ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSTITUTE OF TECHNOLOGY
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PERFORMANCE ANALYSIS OF SPACE TIME CODING ON MIMO AND COOPERATIVE DIVERSITY SYSTEM

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A thesis submitted to the school of Graduate studies Addis Ababa University in partial fulfillment of the requirements for the degree of Masters of Science in Communication Engineering

July, 2011

Declaration

I, the undersigned, declare that this thesis work is my original work, has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been fully acknowledged.

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Date of submission

This thesis has been submitted for examination with my approval as a university advisor.

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DEREJE GIRMA BIRRU

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Abstract

In a wireless network, users can relay information to exploit cooperative diversity, thereby increasing reliability. The uses of multiple transmit and receive antennas (MIMO) can help to exploit transmit and receive diversity respectively. This thesis discusses the application of a technique called space time block coding (STBC) on a system based on the joint use of cooperative diversity and MIMO schemes, which we hope intuitively that the system performance can be increased further. A source node, equipped with two transmits antennas, first encodes incoming data using STBC and then broadcasts the resulting code to relay and destination nodes. Then, the two relay nodes, each equipped with single antenna, either amplify-and-forward (AF) or decode-and-forward (DF) the received codes to the destination. The destination node combines (e.g., using maximum ratio combining (MRC)) signals received from the source's and relay's antennas and decodes the combined signal in order to recover the original data. As the signals from the source and relay are received through different paths, which are assumed to be spatially independent, spatial diversity can be exploited. Compared with point-to-point transmission system and simple Alamouti STBC system with no relays, AF based STBC system obtains one additional benefit, achieving spatial diversity offered by the relays. Moreover, the STBC-based DF cooperative system has two additional benefits. First, it achieves the spatial diversity offered by the relay channel and secondly, it has the ability to introduce the characteristics of STBC into the relay system. In addition, the system model and performance evaluation of these systems in various channel conditions and modulations (using simulation) will be addressed.

Acknowledgements

First of all, I would like to take this opportunity to thank the National Metrology Institute for giving me the chance to carry out my graduate study in Electrical Engineering. Secondly, I am highly thankful towards my advisor Dr.Ing. Dereje Hailemariam for his positivity, support and excellent advice throughout my thesis work.

I am also thankful to my mother for her contribution in one way or the other. Finally, I would like to thank all AAU AAiT instructors who taught me during my graduate study.

Contents

LIST OF FIGURES

LIST OF TABLES

List of Abbreviations

BPSK Binary Phase-Shift Keying

PEP pair wise error probability

CSI Channel-State Information

UMTS Universal Mobile Telephone System

GSM Global System for Mobile Communication

MAC Medium-Access Control Layer

SNR Signal-to-Noise Ratio

TDMA Time-Division Multiple Access

BS Base Station

MS Mobile Station

ASK Amplitude Shift Keying

PSK Phase Shift Keying

4-PSK 4 Phase Shift Keying

3-PSK 3 Phase Shift Keying

FSK Frequency Shift Keying

AWGN Additive White Gaussian Noise

CDMA Code-Division-Multiple-Access

STC Space time coding

FDMA Frequency Division Multiple Access

ISI Inter-symbol Interference

MIMO Multiple-Input Multiple-Output

MISO Multiple-Input Single-Output

SIMO Single-Input Multiple-Output

SISO Single-Input Single-Output

MRC Maximum-Ratio Combining

QPSK Quadrature Phase Shift Keying

1 INTRODUCTION

Relying on the propagation of electromagnetic waves in free space, wireless communications has given people the freedom to communicate from almost anywhere, even when they are traveling. However, the wireless channel has proven to be quite bad as the signals suffer significant attenuation, shadowing, noise, interference, etc [1]. Among the countless efforts to guarantee the quality of service under this bad environment, this thesis focuses on how to combat path loss and fading.

Path loss, or large-scale path loss, significantly reduces the strength of transmitted signals such that the signal-to-noise-ratio (SNR) at the receiver can be very low. Model for the path loss suggest a direct relationship between the path loss and the transmitted distance [1]. To combat the path loss, the transmitter power can be increased. However, the power can not be increased without limit. Another method is to place some repeaters between the transmitter and receiver to periodically amplify the signals or detect and regenerate the signals. The latter method proves to be more efficient than increasing the power.

Fading, also called the small-scale path loss, comes from the multipath propagation of signals. Fading significantly degrades the performance of wireless communication systems. For example, the probability of error for binary-phase-shift-keying (BPSK) in the additive white Gaussian noise channel decreases exponentially in SNR. However, if Rayleigh fading is considered, the probability of error only decreases as 1/SNR [2].Transmitter power control, time, frequency and spatial diversity are the different techniques to combat fading in a wireless channel. Transmitter power control method is not practical due to radiation power limitation and cost of power amplifier, and wastage in bandwidth due to feed back channel information. Both time and frequency diversity have also their own limitations as they increase transmission delay and bandwidth utilization, respectively. Among the diversity techniques, multiple transmit or receive antennas at the same terminal are often desirable for spatial diversity as they do not increase transmission delay or bandwidth. The signal present at each receive antenna is the combination of signals from the transmit antennas, after each has traveled through possibly different fading channels. Here, to insure independent fades across different antennas or to achieve full diversity gain, the spacing of antennas should be greater than the coherent distance.

Space time block coding (STBC) is one coding technique used in MIMO systems. Using STBC, multiple copies of a data stream are sent across a number of antennas. Alamouti invented the simplest code of all STBC, Alamouti code, which is designed for two transmit antenna system[3].

However, in many scenarios, such as in cellular, ad hoc, or sensor networks, multiple antennas is not often practical due to the size limitations of terminals. Cooperative diversity combines the idea of intermediate repeaters and multiple antennas. It avoids the size limitations of multiple antennas at the same terminal and provides spatial diversity by allowing the terminals to relay in parallel, thus sharing multiple antennas belonging to different terminals [4].

1.1 Background

The history of wireless industry started 100 years ago. This technology has removed many problems associated by cables. Today, life does not seem possible without wireless in some form or the other. Wireless technology is getting easy and comfortable. There is an increasing demand of bandwidth to get high data rate. Consequently, wireless designers face an uphill task of limited availability of radio frequency spectrum and complex time varying problems in the wireless channel, such as fading and multipath, as well as meeting the demand for high data rates [5].

The gradual evolution of mobile communication systems follows the need for high data rates, measured in bits/sec (bps), and with a high spectral efficiency, measured in bps/Hz [5].

Table 1-1 A comparison of several standards based on data rate

No	Standards	generation	Operated frequency band	Supported data rate
1	GSM (Global system for Mobile Communication)	2G	1.8GHz	22.8 Kbit/s
2	UMT (Universal Mobile Telephone System)	3G	2GHz	38.4kbit/s-2Mbit/s
3	LTE (Long term Evolution)	4G	1.4MHz-20MHz	100Mb/s-1Gbit/s

The 2G and 3G standards are not sufficient to meet the demand for high data rate. Future wireless broadband applications are likely to require data rates that are hundreds of megabits per second. Therefore, the new standard 4G (such as high data rate transmission and long range communication) is in the way to give full broadband service for fixed and mobile users and it uses the new technology called MIMO because it increases the spectrum efficiency. However, cooperative diversity (virtual MIMO system) is introduced due to practical constraints on the number of antennas at the mobile station. They can realize the advantage of MIMO system.

1.2 Literature survey

To minimize the effect of fading, a lot of researches have been done which most of them have mainly focused on either cooperative or MIMO schemes. We review some of the works in cooperative diversity that is related to our study.

Erkipet et al. investigated the diversity order of various processing schemes at the destination for cooperative diversity with up to two amplifying relays. The results show that the diversity order is equal to the number of independent links combined at the destination. Thus, a network with M relays can provide up to M+1 order diversity gain. On the other hand, the combination of correlated links does not provide diversity [6].

Stefanov et al. showed that cooperative diversity can be exploited together with spatial diversity from multiple transmit or receive antennas. However, it is not clear that whether the combination of cooperative diversity with multiple antennas will continue to substantially improve the performance if the number of relays or antennas is large [7].

Nosratinia et al. combined channel codes with cooperative diversity. A key feature is that the information sequences are not simply repeated by the partner on a symbol-by-symbol basis. Instead, he suggests partitioning the codeword of each user into two sub blocks; one subblock is transmitted by the user and the other by the partner whenever possible. This is referred to as “coded cooperation". It is shown that cooperative diversity with coding achieves impressive gains compared to a non-cooperative system given the same information rate, transmit power, and bandwidth [8].

Laneman et al. introduced cooperative diversity for the three-node cooperation. Several cooperative protocols were proposed and their outage behavior was analyzed. In this work, more practical consideration such as half duplex and orthogonality constraint based on TDMA was considered [9].

L. Chu et al. analyzed the performance of space-time coded cooperative system on slow, quasi-slow and fast fading channels, by deriving the upper bounds of the PEP. From the upper bounds, we could see that user cooperative space time coded system in wireless network can achieve full cooperation diversity gain and coding gains [10].

After reviewing most relevant works, we propose the joint use of cooperative diversity and MIMO (Alamouti cooperative system) with different modulation and channel conditions which we hope that the symbol error rate will be minimized further.

1.3 Statement of the problem

Nowadays, wireless channel has an application over a wide area but the performance of it is different from area to area because wireless channels feature fading, shadowing, interference, and other impairments that make the channel unpredictable. In today's wireless networks, there is an increasing demand for service quality, high data rates, network coverage, and lesser processing time. The scarcity of two fundamental resources for communications, namely, energy and bandwidth, is a serious challenge to fulfill these demands.

To achieve high service quality, high data rate, network coverage and lesser processing time a lot of obstacles exist which is caused by:-

- Energy and bandwidth constraint
- fading
- shadowing
- interference
- other impairments that make the channel unpredictable

Here in this thesis, a strong attention is given on the problem arrived because of fading. Fading affects the performance of wireless network by having an effect on the signal amplitude. As a result here, to overcome the problem, the joint use of MIMO and cooperative schemes is proposed as an alternative means of alleviating the problem arrived because of robust fading.

1.4 Methodology

The methods used to achieve the desired objectives of this thesis were as follows. First, literature reviews about MIMO and cooperative diversity were conducted. Second, we combined both MIMO and cooperative diversity and modeled the system, and then we programmed the system in Mathlab 7.0 software as a simulation tool. Finally, the results were interpreted and conclusion was drawn based on the results obtained.

1.5 Objective

General Objective

The general objective of this thesis is to study and introduce the performance of Alamouti cooperative system.

Specific Objective

The specific objectives of this thesis can be summarized as follows:

- To evaluate the performance of Alamouti cooperative schemes for various channel channel condition.
- To increase reliability of data transmission over time multipath fading channel.
- To compare the performance of Alamouti cooperative schemes with conventional (direct) and non cooperative Alamouti STBC systems.
- To compare the performance of AF based STBC system and DF based STBC system.

1.6 **Outline of the Thesis**

The work of this thesis is organized in to five chapters. Chapter 1 presents the introduction and objectives of this work. In Chapter 2, we are going to see some theoretical parts of wireless communication which are useful to understand the thesis work and in Chapter 3, we will discuss the comparison among simple space time block code with no relays, Amplify-and-forward based cooperative system for a two schemes, STBC based decode-and-forward cooperative system for a two schemes and then in Chapter 4, we will see the symbol error rate performance evaluation of these systems on various channel conditions and for different modulation techniques using simulation. Finally, in Chapter 5, we give conclusions and suggest future work that can consolidate this work.

2 WIRELESS COMMUNICATION

2.1 **Wireless Communication Systems**

The communication system consists of five basic things as shown in the figure 2.1 below.

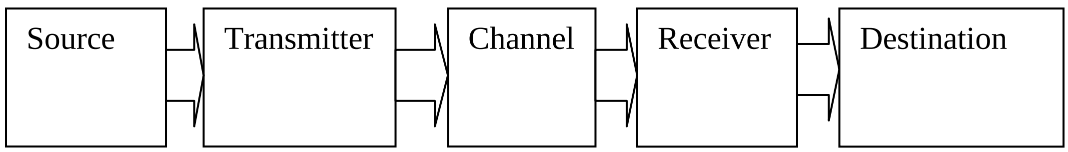

Figure 2-1 Wireless communication system

The source: generates the signal carrying message. The message may be either in analog such as speech signal or digital form like bit stream from computer.

The transmitter: produces a signal suitable for transmission to receiver over a specific channel. The frequency of the transmitted signal is always much higher than maximum frequency component of the message signal.

The channel: in the channel, during transmission, noise and interfering signals is added to the transmitting signal.

The receiver: tries to reproduce the original signal since the received signal is a corrupted version of transmitted signal.

The destination: it is a person or a thing to which the signal is intended.

