EMULATION OF COOPERATIVE COMMUNICATION SYSTEM ON DSP BOARDS

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CERTIFICATE

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ABSTRACT

A communication environment with multiple transmitters and multiple receivers is inherently a competitive environment. The advantages of multiple-input multiple-output (MIMO) systems have been widely acknowledged; to the extent that certain transmit diversity methods have been incorporated into wireless standards. Although transmit diversity is clearly advantageous on a cellular base station, it may not be practical for other scenarios. Specifically, due to size, cost, or hardware limitations, a wireless agent may not be able to support multiple transmit antennas.

To enhance system reliability and performance in resource-limited wireless networks, a new class of methods called cooperative communication enables single antenna mobiles in a multi-user environment to share their antennas and generate a virtual multiple-antenna transmitter that allows them to achieve transmit diversity and hence establish a reliable link for communication. By making use of a basic three node system and single tap Rayleigh channel, we carried out performance comparison of the three cooperative protocols (Amplify and Forward, Detect and Forward, Decode and Forward). Their results based on bit error curves were compared with SISO system for detailed performance analysis. Negative SNR is also incorporated in the simulations. Moreover the communication model is also implemented on DSP Kit in real time for more realistic analysis.

DEDICATION

In the name of Allah, the Most Gracious, the Most Merciful

To

Our Beloved Prophet Muhammad (Peace Be Upon Him)

&

Our Beloved Parents

&

Our Respectful Teachers

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We would like to take this opportunity to pay our humble gratitude to Almighty Allah (S.W.A.T), the most merciful, who blessed us with His divine help in the completion of our project.

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1. INTRODUCTION

1.1 Communication Systems

In the modern digital world, data communication in an efficient and reliable manner is a crucial task. Most systems are being operated in real time remotely and the nature of these systems most often requires error free data communication. Numerous communication techniques over different mediums have evolved to satisfy ever stringent demands over the quality of the data communication network.

Cooperative communications has recently received significant interest as an untapped means for improving performance of relay transmission systems operating over the ever-challenging wireless medium. The common theme of most research in this area is to optimize physical layer performance measures without considering in much detail how cooperation interacts with higher layers and improves network performance measures. Because these issues are important for enabling cooperative communications to practice in real-world networks, especially for the increasingly important class of mobile ad hoc networks (MANETs) [3]. The goal of this project is to analyze basic cooperative communication systems and their comparison with SISO (Single Input Single Output) Systems. Cooperative communication considerably improves the network connectivity.

1.2 Motivation for Project Selection

The reason why we have selected this project is its immense application in our life. *Cooperative Communication* has received significant attention in various communities. The pace of today's life is very fast as the world has become a Global Village. Cooperation at the physical layer offers a number of advantages in flexibility over standard MANET that go beyond simply providing a more reliable physical layer link.

Diversity of cooperative links will provide us with this task of consuming our communication resources economically by reducing their power consumption. Power Consumption is necessary because the available resources are not limitless. We need to use them keeping in mind the task performed is cost-effective.

It has generally been physical layer researchers who have championed the use of cooperative diversity in wireless networks, arguing that nodes equipped with a single antenna, through physical layer coding and signal processing, could achieve similar diversity and coding gains to those of co-located multi-antenna systems, while leveraging the distributed hardware and battery resources that are already available. In addition to offering performance improvements in terms of network metrics such as connectivity, cooperation alleviates certain collision resolution and routing problems because it allows for simpler networks of more complicated links, rather than complicated networks of simple links.

Our strong interest in communication systems has motivated us to explore this upcoming technology in wireless communication that will rule in the coming years once applied on mobile Ad-hoc networks. Studies on the diversity of cooperative links are numerous, and our work will also be a contribution to develop practical schemes with improved performance. Since cooperation is essentially a network solution, instead of a point-to-point solution, finding the appropriate link abstraction for cooperative transmission will raise a number of important research problems for networking and physical layer researchers to investigate further. This task apart from serving as our final degree project will provide us learning which is the actual aim of an engineering student and also prepares us to step in our professional lives with knowledge of one of the emerging technologies to today.

1.3 Project Goals

Our project will include

- Simulations of different cooperative communication techniques like Amplify-and-Forward, Detect-and-Forward & Decode-and-Forward
- Comparison of these techniques
- Analysis of their performance in relation to SISO systems
- Implementation of cooperative communication techniques on DSP Kit

1.4 Project Stages

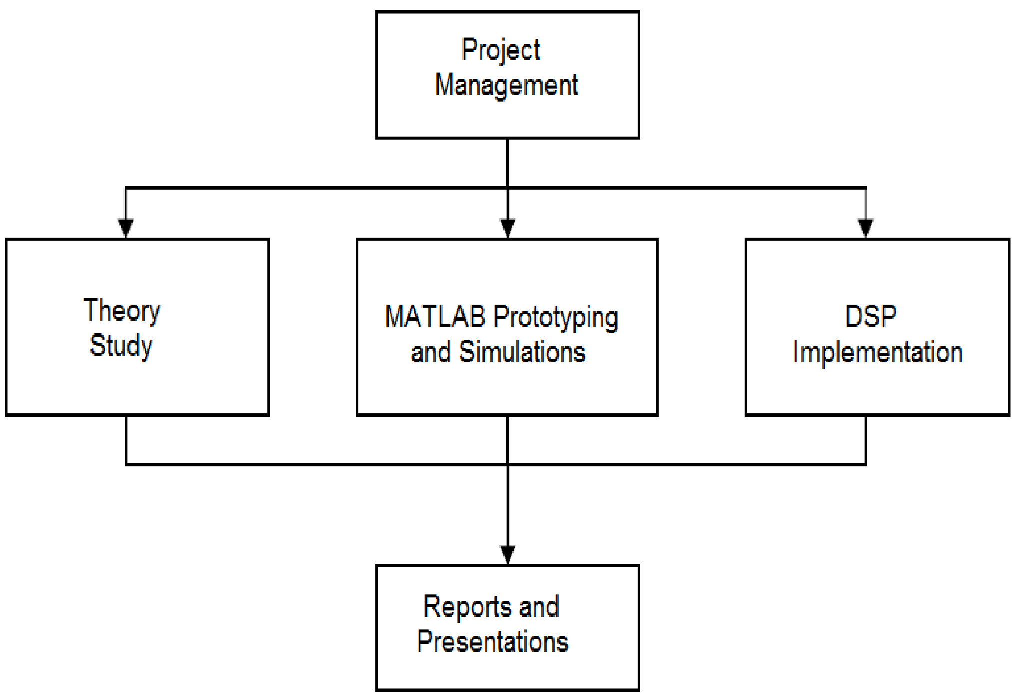

Figure1: **Block Diagram of Project Phases**

1.4.1 Tasks Definition

- **Project Management**

  Distribute the tasks and assure communications among group members, organize weekly meeting and maintain overview of the project's progress.

- **Theory Study**

  Study theory for background knowledge. Collect relevant material for future consultation in case of need.

- **Matlab Prototyping**

  Find algorithms, implement algorithms in Matlab and design a graphic user interface (GUI) for the project.

- **DSP Implementation**

  Learn how to use DSP, Interface DSP Kit with Matlab, implement the Matlab codes in DSP, Debug and optimize the codes

- **Reports and Presentations**

  Write proposal, progress reports, prepare slides and presentations and document thesis.

2. LITERATURE REVIEW

2.1 Wireless Communication

Wireless Communication is generally considered to be a branch of telecommunications where electromagnetic waves, rather than conducting wires carry the information signal over a distance. The distances involved may be short (a few meters as in television remote control) or long (thousands or millions of kilometers for radio communications). Wireless networking is used to meet a variety of communication needs. It encompasses various types of fixed, mobile, and portable two way radios, cellular telephones, personal digital assistants (PDAs), and wireless networking. Other examples of wireless technology include GPS units, garage door openers and or garage doors, wireless computer mice, keyboards and headsets, satellite television and cordless telephones.

In this chapter, we will discuss the wireless communication environment, channel impairments, and the advantages and disadvantages of wireless communication.

2.2 Wireless Channel

Signals in wireless channels suffer certain impairments which are discussed in detail in this section.

2.2.1 Attenuation

Attenuation is the reduction in amplitude and energy of the information signal during transmission from source to destination. Attenuation decreases the intensity of electromagnetic radiation due to absorption or scattering of photons. The primary causes of attenuation in matter are the Photoelectric Effect, Compton Scattering and, Pair Production (for photon energies of above 1.022MeV).

Attenuation varies as function of distance and frequency. It increases with increase in transmission distance (between transmitter and receiver) over any transmission medium. It is directly proportional to frequency of the signal; it is greater at high frequencies.

In order to guarantee the reception of transmitted message correctly, certain factors have to be considered at both the transmitter and the receiver. The transmitter should transmit a signal strong enough so that the received signal would have sufficient strength that enables the receiver to detect and interpret the incoming signal correctly. For longer distances, to compensate for attenuation, a relay or repeater can be used between the transmitter and receiver at fixed intervals to repeat or amplify the transmitted signal [1].

2.2.2 Noise

The term noise refers to unwanted random addition to a wanted signal. It is the most limiting factor in communication system performance.

The different sources of noise are:

- **Thermal Noise**: Thermal noise or Johnson–Nyquist noise is the electronic noise generated by the thermal agitation of electrons inside an electrical conductor at equilibrium, which happens regardless of any applied voltage. Thermal noise is approximately white, the power spectral density of thermal noise constant throughout the frequency spectrum and hence it is referred to as white noise Additionally, the amplitude of the signal has a nearly Gaussian probability density function [1].

- **Intermodulation Noise**: In a transmission medium or device, intermodulation noise is generated during modulation and demodulation, that results from nonlinear characteristics in the device or medium. Intermodulation noise occurs when the frequency sum or difference of a particular signal, S1, interferes with the component frequency sum or difference of another signal, S2. These are called the intermodulation products (or IMPs). Intermodulation is rarely desirable in radio or audio processing, as it essentially creates spurious emissions, which can create minor to severe interference to other operations on the signal. A linear system cannot produce intermodulation [1].

Intermodulation may result from a number of causes:

1. Too high input level to a device drives the device into its non-linear operating region (overdrive)
2. Improper alignment causing a device to function nonlinearly
3. Nonlinear envelope delay

- **Crosstalk Noise**: Crosstalk refers to any phenomenon by which a signal transmitted on one circuit or channel of a transmission system creates an undesired effect in another circuit or channel. Crosstalk is usually caused by undesired capacitive, inductive, or conductive coupling from one circuit, part of a circuit, or channel, to another. In wireless communication, crosstalk is often denoted as co-channel interference [1].

- **Impulse Noise**: This type of noise is non-continuous, consisting of irregular pulses or noise spikes of short duration and of relatively high amplitude. These bursts or discrete impulses are called “hits”. Some types of impulse noise are natural, such as that from lightening [1, 2]. However, man-made impulse noise is ever-increasing, such as from automobile ignition systems, power lines, etc.

2.2.3 Free Space Loss

For all wireless communications, the signal disperses with distance due to spread of signal on space. Free space loss is the theoretical radiation loss that would result from a line-of-sight path through free space, with no obstacles nearby to cause reflection or diffraction. It does not include variable factors such as the gain of the antennas used at the transmitter and receiver, nor any loss associated with hardware imperfections. Free-space path loss is proportional to the square of the distance between the transmitter and receiver, and also proportional to the square of the frequency of the radio signal [1, 4].

$$\begin{aligned} \mathrm{FSPL} &= \left(\frac{4\pi d}{\lambda}\right)^2 \\ &= \left(\frac{4\pi d f}{c}\right)^2 \end{aligned}$$

where:

λ is the signal wavelength in meters (m)

f is the signal frequency in hertz (Hz)

d is the distance from the transmitter in meters (m)

c is the speed of light in a vacuum, 2.99792458 × 10^8 meters per second (m/s)

In decibels, free space loss is measured as:

$$\mathrm{FSPL(dB)} = 20\log_{10}(d) + 20\log_{10}(f) + 32.44$$

where:

f is the signal frequency measured in megahertz (MHz)

d is the distance from the transmitter in kilometers (km)

2.2.4 Multipath

When a radio frequency (RF) signal is transmitted towards the receiver, the general behavior of the RF signal is to grow wider as it is transmitted further. On its way, the RF signal encounters objects that reflect, refract, diffract or interfere with the signal. When an RF signal is reflected off an object, multiple wavefronts are created. As a result of these new duplicate wavefronts, there are multiple wavefronts that reach the receiver.

Multipath propagation occurs when RF signals take different paths from a source to a destination. A part of the signal goes to the destination via line of sight (LOS) path while another part bounces off an obstruction, then goes on to the destination. As a result, part of the signal encounters delay and travels a longer path to the destination. At the destination, if these signals are added constructively, they will improve the signal level. However, if they are added destructively, the signal level declines which reduces the quality of received signal and hence the system's performance [1, 2, 4].

2.2.4.1 Effects of Multipath Distortion

- **Data Corruption:** It occurs when multipath is so severe that the receiver is unable to detect the transmitted information.
- **Signal Nulling:** It occurs when the reflected waves arrive exactly out of phase with the main signal and cancel the main signal completely.
- **Increased Signal Amplitude:** It occurs when the reflected waves arrive in phase with the main signal and add on to the main signal thereby increasing the signal strength.
- **Decreased Signal Amplitude:** It occurs when the reflected waves arrive out of phase to some extent with the main signal thereby reducing the signal amplitude.

2.3 Fading

Signal-fading phenomena can drastically affect the performance of a terrestrial communications system, and hence is the most important factor when describing the channel and predicting system performance. In wireless communications, fading is the attenuation that a carrier-modulated signal experiences over a certain propagation media. The fading may vary with time, geographical position and/or radio frequency, and is often modeled as a random process. This section addresses fading causes, fading types and fading channels.

A fading channel is a communication channel that experiences fading. In wireless systems, fading may either be due to multipath propagation, referred to as "*Multipath Induced Fading*", or due to shadowing from obstacles affecting the wave propagation, sometimes referred to as "*Shadow Fading*" [1, 2, 4].

2.3.1 Multipath Fading

Multipath propagation is a term used to describe the multiple paths a radio wave may follow between transmitter and receiver. Such propagation paths include the ground wave, ionospheric refraction, reradiation by the ionospheric layers, reflection from the earth's surface or from more than one ionospheric layer.

Multipath fading refers to signal attenuation and distortion due to multipath propagation. It is the most challenging problem that is faced by engineers in wireless communication systems.

Wireless radio signals are reflected by physical obstructions that they encounter between a transmitter and a receiver. Those signal elements that travel the most direct routes not only arrive soonest, but also suffer less absorption and diffusion, and hence attenuate the least. Therefore, they are the strongest. Those that travel the least direct routes arrive last and are weakest. Multipath propagation causes fluctuation in signal's amplitude, phase and angle of arrival creating multipath fading. Radio waves that are received in phase reinforce each other and produce a stronger signal at the receiving site, while those that are received out of phase produce a weak or fading signal. Small alterations in the transmission path may change the phase relationship of the two signals, causing periodic fading [1, 4].

2.3.2 Propagation Mechanisms in Multipath Fading

The basic propagation mechanisms that play part in multipath fading are:

- **Reflection**: It is the change in the direction of the wave when a propagating electromagnetic signal encounters a medium such that the intermolecular spaces in that medium are large relative to the signal wavelength.

- **Diffraction**: Diffraction refers to various phenomena which occur when a wave encounters an obstacle that is large as compared to the signal wavelength. It is described as the apparent bending of waves around small obstacles and the spreading out of waves past small openings.

- **Scattering**: Scattering is a general physical process where the light radiation is forced to deviate from a straight trajectory by one or more localized non-uniformities in the medium through which they pass. The reflected radiation obeys law of reflection. Reflections that undergo scattering are often called diffuse reflections.

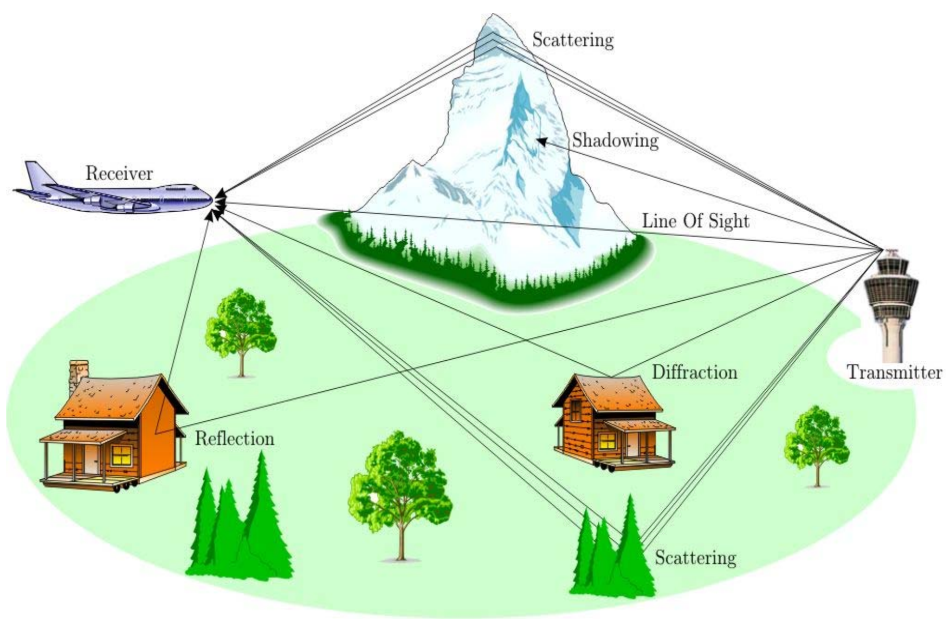

Figure 2: **Propagation mechanisms in Multipath Fading**

Multipath fading heavily contributes to the unreliability of wireless links, causing fairly large deviations from link quality predictions based on path loss models; its impact on wireless sensor networks is considerable. Although analytical models provide a probabilistic description, multipath fading is a deterministic phenomenon.

2.3.3 Types of Fading

Frequency can be classified from time variant view into "*Fast Fading*" and "*Slow Fading*", and from time spreading view into "*Selective Fading*" and "*Flat (Non-selective Fading)*" [1, 4].

- **Slow fading:** Slow fading refers to average signal power attenuation due to moving over large distance area. It arises when the coherence time of the channel is large relative to the delay constraint of the channel. In this scenario, the amplitude and phase change imposed by the channel can be considered roughly constant over the period of use. Slow fading can be caused by events such as shadowing, where a large obstruction such as a hill or large building obscures the main signal path between the transmitter and the receiver.

- **Fast fading:** Fast fading refers to rapid changes in signal power and phase that occur due to small movement over distance of about half wavelength. It occurs when the coherence time of the channel is small relative to the delay constraint of the channel. In this scenario, the amplitude and phase change imposed by the channel varies considerably over the period of use.

- **Flat Fading:** Flat or non-selective fading occurs when all received multipath component of a symbol arrive within the symbol time duration. In flat fading, the coherence bandwidth of the channel is larger than the bandwidth of the signal. Therefore, all frequency components of the signal will experience the same magnitude of fading.

- **Frequency-Selective Fading:** A channel experience selective fading when the received multipath component of a symbol extends beyond the symbol time duration. In selective fading, the coherence bandwidth of the channel is smaller than the bandwidth of the signal. Different frequency components of the signal therefore experience de-correlated fading.

2.3.4 Fading Channel

For most channels, where signal propagates in the atmosphere and near the ground, the free-space propagation model is inadequate to describe the channel behavior and predict system performance. In wireless systems, signal can travel from transmitter to receiver over multiple reflective paths. Thus, when designing a communication system, the engineer has to consider all the parameters and factors that may affect the propagation of the signal. Hence, he needs to estimate the effects of multipath fading, path losses, and noise on mobile channel. Some typical fading channels are introduced in this section.

2.3.4.1 Additive White Gaussian Noise (AWGN) Channel

AWGN channel model is one in which the information is given a single impairment: a linear addition of wideband or white noise with a constant spectral density and a Gaussian distribution of noise samples. The model does not account for the phenomena of fading, frequency selectivity, interference, nonlinearity or dispersion. Wideband Gaussian noise comes from many natural sources, such as the thermal noise in antennas, shot noise, black body radiation from the earth and other warm objects, and from celestial sources such as the Sun [1, 5].

2.3.4.2 Rayleigh Fading Channel

Rayleigh fading is most applicable when there is no dominant propagation along a line of sight between the transmitter and receiver. It represents a worst case scenario for transmission channel. Rayleigh fading models assume that the magnitude of a signal that has passed through such a transmission medium will vary randomly, or fade, according to a Rayleigh distribution. Rayleigh fading is a reasonable model when there are many objects in the environment that scatter the radio signal before it arrives at the receiver. The envelope of the received signal is statistically described by Rayleigh probability density function (PDF) [1, 5].

2.3.4.3 Rician Fading Channel

Rician fading occurs where a dominant non-fading, LOS, component is present in addition to a number of indirect multipath signals; and the line of sight signal, is much stronger than the others. In Rician fading, the amplitude gain is characterized by a Rician distribution. Hence the fading envelop of this model is described by Rician probability density function (PDF) [1, 5].

2.4 Error Compensation Mechanisms

Fading can cause poor performance in a communication system because it can result in a loss of signal power without reducing the power of the noise. Error compensation mechanisms are used to compensate for errors and distortion introduced by multipath fading. These mechanisms fall into three main categories:

- Diversity Techniques
- Error Correction using Coding Techniques
- Equalization

2.4.1 Diversity

Diversity scheme refers to a method for improving the reliability of a message signal by using two or more communication channels with different characteristics. Diversity plays an important role in combating fading and co-channel interference and avoiding error bursts. It is based on the fact that individual channels experience different levels of fading and interference. Multiple versions of the same signal may be transmitted and received and combined in the receiver. Diversity techniques may exploit the multipath propagation, resulting in a diversity gain.

2.4.1.1 Diversity Schemes

The following classes of diversity schemes can be identified:

- **Time Diversity:** Multiple versions of the same signal are transmitted at different time instants. Alternatively, a redundant forward error correction code is added and the message is spread in time by means of bit-interleaving before it is transmitted. Thus, error bursts are avoided, which simplifies the error correction.

- **Frequency Diversity:** The signal is transferred using several frequency channels or spread over a wide spectrum that is affected by frequency-selective fading. Examples include OFDM modulation in combination with subcarrier interleaving and forward error correction and Spread spectrum, for example frequency hopping or DS-CDMA.

- **Space Diversity:** The signal is transferred over several different propagation paths. In the case of wired transmission, this can be achieved by transmitting via multiple wires. In the case of wireless transmission, it can be achieved by antenna diversity using multiple transmitter antennas (transmit diversity) and/or multiple receiving antennas (reception diversity). In the latter case, a diversity combining technique is applied before further signal processing takes place.

- **Polarization Diversity:** Multiple versions of a signal are transmitted and received via antennas with different polarization. A diversity combining technique is applied on the receiver side.

