma) = e^{-b_i\gamma}$, $N_2(\gamma) = \gamma^{\delta_i} K_{\sigma_i+1}(a_i\gamma)$ and $N_1'(\gamma), N_2'(\gamma)$ are the first derivative of $N_1(\gamma)$ and $N_2(\gamma)$ respectively. By putting the values mentioned above and calculating we get

$$M_{\gamma_{T_i}}(s) = -\frac{2m_i m_i (m_j - 1)!}{\bar{\gamma}_1^{m_i} \Gamma(m_i) \Gamma(m_j)} \sum_{v=0}^{m_i-1} \sum_{r=0}^{m_j-1} \sum_{k=0}^r \frac{1}{r!} \binom{r}{k} \binom{m_i - 1}{v} \left(\frac{m_i}{\bar{\gamma}_1}\right)^{-\frac{\sigma_i+1}{2}} \left(\frac{2m_j}{\bar{\gamma}_j}\right)^{r+\frac{\sigma_i+1}{2}} \times [b_i d_1 + (\delta_i - (\sigma_i + 1))d_2 + a_i d_3] \quad (3.34)$$

Where

$$d_1 = -\frac{\sqrt{\pi}(2a_i)^{\sigma_i+1} \Gamma(\delta_i + \sigma_i + 2) \Gamma(\delta_i - \sigma_i)}{(b_i + s + a_i)^{(\delta_i+\sigma_i+2)} \Gamma\left(\delta_i + \frac{3}{2}\right)} \times {}_2F_1\left(\delta_i + \sigma_i + 2, \sigma_i + \frac{3}{2}; \delta_i + \frac{3}{2}; \frac{b_i + s - a_i}{b_i + s + a_i}\right) \quad (3.35)$$

$$d_2 = \frac{\sqrt{\pi}(2a_i)^{\sigma_i+1} \Gamma(\delta_i + \sigma_i + 1) \Gamma(\delta_i - (\sigma_i + 1))}{(b_i + s + a_i)^{(\delta_i+\sigma_i+1)} \Gamma\left(\delta_i + \frac{1}{2}\right)} \times {}_2F_1\left(\delta_i + \sigma_i + 1, \sigma_i + \frac{3}{2}; \delta_i + \frac{1}{2}; \frac{b_i + s - a_i}{b_i + s + a_i}\right) \quad (3.36)$$

$$d_3 = -\frac{\sqrt{\pi}(2a_i)^{\sigma_i} \Gamma(\delta_i + \sigma_i + 1) \Gamma(\delta_i - \sigma_i + 1)}{(b_i + s + a_i)^{(\delta_i+\sigma_i+1)} \Gamma\left(\delta_i + \frac{3}{2}\right)} \times {}_2F_1\left(\delta_i + \sigma_i + 1, \sigma_i + \frac{1}{2}; \delta_i + \frac{3}{2}; \frac{b_i + s - a_i}{b_i + s + a_i}\right) \quad (3.37)$$

Here ${}_kF_1(a_1, \dots, a_k; b_1, \dots, b_1; x)$ is the generalized hyper geometric function. The derived MGF, $M_{\gamma_{T_i}}(s)$ in (3.34) can be used to calculate the average symbol error rate (ASER). Now, the average SER for M-ary PSK at T_i can be represented by

$$P_s^{T_i} = \frac{1}{\pi} \int_0^{(\pi-\pi/M)} M_{\gamma_{T_i}}\left(\frac{h}{\sin^2\theta}\right) d\theta \quad (3.38)$$

where $h = \sin^2\left(\frac{\pi}{M}\right)$ [29].

3.3.1.2 CDF Approach

For analysing the performance of a amplify and forward TWRN with the CDF based approach, the ASER for many modulation schemes can be calculated by using the following equation

$$P_{\text{ASER}}(e) = - \int_0^{\infty} P'_s(e|\gamma') F_{\gamma'}(\gamma') d\gamma' \quad (3.39)$$

where $P'_s(e|\gamma')$ is the first derivative of the conditional symbol error rate w.r.t. instantaneous SNR γ' in AWGN channels and $F_{\gamma'}(\gamma')$ is the CDF for the received SNR. Now let's consider the case of rectangular QAM. Now, the conditional SER for RQAM scheme in AWGN channels is given by

$$P_{\text{ASER}}^{\text{RQAM}}(e|\gamma') = 2pQ(a\sqrt{\gamma'}) + 2qQ(b\sqrt{\gamma'}) - 4pqQ(a\sqrt{\gamma'}) Q(b\sqrt{\gamma'}) \quad (3.40)$$

Where the gaussian Q function $Q(x)$ is represented as

$$Q(x) = \left(\frac{1}{2\pi}\right) \int_x^{\infty} e^{-t^2/2} dt \quad (3.41)$$

p and q are modulation parameter given as

$$p = 1 - \frac{1}{M_I} \text{ and } q = 1 - \frac{1}{M_Q} \quad (3.42)$$

respectively, a is also modulation parameter given by

$$a = \sqrt{\frac{6}{(M_I^2 - 1) + (M_Q^2 - 1)\beta^2}} \quad (3.43)$$

$b = \beta a$ and $\beta = dQ/dI$, where dQ is decisions distance for the quadrature -phase and dI is decisions distance for the in-phase component. Also, the average in-phase component signal energy is $(M_I^2 - 1)/(M_Q^2 - 1)$ times the average energy for the quadrature-phase component signal [8].

According to the above formula given in (3.39) to calculate the ASER expression for RQAM, we need to evaluate first derivative of $P_{\text{ASER}}^{\text{RQAM}}(e|\gamma')$ given

in (3.40) w.r.t. γ' . By using some identities and calculating we get the expression for $P_{ASER}^{RQAM}(e|\gamma')$ can be evaluated as

$$P_{ASER}^{RQAM}(e|\gamma') = \left[\frac{ap(q-1)}{\sqrt{2\pi}} \right] \gamma'^{-\frac{1}{2}} e^{-a^2\gamma'/2} + \left[\frac{b(p-1)q}{\sqrt{2\pi}} \right] \gamma'^{-\frac{1}{2}} e^{-b^2\gamma'/2} - \left[\frac{abpq}{\pi} \right] e^{-(a^2+b^2)\gamma'/2} {}_1F_1\left(1; \frac{3}{2}; a^2\gamma'/2\right) - \left[\frac{abpq}{\pi} \right] e^{-(a^2+b^2)\gamma'/2} {}_1F_1\left(1; \frac{3}{2}; b^2\gamma'/2\right) \quad (3.44)$$