2.2 Propagation Characteristics of the Radio Wave

The mobile radio channel experiences a lot of limitations on the performance of wireless systems. The transmission path can vary from line-of-sight to one severely obstructed by buildings and foliage. Unlike wired channels, radio channels are extremely random and do not offer easy analysis. The speed of motion, for example, impacts on how the signal level fades as the mobile terminal moves in space. This modeling is therefore based more on statistics and requires specific measurements for an intended communication system [5].

Reflection, diffraction, and scattering are the three basic propagation mechanisms for radio waves. Received power is generally the most important parameter predicted by large-scale propagation models and is based on these three phenomena[1].

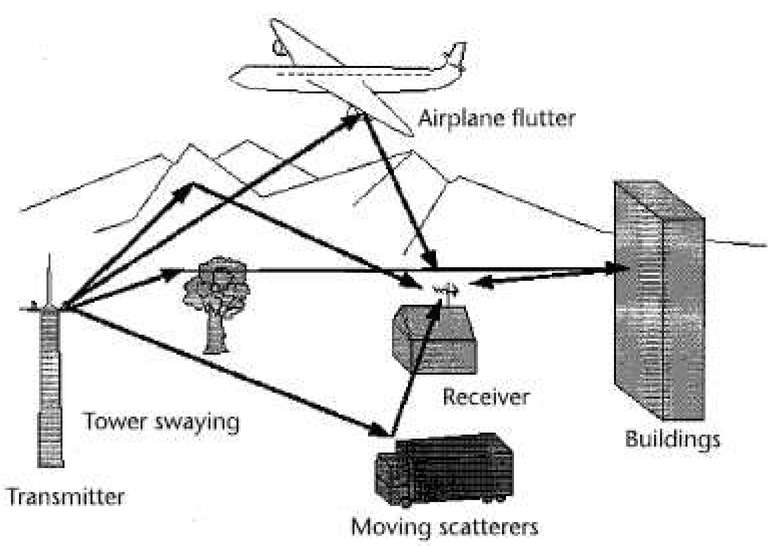

Figure 2-2 Multi-path propagation [5]

Propagation models based on average-received signal strength at a given distance from the transmitter are useful to estimate a radio coverage area and are called large-scale propagation models or macroscopic fading models. They are characterized by a large separation, usually a few kilometers, between the transmitter and receiver. On the other hand, propagation models that characterize the rapid fluctuations of the received signal strength over very short distances (a few wavelengths) or short time durations (on the order of seconds) are called small scale fading models or microscopic fading models.

Small-scale fading movements are rapid fluctuations, whereas large-scale fading movements are much slower average changes in signal strength. The statistical distribution of this mean is influenced by parameters like frequency, antenna heights, and environments [5].

2.2.1 Large-Scale Fading Channel

With path loss model, we can see relation between average received power, p_r and transmitted power signal, p_t .

$$\boldsymbol{p_r = k\frac{p_t G_t G_r}{d^n}} \qquad (2.1)$$

Where K is constant for fixed value of n, d is the separation distance between receiver and transmitter, G_r & G_t are the power gain of transmitted and received antenna respectively, and n is the path loss exponent. Equation 2.1 indicates the average received power is inversely proportional to the distance squared (in case of free space) or the distance to the power of n. The value of n is between 2 and 6 which depend on frequency, antenna height, and propagation environment. For free space and with direct line-of-sight, n is 2, whereas for an indoor transmission with so many obstacles it could be reach up to 6. The constant k for n=2 is given by:

$$K = \left[\frac{\lambda}{4\pi}\right]^2 \qquad (2.2)$$

where λ is the wave length. The gain of antenna is given in terms of effective aperture, A_e and λ wavelength by:

$$G = \frac{4\pi A_e}{\lambda^2} \qquad (2.3)$$

2.2.2 Small-Scale Fading Channel

For most practical channels, the above propagation model is inadequate to describe the channel and predict system performance. Small-scale fading or simply fading is used to describe the rapid fluctuations of the amplitude, phases, or multipath delays of a radio signal over a short period of time or travel distance, so that large-scale path loss effects may be ignored. Fading is caused by a number of signals (two or more) arriving at the reception point through different paths, giving rise to constructive (strengthening) vectorial summing of the signal or destructive (weakening) vectorial subtraction of the signals, depending on their phase and amplitude values. These different signals other than the main signal are called multipath waves. In addition to the multipath propagation, other factors that affect small-scale fading are speed of the destination, speed of surrounding objects, and signal bandwidth [1].

Multipath in a radio channel creates small-scale fading effects. These effects are commonly characterized as causing:

- Rapid changes in signal strength over a small travel distance or time interval.
- Random frequency modulation due to varying Doppler shifts on different multipath signals.
- Time dispersion (echoes) caused by multipath propagation delays.

Even when a line-of-sight exists, multipath still occurs due to reflections from the ground or surrounding structures. Assume that there is no moving object in the channel. In such a case, fading is purely a spatial phenomenon. In such a case, as the mobile moves, it encounters temporal fading as it moves through the multipath field. In a more serious case, the mobile may stop at a particular point at which the received signal is in deep fade. Maintaining good communication in that case becomes very difficult. Antenna diversity techniques can prevent this deep fade [1].

2.2.2.1 Types of small scale fading

Small scale fading can be can be categorized as slow fading vs. fast fading and flat fading vs. frequency selective fading based on time spreading of the signal and time variant nature of the channel.

Flat Fading

The coherence bandwidth of the channel, f_o, is greater than the bandwidth of the transmitted signal, $f = \frac{1}{T_S}$, where T_s is the symbol duration such that all frequency components of the signal will experience the same magnitude of fading. The coherence bandwidth, f_o, is a statistical measure of the range of frequencies over which the channel passes all spectral components with approximately equal gain and linear phase. For a single transmitted impulse, the delay spread T_m between the first and last received component represents the maximum delay during which the multipath signal power falls to some threshold level below that of the strongest component. Delay spread and coherence bandwidth is approximately related by [11]:

$$\boldsymbol{f_o \approx \frac{1}{T_m}} \qquad (2.4)$$

Flat fading could also be viewed, in time domain, to be the result of a multipath propagation whose delay, T_m , is so small compared to the symbol duration, T_s, that they add up to one undistorted signal (or the received signal is not distorted by Inter-symbol Interference (ISI)).

Frequency- Selective Fading

The coherence bandwidth of the channel is smaller than the bandwidth of the signal such that different frequency components of the signal will be affected differently by the channel. In the time domain, the multipath components of the signal will have significant time dispersion compared to the symbol period and this result in ISI.

Time Variant Nature of the Channel

The time-varying nature of the channel is caused by changes in the propagation path (because of a relative motion between the source and destination and/or by movement of objects within the channel). Thus, for a transmitted signal, the destination sees variations in the signal's amplitude and phase. The time variant mechanism will be characterized in the time domain by the channel coherence time, T_c, which is a measure of the expected time duration over which the channel is essentially invariant [11].

The coherence time of the channel is related to a quantity known as the Doppler spread of the channel. When a user (or reflectors in its environment) is moving, the user's velocity causes a shift in the frequency of the signal transmitted along each signal path. This phenomenon is known as the Doppler shift. Signals traveling along different paths can have different Doppler shifts, such that when they add-up at the destination, the resulting signal will have a broader (and possibly shifted) bandwidth than the transmitted signal. This is known as the Doppler spread, represented as f_d and measures this spectral broadening of the signal. In general, coherence time is inversely related to Doppler spread and typically expressed as [11]:

$$f_d \approx \frac{V}{\lambda} \approx \frac{K}{T_c} \qquad (2.5)$$

Where V is the relative velocity, λ is the signal wavelength, and k is a constant taking value in the range of 0.25 to 0.5, T_c is the coherence time. The coherence time determines whether the channel can be described as slow fading or fast fading.

Slow Fading Channel:

It occurs when the coherence time of the channel is greater than the symbol duration of the transmitted signal, i.e, $T_c >> T_s$. In this channel, the amplitude and phase change imposed by the channel can be considered roughly constant over the period of channel use. . In a slow-fading channel, it is not possible to use time diversity because the transmitter sees only a single realization of the channel within its coherence time. A deep fade therefore lasts the entire duration of transmission and cannot be mitigated using channel coding.

Fast Fading Channel:

It occurs when the coherence time of the channel is small relative to the symbol duration of the transmitted signal, i.e., $T_c < T_s$. In this case, the amplitude and phase change imposed by the channel varies considerably over the period of channel use. In the fast-fading channel, the source, using time diversity, may take advantage of channel variations. Although a deep fade may temporarily erase some of a transmitted codeword, use of channel coding coupled with successfully transmitted bits during other time instances can allow the erased bits to be recovered [11].

2.2.2.2 Model of Small-Scale Fading

The equivalent low pass channel is given by:

$$\boldsymbol{h(\tau;t) = \sum_n \beta_n (t) e^{-j2\Pi f_c \tau_n t} \delta(t - \tau_n(t))} \qquad \textbf{(2.6)}$$

where $\beta_n(t)$ and $\tau_n(t)$ are the attenuation factor and propagation delay for n^{th} path. When the impulse response $c(\tau;t)$ is modeled as zero mean complex–valued Gaussian process, the envelope $|h(\tau;t)|$ at any instant time t is Rayleigh distributed.

In this case, the channel is called Rayleigh fading channel because if the multiple reflective paths are large in number and there is no line-of-sight signal component, the envelope of the received signal is statistically described by a Rayleigh probability density function given as:

$$\boldsymbol{p(x) = \begin{cases} \frac{x}{\sigma^2} e^{\frac{-x^2}{2\sigma^2}}, x \geq 0; \\ 0, otherwise \end{cases}} \qquad \textbf{(2.7)}$$

where x is the amplitude of the received signal, and $2\sigma^2$ is the mean power of the multipath signal envelope. When there is a dominant non-fading signal component, such as a line-of-sight propagation path, in addition to randomly moving scattered signal, the small-scale fading envelope is described by a Rician distribution and the resulting channel is called Rician fading channel. The Rician distribution for statistical model is given as [5]:

$$\boldsymbol{p(x) = \frac{2(1+K)}{\sigma^2} e^{-(K - \frac{(K+1)x^2}{\sigma^2})} I_o \ (2x\sqrt{\frac{K(1+K)}{\sigma^2}}) \ u(x)} \qquad \textbf{(2.8)}$$

Where u(x) is unit step function and I_o is the zero-order modified Bessel function of the first kind. The Rician distribution is often defined in terms of the Rician factor, K, which is the ratio of the power in the mean component of the channel to the power in the scattered component. In the absence of a direct path, K = 0 and the Rician PDF reduces to Rayleigh PDF, since $I_o(0) = 1$.

2.3 Wireless Channel Model

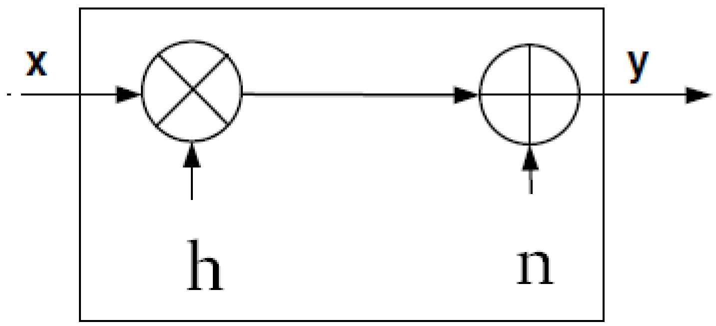

Figure 2-3 Channel model with fading coefficient **h** and noise **n**.

The received signal of this channel model is given by:

$$\boldsymbol{y} = \boldsymbol{h} * \boldsymbol{x} + \boldsymbol{n} \qquad (2.9)$$

where h is a new fading coefficient that combines both the large-scale fading and flat fading. The instantaneous SNR of the received signal can now be written as:

$$\boldsymbol{\gamma} = \frac{|\boldsymbol{h}^2|}{\boldsymbol{N_o}} \boldsymbol{p_t} \qquad (2.10)$$

And the average SNR is given by

$$\Gamma = \boldsymbol{E}[\boldsymbol{\gamma}] = \frac{\boldsymbol{E}[|\boldsymbol{h}^2|]}{\boldsymbol{N_o}} \boldsymbol{p_t} \qquad (2.11)$$

Where $E[.]$ is the expectation operation. For $|h|$ Rayleigh-distributed random variable representing the magnitude of the fading term, the random variable $|h|^2$ corresponding to the signal's power, is exponentially distributed [11].

Flat and slow fading, which is one case of small-scale fading where there is no ISI and the channel remains the same during the period of channel use, with the large-scale fading is considered here in this channel.

We assume the echo delay is small compared to the symbol duration and as a result there is no ISI. Flat fading channel is assumed.

2.4 **Introduction to Antenna**

Recently multiple antenna technologies are emerging to achieve high data rate, high reliability and large coverage areas. Therefore antenna has a vital role in the design of wireless communication system.