- **Multiuser Diversity:** Multiuser diversity is obtained by opportunistic user scheduling at either the transmitter or the receiver. Opportunistic user scheduling is as follows:

the transmitter selects the best user among candidate receivers according to the qualities of each channel between the transmitter and each receiver. In FDD systems, a receiver must feedback the channel quality information to the transmitter with the limited level of resolution.

- **Cooperative Diversity:** Achieves antenna diversity gain by using the cooperation of distributed antennas belonging to each node.

2.4.2 Error Correction Codes

Error detection is the ability to detect the presence of errors caused by noise or other impairments during transmission from the transmitter to the receiver, while error correction is the additional ability to reconstruct the original, error-free data.

Error detection and correction have great importance on improving the performance of fading channels. In this section we will study the error detection and correction codes.

2.4.2.1 Channel Coding

Channel coding is a viable method to reduce information rate through the channel and increase system reliability with acceptable quality and cost. Two key system parameters are signal energy per bit to noise power density ratio (Eb/N0) and channel bandwidth. Since the value that we can assign to Eb/N0 is limited for practical considerations, the only practical option for fixed Eb/N0 for acceptable data quality is to use error control coding. This goal is achieved by adding redundancy to the information symbol vector resulting in a longer coded vector of symbols that are distinguishable at the output of the channel [6, 7]. We consider only two classes of codes, block codes and convolutional codes.

2.4.2.2 Channel Coding Theorem

If *channel capacity C* represents the maximum amount of information transmitted per channel use, c*hannel coding theorem* states that there exists a coding technique such that information can be transmitted across the channel at rates *r* (less than *C*) to achieve error free transmission. It is not possible to find this code if *r* is greater than *C* [9, 11].

The maximum theoretical capacity of a channel with signal to noise ratio (SNR) and bandwidth BW, according to the theorem, is given by:

$$C = BW \times \log_2\left(1 + \frac{S}{N}\right)$$

where

C is the channel capacity in bits/second after error correction is applied

BW is the channel bandwidth in cycles/second (hertz)

S is the total signal power in watts

S/N is the signal to noise ratio comparing the communication data signal to white noise (in decibels)

The graph in the following figure illustrates the limitation of the channel capacity according to channel coding theorem.

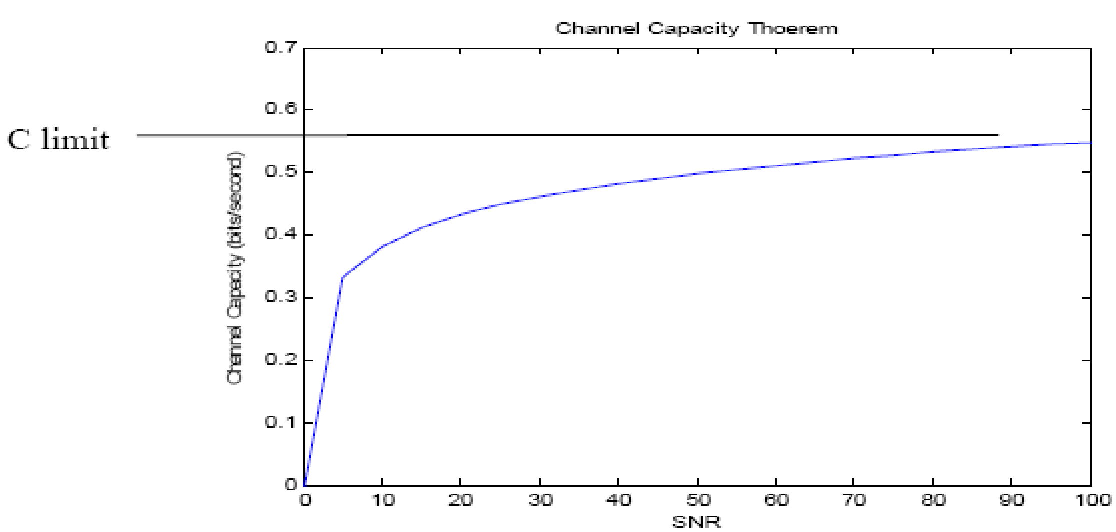

Figure 3: **Channel Coding Theorem capacity limit**

2.4.2.3 Channel Coding Techniques

Techniques to control the error probability are based on insertion of redundancy into the transmitted sequence so the receiver can detect and possibly correct errors that occur during transmission. The redundancy bits are added by an encoder at transmitter side and will be removed by a decoder at receiver side. Although the addition of redundancy decreases the bandwidth efficiency, but the use of error coding may increase the operational range of communication system, reduce the error rates and reduce the required E_b/N_0 for fixed bit error rate. The decrease in the required power for coded system is referred to as *coding gain.* With respect to the properties of the set of code words, we distinguish between linear and nonlinear codes [6, 7]. A code is said to be linear if any two code words in the code can be added in modulo-2 arithmetic to produce a third code word in the code. According to how the system makes use of the code capabilities, we distinguish between error detecting and error correcting codes.

- **Error Detection Codes**:

Error detection is used to implement either error monitoring or automatic repeat request (ARQ). In the case of error monitoring, the decoder monitors the quality of the received sequence and supplies it to the user, so that, when the reliability becomes too low, the sequence can be discarded. In the case of ARQ, the transmitter is asked to repeat unsuccessful transmissions [9, 10].

- **Error Correction Codes:**

In forward error correction (FEC), the decoder attempts to restore the correct transmitted sequence whenever errors are detected in the received sequence. There are many different error correcting codes. These codes have been classified into block codes and convolutional codes. The difference between them is that block codes are memoryless. Block codes and convolutional codes are discussed in the coming sections [10].

2.4.2.3.1 Block Codes

In block coding a message of k bits is mapped into a sequence of n bits. The basic feature of block codes is that the block of *n* digits, known as *code word*, generated by the encoder depends only on the corresponding block of *k* digits generated by the source, known as *data word*. Hence block code encoder has no memory.

Consider then an (*n, k*) linear block code in which *k* bits of the *n* bits are identical to the message sequence to be transmitted. The remaining *n-k* bits are known as *parity bits*. They are computed according to the encoding rule.

Block codes are called *systematic codes* if the message bits are transmitted in an unaltered form [10].

Let message bits m = $m_0, m_1, \ldots, m_{k-1}$ are applied to linear block encoder to produce an *n* bit code word c = $c_0, c_1, \ldots, c_{n-1}$. The n-k bit of c are parity bits b = $b_0, b_1, \ldots, b_{n-k-1}$

In order to have a systematic structure of code, a code word is separated into message bits and parity bits as shown in figure 3:

$b_o, b_1, \ldots, b_{n-k-1}$	$m_o, m_1, \ldots, m_{k-1}$

Figure 4: **Structure of code word of Block Code**

We can define the code word as

$$\mathbf{c} = [\mathbf{b} \quad \mathbf{m}]$$

The *n-k* parity bits are *linear sums* of *k* the message bits, hence

$$\mathbf{b} = \mathbf{mP}$$

Where P is coefficient matrix defined by

$$\mathbf{P} = \begin{pmatrix} p_{00} & \cdots & p_{0n-k-1} \\ \vdots & \ddots & \vdots \\ p_{k-10} & \cdots & p_{k-1n-k-1} \end{pmatrix}$$

where p_{ij} is 0 or 1.

Then we have

$$\mathbf{c=m[P \quad I]}$$

where $\mathbf{I}_k$ is k by k identity matrix

$[\mathbf{P} \quad \mathbf{I}_k]$ is known as generator matrix **G**.

Hence

$$\mathbf{c=mG}$$

The generator matrix G is used by encoder to generate code words of the transmitted message at transmitter.

2.4.2.3.2 Convolutional Codes

Convolutional Coding is more efficient scheme than block coding. In block coding redundant bits are added to the block of bits, unlike convolutional coding. In convolutional coding there are three parameters (n, k, m), k specifies the no of input bits, n specifies number of output bits and m number of memory registers [4].

Code rate of the block is specified by k/n which indicates the efficiency of the code. Constraint length defines the number of bits in the memory of encoder affecting the n number of output bits [5].

Constraint Length = k (m-1)

Suppose there is a convolutional coder with parameters (3, 1, 3). First draw m (3) memory registers with n (3) modulo 2 adders and k (1) input a shown in figure 4:

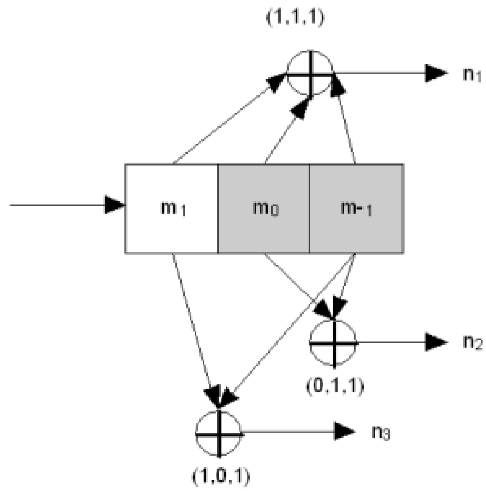

Figure 5: **Rate 1/3 Convolutional coder with constraint length 2**

Convolutional codes are used where message bits come in serially rather than large in blocks. A convolutional encoder operates on the incoming message continuously in a serial manner. Normally convolutional codes are portrayed in graphical forms which take one of three equivalent forms known as code tree, trellis and state diagram.

2.4.2.4 Decoding of Block and Convolutional codes

In the case of block codes as well as convolutional codes the receiver needs to decode the incoming coded message so as to produce the original transmitted massage. There are two types of decoding: *hard decoding* and *soft decoding*. For both block codes and convolutional codes the main decoding technique is called *Maximum Likelihood* (ML). ML is based on the distance between the code words. Upon decoding, the receiver finds the distance between each codeword and the received word. ML is achieved when the decoder chooses the codeword whose distance from the received word is the minimum [4]. The distance method that considered by ML is depends on the type of decoding. For soft decoding the Euclidean distance is used while for hard decoding Hamming distance is used.

- **Hard decoding**

Here the demodulator output is quantized to two levels 0 and 1. The decoder attempts to recover the information sequence by using the code words redundancy for either detecting or correcting the errors that are present at the demodulator output. The receiver use Hamming distance to choose the closest codeword to the received word.

- **Soft decoding**

In soft decoding the decoder use unquantized output of the demodulator. The decoder stores the n outputs corresponding to each sequence of n binary waveforms and builds 2k decision variables. The receiver chooses the transmitted sequence corresponding to the n-bit code word which is closest, in the sense of the Euclidean distance, to the received sequence.

3. COOPERATIVE COMMUNICATION

This chapter gives a complete overview of Cooperative Communication system and the various protocols addressed at relay. The model used is the simplest wireless sensor network comprising three nodes. The chapter also provides the pros and cons of Cooperative Communication systems and their comparison with MIMO systems.

3.1 Background

Information theory of multi-hop communication dates back to the relay channel model. *Relay channel* model consists of source, destination and relay, which is used to facilitate the transform of information form source to destination. Cooperative communication is built on the broadcast nature of wireless communication which suggests that the transmitted signal between source and destination can be overheard at neighboring nodes. Cooperation communication aims to processing and retransmitting of this overheard information towards destination to create spatial diversity, hence to obtain higher throughput and reliability [3, 15].

Though the basic idea behind cooperative communication is the relay channel model, cooperative communication is different from relay channel. The recent developments are motivated by the concept of diversity in fading channel rather than capacity. In most cases of multi-hop systems the destination only process the signal coming from the relay and the relay purpose is only to help the main channel. In cooperative communications the whole system resources act as information sources as well as relay and the destination processes both signals from source and relay. Therefore recent works of cooperation has taken somewhat different emphasis. All relay nodes operate in the same band, so the system can be decomposed into a broadcast channel from the viewpoint of the source and a multiple access channel from the viewpoint of the destination [3].

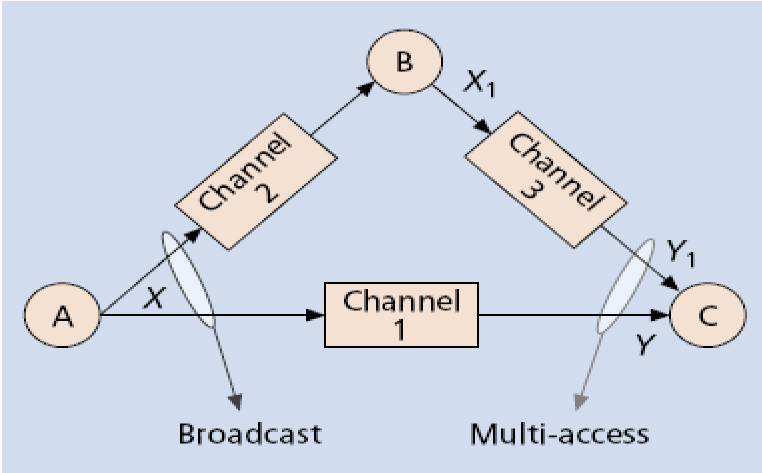

Figure 6: **The relay channel**

3.2 Cooperative Communication

Cooperative communication has emerged as a promising technique to enhance system reliability and performances in resource-limited wireless networks [3]. It is a new communication technique which allows single-antenna mobiles in a multi-user environment to share their antennas and to produce a virtual multiple-antenna array system.

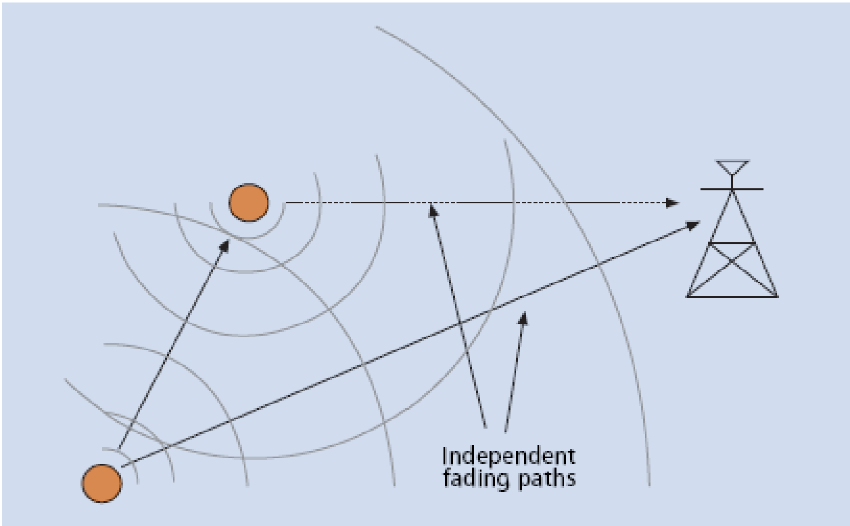

Figure 7: **Cooperative Communication**

3.2.1 Cooperative vs. Multi-hop Network

According to the information theoretic model, the destination can listen to both source and relay, but most multi-hop systems allow the destination to process the relay signal only. This could be justified by the fact that, since the source is generally further away from the destination than the relay, the source signal is much weaker than the relay signal. But when fading is considered, this scheme has considerable amount of loss, especially in diversity, compared to one in which the destination process both signals [15]. Relaying can be used not only to overcome path loss, but also to provide diversity. It can be used to create virtual antenna array, work on multiple antenna systems, which is known as multiple-input multiple-output (MIMO) system.

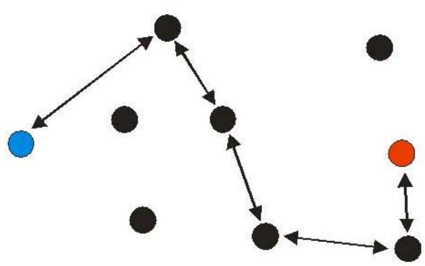

Figure 8: **Multi-hop Network**

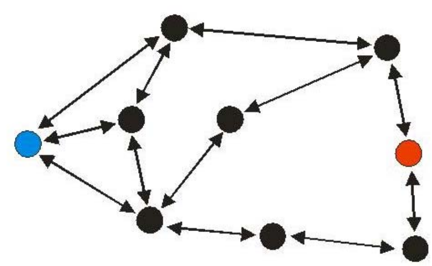

Figure 9: **Cooperative Network**

3.2.2 Cooperative vs. MIMO Systems

Multiple-input multiple-output (MIMO) technology has attracted attention in wireless communications for the good performance it holds. The advantages of MIMO communication has been widely acknowledged, since it offers significant increases in data throughput and link range without additional bandwidth or transmit power. It achieves this by increasing bit rate and reducing fading. It gives higher spectral efficiency which means more bits per second per Hertz of bandwidth [14]. MIMO produces link reliability, or in other word, diversity which reduces fading.

To achieve diversity using MIMO, the transmitter should use more than one antenna. But due to size, cost or hardware limitations many wireless devices may not be able to support more than one antenna. C*ooperative Communications* allow single antenna to reap some of the benefits of the MIMO system. It realizes a new form of space diversity, termed *cooperative diversity*, to combat the effects of severe fading by transmitting independent copies of the signal.

A cooperative system could be considered as a virtual antenna array, where each antenna in the array corresponding to one of the partners who can overhear each other's, process and retransmit to cooperate. This provides additional observations, of the transmitted signal, at destination, the observation which usually discarded and disappeared in space [7].

Motivated by all the above cooperative communication involve two main ideas

- Use relay (multi-hop) to form a system that provide spatial diversity in fading environment
- Envision a virtual antenna array system where each relay (partner) has its own information to send as well as acting as relay for the other partners.

Essentially, cooperative transmissions may be understood as virtual antenna arrays, obtaining all performance improvements associated to MIMO channels: spatial diversity, capacity gain and energy savings [14, 15].

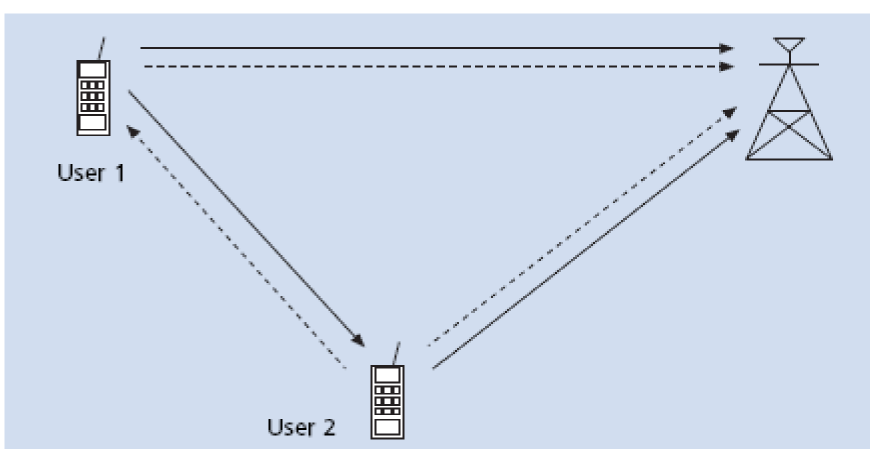

Figure 10: **In cooperative communication each mobile is both a user and relay**

3.3 Cooperative Communication Strategies

The main challenge of the relay channel is the design of appropriate forwarding strategy at the relay. The fundamental relaying protocols analyzed in this project are:

- Amplify-and-Forward
- Decode-and-Forward
- Detect-and-Forward

3.3.1 Amplify and Forward

In this protocol, each user receives a noisy version of the signal transmitted by its partner. The user then amplifies and retransmits this noisy version. The base station combines the information sent by the user and partner, and makes a final decision on the transmitted bit [3]. 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 amplify-and-forward it is assumed that the base station knows the inter-user channel coefficients to do optimal decoding, so some mechanism of exchanging or estimating this information must be incorporated into any implementation [8].

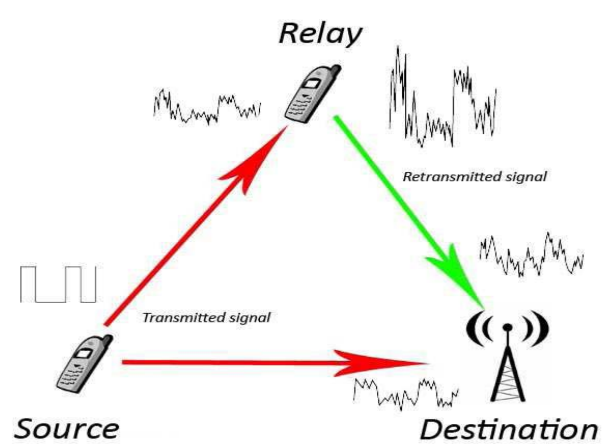

Figure 11: **Amplify and Forward Protocol**

3.3.2 Decode and Forward

In decode and forward protocol the relay decodes the received packet and transmits a fresh codeword using either the same code as the one used at the source or a new one.

This signaling has the advantage of simplicity and adaptability to channel conditions [3]. It is possible that detection by the partner is unsuccessful, in which case cooperation can be detrimental to the eventual detection of the bits at the base station. Also, the base station needs to know the error characteristics of the inter-user channel for optimal decoding.

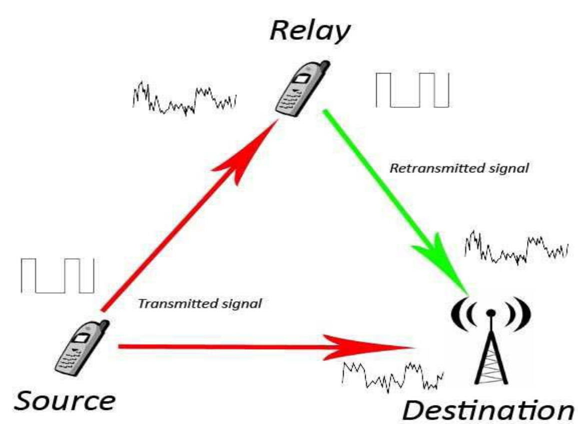

Figure 12: **Decode and Forward Protocol**

3.3.3 Detect and Forward

In this method a user attempts to detect the partner's bits and then retransmits the detected bits. The partners may be assigned mutually by the base station, or via some other technique [3]. The partner provides a second (diversity) data path.

3.4 Coded Cooperation

In coded cooperation each of the users' data is encoded in codeword that's partitioned into two segments. Likewise the data transmission period is divided into two segments. Each user sends its codeword via tow independent fading paths. The basic idea is that each user tries to transmit incremental redundancy to its partner when that is possible; otherwise the users revert to non-cooperative mode. The key to efficiency of coded cooperation is that all this managed automatically through coded design.

Different types of channel coding techniques can be used for coded cooperation. The code may be block or convolutional or combination of both [3].

In addition cooperative relaying can be selectively where the partners choose a suitable cooperative or non-cooperative action according to the measured SNR between them.

