Comparative Analysis of Various Cooperative Communication Schemes

Major Project Report

Submitted in partial fulfillment of the requirements

For the degree of

Master of Technology

In

Electronics & Communication Engineering

(Communication Engineering)

By

Vasani Ekta Hitesh

(09MECC18)

Department of Electronics & Communication Engineering

Institute of Technology

Nirma University

Ahmedabad-382 481

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Under the Guidance of

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Declaration

This is to certify that

i) The thesis comprises my original work towards the degree of Master of Technology in Communication Engineering at Nirma University and has not been submitted elsewhere for a degree.

ii) Due acknowledgement has been made in the text to all other material used.

Vasani Ekta Hitesh

Certificate

This is to certify that the Major Project entitled **"Comparative Analysis of Various Cooperative Communication Schemes"** submitted by **Vasani Ekta Hitesh (09MECC18)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Communication Engineering of Nirma University, Ahmedabad is the record of work carried out by her under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of our knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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- Vasani Ekta Hitesh
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Abstract

Whenever size, power, or other constraints preclude the use of multiple transmit antennas, wireless systems cannot benefit from the well-known advantages of space-time coding methods. Cooperation between wireless users has been proposed as a means to provide transmit diversity in the face of this limitation. This thesis firstly analyse a network with a sender, a destination and a third station acting as a relay is analysed. Different combining methods and diversity protocols are compared. The relative distances between the relay and the stations has a large effect on the performance, which shows that when the relay is midway on the link of source to destination, best performance is achieved. It is then extended by increasing the number of relays, which shows that as number of relay increases system performance improves significantly. Secondly in this thesis Cooperative communication is performed with various well-known codes like convolutional code, punctured convolutional code and Turbo code. Using Convolutional code with cooperative communication provides full diversity and excellent coding gain. Punctured convolutional increasing the rate of the code. Coded cooperation using punctured convolutional code generally performs better than other cooperative methods for moderate to high SNR. Turbo code offer better performance than any of the other codes at very low signal to noise ratio. The analysis of turbo code is then performed using EXIT chart which is mainly influence by SNR, size of interleaver,code polynomail and code rate. Finally, on this basis code is designed and used with cooperative communication. Almouti code is a special code because it is the only STBC with rate 1. Using Alamouti codes shows that AF and DF protocols improves their performs and solves the problem of bad performance at low SNR. Thus it is concluded that cooperative communication with channel coding is better then cooperative communication without channel coding in terms of BER and SNR performance, which overall increase system performance.

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Symbols and Abbreviations

$y_{i,j}$	Signal received at j
$h_{i,j}$	channel gain at i,j
$n_{i,j}$	AWGN noise
X_i	transmitted signal
$a_{i,j}$	Attenuation caused by fading (channel i,j)
$d_{i,j}$	Attenuation caused by pathloss (channel i,j)
P_i	signal power
N_j	Noise power
γ_b	Average signal-to-noise ratio
σ^2	variance
r	code rate
m	memory of order
K	Constraint length
D	Delay
α	Forward metric
β	Reverse state metric
δ	Branch metric
$L_e(\widehat{d})$	Extrinsic information

AF	Amplify and Forward
DF	Decode and Forward
SNR	Signal-to-Noise
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
QPSK	Quadrature Phase Shift Keying
ERC	Equal Ratio Combining
ESNRC	Enhanced Signal-to-Noise
FRC	Fixed Ratio Combining
MRC	Maximum Ratio Combining
SNRC	Signal-to-Noise Ratio Combining
LLR	Log-Likelihood-Ratio
EXIT chart	Extrinsic Information Transfer chart

Chapter 1

Introduction

1.1 Motivation

Now a days, with the revolution in technology, most of the communication systems are going to be wireless. But, Wireless communication performance is badly affected by channel fading which is caused by multipath propagation. One of the possible solution is to deploy multiple antenna at transmitter and receiver.i.e MIMO Systems. But there is difficulty in providing more than one antenna, because of small terminal size. So virtual MIMO also known as cooperative diversity was introduced. It allows to share their antennas during transmission and to form spatial diversity environment and virtual MIMO system. Thus it increases the reliability.

In physical layer an important opportunity arises with cooperation; due to the broadcast nature of wireless medium, as the data is transmitted to its destination in multiple hops, many nodes in the vicinity can hear these transmissions. Transmissions from different nodes are generally affected by different and statistically independent fading. Hence, the final destination of the data can combine all the received signals using traditional combining methods such as Maximal Ratio Combining (MRC) or Selection Combining (SC) and obtain diversity against the hamming effects of fading.

1.2 Wirelss Communication

Recent advances in wireless communication in systems have increased the throughput over wireless channel and even the reliability of wireless communication has been increased. As a result, uses of wireless systems have increased. The main driving force behind wireless communication is the promise of portability, mobility, and accessibility. Although wired communication brings more stability, better performance, and higher reliability, it comes with the necessity of being restricted to a certain location or a bounded environment. As Wireless offer freedom, there is a natural tendency towards getting rid of wires if possible. The main issue for wireless communication systems is to make the conversion from wired systems to wireless systems more reliable and if possible transparent. While freedom is the main driving force for users, there are incredible numbers of challenges such as[1]: a need for high data rates, quality of services, mobility, portability, connectivity in wireless networks, interferences from other users, privacy/security.

1.3 Wireless Channel

In any communication system the received signal differs from the transmitted signal due to various transmission impairments. These impairments introduce different random modifications to the original signal, hence degrade the signal quality. Some of the most important transmission impairments[1][2] are introduced as follows:
Attenuation is due to the reduction in amplitude and energy of the signal during transmission from source to destination due to absorption or scattering of photons.
Noise is the unwanted signal that is received with the transmitted signal and is the most limiting factor in communication system performance. There are many sources for noise these include:
Thermal Noise: Thermal noise is due to the thermal agitation of electronics. Thermal noise places an upper bound on communication system performance because it

is present in all electronic devices and cannot be eliminated.

Intermodulation Noise: Intermodulation noise may result when signals of different frequencies share the same transmission medium. The result of intermodulation is a signal with frequency that could be sum or difference of the original frequencies.

Crosstalk Noise: Crosstalk can occur when unwanted signal is picked up by antenna.

Impulse Noise: It consists of irregular pulses or noise spikes of short duration but high amplitude. It is generated form electromagnetic disturbance such as lighting.

1.4 Fading

For most wireless communication channels, fading is the most important factor to consider when describing the channel and predicting system performance. This section addresses fading causes, fading types and fading channels.

1.4.1 Multipath Fading

Fading occurs due to the change in transmission medium or paths, which causes time variation of received signal power. In a wireless mobile system a signal can travel from transmitter to receiver through multiple reflective paths which is known as multipath propagation. Multipath propagation causes fluctuation in signal's amplitude, phase and angle of arrival creating multipath fading. There are basic three propagation mechanisms[1] playing a role in the multipath fading:

Reflection: occurs when a propagating electromagnetic signal encounters a smooth surface that is large relative to the signal wavelength.

Diffraction: occurs at the edge of a dense body that is large compared to the signal wavelength.

Scattering: occurs when the propagating radio wave encounter a surface with dimensions on the order of the signal wavelength or less, causing the incoming signal to spread out (scatter) into several weaker outgoings in all directions.

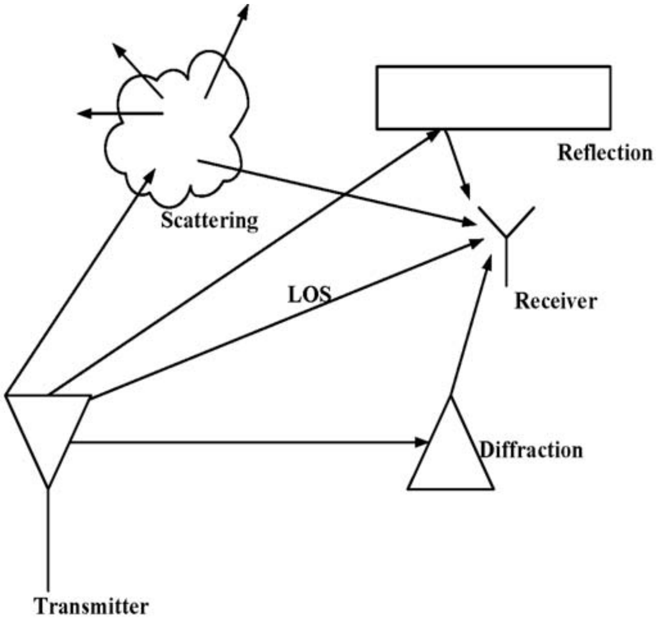


Figure 1.1: An example of different paths in a wireless channel

1.4.2 Types of Fading

Fading can be classified from time variant view point into fast fading and slow fading, and from time spreading view point into selective fading and flat (nonselective) fading[1].

Slow Fading: slow fading represents the average signal power attenuation or path loss due to moving over large or long distance area.

Fast Fading: fast fading refers to the rapidly changes in signal power and phase that occur due to small movement over distance of about half wavelength.

Selective Fading: a channel experience selective fading when the received multipath component of a symbol extends beyond the symbol time duration.

Flat Fading: flat or nonselective fading occurs when all received multipath component of a symbol arrive within the symbol time duration.

1.4.3 Fading channel

Some typical fading channels are introduced in below[1]

Additive White Gaussian Noise (AWGN) Channel: In this channel the only impairment that encounters the propagation of the transmitted signal is the thermal noise, which associated with physical channel itself, as well as the electronics at, or between, transmitter and receiver. In AWGN channel the signal is degraded by white noise which has constant spectral density and a Gaussian distribution of amplitude.

Rayleigh Fading Channel: Rayleigh fading occurs when there are multiple indirect paths between transmitter and receiver and no direct non-fading or line-of sight (LOS) path.

Rician Fading Channel: Rician fading best describes a situation where a dominant non-fading, LOS, component presents in addition to a number of indirect multipath signals.

White Gaussian Noise and Rician channels provide fairly good performance corresponding to an open country environment. While Rayleigh channel, which best describes urban environment fading, provides relatively worse performance.

1.5 Diversity

Based on the fact that individual channels experience independent fading events, multiple channels can be used between transmitter and receiver to compensate for error effects. Diversity reception does not completely eliminate errors but reduces the probability of occurrence of errors caused by fading by combining several copies of the same message received over different multiple channels. The independent fading channels are obtained by antenna, site, time, frequency and polarization.[1]

Antenna (micro) Diversity: Multi array of antennas are used to transmit different copies of the signal and then combine them at receiver to construct the transmitted message. The antennas are located in the same place (e. g. base station tower) and their spacing is of a few wavelengths.

Site (macro) diversity: In site diversity the receiving antennas are located in different places so as not only the multipath fading is independent but also the shadowing and pass loss will be independent to some extent.

Time Diversity: In time diversity the same message is transmitted many times at different instances of time. For effective time diversity, the time difference should be more than coherent time of the channel.

Frequency Diversity: In frequency diversity more than one copy of the message is transmitted by spreading the signal out over large bandwidth or carried on multiple frequency carriers. To achieve effective diversity using frequency diversity, the carrier frequencies should be separated by more than bandwidth coherence.

Polarization Diversity: obstacles scatter waves differently depending on polarization. Polarization diversity use a set of cross polarizes receiving antennas so that the received waves do not cancel each other.

1.6 Cooperative Communication

To overcome fading in any wireless channel, diversity is used. In space diversity, multiple antennas at the transmit, receive, or at both ends of transmit and receive side are used, for transmission purpose, which results in having multiple copies of the same signal at the receiver. This way of communications is called Multiple Input Multiple Output (MIMO) communications. But in some wireless networks like in mobile communications, due to size of mobile or the devices used in the emerging wireless networks like, Ad hoc networks, having multiple antenna at the user terminal is difficult. The solution of this problem is the concept of cooperative communications, first introduced by Sendonaris et al. Cooperative communications is a way in which each wireless user transmits not only its own information, but also act as an assisting agent, called relay, for other user.

In cooperative communications, the other users receiver called its partner, will in some way repeat this information to destination by using some suitable relaying protocol. The main cooperative relaying protocol are described below:

Amplify-and-Forward: This method was proposed and analyzed by Laneman et al in [4]. In this relaying protocol, every cooperating user or partner, after receiving the noisy version of the transmitted signal of its partner, amplifies and re-transmits it to common destination, base station in our case.

Decode-and-Forward An example of decode-and-forward can be found in the work of Sendonaris et al in [6] [7]. With DF relaying protocol, every cooperating user, after receiving the noisy version of the transmitted signal of its partner, decodes and then sends to base station, the re-encoded version of the it.

Coded Cooperation: Coded cooperation[8] is a method that integrates cooperation into channel coding. Coded cooperation works by sending different portions of each users code word via two independent fading paths. The basic idea is that each user tries to transmit incremental redundancy to its partner. Whenever that is not possible, the users automatically revert to a noncooperative mode. The key to the efficiency of coded cooperation is that all this is managed automatically through code design, with no feedback between the users.

Various channel coding methods can be used within this coded cooperation framework. For example, the overall code may be a block or convolutional code, or a combination of both and even punctured convolutional coding and Turbo code is possible.

1.7 Literature Survey

In wireless systems data rate and quality of service are limited and they experience severe variations in signal attenuation due to inferences, thereby necessitating the use of some type of diversity. Thus spatial diversity, in which diversity gains are achieved via the cooperation of mobile users is used.Sendonaris[7] in part I describes the user cooperation strategy, while in part II[11] focuses on implementation issues and performance analysis. Its results show that, even though the interuser channel is noisy, cooperation leads not only to an increase in capacity for both users but also to a more robust system, where users achievable rates are less susceptible to channel variations.

Cooperative communications is a way in which each wireless user transmits not only its own information, but also act as an assisting agent, called relay, for other user. Amplify-and-Forward was proposed and analyzed by Laneman et al in [4]. In this, every cooperating user or partner, after receiving the noisy version of the transmitted signal of its partner, amplies and re-transmits it to common destination, base station in our case. Decode-and-Forward can be found in the work of Sendonaris et al in [7][11]. With DF relaying protocol, every cooperating user, after receiving the noisy version of the transmitted signal of its partner, decodes and then sends to base station, the re-encoded version of the it. Coded Cooperation was first developed by Todd[8] in which the cooperation integrates into channel coding. Cover and Gamal[9] were the first to developed relay channel under additive white Gaussian channel. In this work the relay can simultaneously transmit and receive in the same frequency channel. Das and Mecklenbrauker[10] had given the review of some prominent gains achieved with cooperative communication. In this the achievable rates and error rate performance both for cooperative and non-cooperative communications are also calculated. Andrej and Erkip[13] analyze the performance of channel codes that are capable of achieving the full diversity provided by user cooperation, with the constraint that they also provide the best possible performance in the interuser link.

Alamouti[14] was the first to developed a simple transmit diversity technique for wireless communications. This technique was then implemented in cooperative communication by Bellore[15], which solves the problem of bad performance at low SNR. Turbo code was only code which is close to shannon's limit and developed by Berrou[20]. It was then analysed using EXIT chart[25][26]. EXIT chart gives the performance at low BER value which is not achieved in BER chart. This EXIT chart is then invoke into Cooperative communication. Thus using EXIT chart gives the best performance when used with cooperative communication.

1.8 Problem Statement

The objective of the project is to study and compare various cooperative communication schemes which involves amplify & forward, decode & forward and coded cooperation. In this thesis, various combining techniques are used like Maximal Ratio Combining(MRC), Equal Ratio Combining(ERC), Fixed Ratio Combining(FRC), SNR Combining(SNRC) and Enhanced SNR Combining (ESNRC) to see there effects on system performance.

One combination that achieves a good performance is then used to see the effect on the performance depending on the location of the relay. The position of relay is the crucial to decide the system performance. Thereafter, the number of relays are also increased and the results are observed.

Here in coded cooperation, the cooperative communication is done using the widely used codes like the convolution codes, punctured convolution code and turbo codes. Cooperative communication with Alamouti code is also performed and its outage probability is measured.

1.9 Outline of the thesis

The rest of the thesis is organized as follows

Chapter 2 presents the fundamentals of cooperative communication and comparisons of cooperative communication and non-cooperative communication is shown. The cooperative transmission protocols, amplify & forward and decode & forward are also studied and compared. Various applications of cooperative communication are also discussed.

Chapter 3 explains the arrangement of the diversity system used in this thesis. Two relay protocols are described and various combining methods are introduced. The simulation results for the performance of different combinations of diversity protocols and combination methods are shown, which is then followed by the effect of the location of the relay station are presented and by increasing the number of relays.

Chapter 4 introduces the coded cooperation and its fundamentals. In this chapter cooperative communication is done with various commonly used codes such as convolution code, punctured convolution code, Alamouti code and Turbo code. It includes the fundamentals of the convolutional coding; it's encoding representations and shows the simulation of cooperative communication with convolution code. It also describes how the puncturing is done in convolutional code and simulation of cooperative communication with punctured convolutional code. This chapter also presents the fundamentals of Alamouti code and how it is used in cooperative communication, it also shows its simulation results. The chapter is then followed by the fundamentals of turbo codes, which describes the different configurations of turbo encoder, depending upon their physical realization i.e. serial or parallel. The comparisons of different SISO decoding algorithms, MAP and Max-Log-Map is performed to show their BER performance and finally introduces the cooperative diversity using distributed turbo codes.

Chapter 5 gives the brief of EXIT chart which is used to analysis turbo code. EXIT charts is used to predict the SNR value even for low Bit Error Ratio. Then a system model is designed for using EXIT chart in cooperative communication and the results are observed.

Chapter 6 summarizes the important findings of the various cooperative communication schemes, and concluded the thesis.

Chapter 2

Introduction to Cooperative Communication

Cooperative communications is a new communication technique which allows single-antenna mobiles to share their antennas and to produce virtual multiple-antenna system. This Figure.2.1 shows two mobile agents communicating with the same destination.

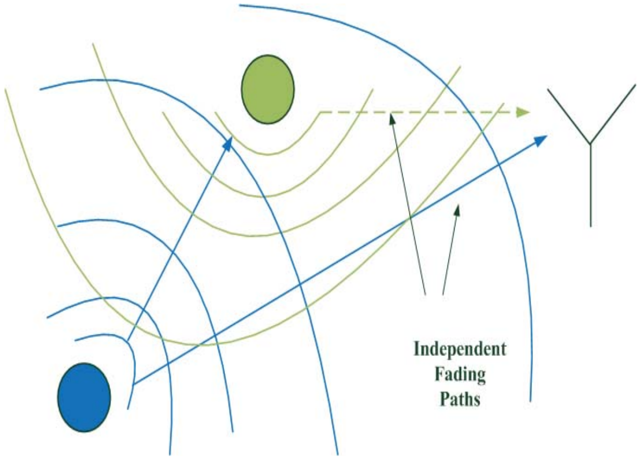


Figure 2.1: Cooperative communication

Each mobile has one antenna and cannot individually generate spatial diversity. However, it may be possible for one mobile to receive the other, in which it can forward some version of "overheard" information along with its own data. Because the fading paths from two mobiles are statistically independent, this generates transmit diversity.

2.1 Background

The basic ideas behind cooperative communication can be traced back to the groundbreaking work of Cover and El Gamal[9] on the information theoretic properties of the relay channel. This work analyzed the capacity of the three-node network consisting of a source, a destination, and a relay. It was assumed that all 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. The relay channel model is shown in Figure.2.2. In this model,transmitter A sends a signal X, whose noisy, attenuated version is received by both the destination C and a relay B. The relay then transmits another signal X1 to the destination, based on what it has received. This model can be decomposed into a broadcast channel (A transmitting, B and C receiving), and a multiple access channel (A and B transmitting, C receiving).

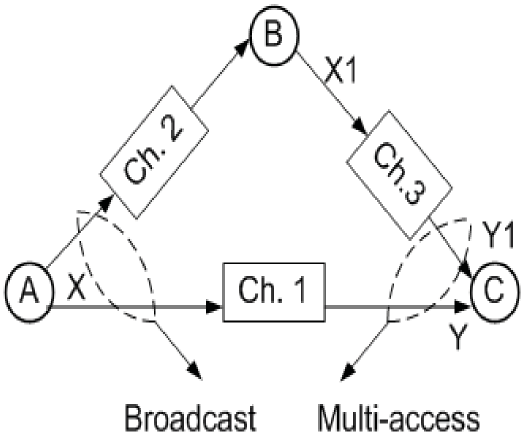


Figure 2.2: Relay Channel

Cover and El Gamal calculated the information theoretic capacity of this channel and found that it is bounded by the minimum of the rates of transmission of the constituent broadcast and multiple access channels. In many instances, the overall capacity is better than the individual capacity between A and C. However, in many respects the cooperative communication is different from the relay channel. First, recent developments are motivated by the concept of diversity in a fading channel, while Cover and El Gamal mostly analyze capacity in an additive white Gaussian noise (AWGN) channel. Second, in the relay channel, the relay's sole purpose is to help the main channel, whereas in cooperation the total system resources are fixed, and users act both as information sources as well as relays.

2.2 Cooperative Communication

Cooperative communication is similar to the relay channel model in some respects but differs significantly in that each wireless user is assumed to both transmit data as well as act as a cooperative agent for another user. In other words, cooperative signaling protocols should be designed so that users can assist other users while still being able to send their own data. This reciprocal arrangement is illustrated in Figure.2.3.

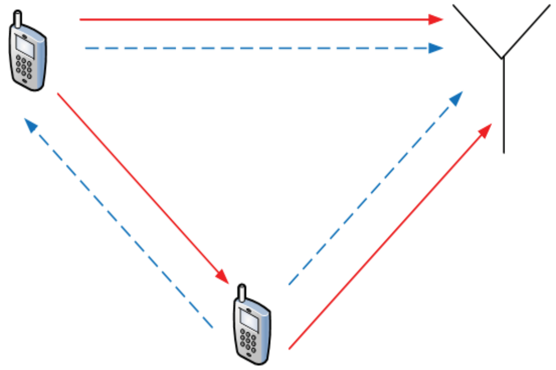


Figure 2.3: In cooperative communication each user is both a source and a relay

Cooperation leads to interesting tradeoffs in code rates and transmit power. In the case of power, it may seem that more power is required because each user, when in cooperative mode, is transmitting for both itself and a partner. However, the point to be made is that the gain in diversity from cooperation allows the users to reduce their transmit powers and maintain the same performance. In the face of this tradeoff, one hopes for a net reduction of transmit power, given everything else being constant.