Antenna is usually a metallic device used to radiate electromagnetic wave or receive radio waves efficiently. There are different kinds of Antenna for different applications. To choose suitable antenna for the correct application, we should carefully consider the four main characteristics of an antenna.

A. **Antenna Radiation Patterns**

Antenna radiation pattern is a plot of radiation properties of antenna that can be done in both 2-D and 3-D. In 2-D, there are two planes corresponding to the vertical and horizontal plane of the antenna. The behaviors of the antenna in the vertical plane are described by the elevation pattern. The behavior of the antenna in the horizontal plane is described by the azimuth pattern. Combining the two graphs together, we get a 3-D plot of the radiation pattern.

B. Power Gain

Power gain is the parameter that we usually see on the datasheets of the antenna. It is the ratio of the power output from the antenna to the power input to the antenna. The unit that is used to describe the power gain is dBi. The “i” stands for the isotropic antenna. The isotropic antenna is used as reference antenna since it has perfect spherical radiation pattern and unity gain.

C. Directivity

Directivity is a measure of how good an antenna can direct its power in a particular direction**.** One can measure the directivity by taking a ratio of radiation intensity to the radiation angle. Usually, directivity and power gain is proportional to one another. An antenna that has high directivity usually has higher power gain since it can concentrate its radiation in one direction rather than radiate into arbitrary direction.

D. Polarization

Polarization is a very important concept in antenna use and design. One can have the best antenna and still get poor reception if the polarization of signal and the antenna do not match. To get maximum performance from the antenna the polarization of transmitting antenna must match to receiving antenna.

Polarization is the orientation of Electric field. It is a convention to refer to only E field when we talk about EM waves in general, since we only need E field to know the direction of H field. Several type of polarization exists. The basics types are Linear, Circular and Elliptical. If the vector that describes the electric field at a point in space as a function of time is always directed along a line, the field is said to be linearly polarized. In general, however, the figure that the electric field traces is an ellipse, and the field is said to be elliptically polarized. Linear and circular polarizations are special cases of elliptical, and they can be obtained when the ellipse becomes a straight line or a circle, respectively [12].

2.5 System Model of Point-to-Point Transmission

In today's wireless network implementations, channel coding and modulation are the widely used techniques. Channel coding is used to detect and possibly correct transmission errors whereas modulation is used to transmit messages into the wireless channel. The modulator sends the block **x** through the channel. The channel outputs a block **y** which is a distorted version of the block **x**. Based on the block **y**, the detector and demodulator generates the estimate, $\hat{u}$ which is further processed by the channel decoder. The aim of channel coding and modulation is to minimize the bit errors between **u** and $\hat{u}$ given the allowed rate R and other constraints, for example the transmission power or energy [11].A general point-to-point communication system model is shown in Figure2.4.

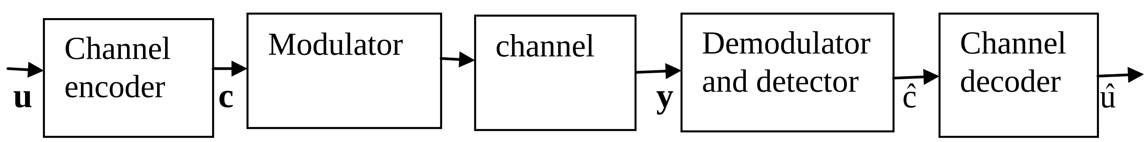

Figure 2-4 System model of point-to-point transmission

2.6 Modulation and Demodulation

Modulation is used in order to transmit coded bits over the wireless channel as it is not possible to send bits directly into this channel. A modulator in a digital communication system maps a sequence of L bits from the output of a channel encoder into a set of corresponding 2^L waveforms. The waveforms are selected such that their characteristics, e.g., bandwidth, match that of the channel [11]. There are different kinds of modulations. We are choosing one of them in such a way that it optimizes the performance in terms of symbol error rate.

Amplitude Shift Keying (ASK)

The 2^L waveforms have a similar shape but differ in amplitude in accordance with the information signal.

Frequency Shift Keying (FSK)

The 2^L waveforms have a similar shape but differ in frequency in accordance with the information signal.

Phase Shift Keying (PSK)

It is similarly to FSK but instead of frequency, the phase of the carrier signal changes in accordance with information signal.

Although the modulated signals are often continuous-time and passband (i.e., centered at carrier frequencies ranging from kHz to GHz), it is often conceptually convenient to model them as discrete-time and baseband (i.e., centered at 0 Hz) signals. Baseband-equivalent models are convenient because they suppress the issues of frequency up- and down-conversion and discrete-time models are attractive because architectures designed for them can be efficiently implemented in digital signal processing hardware[11].

Assuming discrete-time and baseband equivalent representation of a signal, the modulator can be described as an alphabet of 2^L complex numbers and it is not necessary to consider the shape of the waveform.

Each $\boldsymbol{x_i}$ is used to scale the amplitude of the waveform in ASK, shift the phase in PSK, or shift the frequency in FSK. To mention two examples: Binary Phase-Shift Keying (BPSK) with alphabets $\mathbf{X}= \{-1, +1\}$, where each symbol carries L = 1 bit, and Quadrature Phase

Shift Keying (QPSK) with $\mathbf{X} = \{-j, -1, j, 1\}$, where each symbol carries L = 2 bit. In M-ary phase-shift keying (M-PSK), $\boldsymbol{x_i}$ is taken from the alphabet

$$x = \left\{ \sqrt{E_s}, \sqrt{E_s} \exp^{j 2\Pi / M}, \ldots, \sqrt{E_s} \exp^{j 2\Pi (M-1) / M} \right\}$$

Where E_s is energy per symbol. In a block-based transmission of Figure1.8, the modulator maps the codeword **c** of n coded symbols to a block $\boldsymbol{x} = (\boldsymbol{x}_1, \boldsymbol{x}_2, \ldots, \boldsymbol{x}_m)$ of m = n/L symbols where each **x**i is from the X. The rate of both the channel encoder and modulator is defined as R = k/m = (k/n) ·(n/m) = Rc · L[11].

We note here that by increasing L, the data rate can be increased as a single modulated symbol contains more number of coded bits. However, when the energy of the waveform is fixed, the Euclidean distance between the constellation points decreases and the probability of wrong detection increases as well. The Euclidean distance can be increased by increasing the energy of the waveform; however, this may not be desired for energy efficiency reasons or to decrease interference to other nodes [11].

2.7 Information theory

The main goal of information theory is to determine the ultimate data compression (the entropy H) and ultimate transmission rate of communication (the channel capacity) which are fundamental issue in communication theory.

2.7.1 Entropy

Entropy of the source is the average self information (number of bits) per source letter. When $\boldsymbol{x}$ represents the possible output letters from the source with probability function $\boldsymbol{p}(\boldsymbol{x})$, the entropy of the source $\boldsymbol{H}(\boldsymbol{x})$ is defined as follows:

$$H(x) = \sum p(x)\, log_2\, p(x) \qquad (2.12)$$

The conditional entropy, $H(x/y)$, is the average amount of uncertainty (conditional self information) in x after we observe y.

$$H\left({}^{x}/_{y}\right) = \sum_x \sum_y p(x,y)\, log_2 \frac{1}{p\left({}^{x}/_{y}\right)} \qquad (2.13)$$

2.7.2 Mutual information

The average mutual information (the reduction in uncertainty due to another random variable) can be expressed as:

$$I(x;y) = H(x) - H\left({}^{x}/_{y}\right) = \sum_{x,y} p(x,y)\, log_2 \frac{p(x,y)}{p(x)p(y)} \qquad (2.14)$$

I(x;y)=0 if both x and y are independent random variables.

2.7.3 Capacity of Additive White Gaussian Noise Channel

Consider a discrete-input, continuous-output channel. A block $x = (x_1, x_2, \ldots x_m)$ is transmitted by the modulator, where each input symbol, x_i, for $1 \leqslant i \leqslant m$, is drawn from the alphabet X [11]. The AWGN channel is modeled by:

$$y_i = x_i + n_i \qquad (2.15)$$

where n_i is the zero-mean Gaussian random variable with variance N. This channel is a typical example of a discrete-input, continuous-output channel. The output y_i of the channel is continuous (or unquantized) and can assume any value on the real line, i.e., Y = $(-\infty, \infty)$.

Assume that the power constraint on the input block is given as:

$$\frac{1}{m}\sum_{i=1}^{m} x_i^2 \leq p \tag{2.16}$$

This channel is described by the conditional probability density function p (**y**i|**x**i). The capacity of this channel is the maximum rate in bits per channel use at which we can send data over the channel so that the error probability can be made as close to 0 as desired. The capacity, in bits per channel use, is the maximum average mutual information between the discrete input **x**i ∈ X and output **y**i ∈ (−∞,∞) and is given as:

$$C = max_{p(x)}\, I(x; y) \tag{2.17}$$

where P(**x**i) is the probability that **x**i is sent, and I(**x**i; **y**i) is referred as mutual information and physically represents the amount of information that can be deduced about **x**i, based on observing **y**i. The capacity is maximum when x is Gaussian with zero mean and variance p (power constraint).The capacity for the Gaussian channel is given as:

$$C = \frac{1}{2} log_2\left(1 + \frac{p}{N}\right) \; bits\ per\ sample \tag{2.17}$$

The capacity in Equation (2.17) is sometimes called Shannon capacity or the instantaneous capacity. In a case of band limited channel which is the common model over radio network or telephone line, we will have a white Gaussian noise with variance N/2 and a signal of approximately w samples per second according to the Nyquist-Shannon sampling theorem In this case, the energy per sample is p/2w.The Shannon capacity per sample becomes:

$$C = \frac{1}{2} log_2\left(1 + \frac{p/2w}{N/2}\right) = \frac{1}{2}\log_2(1 + \frac{p}{Nw}) \; bits\ per\ sample$$

For 2w samples per second, the capacity becomes:

$$\boldsymbol{C = w\,log_2\left(1+\frac{p}{Nw}\right)\ \ bits\,per\,second} \tag{2.18}$$

2.8 The Factors of Wireless Communication

The channel capacity result is the reason for today wireless MIMO communication research and application. The analysis of information theory based channel capacity is used to determine the maximum transmission data rate between the transmitter and receiver and it provides information how the channel model or the antenna configuration affects the transmission rate[13][14].

2.8.1 Channel Capacity for SISO

Assuming the single channel corrupted by an additive white Gaussian noise (AWGN), the capacity can be expressed as:

$$\boldsymbol{C = log_2(1+\gamma|h|^2)\ \ bit/sec/Hz} \tag{2.19}$$

where γ is signal to Noise ratio (SNR).

2.8.2 Channel Capacity for MISO and SIMO

The capacity for MISO or SIMO can also be expressed as:

$$\boldsymbol{C = log_2(1+\gamma h h^*)\ \ bit/sec/Hz} \tag{2.20}$$

2.8.3 Channel Capacity for MIMO

Let the number of antennas at the transmitter and receiver side is N, M respectively. When the channel is unknown at the transmitter, the capacity is expressed as follows:

$$\boldsymbol{C = log_2[det\left(I_M + \frac{\gamma}{N} hh^*\right)]\ bit/sec/Hz} \qquad \textbf{(2.21)}$$

where $\boldsymbol{I_M}$ is identity matrix. The capacity of MIMO channel increase when the number of antenna elements grows. We can say generally the capacity increase linearly with smallest number of antennas min (N, M) .For equal number of antennas, M = N, the capacity can be expressed as [5]:

$$\boldsymbol{C \approx M\, log_2(1 + \gamma |h|^2)\ bit/sec/Hz} \qquad \boldsymbol{(2.22)}$$

The equation clearly shows that capacity increase linearly with the M.

3 COOPERATIVE DIVERSITY AND SPACE TIME CODING

In this Chapter, we are going to see cooperative diversity and its application. In addition to this, we shall discuss the concept of space- time coding (STC) in cooperative diversity.

3.1 Cooperative diversity

The invention of new technology like, portable terminal (laptop), mobile terminal (cell phones) and consumer devices demand bandwidth. These demands are constantly increasing and frequency spectrum is too crowded. Moreover, we encountered challenge with both an operator and a subscriber side. The operator demands large coverage area (long distance communication) and high capacity (more users) whereas the subscriber demands high reliability (quality) and high data rate (speed). During design, engineers encounters uphill task to increase capacity, reliability and high data rate and large coverage so as to satisfy both the subscriber and the operator demands.

Before introduction of cooperative diversity, there was a popular technology called MIMO which is used to improve the performance of wireless communication in adverse propagation conditions such as fading, multi-path and interference. MIMO transmit different signals from each transmit antennas so that the receiving antennas received the superposition of all the transmitted signals. The main advantage lies on the possibility of transmitting signal over several spatial channels within the same time and frequency slot without extra power waste.

The advantage of MIMO in terms of increasing channel capacity, higher throughput, improved error performance, and better energy efficiency are well established by now. In practice, however, one limitation of MIMO is that installing multiple antennas on mobile station may not be feasible because of limitations in power, cost, and/or size. So transmit diversity may not be feasible in the uplink transmission as the mobile station can not support multiple antennas.

