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Rate Maximization Using Cooperative Ratio Over Rayleigh Fading Channels

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RATE MAXIMIZATION USING COOPERATIVE RATIO OVER RAYLEIGH FADING CHANNELS

by

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Abstract

Cooperative Diversity transmission, a newly upcoming field in the area of wireless communication, has been receiving great attention. This diversity transmission exploits the spatial diversity created by antenna sharing to improve the performance of a wireless network. The working of a cooperative diversity system is such that a source node communicates with a destination node with the help of another partner node. One important question usually raised regarding the operation of this system is that of the amount of power allocation among partnering nodes. Initial stages of research in this area had assumed equal distribution of power resources between the nodes. This approach has been proven as clearly suboptimal. Several works to allocate power optimally are coming up. In this project, optimal power allocation is used as a key approach to analyze the rate performance of the system. This is done with the help of a parameter called cooperative ratio which is the ratio of the power used for cooperative transmission to total power. Simulation results to support the analysis have also been provided.

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Chapter 1

Introduction

1.1 Overview

Wireless communications have seen a remarkably fast technological evolution. Although separated by only a few years, each new generation of wireless devices has brought significant improvements in terms of link communication speed, device size, battery life, applications, etc. In recent years the technological evolution has reached a point where researchers have begun to develop wireless network architectures that depart from the traditional idea of communicating on an individual point-to-point basis with a central controlling base station. Such is the case with ad-hoc and wireless sensor networks, where the traditional hierarchy of a network has been relaxed to allow any node to help forward information from other nodes, thus establishing communication paths that involve multiple wireless hops. One of the most appealing ideas within these new research paths is the implicit recognition that, contrary to being a point to point link, the wireless channel is broadcast by nature. This implies that any wireless transmission from an end-user, rather than being considered as interference, can be received and processed at other nodes for a performance gain. This recognition facilitates the development of new concepts on distributed communications and networking via cooperation.

The technological progress that is taking place in the area of wireless communications is huge. Few of the underlying technologies include integrated circuits, energy storage, antennas, etc. Digital signal processing is one of these underlying technologies contributing to the progress of wireless communications. One of the most important contributions to the progress in recent years has been the advent of MIMO (multiple-input multiple-output) technologies. Generally, MIMO technologies improve the received signal quality and increase the data communication speed by using digital signal processing techniques to shape and combine the transmitted signals from multiple wireless paths which are created by the use of multiple receive and transmit antennas [1].

Cooperative communications is a new paradigm that draws from the ideas of using the broadcast nature of the wireless channel to make communicating nodes help each other. It implements the communication process in a distributed fashion and helps gain the same advantages as those found in MIMO systems. The end result is a set of new tools that improve communication capacity, speed, and performance; reduce battery consumption and extend network lifetime; increase the throughput and stability region for multiple access schemes; and expand the transmission coverage area.

1.2 Background

Wireless Communications have been enjoying its fastest growth period in history, due to enabling technologies which permit widespread deployment. Historically, growth in the mobile communications field has been coupled closely to technological improvements that have come up in our society. In this section a brief introduction about the various works in the area of wireless communications, until date has been provided.The ability to provide wireless communications to entire population was not even conceived until Bell Laboratories developed the cellular concept in the 1960s and 1970s. The development of highly reliable solid state radio frequency hardware gave birth to the wireless communication era.

The recent exponential growth in cellular radio and personal communication systems throughout the world is directly attributable to new technologies of the 1970s, which are mature today. The future growth of consumer based mobile and portable communication systems will be tied more closely to radio spectrum allocations. Further they are affected by the regulatory decisions related to consumer needs and technology advances in the signal processing, access, and network areas.

Wireless communication mainly includes cell phones and internet. Fig 1.1 clearly shows the increase in the rate of use of these technological advances during the recent years [39]. It shows the rapid increase in the use of mobile phones after 1998 to 2006. Though the use of broad band is little low compared to the use of mobile communication, there is definitely an upgradation in the level of using wireless communication, which connects the whole world. It has made everyone just a click away.

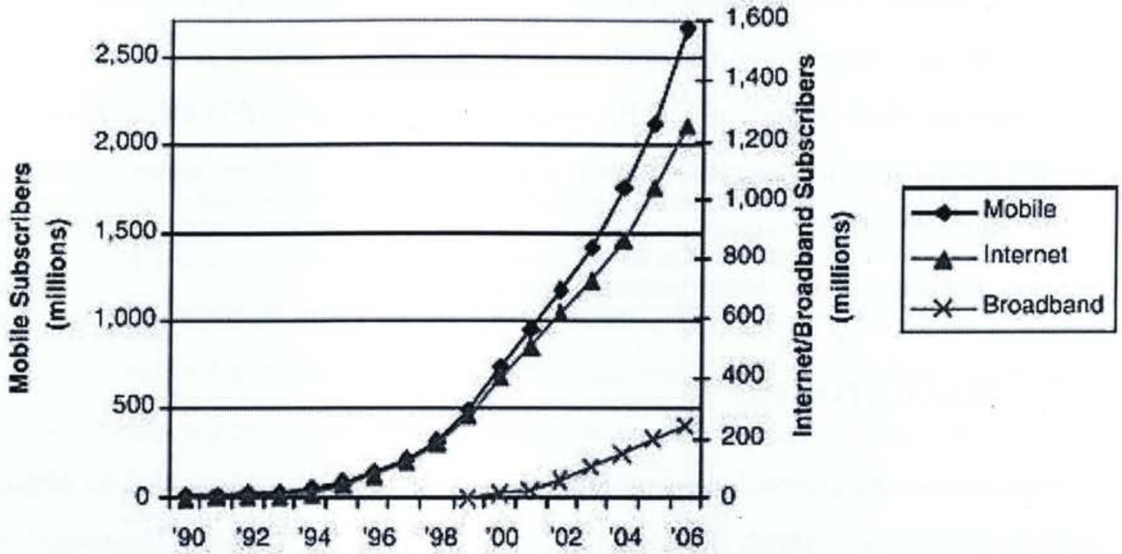

Figure 1.1: Plot describing the rate of increase in the use of wireless communication.

Most people are familiar with a number of mobile radio communication systems used in everyday life. Few examples of mobile radio communication include cordless telephones, walkie - talkies, pagers, cellular phones, remote controllers for television and other home entertainment equipment. However, the cost, complexity, performance, and types of services offered by each of these mobile systems are vastly different.

Mobile radio transmission systems may be classified as simplex, half duplex or full duplex. Simplex systems allow communication in only one direction. Paging system is an example of simplex system in which messages can be received but not acknowledged. Half duplex radio systems permit two way communication. But one important point to be noted is that they use the same radio channel for both transmission and reception. This leads to situation where at any given time, a user can only transmit or receive information. Constraints like to push to talk and release to listen are fundamental features of half duplex systems. Full duplex systems, on the other hand, allow simultaneous radio transmission and reception between a subscriber and a base station. They provide two simultaneous but separate channels on a single radio channel for communication, to and from the user. In place of separate channels they also provide adjacent time slots.

Frequency division duplexing provides simultaneous radio transmission channels for the subscriber and base station, so that they both may constantly transmit, while simultaneously receiving signals from one another. At the base station, separate transmit and receive antennas, are used, for both transmission to and reception from the base station. Apart from this a device called a duplexer is used inside the subscriber unit. This enables the same antenna to be used for simultaneous transmission and reception.

The fact of the possibility to share a single radio channel in time is made use of by Time Division Duplexing. Due to this, a portion of the time is used to transmit from the base station to the mobile and the remaining time is used to transmit from the mobile to the base station. For providing the appearance of a full duplex operation to a user, we require the data transmission rate in the channel to be greater than the end user's data rate. This is because only then can we store the information bursts, to give the impression of a full duplex system at any instant. TDD is only possible with digital transmission formats and digital modulation, and only for indoor or small area wireless applications.

1.2.1 Multiple Access Technologies

One of the most revolutionary developments in telephone service in the late twentieth century was the introduction of a variety of mobile phone services. As the number of subscribers have explosively grown in the wireless communication systems, provision of the mobility in telephone service has been made possible by the technique of wireless cellular communication. As the bandwidth over the wireless link is a scarce resource, one of the essential functions of wireless communication systems is multiple access technique for a large number of users to share the resource. Conceptually, there are mainly three conventional multiple access techniques: FDMA, TDMA, and CDMA.

These techniques can be grouped as narrow band and wide-band systems, depending upon how the available bandwidth is allocated to the users. The Multiple Access technologies can be classified into three main types namely, FDMA, TDMA and CDMA. The important features of the same are provided below.

(a) FDMA

Frequency division multiple access (FDMA) assigns individual frequency channels to individual users. In FDMA if an allocated channel is not in use, then it stays idle.

(b) TDMA

Time Division multiple access (TDMA) systems allows several users to share the same channel by dividing the signal into different time slots. The users transmit one after the other, each using its own time slot.

(c) CDMA

CDMA is a form of multiplexing which allows numerous signals to occupy a single transmission channel, optimizing the use of available bandwidth. It uses a spread spectrum approach for digitally transmitting data or voice over radio frequencies.

1.2.2 Fading Channels

In wireless communications, fading is a deviation of the attenuation that a carrier-modulated telecommunication signal experiences over certain propagation media. The fading may vary with time, geographical position and/or radio frequency. It is often modeled as a random process. A fading channel is a communication channel that experiences fading. In wireless systems, fading may either be due to multipath propagation, referred to as multipath induced fading, or due to shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading.

Few examples of fading models for the distribution of the attenuation are, Rayleigh fading, Nagakami fading, Weibull fading, Lognormal fading. In our project, we assume that the channel between the users and the BS obey Rayleigh Fading.

As explained above, mobile radio channel suffers from fading, implying that within the duration of any given call, mobile users go through severe variations in signal attenuation. The overall system performance can be severely degraded due to this fading. One such example is shown in Fig. 1.2.

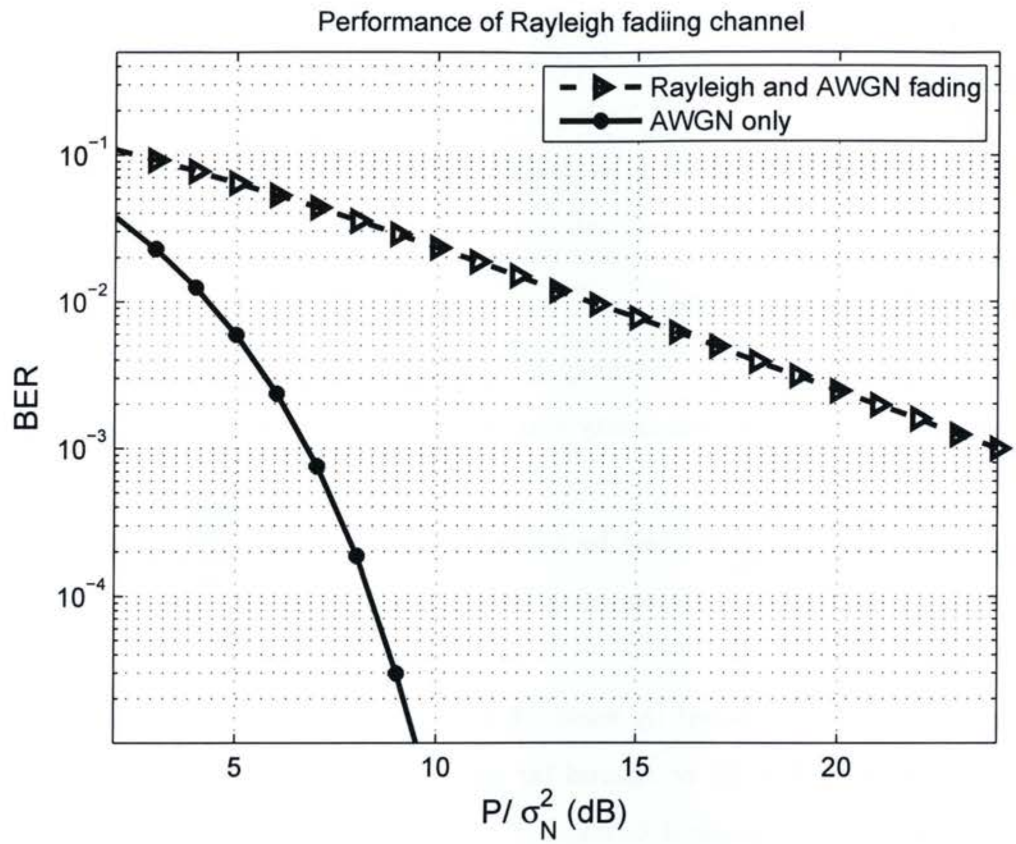

Figure 1.2: System Performance degradation due to fading.