Similarly for the rate of the system. In cooperative communication, each user transmits both its own bits as well as some information for its partner, so it may appear that each user requires more bandwidth. On the other hand the spectral efficiency of each user improves because, due to cooperation diversity, the channel code rates can be increased.

Thus to summarize, in non-cooperative communication users send directly to a common destination, without repeating for one another. The received signal can be written as [10]:

$$Y_{d,r} = h_{d,r}X2 + n_{d,r} = h_{d,r}h_{r,s}X1 + h_{d,r}n_{r,s} + n_{d,r} \tag{2.1}$$

Where $h_{d,r}$ is the channel from the relay to the destination nodes and $n_{r,s}$ is the noise signal added to $h_{d,r}$. In cooperative wireless, users not only transmit their own information, but also repeat other users' information during its transmission to a common destination. During the first slot, Base station receives from user1

$$Y_{s,d} = X1h_{s,d} + n_{s,d} \tag{2.2}$$

Where $Y_{s,d}$ is the signal received at destination from source, x1 is the transmitted signal, $h_{s,d}$ is the channel gain and $n_{s,d}$ is the AWGN noise. In the next time slot, it receives the relayed version of the same information from its partner, user 2 as

$$Y_{s,d} = X1h_{s,d} + n_{s,d} \tag{2.3}$$

Here $Y_{r,d}$ is the signal received at destination from relay or cooperating user, x1rd is the transmitted signal of user 1, relayed be its partner, $h_{r,d}$ is the channel gain, and nr,d is the AWGN noise. These two copies of the same signal received at BS are combined and used by the receiver for decision making or decoding purpose. The error rate performance both for cooperative and non-cooperative communications are shown in Figure.2.4

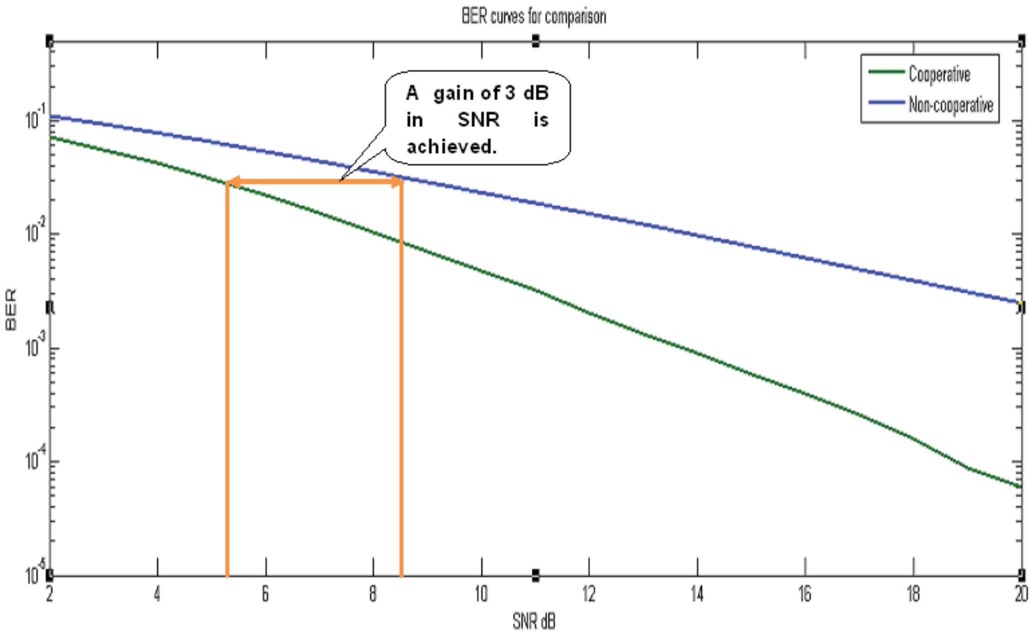


Figure 2.4: Comparisons of Cooperative versus Non-Cooperative

It can be seen from the Figure.2.4 that with cooperative, a considerable gain of 3 dB in SNR is achieved. But there is a tradeoff in cooperative communication that, increase in gain at the cost of losing wireless resources such as frequency, time and power resources.

2.3 Advantages and Disadvantages of cooperative communication

The advantages and disadvantages of the cooperative system are summarized below.

2.3.1 Advantages of cooperative communication

The key advantages of using cooperative relays in the system can be summarized as follows:

- **Performance Gains:** Large system-wide performance gains can be achieved due to pathloss gains as well as diversity and multiplexing gains. These translate into decreased transmission powers, higher capacity or better cell coverage.

- **Balanced Quality of Service:** Whilst in traditional systems users at the cell edge or in shadowed areas suffered from capacity and/or coverage problems, relaying allows to balance this discrepancy and hence give (almost) equal quality of service (QoS) to all users.

- **Infrastructure-Less Deployment:** The use of relays allows the roll-out of a system that has minimal or no infrastructure available prior to deployment. For instance, in disaster-struck areas, relaying can be used to facilitate communications even though the cellular system is nonfunctioning.

- **Reduced Costs:** Compared to a purely cellular approach to provide a given level of QoS to all users in the cell, relaying is a more cost effective solution.

2.3.2 Disadvantages of cooperative communication

Some major disadvantages of using cooperative relays in the system are given below:

- **Complex Schedulers:** Whilst maintaining a single cooperative relaying link is a fairly trivial task, at system level with many users and relays this quickly becomes an arduous task. As such, relaying requires more sophisticated schedulers since not only traffic of different users and applications needs to be scheduled but also the relayed data flows. Any gains due to cooperation at the physical layer dissipate rapidly if not handled properly at medium access and network layers.

- **Increased Overhead:** A full system functioning requires handovers, synchronization, extra security, etc. This clearly induces an increased overhead w.r.t to a system that does not use relaying.
- **Partner Choice:** To determine the optimum relaying and cooperative partners is a fairly intricate task. Also, the complexity of maintaining such cooperative partnership is higher w.r.t. noncooperative relaying.
- **Increased Interference:** If the offered power savings are not used to decrease the transmission power of the relay nodes but rather to boost capacity or coverage, then relaying will certainly generate extra intra- and inter-cell interference, which potentially causes the system performance to deteriorate. An optimum trade-off needs, therefore, to be found at system level.
- **Extra Relay Traffic:** The relayed traffic is, from a system throughput point of view, redundant traffic and hence decreases the effective system throughput since in most cases resources in the form of extra frequency channels or time slots need to be provided.

2.4 Applications

Cooperative sensing for cognitive radio:

In cognitive radio system, unlicensed secondary users can use the resources which are licensed for primary users. When primary users want to use their licensed resources, secondary users has to vacant these resources. Hence secondary users have to constantly sense the channel for detecting the presence of primary user. It is very challenging to sense the activity of specially distributed primary users in wireless channel. Spatially distributed nodes can improve the channel sensing reliability by sharing the information and reduce the probability of false alarming.

Wireless Ad-hoc Network:

This is autonomous and self organizing network without any centralized controller or pre-established infrastructure. In this network randomly distributed nodes forms a temporary functional network and support seamless leaving or joining of nodes. Such networks have been successfully deployed for military communication and have lot of potential for civilian applications include commercial and educational use, disaster management, road vehicle network etc.

Wireless Sensor Network:

Cooperative relaying can be used to reduce the energy consumption in sensor nodes, hence lifetime of sensor network increases. Due to nature of wireless medium, communication through weaker channels require huge energy as compared to relatively stronger channels. Careful incorporation of relay cooperation into routing process can selects better communication links and precious battery power can be saved.

2.5 Summary

In any wireless channel fading occurs, which can be reduced by the placing multiple antenna at transmitter and receiver(MIMO). But whenever size constraints is found, cooperative communication is used. Thus in this chapter cooperative communication system is compared non-cooperative system, which shows that cooperative has low probability of error compared to non-cooperative.

Chapter 3

Cooperative Transmission Protocols

3.1 Amplify and Forward Method

Laneman and Wornell first proposed amplify-and-forward as a cooperative signaling scheme in [4]. Amplify-and-forward is conceptually the most simple of the cooperative signaling methods. Each user in this method receives a noisy version of the signal transmitted by its partner. As the name implies, the user then amplifies and retransmits this noisy signal (see Figure.3.1). The destination will combine the information sent by the user and partner and will make a final decision on the transmitted symbol.

Although the noise of the partner is amplified in this scheme, the destination still receives two independently-faded versions of the signal and is thus able to make better decisions for the transmitted symbols.

A potential challenge in this scheme is that sampling, amplifying, and retransmitting analog values may be technologically on-trivial. Nevertheless, amplify-and-forward is a simple method that lends itself to analysis, and therefore has been very useful in furthering the understanding of cooperative communication systems.[5]

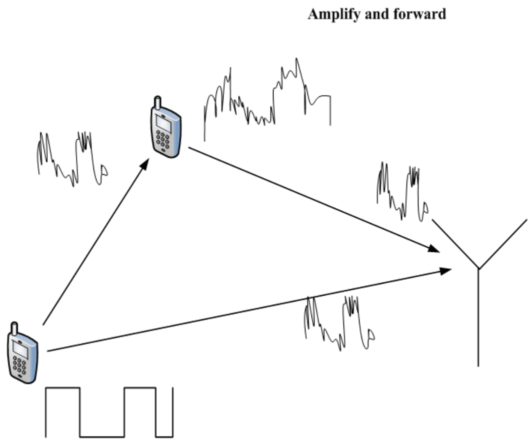


Figure 3.1: Amplify and Forward Method

3.2 Decode and forward Method

The first work proposing a decode-and-forward protocol for user cooperation was by Sendonaris,Erkip, and Aazhang [6][7] (also see [11]). Nowadays a wireless transmission is very seldom analogue and the relay has enough computing power, so Decode and Forward is most often the preferred method to process the data in the relay. The received signal is first decoded and then re-encoded. So there is no amplified noise in the sent signal, as is the case using Amplify and Forward protocol.

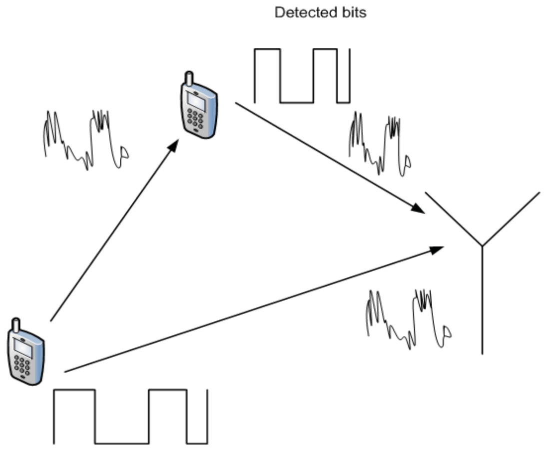


Figure 3.2: Decode and Forward Method

There are two main implementations of such a system.The relay can decode the original message completely [18]. This requires a lot of computing time, but has numerous advantages. If the source message contains an error correcting code, received bit errors might be corrected at the relay station. Or if there is no such code implemented a checksum allows the relay to detect if the received signal contains errors. Depending on the implementation an erroneous message might not be sent to the destination.

But it is not always possible to fully decode the source message. The additional delay caused to fully decode and process the message is not acceptable, the relay might not have enough computing capacity or the source message could be coded to protect sensitive data. In such a case, the incoming signal is just decoded and re-encoded symbol by symbol. So neither an error correction can be performed nor a checksum calculated.

3.3 System Model

There are several approaches to implement diversity in a wireless transmission. Multiple antennas can be used to achieve space and/or frequency diversity. But multiple antennas are not always available or the destination is just too far away to get good signal quality. To get diversity, an interesting approach might be to build an ad-hoc network using another mobile station as a relay. The model of such a system is illustrated in Figure.3.3. The sender S, sends the data to the destination D, while the relay station R is listening to this transmission. The relay sends this received data burst after processing to the destination as well, where the two received signals are combined.

The transferred data is a random bipolar bit sequence which is either modulated with Binary Phase Shift Keying (BPSK) or Quadrature Phase Shift Keying (QPSK). The cooperative transmission protocols used in the relay station are either *Amplify and Forward or Detect and Forward*. These protocols describe how the received data

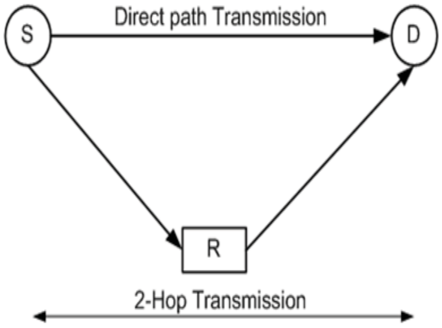


Figure 3.3: system model for multihop

is processed at the relay station before the data is sent to the destination.

The channels from source to relay as well as from the relay to destination are independent Rayleigh fading. Thus, the channel gains from source to relay is denoted by $h_{s,r}$. Here in this thesis thermal noise, path loss and Rayleigh fading are considered. If we consider the channel gains from source to destination, i.e $h_{s,d}$, then the received symbol can be expressed as

$$y_d[n] = h_{s,d}[n].x_s[n] + z_{s,d}[n] = d_{s,d}.a_{s,d}[n].x_s[n] + z_{s,d}[n] \tag{3.1}$$

Here s, d denote the sender and the destination, $x_s[n]$ denote the transmitted symbol. $z_{s,d}[n]$ denotes the noise, $d_{s,d}$ denotes the pathloss and $a_{s,d}$ denotes fading. Each one of this is explained below. The noise $z_{s,d}[n]$ can be simulated as the sum of a real and an imaginary noise vector, both Gaussian distributed, mutually independent and zero mean with variance σ_n^2. The total noise power will be $N_0 = 2\sigma_n^2$. The signal-to noise ratio is widely used value to indicate the signal quality at the destination which is defined as:

$$s_{i,j} = \mid h_{i,j} \mid^2 . \frac{p_i}{N_j} \tag{3.2}$$

The signal is mainly attenuated by pathloss and fading, both included in $h_{s,d} = d_{s,d}.a_{s,d}$. The pathloss is proportional to $(1/R^2)$. In a wireless network it occurs quite often that the line-of-sight link is blocked. The fading coefficient $a_{s,d}$ can be modeled as a zero mean, complex Gaussian random variable with variances $\sigma^2_{s,d}$. This means that the angle $\angle as, d$ is uniformly distributed on $[0, \pi)$ and the magnitude $\mid as, d \mid$ is Rayleigh distributed. This Rayleigh distributed magnitude can have a bad effect on the signal quality at the receiver. The magnitude and the angle of the fading coefficient $a_{s,d}$ of the block is known by the receiver. Even a system with a high SNR might experience significant errors due to fading. The receiver detects the received signal symbol by symbol.

The Bit Error rate is of main interest in the system. For BPSK with single transmission link and Rayleigh fading bit error probability can be calculated as:

$$p_b = \frac{1}{2}(1 - \sqrt{\frac{\gamma_b}{1 + \gamma_b}}) \tag{3.3}$$

For QPSK bit error rate can be calculated as [16]:

$$p_b = \frac{1}{2}(1 - \sqrt{\frac{\gamma_b}{2 + \gamma_b}}) \tag{3.4}$$

Where γ_b is the average signal-to-noise ratio.

The performance of 2-hop with MRC at receiver is expressed as [16]:

$$p_b = \frac{1}{4}(1 - \mu)^2(2 + \mu) \qquad \mu = \sqrt{\frac{\gamma_b}{1 + \gamma_b}} \tag{3.5}$$

3.4 Combining Techniques

As soon as there is more than one incoming transmission with the same burst of data, the incoming signals have to be combined by the following techniques[17]:

3.4.1 Equal Ratio Combining

If computing time is a crucial point, or the 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.

$$y_d[n] = \sum_{i=1}^{k} y_{i,d}[n] \tag{3.6}$$

Thus if one relay is considered then the above Equation.5.1 can be written as:

$$y_d[n] = y_{s,d}[n] + y_{r,d}[n] \tag{3.7}$$

where $y_{s,d}$ denote the received signal from sender to destination and y_{rd} denote the one from the relay.
Similarly for multiple relays the above Equation.5.1 can be written as:

$$y_d[n] = y_{r1,d}[n] + y_{r2,d}[n] + y_{r3,d}[n] \tag{3.8}$$

3.5 Fixed Ratio Combining

A much better performance can be achieved, when Fixed ratio combining is used. Instead of just adding up the incoming signals, they are weighted with a constant ratio, which will not change a lot during the whole communication. The ratio should represent the average channel quality and therefore should not take account of temporary influences on the channel due to fading or other effects. But influences on the channel, which change the average channel quality, such as the distance between the different stations, should be considered. The ratio will change only gently and therefore needs only a little amount computing time. The FRC can be expressed as

$$y_d[n] = \sum_{i=1}^{k} d_{i,d}.y_{i,d}[n] \tag{3.9}$$

where $d_{i,d}$ denotes weighting of the incoming signal $y_{i,d}$. Using one relay station, the Equation.5.4 simplifies to

$$y_d[n] = d_{s,d}.y_{s,d}[n] + d_{s,r,d}.y_{r,d}[n] \tag{3.10}$$

where $d_{s,d}$ denotes the weight of the direct link and $d_{s,r,d}$ the one of the link. Similarly for multiple relays the above Equation.5.4 can be written as:

$$y_d[n] = d_{s,r1,d}.y_{r1,d}[n] + d_{s,r2,d}.y_{r2,d}[n] + d_{s,r3,d}.y_{r3,d}[n] \tag{3.11}$$

3.5.1 Signal-to-Noise Ratio Combining

A much better performance can be achieved, if the incoming signals are weighted on an intelligent way. An often used value to characterize the quality of a link is the SNR, which can be used to weight the received signals.

$$y_d[n] = \sum_{i=1}^{k} SNR_i.y_{i,d}[n] \tag{3.12}$$

Using one relay, the Equation.3.12 can be written as

$$y_d[n] = SNR_{s,d}.y_{s,d}[n] + SNR_{s,r,d}.y_{r,d}[n] \tag{3.13}$$

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

Similarly for multiple relays the above Equation.3.12 can be written as:

$$y_d[n] = SNR_{s,r1,d}.y_{r1,d}[n] + SNR_{s,r2,d}.y_{r2,d}[n] + SNR_{s,r3,d}.y_{r3,d}[n] \tag{3.14}$$

3.5.2 Maximal Ratio Combining

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.

$$y_d[n] = \sum_{i=1}^{k} h^*_{i,d}[n].y_{i,d}[n] \tag{3.15}$$

Using a one relay system, this Equation.3.17 can be rewritten as

$$y_d[n] = h^*_{s,d}[n].y_{s,d}[n] + h^*_{r,d}[n].y_{r,d}[n] \tag{3.16}$$

Similarly for multiple relays the above Equation.3.17 can be written as:

$$y_d[n] = h^*_{r1,d}[n].y_{r1,d}[n] + h^*_{r2,d}[n].y_{r2,d}[n] + h^*_{r3,d}[n].y_{r3,d}[n] \tag{3.17}$$

3.5.3 Enhanced Signal-to-Noise Ratio combining

Another plausible combining method is to ignore an incoming signal when the data from the other incoming channels have a much better quality. If the channels have more or less the same channel quality the incoming signals are rationed equally. It can be expressed as

$$y_d[n] = y_{s,d}[n] \qquad (SNR_{s,d}/SNR_{s,r,d} > 10) \tag{3.18}$$

$$y_d[n] = y_{s,d}[n] + y_{s,r,d}[n] \qquad (0.1 \leq SNR_{s,d}/SNR_{s,r,d} \leq 10) \tag{3.19}$$

$$y_d[n] = y_{s,r,d}[n] \qquad (0.1 \leq SNR_{s,d}/SNR_{s,r,d}) \tag{3.20}$$

Using this combining method, the receiver does not have to know the channel characteristic exactly. An approximation of the channel quality is enough to combine the signals.

3.6 Simulation Results

There are two popular implementations to transmit over a wireless network. One is the simple direct link which sends the data only once. The other is the two sender arrangement which sends the data twice over different antennas.

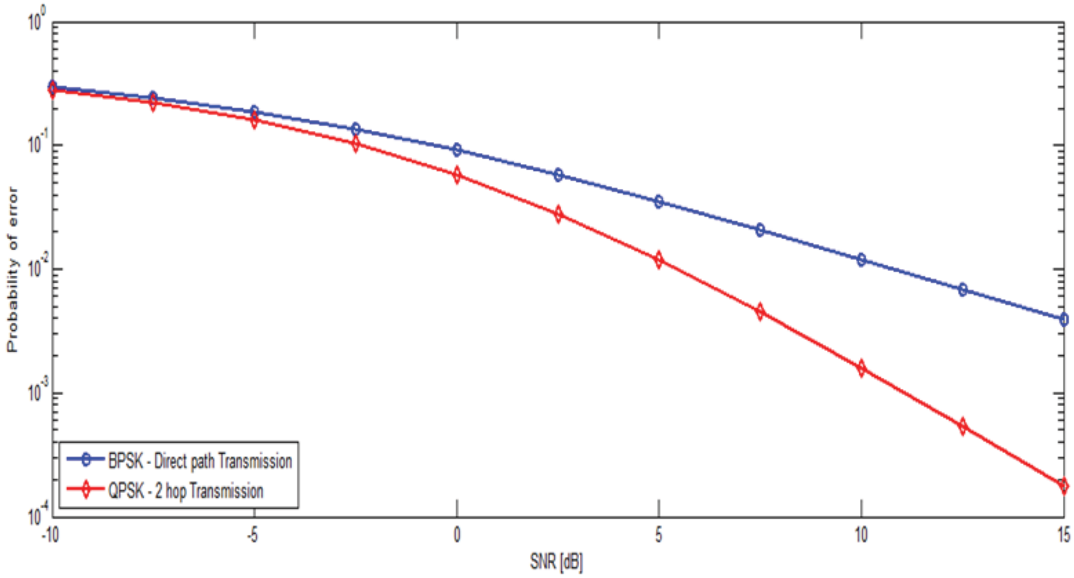


Figure 3.4: Direct path transmission and two-hop transmission are compared. Two-hop Transmission shows better performance

The diversity arrangement has to send the data twice and therefore requires twice the bandwidth of the single link transmission. To compensate for this effect, the single link channel is modulated using BPSK and the diversity arrangement uses QPSK. As QPSK has twice the bandwidth of BPSK both arrangements have the same overall bandwidth. The relay causes a certain time delay for the diversity arrangement. Thus the Figure.3.4 shows the simulation of the Direct path transmission and two-hop transmission in which the two-hop transmission gives better performance.