To overcome the above mentioned drawbacks of MIMO, distributed wireless nodes (active terminals or fixed relays) can be engaged in a cooperative fashion to extract antenna diversity. This mode of gaining antenna diversity is called cooperative diversity. In cooperative transmission, nodes can share their time, frequency, and/or other resources to form a distributed or virtual MIMO [4].

Cooperative diversity has recently attracted a lot of attention due to its ability to improve the system performance. Typically, cooperative diversity concerns a system where users share and coordinate their resources to enhance the transmission quality and optimize the power allocation. Cooperative diversity gains can be achieved through creating distributed virtual antennas across different terminals. Transmitting independent copies of the signal generates diversity and can effectively combat the fading. In particular, spatial diversity is generated by transmitting signals from different locations, thus allowing independently faded versions of the signal at the receiver. Cooperative diversity generates this diversity in a new and interesting way. It allows single-antenna mobiles in a multi-user scenario to “share” their antennas in a manner that creates a virtual MIMO system [15].

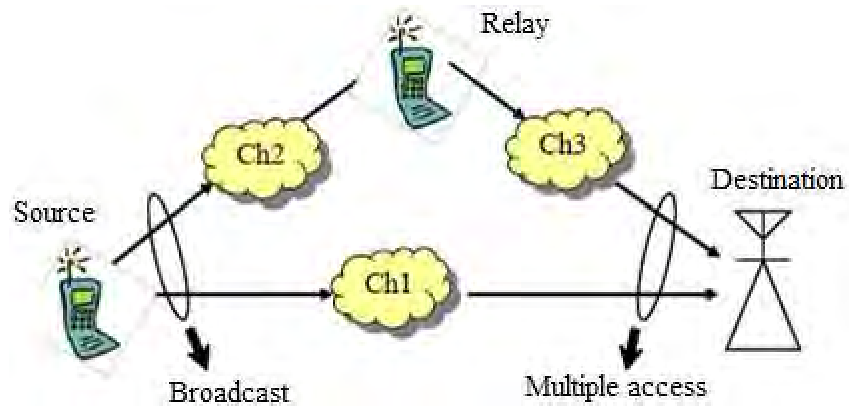

Figure 3-1 Illustration of cooperative diversity [16]

As shown in the Figure 3.1, a cooperative diversity system is composed of source, relay, and destination nodes. Source information is broadcasted to relay and destination nodes. Then, the relay node either amplifies-and-forwards (AF) or decodes-and-encodes the received information and forwards to the destination node. The Information signals that were transmitted from source and relay are multiple-accessed to destination, and then they are combined at the destination. So, cooperative diversity enables single antenna mobiles to generate a virtual multiple antenna transmitter by exploiting relay. Thus, it can achieve transmit diversity. It is also very useful when channel condition of direct path is inferior [16]. In a cooperative diversity system, each wireless user is assumed to transmit data as well as act as a cooperative agent for another user.

Cooperation leads to interesting trade-offs in code rates and transmit power. In the case of power, one may argue on one hand that more power is needed because each user, when in cooperative mode, is transmitting for both users. On the other hand, the baseline transmit power for both users will be reduced because of diversity. In the face of this trade-off, one hopes for a net reduction of transmit power, given everything else being constant.

Similar questions arise for the rate of the system in cooperative communication each user transmits both his/her own bits as well as some information for his/her partner; one might think this causes loss of rate in the system. However, the spectral efficiency of each user improves because due to cooperation diversity the channel code rates can be increased. Again a tradeoff is observed [15].

One may also describe cooperation as a zero sum game in terms of power and bandwidth of the mobiles in the network. The premise of cooperation is that certain (admittedly unconventional) allocation strategies for the power and bandwidth of mobiles lead to significant gains in system performance. In the cooperative allocation of resources, each mobile transmits for multiple mobiles [15].

3.1.1 Review of Cooperative Transmission Protocols

In this section, various cooperative protocols for the three-node cooperation are discussed. One way to view this cooperation is as an extension of the classical relay-channel system, which consists of a source, a relay, and a destination. Figure 3.2 shows a typical relay channel system in the uplink of the mobile communication system. The source broadcasts its message to the relay and destination in a first phase; the relay forwards the message it has received to the destination in a second phase. The destination recovers the source's information bits based on only the message received from the relay. Usually, the relay is located in the path between the source and destination to split a longer path into shorter segments so that the effect of overall path loss is reduced. Even more so, if energy and propagation environment constraints preclude Point-to-Point Transmission, relaying emerges as the only option to provide connectivity. However, spatial diversity is ignored in the relay-channel system. In the case of cooperative transmission, the relay node, after receiving the source's message, resends a processed version of this message to the destination. Consider the solid lines in the first phase of Figure 3.2 that indicate transmission of the source's message. Because of the broadcast nature of the wireless channel, the same message sent by the source is likely to be received by the destination as well. The destination combines the two copies received from the source and relay. This way, spatial diversity is exploited as the two messages are received from potentially uncorrelated channels (contrary to the relay-channel system). Moreover, depending on the location of the relay, cooperative transmission also benefits from the path-loss reduction as in the relay-channel system [11].

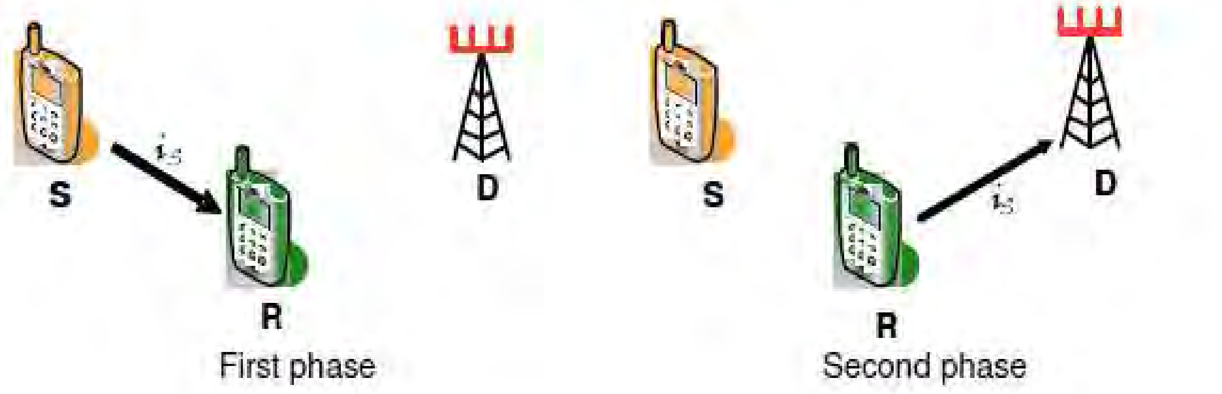

Figure 3-2 Relay-channel system in the uplink of the mobile communication system, where S, R, and D stand for the source, relay, and destination, respectively, and i_S is the message of the source [11]

In general, the cooperative protocols can be broadly categorized based on various parameters, to mention but few: relaying (forwarding strategy), level of adaptiveness to decoding error, and type of coding used in the second phase. Considering the relaying strategy at the relaying node, the relay can employ the following relaying strategies [11]:

Amplify-and-forward (AF):

Relay acts as analog repeater by retransmitting an amplified version of its received signals, which makes the noise increased [17]. In this relaying strategy, the partner simply forwards an amplified version of the received message (works in the analog domain) [9]. Although noise is amplified by cooperation, the base station receives two independently faded versions of the signal and can make better decisions on the detection of information.

In spite of the noise propagation, it was shown that amplify-and-forward can achieve full diversity gain, which is equal to two for one relay.

Decode-and-forward (DF):

In the decode-and-forward-based schemes, once the partner receives the source's message correctly it can employ the following coding strategies before forwarding the message to the destination.

In the repetition coding, relay attempts to decode, regenerate and retransmit an exact copy of the original signals, which potentially may lead to error propagation if the relay wrongly decodes the source's signal [11].

In coded cooperation (incremental redundancy coding), relay attempts to decode and construct codeword that are different from the received codeword, which thereby provides incremental redundancy to a receiver. This message is used as incrementally redundant information and code combining is used to combine it with the message received from the source in the first phase. One drawback of repetition coding and incremental redundancy coding is that all the resources in the second phase are dedicated to either the source or partner only. This leads to unfair cooperation especially when the source-partner and partner-source channels have different quality, where one user may forward for the other but not vice versa. To overcome this drawback, the following coding approaches are proposed [11].

The partner combines the source's message with its own message using space-time coding and forwards to the destination. Using this coding strategy, resource in the second phase is shared between the two users instead of being dedicated to one user. At the destination, this message is *"combined"* with the messages received in the first phase and then decoded to recover the source's message.

In the decode-and-forward-based protocol, when the inter-user channels are bad, the partner is more likely to forward an erroneous message. Moreover, when the source-destination channel is not very bad (or even better than the partner-destination channel), a high percentage of messages transmitted by the source are likely to be received correctly by the destination; in this case transmissions from the partner are a waste. To overcome these drawbacks, relaying protocols can be designed to adapt to decoding results at the partner and/or destination. This leads to further classification of protocols as static and adaptive [11].

Static protocols: In static (or fixed) protocols, the partner always forwards the source's message without checking errors. This protocol is easy to implement, but is exposed to error propagation [11].

Adaptive protocol: Here, the partner decides whether to forward or not, depending on its success of decoding the source's message. If successful, then it may forward the same message or a modified version of it. If decoding fails, then the partner has the options to switch to amplify-and-forward, or transmit its own message, or even remain silent [11].

3.1.2 Multiple Access

Cooperative diversity, as described previously, assumes that the destination can separately receive the original and relayed transmissions. This is accomplished by transmitting the two parts orthogonally so that they can be separated. The most straightforward method is separation in time, that is, the user's data and relayed data are transmitted in non overlapping time intervals. Orthogonality can also be achieved via spreading codes. In principle, it is also possible to achieve separation in frequency. Separation of signals is closely related to the issue of hardware requirements on the mobiles.

In cellular systems, even time-division multiple access (TDMA) ones, the uplink and downlink transmissions are performed on separate frequency bands. Ordinary mobiles receive only in the downlink band, but cooperative mobiles need to also receive in the uplink band, thus requiring additional input filters and frequency conversion.

3.2 Delay Diversity Scheme

Suppose we assume two transmit antennas and one receive antenna (this will be a multiple input and single output (MISO) channel). Initially, let us examine what will happen if we transmit the same signal simultaneously from both antennas. The received signal r may be expressed as:

$$\boldsymbol{r = \sqrt{\frac{E_s}{2}}(h_1 + h_2)s + n} \qquad \textbf{(3.1)}$$

where E_s is the average energy available at the transmitter over a symbol period and is evenly divided between the transmit antennas and n is additive white Gaussian noise sample at the receiver. We know from probability theory that the sum of two complex Gaussian random variables is also complex Gaussian. Hence, $\frac{1}{\sqrt{2}}(h_1 + h_2)$ is also complex Gaussian with zero mean and unit variance.

Hence, $r = \sqrt{E_s} hs + n$

where h is complex Gaussian with zero mean and unit variance. Therefore this technique does not give diversity. In the delay diversity scheme, we do not transmit the same symbol simultaneously from both antennas, but with a delay between the transmissions (i.e., we transmit the data signal from the first antenna and a delayed replica of the same signal from the second antenna after an interval). The effective channel as ‘‘seen’’ by the receiver now becomes two channels as given by [5]:

$$\boldsymbol{h[i] = h_1\delta[i] + h_2\delta[i], i = 0, 1, 2} \qquad \textbf{(3.2)}$$

From the point of view of the receiver, such a channel looks exactly like a two-path channel with independent path fading and equal average path energy. If we now employ a maximum likelihood (ML) detector at the receiver, we can capture full second-order diversity at the receiver. The negative side to this approach is that the method introduces interference between symbols and the complexities of the ML detectors rises exponentially with the number of transmit antennas. Hence, there was a need to look for an alternate approach. This need was fulfilled by Alamouti space time block code [5].