The techniques currently being investigated for meeting next generation goals include advanced signal processing, tailoring system components specifically for the wireless environment [19] - [23]. Among these techniques, diversity is of primary importance due to the nature of the wireless environment.

1.2.3 Diversity Techniques

Diversity is a method for directly combating the effects of fading. It takes advantage of the statistical behavior of the fading channel. It provides two or more inputs at the receiver which are used to get uncorrelated signals.

System performance of fading channels can be improved by diversity techniques as stated above. Instead of transmitting and receiving the desired signal through one channel, we obtain L copies of the desired signal through M different channels [18] i.e., transmitting multiple copies of the same signal. The idea is that while some copies may undergo deep fades, others may not. We might still be able to obtain enough energy to make the correct decision on the transmitted symbol. There are several different kinds of diversity which are commonly employed in wireless communication systems.

(a) Frequency Diversity:

One approach to achieve diversity is to modulate the information signal through M different carriers. Frequency diversity can be used to combat frequency selective fading.

(b) Time Diversity:

Time diversity can be achieved by transmitting the desired signal in M different periods of time, i.e., each symbol is transmitted M times.

(c) Space Diversity:

Space diversity is achieved by using M antennas to receive M copies of the transmitted signal. The antenna should be spaced far enough apart so that different received copies of the signal undergo independent fading.

Thus spatial diversity relies on the principle that signals transmitted from geographically separated transmitters and/or to geographically separated receivers, experience fading that is independent. Hence independent of whether other forms of diversity are being employed, having multiple transmit antennas is desirable due to the spatial diversity they provide [24] - [27]. We see that transmit diversity generally requires more than one antenna at the transmitter. Many wireless devices are limited by size or hardware complexity. Hence its impractical, if not feasible, in the uplink of cellular system, due to the size of the mobile unit.

In order to overcome this limitation, yet still emulate transmit antenna diversity, a new form of diversity has been proposed, whereby diversity gains are achieved via the cooperation of in-cell users. That is, in each cell, each user has a "partner". Each of the two partners is responsible for transmitting not only their own information, but also the information of their partner, which they receive and detect. We are, in effect, attempting to achieve spatial diversity through the use of the partner's antenna. This class of technique is known as cooperative communication.

For preliminary explanation of the ideas behind cooperative communication, we refer to Fig 1.3. This figure shows two mobile agents communicating with the same destination. Each mobile has one antenna and cannot individually generate spatial diversity. However, it may be possible for one mobile to receive the other user's information. In that case it can forward some version of the "overheard" information along with its own data. This generates spatial diversity because the fading paths from two mobiles are statistically independent.

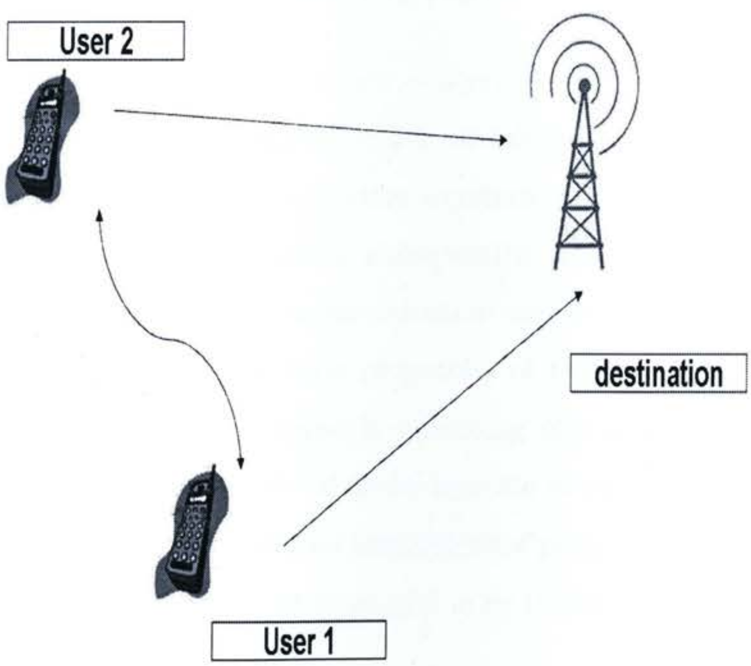

Figure 1.3: Cooperative Communication System.

1.3 Report Organization

The rest of the project report is organized as follows. Chapter 2 introduces and evaluates the related work on the topic of power allocation in user cooperative systems. Chapter 3 describes the system model considered ,the parameters to be analyzed, and the theoretical analysis supporting the proposed scheme. Chapter 4 presents the simulation results supporting our scheme through comparisons with other method of power allocation and transmission. Chapter 5 concludes the report followed by future work.

Chapter 2

Literature Review

In this Chapter we discuss in detail about the operation of a cooperative communication system, the various types of signalling methods it offers and certain practical issues that still provide space for research in the open literature.

2.1 Cooperative Communication

In cooperative wireless communication, we are concerned with a wireless network (either cellular or ad hoc), where the wireless agents, which we call users, may increase their effective quality of service via cooperation. In cooperative communication system, each wireless user is assumed to transmit data as well as act as a cooperative agent for another user (Fig 2.1).

The basic idea behind cooperative communication can be traced back to the ground breaking work on the information theoretic properties of the relay channel [28]. In this paper the capacity of the three node network consisting of a source, a destination and a relay was analyzed. It was assumed that all nodes operate in the same band, so the system can be decomposed into a broad cast channel from the view point of the source and a multiple access channel(Fig 2.2). Many ideas that appeared later in the cooperation literature were explained and reasoned out first in [28].

However in many aspects cooperative communication is different from the relay communication system. First, the recent developments are motivated by the concept of diversity in a fading channel. Second, in the relay channel, the relay's sole purpose is to help the main

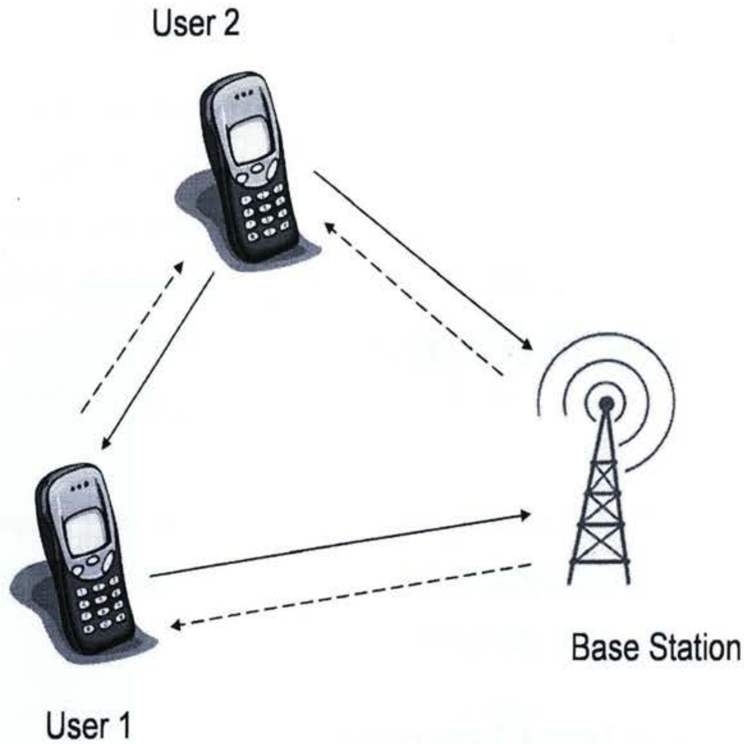

Figure 2.1: In Cooperative Communication each mobile is both a user and a relay.

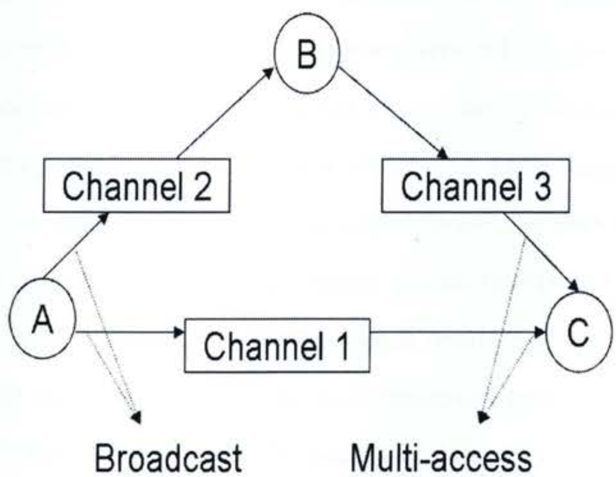

Figure 2.2: The Relay Channel.

channel, whereas in cooperation the total system resources are fixed and users act both as information sources and as relays. Therefore although the historical importance of [28] is indisputable, recent work in cooperation has taken a slightly different emphasis.

2.2 Types of cooperative signalling

There are three main types of cooperative signaling. They are as below:

2.2.1 Decode and Forward Method

This method is closest to the idea of a traditional relay. In this method a user attempts to detect the partner's bits and then retransmits the decoded bits. (Fig 2.3). The partners may be assigned mutually by the base station, or through some other technique. We consider two users partnering with each other, but in reality the only important factor is that, each user has a partner that provides a second data path. The easiest way to visualize this is via pairs, but it is possible to achieve the same effect via other partnership topologies, that remove the strict constraint of pairing. Partner assignment is a really rich topic and there are several researches that are being done still.

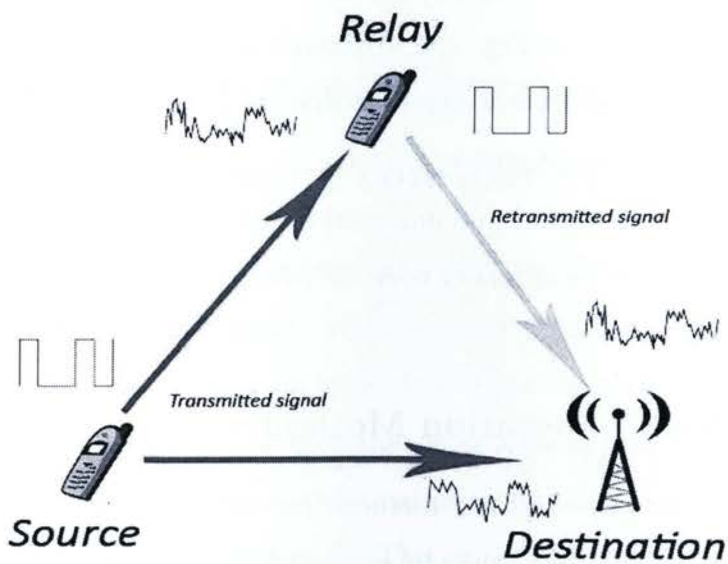

Figure 2.3: Decode and Forward Method.