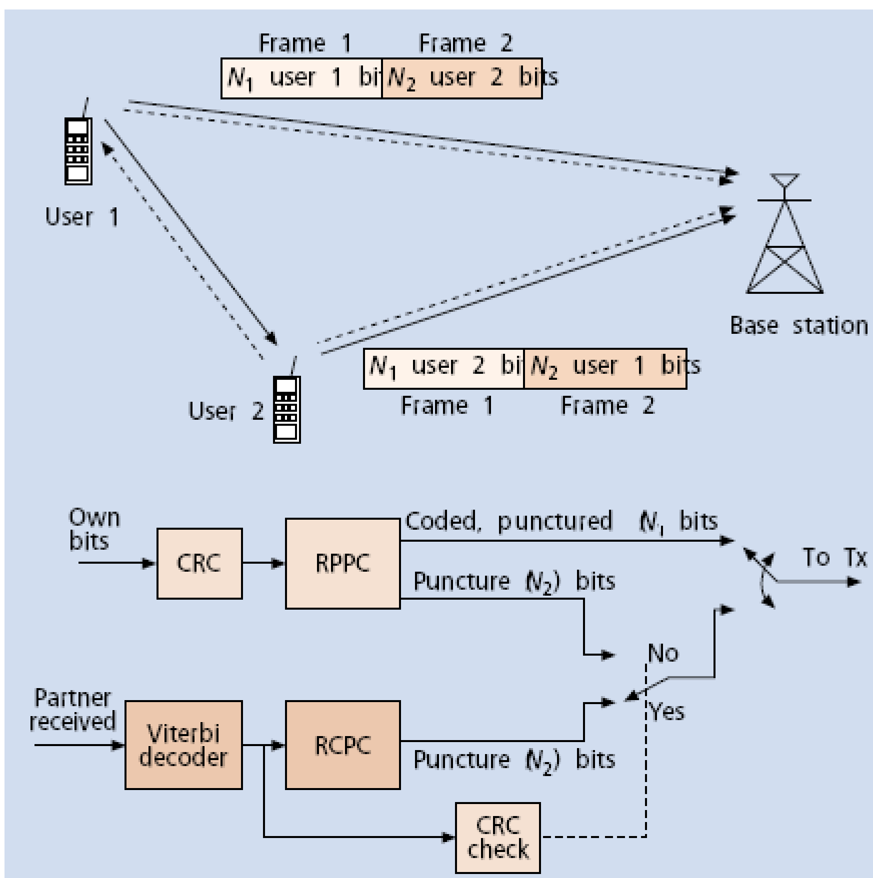

Figure 13: **Coded Cooperation**

3.5 Advantages of Cooperative Communication

Cooperative Communication in wireless ad-hoc networks provides us a variety of advantages, which are:

- Achieve MIMO gains even with one antenna per-node
- Requires less antennas at the nodes
- Less costly
- Small size
- Less hardware required
- Utilizes idle nodes as relays
- Cooperative communication systems achieve lower transmission power
- Increase spectral efficiency
- Reduce outage probability
- Extend battery life
- Extended coverage for cellular communication
- Works even when inter-user channel is bad or one user is closer to the base station
- Improve network connectivity
- Improve throughput

4. SYSTEM ARCHITECTURE

For our project we have chosen the basic three node network. This chapter will give the overview of the system, including the processing blocks at transmitter, relay and destination. Moreover, we have discussed in detail the parameters we have chosen for our simulation model (results of which are included in the next chapter). The performance of cooperative system is compared with that of the SISO for a more realistic analysis.

4.1 SISO System

A single-input-single-output or SISO system is the simplest communication model comprising of a transmitter, a channel and a receiver. The transmitter transmits data over the channel which delivers it to the receiver after adding some noise. At the receiver, the data is detected and bits are recovered back.

Figure 14: **Block Diagram of a SISO System**

4.2 Cooperative System Overview

We have used a baseband equivalent system in this project since it has a number of useful properties which make it an attractive choice for the simulation, e.g. only the slowly varying parts of the signal need to be processed, and the system is not tied to any particular carrier frequency and can be reused if the carrier frequency is changed. Also, the half-duplex system is performed in this project due to the fact that the relay cannot transmit and receive at the same time.

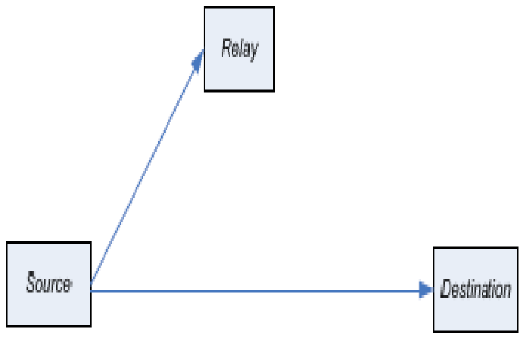

Figure 15: **First Time Slot**

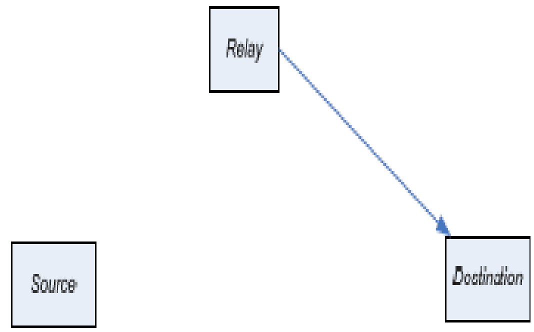

Figure 16: **Second Time Slot**

The system consists of a source, relay, channel, and destination. The output of the source is fed through two different channels. The former channel is the way of transmission from the source to the destination. The latter channel is the one from the source to the relay. The received signal at the relay is then transmitted to the destination, possibly after some processing. The source generates a stream of information bits. Typically, a random bit generator is employed in simulations. These bits are mapped onto symbols and optionally applied with pulse shaping. The output from the source is fed through a channel, which in this project is a single tap Rayleigh fading channel. The destination block takes the output from both channels and does optimal combining and then demodulates the received symbols into information bits. Typically, in a simulation environment, we simply count the number of errors that occurred to gather statistics used for investigating the performance of the system (Bit error probability).

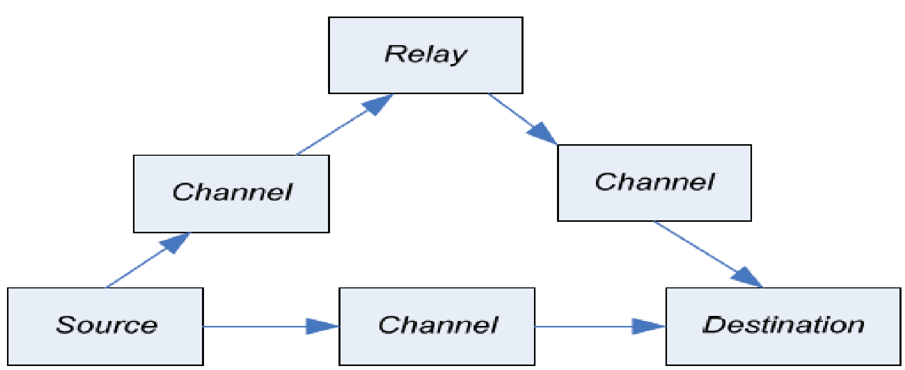

Figure 17: **Block Diagram of channels in Cooperative Communication**

4.3 Nodes of Relay Channel

Relay channel is made up of three nodes:

- **Source**:

  Source is a terminal that transmits information.

- **Relay**:

  Relay is a terminal that both receives and transmits information to enhance communication between the source and destination.

- **Destination**:

  Destination is a terminal that receives information.

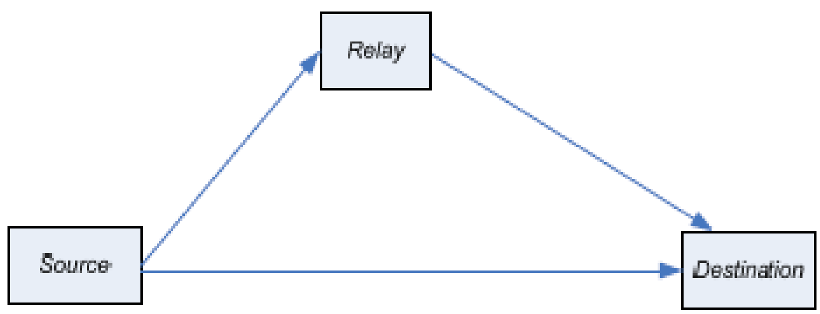

Figure 18: **Nodes of a basic Cooperative Communication System**

Each terminal has one antenna and cannot individually generate spatial diversity. However, the source can benefit from an idle user (relay) by its proximity to the destination by letting the idle user relays its data to the destination. The goal of the relay is thus to help the transmitter to communicate with the destination. Since the information is transmitted through two independent wireless links, a diversity gain is achieved. The main challenge of the relay channel is the design of appropriate forwarding strategy at the relay which improves system performance and reliability.

4.4 Main Blocks of Communication System

The system is simulated with an equivalent complex baseband model divided into the following four parts:

- Transmitter (Source and Relay)
- Relay
- Channel
- Receiver (Relay and Destination)

4.4.1 Transmitter (Source and Relay)

A block diagram of the transmitter is shown in figure below:

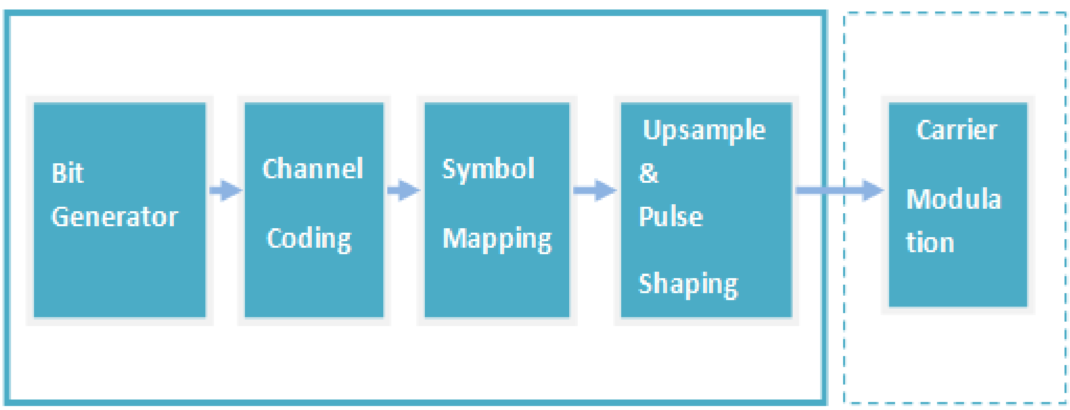

Figure 19: **Block Diagram of Transmitter**

In this project we use the half-duplex system as the implementation of cooperative relaying. Specifically, at time instants n=1,...,N/2 the source transmits the data to both relay and destination, and in the next frame, at time instants n= n/2+1,..,N, the relay transmit what it received from the source to destination while the source does nothing in this time frame. N is the total duration for one successful frame transmission [8]. The frame format is defined in the following figure:

1, 2, 3, …, N/2 (Source)	N/2+1, N/2+2, …, N (Relay)

Figure 20: **Frame Format of Transmitting Data**

4.4.1.1 Bit Generator:

The transmitter generates digital data. The digital data comprises of ones and zeros only. If the data is analog, it is converted into digital signal by passing through the analog to digital conversion module whose output is a binary encoded sequence.

4.4.1.2 Channel Encoder:

This block adds redundant bits to the transmitted block of data in a controlled manner and thus increases the fidelity of the received data at the receiver. In our project we have employed a ½ rate convolutional encoder.

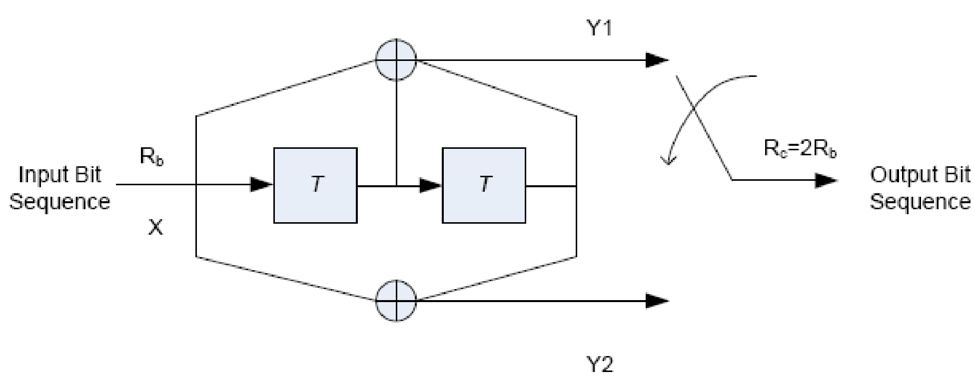

Figure 21: **Half Rate Convolutional Encoder**

4.4.1.3 Symbol Mapping:

After channel coding the bit sequences is mapped using differential quaternary phase shift keying (DQPSK). In differential mapping the 2 bit sequence is assigned a particular change in phase value. This change in phase value is added to the previous phase value of the symbol and the new phase is calculated. As shown below:

BITS	Change in phase
00	exp(j*pi/4)
01	exp(j*3pi/4)
11	exp(j*5pi/4)
10	exp(j*7pi/4)

New phase = previous phase + change in phase

$$\Psi(i) = \psi(i-1) + \Delta\psi$$

It can be seen that gray code has been utilized in assigning the change in phase to the binary sequence. This is due to the fact that gray code reduces the probability of the bit error. A change of one bit is occurred on the next value of the gray sequence.

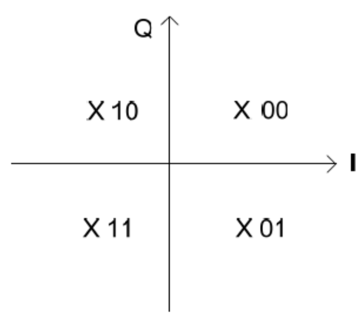

Figure 22: **QPSK with Gray Mapping**

4.4.1.4 Pulse Shaping:

We employ a truncated root raised cosine function for pulse shaping to ensure that the bandwidth can be kept within the range.

We have employed a root- raised cosine filter of central frequency 9.6 kHz as this is the maximum frequency which the DSP kit offers.

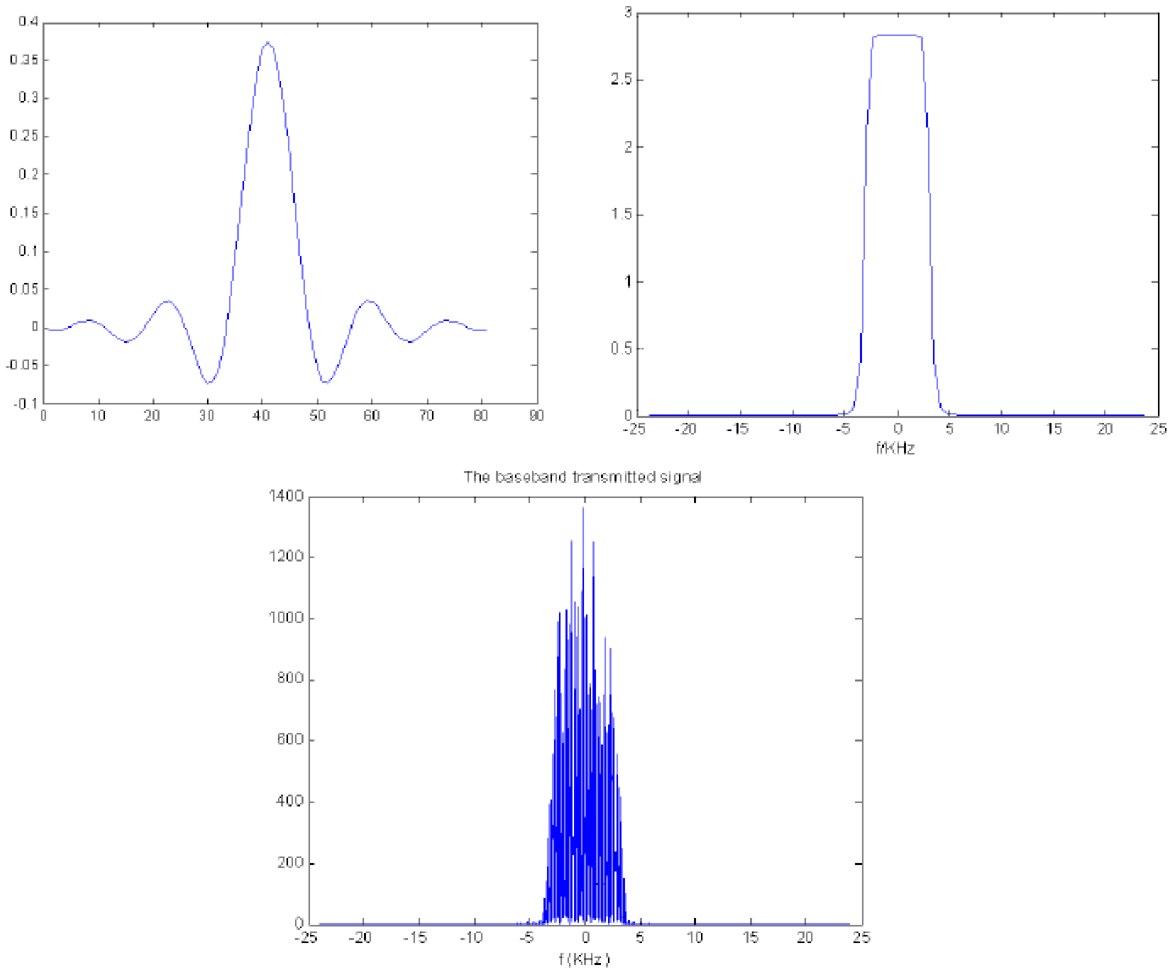

Figure 23: **Pulse shaping at Transmitter using Root-Raised Cosine Filter**

4.4.1.5 Up-conversion

Signal upconversion or upsampling involves raising the power level or amplitude of the signal so it can be transmitted over longer distances.

In Matlab Simulink, the pulse shaping block performs the functionality of upsampling too.

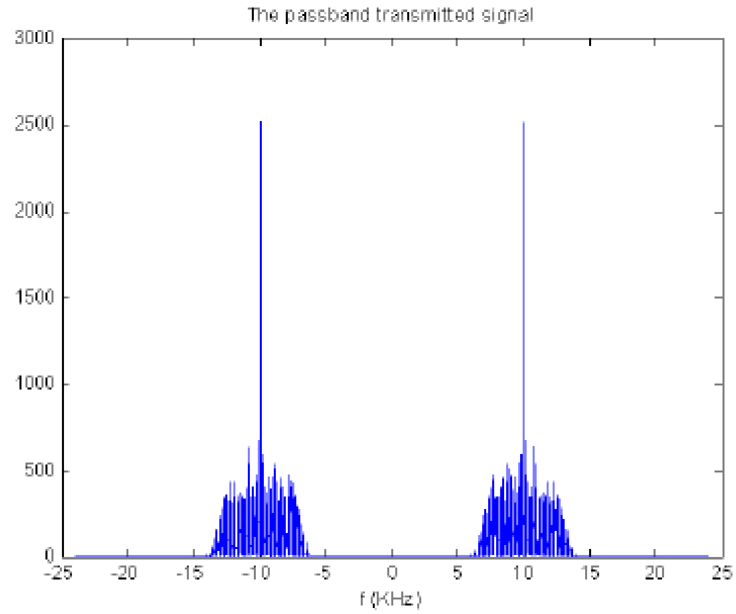

Figure 24: **Passband of Transmitted Signal after Upsampling**

4.4.1.6 Carrier Modulation

The upsampled signal is then modulated using PSK scheme on a RF carrier of high frequency for transmission to a distant receiver.

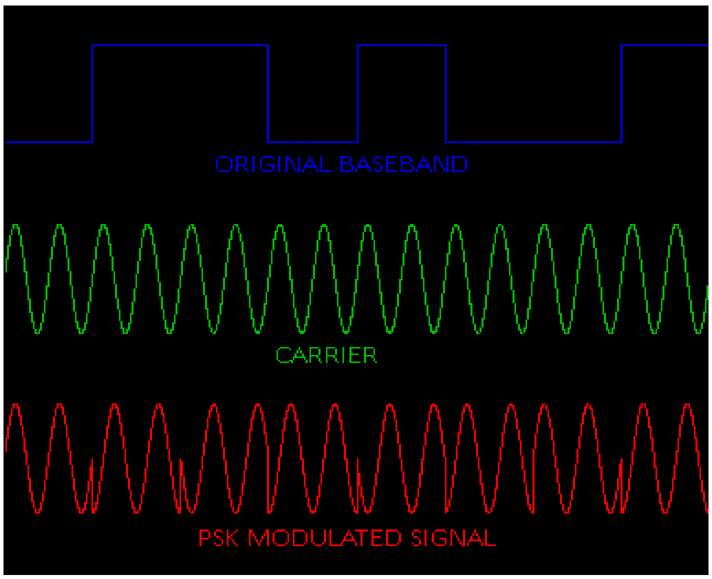

Figure 25: **PSK Modulation of the Transmitted Signal**

4.4.2 Relay

In the project we will use the PAM/QPSK modulation scheme with Gray mapping both in the source and relay with the same signal constellation (The Constellation rearrangement may be performed if we have enough time). The channel between the source and the destination, the source and the relay, and the relay and the destination are modeled as Rayleigh fading channel with variance s^2_{sd}, s^2_{sr} and s^2_{rd} respectively. Also we consider an orthogonal half-duplex system model due to practical limitation, i.e. the relay cannot transmit and receive simultaneously [3, 8].

In the *n*th timeslot the received baseband signals at the relay (y_{sr}) and at the destination (y_{sd}) are given by

$$y_{sr}[n] = a_{sr}\, s[n] + z_r[n] \tag{1}$$

$$y_{sd}[n] = a_{sd}\, s[n] + z_d[n] \qquad n = 1,\ldots, N/2 \tag{2}$$

The relay transmits the signals s_r , and the destination receives

$$y_{rd}[n] = a_{rd}\, s_r[n] + z_d[n] \qquad n = N/2+1,\ldots, N \tag{3}$$

where a_{sr} , a_{sd} and a_{rd} are the channel coefficients between the nodes.

The three fundamental relaying protocols are:

- Amplify and Forward
- Decode and Forward
- Detect and Forward

4.4.2.1 Amplify-and-Forward:

As the name implies the relay simply receives a noisy version of the transmitted signal which is then amplified and forwarded to the destination. Though there is amplification of noise the destination receives two versions of signals and hence achieves diversity. This is the simplest relaying technique possible [8]. The transmitted signals at the relay is

$$s_r\,[\mathrm{n}] = k\, y_{sr} \qquad [\,n - N\,/\,2],\, n = N\,/\,2 + 1,\ldots,\, N \qquad (4)$$

where k is an amplification factor.