3.3 Alamouti Space-Time Block Code

The approach described by Alamouti is shown in Figure 3.3. The information bits are first modulated using an M-ary modulation scheme. The encoder then takes a block of two modulated symbols s_1 and s_2 in each encoding operation and gives it to the transmit antennas according to the code matrix [5].

$$\boldsymbol{s} = \begin{bmatrix} \boldsymbol{s_1} & -\boldsymbol{s_2^*} \\ \boldsymbol{s_2} & \boldsymbol{s_1^*} \end{bmatrix} \quad \textbf{(3.3)}$$

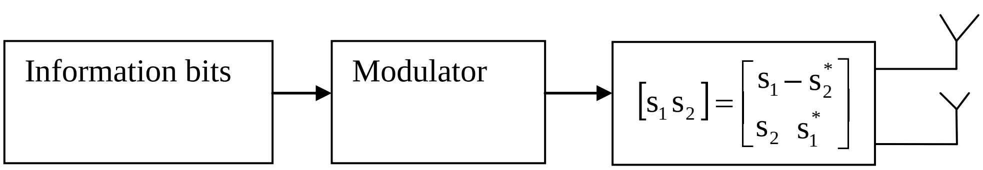

Figure 3-3 A block diagram of Alamouti space time encoder

Space-Time Block Codes (STBC), which is one of STC families, operate on a block of input symbols ,producing a matrix output whose columns represent time and rows represent antennas[18]. This implies that we are transmitting both in space (across two antennas) and time (two transmission intervals). This is space-time coding. STBC has the provision of full diversity with a simple encoding and decoding scheme. The sequences generated by the two transmit antennas are orthogonal. The orthogonality achieved in this cases enables us to achieve full transmit diversity, regardless of the code rate and additionally allows the receiver to decouple the signals transmitted from different antennas. For OSTBC (orthogonal space time block coding), the receiver can apply maximal-likelihood (ML) algorithm to easily decouple the two transmitted symbols. Obviously, OSTBC with two transmit antennas can not only get full diversity gain, full code rate and the optimal decoding delay, but also decode with low complexity. One can extend the scheme with two transmit antennas and one receive antenna to multiple transmit and receive antennas There exists a tradeoff between the code rate and bandwidth. So, in the process of designing the OSTBC matrix, we must maximize the code rate to save limited bandwidth and decrease the decoding delay as much as possible [19].

To put it in a nut shell, Alamouti described his scheme to the case of two transmit antennas and MR receive antennas and showed that the scheme provided a diversity order of 2MR. Characteristics of this scheme include [5]:

- No feedback from receiver to transmitter is required for channel state information (CSI) to obtain full transmit diversity.
- No bandwidth expansion (as redundancy is applied in space across multiple antennas, not in time or frequency).
- Low complexity decoders.
- Identical performance as MRC if the total radiated power is doubled from that used in MRC. This is because, if the transmit power is kept constant, this scheme suffers a 3-dB penalty in performance since the transmit power is divided in half across two transmit antennas.
- No need for complete redesign of existing systems to incorporate this diversity scheme. Hence, it is very popular as a candidate for improving link quality based on dual transmits antenna techniques, without any drastic system modifications.

3.4 Two Transmitter and One Receiver System

Two symbols are considered at a time, say s_1 and s_2, they are transmitted in two consecutive time slots. In first time slot, s_1 is transmitted from antenna one and s_2 is transmitted from antenna two. In the second time slot, $-s_2^*$ is transmitted from antenna one while s_1^* is transmitted from antenna two.

In the single-antenna receiver end, the two received signals in the first and second time slot can be expressed respectively as:

$$\boldsymbol{r_1 = h_1 s_1 + h_2 s_2 + n_1} \qquad (3.4)$$

$$\boldsymbol{r_2 = -h_1 s_2^* + h_2 s_1^* + n_2} \qquad (3.5)$$

where n_1, n_2 are the receiver additive white Gaussian noise. By applying the maximum ratio combining (MRC) in the receiver, we have the estimated signals as:

$$\boldsymbol{\widetilde{s_1} = h_1^* r_1 + h_2 r_2^* = (|h_1|^2 + |h_2|^2) s_1 + h_1^* n_1 + h_2 n_2^*} \qquad (3.6)$$

$$\boldsymbol{\widetilde{s_2} = h_2^* r_1 - h_1 r_2^* = (|h_1|^2 + |h_2|^2) s_2 + h_2^* n_1 - h_1 n_2^*} \qquad (3.7)$$

The combined detected signals just depend on their corresponding signals. Since diversity is characterized by the number of independent copies of the basic signal that was transmitted. In this way, dual diversity can be obtained. And also, the receiver just needs to make the maximum likelihood detection (MLD) which is used at the receiver to recover s_1 and s_2 for each of the transmitted signal.

The above system, which uses two antennas at the transmitter side and one antenna at the receiver side, has the ability to resist the influence of wireless fading channel and provide higher diversity (better system performance) than single link systems in wireless communications. However, when there is a further demand for high transmission quality in the condition of limited spectral resource and power consumption. With these requirements, the theoretical analysis of cooperative systems generates more spatial diversity in wireless scenarios in a new and interesting way.

3.5 **System Model**

In our model of the wireless channel, transmissions suffer from the effect of slow Rayleigh fading channels, in which the fading remains constant over the two symbol periods and also additive white Gaussian noise. In addition, practical system constraints such as orthogonal transmission and half-duplex constraints are considered (refer Figure 3.4). The orthogonal transmission constraint allows for the system to be readily integrated into existing networks and makes the analysis of error probability more tractable and convenient for exposition.

The orthogonality constraint is fulfilled by two preliminary solutions. First, cooperating users may agree to "timeshare" their transmission, so between the two they will create a mini-TDMA scenario where each transmits for 50 percent of the time at twice the power. A second solution is arrived at which more than one frequency band is allocated to the down link channel. Then the base station may require that cooperating mobiles reside on separate band. The medium access control (MAC) sub layer typically performs this function.

In this thesis, we will describe in detail the two scenarios of the STBC based cooperative communication systems as shown Figure 3.4 and 3.5, respectively. In the relay, we consider two relay functions, amplify-and-forward and decode-and-forward which are based on space time block coding (STBC).

3.5.1 Alamouti Cooperative System

This system consists of the base station with two transmit antenna, two relay single antenna terminal, and one destination single antenna terminal. In the first two time slot, the source base station transmits signal to the relay terminals and destination node. In the last two time slots, the relays transmit the signals received in the first two time slots to the destination.

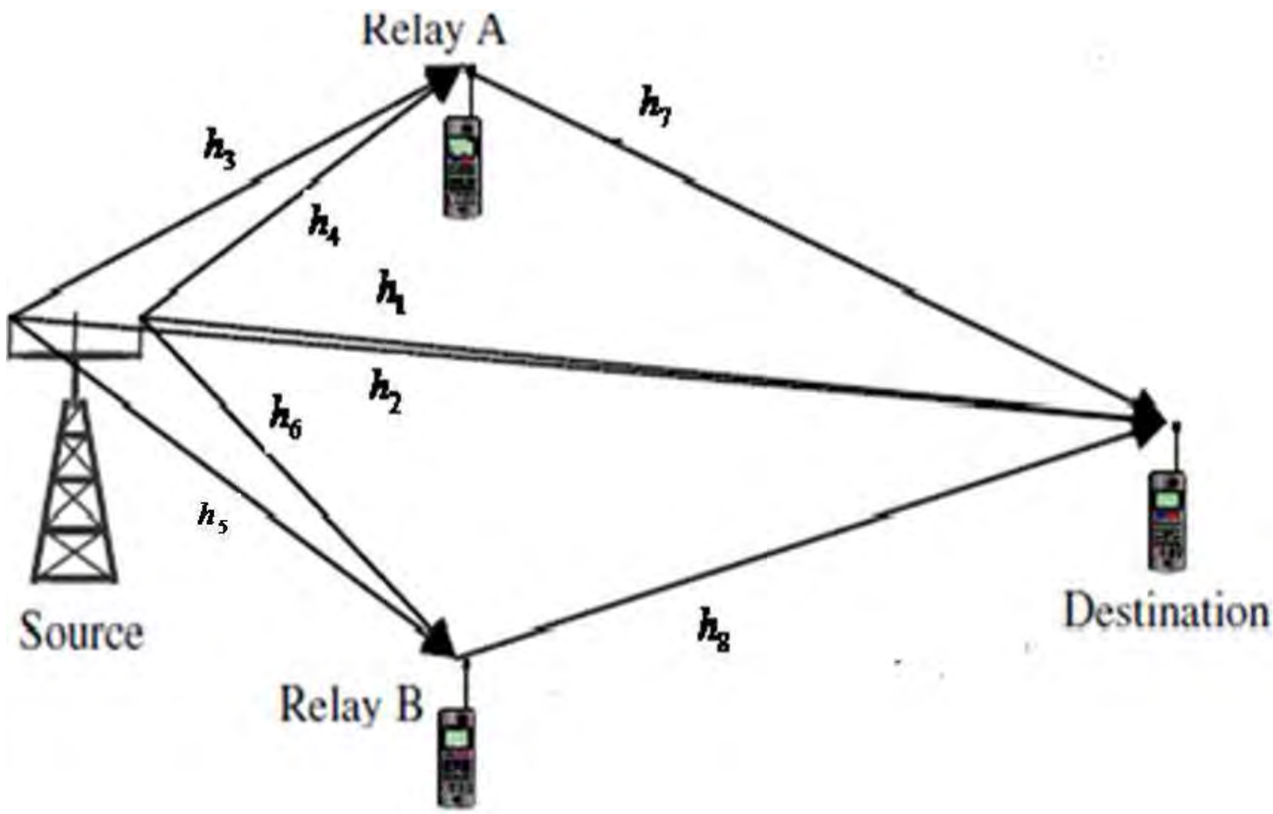

Figure 3-4 STBC based downlink cooperative system

At the destination node, the received signals in the first and second time slots respectively can be given as follows:

$$r_1 = h_1 s_1 + h_2 s_2 + n_1 \tag{3.8}$$

$$r_2 = -h_1 s_2^* + h_2 s_1^* + n_2 \qquad (3.9)$$

At the relay A, the received signals in the first and second time slots respectively can be given as follows:

$$r_3 = h_3 s_1 + h_4 s_2 + n_3 \qquad (3.10)$$

$$r_4 = -h_3 s_2^* + h_4 s_1^* + n_4 \qquad (3.11)$$

At the relay B, the received signals in the first and second time slots respectively can be given as follows:

$$r_5 = h_5 s_1 + h_6 s_2 + n_5 \qquad (3.12)$$

$$r_6 = -h_5 s_2^* + h_6 s_1^* + n_6 \qquad (3.13)$$

where r_1, r_3, r_5 are the received signals in the first time slot; r_2, r_4, r_6 are the received signals in the second time slot; $h_1, h_2, h_3, h_4, h_5, h_6$ are the channel attenuation amplitudes, which keep constant in the two symbol period, from the base station to the relay and the destination terminals; $n_1, n_2, n_3, n_4, n_5, n_6$ are the receiver white Gaussian noise in the two time slots of the destination and relay nodes.

The two relaying strategies, amplify-and-forward and STBC-based decode-and-forward, is presented next.

3.5.1.1 Amplify-and-Forward

In this relaying strategy, the relays receive and amplify the received signal and then forward the amplified signal to the destination. In this thesis, the amplification power is taken to be one for the simplification. In the last two time slots, the third and fourth time slots, the destination receives the signals as:

$$r_7 = h_7 r_3 + h_8 r_5 + n_7 \qquad (3.14)$$

$$r_8 = h_7 r_4 + h_8 r_6 + n_8 \qquad (3.15)$$

where h_7, h_8 are the channel attenuation amplitudes from the relay nodes to the destination node in these two time slots respectively. n_7, n_8 are the receiver additive white Gaussian noise of these two time slots respectively.

With the application of the maximum ratio combining (MRC) of the received signal from both the base station and the relay node, the destination node obtains the detected signal as:

$$\tilde{s}_1 = \tilde{s}_{1,d} + \tilde{s}_{1,r} \qquad (3.16)$$

$$\tilde{s}_2 = \tilde{s}_{2,d} + \tilde{s}_{2,r} \qquad (3.17)$$

Where

$$\widetilde{s_{1,d}} = h_1^* r_1 + h_2 r_2^* = (|h_1|^2 + |h_2|^2) s_1 + h_1^* n_1 + h_2 n_2^* \qquad (3.18)$$

$$\widetilde{s_{2,d}} = h_2^* r_1 - h_1 r_2^* = (|h_1|^2 + |h_2|^2) s_2 + h_2^* n_1 - h_1 n_2^* \qquad (3.19)$$

$$\widetilde{s_{1,r}} = H_1^* r_7 + H_2 r_8^* = (|H_1|^2 + |H_2|^2) s_1 + H_1^* N_1 + H_2 N_2^* \qquad (3.20)$$

$$\widetilde{s_{2,r}} = H_2^* r_7 - H_1 r_8^* = (|H_1|^2 + |H_2|^2) s_2 + H_2^* N_1 - H_1 N_2^* \qquad (3.21)$$

where

$$H_1 = h_7 h_3 + h_8 h_5, \; H_2 = h_7 h_4 + h_8 h_6 \quad , N_1 = h_7 n_3 + h_8 n_5 + n_7$$

$$N_2 = h_7 n_4 + h_8 n_6 + n_8$$

In this way, the instantaneous SNR of the detected signal γ_y is increased and for instance, the symbol error probability of BPSK modulation conditioned on the instantaneous SNR γ_y, $P_e = Q\left(\sqrt{2\gamma_y}\right)$, will be reduced and diversity order of four is obtained.