An example of decode and forward signalling can be found in [3]. This work presents analysis and a simple code division multiple access(CDMA) implementation of decode and forward cooperative signaling. In this scheme, two users are paired to cooperate with each other. Each user has its own spreading code. Each signalling period consists of three phases.

In the first and second phases, each user transmit its own bits. Each user then detects the other user's second bit. In the third phase, both the users transmit a linear combination of their own second bit, each multiplied by the appropriate spreading code. The transmit powers for the first, second, and third phases are variable, and by optimizing the relative transmit powers according to the conditions of the uplink and interuser channels, this method provides adaptability to channel conditions.

2.2.2 Amplify and Forward Method

Another cooperative communication method is the amplify and forward method. 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 version. The base station combines the information sent by the user and the partner, and makes a final decision on the transmitted bit as shown in Fig. 2.4. Although noise is amplified by cooperation, the base station receives two independent faded versions of the signal and can make better decisions on the detection of information.

This method was proposed and analyzed in [29]. It has been shown that for the two user case, this method achieves diversity order of two, which is the best possible outcome at high SNR.

2.2.3 Coded Cooperation Method

Coded Cooperation [30] - [31] is a method that integrates cooperation into channel coding (Fig 2.5). Coded cooperation works by sending different portions of each user's 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 non cooperative mode. The key to the efficiency of coded cooperation is that all processes are managed automatically through code design, with no feedback between the users.

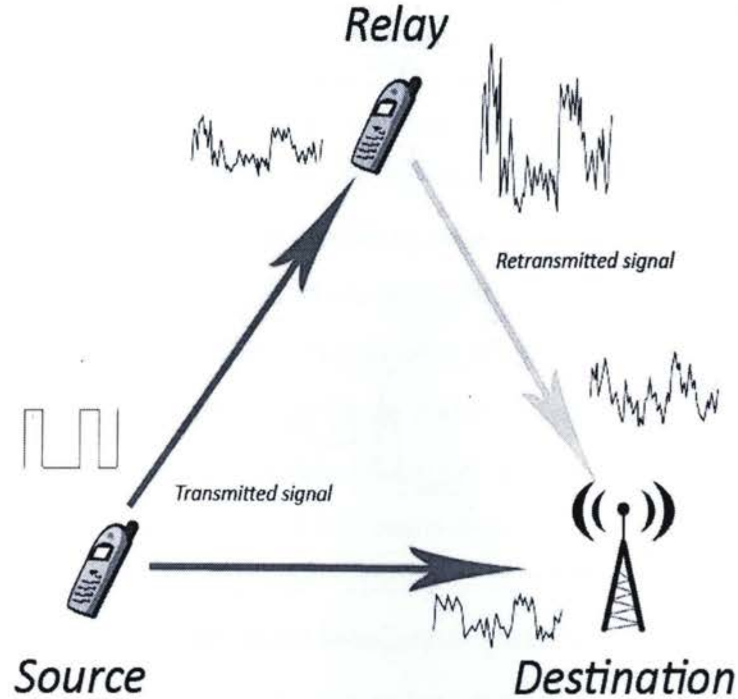

Figure 2.4: Amplify and Forward Method.

2.3 Practical Issues to be considered

One of the important issue to be considered about is the development of power control mechanisms for cooperative transmission. Work in early literature had assumed that users transmitted with equal power. It may be possible to improve performance even further by varying transmit power for each user based on the instantaneous uplink and interuser channel conditions. Furthermore, power control is critical in CDMA-based systems to manage the near far effect and minimize the interference. Therefore, power control schemes that work effectively in the context of cooperative communications have great practical importance.

In the work of [6], the outage and the ergodic capacity behavior of various cooperative protocols are analyzed for a three-user case under quasi-static fading channels. The paper discusses the ways of reaping powerful benefits of spatial diversity just by using distributed

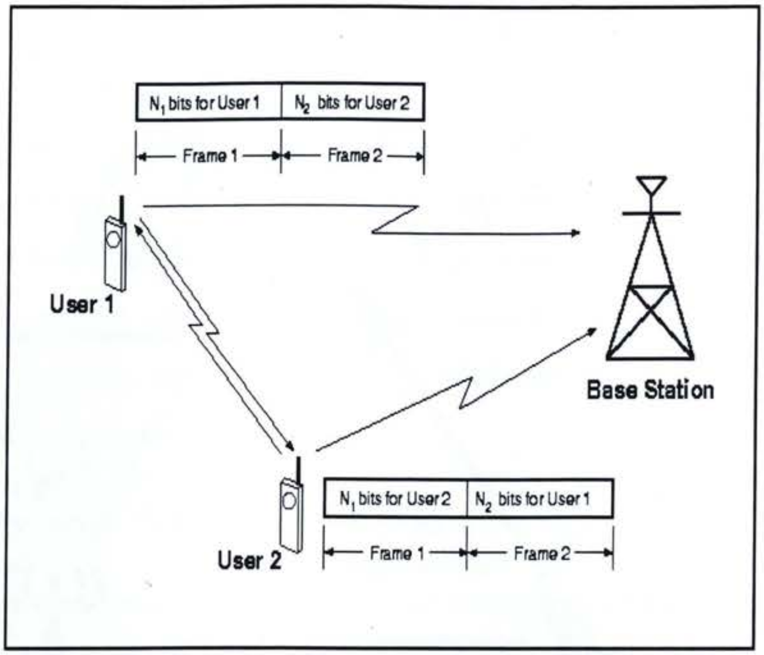

Figure 2.5: Coded Cooperation Method.

antennas. [8] investigates optimal power allocation, from an aspect of how it could be used to maximize the set of ergodic rates achievable by block Markov superposition coding using sub-gradient methods.

One of the important aspects of concern, regarding wireless networks, is channel fluctuation and interference. There exists a large body of research, in literature, on the ways of controlling it. Power control/ power allocation is one such factor, which has long been playing an important role to dynamically combat channel fluctuation and co-channel interference. This has been dealt with in detail in [9].

As we discuss about this power allocation, one important question that strikes our mind regarding user cooperation, is the amount of power to be allocated between users for self information transmission and for cooperative transmission. This question has been attracting a great deal of research attention.

[10] explains an efficient power allocation strategy to satisfy the target SNR requirement for an orthogonal amplify and forward network. A frame work for power allocation is developed based on the concept of " cooperative ratio". Expressions for the transmit power

required by each source to achieve their target SNR requirement are derived as a function of the cooperative ratio. The authors have drafted ways that might lead to a reduction in average required transmit power for both sources.

[11] also proposes an optimal power allocation scheme. Here the authors propose a novel adaptive protocol for cooperative systems based on minimizing the asymptotic SER of such systems. The proposed adaptive protocol helps to achieve the maximum achievable diversity gain without sacrificing any transmission rate or power. Hence the power allocation is optimized by optimizing the derived approximate symbol error rate subject to fixed transmission rate and total transmit power constraints for an AaF cooperative system.

In [12], optimal power and bandwidth allocation algorithm is solved to maximize the overall system capacity for FDMA-based DF multi-hop links. The results presented in the paper shows that the achieved end to end capacity is up to 45 percent higher, if compared to a trivial allocation strategy with equal resources. [13] discusses how the optimal power allocation problem is solved to minimize the outage probability. It explains how iteration is required to obtain the optimal power allocation for Decode and Forward system with diversity. While for amplify and forward system with diversity the authors suggest to use the same solution as that of Decode and forward due to difficulty in formulation.

[14] formulates an optimum, centralized power allocation scheme appropriate for a cooperative network that employs transparent relaying. The results presented in the paper show that the proposed scheme outperforms the equal power allocation scheme by up to 5dB. The paper also proposes a distributed power allocation scheme where each node independently calculates its power allocation factors and it is shown that it converges to the optimum allocation yielded by the centralized approach.

[15] derives a general closed form symbol error rate expression for amplify and forward cooperative systems. Initially a two user case is analyzed and later this is extended to a multi-node scenario. In [16] the authors present a theoretic analysis for a class of multi-node cooperative protocols. It also provides an optimal power allocation algorithm for the multi-node relay problem based on the obtained approximate expression for the symbol error

rate (SER). The optimal power allocation reported in the literature is mainly based on the approximated SER or outage performance bounds. The actual optimum power allocation for cooperative diversity in fading channels with knowledge of channel statistics is still an open problem.

In [17], efficient power allocation schemes for amplify and forward systems are obtained from theoretical BER analysis and simulations. Actually power allocation is solved here by finding the desirable ratio power used for cooperative information transmission to that of total power in an attempt to minimize bit error rate (BER) with a constraint of fixed total transmit power for each user. User fairness is also considered in the analysis.

As we have discussed in this section, there are several approaches available in literature, trying to optimize the power for a communication system. But each work aspire to optimize power with a different objective, though all plan towards the improvement of overall system performance. For example, [11] provides a protocol to optimize power intending to minimize SER, [12] provides an algorithm with the aim of maximizing system capacity, while [10] seeks to optimize power with the aim of reaching the target SNR value. Further [17] provides an effective power optimization protocol with the aim of minimizing BER. Thus drawing inspiration from [17], here in this project we plan to investigate the performance gain from information theoretic point of view i.e., through analysis of achievable system throughput and the rate region.

2.4 Motivation

Increase in rate of the communication system could be achieved by proper allocation of power in the system. We have seen how Power allocation has been playing an important role in wireless networks, to dynamically combat channel fluctuations and control the co-channel interference. Hence one of the important question that has been usually raised in case of user cooperative systems is regarding how much power should be allocated for self information transmission and cooperative information transmission. Though this has attracted research interest in recent years, there is still space for potential research.

After studying the existing conventional methods of allocating power for various reasons and identifying areas for potential research, we focussed our study on,

1. Developing a fair power allocation scheme that takes into account all the channel conditions that would increase the information rate of the system.

2. Investigating the relative performance of the proposed amount of optimal power allocation according to our scheme, with conventional methods of allocating power and transmission schemes (direct transmission).

Chapter 3

Rate Maximization Through Power Allocation Protocol

In this project, our primary goal, besides introducing the concept of user cooperation, is to propose possible user cooperation schemes, analyze their throughput, information rate and hence the overall performance. We provide an analysis of user cooperation based on information theoretic concepts. This is important not only for understanding the limits of any proposed user cooperation scheme, but also for providing insight as to how a user cooperation scheme should be structured. During the process of analyzing various cooperation schemes proposed in literature, we observed that within a given transmission framework, the system that most closely emulated the signal structure of the information theoretic capacity - maximizing system, also had the highest throughput. Therefore, for completeness and for a better grasp of the subject of user cooperation, we present here the most important results from the capacity analysis of user cooperation.

Information Theory literature has investigated multiple-access channels with varying degrees of cooperation between the encoders such as [44]- [47]. However most of that work involves abstract settings that [3] illustrates, how user cooperation can lead to higher rates and diversity in wireless systems.

Further in our project we formulate and solve power allocation problems for a two user cooperation scenario in cellular networks, considering amplify and forward systems. We analyze the rate performance of the system under both equal power allocation between the users as well as under optimal power allocation between them. The equal power allocation constraint, which was once used, is applicable only for static wireless networks. Since mobile users keep changing their locations, we may no longer proceed with such assumptions. Here we have come up with an optimum power allocation scheme based on cooperative ratio, with the aim of maximizing Information rate of the system.