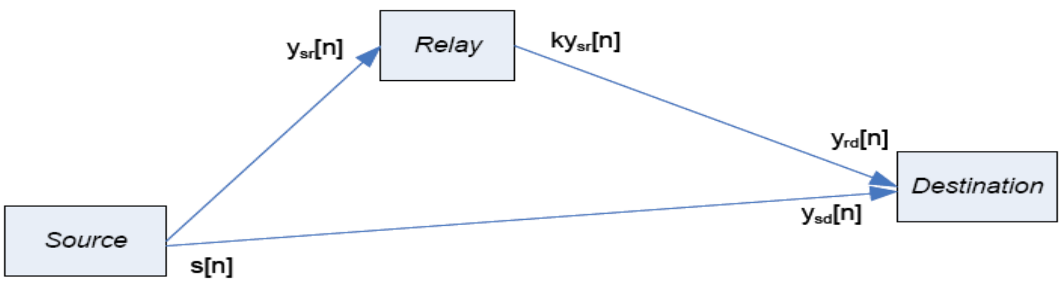

Figure 26: **Amplify and Forward Method**

4.4.2.2 Decode-and-Forward

Decoding at the relay would employ full decode of the transmitted codeword and forward it to the destination.

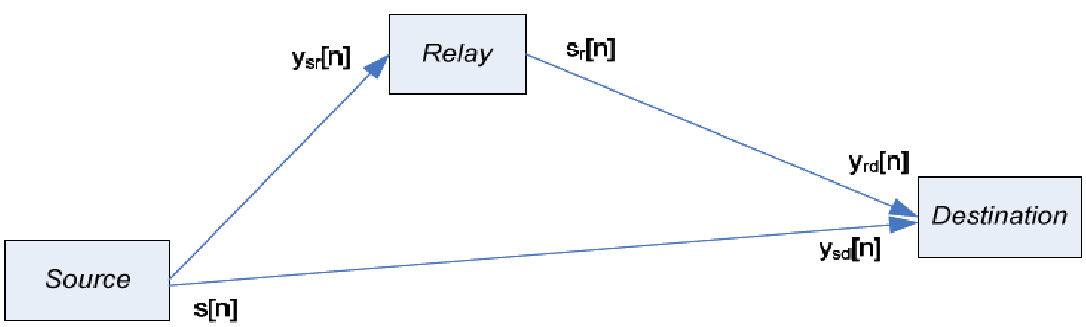

Figure 27: **Decode and Forward Method**

4.4.2.3 Detect-and-Forward

In this method, a relay attempts to detect the transmitter's symbols and then retransmits the detected symbols [8]. This protocol is actually the uncoded scheme of decode-and-forward where the information bits are transmitted without coding:

$$sr[n] = \hat{s}[n - N/2] \qquad n = N/2 + 1, \dots, N \qquad (5)$$

During this interval, the relay processes $y_{sr}[n]$ by decoding an estimate $\hat{s}[n]$ of the source transmitted signal.

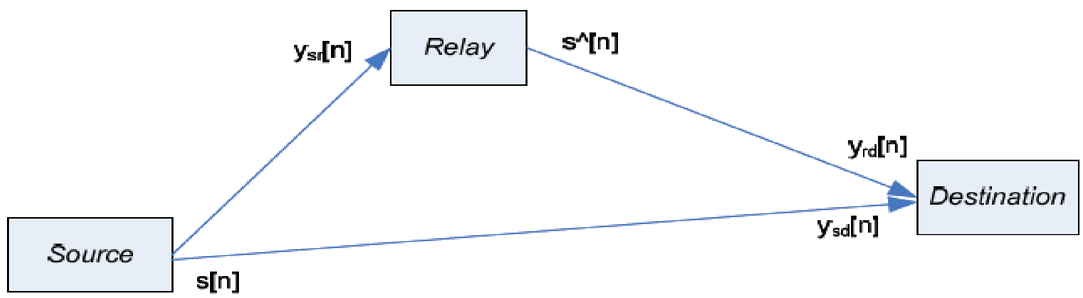

Figure 28: **Detect and Forward Method**

4.4.3 Channel

In simulation the channel is modeled mathematically as a complex channel

$$a = X + iY \qquad (6)$$

where X and Y are independent white Gaussian components with variance N0/2 [8].
The channel enumerated on the DSP board has a bandwidth of 9.6 kHz.

For our project it is assumed that the channel is a known channel. Hence at the receiver we have based our equalization according to the known channel parameters.

4.4.4 Receiver (Destination and Relay)

A block diagram of the receiver is shown in the figure below:

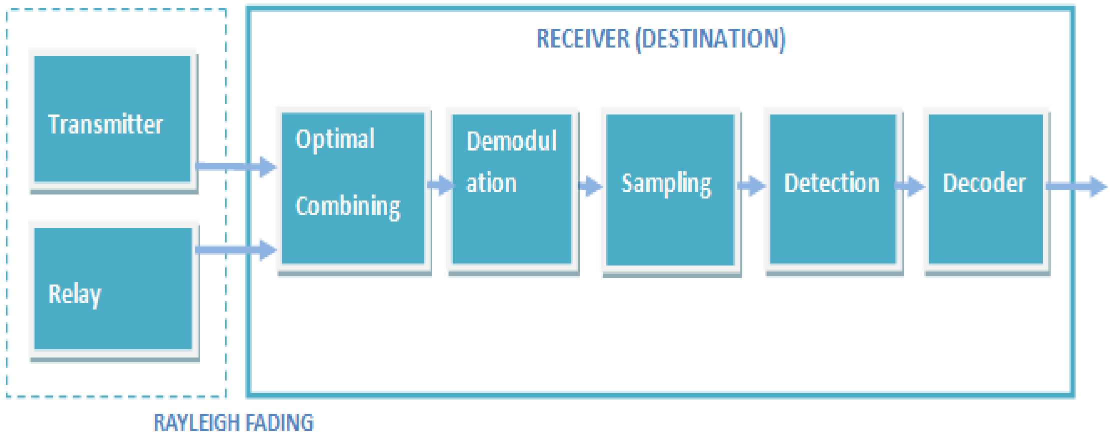

Figure 29: **Block Diagram of Receiver**

4.4.4.1 Combiner

An optimum combining technique is employed at the receiver to achieve diversity gains. For our project simulations, we have used Equal Gain Combining (EGC) and Maximal Ratio Combining (MRC) schemes.

4.4.4.1.1 Equal Ratio Combining (ERC)

If channel quality could not be estimated, all the received signals can just be added up. This is the easiest way to combine the signals, but the performance will not be that good in return [11].

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

Within this thesis one relay station is used, so the equation simplifies to

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

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

4.4.4.1.2 Maximum Ratio Combining (MRC)

The *Maximum Ratio Combiner* (MRC) achieves the best possible performance by multiplying each input signal with its corresponding conjugated channel gain. This assumes that the channels' phase shift and attenuation is perfectly known by the receiver [11].

$$y_d[n] = \sum_{i=1}^{k} h^*_{i,d}[n] \cdot y_{i,d}[n]$$

Using a one relay system, this equation can be rewritten as:

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

The MRC only considers the last hop (i.e. the last channel) of a multi-hop link.

4.4.4.2 Demodulation

Differential Demodulation would be used to recover the data bits from D4PSK symbols. DPSK demodulation is used as compared to coherent demodulation due to its simple implementation on hardware.

4.4.4.3 Decoder

The decoder block checks for parity errors in the frame and revert correctable errors. A *Viterbi Decoder* is used to implement decoding of channel coding (convolution coding). Again viterbi decoding is used due to its simple implementation on hardware, reliability and robustness at low constraint length. The decoder provides us with the binary bits encoded through convolution coding.

4.4.4.4 Decision

The symbols are converted back to their bit streams by comparing the received symbols with the optimal thresholds values (hard decision).

5. IMPLEMENTATION

In first phase, the basic three node Cooperative Communication network with channel coding, and PSK Modulation has been simulated on MATLAB through m files. Simulations were carried out for all three relay protocols namely Amplify & Forward, Detect & Forward and Decode & Forward.

In second phase the overall project was build in SIMULINK by making interconnections and setting parameters of the individual communication system blocks (Software Implementation).

In the final and last phase, SIMULINK model was burnt on the DSP kit by generating its C code in the code composer studio (Hardware Implementation). The design flow for implementation is shown in figure 29.

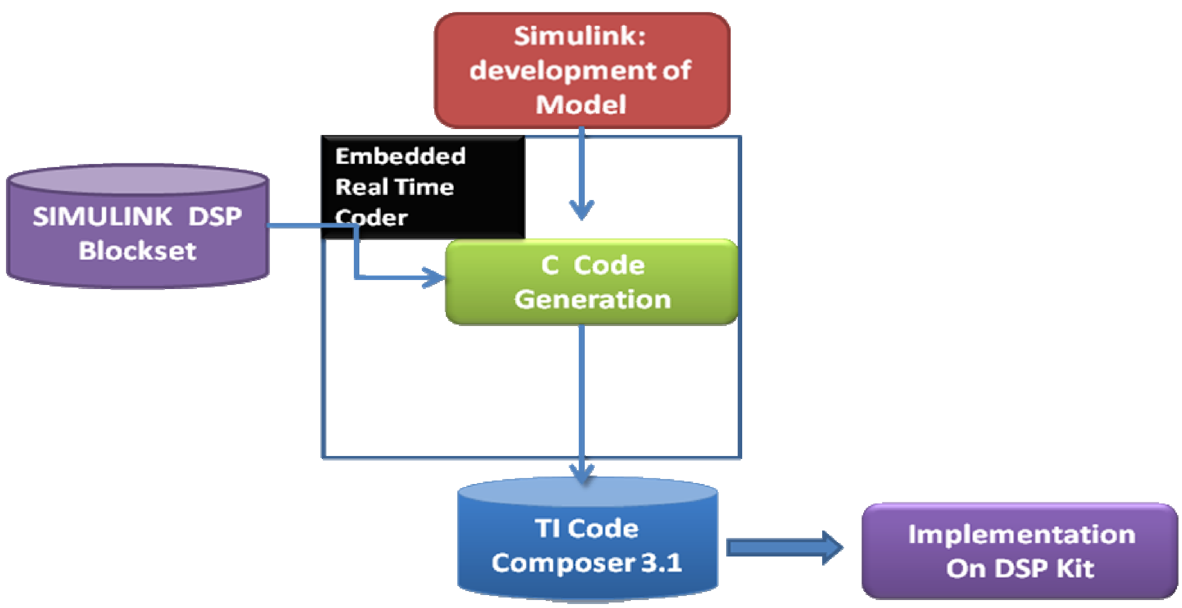

Figure 30: **Design Flow for Implementation**

5.1 MATLAB Implementation

In software implementation, individual blocks for cooperative communication model have been coded by utilizing in built functions of MATLAB tool. For channel coding, diversity gains, and combining, algorithms from different research papers have been coded in to m files.

5.1.1 Transmitter

5.1.1.1 Bit Generator

Digital Data comprises of a bit stream of zeros and ones. It is randomly generated by using randint command in MATLAB.

data_bits = randint(1,x,[0 1]);

5.1.1.2 Convolutional Encoder

In this step the binary data is convolutionally encoded through ½ rate encoder.

code = convenc(i_bits,trellis);

The command (CONVENC) for this function requires the data to be encoded and constraint length (no of registers).

5.1.1.3 QPSK Symbol Mapping Block

Now the data will be mapped on to 4 different symbols to represent the different combinations of bits as shown below:

00 exp(j*2*pi)

01 exp(j*pi/2)

10 exp(j*pi)

11 exp(j*3pi/2)

5.1.1.4 Pulse Shaping

Root raised cosine filter is employed for pulse shaping so the frequency remains within the limits. For DSP Kit, this limit is 9.6 kHz.

5.1.2 Channel

Now the transmitted data has been passed through two different kinds of channels:

- Raleigh Fading channel
- AWGN channel

5.1.2.1 AWGN Channel

AWGN Channel adds white Gaussian noise to the vector signal x. The scalar snr specifies the signal-to-noise ratio per sample, in dB. If x is complex, awgn adds complex noise.

y = awgn(x,snr)

5.1.2.2 Rayleigh Fading Channel

For MATLAB simulations, a single tap Rayleigh channel is considered with known coefficients and it is assumed that the Rayleigh channel is flat fading channel.

5.1.3 Relay

The relay is simulated by a 'dfilt' command. The original signal is varied in SNR, given some delay according to its distance from transmitter and receiver and forwarded to the destination.

At the relay the different forwarding protocols are employed. The algorithms for these protocols have been taken from a number of research papers.

5.1.4 Receiver

5.1.4.1 Combining

We have used two types of combining techniques in our project, the maximum ratio combining (MRC) and equal gain combining (EGC). In equal gain combining, the signals coming from transmitter and relay are added in equal weight age. However, in maximum ratio combining, the bits coming from each channel are multiplied with the conjugate of the channel response before they are added.

5.1.4.2 QPSK Demodulation

Serial data is then mapped to different bit combinations depending upon the input symbol received by the following command:

z = pskdemod(AtRx_P2S,4);

The command requires the symbols to be demodulated and the demodulation scheme to be specified. In this case differential demodulation scheme have been utilized which have been explained in the previous sections. The output of this function is in decimal format specifying the 4 different phases as 0,1,2,3.

So to convert in bit format the data is passed through decimal to binary converter which generates the corresponding bit sequence for the retrieved phase number.

5.1.3.3 Viterbi Decoder

Now the data in the bit format is passed through channel decoder decoding the channel coding effect. The block requires the trace back length, which on increasing, efficiently decode the received bits.

5.1.3.4 Detection

The decoded bits are then mapped onto binary one or binary zero according to a hard decision taken during the detection process.

5.2 SIMULINK Implementation

5.2.1 Introduction

SIMULINK is a very effective MATLAB tool which is a graphical utility minimizing the need for basic MATLAB coding. It minimizes and to some extent removes the need of tedious task of coding in MATLAB by providing its own rich library of built in block sets. This library of blocks is composed of quiet large number of domains, varying from communications and signal processing block sets to Instrumentation block set. These blocks could then be reconfigured and utilized in a large number of ways. It also makes it possible to design systems compromising of different domains, as most systems are multi domain; this is an effective tool to design such systems. Above all, the real time display of SIMULINK makes it worth using as a design tool. Besides it’s built in block library, SIMULINK also provides the facility to include custom made blocks into the system design by using S functions.

5.2.2 Cooperative Communication System on SIMULINK

SIMULINK was employed to design a basic three node Cooperative Network and by introducing different wireless channels. Most importantly, the path to use **REAL TIME WORKSHOP EMBEDDED CODER** (MATLAB Application for hardware implementation) relies heavily on SIMULINK design model. This application of SIMULINK would be explained in detail in the Hardware implementation section.

5.2.3 Cooperative Communication System Model

The basic three node Cooperative Communication Network was designed using different libraries of SIMULINK but the communications and signal processing library block sets are most abundantly utilized.

5.2.4 SISO Model

The SISO Model is also implemented on SIMULINK for performance comparison with Cooperative Communication strategies. The channel simulated for this purpose is AWGN channel. The Bernoulli binary generator is used to generate the data bits.

The other blocks which are used include:

- Bernoulli binary Generator
- Bit to Integer Converter
- QPSK Modulator
- Root raised Cosine filter

The result is analyzed on basis of scatter plots, eye diagrams and bit error rate curves.

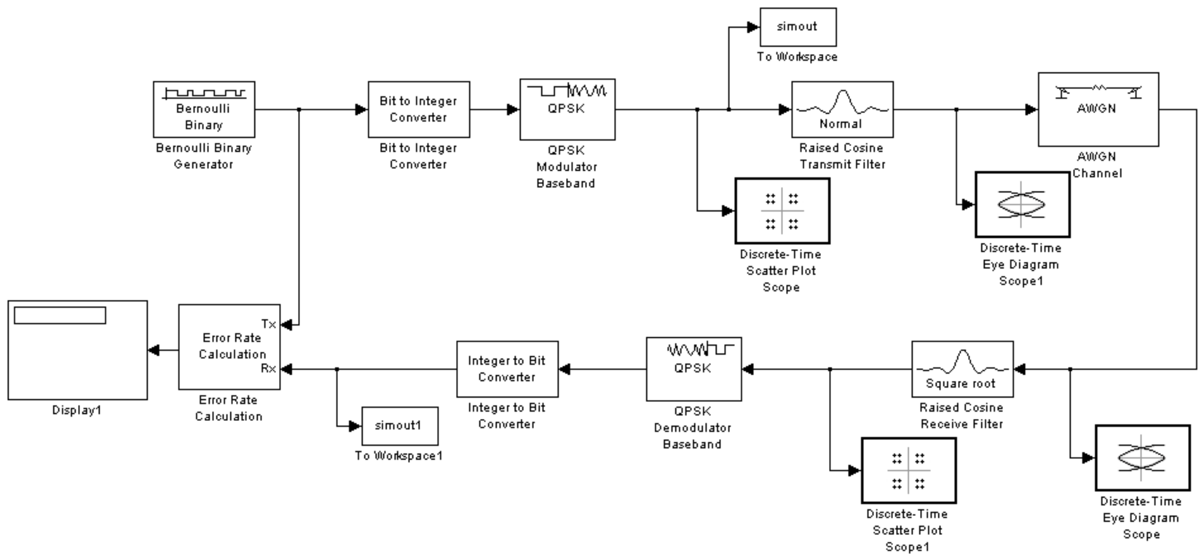

Figure 31: **Simulink Model for SISO System**

5.2.5 Blocks in Cooperative Communication Model

5.2.5.1 Transmitter Blocks

The transmitter consists of the following main blocks:

- **Bit Generator Block**
- **Integer to Bit Convertor**
- **Channel Coding Block**
- **Constellation Mapping Block**

A detailed analysis involving block functionality and parameters involved of each of these blocks is given below.

Bit Generator Block

The output data type used in design of the Cooperative Communication model is double. The Bernoulli Generator is used in this system which generates binary random data of the specified length.

Integer to bit convertor Block

If in the data generator or acquisition blocks, output data type is an integer than an integer to bit convertor block is used to pass the data bits to the digital systems of the modem.

The most important parameters involved in this block are the number of bits per integer. It defines the resolution used to represent each integer. The more bits used to represent each integer, the better the performance in terms of redundancy but the system load increases.

Channel Coding

To introduce redundancy into the data, we have employed the convolution coding into our system. There are two types of options available for channel coding in SIMULINK library namely:

a) **Block Coding**

b) **Convolution Coding**

The Cooperative Communication model is utilizing convolution coding as a channel coding technique. The most important parameter in convolution coding block is the trellis structure. The model incorporates a trellis structure defined by the MATLAB function. The detail of this function and parameters involved is given in the literature review block.

Symbol Mapping Block

In this block, the data bits along with the redundant bits are mapped with complex signals. Different mapping techniques are available. The model uses the Quadrature Phase shift Keying (QPSK).

5.2.5.2 Channel Effects Blocks

To introduce the impact of the channel on the model, various channels are available in the simulink. The two channels used in the simulations are:

1) **AWGN Channel**
2) **Rayleigh Channel**

AWGN Channel

In the AWGN Channel, SNR of the channel could be varied. This block emulates the effect of Additive White Gaussian Noise on the data generated by the transmitter. By varying the Signal to Noise ratio, the impact of the channel on the data could be varied.

Rayleigh Channel

In case of Rayleigh Channel, we could simulate the effects of the timing delay, multi path effects and the effect of Doppler shift on the performance of the OFDM Modem. All these parameters could be varied by using the Rayleigh channel block.

5.2.5.3 Receiver Blocks

At the receiver end, the following blocks are used:

- **Symbol De-Mapping Block**
- **Viterbi Decoder Block**
- **Error Calculation Block**
- **Display Block**

A detailed analysis involving block functionality and parameters involved of each of these blocks is given below.

Symbol De-Mapping Block

In this block, the MODEM transfers the complex symbols back to binary bits. This is done by using DQPSK demodulator, which maps the 4 unique symbols already stored in a lookup table back to the binary bits.

Viterbi Decoder Block

The data bits generated by the symbol de mapping block also includes the redundant bits. The viterbi decoder used these redundant bits to generate the actual data bits generated at the transmitter. It uses the trellis function employed at the convolution encoder block.

An important parameter is the trace back length, which decided how precise the values are generated and decided the extraction power of the decoder. Greater the trace back length, greater the precision which makes the system heavier.

Error Calculation Block

To evaluate the performance of the Modem, we would compare the bits generated at the transmitter with that recovered by the viterbi decoder.

Display Block

The display block is used to display different parameters. It is employed in the simulation to display the output of the error calculation block. It is also used to simultaneously display the number of erroneous bits.