Now over i.n.i.d. Nakagami-m fading channel for integer value of fading parameter m the expression of CDF $F_{\gamma'T_i}(\gamma')$ for received SNR $\gamma'T_i$ can be represented by

$$F_{\gamma'T_i}(\gamma) = 1 - \frac{2m_i m_i e^{-b_i \gamma'} (m_j - 1)!}{\gamma'_i m_i \Gamma(m_i) \Gamma(m_j)} \sum_{v=0}^{m_i-1} \sum_{r=0}^{m_j-1} \sum_{k=0}^r \frac{1}{r!} \binom{r}{k} \binom{m_i-1}{v} \left(\frac{m_i}{\gamma_i}\right)^{-\frac{\sigma_i+1}{2}} \left(\frac{2m_j}{\gamma_j}\right)^{r+\frac{\sigma_i+1}{2}} \gamma'^{\delta_i} K_{\sigma_i+1}(a\gamma'). \quad (3.45)$$

where $\delta_i = m_i + r, \sigma_i = v + k$ (3.46)

and $b_i = \frac{m_i}{\gamma'_i} + \frac{2m_j}{\gamma'_j},$ (3.47)

$$a_i = 2 \sqrt{2m_i m_j / \gamma'_i \gamma'_j} \quad (3.48)$$

and $K_v(\cdot)$ is the v^{th} order modified Bessel function of second kind. Now putting the values of $P_{ASER}^{RQAM}(e|\gamma')$ from (3.44) and CDF $F_{\gamma'T_i}(\gamma')$ from (3.45) in formula of $P_{ASER}(e)$ given in (3.39) and evaluating, we get an exact closed-form expression of average symbol error rate (ASER) for RQAM modulation scheme as

$$\begin{aligned}
P_{\text{ASER}}^{\text{RQAM}}(e) = & p + q - 2pq + \frac{2a_0b_0pq}{\pi(a_0^2+b_0^2)} \left[F_1 \left(1,1; 1.5; \frac{a_0^2}{(a_0^2+b_0^2)} \right) + \right. \\
& F_1 \left(1,1; 1.5; \frac{b_0^2}{(a_0^2+b_0^2)} \right) \left. \right] - N_0 \left\{ \frac{a_0p(1-q)}{\sqrt{2\pi}} \theta(0, b_0, 0) + \frac{b_0q(1-p)}{\sqrt{2\pi}} \theta(b_0, 0, 0) + \right. \\
& \left. \frac{a_0b_0pq}{\pi} \left[\sum_{z=0}^{\infty} \nabla \left(z, \frac{a_0^2}{2} \right) \theta \left(a_0, b_0, z + \frac{1}{2} \right) + \sum_{v=0}^{\infty} \nabla \left(v, \frac{a_0^2}{2} \right) \theta \left(a_0, b_0, v + \frac{1}{2} \right) \right] \right\}
\end{aligned} \tag{3.49}$$

$$\begin{aligned}
\text{where } N_0 = & \frac{2m_i m_j e^{-b_i \gamma'} (m_j - 1)!}{\gamma_1^{m_i} \Gamma(m_i) \Gamma(m_j)} \sum_{v=0}^{m_i-1} \sum_{r=0}^{m_j-1} \sum_{k=0}^r \frac{1}{r!} \binom{r}{k} \binom{m_i-1}{v} \left(\frac{m_i}{\gamma_1} \right)^{-\frac{\sigma_i+1}{2}} \\
& \left(\frac{2m_j}{\gamma_1'} \right)^{r+\frac{\sigma_i+1}{2}}
\end{aligned} \tag{3.50}$$

$$\begin{aligned}
\theta(x, y, z) = & \frac{\sqrt{\pi} (2a_i)^{\sigma_i+1} \Gamma \left(\delta_i + \sigma_i + \frac{3}{2} + z \right) \Gamma \left(\delta_i - \sigma_i - \frac{1}{2} + z \right)}{\left(b_i + \frac{x^2 + y^2}{2} + a_i \right)^{\left(\delta_i + \sigma_i + \frac{3}{2} + z \right)} \Gamma(\delta_i + 1 + z)} \\
& \times {}_2F_1 \left(\delta_i + \sigma_i + \frac{3}{2} + z, \sigma_i + \frac{3}{2}; \delta_i + 1 + z; \frac{b_i + \frac{x^2 + y^2}{2} - a_i}{b_i + \frac{x^2 + y^2}{2} + a_i} \right)
\end{aligned} \tag{3.51}$$

$$\nabla(\omega, \vartheta) = \frac{(1)_{\omega}(\vartheta)^{\omega}}{(1.5)_{\omega} \omega!} \tag{3.52}$$

and $(\vartheta)_n = \Gamma(\vartheta + n) / \Gamma(\vartheta)$ represents Pochhammer symbol. The expression of ASER for RQAM, given in (3.49) is valid for integer values of m which is fading parameter. The expressions for other cases of RQAM can be derived by putting $M_I = M_Q = \sqrt{M}$ and $\beta = 1$ in (3.49). In the same way, for $M_I = 2, M_Q = 1, p=0.5, q=0, a=\sqrt{2}$ and $\beta=0$ values we get the expression for BPSK modulation scheme [8].

CHAPTER – 4

PERFORMANCE OF TWO WAY AF RELAYING NETWORK

As discussed in the section below for the performance analysis purpose of wireless system we derive expressions for the conditional SER for MPSK modulation scheme. The ASER can be obtained by averaging the probability density function (PDF) of the output signal to noise ratio and the conditional symbol error rate (SER) for Nakagami-m channel. We have also used MGF approach in which we have calculated MGF using CDF and finally calculated ASER.

4.1 ASER FOR MPSK OVER NAKAGAMI-M CHANNEL WITH CDF APPROACH

The average SER expression for MPSK modulation scheme can be calculated by using the following equation

$$P_{\text{ASER}}(e) = - \int_0^{\infty} P'_s(e|\gamma) F_{\gamma}(\gamma) d\gamma \quad (4.1)$$

where $P'_s(e|\gamma)$ is the first derivative of the conditional symbol error rate w.r.t. instantaneous SNR γ in AWGN channels and $F_{\gamma}(\gamma)$ is the CDF for the received SNR. Now let's consider the case of MPSK modulation. The conditional SER for MPSK modulation scheme in AWGN channels is mentioned in [30]

$$P_{\text{ASER}}^{\text{MPSK}}(e|\gamma) = \text{erfc} \left(\sqrt{\frac{1 - \cos(2\pi/M)\gamma}{2}} \right) \quad (4.2)$$

We know that

$$Q(x) = \frac{1}{2} \text{erfc} \left(\frac{x}{\sqrt{2}} \right) \quad (4.3)$$

Putting the value in the form of Q function and evaluating we get

$$P_{\text{ASER}}^{\text{MPSK}}(e|\gamma) = 2Q \left(\sqrt{1 - \cos \left(\frac{2\pi}{M} \right) \gamma} \right) \quad (4.4)$$

We know that, other form Q function can be defined as

$$Q(g) = \frac{1}{\sqrt{2\pi}} \int_g^{\infty} e^{-t^2/2} dt \quad (4.5)$$

Now expressing conditional symbol error rate given in the (4.4) in the form of Q function given in (4.3)

$$P_{ASER}^{MPSK}(e|\gamma) = \frac{2}{\sqrt{2\pi}} \int_{\sqrt{1-\cos(\frac{2\pi}{M})\gamma}}^{\infty} e^{-t^2/2} dt \quad (4.6)$$