3.1 System Model

A cooperative transmission scheme, where each cooperative interval consists of two phases in a wireless network is considered. In phase I each mobile user tries to transmit its data towards the destination. At the same time , this data is also received by its partner. This phase is called the '*Self information Transmission Phase*'. In phase II each user transmits its partner's data, received during phase I, towards the destination, thus helping each other. This phase is termed as '*Cooperative Information Transmission Phase*'. In practice, to isolate the transmitted signal from the received one, it may be necessary to use two separate channels, two collocated antennas, or some other means. This orthogonality of different user information can be achieved by using multiple access techniques like TDMA, FDMA or CDMA, etc. Though other frameworks such as frequency division multiple access (FDMA) or Time division multiple access (TDMA) may be equally suitable, each with their own advantages and challenges, in this paper we apply CDMA as proposed in [3]. Data modulation applies BPSK scheme. The basic model is shown in Fig.3.1

The transmit power levels for each user during each phase is listed in table 3.4. The total power for each user is assumed to be fixed, P. Each user divides its P into two parts, one for self information transmission and the other part for cooperative information transmission.

The powers, P_1^t and P_2^t, are the allocated powers to transmit users self-information directly to the destination; while P_1^c and P_2^c are the powers for cooperative transmission in phase II. Assuming that the total power is fixed for each user, i.e., $P_i^t + P_i^c = P, i = [1, 2]$, where P is the total power for each user.

In our model, we assume that all receivers have channel state information and use coherent

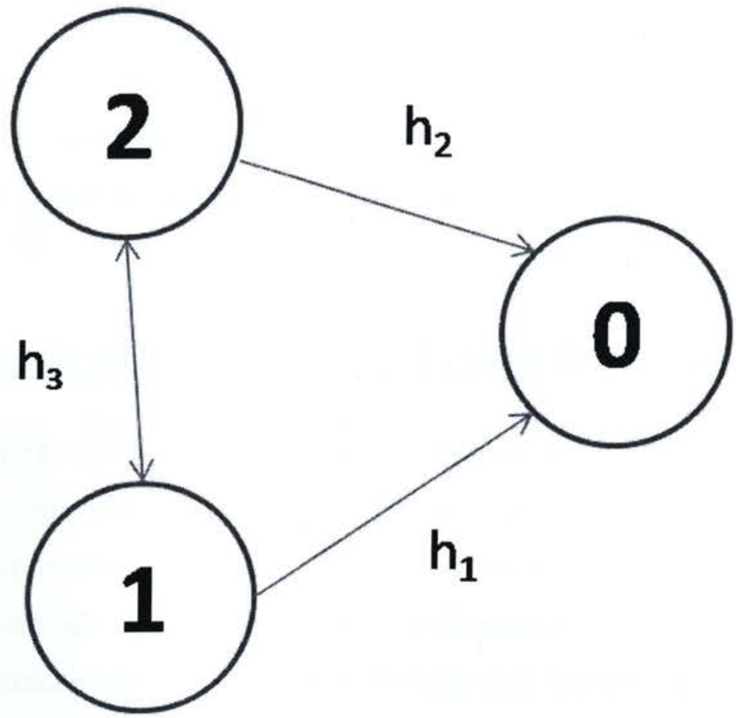

Figure 3.1: Model for User Cooperation.

Table 3.1: Description of Power terms in the system

User I	P_1^t	For tx directly to the destination
User I	P_1^c	For tx to the destination via partner
User II	P_2^t	For tx directly to the destination
User II	P_2^c	For tx to the destination via partner

detection as proposed in [17]. Therefore in our analysis we only need to consider the fading coefficient magnitude. The transmission scheme equations are provided for a single user and is common to the other user too, when considered as the source. Here Y_{10} denotes the received signal at the destination during phase I, and Y_{12}, denotes the received signal at the partner during the same phase. The equation explaining these expressions, are as follows,

$$Y_{10} = h_1 x_1 + z_0 \tag{3.1}$$

$$Y_{12} = h_3 x_1 + z_2 \tag{3.2}$$

Here the first subscript in the expressions denote the phase, i.e., 1 or 2. While the second subscript could have three different values namely, $0, 1, 2$, where 1 denotes the user I, 2 denotes user II or the partner, and 0 denotes the destination or the Base station. The terms z_0 and z_2 denote the zero mean background noise at nodes 0, 2 with variances σ_0^2, σ_2^2. The terms h_1, h_3, h_2 are the fading power gain for the channels of user I and destination, user I and user II, user II and destination respectively. Each h_i^2 (i= 1,2,3), follows exponential distribution. The amplitude gain h_i (i=1,2,3), follows Rayleigh Distribution. The term h_i is a complex quantity while in case of the system model used in this project, it has been assumed to take real values. The received signal at the destination during phase II, depends on the type of cooperative algorithm used. In case of decode and forward (DF) algorithm, the users decode the partners information received during the phase I before transmitting towards the BS. Whereas, in case of Amplify and Forward (AaF), the users do not attempt to decode, but simply amplify and forward whatever was received during phase I. Here in this project we consider only Amplify and Forward (AaF) scheme.

The signal received at the destination during Phase II, is the signal received by the user under consideration now, from its partner during Phase I. The received signal at 0, Y_{20}, can be expressed as,

$$Y_{20} = h_2.\alpha.Y_{12} + z_0 \tag{3.3}$$

where α is the amplifying factor at the partner and the value for Y_{12} is given in eqn (3.2). Now substituting the value for Y_{12}, we have,

$$Y_{20} = h_2.\alpha.(h_3 x_1 + z_2) + z_0 \tag{3.4}$$

The amplifying factor α, at the partner should satisfy the power constraint. It is given by [7],

$$\alpha = \sqrt{\frac{P}{|h_3|^2 P + \sigma_2^2}} \tag{3.5}$$

The term σ_2^2 in the above expression denotes the variance of the background noise associated with the node 2 i.e., user 2.Thus the above transmission equations are common to both the users i.e., as explained earlier during the definition of cooperative communication. Each user is assumed to transmit data as well as act as cooperative agent for the other.

3.2 Power Allocation

The performance of cooperative networks can be characterized in terms of BER performance, ergodic capacity, Outage, Mutual information rate. Here we focus on Information Rate Analysis as the metric to be optimized. Thus for this optimization process we make use of a parameter, $\beta (0 \leq \beta \leq 1)$, called the cooperative ratio as proposed in [17], for allocating power. The cooperative ratio implies the ratio of power used for cooperative transmission over the total power. In this section we analyze the allocation of power for self information transmission phase and the cooperative information transmission phase, for both the users so as to maximize the total rate for the system.

Hence we now write down the expressions for power allocated to the two users during the two different phases in terms of this parameter β. Let 'P' denote the total power for each user. The corresponding power allocation are given in Table 3.2

Table 3.2: Power Allocation

User I	$P_1^t = (1-\beta)P$	$P_1^c = \beta P$
User II	$P_2^t = (1-\beta)P$	$P_2^c = \beta P$

From user 1's point of view, it is expected to have P_1^t and P_2^c as large as possible; while for user 2, it is expected to have P_2^t and P_1^c as large as possible. Now the problem is to find the desirable value of β.

3.3 Mutual Information Rate Analysis

Here we compute the maximum average mutual information for amplify-and-forward transmission. We can write the transmission equations in previous section into a compact matrix form given below [24].

$$\mathbf{Y} = \mathbf{H}x_1 + \mathbf{BZ} \tag{3.6}$$

where,

$$\mathbf{Y} = \begin{bmatrix} Y_{10} \\ Y_{20} \end{bmatrix} \tag{3.7}$$

$$\mathbf{H} = \begin{bmatrix} h_1 \\ \alpha h_2 h_3 \end{bmatrix} \tag{3.8}$$

$$\mathbf{B} = \begin{bmatrix} 0 & 1 & 0 \\ \alpha h_2 & 0 & 1 \end{bmatrix} \tag{3.9}$$

$$\mathbf{Z} = \begin{bmatrix} z_2 \\ z_0 \\ z_0 \end{bmatrix} \tag{3.10}$$

3.3.1 Direct Transmission

To establish baseline performance under direct transmission, the source terminal transmits over the channel. The information rate for the system is obtained based on *Shannon's Channel Capacity Theorem.* The maximum average mutual information between input and output in this case, achieved by independent and identically distributed zero mean, symmetric complex gaussian outputs, is given by [6],

$$I = log\ (1 + SNR_{10}) \tag{3.11}$$

3.3.2 Cooperative Transmission

For a cooperative system trying to transmit using amplify and forward protocol, the average mutual information rate expression is framed following the work in [6]. Here we determine mutual information for arbitrary transmit powers, relay amplification, and noise levels. Since the channel is memoryless, the average mutual information rate satisfies,

$$I \leq log\ (det(I + (PAA\dagger)(BE[ZZ\dagger]B\dagger)^{-1})) \quad (3.12)$$

where † represents the complex conjugate transposition, and the other terms in terms of our system parameters are,

$$AA\dagger = \begin{bmatrix} |h_1|^2 & h_1(h_2\alpha h_3)^*) \\ h_1^*(h_2\alpha h_3) & |h_2\alpha h_3| \end{bmatrix} \quad (3.13)$$

$$BE[ZZ\dagger]B\dagger = \begin{bmatrix} z_0 & 0 \\ 0 & |h_2\alpha|^2 z_2 + z_0 \end{bmatrix} \quad (3.14)$$

where h_1 denotes the fading gain along the channel between the user 1 and destination, while h_2 denotes the fading gain along the channel between the user 2 and destination, h_3 denotes the fading gain between the users. Apart from these terms, α denotes the amplification factor.

Finally after the mathematical substitutions and algebraic manipulations we have,

$$I = \frac{1}{2}\ log\ (1 + SNR_{10} + f\,(SNR_{12}, SNR_{20})) \quad (3.15)$$

where,

$$f\ (x,y) = \frac{xy}{x + y + 1} \quad (3.16)$$

Here SNR_{10} denotes the signal to noise ratio along the path between user 1 and destination, while SNR_{12} denotes the signal to noise ratio along the channel between the users. And finally SNR_{20} denotes the signal to noise ratio along the channel between the user 2 and destination.

3.3.3 SNR Expression

The values for the signal to noise ratio used in the previous sections can be written in terms of the fading parameters, cooperative ratio (β), and Power. They are as listed in the Table 3.3.

Table 3.3: SNR Expressions

SNR_{10}	$\frac{h_1 P_1^t}{\sigma_0^2}$	$\frac{h_1(1-\beta)P}{\sigma_0^2}$
SNR_{12}	$\frac{h_3 P_1^c}{\sigma_2^2}$	$\frac{h_3 \beta P}{\sigma_2^2}$
SNR_{20}	$\frac{h_2 P_2^t}{\sigma_0^2}$	$\frac{h_2(1-\beta)P}{\sigma_0^2}$

Here the first column gives the value of the SNR's along the three different channels in terms of P_1^t, P_1^c and P_2^t. These are then substituted in terms of the power allocation discussed. Hence the cooperative ratio term has been introduced into the expression for calculating the rate of the system. This section develops the optimal power allocation among source and partner nodes by means of fixing appropriate value for cooperative ratio to maximize I.