5.2.6 SIMULINK Models for Relaying Protocols

5.2.6.1 Amplify and Forward Simulink Model

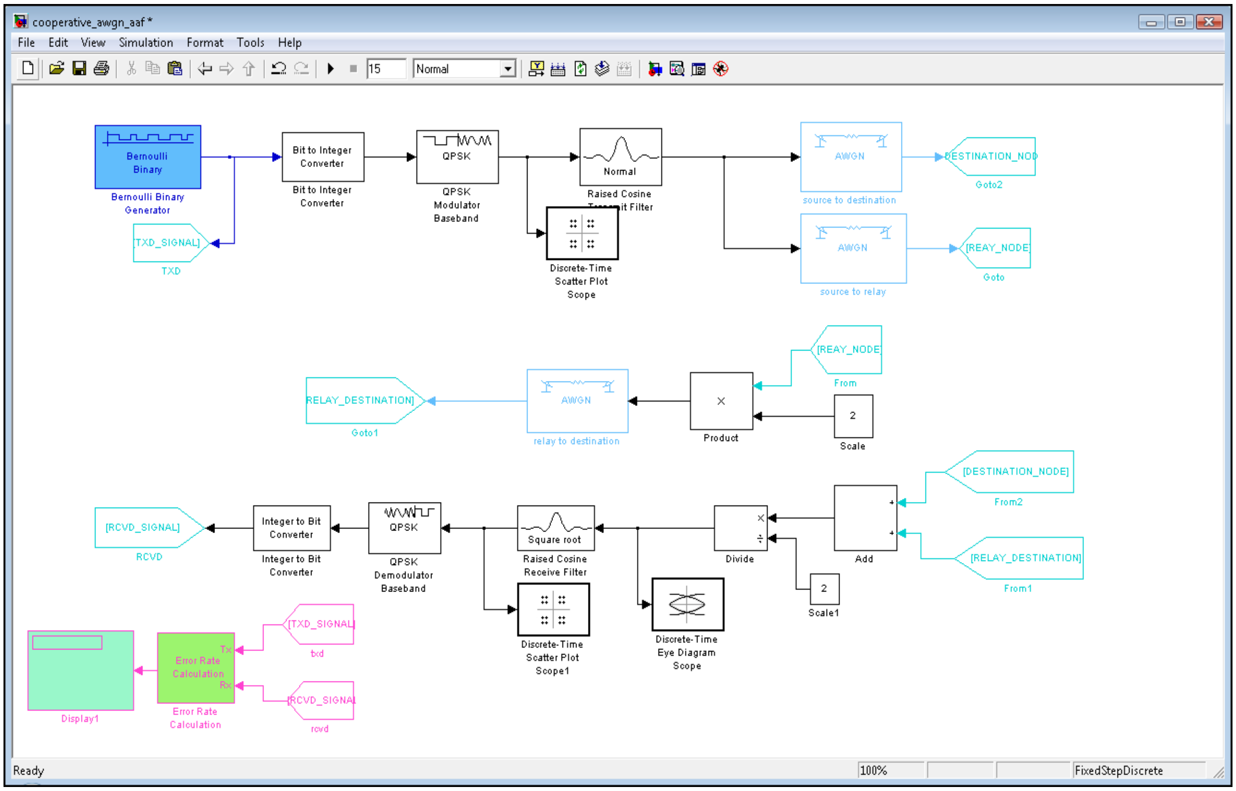

Figure 32: **Simulink Model for Amplify & Forward Protocol**

5.2.6.2 Detect and Forward Simulink Model

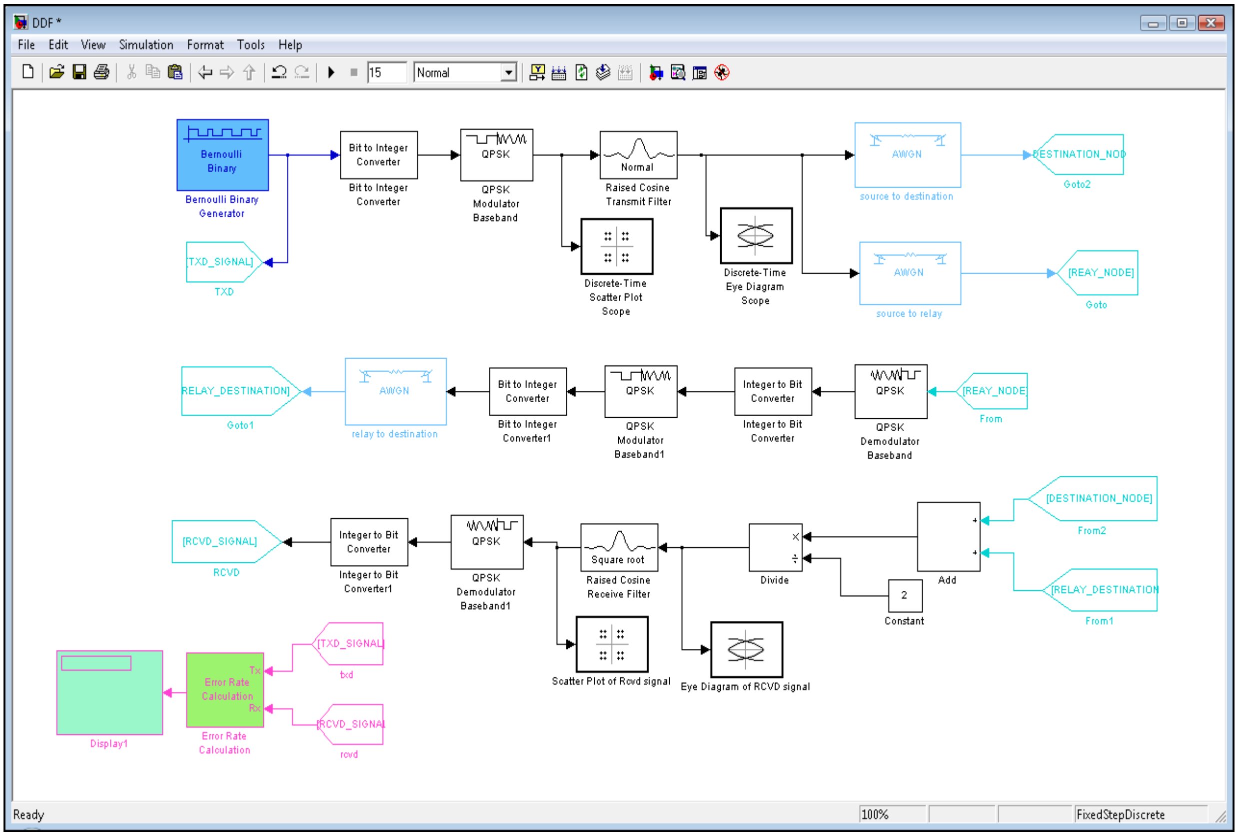

***Figure 33:* Simulink Model for Detect & Forward Protocol**

5.2.6.3 Decode and Forward Simulink Model

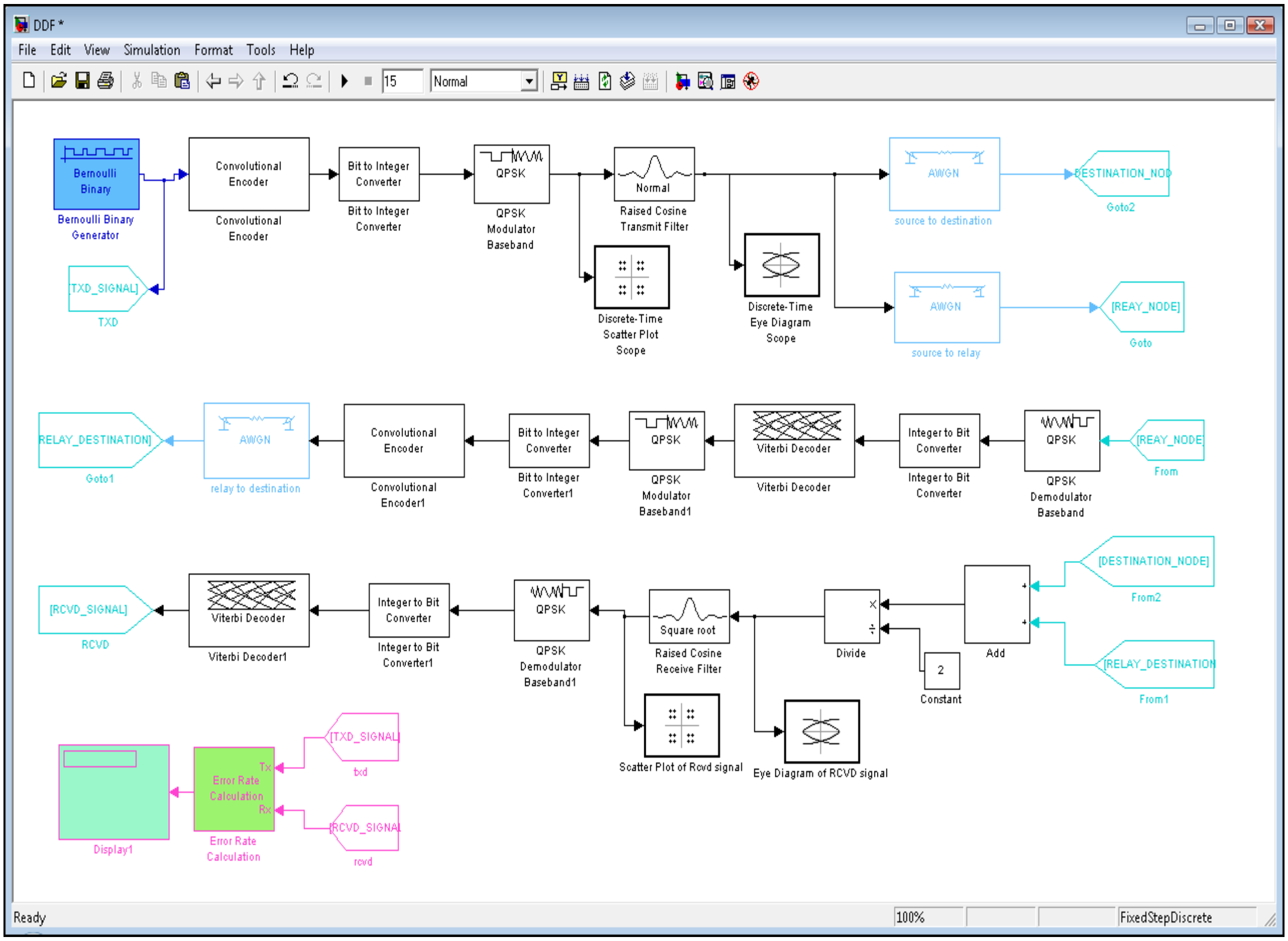

Figure 34: **Simulink Model for Decode & Forward Protocol**

5.3 Hardware Implementation

5.3.1 Introduction of DSP KIT

5.3.1.1 DSK6713 Overview

The C6713 DSP Starter Kit (DSK) is a low-cost platform which lets customers evaluate and develop applications for the Texas Instruments C67X DSP family.

Functional Diagram

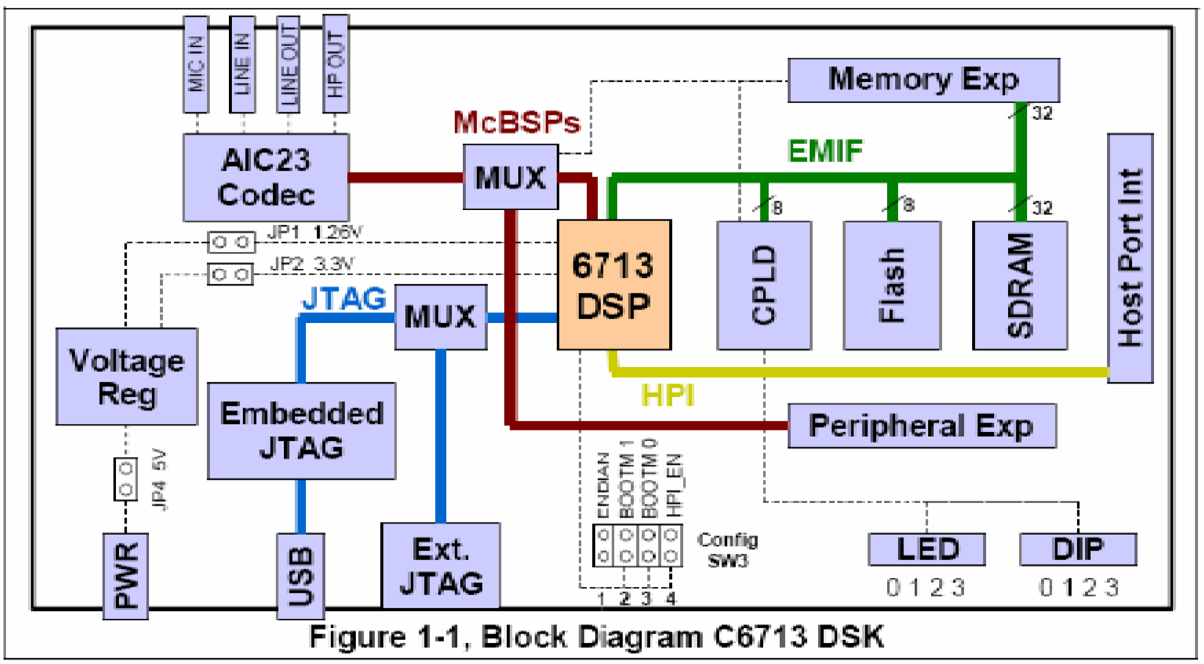

Figure 35: **Block Diagram of C6713 DSK of Texas Instruments**

Digital Signal Processor (DSP)

A specialized microprocessor designed specifically for digital signal processing, (mostly in real-time computing).

Features

- Specialized Design for real-time process
- Specialized High Speed Arithmetic
- Multiple Memory access

Floating Point

Since 6713 DSP Starter Kit (DSK) is a floating point so following are the features of floating point:

- Dynamic Range
- High SNR
- Costly
- Easier Design
- Slower
- Audio Processing , Radar

C6713 DSK Overview

1. **225 MHz TMS320C6713 *floating point* DSP**
2. **AIC23 stereo codec (ADC and DAC)**
   1. Ideal for audio applications
   2. 8-96 kHz sample rates
3. **Memory**
   1. 16 MB dynamic RAM
   2. 512 KB nonvolatile FLASH memory
4. **General purpose I/O**
   1. 4 LEDs
   2. 4 DIP switches
5. **USB interface to PC**

5.3.1.2 DSK6416 Overview

- A Texas Instruments TMS320C6416 fixed-point DSP operating at 1 GHz
- An AIC23 stereo codec (8-96 kHz sample rates)
- 16 Mbytes of synchronous DRAM and 512 Kbytes of non-volatile Flash memory (256 Kbytes usable in default configuration)
- User accessible LEDs and DIP switches and sixteen general-purpose I/O pins
- Software board configuration through registers implemented in CPLD
- Configurable boot options
- Standard expansion connectors for daughter card use
- JTAG emulation through on-board JTAG emulator with USB host interface or external emulator
- Single voltage power supply (+5V)

Functional Diagram

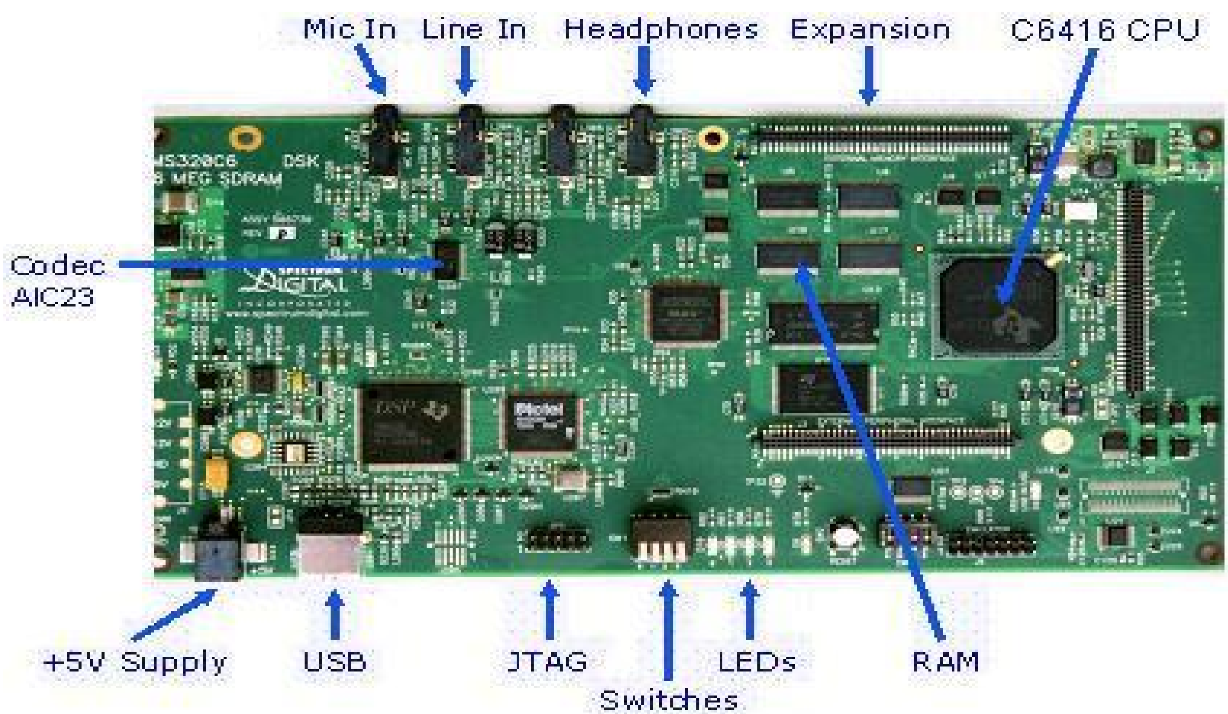

Figure 36: **Block Diagram of C6416 DSK of Texas Instruments**

5.3.2 Explanation of DSP Architecture

AIC 23 Codec

The codec samples analog signals on the microphone or line inputs and converts them into digital data that can be processed by the DSP.

When the DSP is finished with the data it uses the codec to convert the samples back into analog signals on the line and headphone outputs so the user can hear the output.

CPLD

The C6713 DSK uses an Altera EPM3128TC100-10 Complex Programmable Logic Device (CPLD) device to implement:

- Memory-mapped control/status registers that allow software control of various board features
- Control of the daughter card interface and signals
- Assorted "glue" logic that ties the board components together

Memory on DSK

The DSK uses a 64 megabit Synchronous DRAM (SDRAM) on the 32-bit EMIF. Total available memory is 16 megabytes. It uses a 512Kbyte external Flash as a boot option.

JTAG- Joint Test Action Group

JTAG -JTAG refers to a set of design rules that encompass testing, programming and debugging of chips. The JTAG interface allows a user to examine signals and registers on a chip through an external interface that only uses five extra pins on the chip.

In a TI DSP development environment Code Composer uses the JTAG interface to debug programs non-intrusively through a hardware device called a JTAG emulator.

Onboard Switches

The four DIP switches allow simple feedback from the user. The DIP switches can be read through the CPLD USER_REG register. It has 4 configuration switches that allow users to control the operational state of the DSP when it is released from reset.

- Configuration switch 1 controls the endianness of the DSP
- Switches 2 and 3 configure the boot mode that will be used when the DSP starts executing
- Switch 4 determines whether the HPI or McASP signals come out on shared pins

DSK Power on Self Test

Power on Self Test (POST) program stored in FLASH memory automatically executes. It takes 10-15 seconds to complete

All DSK subsystems are automatically tested. During POST, a 1 kHz sinusoid is output from the AIC23 codec for 1 second. If POST is successful, all four LEDs blink 3 times and then remain on

5.3.3 Applications of DSP

- **Medical**
    - Diagnostic imaging (CT, MRI, ultrasound, and others)
    - Electrocardiogram analysis
    - Medical image storage/retrieval

- **Industrial**
  - Oil and mineral prospecting
  - Process monitoring & control
  - Nondestructive testing
  - CAD and design tools
- **Space**
  - Space photograph enhancement
  - Data compression
  - Intelligent sensory analysis by remote space probes
- **Scientific**
  - Earthquake recording & analysis
  - Data acquisition
  - Spectral analysis
  - Simulation and modeling
- **Commercial**
  - Image and sound compression for multimedia presentation
  - Movie special effects
  - Video conference calling
- **Telephone**
  - Voice and data compression
  - Echo reduction
  - Signal multiplexing
  - Filtering
  - Wireless Phones

- Modems
- Encryption

- **Military**
  - Radar
  - Sonar
  - Ordnance guidance
  - Secure communication

5.3.4 Code Composer Studio

5.3.4.1 Introduction

CCS provides an IDE to incorporate the software tools required to work with the DSK .It includes tools for code generation, such as a C compiler, an assembler, and a linker.

The C compiler compiles a C source program with extension .c to produce an assembly source file with extension.*asm*.The assembler assembles *.asm* source file to produce a machine language object file with extension *.obj*.The linker combines object files and object libraries as input to produce an executable file with extension *.out*. This executable file can be loaded and run directly on the C6713 processor.

5.3.4.2 Important Features of CCS

1. Debugging
2. It supports real-time debugging.
3. Debugging features available are
    i. setting breakpoints
    ii. probe points
    iii. watching variables
    iv. viewing memory ,registers
4. Graphical Capabilities like graphing results, Animations
5. Profiling and optimization Features
    a. Monitoring execution time.
6. Application Code Tuning
7. Real-time analysis can be performed using real-time data exchange (RTDX)
8. RTDX allows for data exchange between the host PC and the target DSK, as well as analysis in real time without stopping the target

5.3.5 Real Time Data Exchange (RTDX)

5.3.5.1 Features of RTDX

- RTDX allows for data exchange between the host PC and the target
- Analysis in real time without stopping the target
- Key statistics and performance can be monitored in real time
- Through the joint team action group (JTAG), communication with on-chip emulation support occurs to control and monitor program execution
- Send and retrieve data from memory on the processor

5.3.5.2 Interfacing Host and Target

RTDX enables non-obtrusive two-way communication between the host PC and the DSP. All transfers are made via RTDX calls in DSP application code.

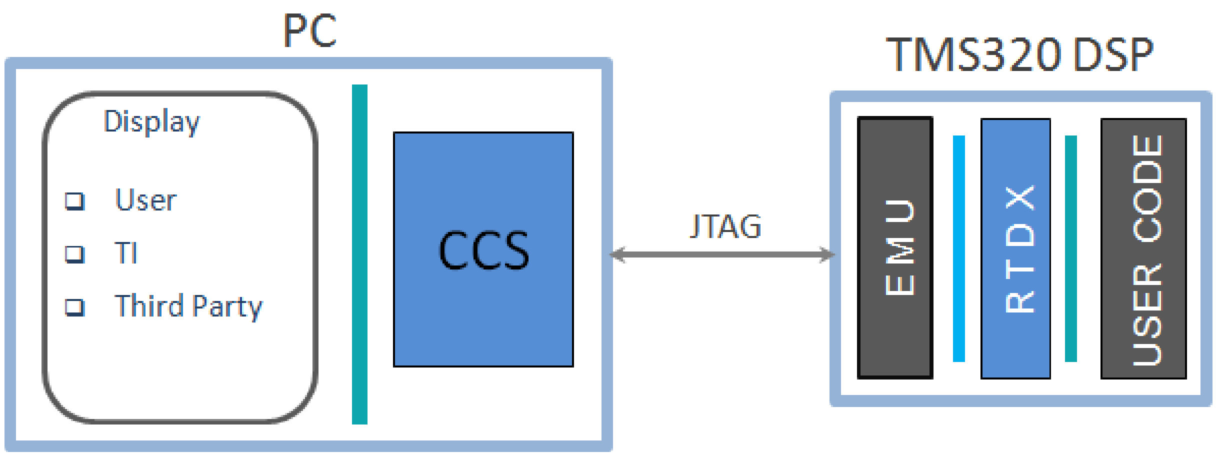

Figure 37: **Interfaces between Host and Target DSP Kit**

5.3.6 Features of DSP BIOS

- **Real-Time Scheduler**
    - Preemptive thread management kernel
- **Real-Time Analysis Tools**
    - Allows application to run unimpeded while displaying debug data
- **Real-Time Data Exchange (RTDX)**
    - Allows two-way communication (target ⇔ host) while target is running

5.3.6 MATLAB Link for CCS Development Tools

- Execute CCS commands from MATLAB for debugging, analysis, and automation
- Upload data from DSP memory
- Download program data, parameters, and test vectors
- Exchange real-time data between MATLAB and a running DSP via RTDX without halting the DSP program