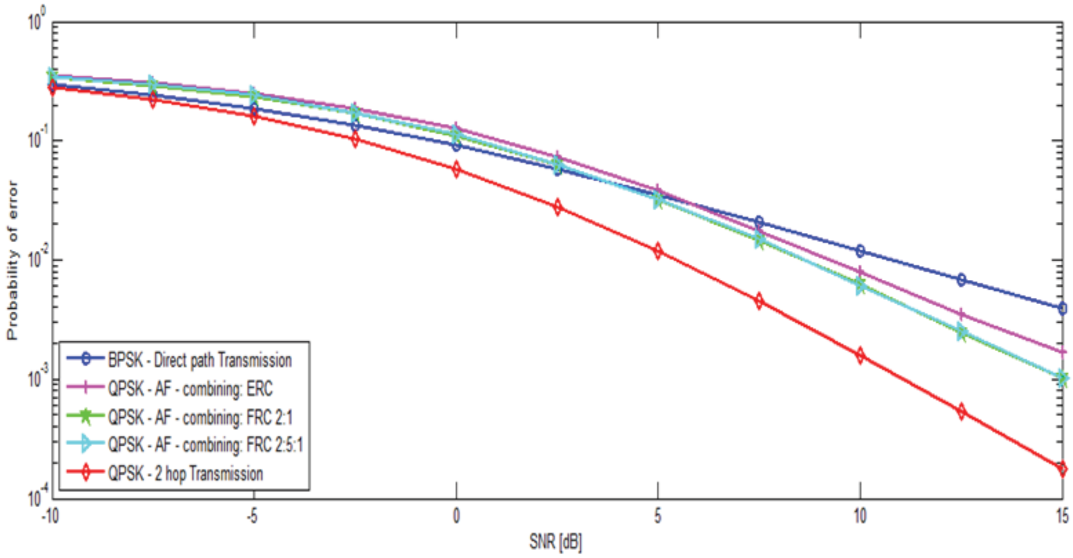


Figure 3.5: To estimate the best ratio for FRC different ratios are plotted. The ratio 2:1 gives a good result

To compare the benefits of the different combining method, the optimal ratio for the FRC needs to be evaluated first. Figure.3.5 illustrates the effects of the different weighting. As seen, a much better performance is achieved using FRC instead of ERC simply by assuming that the direct link has in general a better quality than the multi-hop link. This is obvious in an equidistant arrangement, where the signal over the multi-hop has to propagate over twice the distance than over the direct link. The result of the simulation illustrated in Figure.3.5 shows that the best performance using FRC is achieved with a ratio of 2:1. FRC with this ratio is now used to compare performances with one of the other combining types.

In Figure.3.6 the effect on the performance of the different combining types using a AF protocol can be seen. The BPSK single link transmission should demonstrate if there is any benefit at all using diversity, while the QPSK two senders link indicates a lower bound for the transmission. Using the equidistant arrangement, the aim is to get as close to the latter curve as possible or to get an even better performance.

The first pleasant result is that whatever combining type is used, the AF diver-

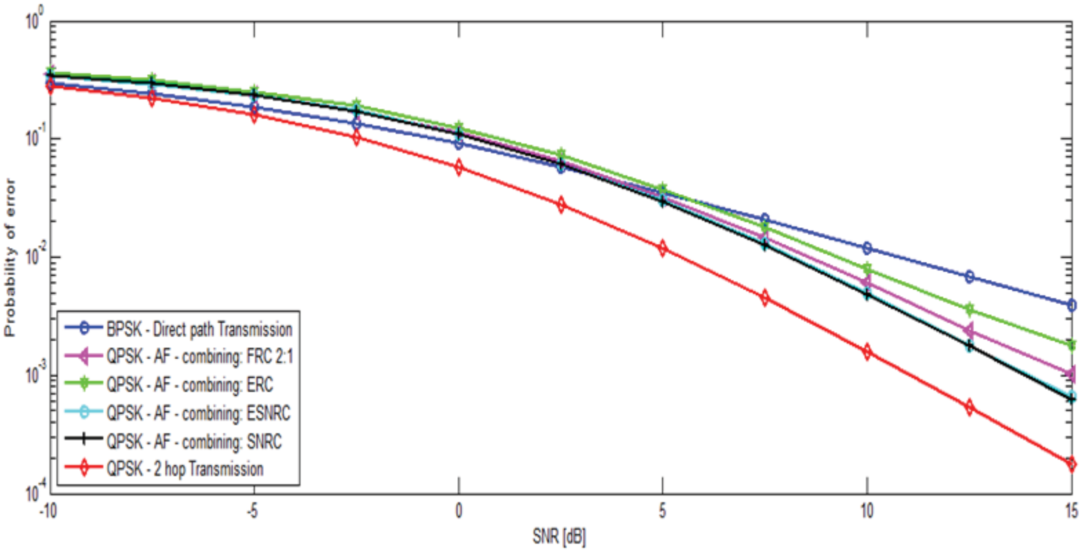


Figure 3.6: The different combining types are compared with each other. The best performance results when using SNRC/ESNRC

sity protocol achieves a benefit compared to the direct link. Even the equal ratio combining shows advantages. But compared to the fixed ratio combining, the performance looks quite poor. The signal-to-noise ratio combining (SNRC) and the enhanced signal-to- noise ratio combining (ESNRC) show roughly the same performance, which is much better then the one using FRC/ERC, it is because the former two combining methods are using much more detailed channel information than the latter two.

The other unexpected thing is that the SNRC shows approximately the same performance than the ESNRC. The ESNRC a roughly estimated channel quality for every single block is sufficient,while the SNRC needs exact information of the channel quality for every single block. This means that the transferred signal in an AF system contains some information that allows correcting of a small difference in the channel quality. Using the AF protocol, there is no point in wasting a lot of computing power and bandwidth to get some exact channel information. And even if the channel quality could not be estimated at all (and therefore ERC is used), there is still a benefit using diversity. To compare the benefits of the different combining method,

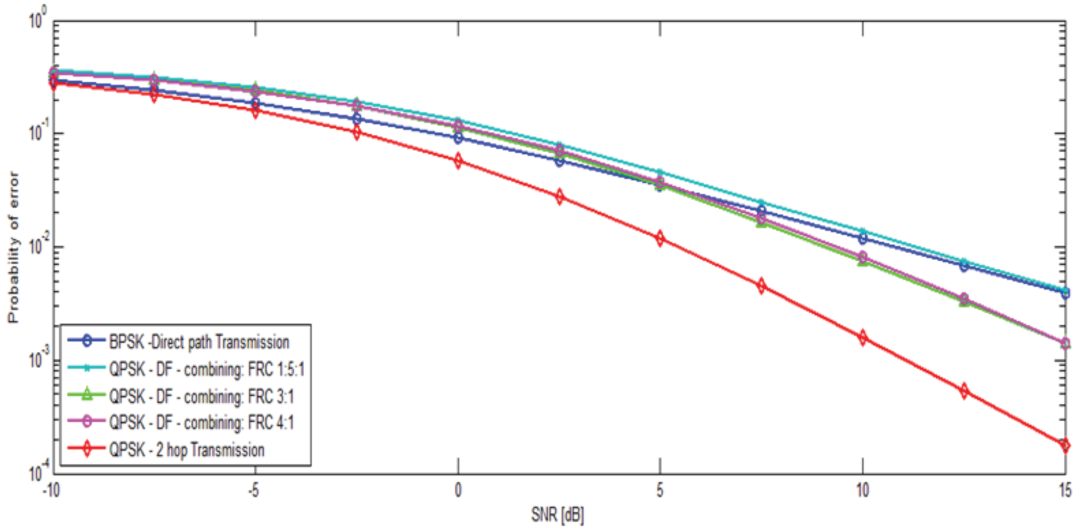


Figure 3.7: To estimate the best ratio for FRC different ratios are plotted. The ratio 3:1 results in the best performance

the optimal ratio for the FRC needs to be evaluated first, which is done exactly in the same way as before. The FRC is simulated with different weighting to estimate the ratio that results in the best performance. The simulations, illustrated in Fig.3.6, show the best performance when a ratio of 3:1 is used.

The different combining methods using the DF protocol are illustrated in Figure.3.8. The first thing that attracts attention is the bad performance of the equal ratio combining. Especially for a small SNR the performance is significantly worse than the one of the BPSK single link transmission and therefore should not be used at all. The fixed ratio combing shows obviously a much better performance than the BPSK single link transmission. To achieve a BER of about 10^{-2} the required SNR for the FRC is about 2.5 dB less than the one for the single link transmission. In contrast to the AF protocol, a big benefit results using one of the block analysing combining methods (SNRC/ESNRC). Using the DF protocol shows now the benefit estimating every single block separately and hence using more computing power.

There is now an additional benefit, to estimate every block precisely when using SNRC, instead of just approximating the channel quality combining the signals with

ESNRC. But considering that the achievable benefit is about half a decibel it might not be worth wasting the additional computing power and bandwidth which is required to get a precise channel estimation. If AF is used, there is no benefit at all, using the SNRC instead of ESNRC.

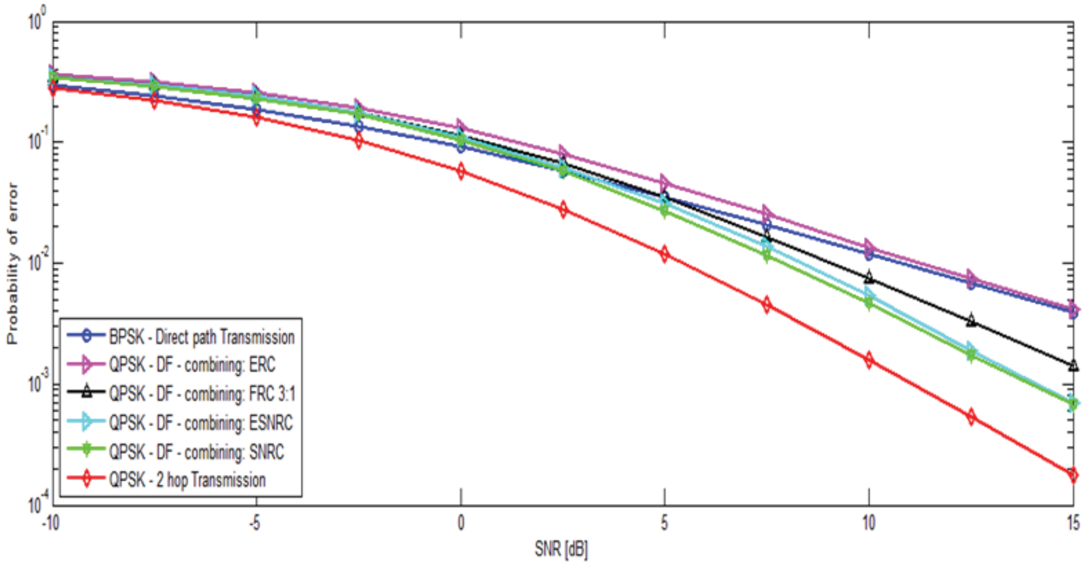


Figure 3.8: The different combining types are compared with each other. The best performance results when using SNRC

The effect on the channel quality using error correcting code is illustrated in Figure.3.9. The DF system with the error correcting code shows a much better performance than the AF system. As seen in Figure.3.9, the combining method does not make a big difference in the bit error ratio when a DF system with a error correcting code is used. The performance of the maximum ratio combining is less than half a decibel better than the one using equal ratio combining. The system using a error correcting code gets close to the performance of the two sender system, which is a quite nice benefit. All the simulations illustrated in Figure.3.9 have approximately the same slope as the two sender system and therefore show full second level diversity.

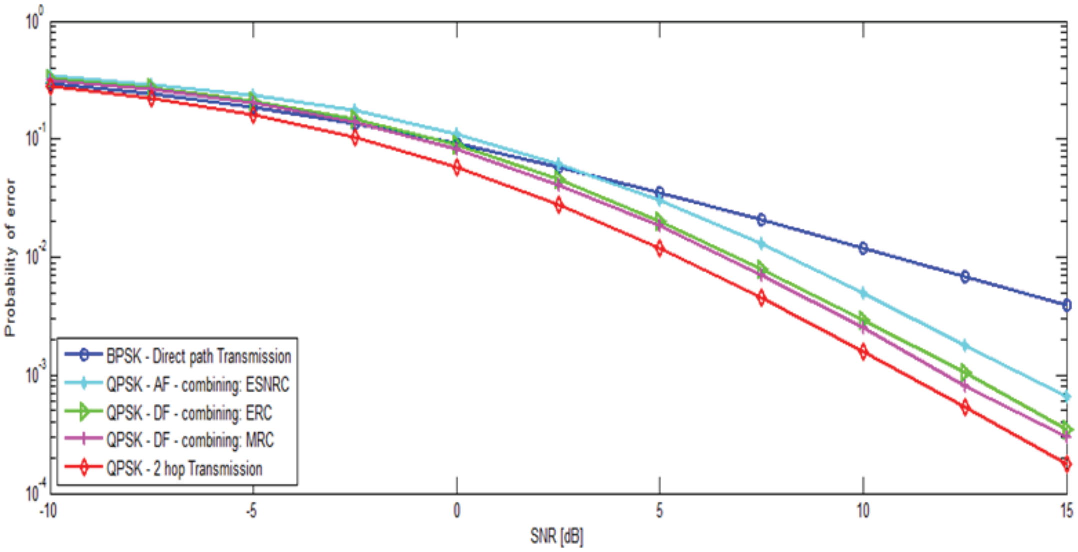


Figure 3.9: The effect of an error correcting code is simulated

3.6.1 Moving the relay

So far, the three stations were positioned equidistantly and therefore the three channels had all the same average signal-to-noise ratio. In this section the effect is shown when the relay station is moved. For the following simulations the AF diversity protocol is used and the incoming signals at the destination are combined using ESNRC.

The x-axis in the figures shows the average signal-to-noise ratio, for a channel of length one. In this section, the relay is moved, so the distance from the relay to the sender/destination will change. But in all the simulations, the distance between the sender and the destination is set to one, and therefore the signal-to-noise ratio shown in the x-axis is only valid for the direct link.

Relay between sender and destination

The propagation over the multi-hop link does not need to make any detour, when the relay is situated between the sender and the destination. This is the optimal scenario and should result in the best possible performance.

If the relay is situated very close to the sender, the whole arrangement corresponds approximately to a two sender system. The effect on the signal quality when moving the relay between the two other stations is shown in Figure.3.10. With this optimal configuration, the resulting benefit is huge and much better than the one for the two sender system. The best performance is achieved, when the relay is situated in the middle between the sender and the destination, or slightly closer to the sending station.

The resulting performance is not symmetrical at all. The preferred position of the relay is in the middle between the sender and the destination. When this is not possible the relay should be closer to the sender than to the destination. In AF The noise received in the relay station is amplified with the signal. So on one hand it is desirable, that the received noise at the relay station does not has much energy. On the other hand, the closer the relay comes to the sender, the further away is the destination and therefore the worse is the channel quality of the second hop. The quality of the first hop is more important for the overall channel quality than the second hop, so the performance is not symmetrical.

Another point that should be paid attention to is the huge benefit compared to the BSPK direct link. To achieve a BER of about 10^{-2} the SNR is up to eight decibels less than using only a direct link transmission.

Equidistant Position of the Relay

Normally there is no relay station available just between the sender and the destination. To see the effect the length of the multi-hop link has on the system performance, the relay is moved away gently from the optimum position between the sender and the destination. This is illustrated in Figure.3.11.

The first thing that attracts attention is how fast the performance gets worse when the distance of the relay increases. By increasing the distance by fifty percent, the resulting performance is roughly the same as the one for a two sender system, which is about three decibels less than the one of the optimal position. The position of the relay, where all three stations are equidistant, results in another 2.5 decibel loss

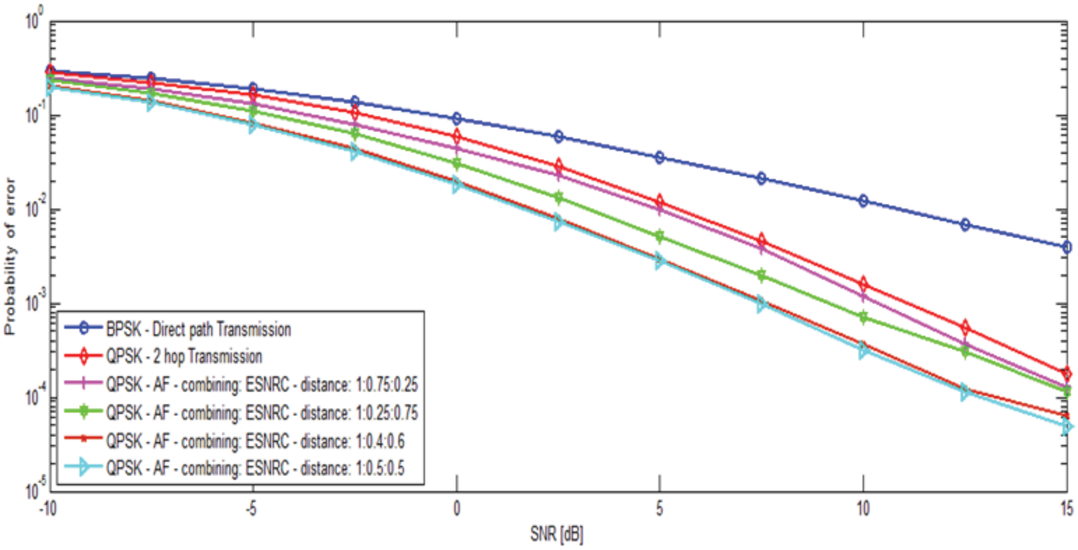


Figure 3.10: A big benefit results when the relay is located between the sender and the destination

in the system performance. This equidistant arrangement still shows an advantage compared to the BPSK single link transmission.This changes pretty fast, when the distance of the relay is increased further. Another fifty percent, result in a situation, where there is no useful advantage anymore using the relay link. But the higher diversity level can still be recognised.

When the relay is situated in the double distance of the equidistant arrangement, there is no benefit at all using the relay link. The resulting performance is roughly the same as the one of the QPSK single link transmission. This means, that the relay link, does not contain any useful information anymore. There is now just too much noise in the signal to get any benefit.

Moving the Relay Close to the Sender/Destination

In Figure.3.12 the arrangement is illustrated where the relay is much closer to either the sender or the destination. In contrast to the situation where the relay was situated between the two other stations, the arrangement shows now much more symmetry. The reason for that is that the direct link contains the better signal quality and

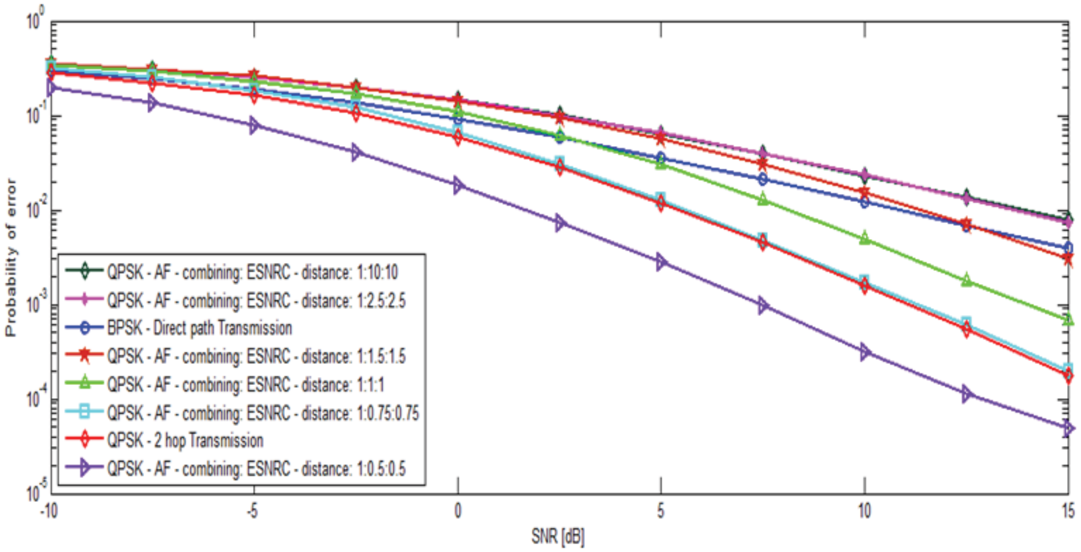


Figure 3.11: Shows the effect of increasing the distance of the relay to the sender and the destination

therefore is mainly responsible for the performance.

The main interest is now to determine where a mobile station can be located so that there is some benefit from using it as a relay station. Looking at Figure.3.11 and Figure.3.12 you can get the basic idea. If the relay is located close to the sender or the destination, the distance to the other station can be about forty percent longer then the one to the direct link. When the relay is roughly the same distance from both stations, this distance should not be much longer than the direct link to get a benefit. This results roughly in an elliptical region between base and mobile, where a second mobile station has to be situated to make it an attractive candidate as a relay.