The expression for I given in equation 3.15 serves as an upper bound for the information rate. The expression is of the form, $log\ (1+x)$, which is a strictly increasing function in terms of x. Hence the maximization of I can be obtained as we obtain the maximum of the term, $SNR_{sd} + f(SNR_{12}, SNR_{20})$. Thus solving the optimization problem for maximizing the information rate in a closed form appears to be difficult. We relax the problem to a reasonable one as used in [43] for maximizing rate. After reducing the complexity we have,

$$I = \frac{1}{2}\ log\ (1 + max(SNR_{10} + f\,(SNR_{12}, SNR_{20}))) \tag{3.17}$$

3.4 Cooperative Ratio

The cooperative ratio can be obtained from the above expression by taking the first derivative of the function to be maximized with respect to β and equating to zero. Here the final term for finding derivative has the average branch SNR terms i.e., SNR which are obtained by replacing h_i with H_i. Thus taking the first derivative of I upper bound with respect to β and equating to zero, we can solve the optimal β value to maximize I. The expression for β is obtained as below,

$$\beta = \frac{2ad - \sqrt{4(acde + ac^2d - ac^2e)}}{2a(d-c))} \tag{3.18}$$

where the terms a, c, d, e are as below.

Table 3.4: Parameters in β

a	$H_1H_2 - H_1H_3 + H_2H_3$
c	H_2
d	H_3
e	H_1H_3

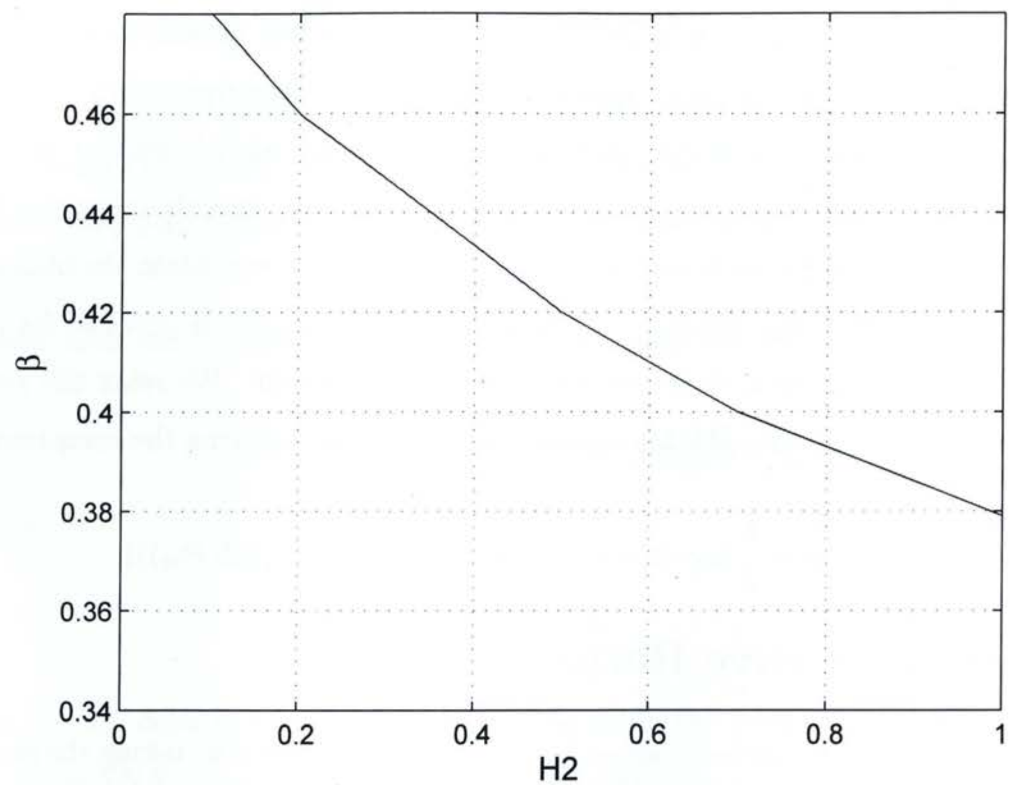

Figure 3.2: Solution for β as a function of H2 with H3 fixed.

The value of β has a few interesting features. Firstly it is mainly related only to the link gains, i.e., H_1, H_2, H_3. Second it is a monotonic decreasing function of the H_2 if H_3 is fixed. Thirdly when $H_3 > H_2$, i.e., $d > c$ which is a reasonable assumption, for the range of β is between $[0, 1/2]$. The second point can be better understood from the figure 3.2.

Proof:

First we prove that eqn 3.18 is greater than 0. If $H_3 > H_2$, i.e., $d > c$ the derivation is below,

$$(d - c) > 0$$

multiply by (ad-ce),

$$(d - c)(ad - ce) > 0$$

expanding the term we have,

$$ad(d - c) - ce(d - c) > 0$$

$$ad(d - c) + ce(c - d) > 0$$

expanding,

$$ad^2 - dec - acd + ec^2 > 0$$

Rearranging we have,

$$ad^2 > dec + acd - ec^2$$

multiplying by $4a$ on both sides and taking square root,

$$2ad > \sqrt{4(acde + ac^2d - ac^2e)}$$

simplification of this yields, finally

$$\beta > 0$$

Both the numerator and the denominator are greater than zero, therefore the ratio is greater than zero. If $c > d$, similarly we can show that both numerator and the denominator would be less than zero and therefore the ratio is greater than zero.

Next we prove that if $H_3 > H_2$, i.e., $\beta < 0.5$.

If $c < d$,

$$(c - d) < 0$$

multiplying by [a(c-d)+4ce], we have,

$$(c-d)[a(c-d)+4ce] < 0$$

This could be rewritten as,

$$a(c-d)^2 + 4ce(c-d) < 0$$

expanding we have,

$$a(d^2 + c^2 - 2cd) + 4ce(c-d) < 0$$

$$ad^2 + ac^2 - 2acd + 4c^2e - 4ced < 0$$

multiplying by a,

$$a^2d^2 + a^2c^2 - 2a^2cd + 4ac^2e - 4aced < 0$$

rearranging,

$$a^2d^2 + a^2c^2 < 2a^2cd - 4ac^2e + 4aced$$

add $4a^2d^2 + 2a^2cd$ on both sides,

$$a^2d^2 + a^2c^2 + 2a^2dc + 4a^2d^2 < 4a^2d^2 + 4a^2cd - 4ac^2e + 4aced$$

rearranging,

$$a^2d^2 + a^2c^2 + 2a^2dc < 4a^2d^2 - 4[a^2d^2 - a^2cd + ac^2e - aced]$$

$$(ad + ac)^2 < 4a^2d^2 - 4[(ad - ac)(ad - ec)]$$

$$(2ad - ad + ac)^2 < [\sqrt{4a^2d^2 - 4[(ad - ac)(ad - ec)]}]^2$$

$$(2ad - a(d - c))^2 < [\sqrt{4a^2d^2 - 4[(ad - ac)(ad - ec)]}]^2$$

taking square root we have,

$$(2ad - a(d-c)) < [\sqrt{4a^2d^2 - 4[(ad-ac)(ad-ec)]}]$$

$$(2ad - [\sqrt{4a^2d^2 - 4[(ad-ac)(ad-ec)]}]) < a(d-c)$$

$$(2ad - [\sqrt{4a^2d^2 - 4[(ad-ac)(ad-ec)]}]) < 0.5 \times 2a(d-c)$$

finally rearranging and simplifying we have,

$$\frac{2ad - \sqrt{4(acde + ac^2d - ac^2e)}}{2a(d-c)} < 0.5$$

Hence,

$$\beta < 0.5 \tag{3.19}$$

These limit values can also be verified from the simulation results presented in the next chapter. Furthermore here β is solved to maximize I of user 1. Except Symmetric situation β calculated from user 2's point of view will be different. This has to be investigated from a two dimensional power allocation aspect.

Chapter 4

Simulation Results

Simulation is used to determine the benefits of the proposed optimum power allocation algorithm based on cooperative ratio. In this chapter, the performance of optimal power allocation scheme is compared with equal power allocation method and Direct transmission method.

4.1 Simulation Model

4.1.1 Simulation Setup

We consider a two user communication system, trying to transmit data towards the base station following code division multiple access. The structure of the system is as shown in the figure 4.1. The channel between the users and the BS is assumed to obey Rayleigh Fading.

The results presented here are obtained by considering user 1 as source and user 2 as its partner (mentioned as relay in the Figure 4.1). However they remain the same if considered vice versa too. The parameters used for simulation are presented in the Table 4.1.

Here we have also presented a two dimensional performance graph, which splits β into two terms namely $\beta 1$ and $\beta 2$.

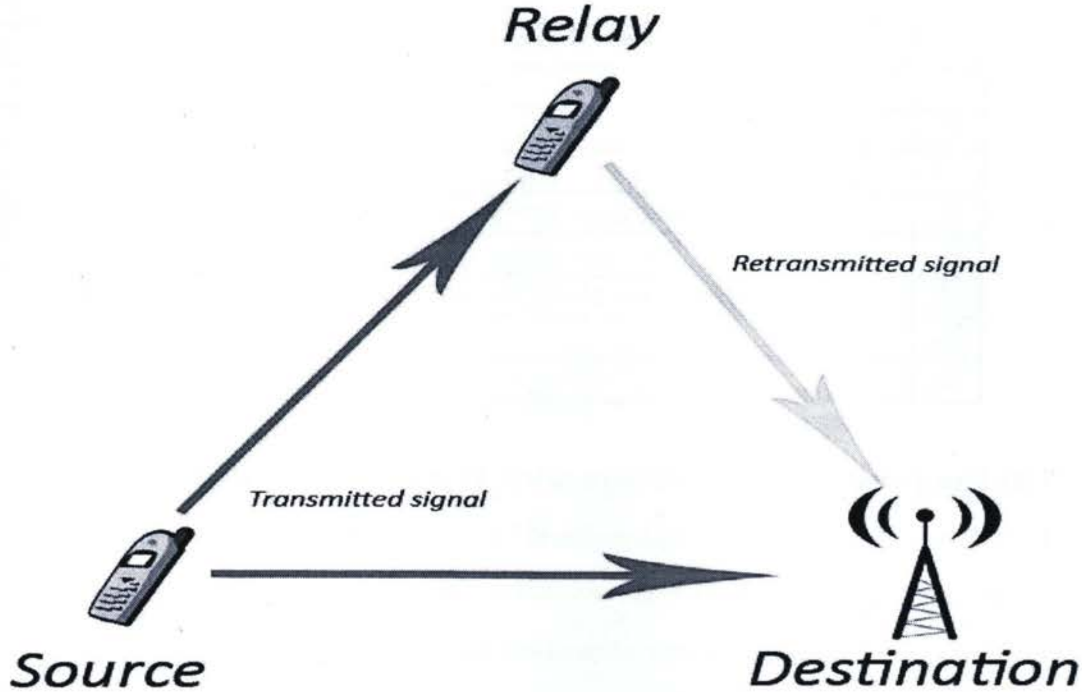

Figure 4.1: Cooperative communication model

4.1.2 Simulation Process

In the simulation, we generate 5,000,000 fading realizations and capture the average performance. From the simulation results, the numerical solution to maximize the rate of the system in terms of β are obtained. More insights of the effects of proper power allocation can be gained through simulation analysis. We have simulated results for three different processes.

(A) Direct Transmission User transmits directly to the BS. It does not use any other user to act as a relay or a partner. This is a conventional method of transmission. Here the power used for transmission is solely used by the transmitting mobile user. There is no need for considering the cooperative ratio. The mutual information for such a system is given by equation 3.11.

Table 4.1: Power Allocation

β	Cooperative Ratio
P	Total Power available to the system
z_i	Background Noise
σ_i^2	Variance of the background Noise
I	Mutual Information
H_1	Average Fading gain along the channel between user 1 and BS
H_2	Average Fading gain along the channel between user 2 and BS
H_3	Average Fading gain along the channel between user 1 and user 2
R_1	Transmission Rate for user 1
R_2	Transmission Rate for user 2

(B) Cooperative Transmission with Equal Power Allocation

Here User Cooperation is implemented for transmission purpose. We follow Amplify and Forward (AaF) protocol. Hence the cooperation ratio comes into play. We assume that the value of $\beta = 0.5$ i.e., equal power allocation between both the phases. The expression for I is same as shown in equation 3.15.