3.5.1.2 STBC-Based Decode-and-Forward

The relay nodes decode the received signal and then transmit the decoded signal using space time block coding to the destination. We assume here that the recovered signal at relay A and Relay B are equal($(s_1', s_2') = (s_1'', s_2'')$). The relay node A and relay node B recover the received signal as (s_1', s_2') and(s_1'', s_2'') respectively, where, s_1'= as_1 and $s_2' = bs_2$ $\quad a, b \in \{-1,1\}$

The destination gets the signal during the third and fourth time slots respectively as follows.

$$\boldsymbol{r_7 = h_7 s_1' + h_8 s_2' + n_7} \tag{3.22}$$

$$\boldsymbol{r_8 = -h_7 s_2'^* + h_8 s_1'^* + n_8} \tag{3.23}$$

With the application of MRC in the receiver end, the decision signal can be obtained as:

$$\boldsymbol{\widetilde{s}_1 = \tilde{s}_{1,d} + \tilde{s}_{1,r}} \tag{3.24}$$

$$\boldsymbol{\widetilde{s}_2 = \tilde{s}_{2,d} + \tilde{s}_{2,r}} \tag{3.25}$$

where

$$\widetilde{s_{1,d}} = h_1^* r_1 + h_2 r_2^* = (|h_1|^2 + |h_2|^2) s_1 + h_1^* n_1 + h_2 n_2^* \quad (3.26)$$

$$\widetilde{s_{2,d}} = h_2^* r_1 - h_1 r_2^* = (|h_1|^2 + |h_2|^2) s_2 + h_2^* n_1 - h_1 n_2^* \quad (3.27)$$

$$\widetilde{s_{1,r}} = h_7^* r_7 + h_8 r_8 = (|h_7|^2 + |h_8|^2) s_1 + (h_7^* n_7 + h_8 n_8^*) * a \quad (3.28)$$

$$\widetilde{s_{2,r}} = h_8^* r_7 - h_7 r_8^* = (|h_7|^2 + |h_8|^2) s_2 + (h_8^* n_7 - h_7 n_8^*) * b \quad (3.29)$$

In this case also, the instantaneous SNR of the detected signal γ_{y} is more increased as it extracts more transmit diversity from the relays because of STBC.

3.5.2 Virtual Alamouti Cooperative System

As for the transmission of this scheme shown in Figure 3-1, the source terminal broadcasts symbol block (s_1, s_2) to the relay and destination nodes in the first time slot. In the second time slot, the source and relay node transmit each of their symbol blocks to the destination node, which means the source transmits $(-s_2^*, s_1^*)$ and the relay sends the signal (s_1', s_2') with either Amplify-and-forward or STBC-based decode-and-forward to the destination. This transmission process is similar to virtual MIMO scheme.

Since we have two available time slots for transmission, the received signal in the first half and second half of time slot1 respectively at the destination can be expressed as follows:

$$r_{11,d} = h_1 s_1 + n_{11.d} \quad (3.30)$$

$$r_{12,d} = h_1 s_2 + n_{12,d} \quad (3.31)$$

The received signal in the first half and second half of time slot1 respectively at the relay can also be expressed as follows:

$$\boldsymbol{r_{1,r} = h_2 s_1 + n_{1,r}} \qquad (3.32)$$

$$\boldsymbol{r_{2,r} = h_2 s_2 + n_{2,r}} \qquad (3.33)$$

where $\mathrm{r}_{11,\mathrm{d}}$, $\mathrm{r}_{1,\mathrm{r}}$ are the received signal of the destination and the relay in the first half of time slot 1,repectively. $\mathbf{r}_{12,\mathrm{d}}$, $\mathbf{r}_{2,\mathrm{r}}$ are the received signal of the destination and the relay in second half of time slot 1. $\mathbf{n}_{11,\mathrm{d}}$, $\mathbf{n}_{12,\mathrm{d}}$, $\mathbf{n}_{1,\mathrm{r}}$, $\mathbf{n}_{2,\mathrm{r}}$ are the receiver additive white Gaussian noise of the time slot1.

The two relaying strategies, amplify-and-forward and STBC-based decode-and-forward, is also presented next for this scenario.

3.5.2.1 Amplify-and-Forward

In this relaying strategy, the relays just receive and amplify the received signal and then forward the amplified signal to the destination. In this thesis, the amplification power is taken to be one for the simplification. The received signal of the destination in the first half and second half time slot2 respectively from the source and the relay can also be expressed as follows:

$$\boldsymbol{r_{21,d} = -h_2 s_2^* + h_3 r_{1,r} + n_{21,d}} \qquad (3.34)$$

$$\boldsymbol{r_{22,d} = h_2 s_1^* + h_3 r_{2,r} + n_{22,d}} \qquad (3.35)$$

where $r_{21,d}$, $r_{22,d}$ are the received signals at the destination in the first and second half of time slot 2.

With the application of maximum ratio combining (MRC) of the received signal from both the base station and the relay node, the destination node obtains the detected signal as:

$$\tilde{s}_1 = \tilde{s}_{1,d} + \tilde{s}_{1,r} \quad (3.36)$$

$$\tilde{s}_2 = \tilde{s}_{2,d} + \tilde{s}_{2,r} \quad (3.37)$$

where

$$\tilde{s}_1 = h_3^* h_2^* r_{21,d} + h_1 r_{22,d}^* + h_1^* h_1 r_{11,d} \quad (3.38)$$

$\tilde{s}_1$ can also be given in more expressive way by manipulating the above equation further as follows:

$$\tilde{s}_1 = (2|h_1|^2 + |h_2 h_3|)s_1 + h_2^* h_3^* (h_3 n_{1,r} + n_{21,d}) + h_1 (h_3 n_{2,r} + n_{22,d})^* + h_1^* n_{11,d} \quad (3.39)$$

$$\tilde{s}_2 = h_3^* h_2^* r_{22,d} - h_1 r_{21,d}^* + h_1^* h_1 r_{12,d} \quad (3.40)$$

$\tilde{s}_2$ can also be given in more expressive way by manipulating the above equation further as follows:

$$\tilde{s}_2 = (2|h_1|^2 + |h_2 h_3|)s_2 + h_2^* h_3^* (h_3 n_{2,r} + n_{22,d}) - h_1 (h_3 n_{1,r} + n_{21,d})^* + h_1^* n_{12,d} \quad (3.41)$$

3.5.2.2 STBC-Based Decode-and-Forward

The relay nodes decode the received signal and then transmit the decoded signal using space time block coding to the destination. We assume here that if s_1 signal at relay node is recovered correctly in the receiver end, s_2 signal is assumed to be decoded correctly. The relay node recovers the received signal as (s_1', s_2'), where, $s_1' = as_1$ and $s_2' = bs_2$ $a, b \in \{-1,1\}$

The destination gets the signal during the first half and second half of time slot2 respectively as follows:

$$\boldsymbol{r_{21,d} = -h_2 s_2^* + h_3 s_1' + n_{21,d}} \tag{3.42}$$

$$\boldsymbol{r_{22,d} = -h_2 s_1^* + h_3 s_2' + n_{22,d}} \tag{3.43}$$

With the application of maximum combining ratio (MRC) in the receiver end, the symbol estimation signal can be obtained as:

$$\boldsymbol{\tilde{s}_1 = \tilde{s}_{1,d} + \tilde{s}_{1,r}} \tag{3.44}$$

$$\boldsymbol{\tilde{s}_2 = \tilde{s}_{2,d} + \tilde{s}_{2,r}} \tag{3.45}$$

where

$$\boldsymbol{\tilde{s}_1 = b h_2^* r_{21,d} + h_1 r_{22,d}^* + h_1^* h_1 r_{11,d}} \tag{3.46}$$

$\tilde{s}_1$ can also be given in more expressive way by manipulating the above equation further as follows:

$$\tilde{s}_1 = (2|h_1|^2 + ab|h_3|^2)s_1 + bh_3^*(n_{21,d}) + h_1(n_{22,d})^* + h_1^* n_{11,d} \quad (3.47)$$

$$\tilde{s}_2 = ah_3^* r_{22,d} - h_1 r_{21,d}^* + h_1^* h_1 r_{12,d} \quad (3.48)$$

$\tilde{s}_2$ can also be given in more expressive way by manipulating the above equation further as follows:

$$\tilde{s}_2 = (2|h_1|^2 + ab|h_3|^2)s_2 + ah_3^*(n_{22,d}) - h_1(n_{21,d})^* + h_1^* n_{12,d} \quad (3.49)$$

As we can see from the given equations, the STBC-based decode-and-forward performs better than amplify-and-forward as the product of a and b is always one.

4 SIMULATION RESULT AND DISCUSSION

In Chapter one, we tried to cover some theoretical part which helps to understand this thesis work and in Chapter two, we discussed STBC based cooperative diversity in comparison with direct communication and simple STBC(Alamouti code) which is transmit diversity.

In this Chapter, we are going to demonstrate simulation results on the basis of ideas discussed in previous two Chapters using MATLAB 7.0.

For comparison one must take note that unlike amplify-and-forward, decode-and- forward is based on space time block coding (STBC). In order to present equitable (fair) comparison, we assume that the total transmitted power level from two antennas for the Alamouti scheme is the same as the transmit power from the single transmit antenna for the point-to-point transmission. In all cases we also employ the same transmission rates (i.e., we consider the same overall transmission time T where T would be the total time allocated to transmit symbols (s_1, s_2) if the point-to-point transmission were used).

Table 4-1 Simulation parameters

Modulation	BPSK,QPSK,3-PSK,4-PSK
Transmit power	Equally distributed among all antennas
Coding	STBC, Channel coding is not considered.
Performance metric	Symbol Error Rate (SER) which is the difference between the modulated signal and demodulated signal.
Number of realization per SNR	1,ooo,ooo
Channel Model	AWGN and Rayleigh fading (for outdoor scenario), AWGN and Rician fading (for indoor scenario).

4.1 Flow Chart

It is essential to visualize the simulation using flow chart since it describes the one's understanding of the whole process easily and it also gives a chance to think where the process can be improved .Flow chart is shown in Figure 4.1 below.

4.2 Symbol Error Rate (SER)

Suppose we have N transmitted symbols, then the symbol error rate is the average number of symbols received with error from N transmitted symbols. Normally symbol error rate is small number like 10^{-6}. It is easy to achieve very small error symbol error rate in wired channel without wasting large amount of transmission power since wired channel is less susceptible with noise and interference than wireless channel. However, in wireless channel, it is challenging to obtain very small symbol error rate but it is possible to obtain it using cooperative diversity technique.

4.3 Channel Capacity

Channel capacity is the upper limit of transmission rate for reliable communication. Channel capacity depends on signal to noise ratio (SNR), number of antenna elements (in MIMO) and bandwidth. In the next section, we will see the simulation result for Shannon channel capacity (i.e., in bits/s/Hz) of two transmit and two receive antenna for Rayleigh fading channel and Rician fading channel with an intention of comparing the amount of SNR required for the same SER of the two different channels (Rayleigh and Rician fading). Since this thesis is focused to enhance diversity only, by comparing the two graphs of Rayleigh and Rician channel to be seen later, we can confirm that Rician fading outperforms Rayleigh fading as it has a strong signal component.