Now we know the integration solution of $e^{-t^2/2} dt$ is given by

$$\int e^{-t^2/2} dt = \sqrt{\frac{\pi}{2}} \operatorname{erfc}\left(\frac{t}{\sqrt{2}}\right) \quad (4.7)$$

Putting this solution in (4.6) and calculating we obtain

$$P_{ASER}^{MPSK}(e|\gamma) = \frac{2}{\sqrt{2\pi}} \left[\sqrt{\frac{\pi}{2}} \operatorname{erfc}\left(\frac{t}{\sqrt{2}}\right) \right]_{\sqrt{1-\cos(\frac{2\pi}{M})\gamma}}^{\infty} \quad (4.8)$$

$$P_{ASER}^{MPSK}(e|\gamma) = \operatorname{erfc}\left(\sqrt{\frac{1-\cos(\frac{2\pi}{M})\gamma}{2}}\right) \quad (4.9)$$

$$P_{ASER}^{MPSK}(e|\gamma) = 1 - \operatorname{erf}\left(\sqrt{\frac{1-\cos(\frac{2\pi}{M})\gamma}{2}}\right) \quad (4.10)$$

According to the above formula given in (4.1) to calculate the ASER expression for MPSK, we need to evaluate first derivative of $P_{ASER}^{MPSK}(e|\gamma)$ given in (4.2) w.r.t. γ . For calculating the

expression for $P_{ASER}^{\prime MPSK}(e|\gamma)$ we do following steps

$$P_{ASER}^{\prime MPSK}(e|\gamma) = \frac{d}{d\gamma} \left[1 - \operatorname{erf}\left(\sqrt{\frac{1-\cos(\frac{2\pi}{M})\gamma}{2}}\right) \right] \quad (4.11)$$

Now we know that differentiation of $\operatorname{erf}(x)$ is given by

$$\frac{d}{dx} \operatorname{erf}(x) = \frac{2}{\sqrt{\pi}} e^{-x^2} \quad (4.12)$$

$$P_{\text{ASER}}^{\text{MPSK}}(e|\gamma) = -\frac{1}{\sqrt{\pi\gamma}} \sqrt{\frac{1 - \cos\left(\frac{2\pi}{M}\right)\gamma}{2}} e^{-\frac{1 - \cos\left(\frac{2\pi}{M}\right)\gamma}{2}} \quad (4.13)$$

Now over i.n.i.d. nakagami-m fading channel for integer value of m which is fading parameter, the expression of CDF $F_{\gamma T_i}(\gamma)$ for received SNR γT_i can be represented by (4.14) given in [8, (5)]

$$F_{\gamma T_i}(\gamma) = 1 - \frac{2m_i^{m_i} e^{-b_i\gamma} (m_j - 1)!}{\bar{\gamma}_i^{m_i} \Gamma(m_i) \Gamma(m_j)} \sum_{v=0}^{m_i-1} \sum_{r=0}^{m_j-1} \sum_{k=0}^r \frac{1}{r!} \binom{r}{k} \binom{m_i - 1}{v} \left(\frac{m_i}{\bar{\gamma}_i}\right)^{-\frac{\sigma_i+1}{2}} \left(\frac{2m_j}{\bar{\gamma}_j}\right)^{r+\frac{\sigma_i+1}{2}} \gamma^{\delta_i} K_{\sigma_i+1}(a\gamma). \quad (4.14)$$

where

$$\delta_i = m_i + r, \sigma_i = v + k \quad (4.15)$$

and

$$b_i = \frac{m_i}{\bar{\gamma}_i} + \frac{2m_j}{\bar{\gamma}_j}, \quad (4.16)$$

$$a_i = 2\sqrt{2m_i m_j / \bar{\gamma}_i \bar{\gamma}_j} \quad (4.17)$$

and $K_\nu(\cdot)$ is the ν^{th} order modified Bessel function of second kind. $F_{\gamma T_i}(\gamma)$ can be written as

$$F_{\gamma T_i}(\gamma) = 1 - R_0 e^{-b_i\gamma} \gamma^{\delta_i} K_{\sigma_i+1}(a\gamma) \quad (4.18)$$

where

$$R_0 = \frac{2m_i^{m_i} (m_j - 1)!}{\bar{\gamma}_i^{m_i} \Gamma(m_i) \Gamma(m_j)} \sum_{v=0}^{m_i-1} \sum_{r=0}^{m_j-1} \sum_{k=0}^r \frac{1}{r!} \binom{r}{k} \binom{m_i - 1}{v} \left(\frac{m_i}{\bar{\gamma}_i}\right)^{-\frac{\sigma_i+1}{2}} \left(\frac{2m_j}{\bar{\gamma}_j}\right)^{r+\frac{\sigma_i+1}{2}} \quad (4.19)$$

Now putting the values of $P_{\text{ASER}}^{\text{RQAM}}(e|\gamma)$ from (4.13) and CDF $F_{\gamma T_i}(\gamma)$ from (4.14) in formula of $P_{\text{ASER}}(e)$ given in (4.1) and evaluating,

$$P_{\text{ASER}}(e) = \int_0^\infty \frac{1}{\sqrt{\pi\gamma}} \sqrt{\frac{1 - \cos\left(\frac{2\pi}{M}\right)\gamma}{2}} e^{-\frac{1 - \cos\left(\frac{2\pi}{M}\right)\gamma}{2}} \left(1 - R_0 e^{-b_i\gamma} \gamma^{\delta_i} K_{\sigma_i+1}(a\gamma)\right) d\gamma \quad (4.20)$$

$$P_{ASER}(e) = \sqrt{\frac{1-\cos\left(\frac{2\pi}{M}\right)}{2}} \int_0^\infty \frac{1}{\sqrt{\gamma}} e^{-\frac{1-\cos\left(\frac{2\pi}{M}\right)\gamma}{2}} d\gamma - R_0 \sqrt{\frac{1-\cos\left(\frac{2\pi}{M}\right)}{2}} \int_0^\infty \frac{1}{\sqrt{\gamma}} e^{-b_i\gamma} e^{-\frac{1-\cos\left(\frac{2\pi}{M}\right)\gamma}{2}} \gamma^{\delta_i} K_{\sigma_i+1}(a\gamma) d\gamma \quad (4.21)$$

$$P_{ASER}(e) = I_1 + I_2 \quad (4.22)$$

Calculating I_1 and I_2 and putting in equation (4.22), we obtain

$$I_1 = \sqrt{\frac{1-\cos\left(\frac{2\pi}{M}\right)}{2}} \int_0^\infty \frac{1}{\sqrt{\gamma}} e^{-\frac{1-\cos\left(\frac{2\pi}{M}\right)\gamma}{2}} d\gamma \quad (4.23)$$

$$I_1 = \sqrt{\frac{1-\cos\left(\frac{2\pi}{M}\right)}{2}} \left[\frac{\sqrt{2\pi}}{\sqrt{1-\cos\left(\frac{2\pi}{M}\right)}} \right] \quad (4.24)$$

$$I_1 = 1 \quad (4.25)$$

Now calculating I_2 ,

$$I_2 = R_0 \sqrt{\frac{1-\cos\left(\frac{2\pi}{M}\right)}{2}} \int_0^\infty e^{-(b_i+\frac{1-\cos\left(\frac{2\pi}{M}\right)}{2})\gamma} \gamma^{\delta_i-1/2} K_{\sigma_i+1}(a\gamma) d\gamma \quad (4.26)$$