(C) Cooperative Transmission with Optimal Power Allocation

Here User Cooperation is implemented for transmission purpose. We follow Amplify and Forward (AaF) protocol. Hence the cooperation ratio comes into play. We assume that the value of β is optimum i.e., a value at which the rate of the system is maximized.The expression for I is same as shown in equation 3.15.

In the simulation we have presented the results comparing the performance of these three schemes for information rate, SNR values and few other plots to calculate optimum value of β. Apart from these, the achievable rate region graph is also presented for the purpose of comparison.

4.1.3 Achievable Rate Region

An achievable rate region with user cooperation is obtained by considering cooperative strategy explained in the model with constant attenuation factors as proposed in [3] incorporating the randomness using [32]. An achievable rate region for the system given (1) to (3) for the

2 users considered is the closure of the convex hull of all rate pairs (R_1, R_2) such that,

$$R_1 = R_{12} + R_{10}$$

$$R_2 = R_{21} + R_{20}$$

The rates for calculation are as follows [3],

$$R_{12} < C(\frac{H_3 P_1^t}{H_3 P_1^t + Z_1}) \tag{4.1}$$

$$R_{21} < C(\frac{H_3 P_2^c}{H_3 P_2^t + Z_2}) \tag{4.2}$$

$$R_{10} < C(\frac{H_1 P_1^t}{Z_0}) \tag{4.3}$$

$$R_{20} < C(\frac{H_2 P_2^t}{Z_0}) \tag{4.4}$$

The function of $C(x)$ here is given by $\frac{1}{2}log_2(1+x)$. The achievable rate region under our proposed cooperative strategy with different power allocation, together with the capacity region of the non cooperative strategy is shown in the results.

4.2 Simulation Results

Fig 4.2. shows the average information rate for user 1 as a function of β. The curves are obtained for different values of $P/\sigma^2 = 10, 12, 14, 16\ dB$ respectively.The mean fading gains are $H_1 = 0.5,\ H_2 = 1,\ H_3 = 2$. It is clear that different values of β leads to different values of information rate. From the plot we find that a maximum value of rate is obtained for the system when β is equal to 0.3 through simulation. While the value of optimum β through calculation was found to be 0.3670. The performance of the system is thus better than at equal power allocation for the two phases.

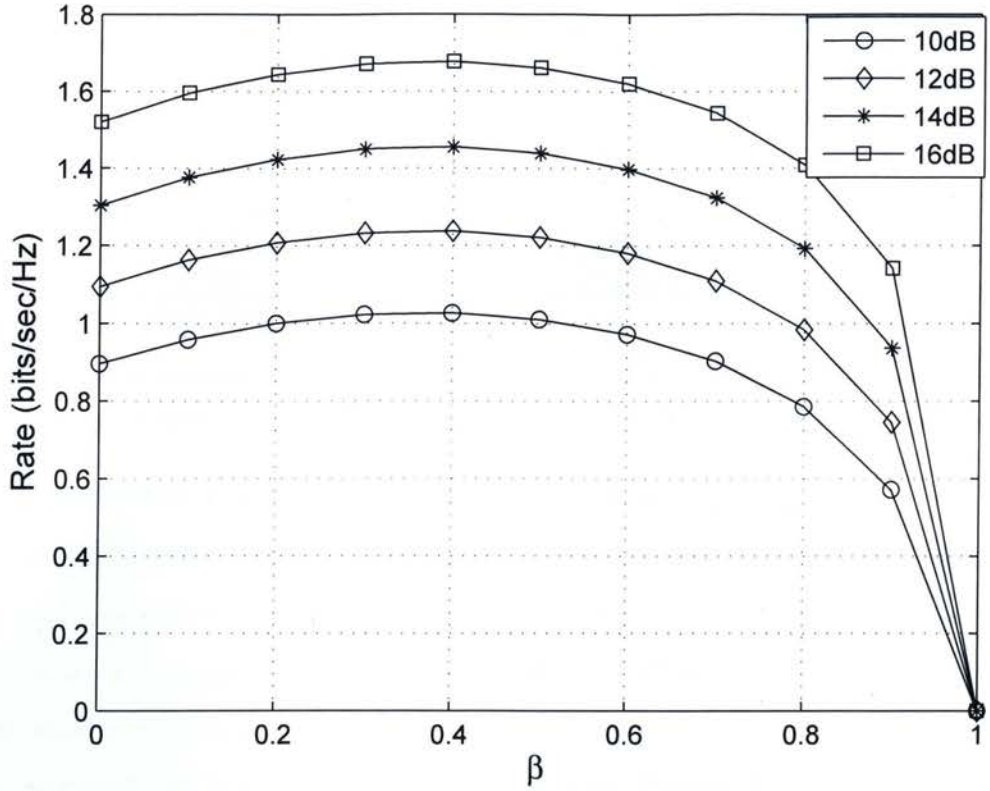

Figure 4.2: Rate performance for user 1 ($P/\sigma^2 = [10, 12, 14, 16]dB, H_1 = 0.5, H_2 = 1, H_3 = 2$)

Fig 4.3. shows the rate Vs β with different values of interuser channel fading gain. The plot shows that with the increasing of H_3, rate increases , and the optimal β has a trend to increase i.e., allocate more power for cooperative transmission. When H_3 changes from 2 to 4, the desired β values obtained through simulation are 0.3, 0.4, 0.4 respectively while the ones calculated from our expression are 0.3670, 0.43, 0.46 respectively.

Fig 4.4. shows rate performance as a function of SNR. The circle marked curve denotes the system performance in terms of rate with no cooperation with increasing SNR. The diamond marked curve and the asterix marked curves are the simulated rate results for AaF transmission with cooperative ratio 0.3 and 0.5 respectively. It can be observed that $\beta = 0.3$ is a better choice over the equal power $\beta = 0.5$. And we do find that the performance shows improvement with increase in SNR values.

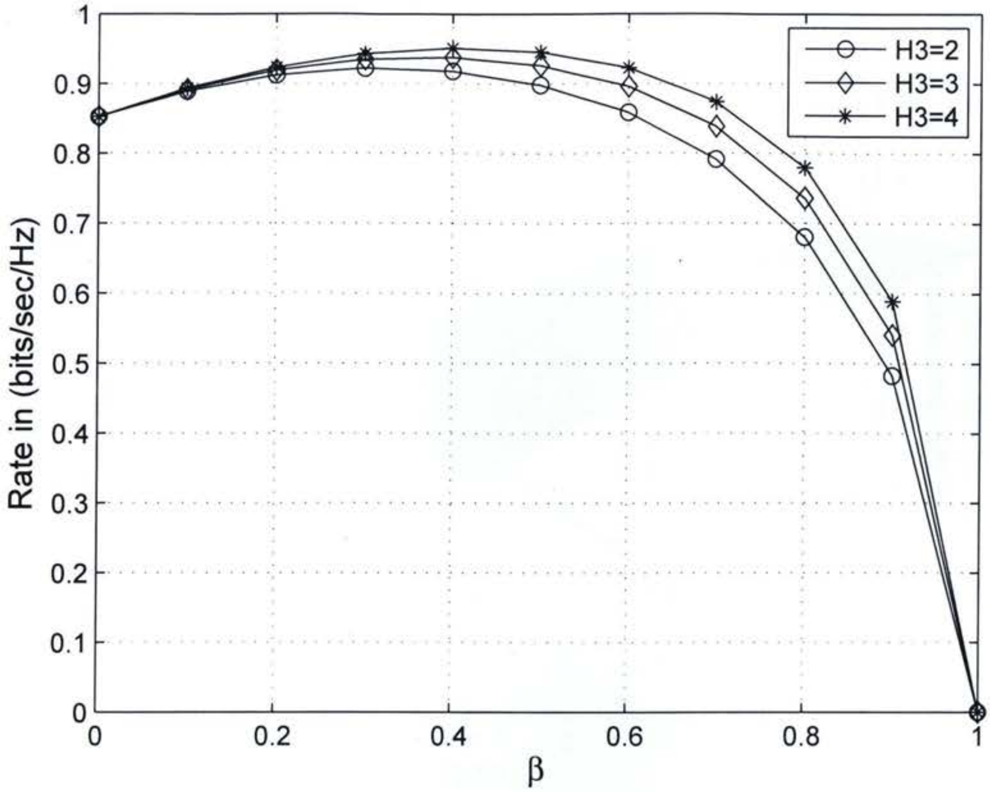

Figure 4.3: Rate performance for user 1 ($P/\sigma^2 = 10dB, H_1 = 0.5, H_2 = 1, H_3 = [2, 3, 4]$)

Fig. 4.5 shows user 1's rate when users 1 and 2 apply 2-dimensional power ratios $\beta 1$ and $\beta 2$ respectively. In this figure, the value of SNR is chosen as 10 dB. Other parameters are the same as in Fig 3. It shows that the maximum rate is obtained when β_1 is minimum and β_2 is the maximal values. It makes sense intuitively. For user 1, the maximum benefit can be obtained when its full power is allocated for self information transmission, leading user 2 serving as a pure relay for user 1. At this setting, it shows that the value of rate for user 1 reaches 1.445 which is an improvement over rate value for user 1 in Fig 3. (0.9). However, the price for this improvement is that no information could be transmitted for user 2.

The achievable rate region under our proposed cooperative strategy with different power allocation, together with the capacity region of the non cooperative strategy is shown in Figs. 4.6 and 4.7 , for different scenarios of channel quality. For the no-cooperation case, the

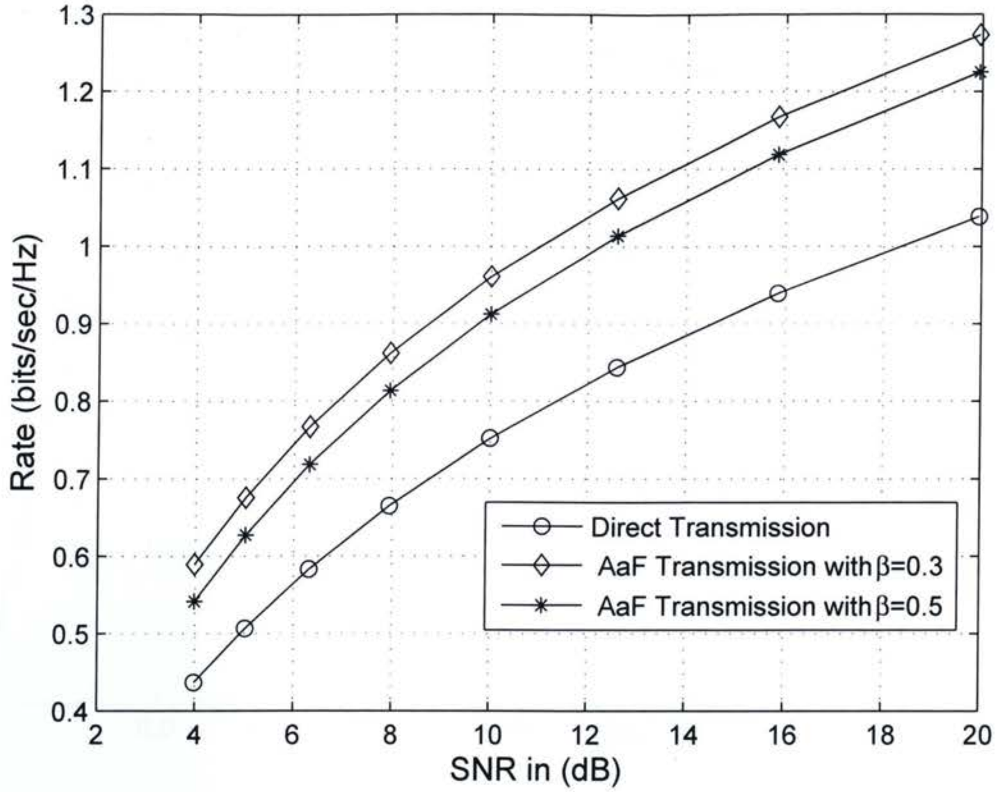

Figure 4.4: Rate performance as a function of SNR

users ignore the signal Y_{12}, hence this is equivalent to the well known multiple access channel capacity region. Also included in these figures is the achievable rate region of cooperation under the assumption of a noiseless interuser channel ($Z_1 = Z_2 = 0$). This is referred to as ideal cooperation, and is used mostly as upper bound for the performance of any cooperation scheme.