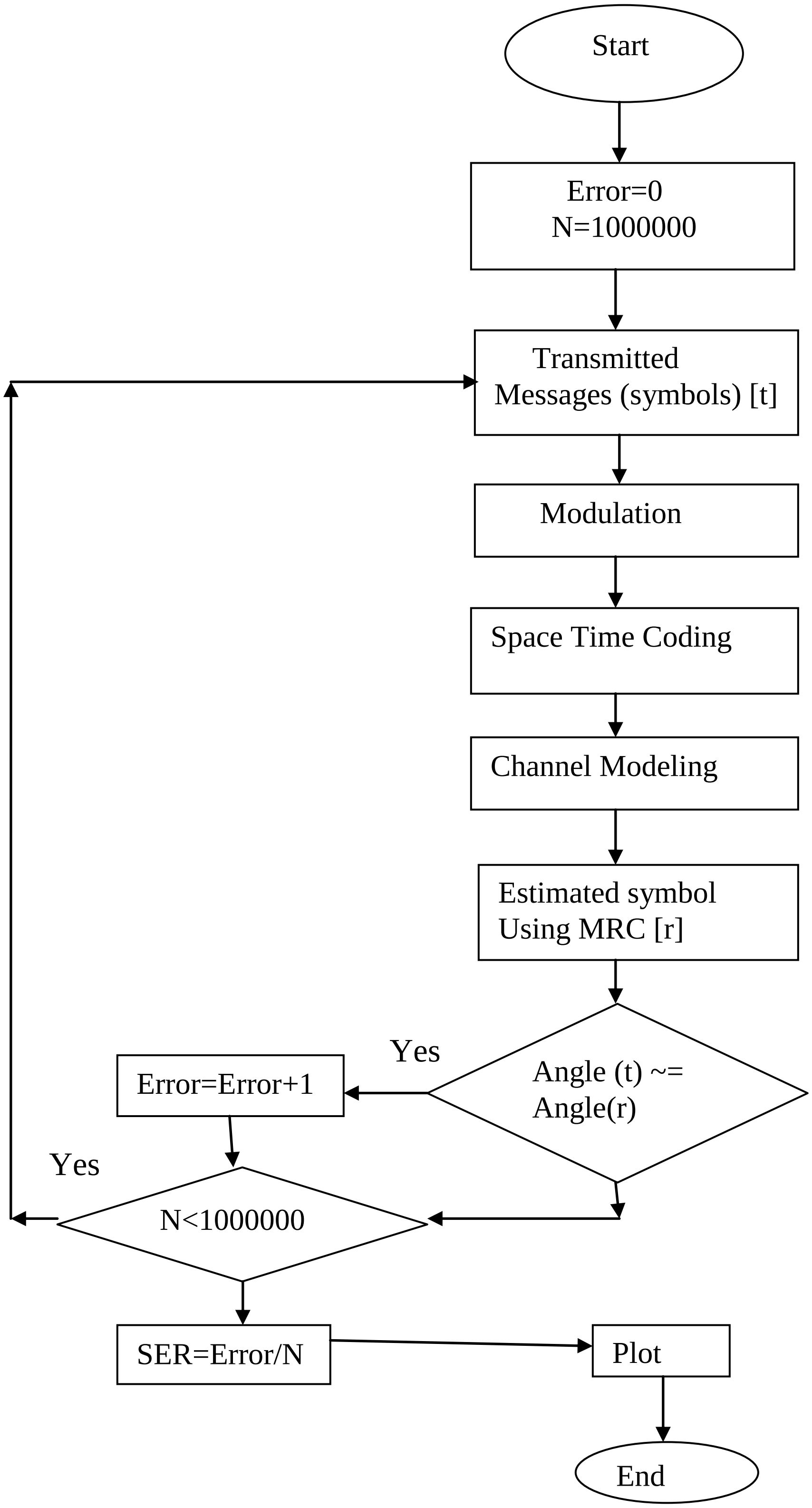

Figure 4-1 Flow chart for the simulation

4.4 Simulation Results and Discussion

As we can see from the simulation results in Figure 4.2, Alamouti cooperative system (DF and AF) perform better than direct non cooperative system (1Tx,1Rx), simple transmit diversity system (2Tx,1Rx) and virtual Alamouti cooperative system because of the applications of multiple transmit antennas and two relay nodes. Numerically, when SER is about 10^{3} in the Fig 4.2 below, Alamouti cooperative system with STBC-based decode-and-forward(DF) obtains about 1.8, 2.0, 5.5 and 7.0 dB gains compared with Alamouti cooperation system with amplify-and-forward(AF), virtual Alamouti cooperative system with DF, virtual Alamouti cooperative system with AF, simple Alamouti's STBC system, respectively.

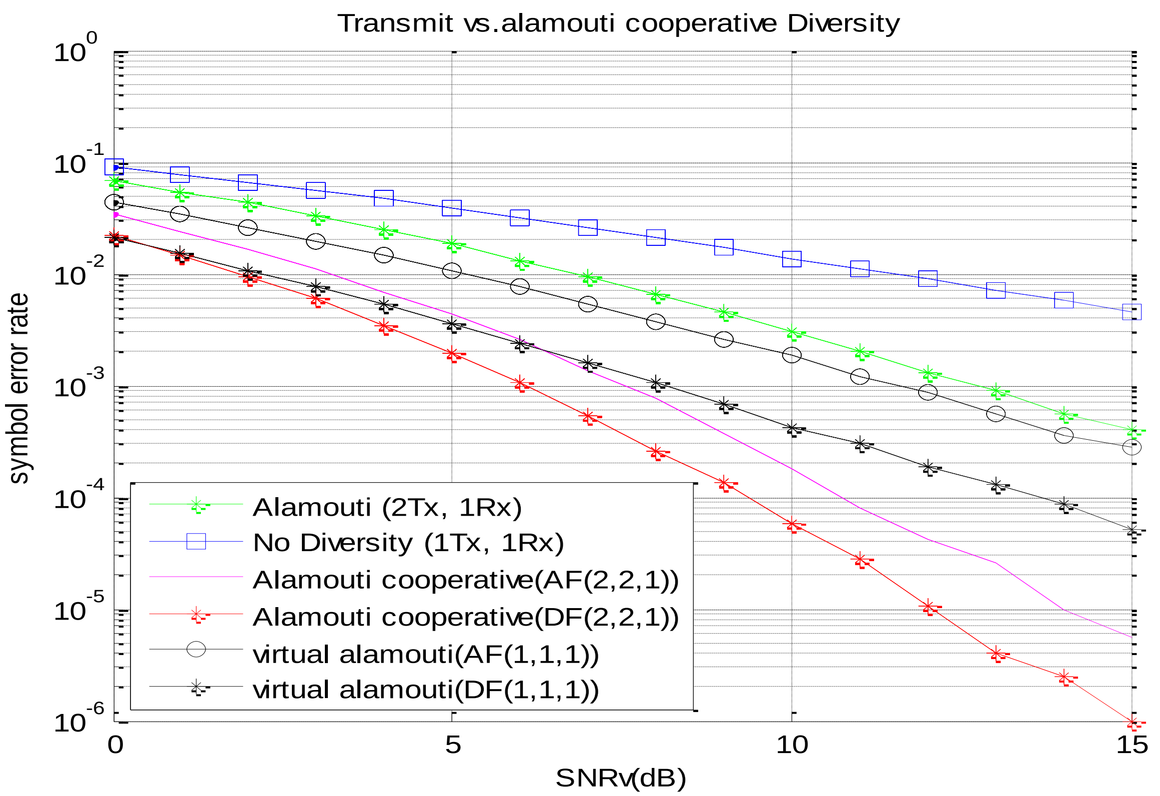

Figure 4-2 The symbol error rate performance comparison among DF(2,2,1), AF(2,2,1), DF(1,1,1), AF(1,1,1), (1Tx,1Rx), and (2Tx,1Rx)

The previous first plot in figure 4.2 illustrates a case that all channels (direct (source) down link channel, inter-user channel, partner down link channel) have the same mean SNR.

The second plot illustrates a case in which the direct down link channel quality is 10 dB poorer than that of the inter user channel.

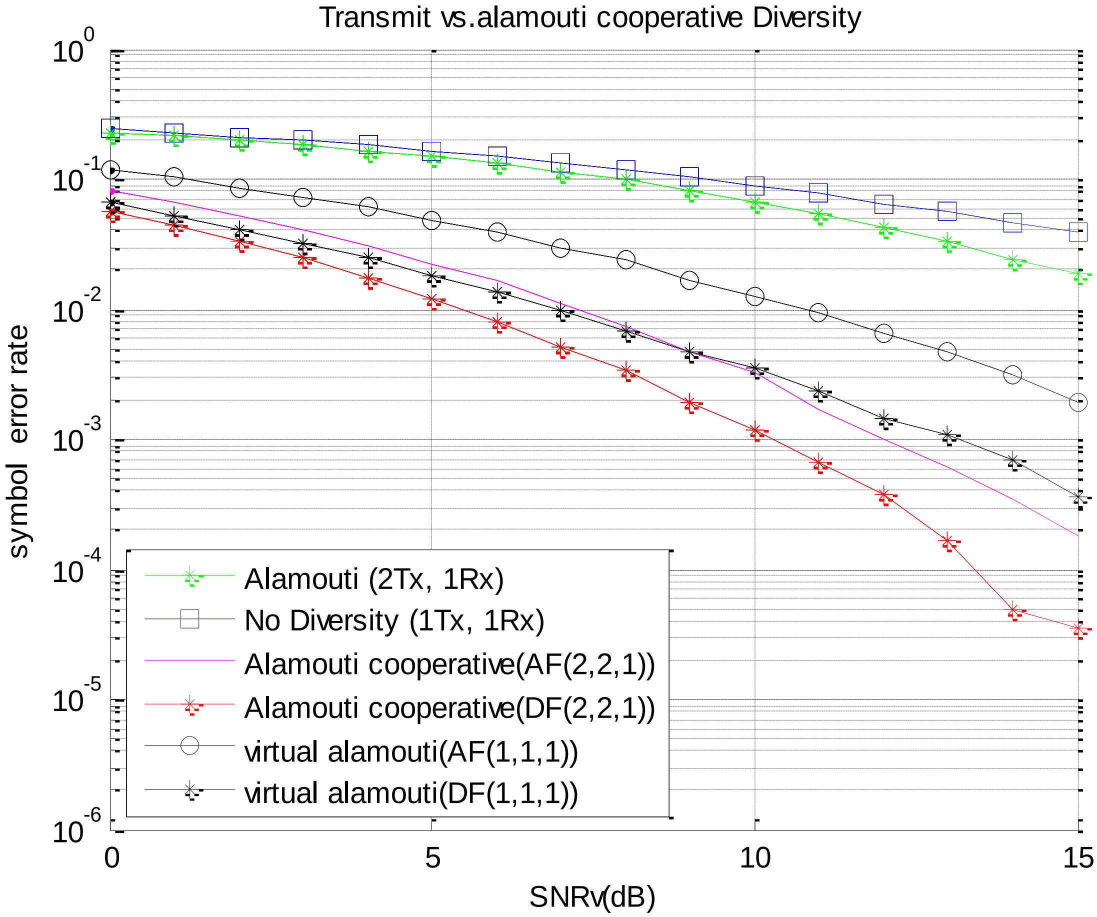

Figure 4-3 SER performance comparison of different systems when the direct down link channel is -10dB

Now in the third plot in Figure 4.4, we try to investigate the effect of the different kind of modulation techniques with an intention of achieving small SER. When the transmit power SNR is 15dB, the SER for BPSK ,QPSK,3-PSK,4-PSK is almost about 0.00006,0.0005,0.0055,0.0057, respectively as one can see them clearly from the Figure 4.4 below.

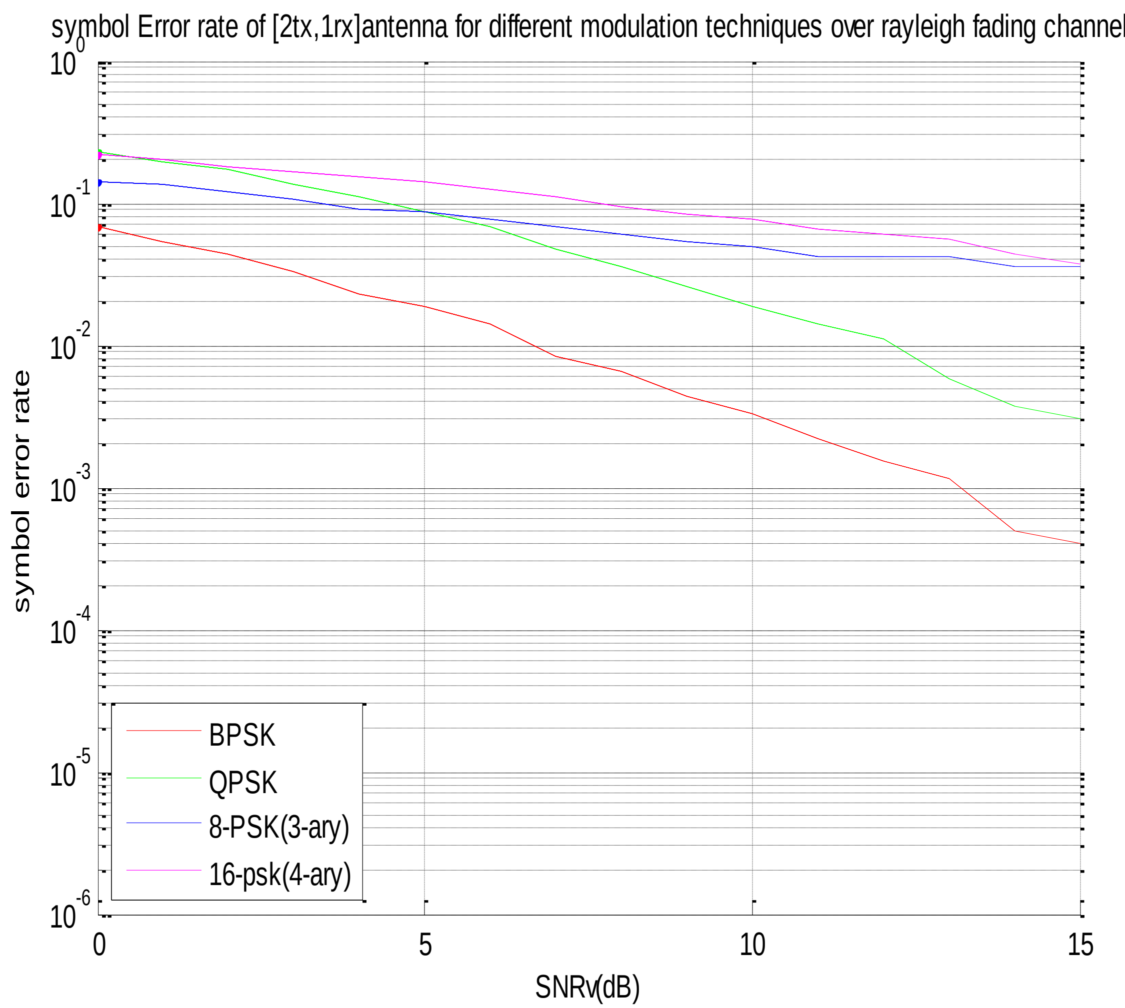

Figure 4-4 The SER performance comparison among BPSK, QPSK, 3-PSK and 4-PSK

The following two plots illustrates the four * representing the values of SNR at which the symbol error rate is 0.02 for 1, 2, 3 and 4 bits per symbol respectively. The values of these SNR are assumed to be in the region of SNR which makes the four modulations at full rate (1, 2, 3, 4 bits per symbol).The green line represents channel capacity for the Gaussian input. Numerically, for the achievement of 0.02 SER, the BPSK obtains about 5, 12, and 14 dB gains compared with QPSK, 3-PSK, 4-PSK, respectively.