Using the identity (6.621.3) from [32], which is as following

$$\int_0^\infty x^{u-1} e^{-\alpha x} K_\nu(\beta x) dx = \frac{\sqrt{\pi}(2\beta)^\nu}{(\alpha+\beta)^{u+\nu}} \frac{\Gamma(u+\nu)\Gamma(u-\nu)}{\Gamma(u+\frac{1}{2})} F\left(u+\nu, \nu+\frac{1}{2}; u+\frac{1}{2}; \frac{\alpha-\beta}{\alpha+\beta}\right) \quad (4.27)$$

Using this identity in (4.26) and calculating we get

$$\begin{aligned}
I_2 = R_0 & \sqrt{\frac{1 - \cos\left(\frac{2\pi}{M}\right)}{2\pi}} \left[\frac{\sqrt{\pi}(2a)^{\sigma_i+1}}{\left(b_i + \frac{1 - \cos\left(\frac{2\pi}{M}\right)}{2} + a\right)^{\delta_i + \sigma_i + \frac{3}{2}}} \right. \\
& \times \frac{\Gamma\left(\delta_i + \sigma_i + \frac{3}{2}\right) \Gamma\left(\delta_i - \sigma_i - \frac{1}{2}\right)}{\Gamma(\delta_i + 1)} \\
& \left. \times F\left(\delta_i + \sigma_i + \frac{3}{2}; \sigma_i + \frac{3}{2}; \delta_i + 1; \frac{b_i + \frac{1 - \cos\left(\frac{2\pi}{M}\right)}{2} - a}{b_i + \frac{1 - \cos\left(\frac{2\pi}{M}\right)}{2} + a}\right) \right] \tag{4.28}
\end{aligned}$$

$$\begin{aligned}
P_{\text{ASER}}(e) = 1 - R_0 & \sqrt{\frac{1 - \cos\left(\frac{2\pi}{M}\right)}{2\pi}} \left[\frac{\sqrt{\pi}(2a)^{\sigma_i+1}}{\left(b_i + \frac{1 - \cos\left(\frac{2\pi}{M}\right)}{2} + a\right)^{\delta_i + \sigma_i + \frac{3}{2}}} \right. \\
& \times \frac{\Gamma\left(\delta_i + \sigma_i + \frac{3}{2}\right) \Gamma\left(\delta_i - \sigma_i - \frac{1}{2}\right)}{\Gamma(\delta_i + 1)} \\
& \left. \times F\left(\delta_i + \sigma_i + \frac{3}{2}; \sigma_i + \frac{3}{2}; \delta_i + 1; \frac{b_i + \frac{1 - \cos\left(\frac{2\pi}{M}\right)}{2} - a}{b_i + \frac{1 - \cos\left(\frac{2\pi}{M}\right)}{2} + a}\right) \right] \tag{4.29}
\end{aligned}$$

The above expression given in (4.29) represents average symbol error rate of MPSK modulation scheme for amplify and forward TWRN for nakagami-m fading channel for integer value of m which is fading parameter.

4.2 ASER FOR RQAM OVER NAKAGAMI-M CHANNEL WITH MGF APPROACH

When m (fading parameter) is integer, CDF of γ_{T_i} is expressed in [8, (5)] as

$$F_{\gamma_{T_i}}(\gamma) = 1 - \frac{2m_i^{m_i} e^{-b_i \gamma} (m_j - 1)!}{\bar{\gamma}_i^{m_i} \Gamma(m_j) \Gamma(m_j)} \sum_{v=0}^{m_i-1} \sum_{r=0}^{m_j-1} \sum_{k=0}^r \frac{1}{r!} \binom{r}{k} \binom{m_i-1}{v} \left(\frac{m_i}{\bar{\gamma}_i}\right)^{-\frac{\sigma_i+1}{2}}$$

$$\left(\frac{2m_j}{\bar{Y}_j}\right)^{r+\frac{\sigma_i+1}{2}} \gamma^{\delta_i} K_{\sigma_i+1}(a_i \gamma) \quad (4.30)$$

where $\delta_i = m_i + r, \sigma_i = v + k$ (4.31)

$$b_i = \frac{m_i}{\bar{Y}_i} + \frac{2m_j}{\bar{Y}_j}, \quad (4.32)$$

$$a_i = 2\sqrt{2m_i m_j / \bar{Y}_i \bar{Y}_j} \quad (4.33)$$

and $K_\nu(\cdot)$ is the ν^{th} order modified Bessel function of second kind. MGF can be expressed in [29, (11)] and given as

$$M_{\gamma_{T_i}}(s) = -\frac{2m_i^{m_i}(m_j-1)!}{\bar{Y}_i^{m_i} \Gamma(m_i) \Gamma(m_j)} \sum_{v=0}^{m_i-1} \sum_{r=0}^{m_j-1} \sum_{k=0}^r \frac{1}{r!} \binom{r}{k} \binom{m_i-1}{v} \left(\frac{m_i}{\bar{Y}_i}\right)^{-\frac{\sigma_i+1}{2}} \left(\frac{2m_j}{\bar{Y}_j}\right)^{r+\frac{\sigma_i+1}{2}} \times [b_i d_1 + (\delta_i - (\sigma_i + 1))d_2 + a_i d_3] \quad (4.34)$$