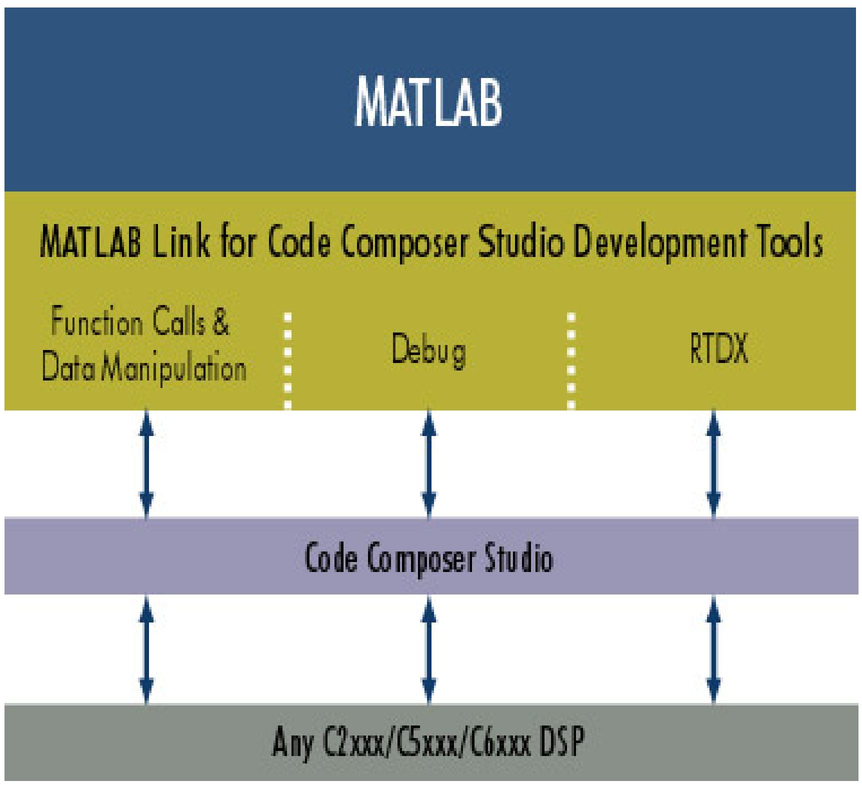

Figure 38: **MATLAB Link for CCS Development Tools**

5.3.8 Overview of Hardware Implementation

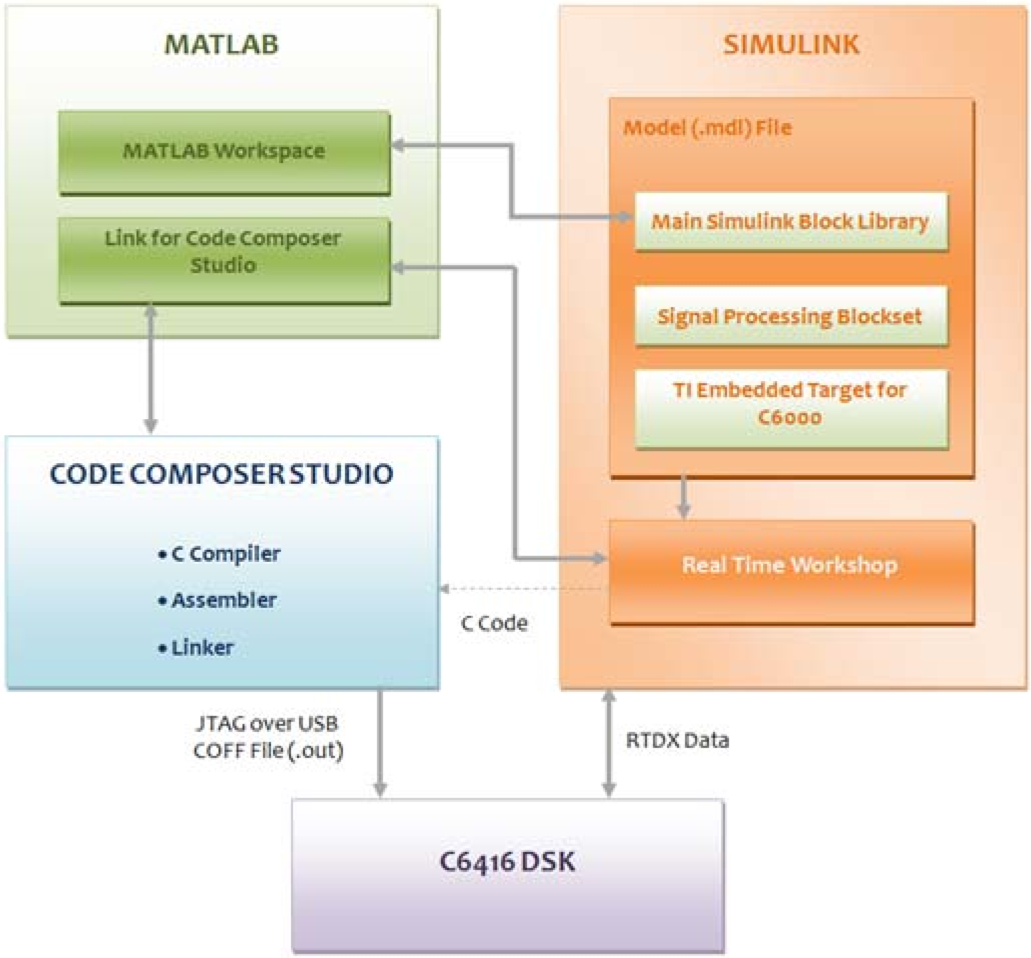

Figure 39: **Block Diagram for Hardware Implementation**

5.3.8.1 Model Mapping

- Design and simulate model from:
  - Simulink
  - Stateflow
- Connect board specific blocks
  - A/D, D/A, JTAG, RTDX
  - Automated code compile, link, load, and execute-on-target support

5.3.9 Hardware implementation on DSP Board

For our project we have implemented the cooperative relaying strategies on DSK6416. Below is the sequential hardware/software model for overall system analysis, which has been implemented in DSP kit.

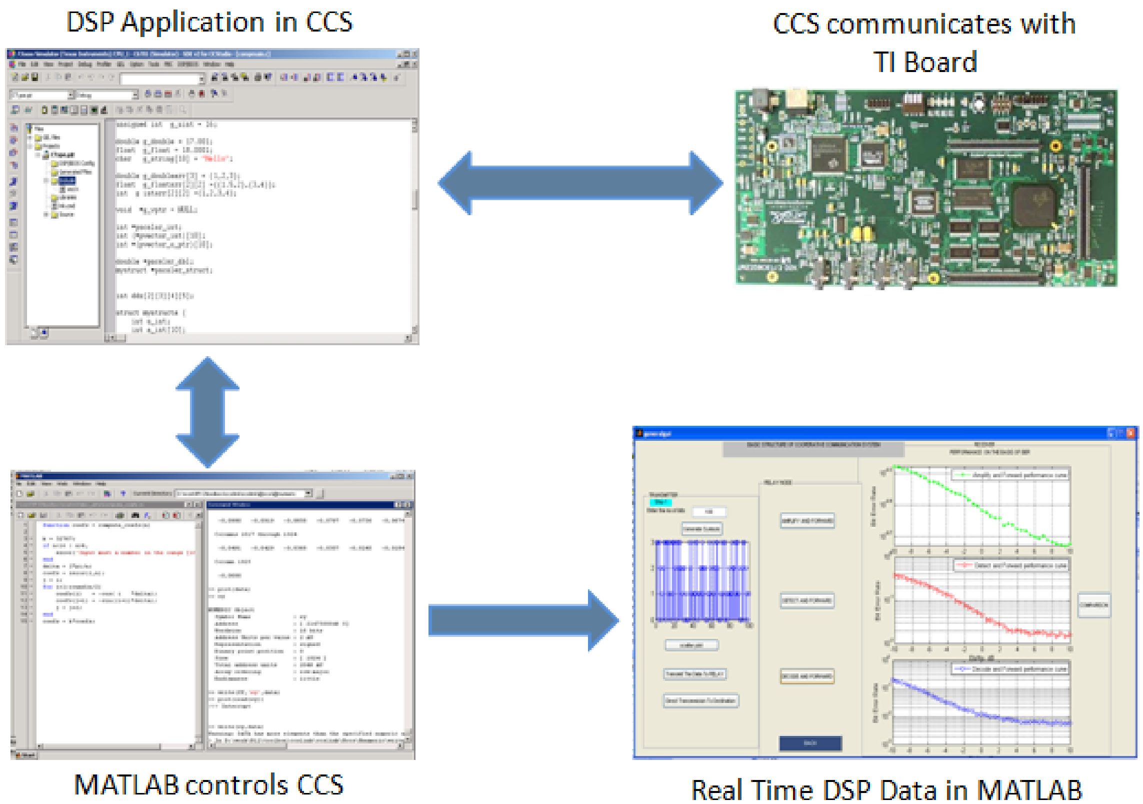

Figure 40: **Graphical procedure for Hardware Implementation**

First the power on self test has been done to verify that all the connections are made and DSP kit is connected to the code composer.

Then configuration parameters have to be checked to verify that whether memory addresses have been assigned or not.

In the next phase SIMULINK model for the Cooperative communication model is opened in the SIMULINK.

The RTDX channels are first opened by running specific SIMULINK model. Next, the required models are burnt on the DSP Kit. This model is then implemented on the DSP kit. The output signal from the DSP kit is returned back to the system and compared with results of simulations. This will give us real time analysis of system performance.

5.3.9.1 Amplify and Forward

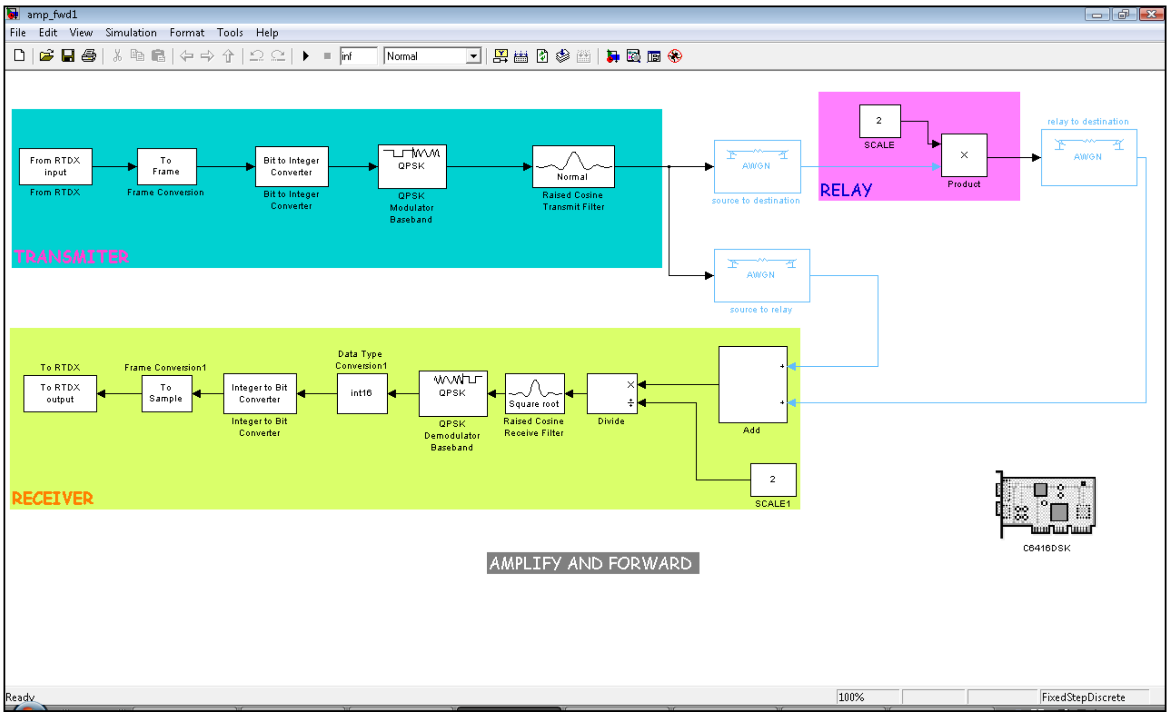

Figure 41: **Amplify and Forward RTDX Model**

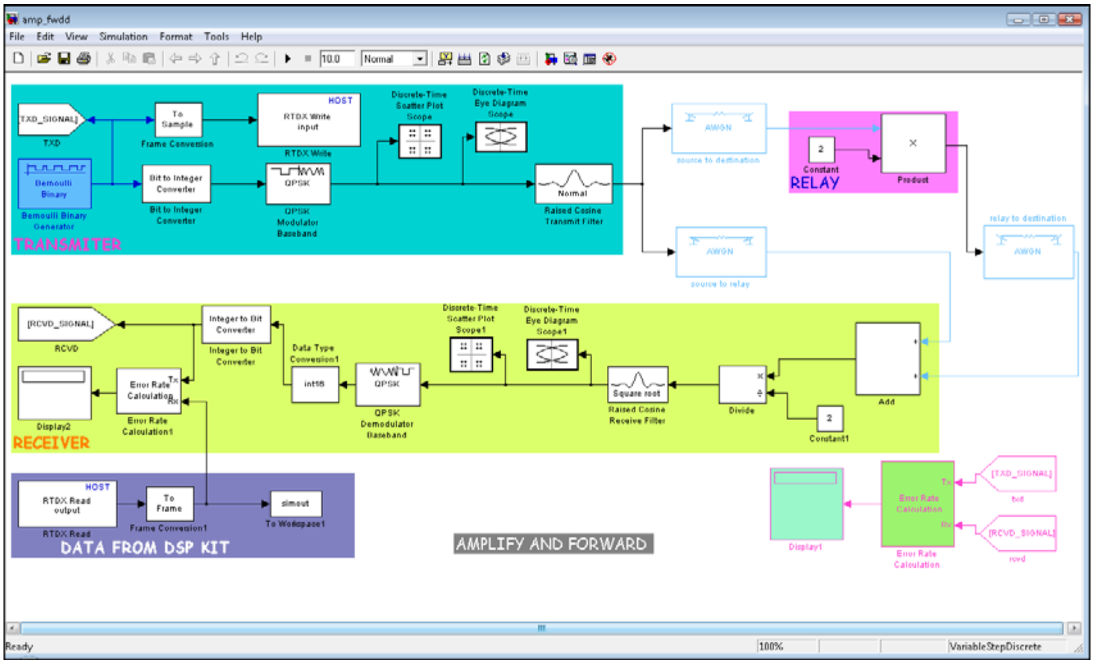

Figure 42: **Amplify and Forward Simulink Model for Implementation on DSK**

5.3.9.2 Detect and Forward

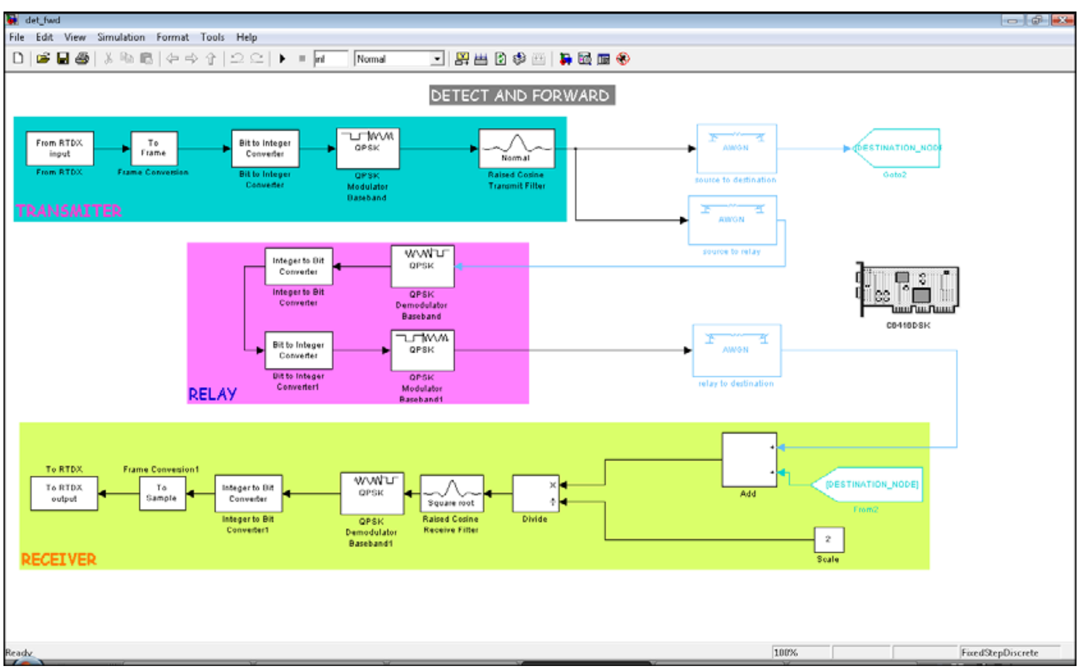

Figure 43: **Detect and Forward RTDX Model**

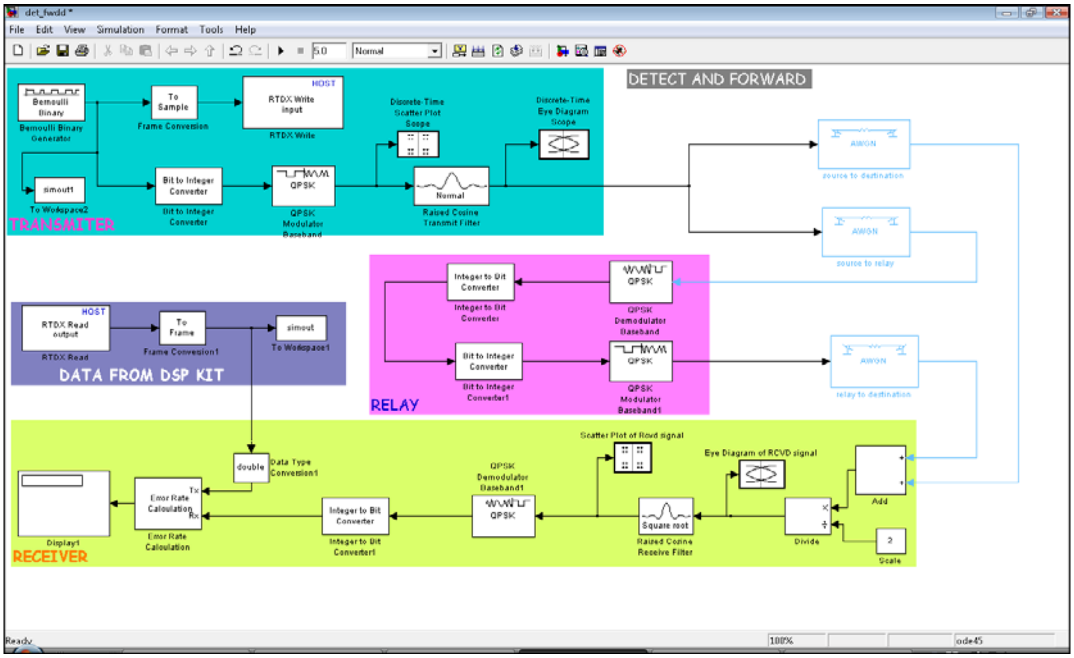

Figure 44: **Detect and Forward Simulink Model for Implementation on DSK**

5.3.9.3 Decode and Forward

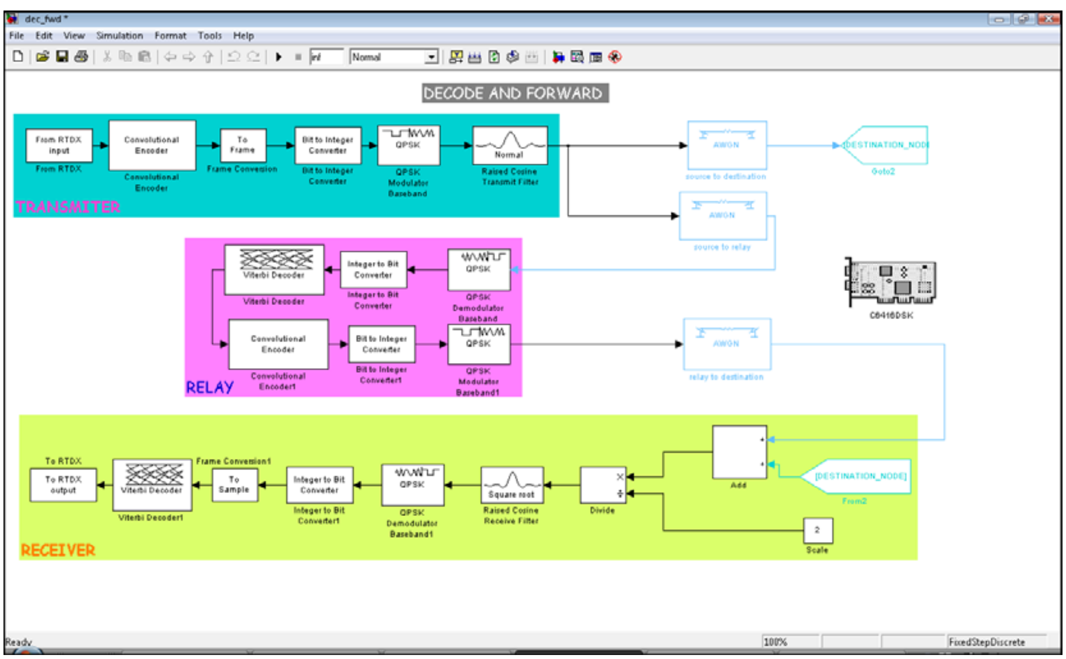

Figure 45: **Decode and Forward RTDX Model**

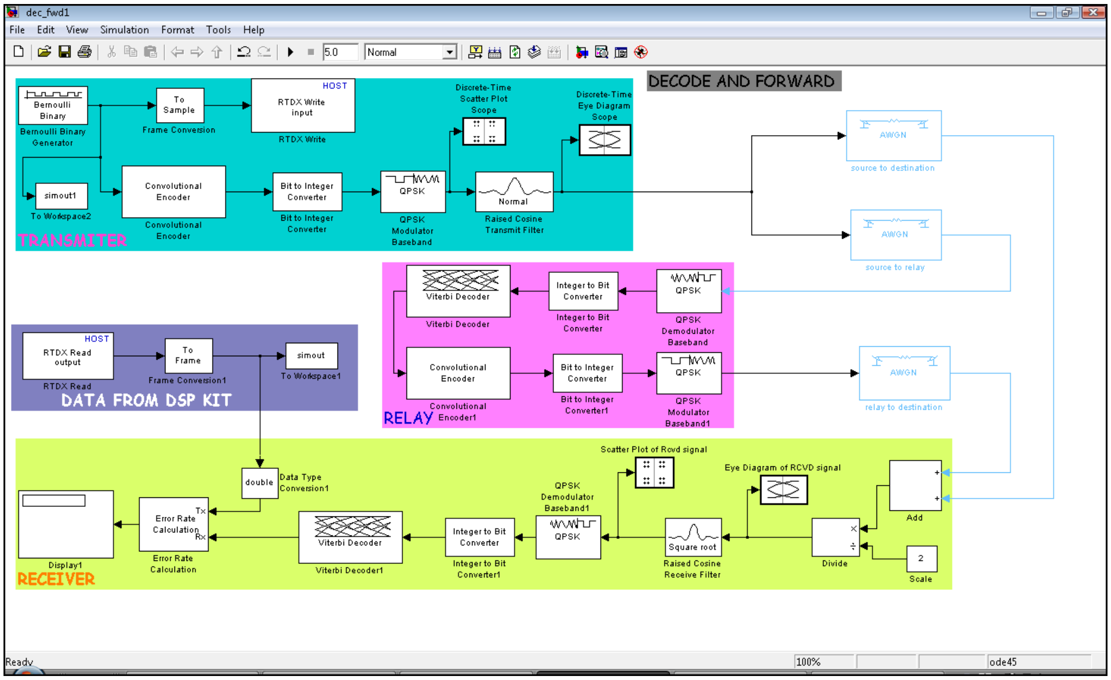

Figure 46: **Decode and Forward Simulink Model for Implementation on DSK**

6. Simulations and Analysis

6.1 Introduction

The performance and reliability of any communication system depends on error free data transmission. This chapter deals with the results of simulations performed in MATLAB for various cooperative protocols and their comparison with each other and simple SISO systems.