3.7 Multiple Relay

Multihop transmission can lead to significant transmit power reduction compared with direct single-hop transmission. Multihop transmission can also lead to significant coverage extensions. Another advantage of relaying is its ability to avoid obstacles

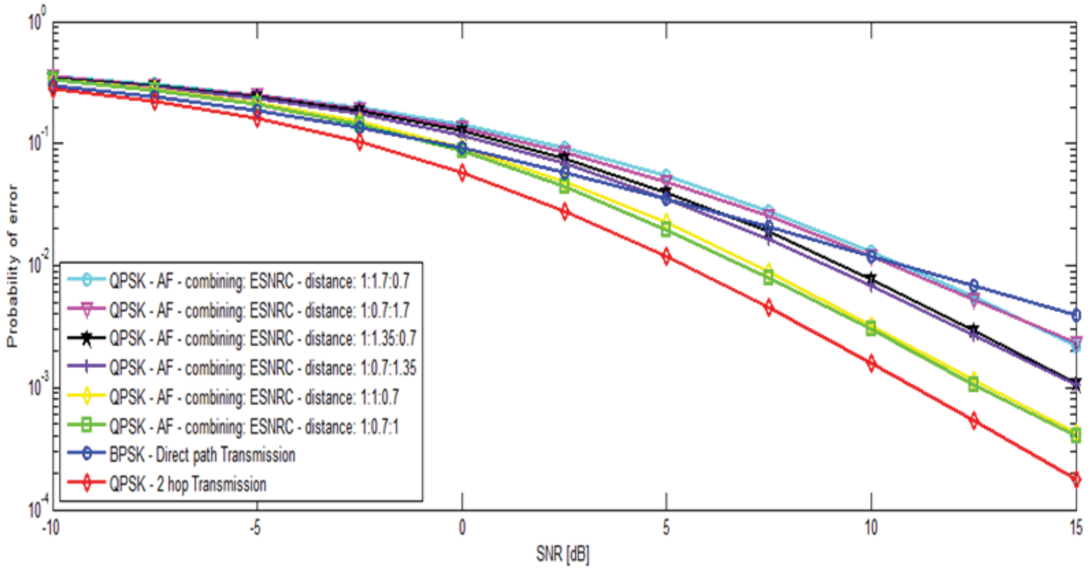


Figure 3.12: The relay is moved close to the sender/destination

and thus combat the fading. In addition to coverage enhancement relaying can also be used to enhance user capacity and QoS by reducing interference, increasing frequency reuse, enabling cooperative diversity and path redundancy, reducing call blocking probability by routing traffic between cells, etc. Thus in turn it adds flexibility to the design of cellular networks. Cooperative transmission by relay nodes has the ability to improve the overall performance.

From the above section it is shown that when the relay is located in the midway of the link between source and destination, the system performance is improved. Thus in this system model the relay is located in the midway of the link between source and destination. Figure.3.14 shows a schematic of the network with N no. of relays. The source S transmits the data to the destination through the relay, which listens to this transmission. The channels from source to relay as well as from the relay to destination are independent Rayleigh fading. Thus, the channel gains from source to relay denoted by $h_{s,r1}, h_{s,r2}, ...h_{s,rN}$ and from relay to destination, denoted by $g_{r1,d}, g_{r2,d}....g_{rN,d}$.

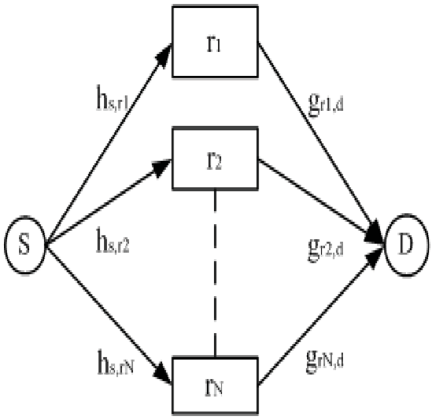


Figure 3.13: system model for multiple relays

3.7.1 Simulation Results

In this section, simulations for stations (sender, relay and destination) having an equal distance from each other and therefore the same path loss and average signal-to-noise ratio is assumed. With this equidistant arrangement MRC combining and decode and forward are used to see their advantages and disadvantages. Here simulation is also performed when the relay is located close to source and close to destination, to see the effect on the performance of the system. QPSK modulation with equal transmit power is assumed. The channels are mutually independent with rayleigh fading that remains constant over each source block. Each receiver has perfect CSI

Table 3.1: Various parameters for system model

Parameters	Value
No. of bits	$2^{1}0$
No. of blocks	10^4
Bits/symbol	2
No.of source	1
No. of relays	3
No. of destination	1
Combining Techniques	MRC
Channel	Rayleigh

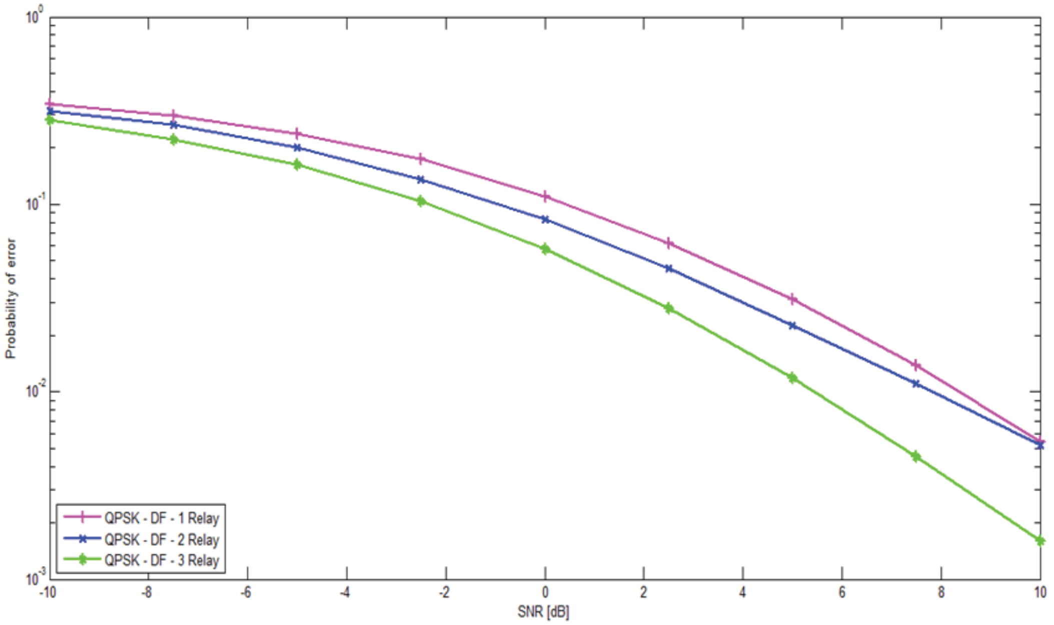


Figure 3.14: Best Performance with multiple relays and midway distance

and employs coherent detection.Thus to summarized various parameters are described in the following Table.3.1.

Figure.3.14 shows the effect of multiple relay and the distance on the system performance. It can be seen from the figure that gain of almost 2.5dB of SNR at BER 10^{-2} is achieved when simulation is performed with three decode and forward relays.

3.8 Summary

In this chapter the different aspects of a multi-hop have been presented. First two different transmission protocols Amplify and Forward (AF) and Decode and Forward (DF) have been described. When the destination receives different samples of the same data, these samples need to be combined. The Equal Ratio Combining (ERC) just adds up the different received signal while the Fixed Ratio Com- bining (FRC) is weighting the incoming signals with a fixed ratio. When the channel quality is estimated precisely, more powerful combining methods as Maximum Ratio Combining (MRC), Signal-to-Noise Ratio Combining (SNRC) or Enhanced Signal-to-Noise Combining (ESNRC) can be used. The location of the relay is crucial to the performance. The latter part shows the effect of relay stations. The best performance was achieved when the relay is at equal distance from the sender and the destination or slightly closer to the former. Furthermore, by increasing the number of relays the best performance is achieved.

Chapter 4

Coded Coooperation

In coded cooperation, cooperative signaling is integrated with channel coding. The basic idea behind coded cooperation is that each user tries to transmit incremental redundancy for its partner. Whenever that is not possible, the users automatically revert back to a non-cooperative mode[8]. The key to the efficiency of coded cooperation is that all this is managed automatically through code design and there is no need for feedback between users. This method has two key characteristics.[8] First, cooperation occurs through partitioning a user's code word such that part of the code word is transmitted by the user itself, while the remainder is transmitted by

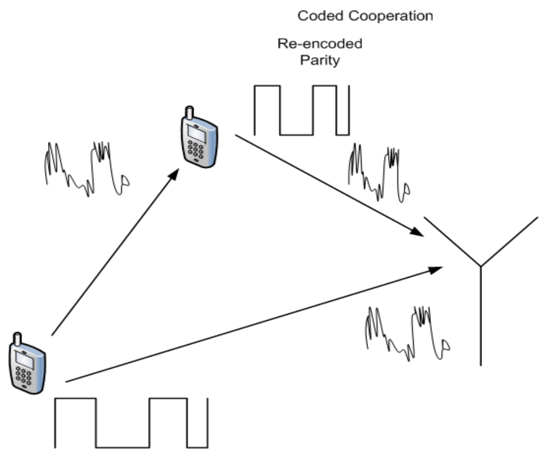


Figure 4.1: Coded cooperation

the partner through partial or complete decoding. In previous methods cooperation occurs via repetition, which may not be the best use of available bandwidth. Secondly, error detection is employed at the partner to avoid error propagation. Many of the previous methods either admit forwarding of erroneous estimates of the partner's symbols, or include propagation of the partner's noise. Error propagation diminishes the performance, particularly when the channel between partners is poor.

It is possible to implement these characteristics in a natural and simple manner by a method that uses common error control codes. Furthermore, the incorporation of cooperation with channel coding allows a great degree of flexibility, since by varying the associated code rate, the coupling between the cooperating users can be controlled and adapted to channel conditions. The users segment their source data into blocks which are augmented with a cyclic redundancy check (CRC) code, for a total of K bits per source block (including the CRC bits). Each block is then encoded with a forward error-correcting code, so that, for an overall rate R code, we have N = K/R total code bits per block.

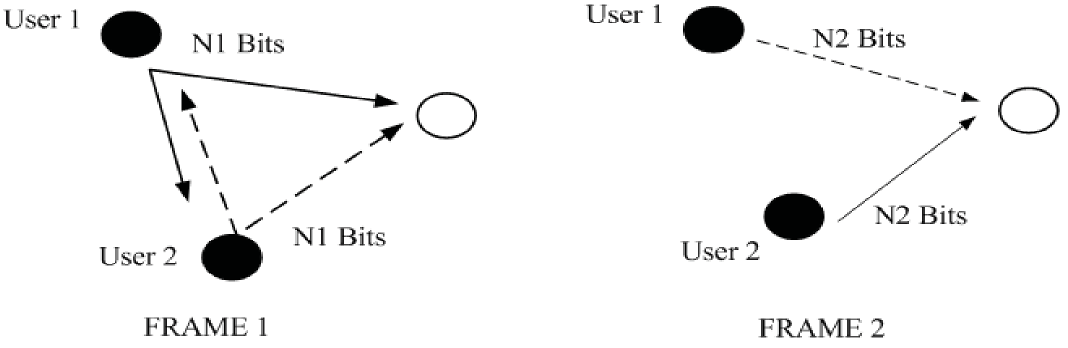


Figure 4.2: Cooperative Transmission Scheme

The two users cooperate by dividing the transmission of their N-bit code words into two successive time segments, or frames. In the first frame, each user transmits a rate $R1 > R$ code word with N1 = K/R1 bits. Each user also receives and decodes the partner's transmission. If the user successfully decodes the partner's rate R1 code word, determined by checking the CRC bits, the user computes and transmits N2 additional parity bits for the partner's data in the second frame, where N1 + N2 = N. These additional parity bits are selected such that they can be combined with the first frame code word to produce a more powerful rate R code word. If the user does not successfully decode the partner, N2 additional parity bits for the user's own data are transmitted. Each user always transmits a total of N bits per source block over the two frames, and the users only transmit in their own multiple access channels. Figure.4.2 illustrates the general coded cooperation framework.

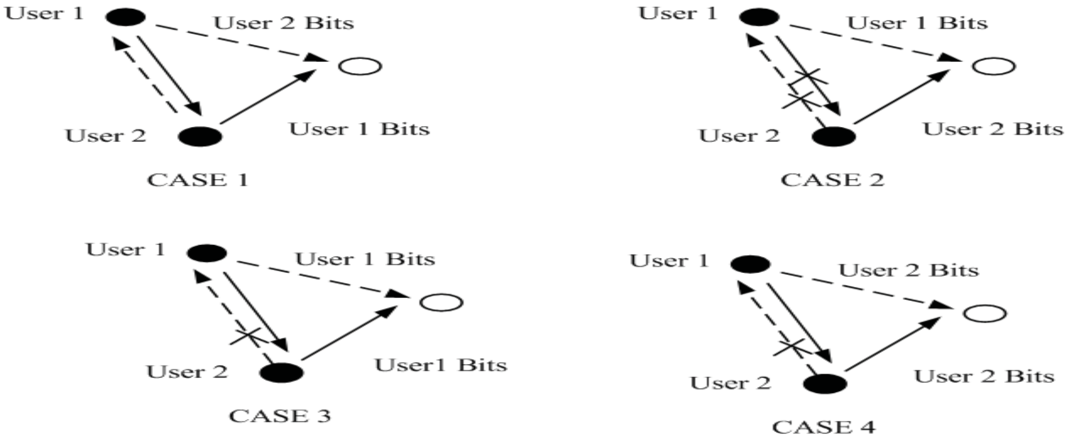


Figure 4.3: Four cooperative cases for second frame transmission based on the first frame decoding results

The users act independently in the second frame, with no knowledge of whether their own first frame was correctly decoded. As a result, there are four possible cooperative cases for the transmission of the second frame, illustrated in Figure.4.3 In Case 1, both users successfully decode each other, so that they each transmit for their partner in the second frame, resulting in the fully cooperative scenario depicted in Figure. 4.2. In Case 2, neither user successfully decodes their partner's first frame, and the system reverts to the non-cooperative case for that pair of source blocks. In Case 3, User 2 successfully decodes User 1, but User 1 does not successfully decode User 2. Consequently, neither user transmits the second set of code bits for User 2 in the second frame, but instead both transmit the second set for User 1. These two independent copies of User 1's bits are optimally combined at the destination prior to decoding. Case 4 is identical to Case 3 with the roles of User 1 and User 2 reversed. Clearly the destination must know which of these four cases has occurred in order to correctly decode the received bits. In general, various channel coding methods can be used within this coded cooperation framework. For example, the overall code may be a block or convolutional code, or a combination of both. Thus, it can be summarized from the above discussion that cooperative communication with channel coding has better BER performance i.e., 10^{-2} then the one without channel coding i.e., 10^{-1}.In this section cooperative communication with various codes like convolutional code, Punctured Convolutional code, Alamouti code and Turbo code.

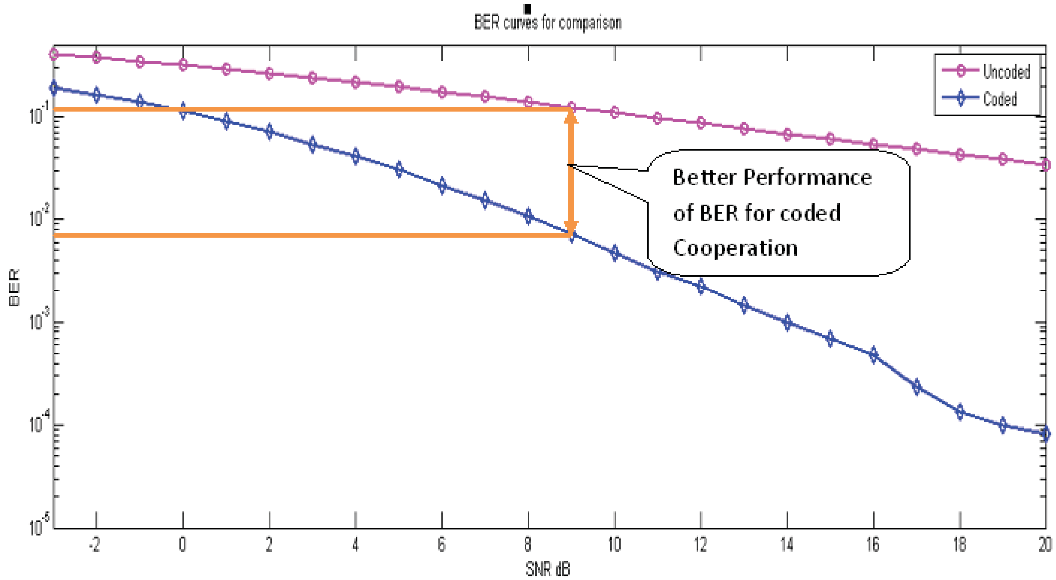


Figure 4.4: Comparisons between cooperative communication with channel coding and without channel coding

4.1 Convolutional coding

4.1.1 Introduction

In this section cooperative communication with convolutional code is studied and design. In cooperative communication, the cooperative code has to simultaneously carry information for the destination and the partner. Therefore, part of the code used to transfer information to the partner has to be a good code for the interuser channel.

Convolutional codes have been used due to many reasons; it is widely used in applications such as space and satellite communication, cellular mobile, digital video broadcasting etc. Their popularity stems from simple structure and availability of easily implementable maximum likelihood soft decision decoding methods. In convolutional code even the extension to higher order modulations are also possible. Using Convolutional code with cooperative communication provides full diversity and excellent coding gain.

4.1.2 Convolutional Encoding

Convolutional codes operate on serial data, one or a few bits at a time. Data sequence is divided into k bits message. Each message is encoded into n bits codeword. The codeword depends not only on the corresponding k-bits message but also on previous m messages. Hence the encoder has memory of order m.[3]

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.

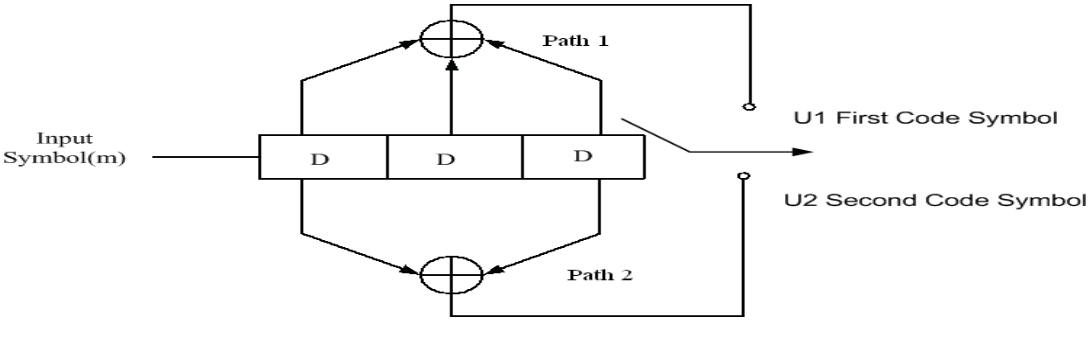


Figure 4.5: Convolutional encoder with R = 1/2 and K = 3

In convolutional encoder the information bits are input into shift registers and the output encoded bits are obtained by modulo-2 addition of the input information bits and the contents of the shift registers. The code rate r for a convolutional code is defined as r = k/n, where k is the number of parallel input information bits and n is the number of parallel output encoded bits at one time interval. The constraint length K for a convolutional code is defined as

$$k = m + 1$$

where m is the maximum number of stages (memory size) in any shift register. The shift registers store the state information of the convolutional encoder and the constraint length relates the number of bits upon which the output depends. For the convolutional encoder shown in Figure.4.5, the code rate R = 1/2, the memory size m = 2,and the constraint length K = 3, Where D represents delay.

4.1.3 Cooperative communication with Convolutional coding

In these scheme, each codeword of the source node is partitioned into two frames that are transmitted in two phases. In the first phase, the first frame is broadcast from the source to the relays and destination. In the second phase, the second frame is transmitted on orthogonal subchannels from the source and relay nodes to the destination. Each relay is assumed to be equipped with a cyclic redundancy check (CRC) code for error detection. Only these relays (whose CRCs check) transmit in the second phase. Otherwise, they keep silent. At the destination, the received replicas (of the second frame) are combined using maximal ratio combining. The entire codeword, which comprises the two frames, is decoded via viterbi algorithm.

For cooperative channel coding, finite block lengths N has been considered for cooperative. The Coded cooperative scheme is considered as shown in the Figure.4.7. Assume slow or quasi-static fading that is each link has a constant fading level for N symbols. Use of the cyclic redundancy check (CRC) is commonly used for error detection in wireless communication systems. Excluding the CRC, in a non-cooperative

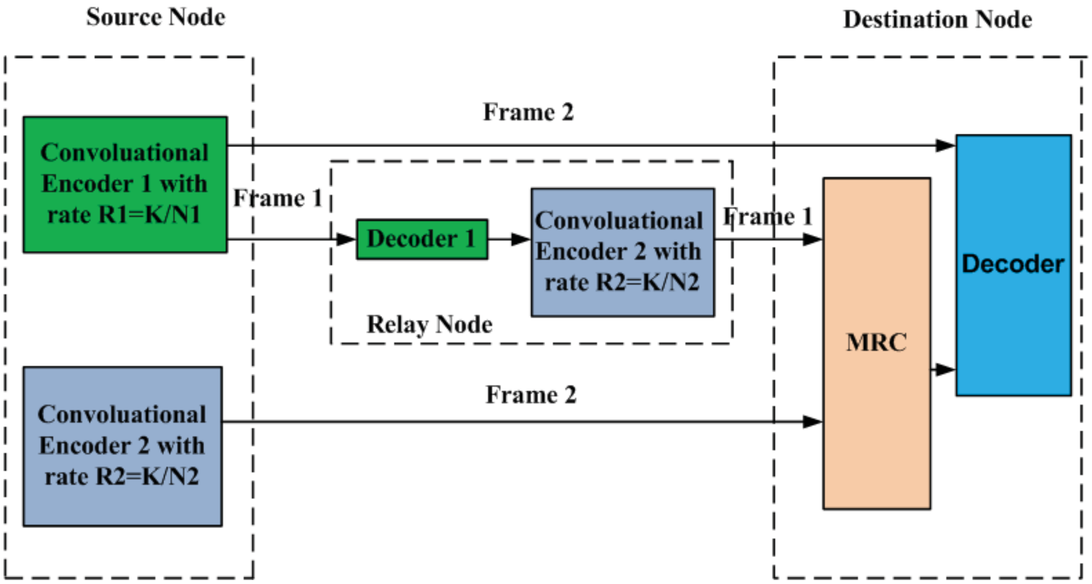


Figure 4.6: Block Diagram of cooperative communication with convolutional coding

system each terminal sends N coded bits per frame. In order to cooperate, S multiplexes these N bits properly and only sends half of its coded bits. If the original channel code had rate R, this corresponds to an effective coding rate of 2R. These bits are received by both the destination and the partner. The partner decodes these N1 bits and detects whether there are any errors using the CRC. If the partner has the correct information, it re-encodes and sends the additional N2 coded bits s did not transmit. This is illustrated in Figure 4.8 for a convolutional code of rate k/n.[13] Otherwise, s is informed and it continues its transmission of the remaining N2 coded bits. The destination waits until the end of the frame and combines both observations to decode the information bit stream. Assuming the destination estimates the current fading level every N1 bits, there is no need to notify it as to whether the partner received the information correctly or not.