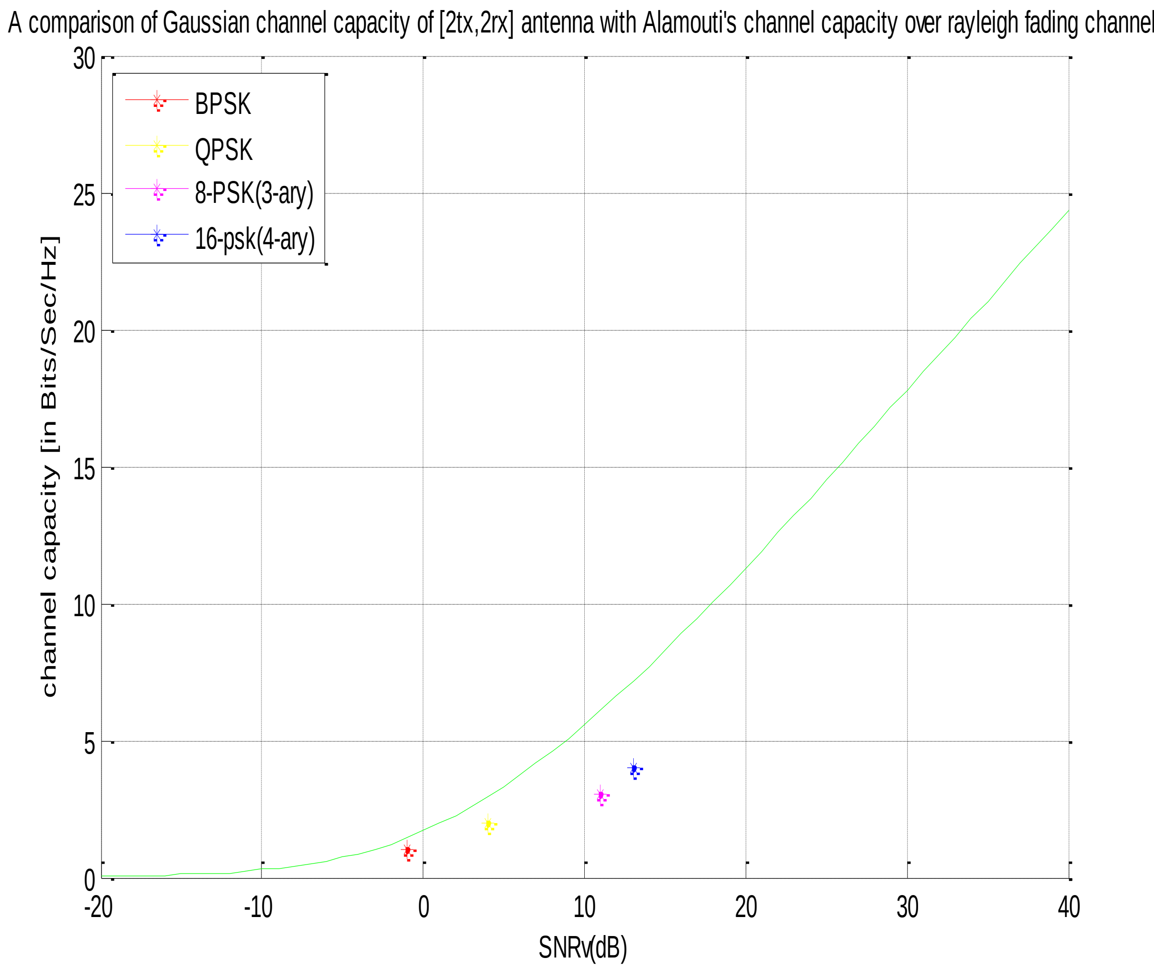

Figure 4-5 A comparison of Gaussian Rayleigh fading channel capacity with Alamouti's channel capacity

Theoretically, for indoor scenario or for environment having line of sight component, the behavior of the channel is better characterized by Rician fading than Rayleigh fading. For outdoor and for long distance communication, the behavior of the channel is better characterized by Rayleigh fading. Alamouti's channel capacity is close to Gaussian fading capacity channel that means Alamouti code might be good code. By observing the following Figure 4.6 and comparing with the previous Figure 4.5, we can see that Rician fading channel gives the same Alamouti's channel capacity as Rayleigh fading channel but with lesser SNR for the same symbol error rate which is 0.02 as there is a line of sight component (strong signal component) in the Rician fading channel.

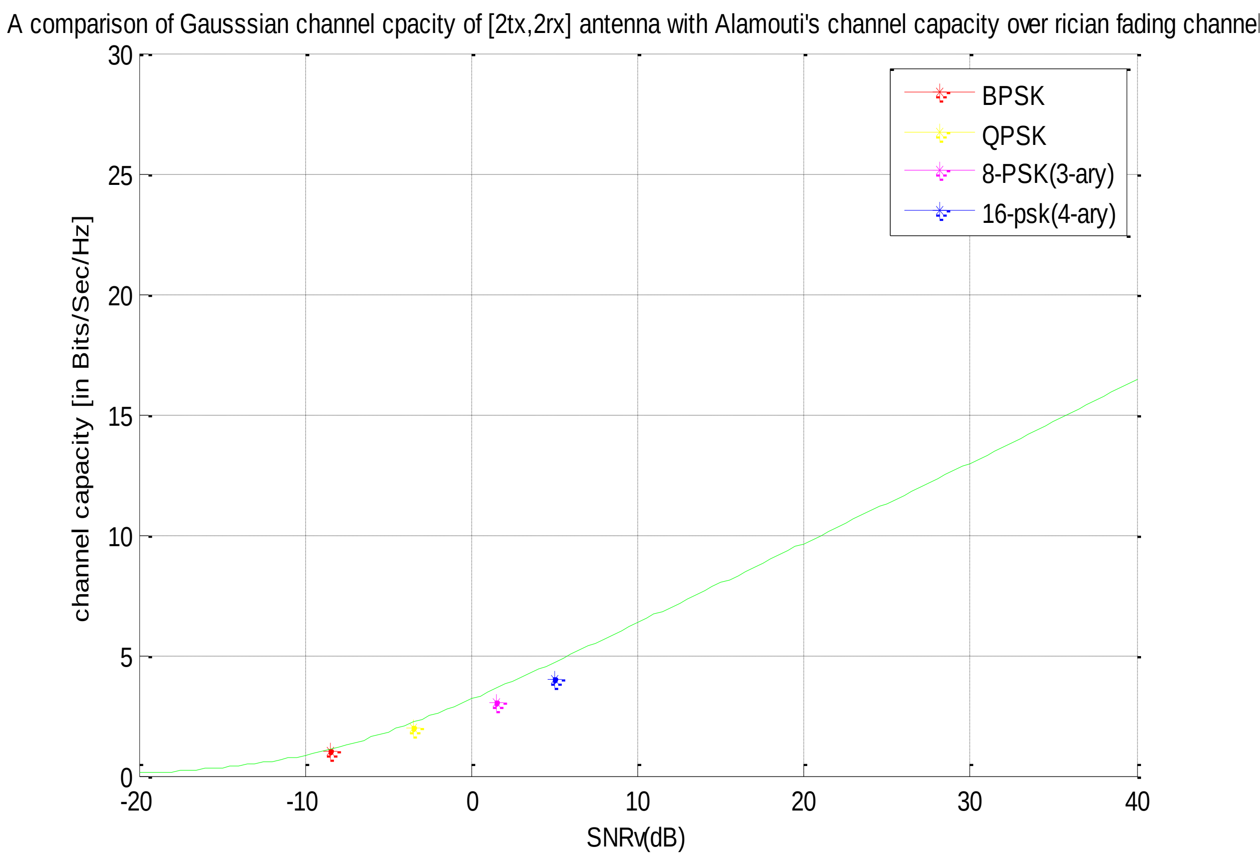

Figure 4-6 A comparison of Gaussian Rician fading channel capacity with Alamouti's channel capacity

5 CONCLUSION AND FUTURE WORK

5.1 Conclusion

Based on the simulation results we have in Chapter 4, we conclude the following.

1. Alamouti cooperative system (2,2,1) have advantages in SER performance compared to direct non cooperative system (1Tx,1Rx), simple transmit diversity system (2Tx,1Rx) and virtual Alamouti cooperative system (1,1,1) with the feasible increase in system complexity because of the applications of multiple transmit antennas and two relay nodes.
2. Alamouti cooperative system with STBC-based decode-and-forward (DF) performs better than Alamouti cooperation system with amplify-and-forward (AF) as decode- and- forward is based on space time block coding (STBC).
3. As one can see clearly from the graph, we can achieve small symbol error rate using different modulation techniques.
4. By comparing figure 4.5 and 4.6, we can say that Rician fading channel gives the same Alamouti's channel capacity with lesser SNR as compared to Rayleigh fading channel as Rician fading channel has line of sight component.

5.2 Drawbacks

1. In Alamouti cooperative system, a total of four time slots per two symbols are required to complete the information transfer, whereas in simple STBC scheme, we need two time slots per two symbols to complete the information transfer. As a result, to send the same information bits in cooperation and point-to-point transmission, the symbols in the former should have double the information rate of the latter. To conclude, we see that comparing the cooperation and point-to-point transmission, the latter is good in terms of spectral efficiency and bad in terms of

reliability of transmission, where as the former is good in terms of reliability and bad in terms of spectral efficiency.

2. There is an increase in system complexity because the system requires managing interference between the symbols and partner selection.

5.3 Recommendation for Future Work

There are a few open questions that need to be explored before we implement it in real network. In the following, we propose a few promising future works.

1. In this thesis, we considered both amplify-and-forward and STBC-based decode-and-forward relaying strategy where in both cases decisions are based on hard information bits for the sake of reducing computational burden. The use of soft-bit information at the receiver for these cooperative schemes could be interesting area to investigate.
2. The results presented in this thesis are based on the simulation and the recovered signal at the relay A and relays B are assumed to be same. Moreover, two signals are transmitting from the base station using STBC. If one of the two signals is correctly decoded at the relay, the other signal is also assumed to be decoded correctly. The above two assumptions is not usually the case in real condition and studying the impact of real assumptions on the performance evaluation of these schemes need to be addressed.
3. The two relays have no messages of their own and serve the two transmit antenna at the base station only. An evaluation of the system that includes the message of the relays could be another study.
4. This thesis is limited to Alamouti's coding based cooperative system which focuses only to enhance diversity but, for this cooperation system, a total of four time slots are required to complete the transmission of the two signals from the base station and as a result we sacrifice two extra time slots. So, we have a loss in transmission rate. To overcome this loss to some extent, we can use the idea of superposition.

The basic idea is the source sends the super position of its own message and partner previous message. A study in this area is another work.

5. This thesis neglects the different channel codes. Using different channel coding techniques e.g convolutional codes that improve performance is another future research work.
6. In our analysis, all channels were assumed to be slow-fading and Rayleigh distributed. In slow fading channels, cooperation does not benefit from time diversity. In a case of fast fading channels, channel fading coefficients vary within a symbol and the slow fading assumption does not hold. Therefore, performance of these cooperation systems in fast fading channel environments could be one area of future study.
7. So far, we assumed frequency nonselective flat fading channels belonging to narrowband systems. However, such narrow band systems are not readily found in nature. In the real world we have what are called frequency-selective fading channels. In wideband wireless communications, the coherent bandwidth is narrower than the signal bandwidth. This implies that the signals will experience independent fading, where in certain frequencies will fade more than other frequencies. Investigating the effect of frequency-selective fading on the performance could be another future work.

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