The simulations are performed in SIMULINK. Their analysis is performed in real time using DSK6416 DSP Kit to give a more realistic approach towards study of Cooperative Communication scheme

6.2 Assumptions for Simulation

The simulations in MATLAB and on DSP Kit are performed for negative as well as positive SNR. Negative SNR describes channel in outage conditions where the noise power exceeds the signal power level. Hence the longer distance communications are affected in such scenarios. For short distance relaying it provides better performance.

The signal is attenuated during propagation by Additive White Gaussian Noise. The channel used is a single tap Rayleigh Channel with known coefficients.

Optimal combining technique is chosen between Equal Gain Combining (EGC) and Maximum Ratio Combining (MRC).

6.3 Performance Metrics

Performance is carried out on basis of Signal-to-Noise Ratio (SNR). The x-axis contains SNR values in decibels going from -10 dB to +10 dB, whereas, the y-axis is labeled with Bit Error Rate (BER) values.

The correct symbol transmission is ensured by transmitter and receiver scatter plots and eye diagrams which are included in the project Graphical User Interface (GUI).

6.4 Results of MATLAB Simulations

The BER curves of the various cooperative protocols are given below:

6.4.1 BER Curve for Amplify and Forward

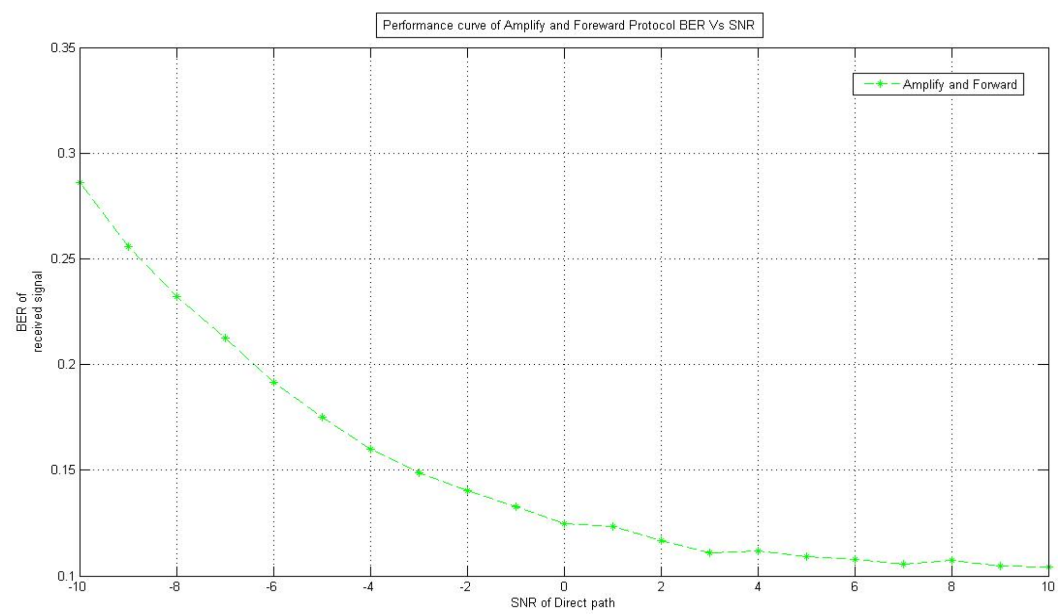

Figure 47: **BER curve for Amplify and Forward protocol**

6.4.2 BER Curve for Detect and Forward

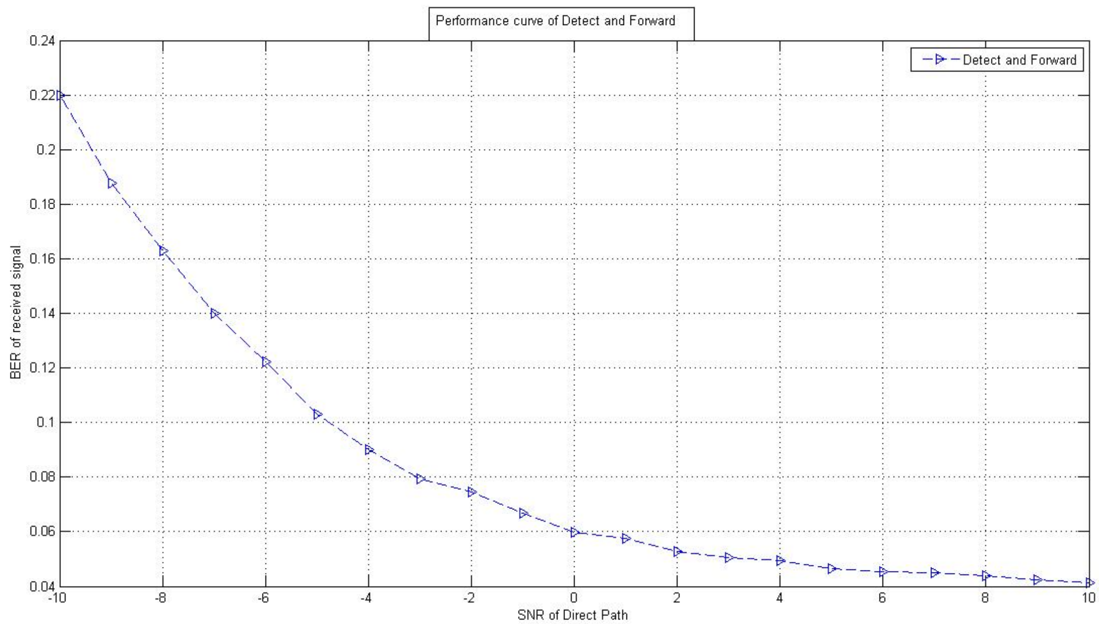

Figure 48: **BER curve for Detect and Forward protocol**

6.4.3 BER Curve for Decode and Forward

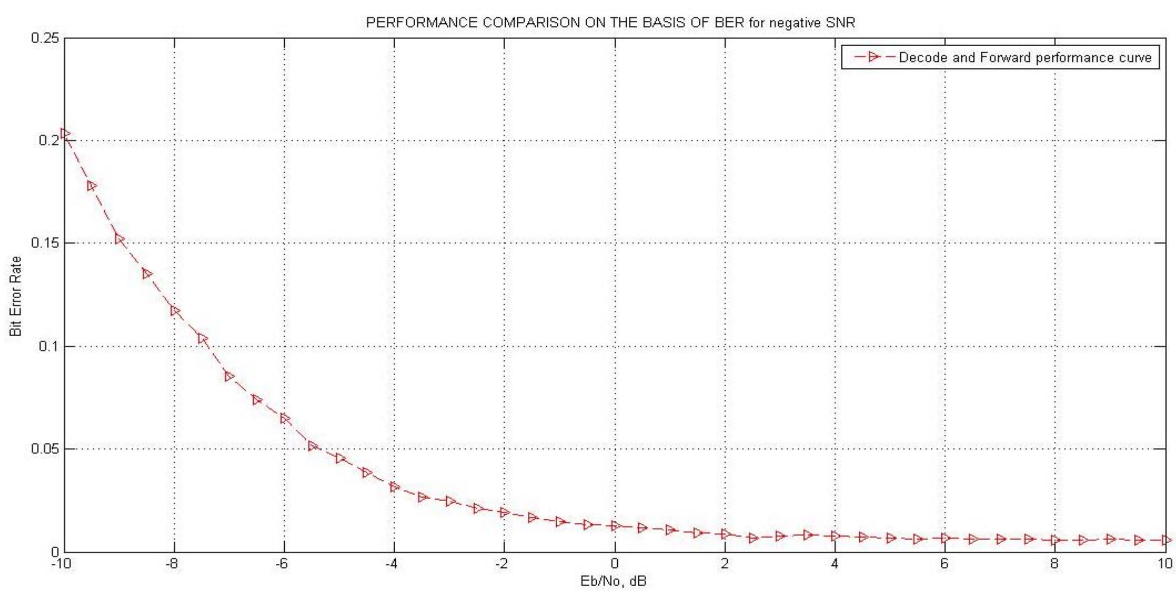

Figure 49: **BER curve for Decode and Forward protocol**

6.5 Comparison between Cooperative protocols

For negative SNR conditions, cooperative protocols provide better performance as compared to SISO systems.

As Signal-to-Noise Ratio (SNR) increases, the performance of SISO systems starts improving/ getting better.

Among the three cooperative protocols (Amplify & Forward, Decode & Forward and Detect & Forward), Decode & Forward has the best performance as it reduces Bit Error Rate (BER) to high extent as compared to Amplify & Forward and Detect & Forward protocols. However, this protocol has increased processing delay due to channel decoding/ encoding involved at relay.

Beyond SNR of +10 dB, the SISO systems provide better performance; however, such high channel gains are impractical.

6.6 Optimal Combining Technique

There are two types of combining techniques we have used in our project.

- **Equal Gain Combining (EGC)**
- **Maximum Ratio Combining (MRC)**

To reap as much advantage of diversity, we need to employ an optimum combining technique at the receiver so as to reduce the BER and improve link reliability. By using both these combining techniques, we were able to conclude that Maximum Ratio Combining (MRC) provides us better performance as compared to Equal Gain Combining. The effect of Equal Gain Combining (EGC) on the three cooperative protocols is shown in figure below:

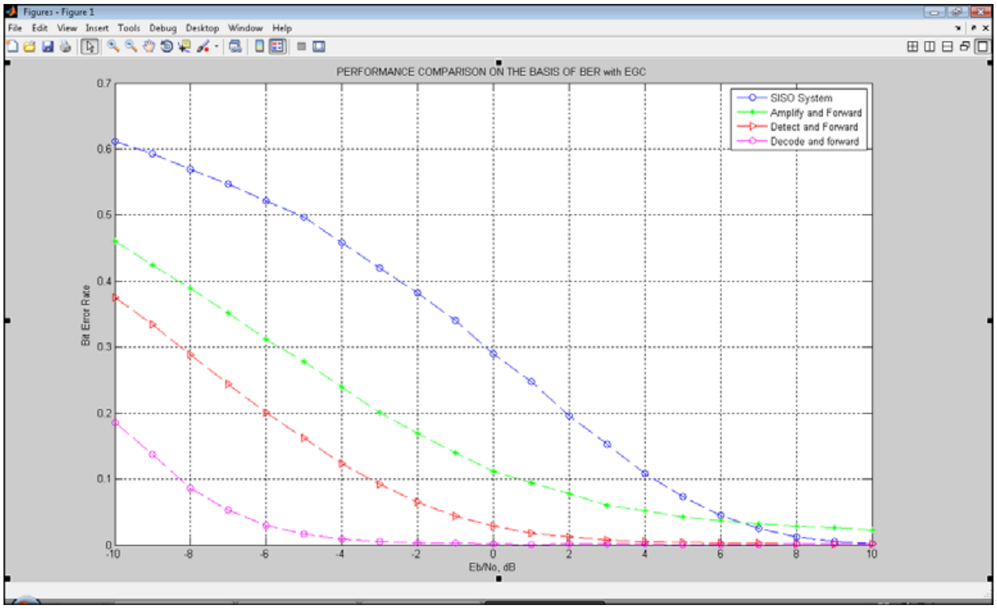

Figure 50: **Comparison of Cooperative Protocols and SISO Systems for SNR [-10 10] for Equal Gain Combining**

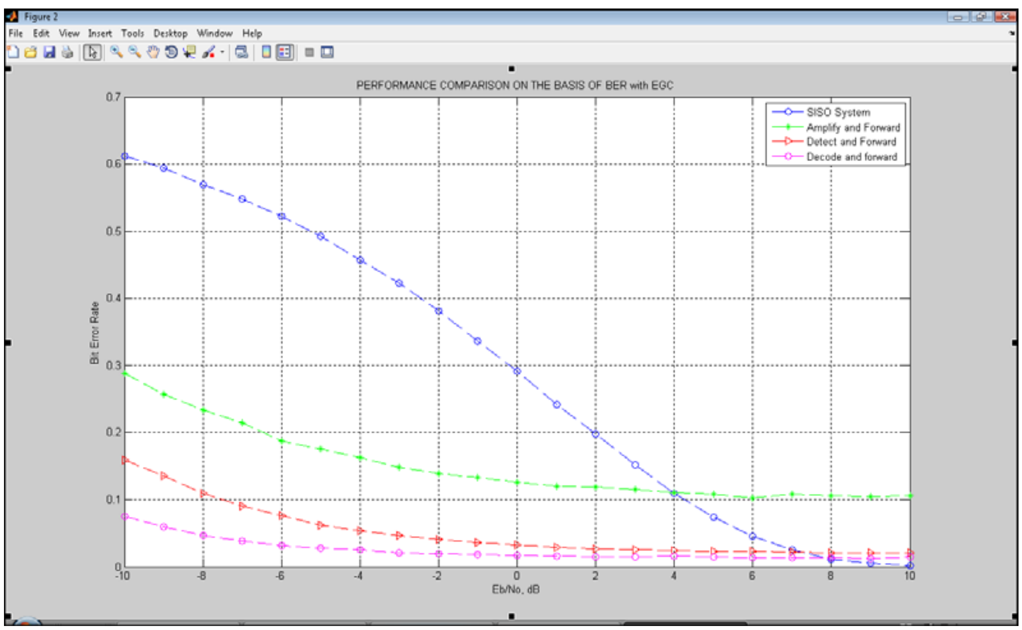

Figure 51: **Comparison of Cooperative Protocols and SISO Systems for SNR [-10 10] for Maximal Ratio Combining**

7. COOPERATION IN FIVE NODE NETWORK

7.1 Introduction

We started our project with the basic three node cooperative network, comprising a source, a relay and a destination. After implementing the basic cooperative network in MATLAB and on the DSP Kit, we were left with ample time to extend our network to five nodes and implement the same cooperative strategies on them. This chapter deals with the five node cooperative network and its technicalities like node selection and system performance, followed by simulation results in MATLAB.

7.2 Overview of Three Node Network

The three node network consisted of relays with fixed tasks. One node was the source, the second was relay and the third node was the destination node. The source just acted as a transmitter and the destination only acted as a receiver of information. The relay acts as a transceiver; in one time slot it receives signal from source and in the next time slot it transmits signal to the destination after certain processing as discussed in earlier chapters.

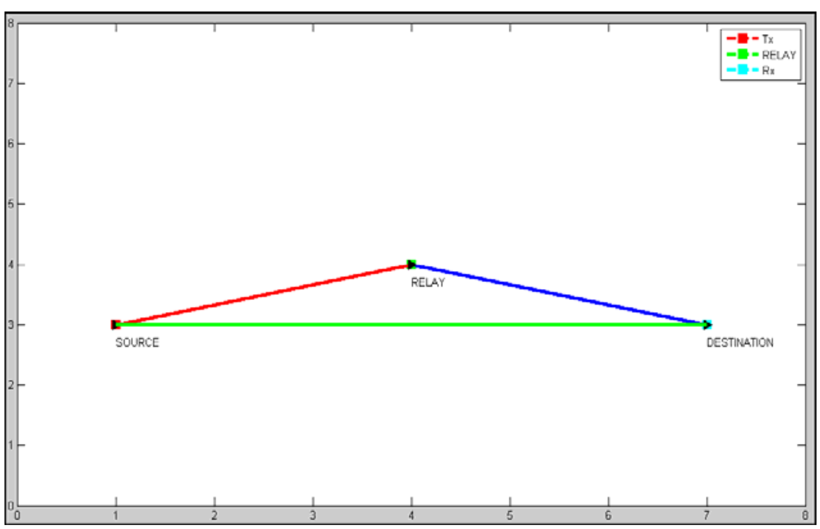

Figure 52: **MATLAB Plot for Three Node Network**

7.3 Five Node Cooperative Network

It is an extension of the basic three node network. It works like a wireless environment with mobile nodes. The nodes are changing their position with each time instant. Thus a certain source node can never be associated or linked with a fixed relay node. As the source moves, it changes its relay node accordingly.

As an extension to the project, we have introduced three relay nodes in between the source and destination. The same forwarding strategies are implemented and analyzed at the relay as in case of three node network. The same channel coding algorithms, combining techniques and other processes, as discussed in earlier chapters, are implemented in this network too. The additional task is basically the relay selection from among the three available nodes.

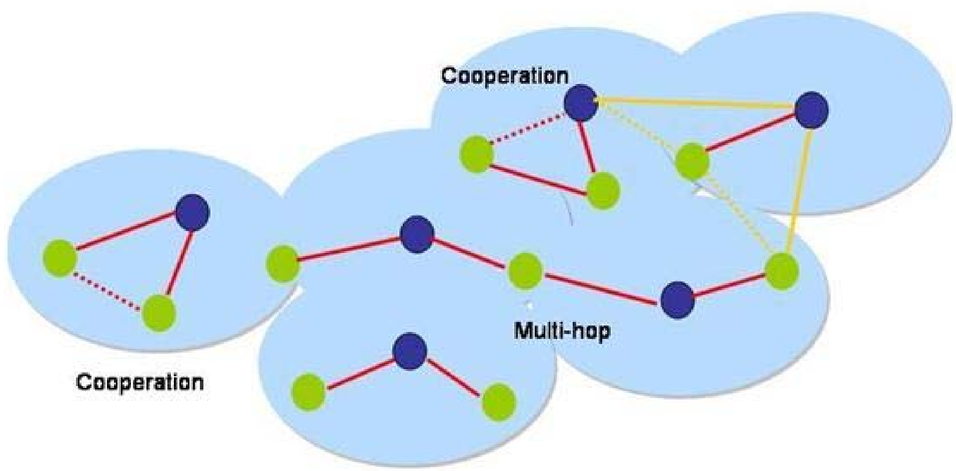

Figure 53: **Multi-node Cooperative Network**

7.4 Distance Based selection of Relay Node

In this scheme, the relay node is chosen on grounds of its distance from the source. The distance of first potential relay node from the source is d1, the distance of second node from source is d2 and that of the third node is d3. This distance changes with time as all nodes are mobile. At a particular instant, the source chooses that node which is nearest to it. This node then acts as a relay node and protocols of forwarding are implemented on this node.

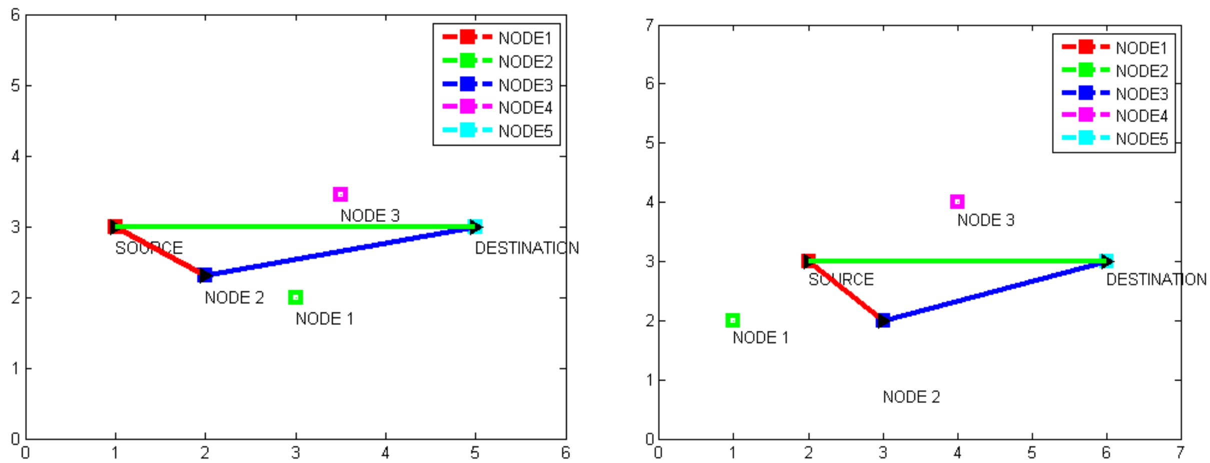

Figure 54: **MATLAB Plot for Five Node Network**

At the start of communication, every node has a certain peak power equal to P_o. With each transmission, this peak power falls by a certain factor of this peak power P_o. In case when two nodes are equidistant from the source, the node with the higher power is chosen as a relay. The relay changes as source finds a new better cooperating partner from the available pool of nodes [13].