From Fig. 4.6, we observe that when the channels from the users to the BS have similar quality (h_1 and h_2 have the same mean) and the channel between the users is better (h_3 has larger mean), the cooperation scheme greatly improves the achievable rate region. This case of h_3 having larger mean could occur, for example, if two users are walking on the same street but neither has a direct line of sight link with the BS, thus making the interuser channel of higher quality than the two user - BS links. As the interuser channel degrades and the

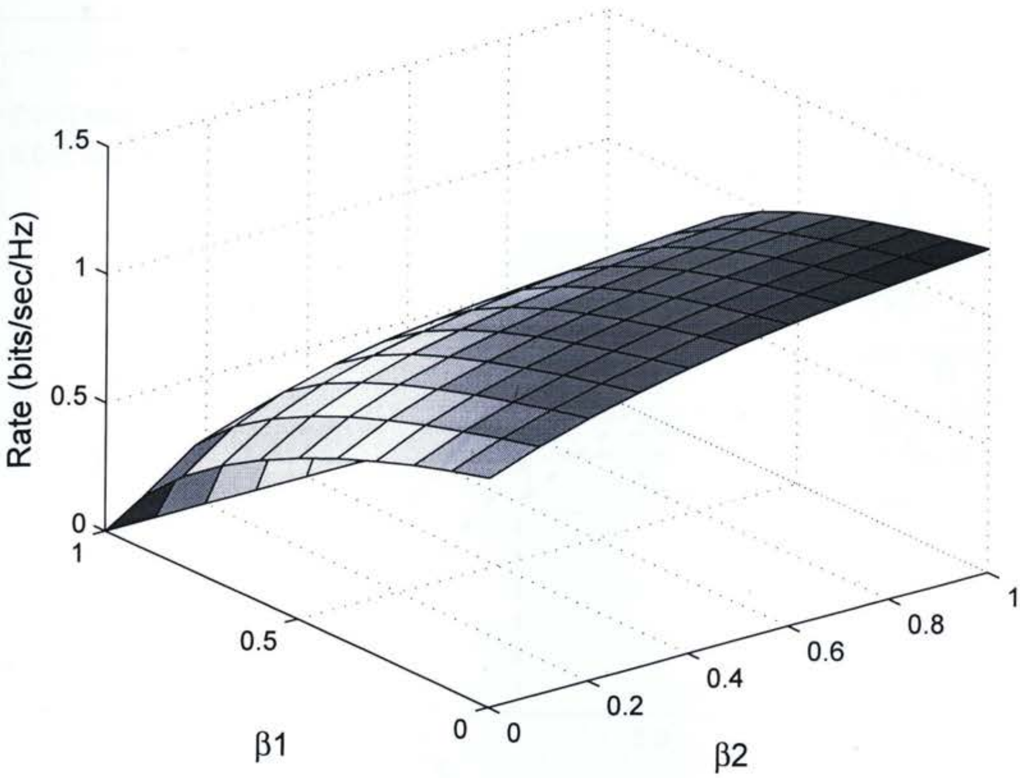

Figure 4.5: Rate performance as a function of SNR, $\beta 1$ and $\beta 2$

severity of the interuser fading increases, performance approaches that no cooperation.

When the user - BS links of the two users experience fading with different means, cooperation again improves the achievable rate region, as shown in Fig. 4.7. This case is as would occur, for example, if two users were at different distances from the BS. In this case, the user with more fading, benefits most from the cooperation. The equal rate point ($R_1 = R_2$) or the maximum rate sum point ($R_1 + R_2$)is increased considerably with cooperation.

It should be pointed out in the figure that the point where any achievable rate curve intersects the Y axis corresponds to user 2 becoming a relay for user 1, and the point where the curve intersects the X axis corresponds to user 1 becoming a relay for user 2. This demonstrates that the relay problem is a special, degenerate case of user cooperation, since the latter corresponds to an entire continuum of possible achievable rate pairs between the

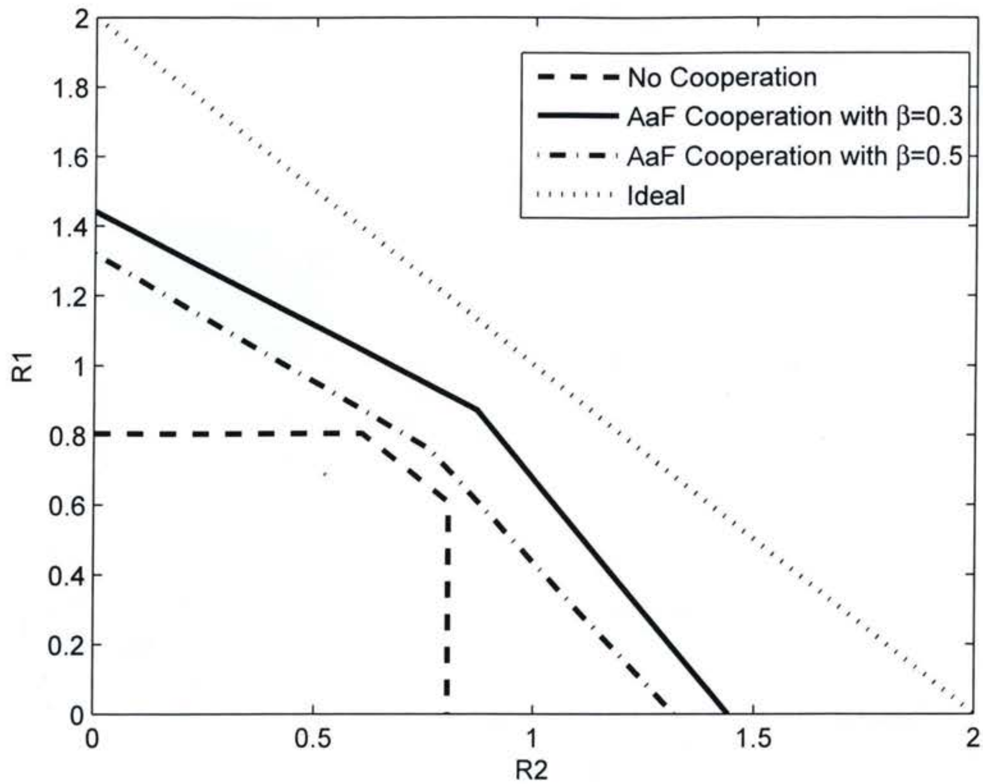

Figure 4.6: Achievable rate region when the two users face statistically similar channel towards the BS (h_1 and h_2 have the same mean)

two extremes $(R_1^{max}, 0)$ and $(0, R_2^{max})$.

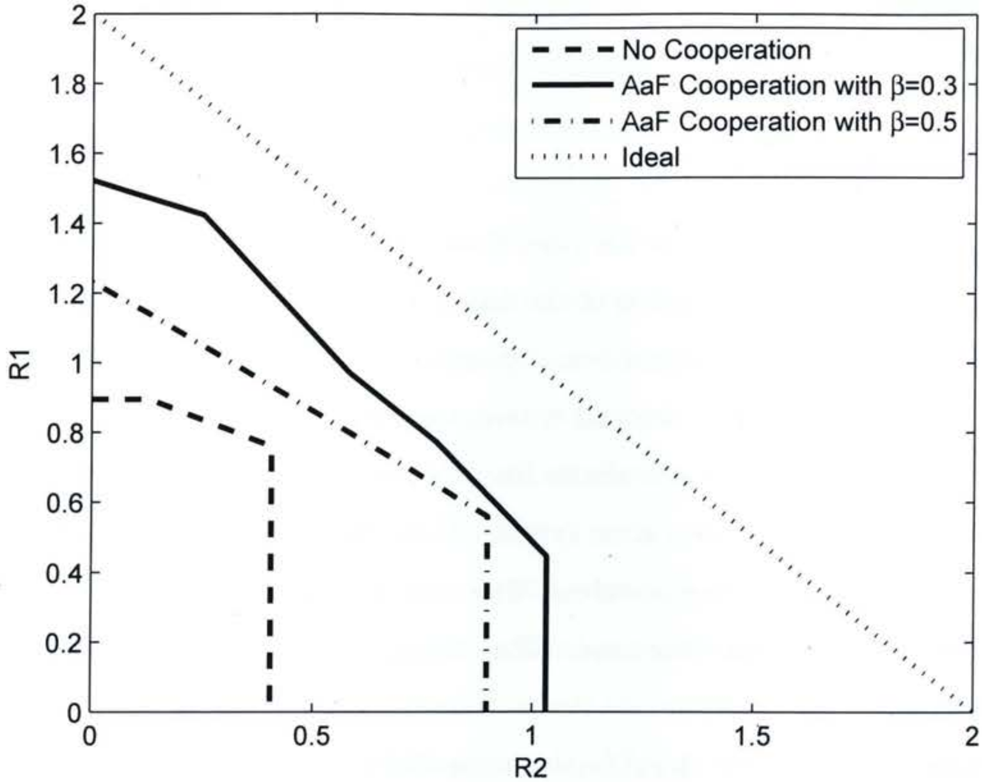

Figure 4.7: Achievable rate region when the two users face statistically dissimilar channel towards the BS (h_1 and h_2 experience different mean)

Chapter 5

Summary and Future Extensions

5.1 Summary

Wireless communication sector has been showing rapid evolution technologically during the recent years. With the evolution of the fourth generation communication systems, the demand for building up new transmission systems, with the higher speed rates has been on the increase. These techniques demand transmission schemes with premium quality and high rate of security. One such solution as discussed in this project was the implementation of user cooperation in communication systems, thus exploiting the benefits of spatial diversity, at the same time preserving resources. The various techniques and schemes of user cooperation from literature were discussed. The reasons for the core content of our project work was presented.

In this project power allocation strategies for amplify and Forward (AaF) cooperative transmission systems were investigated. It was shown that by exploiting spatial diversity in wireless channels, Information rate performance can be significantly improved by properly allocating powers for self information transmission under the constraint of fixed total transmit power of each user.

We investigated cooperative ratio, which is defined as the ratio of the cooperative information transmission power over total power. A closed form expression, denoted as β was obtained to maximize the mutual information upper bound. This value was a function of the average fading gain of the users direct channels towards destination and the interuser channel. Based on the assumption that the interuser channel has a higher average channel gain over the relay to destination channel, β was found to lie in the range [0.36,0.5]. Simulation results also showed that the optimal cooperative ration is related to SNR, besides channel fading gains.

5.2 Future Work

The results presented both analytically and through simulation denote the case of a single dimensional power allocation. We could further extend this to a case of two dimensional power allocation. As mentioned in our project, except during symmetric situation β calculated from user 2's point of view would be different. This could serve as a motivation to investigate two dimensional optimum power allocation problem. This could be based on the optimal solution of the user who has a weaker channel fading gain to the destination, i.e., the bottleneck user. The mutual information rate of the user with better channel condition, is less sensitive to the minor changes in cooperative ratio.