Where,

$$d_1 = -\frac{\sqrt{\pi}(2a_i)^{\sigma_i+1} \Gamma(\delta_i + \sigma_i + 2) \Gamma(\delta_i - \sigma_i)}{(b_i + s + a_i)^{(\delta_i+\sigma_i+2)} \Gamma\left(\delta_i + \frac{3}{2}\right)} \times {}_2F_1\left(\delta_i + \sigma_i + 2, \sigma_i + \frac{3}{2}; \delta_i + \frac{3}{2}; \frac{b_i + s - a_i}{b_i + s + a_i}\right) \quad (4.35)$$

$$d_2 = \frac{\sqrt{\pi}(2a_i)^{\sigma_i+1} \Gamma(\delta_i + \sigma_i + 1) \Gamma(\delta_i - (\sigma_i + 1))}{(b_i + s + a_i)^{(\delta_i+\sigma_i+1)} \Gamma\left(\delta_i + \frac{1}{2}\right)} \times {}_2F_1\left(\delta_i + \sigma_i + 1, \sigma_i + \frac{3}{2}; \delta_i + \frac{1}{2}; \frac{b_i + s - a_i}{b_i + s + a_i}\right) \quad (4.36)$$

$$d_3 = -\frac{\sqrt{\pi}(2a_i)^{\sigma_i} \Gamma(\delta_i + \sigma_i + 1) \Gamma(\delta_i - \sigma_i + 1)}{(b_i + s + a_i)^{(\delta_i+\sigma_i+1)} \Gamma\left(\delta_i + \frac{3}{2}\right)} \times {}_2F_1\left(\delta_i + \sigma_i + 1, \sigma_i + \frac{1}{2}; \delta_i + \frac{3}{2}; \frac{b_i + s - a_i}{b_i + s + a_i}\right) \quad (4.37)$$

Here ${}_kF_1(a_1, \dots, a_k; b_1, \dots, b_l; x)$ is the generalized hyper geometric function. The derived MGF, $M_{\gamma_{T_i}}(s)$ in (4.34) can be used to calculate the average SER. By using (4.30) for CDF, PDF will be calculated with the help of this, we can calculate MGF given in (4.34) which is then used for calculating final expression of ASER given in (4.38), the average SER for RQAM at T_i can be represented by [27, (4)]

$$\begin{aligned}
P_s^{T_i} = & \frac{2p}{\pi} \int_0^{\pi/2} M_{\gamma_{T_i}} \left(\frac{a_0^2}{2\sin^2\theta} \right) d\theta \\
& + \frac{2q}{\pi} \int_0^{\pi/2} M_{\gamma_{T_i}} \left(\frac{b_0^2}{2\sin^2\theta} \right) d\theta - \frac{4pq}{2\pi} \left[\int_0^{\frac{\pi}{2} - \arctan\left(\frac{a_0}{b_0}\right)} M_{\gamma_{T_i}} \left(\frac{a_0^2}{2\sin^2\theta} \right) d\theta \right. \\
& \left. + \int_0^{\arctan\left(\frac{a_0}{b_0}\right)} M_{\gamma_{T_i}} \left(\frac{b_0^2}{2\sin^2\theta} \right) d\theta \right]
\end{aligned} \tag{4.38}$$

The above expression given in (4.38) represents average symbol error rate of RQAM modulation scheme for amplify and forward TWRN for Nakagami-m fading channel for integer value of m which is fading parameter.

4.2.1 ASER for 32-Cross QAM for Nakagami-m Channel

Generally the ASER for 32 XQAM modulation scheme can be calculated by

$$P_s(e) = \int_0^{\infty} P_{ASER}^{XQAM}(e|\gamma_t) f_\gamma(\gamma_t) d\gamma_t \tag{4.39}$$

where $f_\gamma(\gamma_t)$ is probability density function of γ_t which is represented by (3.32) and $P_{ASER}^{XQAM}(e|\gamma_t)$ is the conditional SER of 32-cross QAM scheme. The conditional SER for 32-cross QAM scheme in additive white Gaussian noise (AWGN) channels is given in [8, (7)] as

$$P_{ASER}^{XQAM}(e|\gamma_t) = \frac{1}{8} [26Q(\sqrt{2c_0\gamma_t}) + Q(2\sqrt{c_0\gamma_t}) - 23Q^2(\sqrt{2c_0\gamma_t})] \tag{4.40}$$

Where,

$$c_0 = \frac{48}{(31M - 32)} \tag{4.41}$$

$$M=M_I \times M_Q \quad (4.42)$$

Substituting value of $P_{ASER}^{XQAM}(e|\gamma_t)$ in (4.39) which represent ASER and then rearranging values, we obtain

$$P_s(e) = \frac{1}{8} \left[26 \int_0^\infty Q(\sqrt{2c_0\gamma_t}) f_\gamma(\gamma_t) d\gamma_t + \int_0^\infty Q(2\sqrt{c_0\gamma_t}) f_\gamma(\gamma_t) d\gamma_t - 23 \int_0^\infty Q^2(\sqrt{2c_0\gamma_t}) f_\gamma(\gamma_t) d\gamma_t \right] \quad (4.43)$$

$$P_s(e) = \frac{1}{8} [26I_1 + I_2 - 23I_3] \quad (4.44)$$

$$M_{\gamma_{T_i}}(s) = E\{e^{sY}\} = \int_0^\infty e^{sY} f_\gamma(\gamma_t) d\gamma_t \quad (4.45)$$

$$Q(x) = \frac{1}{\pi} \int_0^{\pi/2} \exp\left(-\frac{x^2}{2\sin^2\theta}\right) d\theta \quad (4.46)$$

$$Q^2(x) = \frac{1}{\pi} \int_0^{\pi/4} \exp\left(-\frac{x^2}{2\sin^2\theta}\right) d\theta \quad (4.47)$$

Using (4.45), (4.46) as given in [30, 4.2] and (4.47) given as [30, 4.9] in (4.43) and solving we get the value of ASER in the form of MGF

$$P_s(e) = \frac{1}{8} \left[\frac{26}{\pi} \int_0^{\pi/2} M_{\gamma_{T_i}}\left(\frac{4c_0^2}{2\sin^2\theta}\right) f_\gamma(\gamma_t) d\gamma_t + \frac{1}{\pi} \int_0^{\pi/2} M_{\gamma_{T_i}}\left(\frac{2c_0^2}{2\sin^2\theta}\right) f_\gamma(\gamma_t) d\gamma_t - \frac{23}{\pi} \int_0^{\pi/4} M_{\gamma_{T_i}}\left(\frac{c_0^2}{2\sin^2\theta}\right) f_\gamma(\gamma_t) d\gamma_t \right] \quad (4.48)$$

The value of moment generating function $M_{\gamma_{T_i}}(s)$ which is given in (4.34) will be used and ASER will be calculated. The above expression given in (4.48) represents average symbol error rate of XQAM modulation scheme for two way AF relaying network for Nakagami-m fading channel for integer value of m which is fading parameter.

CHAPTER-5

RESULTS AND DISCUSSION

In this chapter results are presented which are obtained for the performance analysis of two way AF relaying network with MGF and CDF approach given in chapter 4. The results presented in the following sections are obtained for different modulation schemes using analytical expressions as well as Monte Carlo simulation for the Symbol Error Rate over a range of SNR values.