7.4.1 Results of MATLAB Simulations

The BER curves of the various cooperative protocols when implemented on a five node network are given below:

7.4.1.1 BER Curve for Amplify and Forward

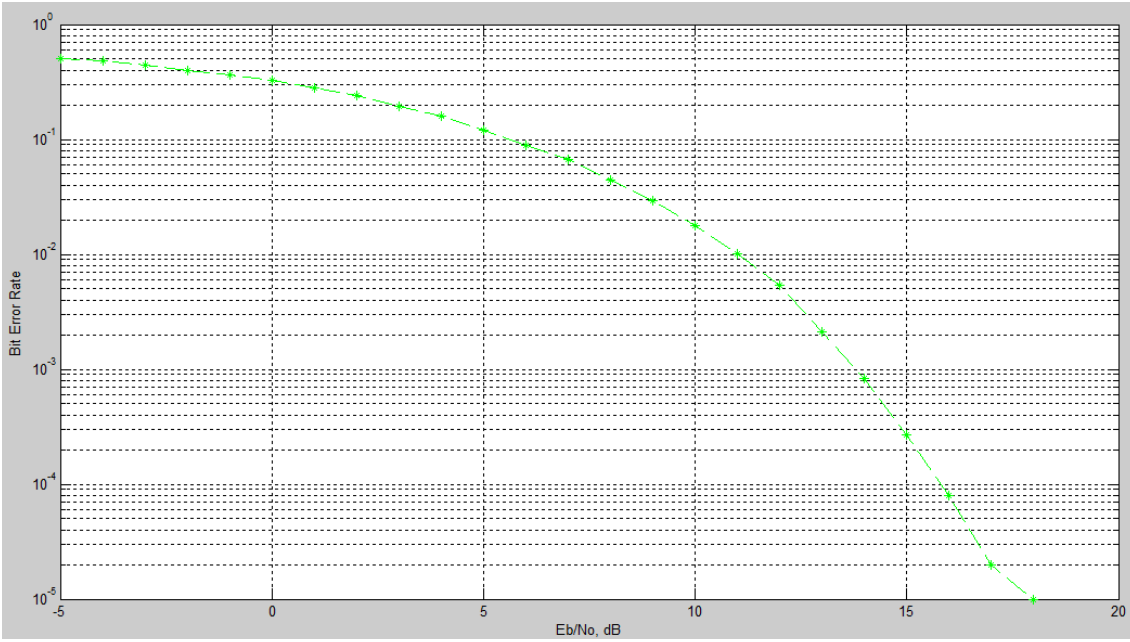

Figure 55: **BER curve for Amplify and Forward protocol**

7.4.1.2 BER Curve for Detect and Forward

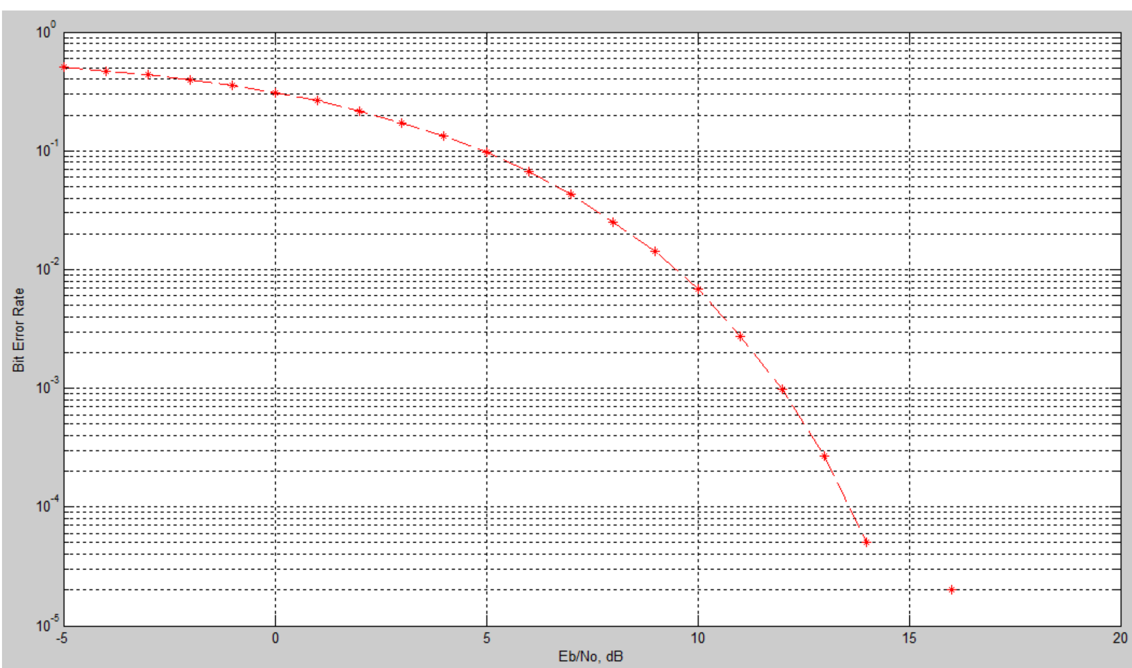

Figure 56: **BER curve for Detect and Forward protocol**

7.4.1.3 BER Curve for Decode and Forward

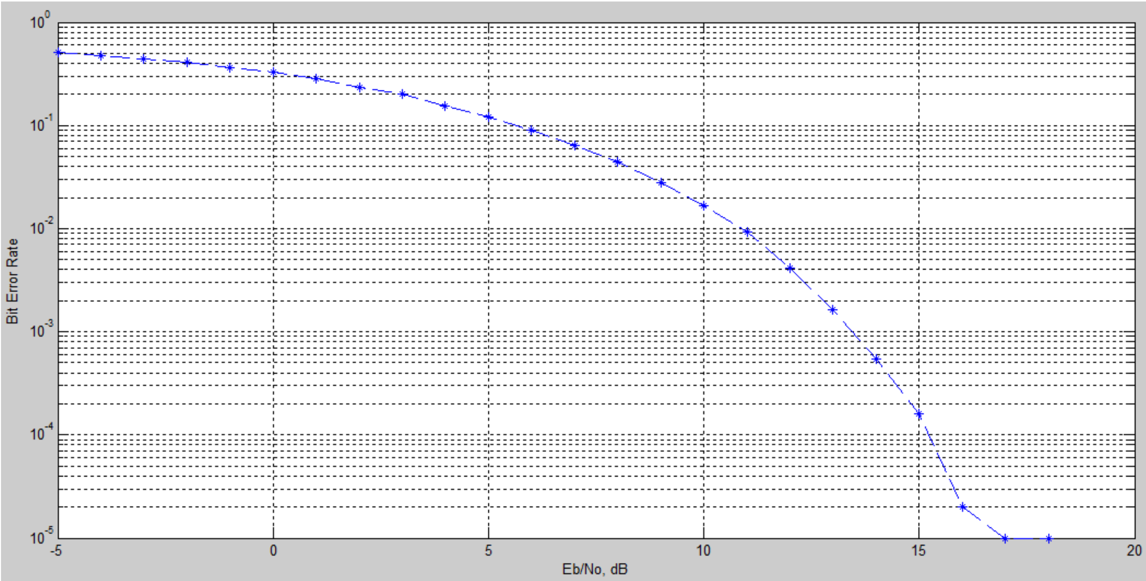

Figure 57: **BER curve for Decode and Forward protocol**

7.4.1.4 Comparison of Three Cooperative Strategies

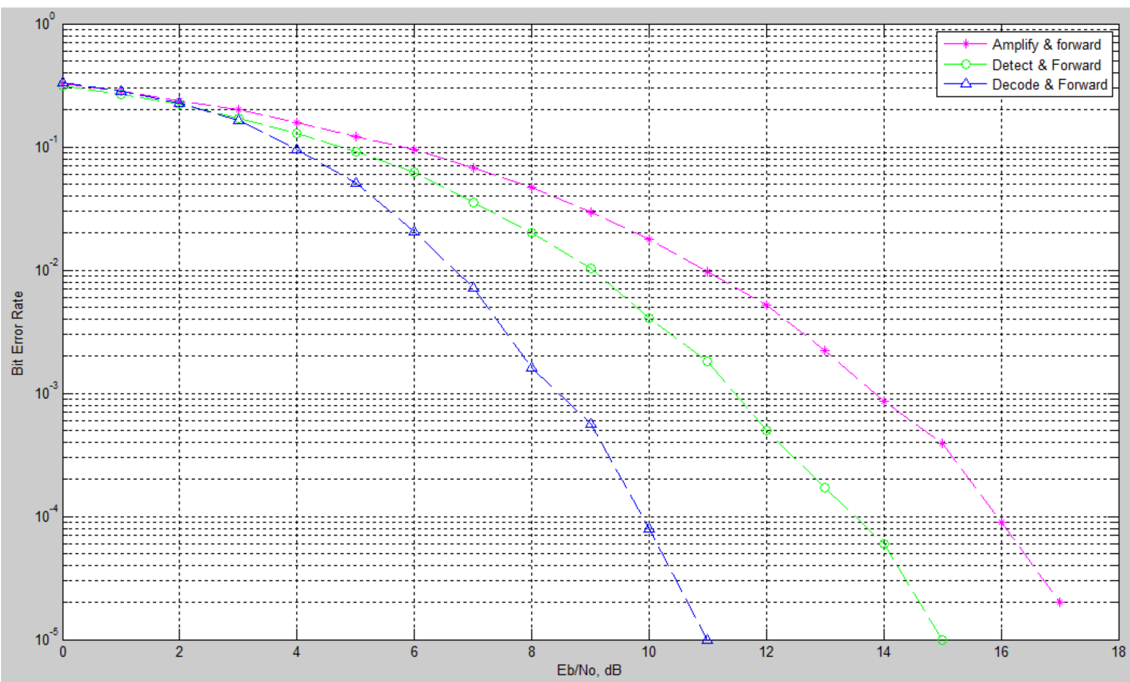

Figure 58: **Comparison between three Cooperative protocols**

7.5 Power Aware Routing of Relay Signals

In power aware routing, the source broadcasts the message signal to all nodes in its vicinity. All the nodes which hear this signal transmit it to the destination [12]. The destination receives multiple copies of the signal; one from each relay. A direct link signal is also received. Diversity techniques are employed to correctly interpret the signal. The combining techniques used are same as discussed in the earlier chapters.

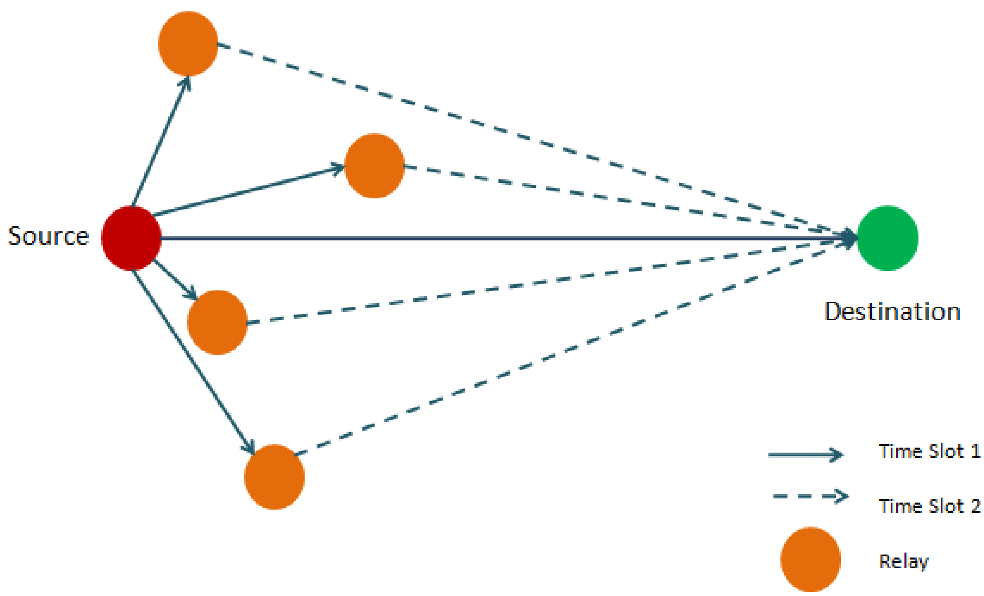

Figure 59: **Power Aware Routing of Relay Signals**

7.5.1 Results of MATLAB Simulations

The code is written in MATLAB. Simulation results include BER curves of the various cooperative protocols when implemented on a five node network, using power aware routing. The simulation plots included in this case are listed below:

1. BER Curve for Amplify and Forward
2. BER Curve for Detect and Forward
3. BER Curve for Decode and Forward
4. Comparison between the above protocols

7.5.1.1 BER Curve for Amplify and Forward

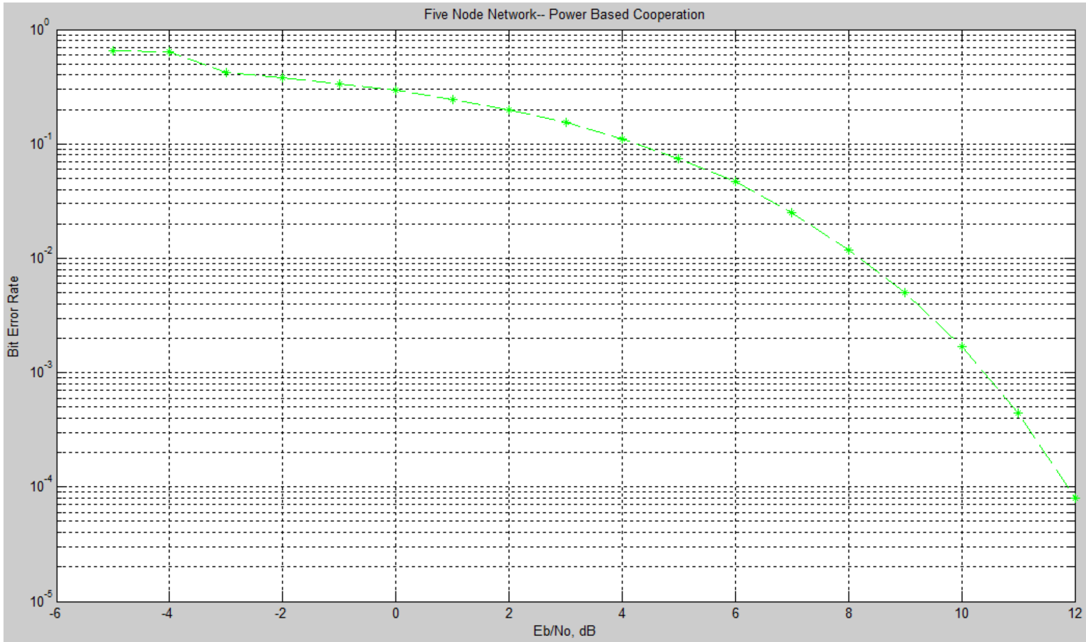

Figure 60: **BER curve for Amplify and Forward protocol**

7.5.1.2 BER Curve for Detect and Forward

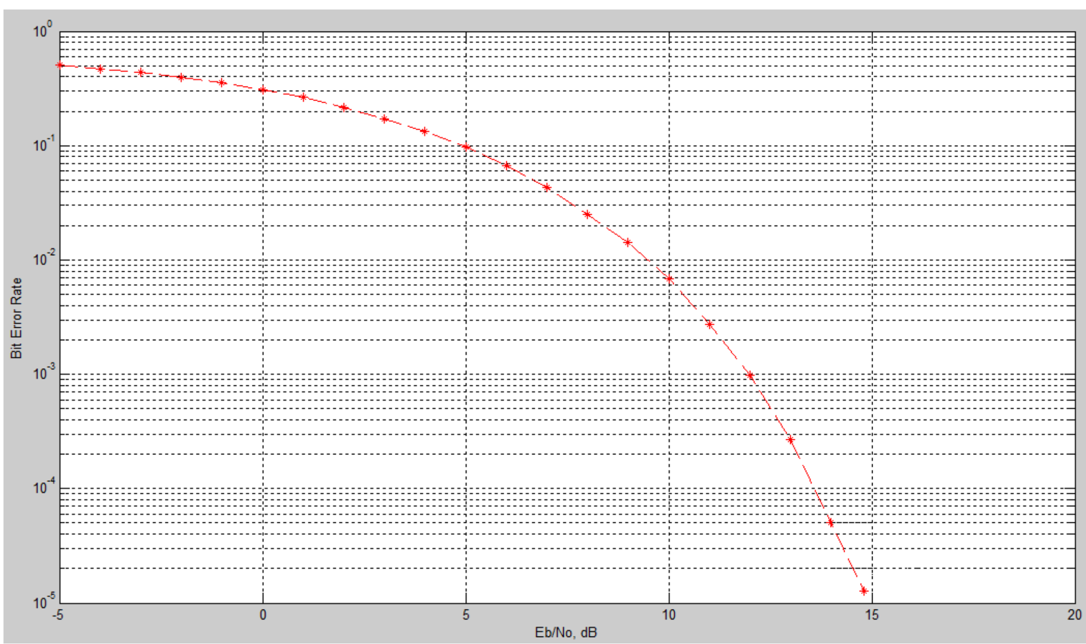

Figure 61: **BER curve for Detect and Forward protocol**

7.5.1.3 BER Curve for Decode and Forward

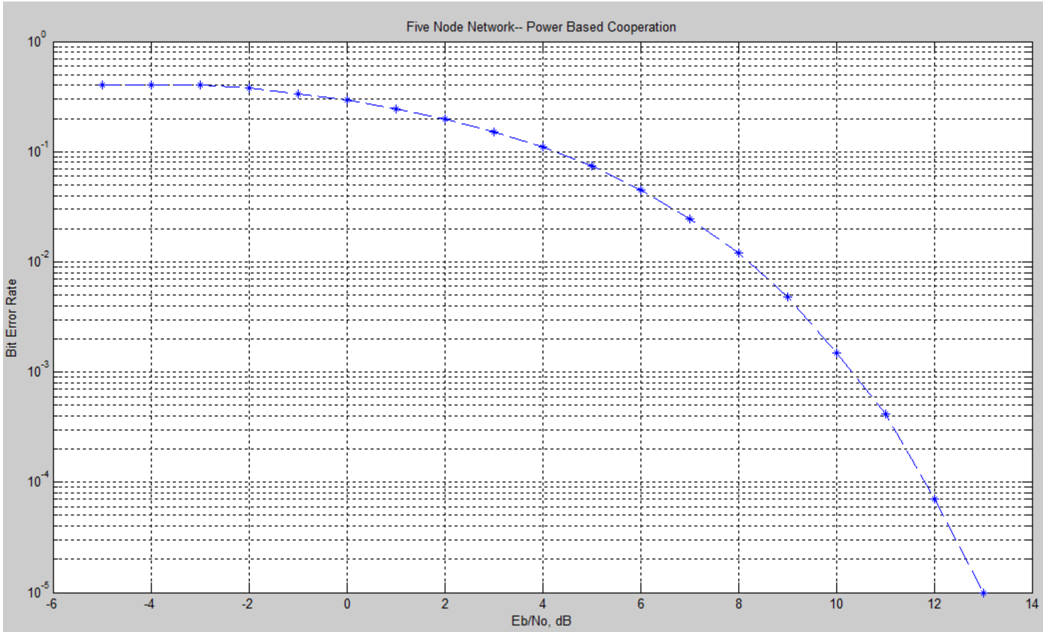

Figure 61: **BER curve for Decode and Forward protocol**

7.5.1.4 Comparison of Three Cooperative Strategies

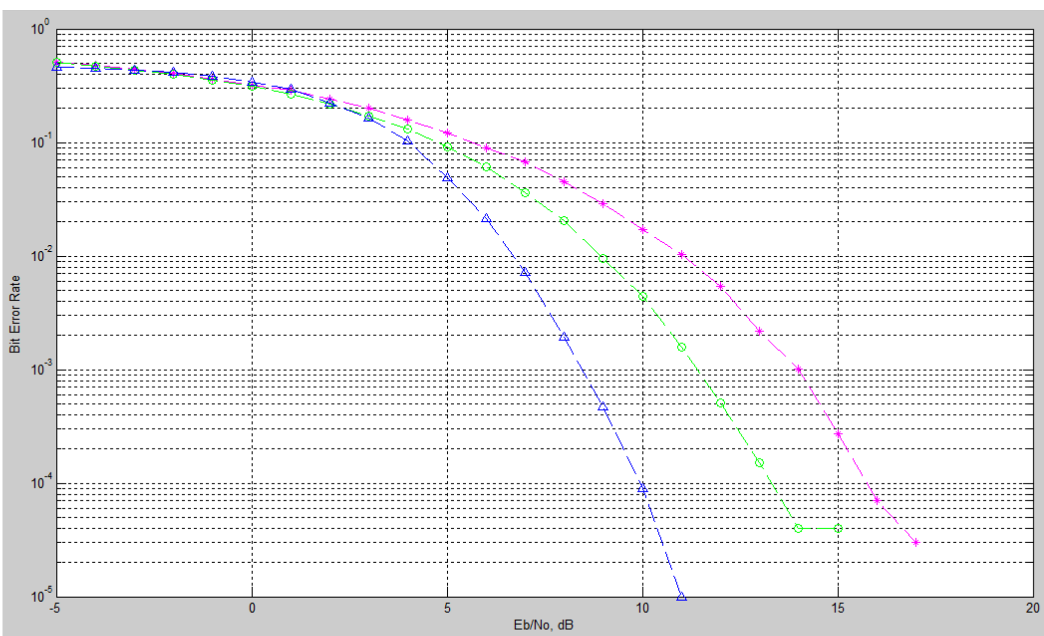

Figure 63: **Comparison of three Cooperative Strategies**

8. Applications and Future Enhancements

8.1 Project Conclusion

In this thesis we considered the design of basic three node cooperative communication system and examined its performance. We studied amplify & forward, decode & forward and detect & forward cooperative protocol for simple fading relay channel. The coding technique which is used in this work is the convolutional coding. We computed the probability of error for various protocols of cooperative system so as to analyze its performance. We showed that for negative SNR conditions, the relay channel can be used for cooperation and can achieve good performance for the communication networks.

We illustrated the benefits of cooperative coding in providing diversity and coding gains via simulation results. The results indicate that spatial diversity could be achieved using cooperative techniques. We showed that cooperative diversity can significantly enhance the performance of the communication system by reducing the probability of error of the system.

The reduction in probability of error is direct proportional to the SNR. The results showed that the cooperative techniques provide greater gains with respect to non-cooperative case.

We have seen that error correction protocols can be used to significantly enhance the performance of the communication system.

We built SIMULINK models for cooperative protocols in Matlab and burnt them on DSK6416. The models were tested in real time using RTDX. The results showed that cooperative protocols provide better performance than SISO systems under negative SNR conditions.

We conclude by noting that the idea of mapping cooperative protocol onto simple relay channel can be extended to large networks and more complex transmission scheme. The result will be an effective virtual MIMO channel which has better performance compared to classical relay fading channel.

8.2 Applications of Cooperative Communication

- Wireless Sensor Networks
- Mobile Ad-hoc Networks (MANETs)
- Military Combat Networks for battlefield communications
- Cognitive radios can also use cooperative strategies for sensing the spectrum, so that the hidden terminal issues are addressed
- Dragon Warrior Communications Relay

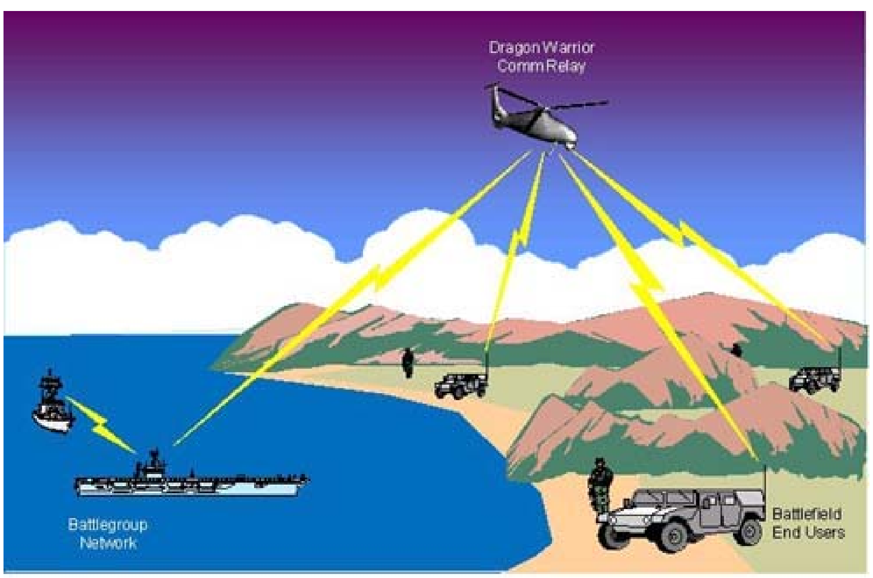

Figure 64: **Dragon Warrior Communications Relay**

8.3 Future Extensions

While many key results for cooperative communication have already been obtained, there are many more issues that remain to be addressed.

- Partners' assignment and management in multi-user networks. In other words, how is it determined which users cooperate with each other, and how often are partners reassigned?

- Extension of the proposed cooperative methods to allow a user to have multiple partners. The challenge here is to develop a scheme that treats all users fairly, does not require significant additional system resources, and can be implemented feasibly in conjunction with the system's multiple access protocol.

- Development of power control mechanisms for cooperative transmission. Work thus far generally assumes that the users transmit with equal power. It may be possible to improve performance even further by varying transmit power for each user based on the instantaneous uplink and inter-user channel conditions.

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