Even though we only discussed AaF protocol, similar approaches can be applied to investigate Decode and Forward protocol too. Our future work would include further investigation of the closed form expressions for the rate under realistic cooperative transmission, tradeoff between performance gains and overhead of user cooperation, and adaptive power allocation strategies. In addition, in a wireless network, where there exists a large number of parallel transmissions if using CDMA or FDMA protocols, AWGN accumulation and propagation may become prohibitive for AaF cooperative protocol. Our future work also includes analyzing this factor and to provide design guidelines for when to cooperate and when not to cooperate.

Bibliography

[1] G. J. Foschini and M. J. Gans, "On limits of wireless communications in a fading environment when using multiple antennas," *Wireless Personal Communications*, Volume: 6, Number: 3, 1998, Page(s): 311-335.

[2] J.G. Proakis, "Digital Communication," *McGrawHill Higher Education*, Edition 4.

[3] E. Erkip , A. Sendonaris and B. Aazhang, "User cooperation diversity. Part I. System description," *IEEE Transactions on Communications,*, volume : 51, Number :11, page(s) : 1927-1938, Nov 2003

[4] E. Erkip , A. Sendonaris and B. Aazhang, "User cooperation diversity. Part II. Implementation aspects and performance analysis," *IEEE Transactions on Communications,*, volume : 51, Number :11, page(s) : 1939-1948, Nov 2003

[5] A. Nosratinia, T.E. Hunter, and A.Hedayat "Cooperative communication in wireless networks," *IEEE Communications Magazine,*, page(s) : 74-80, Oct. 2004

[6] J. N. Laneman, D. N. C. Tse, and G. W. Wornell "Cooperative diversity in wireless networks: efficient protocols and outage behaviour," *IEEE Transactions on Inform. Theory,*, volume : 50, page(s) : 3062-3080, 2004

[7] Y. Shi, S. Sharma, Y. T. Hou and S. Kompella "Optimum Relay Assignment for Cooperative Communications," *in Proc. ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc)*, May 26-30, 2008, Hong Kong, China.

[8] O. Kaya and S. Ulukus "Power control for fading multiple access channels with user cooperation," *Proc. International Conference on Wireless Networks, Communications and Mobile Computing,*, page(s) : 1443-1448, 2005

[9] L. Zhao, J. W. Mark, and J. Ding, "Power distribution/allocation in multirate wideband cdma systems," *IEEE Trans. Wireless Communications,*, volume : 5, Number :9, page(s) : 2458 - 2467, Sept 2006

[10] D. R. Brown III "Resource allocation for cooperative transmission in wireless networks with orthogonal users," *Proc. Asilomar Conf. on Signals, Systems and Computers,*, volume : 2, page(s) : 1473 - 1477, 2004

[11] C. Pirak, Z. J. Wang, and K. J. R. Liu, "An Adaptive protocol for cooperative communications achieving asymptotic minimum symbol-error-rate," *Proc. IEEE Acoustic, speech and signal processing*, volume : 4, page(s) : 1453 -1456, 2006

[12] M. Dohler, A. Gkelias, and H. Aghvami, "Resource allocation for FDMA-based regenration multihop links," *IEEE Trans. Wireless Communications,*, volume : 3, Number :6, page(s) : 1989-1993, Nov. 2004

[13] M. O. Hasna and M.S. Alouini, "Optimal power allocation for relayed transmissions over Rayleigh-Fading channels," *IEEE Trans. Wireless Communications,*, volume : 3, Number :6, page(s) : 1999-2004, Nov. 2004

[14] J.Adeane, M. Rodrigues, and I.J. Wassell, "Centralized and distributed power allocation algorithms in cooperative networks," *Proc. IEEE 6th Workshop on Signal Processing Advances in Wireless Communications,*, page(s) : 333-337, 2005

[15] A. Ribeiro, X. Cai, and G. B. Giannakis, "Symbol error probabilities for general cooperative links," *IEEE Trans. Wireless Communications,*, volume : 4, Number :3, page(s) : 1264-1273, May 2005

[16] A. K. Sadek, W. Su,and K. J. R. Liu, "A Class of Cooperative Communcation protocol for multi-node wireless networks," *Proc. IEEE International Workshop on Signal Processing Advances in Wireless Communications,*, 2005

[17] L. Zhao and Z. Liao, "Power Allocation for Amplify and Forward Cooperative Transmission Over Rayleigh Fading Channel," *Journal of Communications,*, volume : 3, Number :3, page(s) : 33-42, July 2008

[18] Schwartz, Bennett, and Stein "Communication Systems and Techniques," *McGraw Hill,*, 1966

[19] A. R. Calderbank," The art of signalling: Fifty years of coding theory," *IEEE Trans. Inform. Theory,*, volume : 44, page(s) : 2561-2595, Oct. 1998

[20] S.Verdu," Wireless bandwidth in the making," *IEEE Commun. Mag.,*, page(s) : 53-58, July 2000

[21] A. Naguib, N. Seshadri, and A. R. Calderbank," Increasing data rate over wireless channels," *IEEE Signal Processing Mag.,*, page(s) : 76-92, May 2000

[22] J. Hagenauer and T. Stockhammer,"Channel Coding and Transmission aspects of wireless multimedia," *Proc. IEEE,*, volume : 87,page(s) : 1764-1777, Oct. 1999

[23] S. S. Hemami," Robust image communication over wireless channels," *IEEE Commun. Mag.,*, page(s) : 120-124, Nov. 2001

[24] I. Telatar,"Capacity of multi-antenna Gaussian channels," *Eur. Trans. Telecommun.,*, volume : 10, Number :6, page(s) : 585-595, Nov./Dec 1999

[25] G. J. Foschini and M. J. Gans, "On limits of wireless communications in a fading environment when using multiple antennas," *Wireless Personal Communications*, Volume: 6, Number: 3, 1998, Page(s): 311-335

[26] E. Biglieri, J. Proakis, and S. Shamai, " Fading Channels: Information Theoretic and communication: Performance criterion and code construction," *IEEE Trans. Inform. Theory,*, volume : 44, page(s) : 2619-2692, Oct. 1998

[27] V. Tarokh, N. Seshadri, and A. Calderbank, " Fading Channels: Information Theoretic and communication: Performance criterion and code construction," *IEEE Trans. Inform. Theory,*, volume : 44, page(s) : 744-765, Mar. 1998

[28] T. M. Cover and A. A. E. Gamal, " Capacity Theorems for the relay channel," *IEEE Trans. Inform. Theory,*, volume : 25, page(s) : 572-584, Sept. 1979

[29] J. N. Laneman, G. W. Wornell, and D. N. C. Tse, " An Efficient Protocol for realizing Cooperative Diversity in Wireless Networks," *Proc. IEEE ISIT,*, page(s) : 294, June 2001

[30] T. E. Hunter and A. Nosratinia, " Cooperative Diversity through Coding," *Proc. IEEE ISIT,*, page(s) : 220, June 2002

[31] T. E. Hunter and A. Nosratinia, " Diversity through Coded Cooperation," *IEEE Trans. Wireless. Theory,*, 2004

[32] R. Gallager, " An inequality on the capacity region of multiaccess fading channels," *Communications and Cryptography-Two Sides of One Tapestry,*, 1994

[33] D. Collins and C. Smith , "3G Wireless Networks," *McGrawHill Higher Education,*, 2002

[34] W.P.Siriwongprairat, Z.Han and K.J.Ray Liu," Lifetime maximization via cooperative nodes and relay deployment in wireless networks," *IEEE Journal on Selected Areas in Commun.,*, volume : 25, page(s) : 306-317, Feb. 2007

[35] A. Nosratinia and T.E. Hunter," Grouping and partner selection in cooperative wireless networks," *IEEE Journal on Selected Areas in Commun.,*, volume : 25, page(s) : 369-378, Feb. 2007

[36] V. Mahinthan, L. Cai, J. W. Mark and X. S. Shen," Partner Selection Based on Optimal Power Allocation in Cooperative Diversity Systems," *IEEE Transaction on Vehicular Technology,*, volume : 57, page(s) : 511-520, Jan. 2008

[37] S. Wei, D. L. Goeckel, and M. Valenti.," Asynchronous Cooperative Diversity," *IEEE Trans. Wireless Communications,*, volume : 5, page(s) : 1547-1557, April. 2006

[38] D. Vardhe, K.G. Reynolds," The Performance of Space-Time Coded Cooperative Diversity in an Asynchronous Cellular Uplink," *in proc. IEEE Military Communications Conference,*, Oct. 2006

[39] T.S. Rappaport," Wireless Communications: Principles and Practice," *Englewood Cliffs, NJ: Prentice-Hall,*, 1996

[40] Y.Chen, P. Cheng, P. Qiu and Z. Zhang," Optimal Partner Selection Strategies in Wireless Cooperative Networks with Fixed and Variable Transmit Power," *in Proc. IEEE Wireless Communications and Networking Conf.,*, page(s) : 4080-4084, Mar. 2007

[41] W. Su, A. K. Sadek, and K. J. R. Liu," SER performance analysis and optimum power allocation for decode-and-forward cooperation protocol in wireless networks," *in Proc. IEEE Wireless Communications and Networking Conf.,*, volume : 2, page(s) : 984-989, Mar. 2005

[42] F. Berggren,S. L. Kim," Energy-Efficient Control of Rate and Power in DS-CDMA Systems," *IEEE Transactions on Wireless Communications*, volume : 3, page(s) : 725-733, May. 2004

[43] Y. Zhao, R. Adve, and T. J. Lim," Improving Amplify-and-Forward Relay Networks: Optimal Power Allocation versus Selection," *IEEE Transactions on Wireless Communications*, volume : 6, page(s) : 3114-3123, Aug. 2007

[44] T. Cover and C. Leung," An achievable rate region for the multipleaccess channel with

versus Selection feedback," *IEEE Trans. Inform. Theory*, volume : 27, page(s) : 292-298, May. 1981

[45] F. M. J.Willems," The discrete memoryless multiple access channel with partially co-operating encoders," *IEEE Trans. Inform. Theory*, volume : 29, page(s) : 441-445, May. 1983

[46] F. M. J. Willems, E. C. van der Meulen, and J. P. M. Schalkwijk," Achievable rate region for the multiple access channel with generalized feedback," *in Proc. Annu. Allerton Conf. Communication, Control, Computing*, page(s) : 284-292, 1983

[47] F. Willems and E. V. D. Meulen," The discrete memoryless multipleaccess channel with cribbing encoders," *IEEE Trans. Inform. Theory,*, page(s) : 313-327, May 1985

Appendix A

Abbreviation List

CDMA	Code Division Multiple Access
TDMA	Time Division Multiple Access
FDMA	Frequency Division Multiple Access
BER	Bit Error Rate
AaF	Amplify and Forward
BS	Base Station
TDD	Time Division Duplexing
FDD	Frequency Division Duplexing
DF	Decode and Forward
MIMO	Multiple Input Multiple Output
QoS	Quality of Service
GSM	Global System for Mobile communications
AMPS	Advanced Mobile Phone System
TACS	Total Access Communication System
RTMI	Radio Telefono Mobile Integrato
NTT	Nippon Telegraph and Telephone Corporation
JTACS	Japanese Total Access Communication System
GPRS	General Packet Radio Service
RTT	round-trip delay time
HSCSD	High-speed circuit-switched data
PCS	Partitioning Communication System
PDC	Primary Domain Controller
ITU	International Telecommunication Union
SNR	Signal to Noise Ratio
SER	Symbol Error Rate
AWGN	Additive White Gaussian Noise