4.1.4 Simulation Results

In this section, the performance of the cooperative coding scheme is presented via simulations to illustrate the potential benefits. Here, a Rayleigh slow fading channel is

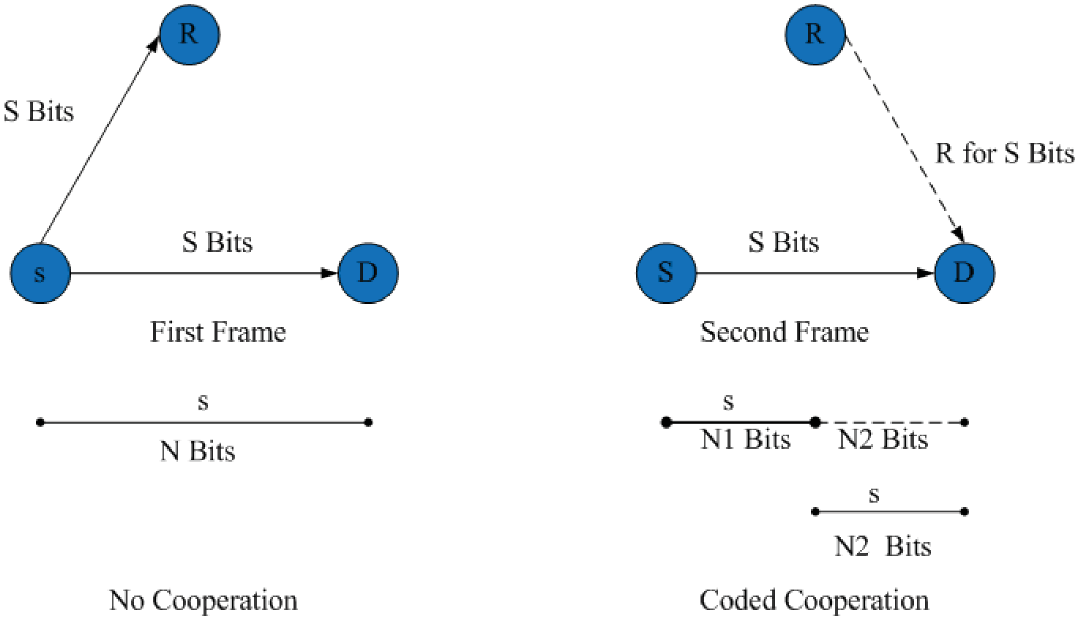


Figure 4.7: (a) No Cooperation and (b) Coded Cooperation

assumed. Hence, a quasi-static model, where the fading coefficients remain the same for the duration of the entire frame for each user is taken into consideration. However, the users observe independently faded channels. As an illustrative example,a convolutional code with constraint length K = 3, generator polynomials (7,5) and BPSK modulation is considered. This is an appealing solution due to the widespread use of convolutional codes and the simple maximum likelihood decoding algorithm. The extensions to higher order modulations are also possible. The performance of (7, 5) convolutional code, for the rate of k =1/2, is shown in terms of Bit Error Rate (BER) versus Signal to Noise Ratio. The bit error rates of non-cooperative, Amplify and forward and decode and forward are compared. Results are summarized in Figure.4.9

4.2 Punctured Convolutional Coding

Puncturing is accomplished by periodically removing bits from one or more of the encoder output streams. This has the effect of increasing the rate of the code[3]. For

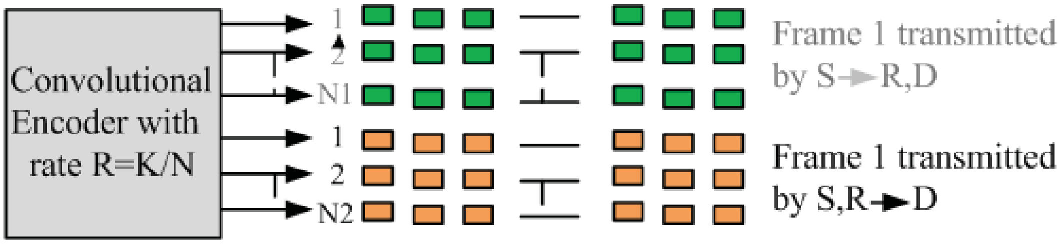


Figure 4.8: An example of the bit mapping for cooperation for a rate k/n convolutional code

this scheme, rate R=1/2 code, the coded output sequence can be

$$c = (c_0^{(1)}, c_0^{(2)}, c_1^{(1)}, c_1^{(2)}, c_2^{(1)}, c_2^{(2)}, c_3^{(1)}, c_3^{(2)}.......)$$

When the code is punctured by removing every fourth coded symbol, the punctured sequence is

$$c' = (c_0^{(1)}, c_0^{(2)}, c_1^{(1)}, -, c_2^{(1)}, c_2^{(2)}, c_3^{(1)}, -, ...)$$

The – symbols merely indicate where the puncturing takes place; they are not transmitted. The punctured sequence thus produces three coded symbols for every two input symbols, resulting in a rate R = 2/3 code.

Decoding of a punctured code can be accomplished using the same trellis as the unpunctured code, but simply not accumulating any branch metric for the punctured symbols. One way this can be accomplished is by inserting symbols into received symbol stream whose branch metric computation would be 0, then using conventional decoding.

The pattern of puncturing is often described by means of a puncturing matrix P. For a rate k/n code, the puncture matrix has n rows. The number of columns is the number of symbols over which the puncture pattern repeats. For example, for the puncturing of above the example,

$$\begin{pmatrix} 1 & 1 \\ 1 & 0 \end{pmatrix}$$

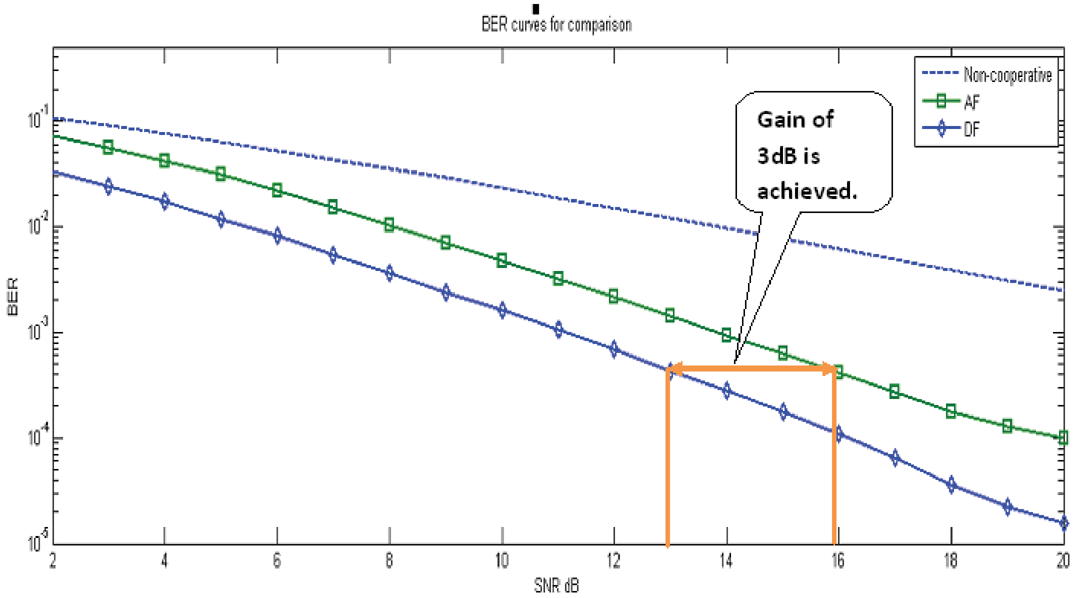


Figure 4.9: Comparisons of non-cooperative, AF and DF with convolutional code (7,5), for rate = 1/2 and constraint length k =3

4.2.1 Cooperative Communication using Punctured Convolutional Coding

In this section, Amplify and forward using Punctured convolutional coding has been described. In many communication systems, convolutional codes are used with finite length input sequences. The conventional termination method is to encode an information sequence followed by additional tail bits. To minimize the overhead of the tail bits, it is efficient to increase the length of input sequence. In many practical applications, the desired code rate is achieved by puncturing some coded symbols of convolutional codes. With the conventional punctured convolutional codes, some coded symbols are periodically punctured to generate higher rate codes.

A source and one relay cooperate in time-division manner to transmit a message to a destination. The source encodes the message and transmits it in the first time slot. In the second time slot, either the source or relay retransmits the message to the destination. When the relay transmits, it either fully decodes and re-encodes

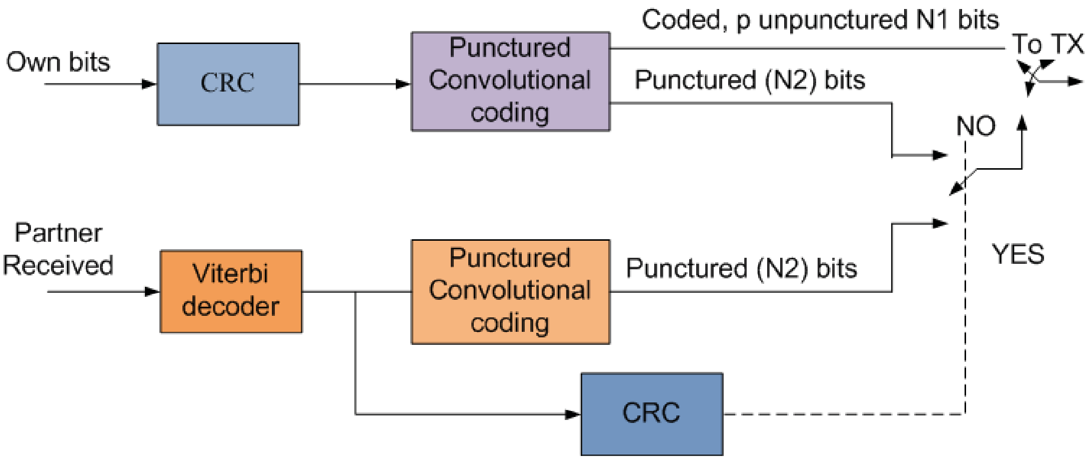


Figure 4.10: Cooperative communication using Punctured convolutional coding

the message, or it amplifies and forwards its received signal. Here, source encodes punctured code, by encoding with the lower rate code then puncturing. The two users transmit a code word punctured to rate 1/2 in the first frame. In the second frame, the relay transmits the bits punctured from the first frame such that the total bits received for each user form a rate 2/3 code word.

The channel propagation model includes path loss with distance and Rayleigh fading that is constant during the two-slot transmission and independent from one transmission to the next. Furthermore, the fading is mutually independent among the three links in the system. The channel also includes additive white Gaussian noise with two-sided power spectral density N0/2. The sampled output of the demodulator of a receiver is thus modeled as

$$y_i = a_i s_i + n_i \tag{4.1}$$

where $a_i s_i$ is the attenuated signal contribution, ni is the noise contribution, all terms are complex representing in-phase and quadrature components, and the subscript $i \epsilon \{0, 1, 2\}$ denotes the source-destination, source-relay, and relay-destination links, respectively.

4.2.2 Simulation Results

The Error Rate Performance for both amplify and forward with convoltuional code and amplify and forward with punctured convolutional code are shown. It can be shown from Figure.4.11 that there is considerable gain of 3dB in SNR is achieved at high value of SNR. In comparing the three cooperative transmission schemes, it is observed that both amplify-and-forward and decode-and-forward are not very effective at low SNR. This is due to the fact that their signaling is equivalent to repetition coding, which is relatively inefficient at low SNR. Coded cooperation using punctured convolutional code, however, has graceful degradation and performs better than or as well as a comparative noncooperative system at all SNRs. In addition, coded cooperation using punctured convolutional code generally performs better than other cooperative methods for moderate to high SNR.

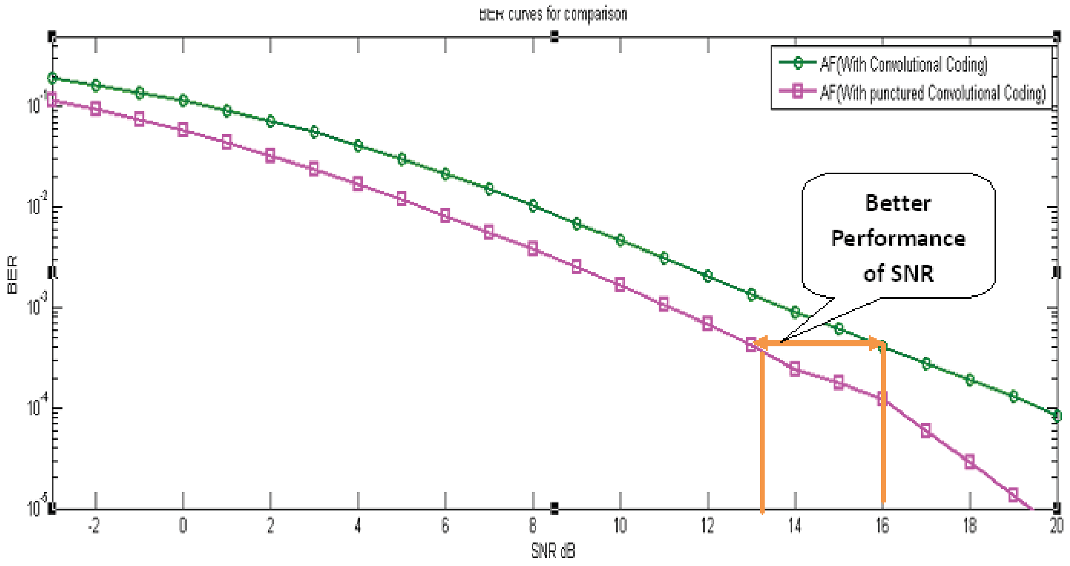


Figure 4.11: comparisons of Amplify and forward with convolutional coding and punctured convolutional coding

4.3 Alamouti Scheme

It is a simple method for achieving spatial diversity with two transmits antennas. The scheme is as follows. Consider a transmission sequence, for example x1, x2, x3.......xn. In normal transmission, x1 will be send in the first time slot, x2 in the second time slot, x3 and so on. However, Alamouti suggested that we group the symbols into groups of two. In the first time slot, send x1 and x2 from the first and second antenna. In second time slot send -x2* and x1* from the first and second antenna. In the third time slot send x3 and x4 from the first and second antenna.In fourth time slot, send -x4* and x3*from the first and second antenna and soon.

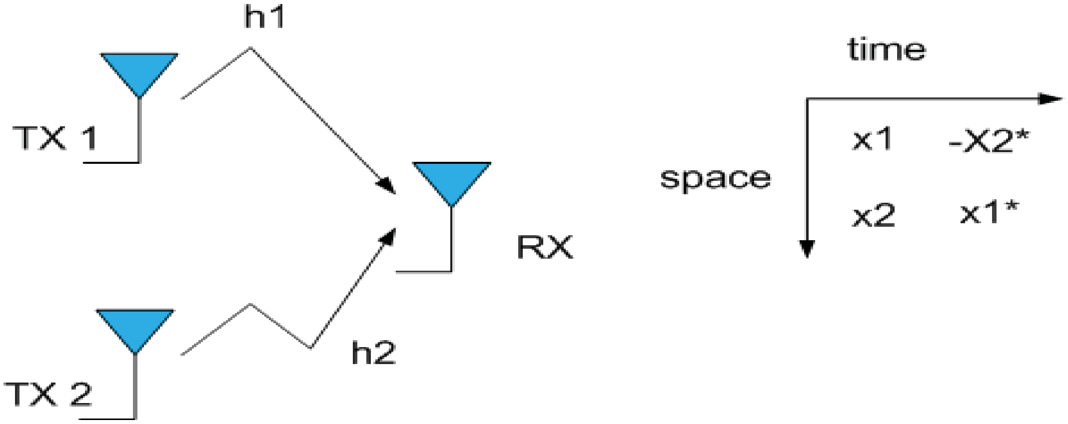


Figure 4.12: 2-Transmit, 1-Receive Alamouti STBC coding

This is a very special STBC because it is the only code with rate 1. That is to say that it is the only STBC that can achieve its full diversity gain without needing to sacrifice its data rate[14]. Strictly, this is only true for complex modulation symbols. Since almost all constellation diagrams rely on complex numbers however, this property usually gives Alamouti's code a significant advantage over the higher-order STBCs even though they achieve a better error-rate performance.

4.3.1 Cooperative Communication with Alamouti Code

In this scheme, an amplify-and-forward (AF) protocol and a decode-and-forward (DF) protocol based on the Alamouti space-time (ST) code is shown, it is chosen because of its decoding simplicity. An AF and DF protocol improve their performance and solves the problem of bad performance at low SNR[15].

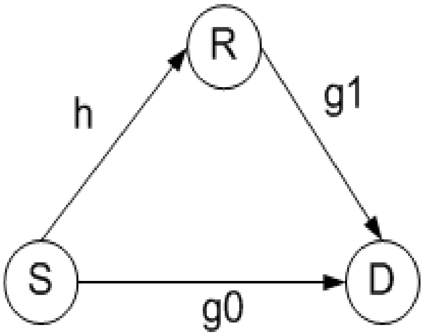


Figure 4.13: Channel model: one source, one relay and one destination

Here, to perform cooperative communication with alamouti code, considering a wireless network with one relay, one source and one destination. The channel is half-duplex, which means that terminals cannot receive and transmit at the same time. The channel coefficients of the link between source and destination, source and relay and relay and destination are g0, h and g1 respectively.

In this scheme, during the first phase, the source sends the first line of the Alamouti code matrix: x1 and x2, while the relay listens. In the second phase, the relay sends an amplified version of the received signal in the AF case, where the optimal amplifying factor, $\beta = 1/(\sqrt{1} + SNR|h|^2)$ or a decoded version of it in the DF case, while the source sends the second line of the Alamouti codematrix: -x2* and x1*.Any DF protocol supposes that signals are correctly decoded at the relay during the first phase of the transmission. This is usually done by considering a selection between the DF and the SISO schemes with the outage event of the source-relay link as a criterion. Indeed, according to Shannon's theorem, if the link is in outage, no detection without error is possible: DF strategy is not efficient. In the other case, detection is possible and we use cooperation, assuming that signals have been correctly decoded. Outage probability[15] is

$$P_0(R) = Plog(1 + SNR|h|^2) < 2R \tag{4.2}$$

Where R is the global spectral efficiency and 2R is the one of the source-relay link.

The Decoding for Alamouti AF can be performed as shown below:

Here Received signals at relay are:

$$y_{r1} = \sqrt{SNR} h_{x1} + v_1 \tag{4.3}$$

and

$$y_{r2} = \sqrt{SNR} h_{x2} + v_2 \tag{4.4}$$

And received signals at destination

$$y_1 = \sqrt{SNR} g_0 x_1 + w_1 \tag{4.5}$$

$$y2 = \sqrt{SNR} g_0 x_2 + w_2 \tag{4.6}$$

$$y3 = \frac{\sqrt{SNR}}{2}(g_0 x_2^* + g_1 \beta y_{r1}) + w_3 \tag{4.7}$$

$$y4 = \frac{\sqrt{SNR}}{2}(g_0 x_1^* + g_1 \beta y_{r2}) + w_4 \tag{4.8}$$

The system of equation can then be rewritten in the form $Y = \sqrt{SNR} HX + W$ with the equivalent channel matrix H being orthogonal and the linear decoding can be performed.

Decoding for Alamouti DF is as shown below:

In the first phase, received signals at destination are the same, and in the second phase

$$y_3 = \frac{\sqrt{SNR}}{2}(-g_0 x_2^* + g1\widetilde{x_1}) + w_3 \tag{4.9}$$

$$y_4 = \frac{\sqrt{SNR}}{2}(g_0 x_1^* + g_1 \widetilde{x_2}) + w_3 \tag{4.10}$$

Where $\widetilde{x1}$ and $\widetilde{x2}$ are the signals decoded at relay in the considered constellation.

Outage Probability:

Outage probability is defined as

$$P_{out}(R) = P\{C(H) < R\} \tag{4.11}$$

Where R is the spectral efficiency.

1) Alamouti AF case:

Instantaneous capacity can be calculated from the expression of H

$C_{ALAF}(H) = \frac{1}{4}log(det(I + SNRHH^H))$

$$= \frac{1}{2}log(1 + SNR(|g_0|^2 + \frac{|g_0|^2 + SNR|g_1|^2\beta^2|h|^2}{n^2})) \tag{4.12}$$

And then the outage probability is

$$P_{outALAF}(R) = P\{C_{ALAF}(H) < R\} \tag{4.13}$$

2) Alamouti DF case:

Let's assume the source-relay link is not in outage,then

$C_{ALDF}(H) = \frac{1}{4}log(det(I + SNRHH^H))$

$$= \frac{1}{2}(1 + SNR(|g_0|^2 + \frac{|g_0|^2 + |g_1|^2}{2}) \tag{4.14}$$

And $\widetilde{P_{outALDF}}(R) = P\{C_{ALDF(H)} < R\}$.