5.1 ASER OF MPSK FOR AMPLIFY AND FORWARD TWRN

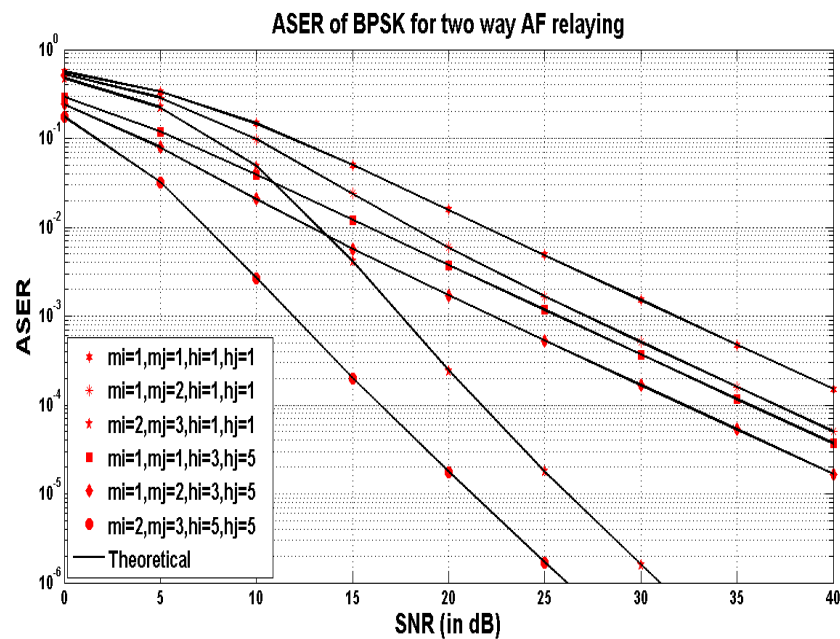


Figure 5.1 ASER of BPSK for two-way AF relaying

This section presents simulation to validate and to prove utility of our analytical expressions. For numerical results, the special function which we are using here can be calculated by using various mathematical software packages like Mathematica. The solid lines in figures depict the theoretical results for average SER, which are attained by the analytical expressions given in chapter 4, while the other lines (dashed lines) depicts the simulation results.

Figures in this section represent average symbol error rate performance of MPSK that is for different values of m for amplify and forward two-way relaying network for nakagami- m fading channel. It shows the ASER results for MPSK modulation for integer value of m which

is fading parameter. For the purpose of comparing the results, we are considering two different cases: first is i.i.d.case (e.g. $h_1 = h_2 = 1$) and second is i.n.i.d.case (e.g. $h_1 = 3, h_2 = 5$). Various fading conditions are used, such as different values of fading parameters, are considered for comparison. Graphs depicts curves of ASER versus transmit SNR (in dB) for different values of m which is fading parameter.

In figure 5.1 ASER for BPSK for AF two way relaying network for nakagami- m channel for integer value of m which is fading parameter. In case of BPSK the value of M is considered as 2. This figure highlights the effect of fading parameter m on the performance of the system.

We can conclude that the simulation results here are closely matching with the analytical results. Now as we can see from the figure when the value of average SER equals to 10^{-2} for $h_1 = h_2 = 1$ that is for i.i.d. case, when fading parameters m goes from $m_1 = 1, m_2 = 1$ to $m_1 = 2, m_2 = 3$, a gain of 9 dB in SNR is attained and when the value of average SER equals to 10^{-2} for $h_1 = 3, h_2 = 5$ that is for i.n.i.d. case, when fading parameters m goes from $m_1 = 1, m_2 = 1$ to $m_1 = 2, m_2 = 3$, a gain of 7.5 dB in SNR is attained. Now as the results depicts that system performance that is ASER is significantly improving for various values of m (fading parameters).

In figure 5.2 depicts ASER for QPSK for amplify and forward two-way relaying network for nakagami- m channel for integer value of m which is fading parameter for both the analytical results and for Monte Carlo Simulation with distinct values of h_1 and h_2 . In case of QPSK the value of M is considered as 4. This figure highlights the effect of fading parameter on the system performance.

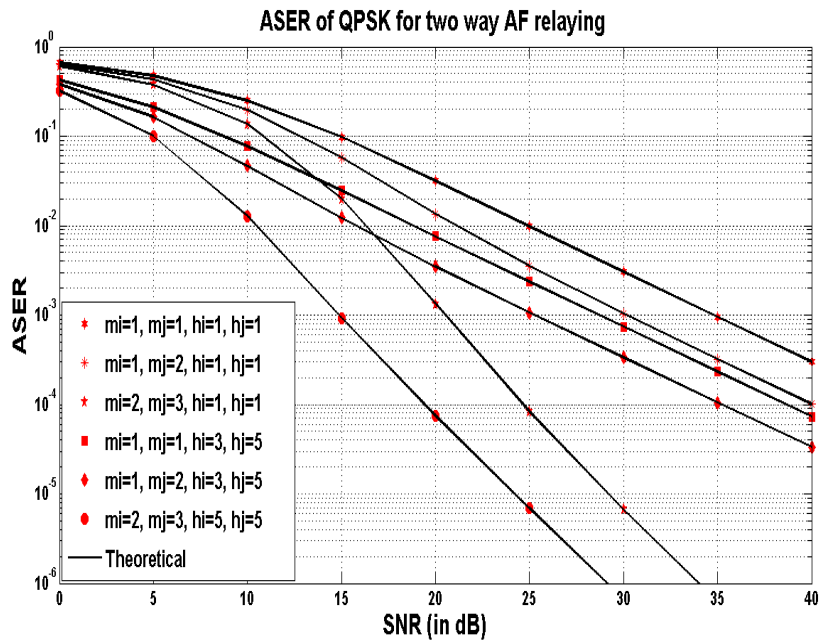


Figure 5.2 ASER of QPSK for two-way AF relaying network

Now as we can see from the figure when the value of average SER equals to 10^{-2} for $h_1 = h_2 = 1$ that is for i.i.d. case, when fading parameters change from $m_1 = 1, m_2 = 1$ to $m_1 = 1, m_2 = 2$, a gain of 3.5 dB in SNR is attained and when the value of average SER equals to 10^{-2} for $h_1 = 3, h_2 = 5$ that is for i.n.i.d. case, when fading parameters change from $m_1 = 1, m_2 = 1$ to $m_1 = 1, m_2 = 2$, a gain of 3 dB in SNR is attained. Now as the results depict that the system performance that is ASER is significantly improving for various values of m (fading parameters).

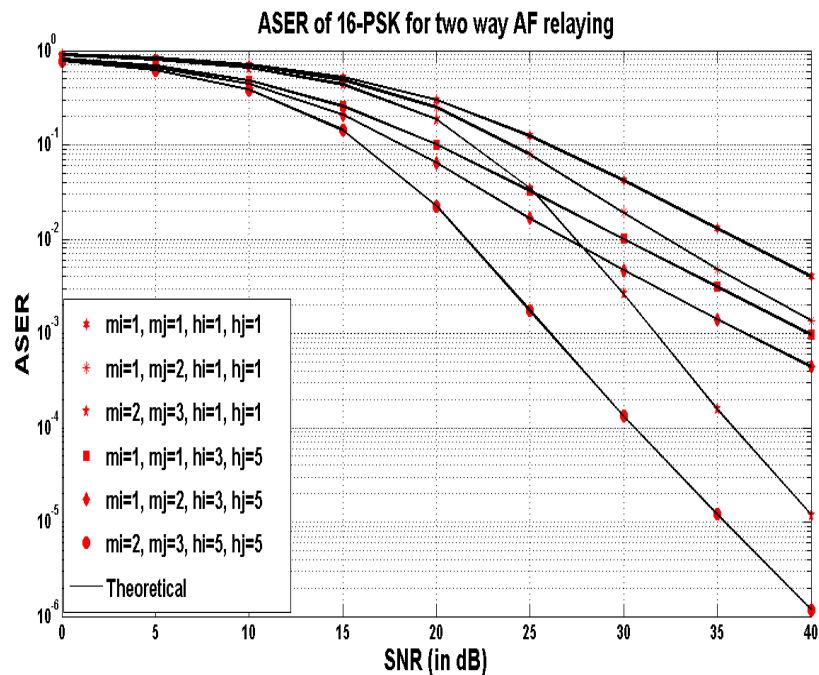


Figure 5.3 ASER of 16-PSK of two way AF relaying network

In figure 5.3 depicts ASER for 16-PSK for amplify and forward two-way relaying network for Nakagami-m channel for integer value of m which is fading parameter for both the analytical results and for Monte Carlo Simulation with distinct values of h_1 and h_2 . In case of 16-PSK the value of M is considered as 16. This figure highlights the effect of fading parameter m on the performance of the system.

Now as we can see from the figure when the value of average SER is 10^{-1} for $h_1 = h_2 = 1$ that is for i.i.d. case, when fading parameter m goes from $m_1 = 1, m_2 = 1$ to $m_1 = 2, m_2 = 3$, a gain of 4 dB in SNR is attained and when the value of average SER is 10^{-1} for $h_1 = 3, h_2 = 5$ that is for i.n.i.d. case, when fading parameters m goes from $m_1 = 1, m_2 = 1$ to $m_1 = 2, m_2 = 3$, a gain of 4 dB in SNR is attained. Now as the results depict that the system performance that is ASER is significantly improving for various values of m which is fading parameters. It can be seen that our results reduce to Rayleigh fading channels at particular values as special cases.

5.2 ASER OF RQAM FOR AF TWO-WAY RELAYING NETWORK

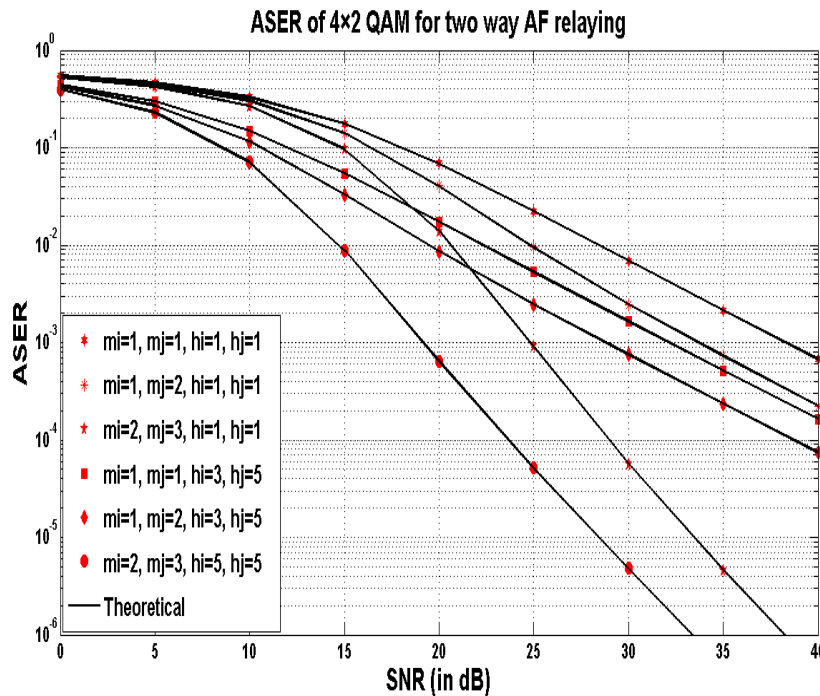


Figure 5.4 ASER of 4×2 QAM for AF two-way relaying network

This section presents the comparison between the exact closed-form expressions of average symbol error rate calculated using Mathematica and Monte Carlo simulations and give the

effect of fading parameter m on the performance of the system. The solid lines in figures depict the theoretical results for average SER, which are attained by the analytical expressions given in chapter 4, while the other lines (dashed lines) depicts the simulation results.

Figures in this section depicts theoretical results and simulated results for ASER for RQAM and XQAM schemes in AF two way relaying network (TWRN) over independent but not identical distributed (i.n.i.d) Nakagami- m channels. Graphs depicts curves of ASER versus transmit SNR (in dB) for different values of m which is fading parameter. It can be seen that the improvement in ASER below 10 dB is not observable for even better fading environments, but when we increase the value of SNR system performance that is ASER improves significantly with the increasing value of fading parameter.

In figure 5.4 ASER for 4×2 QAM for amplify and forward two-way relaying network for Nakagami- m channel for integer value of m which is fading parameter. In case of 4×2 QAM the value of M is equal to $M_I \times M_Q$ and here $M_I = 4$ and $M_Q = 2$ so M is equal to 16, so it is called 16 QAM. This figure highlights the effect of changing of fading parameter m on the performance of the system.

Now as we can see from the figure when the value of average SER equals to 10^{-2} for $h_1 = h_2 = 1$ that is for i.i.d. case, when fading parameters change from $m_1 = 1, m_2 = 1$ to $m_1 = 1, m_2 = 2$, a gain of 3 dB in SNR is attained and when the value of average SER equals to 10^{-2} for $h_1 = 3, h_2 = 5$ that is for i.n.i.d. case when fading parameters change from $m_1 = 1, m_2 = 1$ to $m_1 = 1, m_2 = 2$, a gain of 2.5 dB in SNR is attained. From the curves, we can see that when for different links the value of fading parameter m is increased, then an improvement in diversity order of the system is observed.