If the source-relay link is in outage, we use the noncooperative scheme.

$$P_{outSISO}(R) = Plog(1 + SNR|g_0|^2) < R \tag{4.15}$$

Finally,it can be written as

$$P_{outALDF}(R) = P_{out\widetilde{ALDFO}}(R)\widetilde{PO(R)} + P_{outSISO}(R)PO(R) \tag{4.16}$$

4.3.2 Simulation Results

Figure.4.14 and Figure.4.15 shows the capacity and outage probabilities of the SISO, Alamouti AF and DF protocols as functions of the SNR. The spectral efficiency is 2 bits pcu. At low spectral efficiency, the Alamouti AF and DF perform shows better performance than SISO. Moreover, the Alamouti DF has slightly better performance than the Alamouti AF for low SNR.

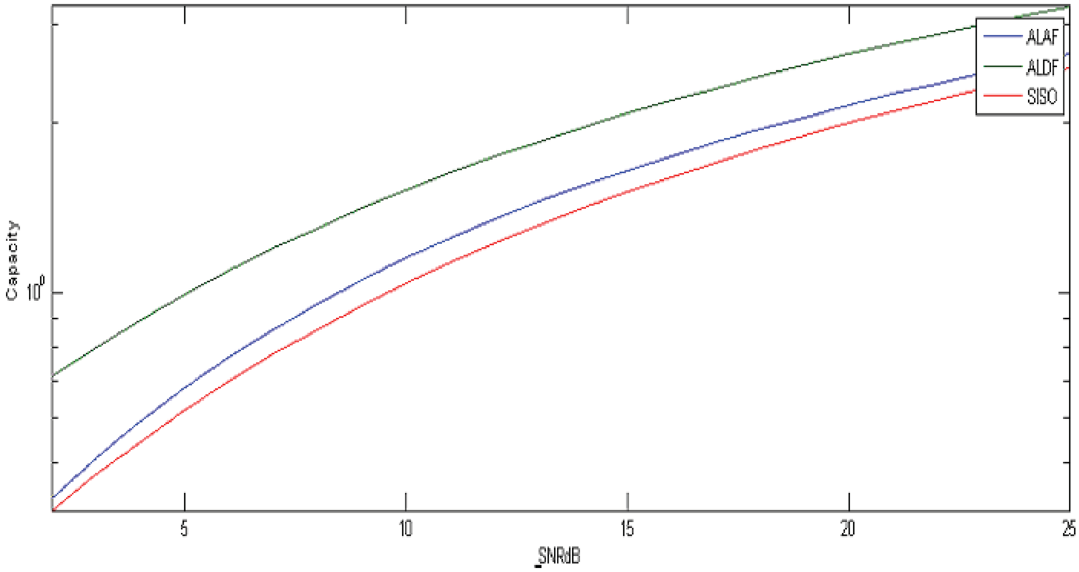


Figure 4.14: Comparison of the capacity of the SISO, AF and DF protocols

Thus the simulations shows that AF and DF protocols improves their performs and solves the problem of bad performance at low SNR.

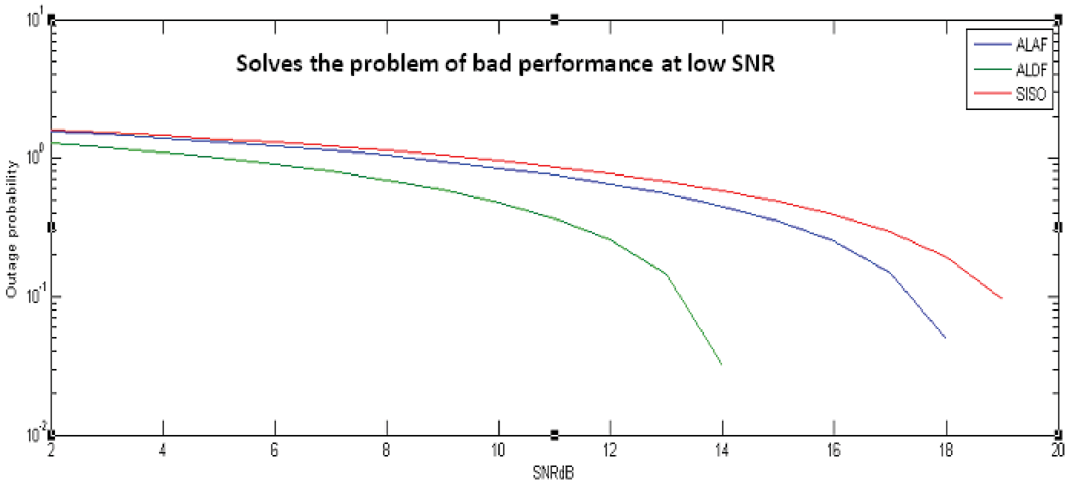


Figure 4.15: Comparison of the outage probabilities of the SISO, Alamouti AF and DF protocols for 2 bits spectral efficiency

4.4 Turbo Codes

Turbo codes were presented in 1993, by C. Berrou and since then these codes have received a lot of interest from the research community as they offer better performance than any of the other codes at very low signal to noise ratio. Turbo codes achieve near Shannon limit error correction performance with relatively simple component codes.

Applications of Turbo codes:

- WLAN (Wireless LAN)
- Image Processing
- Digital Video Broadcasting
- Microwave link communication to combat fading
- Satellite communication for FEC.

Turbo coding is a forward error correction (FEC) scheme. Iterative decoding is the key feature of turbo codes. Turbo codes consist of concatenation of two convolution codes. Turbo codes give better performance at low SNRs.

4.4.1 Turbo encoder

In the basic configuration of turbo encoder two convolutional encoders are used along with a interleaver. These two convolutional encoders can be connected in either parallel or serial configuration. The function of the interleaver is to spread bits in time domain. So, if there is a deep fade or noise burst in the channel then the important bits from the block of source data are not corrupted at the same time. Also the pairing of low-weight codeword from one encoder with low weight codeword from the other decoder can be avoided by proper design of interleaver.

Two configurations for the rate 1/3 turbo encoder are shown in Figure.4.16 and Figure.4.17

Parallel Configuration

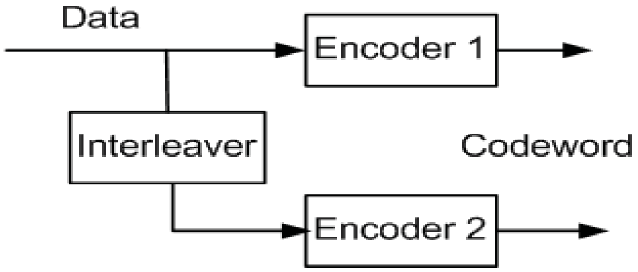


Figure 4.16: Parallel configuration of turbo encoder

Serial Configuration

Figure 4.17: serial configuration of turbo encoder

Basic Component Encoder

Generally, as a basic encoder RECURSIVE CONVOLUTIONAL ENCODER (RSC) is used. If the component encoder is not recursive, the unit weight input sequence (0 0 0...1 0 0..) will always generates a low weight codeword at the input of the second encoder for any interleaver design.In other words, interleaver would not influence the output codeword weight distribution if the component encoders were not recursive. However, it the component encoders are recursive, a weight -1 input sequence does not yield the minimum weight codeword out of encoder. The encoded output weight is kept finite only by trellis termination, a process that forces the coded sequence to terminate in such away that the encoder returns to zero state.

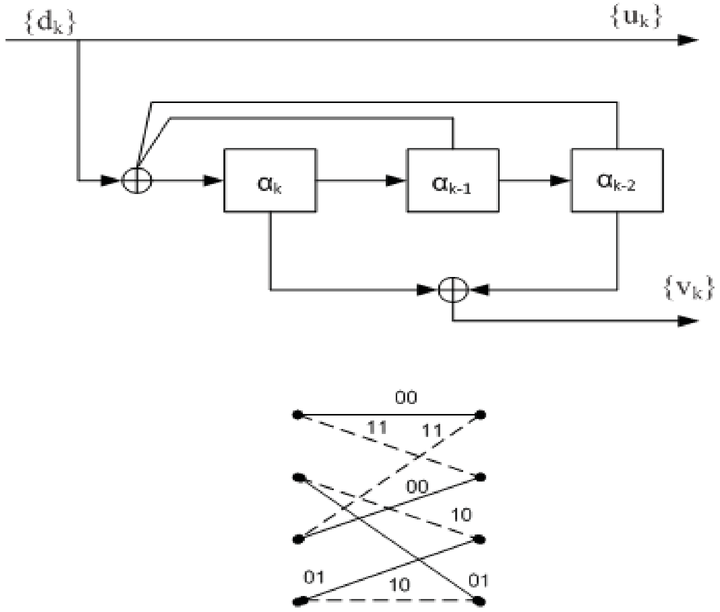


Figure 4.18: Four state RSC encoder and associated trellis structure

Using Figure.4.18, the parallel configuration for the turbo encoder is shown Figure.4.19. Good turbo codes have been constructed from component codes having short constraint lengths(k = 3 to 5), where the switch yielding v_k provides puncturing, making the overall code rate 1/2. Without the switch, the code would be rate

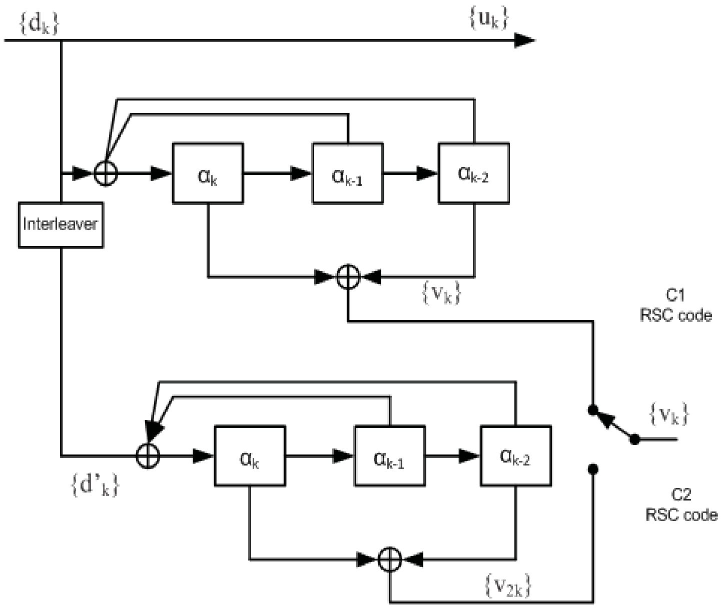
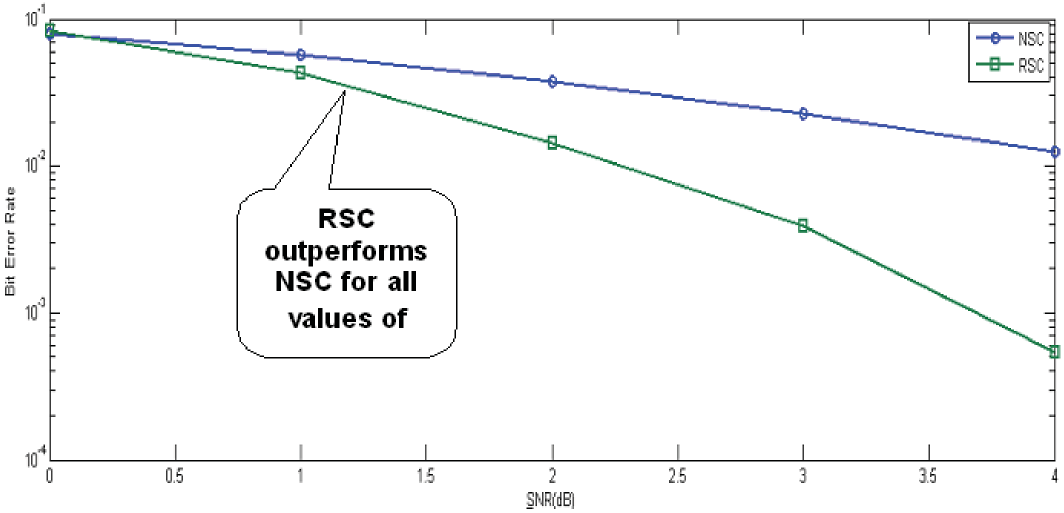


Figure 4.19: parallel configuration of turbo encoder using RSC encoder as a component

1/3. There is no limit to the number of encoders that may be concatenated, and in general the component codes need not be identical with regard to constraint length and rate.

The turbo encoder in Figure.4.19 produces codewords from each of two component encoders. The weight distribution for the codewords out of this parallel concatenation depends on how the codewords from one of the component encoders are combined with codewords from the other encoder. Intuitively,should avoid pairing low-weight codewords from one encoder with low-weight codewords from the other encoder. Many such pairings can be avoided by proper design of the interleaver. An interleaver that permutes the data in a random fashion provides better performance than the familiar block interleaver.[20]

The simulation in the Figure.4.20,shows the comparisons of RSC and NSC Encoder. As indicated the recursive systematic code (RSC) outperforms the nonsystematic convolutional code(NSC) for all values of SNR. This is because of the IIR



RSC outperforms NSC for all values of

Figure 4.20: Performance comparisons of RSC and NSC Encoder

(Infinite Impulse Response) property of the RSC codes in which the previously encoded information bits are continually fed back to the encoder.

4.4.2 Turbo Decoder

In a typical communication receiver, a demodulator is often designed to produce soft decisions which are then transferred to a decoder. With Turbo codes, where two or more component codes are used and decoding involves feeding outputs from one decoder to the input of other decoders in an iterative fashion Soft Input Soft Output(SISO) decoder is used.

As shown in Figure.4.21, the output LLR of a systematic decoder can be represented as having three LLR elements-

1. Channel measurement $L_c(x)$.

2. Priori knowledge of the data L(d).

3. Extrinsic LLR stemming solely from the decoder $L_e(\hat{d})$.

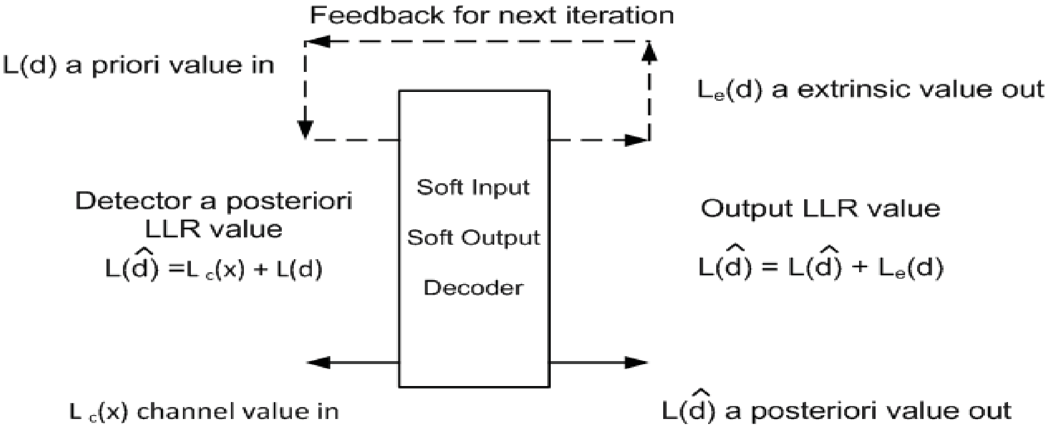


Figure 4.21: Soft Input Soft Output decoder (for systematic)

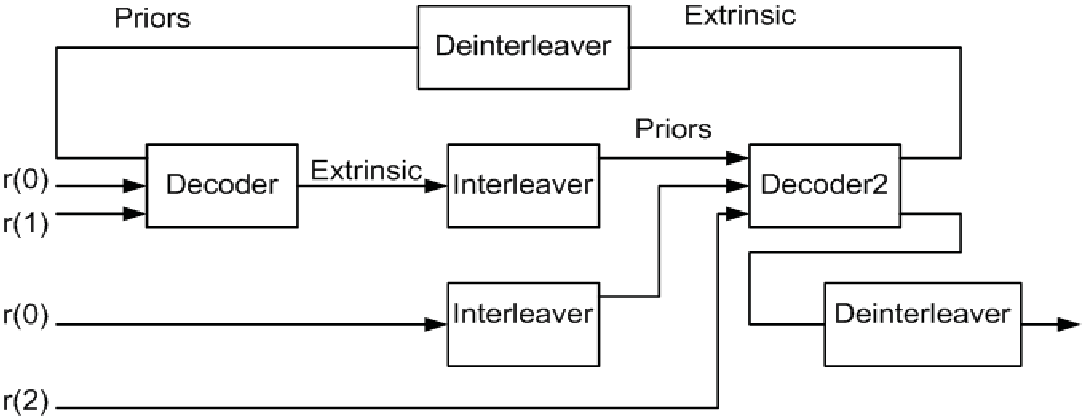


Figure 4.22: Block Diagram of Turbo decoder

The block diagram of the turbo decoder is shown in Figure.4.22. The received systematic bit and parity bit (r(0),r(1)) associated with the first encoder are fed to decoder1. This decoder initially uses uniform priors on the transmitted bits and produces probabilities are called the extrinsic probabilities of the bits conditioned on the observed data. The output probabilities of decoder1 are interleaved and passed to decoder2, where they are used as "prior" probabilities in the decoder,along with the data associated with the second encoder, which are received systematic bit r(0) and parity bit r(2). The extrinsic output probabilities of decoder2 are deinterleaved and passed back to become prior probabilities to decoder1. The process of passing probability information back and forth continues until the decoder determines that the process has converged, or until some maximum number of iterations is reached.

The heart of the decoding algorithm is a soft decision algorithm which provides estimates of posterior of each input bit. The algorithm most commonly used for the soft-decision decoding algorithm is the MAP algorithm, also commonly known as BCJR algorithm.

4.4.3 MAP Algorithm

In this section the iterative decoding process of the turbo decoder is described. The maximum a posteriori algorithm (MAP) is used in the turbo decoder.Another two variants of Map algorithm are Max-Log-MAP and Log-MAP. The MAP algorithm is a forward-backward recursion algorithm, which minimizes the probability of bit error, has a high computational complexity and numerical instability. The solution to these problems is to operate in the log-domain. One advantage of operating in log-domain is that multiplication becomes addition. Addition, however is not straight forward.Addition is a maximization function plus a correction term in the log domain. The max-Log-MAP algorithm approximates addition solely as a maximization.

Decoder Trellis diagram for three input bits concerned with four state encoder is shown in Figure.4.22.The important parameters associated with trellis diagram are:

1. Branch Metric δ
2. Forward Metric α
3. Reverse state Metric β
4. Log Likelihood(LLR)
5. Extrinsic information $L_e(\hat{d})$

1. Branch metric

In turbo decoding algorithm[21], the first computational block is branch metric computation. The branch metric is computed based on the knowledge of input and output associated with the branch during the transition from one state to another state. The computation of branch metric is as follows:

$$\delta_k^{i,m} = A_k \Pi_k^i [\frac{1}{\sigma^2}(x_k u_k^i + y_k v_k^{i,m}] \tag{4.17}$$

For this, if the data bits are assumed equally likely for all time and for simplicity assume $A_k = 1$ for all time and that $\sigma^2 = 1$. Thus,$\delta_k^{i,m}$ becomes

$$\delta_k^{i,m} = 0.5exp[x_k u_k^i + y_k v_k^{i,m}] \tag{4.18}$$

where, k =Time instant

x_k =Received information bit

y_k= Received parity-bit from encoder1

u_k^i = Information bit from trellis structure

$v_k^{i,m}$ = Parity bit from trellis structure

2. Forward State Metric

The forward state metric α is the next computation in the algorithm, which represents the probability of a state at time k, given probabilities of states at previous time instances, it also represents the probability of the past sequence that is only dependent on the current state induced by this sequence.

Forward state metric α is calculated using:

$$\alpha_k^m = \sum \alpha_{k-1}^{b(j,m)} \delta_{k-1}^{j,b(j,m)} \tag{4.19}$$

Equation4.19 indicates that a new forward state metric at time k and state m is obtained by summing two weighted state metrics from time k-1. The weighting consists if the branch metrics associated with the transitions corresponding to data bits 0 and 1.

3. Reverse State Metric

The reverse state metric being in each state of the trellis at each time k, given the knowledge of all future received symbols, is recursively calculated and stored. The reverse state metric β is computed in reverse direction, going from the end to the beginning of the trellis at time instance k-1,given the probabilities at time instance k.

$$\beta_k^m = \sum \delta_k^{j,m} \beta_{k+1}^{f(j,m)} \tag{4.20}$$

Equation4.20 indicates that a new reverse state metric at time k and state m is obtained by summing two weighted state metrics from time k+1. The weighting consists if the branch metrics associated with the transitions corresponding to data bits 0 and 1.

4. Log likelihood ratio(LLR)

Log likelihood ratio LLR is the output of the turbo decoder. This output LLR for each symbol at time k is calculated as:

$$L(\hat{d_k}) = \log \frac{\sum \lambda_k^{1,m}}{\sum \lambda_k^{0,m}} \tag{4.21}$$

Decoding Decision

Depending upon the sign of $L\hat{d_k}$ at instant k decoding decision is made.

$$\hat{d_k} = 1 if L(\hat{d_k}) > 0$$

$$\hat{d_k} = 0 if L(\hat{d_k}) < 0$$

5. Extrinsic Information $L_e(\hat{d})$

It is known that the LLR of decoding bit consists of three terms such as

$$L(\hat{d}) = L_c(x) + L(d) + L_e(\hat{d})$$

The extrinsic information can be obtained by subtracting the prior information L(d) and channel information $L_c(x)$ from the LLR of decoded bit $L_e(\hat{d})$ i.e.,

$$L_e(\hat{d}) = L(\hat{d}) - L_c(x) - L(d) \tag{4.22}$$

4.4.4 Max-Log-MAP Algorithm

Here, Max-Log-MAP Algorithm is introduced, which propagates approximations to logarithms α and β. This not only avoids some round off properties, but also has lower complexity than MAP algorithm at the cost of degraded performance. since, this is the variant of MAP algorithm all the required parameters to be calculated are same as that of MAP algorithm.

1. Branch metric

The computation of branch metric is as follows:

$$\tau_k^{i,m} = ln\delta_k^{i,m} = 0.5[x_k u_k^i + y_k v_k^{i,m}] \tag{4.23}$$

2. Forward State Metric

The computation of Forward State metric is as follows:

$$A_k^m = max(\alpha_k^m) = \ln \sum \alpha_{k-1}^{b(j,m)} \delta_{k-1}^{j,b(j,m)} = \ln \sum exp(A_{k-1}^{b(j,m)} + tau_{k-1}^{j,b(j,m)})$$

At this point, an approximation is made in the interest of developing a fast algorithm:

$$\ln(\sum exp(x_i)) \approx max(x_i)$$

Using this approximation, we can obtain

$$A_k^m \approx max(A_{k-1}^{b(j,m)} + \tau_{k-1}^{j,b(j,m)}) \tag{4.24}$$

3. Reverse State Metric

The computation of Reverse State metric is as follows:

$$B_k^m = ln\beta_k^m = ln\sum \delta_k^{j,m} \beta_{k+1}^{f(j,m)} = ln\sum exp(\tau_k^{j,m}) + B_{k+1}^{f(j,m)} \tag{4.25}$$

4. Log likelihood ratio(LLR)

$$L(d_k) = max\sum \lambda_k^{1,m} - \sum \lambda_k^{0,m} \tag{4.26}$$

Decoding Decision

Depending upon the sign of $L(d_k)$ at instant k decoding decision is made.

$$d_k = 1 if L(d_k) > 0$$

$$d_k = 0 if L(d_k) < 0$$

5. Extrinsic Information $L_e(\hat{d})$

$$L_e(\hat{d}) = L(\hat{d}) - L_c(x) - L(d) \tag{4.27}$$

The simulation in Figure.4.23, shows the comparisons between MAP and Max-Log-MAP Algorithm.Max-Log-MAP are relatively easy to implement compared to MAP algorithm. At the same time the error performance degrades. Using Max-Log-MAP reduces the decoding latency.

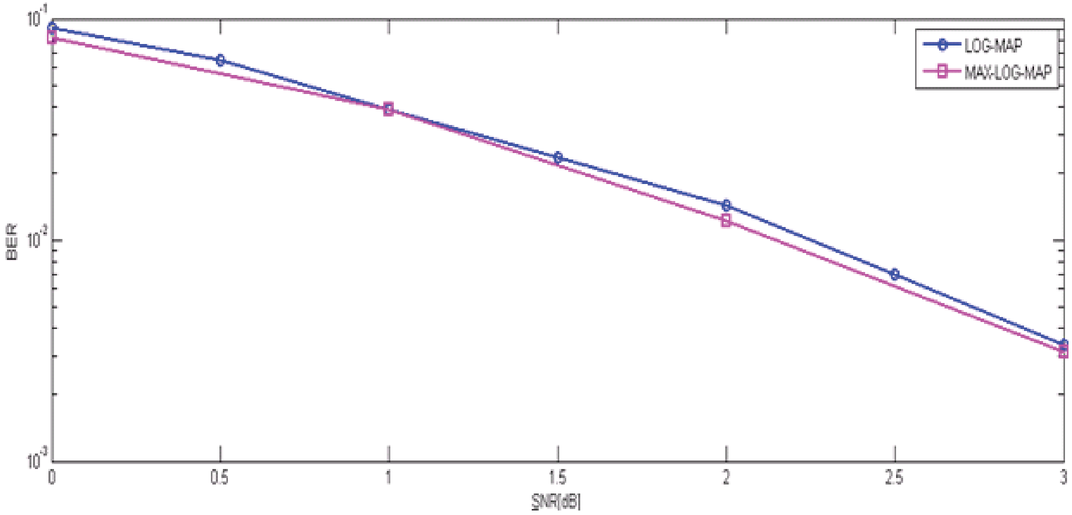
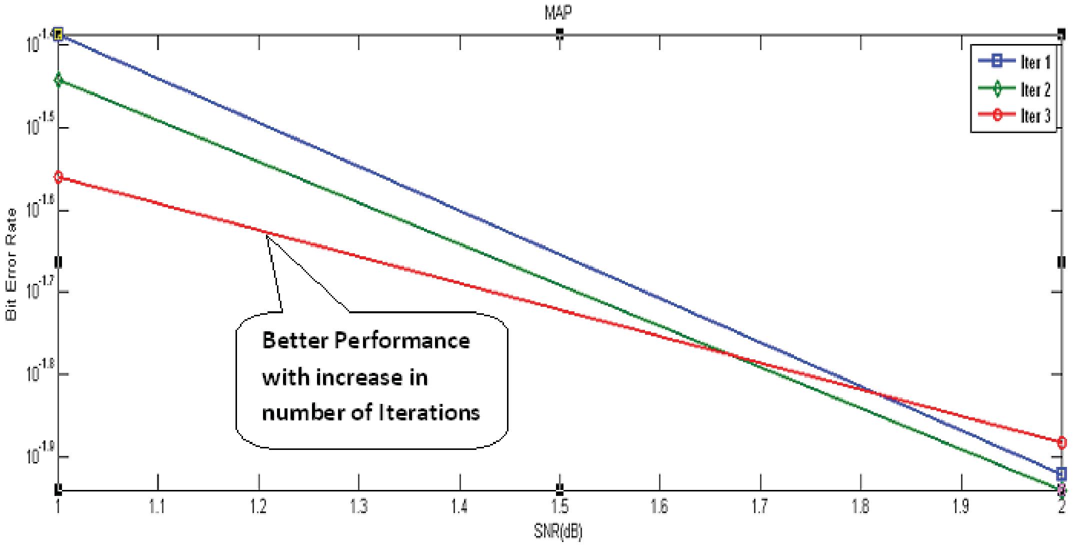


Figure 4.23: comparison of MAP and Max-Log-MAP algorithm

Effect of iterations on error performance

The error performance improves with the iterations. However, at large SNR the performance improvement is not very significant. This phenomenon is referred to as 'Error Floor'. This error floor is due to the presence of low weight codewords. A low weight codeword may exist if a single 1 appears at the end of the data stream or if both the component encoders result in low weight codewords or if puncturing is used, it may puncture out all the 1s.



Better Performance with increase in number of Iterations

Figure 4.24: Effect of iterations on error performance

4.4.5 Cooperative Diversity using Distributed Turbo Codes

Here, consider a single relay system,consisting of one source one relay and one destination. Figure.4.25 gives a block diagram of the two-hop relay system with a direct link from the source to the destination. A block diagram of a parallel concatenated DTC system is shown in Figure.4.26. The binary information sequence to be transmitted is first encoded by a channel encoder. Here a 4 state recursive systematic convolutional encoder shown in Figure.4.6 is considered[19].

The binary symbol stream is then mapped into a modulated signal stream. For this a binary phase-shift keying modulation is taken into consideration. This modulated symbols are transmitted over a channel subjected to AWGN. This noisy data is received by a relay, where it is first decoded then interleaved and futher encoded for retransmission. At the relay side it is assumed that the received data is perfectly decoded.

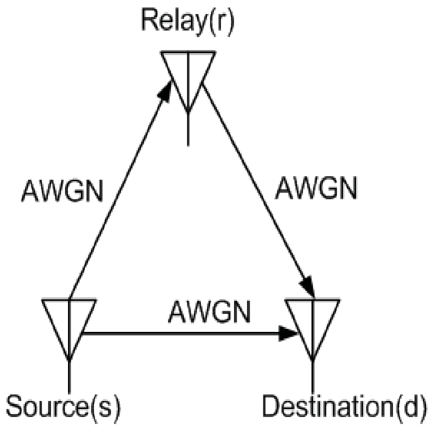


Figure 4.25: Cooperative diversity system using one relay

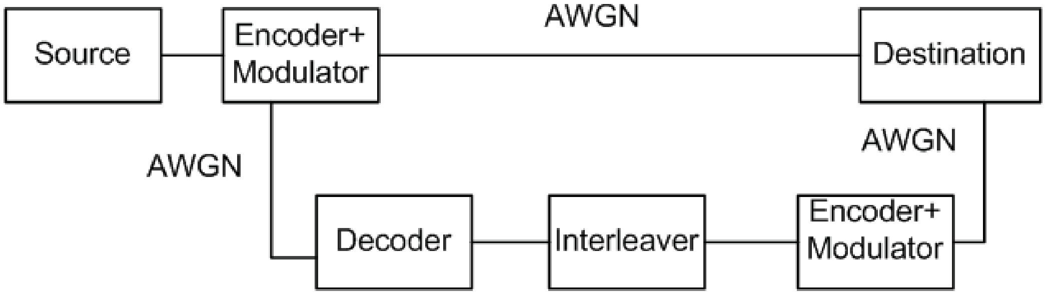


Figure 4.26: Block Diagram of a parallel concatenated DTC system

For this system model, considering DTC schemes as perfect DTC. This scenario can be realized by automatic repeat request protocol(ARQ) in the link from the source to the relay. However, the use of ARQ will reduce the system transmission throughput. Relay can retransmit the data in two ways. In a repetition-coded scheme, the relay sends a repetition of the coded packet sent by the source, while in a non-repetition scheme, the relay sends a distinct coded packet derived from the same message. The destination receives this as well, resynchronizes and demodulates, and jointly decodes the two received data streams. For reducing computational complexity, Max-Log-Map algorithm is used. In this simulation, model shown in Figure.4.27

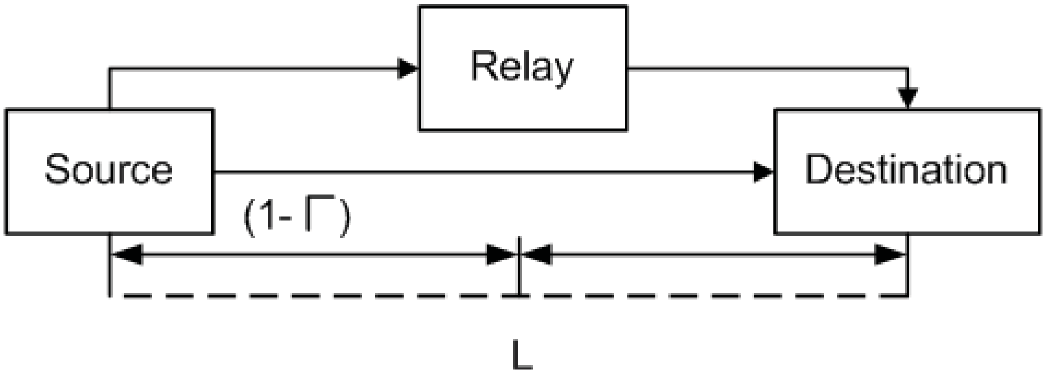


Figure 4.27: Simulation model

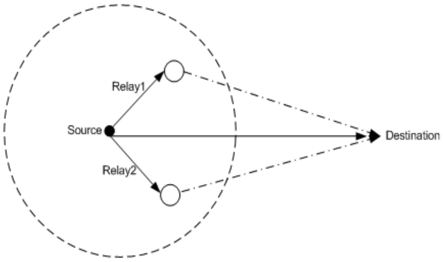


Figure 4.28: Multiple Relay Network

is used, where relay is considered to be on a direct path between source and destination. This assumption is not necessary as in actual system instead of single relay more number of relays can be used as shown in Figure.4.28. Once the source to destination SNR_{sd} is known the source to relay SNR_{sr} and relay to destination SNR_{rd} can be determined as:

$$SNR_{sr} = \frac{SNR_{sd}}{(1-\tau)^2} \tag{4.28}$$

$$SNR_{rd} = \frac{{SNR_{sd}}^2}{\tau} \tag{4.29}$$

Depending on these SNRs, Noise variances for source to relay and relay to destination used in Max-Log-Map decoder can be calculated as

$$\sigma_{sr}^2 = (1-\tau)^2\sigma_{sd}^2$$

$$\sigma_{rd}^2 = \tau^2\sigma_{rd}^2 \tag{4.30}$$

where, τ is expressed as a function of total distance between source and destination.

4.4.6 Simulation Results

When user cooperation diversity is employed, the performance is improved compared to non-cooperative case. A single relay has been employed in the simulation and the relay uses decode and forward approach. The destination uses data bits and parity bits received directly from the source and the parity bits received from the relay to decode the data.

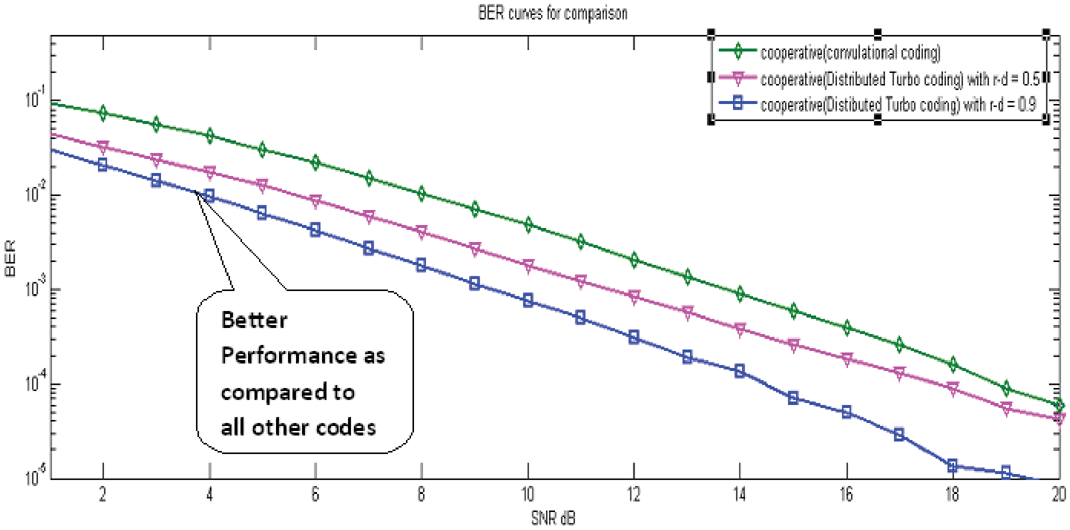


Figure 4.29: Performance of distributed turbo code (DTC) in cooperative and Non cooperative communication

4.5 Summary

From a channel coding point of view, repetition coding is not the most efficient use of the available bandwidth. Thus coded cooperation was developed. In this framework, cooperative signaling is integrated with channel coding. Coded cooperation does achieve full diversity. Secondly ,in this chapter, examples of convolutional code, punctured convolutional code and turbo code with cooperative communication are shown. It finally concludes that the cooperative communication gives the best performance than the other two. Thereafter, cooperative communication is also performed with Alamouti code and its outage probability is measured. The results shows that using Alamouti code solves the problem at low SNR.

Chapter 5

Analysis of Turbo code using EXIT chart

The Turbo-like decoding algorithm generally does not converge to a maximum-likelihood solution, although it is able to provide a good performance in practice. The convergence behavior can be analyzed through extrinsic information transfer charts, density evolution, and other related tools. In this thesis, mostly extrinsic information transfer charts is used as tool to analyze the convergence behavior.

Extrinsic information transfer charts, commonly referred to as EXIT charts, were developed by Stephan ten Brink in [22][25] to describe the flow of extrinsic information through constituent SISO decoders. The exchange of extrinsic information is visualized as a decoding trajectory in the EXIT chart. EXIT charts constitute a semi-analytical tool used to predict the SNR value, where an infinitesimally low Bit Error Ratio (BER) can be achieved without performing time-consuming bit-by-bit decoding employing a high number of decoding iterations.

In this chapter parallel-concatenated coding scheme[26] using iterative decoding for cooperative communication is proposed. First design a PCCC-ID scheme for the sake of achieving decoding convergence at low SNR, using EXIT charts. Then invoke this PCCC-ID scheme for cooperative communications, where the source employs a

PCCC-ID encoder and the relay encoding, interleaving and re-encoding which is then combined at destination using MRC.

5.1 System Model

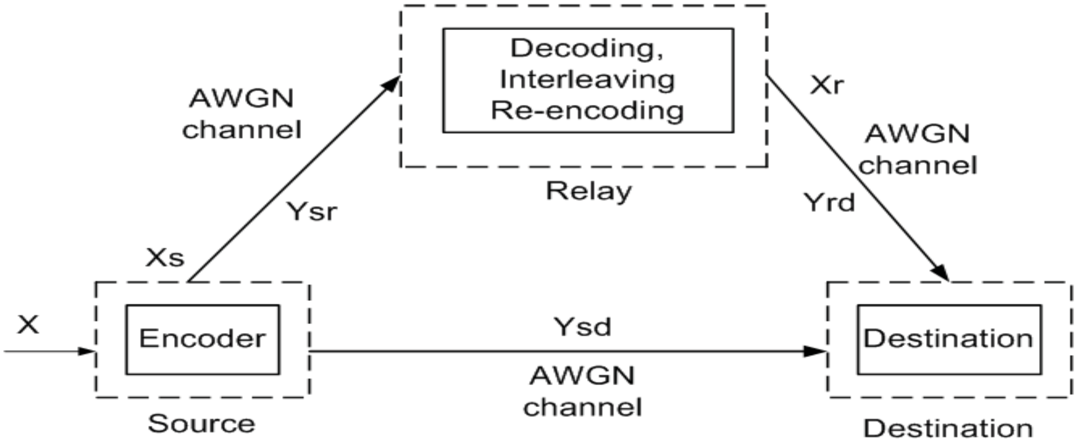


Figure 5.1: System model with turbo coding and iterative decoding

Here a single source-destination pair that has a single relay is considered. The units use a time-division duplexing access protocol and use time orthogonal transmission by either the source or relay terminal. No feedback is available in the system. Channel model is a standard AWGN model, with independent fading on all links. The relative proximity of the various terminals will change the mean SNR on the links. Normally, the relay terminal will be in fairly close proximity to the source, relative to the proximity of the destination, so that the source-relay link may be approximated as reliable link, whereas the source destination link is much less reliable. The transmission scheme depicted in Figure.5.1 which realizes a parallel concatenated coding scheme with component codes C_s and C_r at the source and the relay, respectively.

The transmission is carried out in two phases: in a broadcast phase, a channel-encoded version X_s of the bit vector X with elements $X_s \in \{-1, +1\}$ and $X \in \{0, 1\}$, respectively, is transmitted from the source node to the relay and the destination.

The relay decodes, interleaves, and re-encodes the received message considering the interleaver and the code C_r. During the second phase, the resulting symbol vector X_r is transmitted from the relay to the destination while the source keeps silent. An iterative decoder as shown in Figure.5.1 is employed by the receiver to decode the resulting code. It is based on the component decoders for the codes C_s and C_r. Throughout this thesis the communication channels are realized by additive white Gaussian noise channels parameterized either by the respective input-output mutual information I(X; Y) or equivalently by the signal-to-noise ratio expressed in terms of Eb/N0.

5.1.1 Introduction to EXIT Chart

With Wide application of turbo principle[23] originally invented for decoding concatenated codes, the EXIT charts has been a powerful tool to visualize the convergence behavior of iterative decoding process based on mutual information. The Extrinsic Information Transfer EXIT chart was first introduced by Stepan ten Brink in [25][26]. The EXIT chart was mainly introduced due to the problem that occurs with BER chart when iteratively decoding is that it gives bad performance at low SNR. The iterative decoder for PCC is shown in Figure.5.2 For each iteration the two decoder

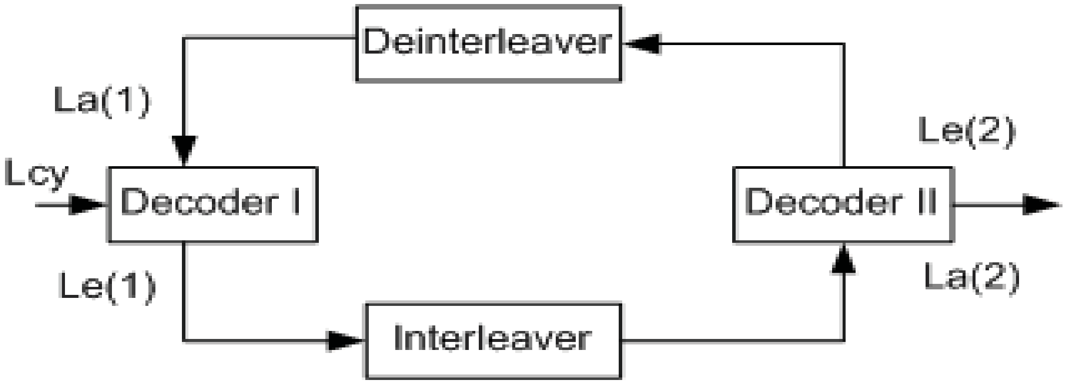


Figure 5.2: Iterative decoder for parallel concatenated codes

are soft-in/soft-out decoders that accept and deliver probabilities or soft values and extrinsic part of the soft-output of one decoder is passed on to other decoder to be used as a priori input. Thus it constitutes an iterative process with an information transfer between the two decoders which is analyzed using EXIT chart. For EXIT chart we require following parameters:

a. Mutual Information

b. Mutual information Transfer characteristics of iterative decoders

c. Combination of Transfer characteristics

For Mutual Information, Let X and Y be two real valued random variables. Then Shannon's mutual is defined as

$$I(X;Y) = \int\int f(x,y) log \frac{f(x,y)}{f(x).f(y)} dxdy \tag{5.1}$$

with

$$I(X;Y) = H(Y) - H(Y/X) \tag{5.2}$$

where

$$H(Y/X) = \int\int f(x,y) log \frac{1}{f(y/x)} dxdy \tag{5.3}$$

For an additive channel with Y = X + Z with statistically independent Z

$$H(Y/X) = H(Z) \tag{5.4}$$

With the transmit power $P_x = \sigma_x^2 = E_s.(1/T)$, the noise power $P_n = \sigma_n^2 = \sigma_z^2 = (N0/2).(1/T)$ and the receive power $P_y = \sigma_y^2 = \sigma_x^2 + \sigma_n^2 = P_y = P_x + P_n$ we have

$$I(X;Y) = H(Y) - H(Z) \tag{5.5}$$

$$I(X;Y) \leq \frac{1}{2} log(1 + \frac{p_x}{p_n}) \tag{5.6}$$

$$I(X;Y) \leq \frac{1}{2}log(1+\frac{2E_s}{N_0}) \tag{5.7}$$

with $f(y) = \frac{1}{2}(f(y/x=+1)+f(y/x=-1))$ and $f(y/x=+1) = \frac{1}{\sqrt{2\pi\sigma}}e^{-\frac{(y\pm1)^2}{2\sigma^2}}$ where $\sigma^2 = N_0/2E_s$.