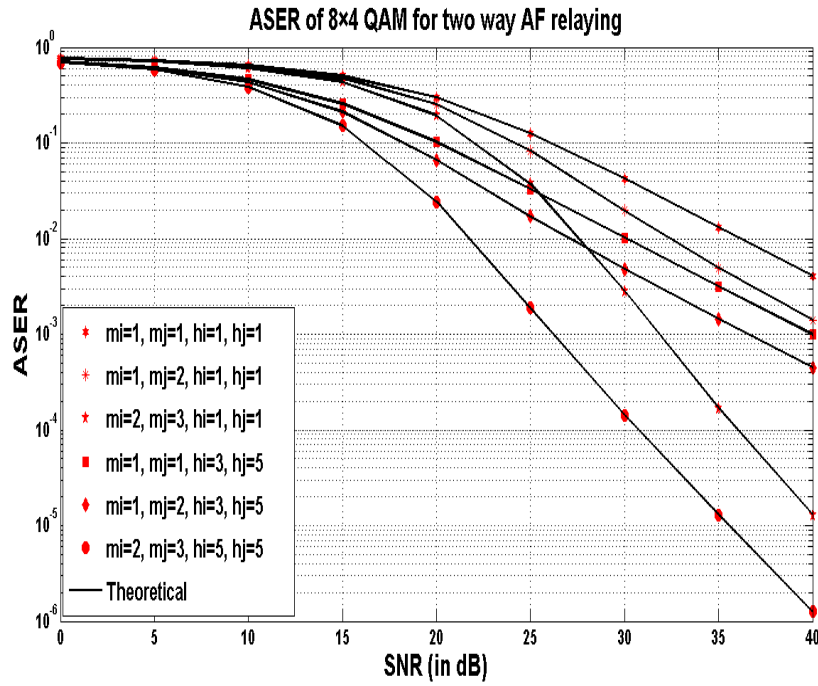


Figure 5.5 ASER of 8×4 QAM for AF two-way relaying network

In figure 5.5 ASER for 8×2 QAM for amplify and forward two way relaying network for nakagami-m channel for integer value of m which is fading parameter. In case of 8×2 QAM the value of M is equal to $M_I \times M_Q$ and here $M_I = 8$ and $M_Q = 4$ so M is equal to 32, so it is called 32 QAM. This figure highlights the effect of changing of fading parameter on the system performance.

Now as we can see from the figure when the value of average SER is 10^{-1} for $h_1 = h_2 = 1$ that is for i.i.d. case, when fading parameters m goes from $m_1 = 1, m_2 = 1$ to $m_1 = 2, m_2 = 3$, a gain of 4 dB in SNR is attained and when the value of average SER is 10^{-1} for $h_1 = 3, h_2 = 5$ that is for i.n.i.d. case, when fading parameters m goes from $m_1 = 1, m_2 = 1$ to $m_1 = 2, m_2 = 3$, a gain of 3.5 dB in SNR is attained. Now as the results depict that the system performance that is ASER is significantly improving for various values of m which is fading parameters. It can be seen that our results reduce to Rayleigh fading channels at particular values as special cases.

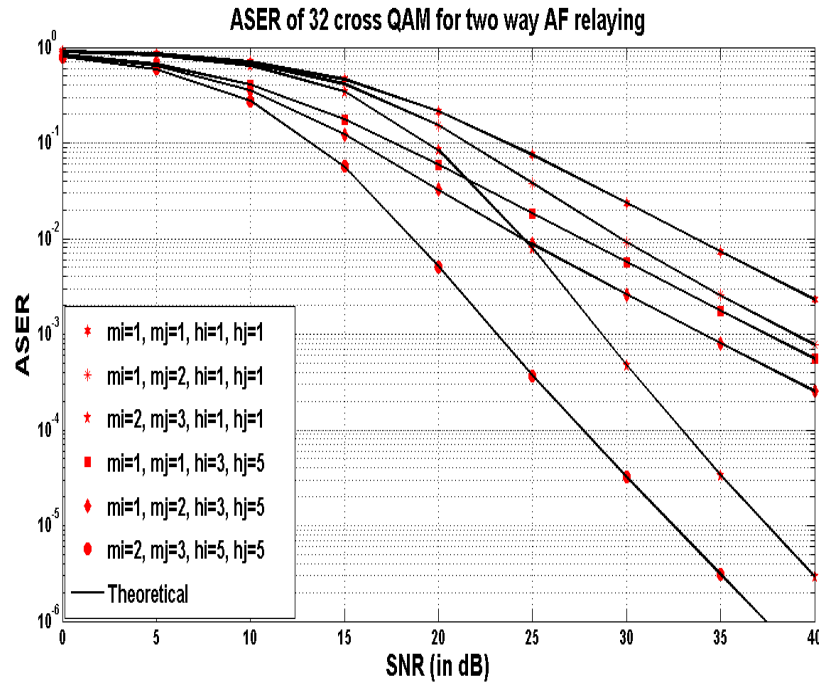


Figure 5.6 ASER of 32 cross QAM for AF two-way relaying network

In figure 5.6 ASER for 32 cross QAM for amplify and forward two way relaying network for nakagami-m channel for integer value of m which is fading parameter. In case of 32 cross QAM the value of M is equal to 32, so it is called 32 cross QAM. This figure highlights the effect of changing of fading parameter m on the performance of the system.

Now as we can see from the figure when the value of average SER is 10^{-1} for $h_1 = h_2 = 1$ that is for i.i.d. case, when fading parameters m goes from $m_1 = 1, m_2 = 1$ to $m_1 = 2, m_2 = 3$, a gain of 4.25 dB in SNR is attained and when the value of average SER is 10^{-1} for $h_1 = 3, h_2 = 5$ that is for i.n.i.d. case, when fading parameters m goes from $m_1 = 1, m_2 = 1$ to $m_1 = 2, m_2 = 3$, a gain of 4.5 dB in SNR is attained. Now as the results depict that the system performance that is ASER is significantly improving for various values of m which is fading parameters. It can be seen that our results reduce to Rayleigh fading channels at particular values as special cases.

CHAPTER-6

CONCLUSION AND FUTURE SCOPE

This chapter concludes the dissertation which has assembled a comprehensive study and analysis of a two way amplify and forward (AF) cooperative diversity communication system model under various fading environments and over a range of signal-to-noise ratios.

By using analytical evaluations and Monte Carlo simulation, the values of performance parameter like average symbol error rate have been verified. This attains the task to show that two way AF cooperative networks provides a promising technique to deal with the serious fluctuations or fading produced in a wireless fading environment as well as it provides higher data rates to meet the demands of the modern wireless applications. The cooperative communication system provides reasonable reliability such that it can be used in wireless ad-hoc networks, cellular networks and wireless sensor networks to overcome the restrictions of size and the transmitter power.

Basic two-way amplify and forward cooperative diversity communication system model is a strong technique that can find many new applications in different areas of research in wireless communication engineering. The analysis given in this dissertation can also be applied to many other fading scenarios. The analysis mentioned in this dissertation can also be extended other diversity techniques like Equal Gain Combining and Selection Combining and it can also be extended to two-way decode and forward relaying network for different fading channels like nakagami, two-wave with diffuse power, $k-\mu$ and $\eta-\mu$ fading channels.

As a scope for future research, the performance of the system model given in the dissertation can be evaluated for two-wave with diffuse power (TWDP) fading channel for different fading parameters. The TWDP model considers that received signal at the receiver has two relatively strong multipath components and many low power diffuse components.

It is suggested that the evaluation of two wave with diffuse power fading channel with two-way amplify and relaying networks will provide more efficient evaluation of performance of communication systems which are based on mobile wireless communication.

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