The loglikelihood ratio(LLR) or L-value of the binary random variable is

$$L(u) = ln\frac{P(u=+1)}{P(u=-1)} \tag{5.8}$$

With the inverse

$$p(u\pm1) = \frac{e^{\pm L(u)/2}}{e^{+L(u)/2}+e^{-L(u)/2}} \tag{5.9}$$

The sign of L(u) is the hard decision and the magnitude —L(u)— is the reliability of this decision.

The a posteriori probability after transmitting x over a noisy multiplicative fading channel with amplitude a yielding y = ax+n and the Gaussian probability density function

$$p(y/x) = \frac{1}{\sqrt{2\pi\sigma_c^2}}e^{-\frac{(y-ax)^2}{2\sigma_c^2}} \tag{5.10}$$

is

$$p(x/y) = \frac{p(y/x)p(x)}{p(y)} \tag{5.11}$$

and the complementary APP LLR equals

$$L_{CH} = L(x/y) = ln\frac{p(x=+1/y)}{P(x=-1/y)} = L_c.y + L(x) \tag{5.12}$$

L(x) is the a priori LLR of x and Lc is the channel state information: $L_c = \frac{2a}{\sigma_c^2} = 4aE_s/N_0$ Furthermore, for statistical independent transmission, such as dual diversity or repetition code, we have

$$L(x/y1,y2) = L_{c1}.y1 + L_{c2}.y2 + L_x \tag{5.13}$$

The mutual information between the equally likely X and the respective LLR's L for symmetric and consistent L-values simplifies to

$$I(X;Y) = 1 - \int_{-\infty}^{+\infty} p(L/x = +1) log_2(1 + e^{-L}) dL \tag{5.14}$$

$$I(X;Y) = 1 - E\{log_2(1 + e^{-L})\} dL \tag{5.15}$$

The expectation is over the one parameter distribution

$$P(L/x = +1) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(L - x\sigma^2/2)^2/2\sigma^2} \tag{5.16}$$

If the input values are not equally likely then the Equation.5.15 can be generalized to

$$I(L;X) = H_b(P(x) - E\{log_2(1 + e^{-L})\}) \tag{5.17}$$

Where Hb is the binary enropy function.

Now to measure the mutual between information bits x which after encoding are transmitted over a noisy channel and the L-values of these bits decoding. The decoder receives not only the transmitted values normalized by the channel state information but also a priori knowledge in the form of L-values from other serial or parallel decoder. Due to the non-linearity of the decoder the L-value distribution of the output is in general unknown and no longer Gaussian. However, by invoking the ergodicity theorem- namely that the expectation can be replaced by the time average- we can measure the mutual information from a large number N of samples even for non-gaussian or unknown distribution:

$$I(L;X) = 1 - E\{log_2(1 + e^{-L})\} \approx 1 - \frac{1}{N} \sum_{n=1}^{N} log_2(1 + e^{-x_n \cdot L_n}) \tag{5.18}$$

The N decoder output samples are corrected by x_n to account for pdf over positive x. Even this knowledge of x_n is not necessary if one observes that we can write

$L_n = sgn(L_n) =$ -1 occurs with probability of

$$p_{en} = \frac{e^{+|L_n|/2}}{e^{+|L_n|/2} + e^{-|L_n|/2}} \tag{5.19}$$

This leads to

$$I(L;X) \approx 1 - \frac{1}{N}\sum_{n=1}^{N} H_b(P_{en}) = 1 - \frac{1}{N}\sum_{n=1}^{N} H_b(\frac{e^{+|L_n|/2}}{e^{+|L_n|/2} + e^{-|L_n|/2}}) \tag{5.20}$$

This is the new nonlinear transformation and the averaging of the $\mid L_n \mid$ values allows us to estimate the mutual information only from the magnitudes without knowing the correct data. Thus viewing to the above values, the extrinsic information transfer characteristics are defined as

$$I(L_E;X) = T(I(L_A;X), E_b/N_0) \tag{5.21}$$

Or, for fixed, just

$$I(L_E;X) = T(I(L_A;X)) \tag{5.22}$$

5.2 Simulation Results

The simulation results shows the EXIT chart for the system model described in this chapter, in which the relay plays the most important role i.e relay decoding, interleaving and re-encoding is done. Figure.5.3 shows the transfer characteristics $I(L_E;X) = T(I(L_A;X), Eb/N0)$ based on the influence of Eb/N0. The Eb/N0 value serves as a parameter to the curves. The BCJR algorithm is applied to a rate 1/2 recursive systematic convolutional code of memory 4; the parity bits are punctured to obtain a rate 2/3 constituent code. The code polynomials (1010,1110) is used.The influence of different code polynomials is for the prominent case of a memory 4 code. The (1001, 1111)-code provides good extrinsic output at the beginning, but returns diminishing output for higher a priori input. For the (1101, 1110)-code it is the other way round. The constituent code of the classic rate 1/2 PCC with polynomials (1110, 1010) has good extrinsic output for low to medium a priori input.

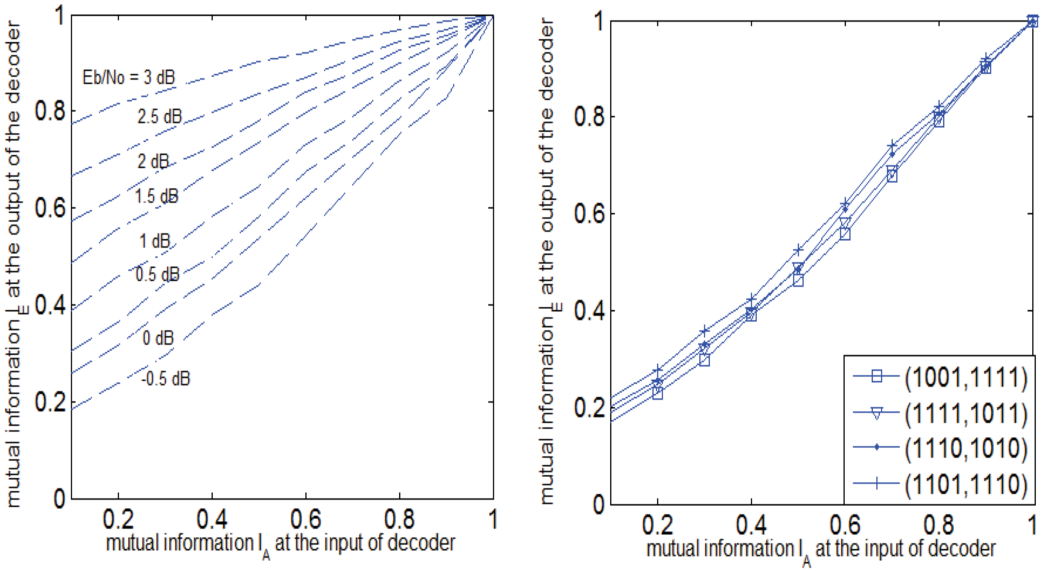


Figure 5.3: Influence of Eb/No and code polynomial on transfer characteristics

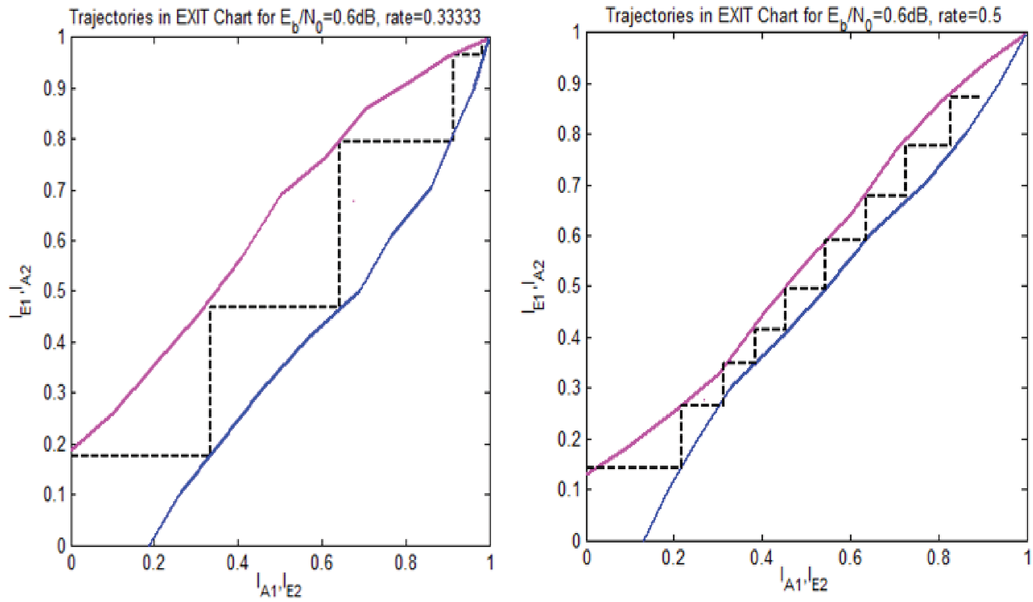


Figure 5.4: Exit chart for Eb/N0 = -0.2dB, rate = 0.33333 and Exit chart for Eb/N0 = 0.6 dB, rate = 0.33333

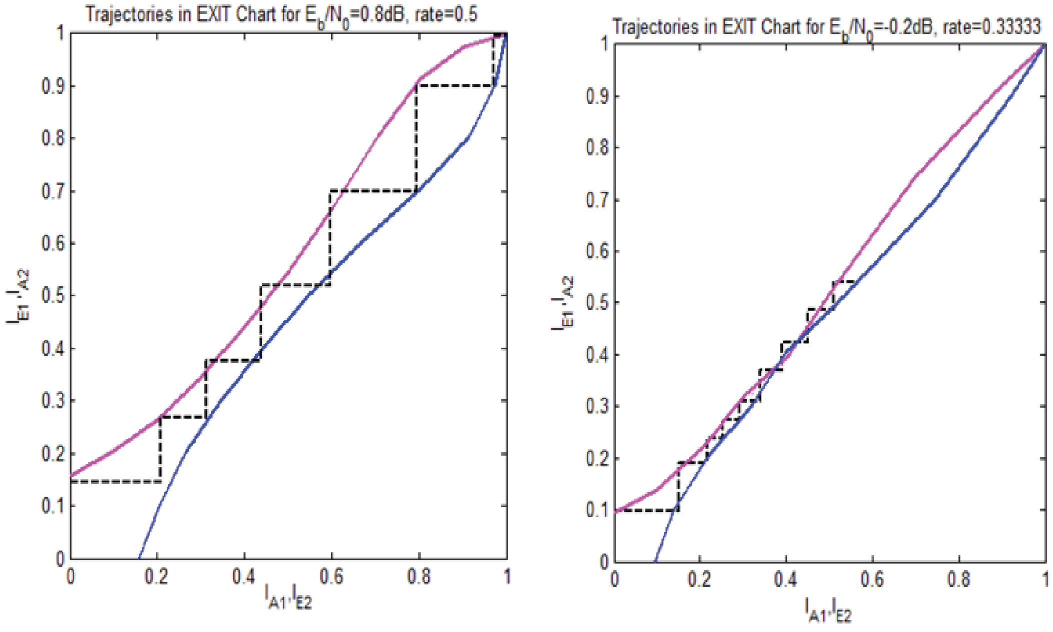


Figure 5.5: Exit chart for Eb/N0 = 0.6dB, rate = 0.5 and Exit chart for Eb/N0 = 0.8dB, rate = 0.5

Figure.5.4 and Figure.5.5 shows the influence of code rate on transfer characteristics. To account for the iterative nature of the suboptimal decoding algorithm, both decoder characteristics are plotted into a single diagram. However, for the transfer characteristics of the second decoder the axes are swapped. Thus from the results it shows that the rate=1/2 gives better performance as there is more convergence.

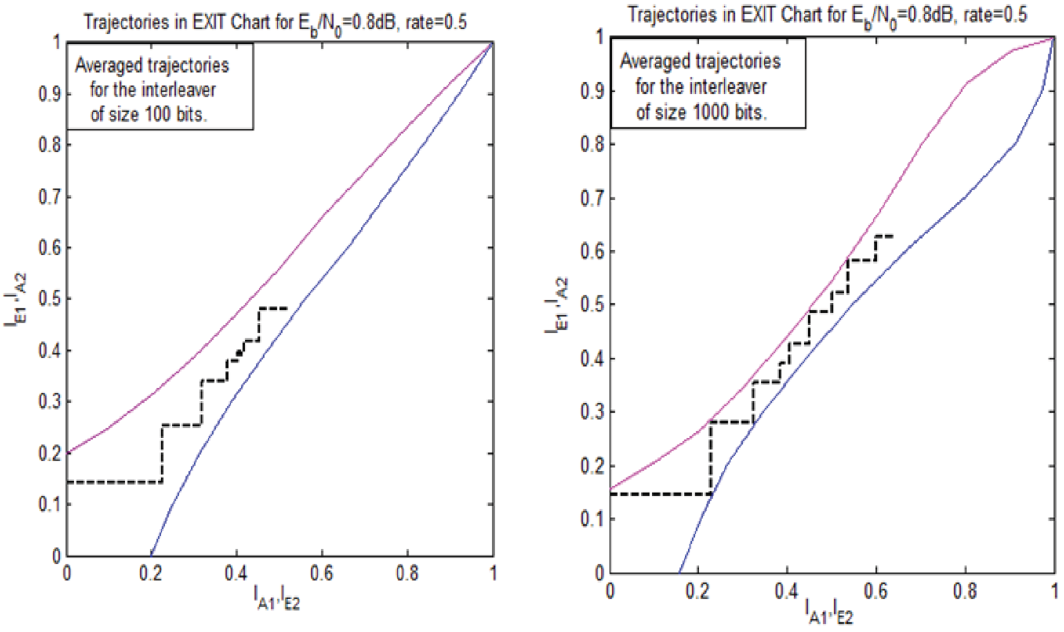


Figure 5.6: Exit chart for Eb/N0 = 0.8dB, rate = 0.5 with interleaver of size 100 bits and Exit chart for Eb/N0 = 0.8dB, rate = 0.5 with interleaver of size 1000 bits

Figure.5.6 and Figure.5.7 shows the influence of size of interleaver on transfer characteristics. If the interleaving depth is quite big, the decoding trajectory matches fairly well with the transfer characteristics; however, small deviations at the beginning can accumulate to big differences among the trajectories after some iteration. For short interleaver size, increasing correlations of extrinsic information let the averaged trajectory literally "die out" after some iteration. As we increase the interleaver size from 10^2 to 10^5 bits, the agreement of averaged trajectory and decoder transfer characteristics gradually improves.

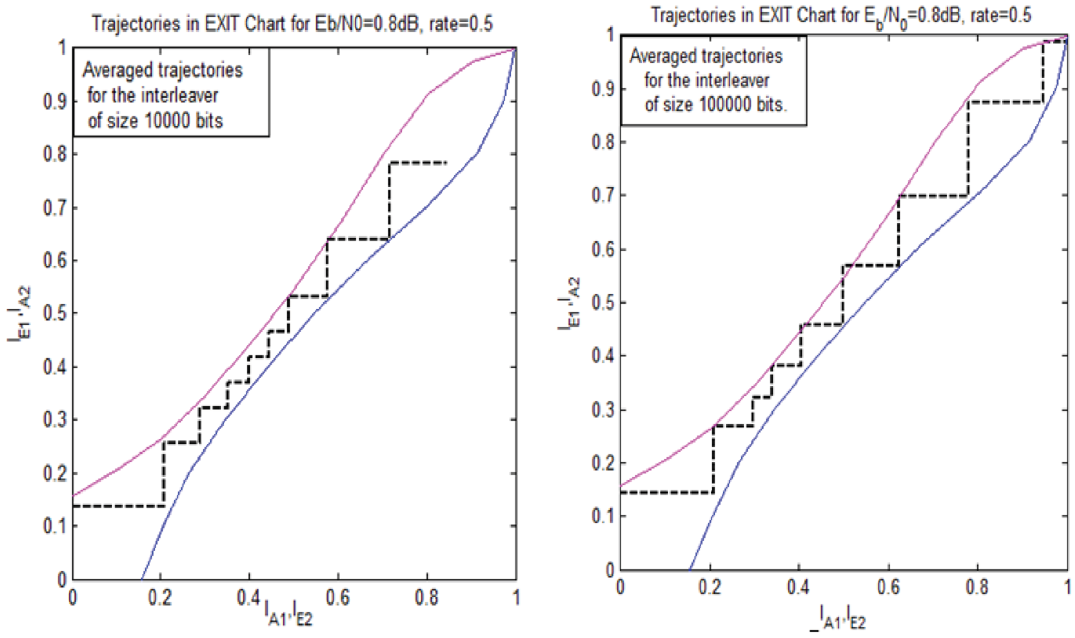


Figure 5.7: Exit chart for Eb/N0 = 0.8dB, rate = 0.5 with interleaver of size 10000 bits and Exit chart for Eb/N0 = 0.8dB, rate = 0.5 with interleaver of size 100000 bits

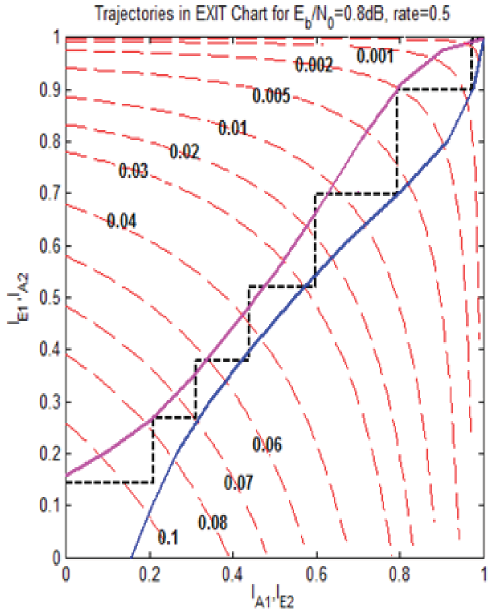


Figure 5.8: Comparision between BER chart and EXIT chart

The EXIT chart can be used to obtain an estimate on the BER after an arbitrary number of iterations. Figure.5.8 shows transfer characteristics and respective simulated decoding trajectory of PCC with memory 2 and codes at 0.8 dB. It can provide reliable BER predictions down to 10^{-3} that is in the region of low Eb/N0.

5.3 Summary

In this chapter,a technique is proposed, discussed, and analyzed for Turbo codes. The analysis was based on the EXIT chart method and explained new design aspects resulting from the new structure of the codes. This is then invoke into the cooperative communication system which leads to an improved error-floor performance and an increased system performance.

Chapter 6

Conclusion and Future Scope

In this final chapter, summary of the contributions of the work presented in this thesis and several avenues for future research in the area of cooperative com- munications.

6.1 Conclusion

This thesis has shown the possible benefits of a wireless transmission using cooperative diversity to increase the performance. The diversity is realized by building an ad-hoc network using a third station as a relay. The data is sent directly from the base to the mobile or via the relay station. Such a system has been simulated to see the performance of different diversity protocols and various combining methods.

The location of the relay is crucial to the performance. The best performance was achieved when the relay is at equal distance from the sender and the destination or slightly closer to the former. In general the relay should not be to far from the line between the two stations.

From a channel coding point of view, repetition coding is not the most efficient use of the available bandwidth. In this a framework for cooperative communications called coded cooperation is analysed. The coded cooperation framework is quite flexible in the sense that it can be implemented with either block or convolutional codes, and the additional parity transmitted by the partner may be obtained through the use of punctured codes, product codes, or other forms of concatenation. In this thesis examples of coded cooperation using convolutional codes, Punctured Convolutional codes and Turbo codes are given. The cooperative communication with convolutional coding shows that when it is compared with non-cooperative communication and AF, it shows a gain of 2.5dB. Puncturing is generally used to increase the rate. Thus by using the cooperative communication with punctured convolutional shows that the system performance is improved for moderate to high SNR. In turbo code with cooperative communication a single relay has been employed in the simulation and the relay uses decode and forward approach. The destination uses data bits and parity bits received directly from the source and the parity bits received from the relay to decode the data. Thus the turbo code shows better performance than the other codes.Future it is extend by analaysizing the turbo code using EXIT chart which is influenced by SNR,size of interleaving, code polynomial and code rate. Thus by designing a turbo code, it is then used with cooperative communication which shows that there is a gain of almost 5dB ad compared to cooperative communication with convolutional coding.

In this analysis coded cooperation with space time coding is performed, for which Alamouti code is selected. This code is very special because it is the only code with rate 1. In this thesis simulation of outage probability versus SNR is performed which shows that it solves the problem of bad performance at low SNR.

6.2 Future Scope

While several key results for cooperative communication have already been obtained, many more issues remain to be addressed, and many possible directions for future research exist. Throughout this dissertation, the case of Rayleigh fading is considered to highlight the spatial diversity provided by coded cooperation. It would also be interesting to extend the results and examine the performance of coded cooperation for other fading distributions, such as Ricean and Nakagami fading. Also in this work the users transmit with equal and constant power, equal rate, and with a constant modulation and coding scheme. A research is going on improving the capacity and performance of conventional non-cooperative wireless systems through real-time feedback and adaptation of transmit power, information rate , modulation scheme, coding scheme and rate, and various combinations of these parameters.

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List of Publications

[1] Vasani Ekta and Manisha Upadhyay, ”Multiple Relay aided Cooperative Communication Schemes”, *International Journals of Electronics and Communication Technology*,2011.

[2] Vasani Ekta and Manisha Upadhyay, ”Coded Cooperative Communication based Punctured Convolutional Coding”,*Coimbatore Institute of Information Technology*,2011