PERFORMANCE ANALYSIS OF COOPERATIVE COMMUNICATION USING SPACE TIME NETWORK CODES

PROJECT REPORT

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Certified that this project report titled **"PERFORMANCE ANALYSIS OF COOPERATIVE COMMUNICATION USING SPACE TIME NETWORK CODES"**, is the bonafide work of **LAVANYA.D [Reg. No. 13MCO12]** who carried out the research under my supervision. Certified further that, to the best of my knowledge the work reported herein does not form part of any other project or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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ABSTRACT

It is well-known that the performance of communication systems degrades when operating in radio-frequency (RF) environments characterized by multipath fading, path loss and shadowing. Diversity techniques like time, frequency, and spatial diversity can be utilized to resolve the above problems. The multiple-input multiple-output (MIMO) technologies in which communication devices are equipped with multiple transmit and/or multiple receive antennas, can significantly increase communication reliability through the use of spatial diversity. Although MIMO provides spatial diversity to improve communication performance, the use of MIMO technology possesses a number of issues in practical applications.

Cooperative diversity has been proposed as a way to form virtual antenna arrays that provide dramatic gains in fading wireless environments. Nodes in a network acting as relays can retransmit overheard information to a destination, where the intended information from the source signal and the relay signals is combined and detected. The distributed antennas among the relays are used to provide spatial diversity without the need to use multiple antennas at the source. In this project, we have analyzed the performance of various relaying protocols such as decode and forward, amplify and forward with single and multiple relays derived using BPSK over Rayleigh channel with maximum ratio combining technique. Results reveals that the cooperative communication is efficient, compared to the conventional non-cooperative scheme.

To save channel use for data forwarding phase, the relay combines different source messages via network coding and forward a single mixed message rather than forward the individual messages separately. This is achieved by using Space

Time Network Codes, which involves combining information from different sources at a relay node, which gives rise to the concept of network coding and transmitting the combined signal in a dedicated time slot, which makes the space–time concept. In this project we have applied this in the case of Multipoint to Point (M2P) cooperative communication and analyzed for both Decode and Forward (DF) and Amplify and Forward (AF) relaying protocol. Here four client nodes and two relay nodes are used with BPSK modulation over Rayleigh fading channel with AWGN. The STNC is compared with the direct transmission in which the previous technique gives a reduced error rate compared to the latter one.

Comparative analysis of cooperative communication and M2P STNC has been carried out for both DF and AF relay protocols. The results show that M2P STNC shows improved performance than the traditional cooperative communication.

Further this work can be extended in Rician fading channel and over frequency selective fading. The same technique can also be applied to Point to Multipoint (P2M) communication.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

MIMO	-	Multi Input Multi Output
CC	-	Cooperative Communication
WNC	-	Wireless Network Cocast
STNC	-	Space Time Network Codes
M2P	-	Multipoint to Point
DF	-	Decode and Forward
AF	-	Amplify and Forward
DTX	-	Direct Transmission
AWGN	-	Additive White Gaussian Noise
QoS	-	Quality of Service
MRC	-	Maximal Ratio Combining
SNR	-	Signal to Noise Ratio
BER	-	Bit Error Rate

CHAPTER 1

INTRODUCTION

1.1 COMMUNICATION SYSTEMS

Today, Communication enters our daily lives in so many different ways. The telephone at our hands, the radios, the television, the computer terminals with access to the internet in offices and homes are all capable of providing rapid communications from every corner of the globe. Indeed, the list of applications involving the use of communication in one way or another is almost endless.

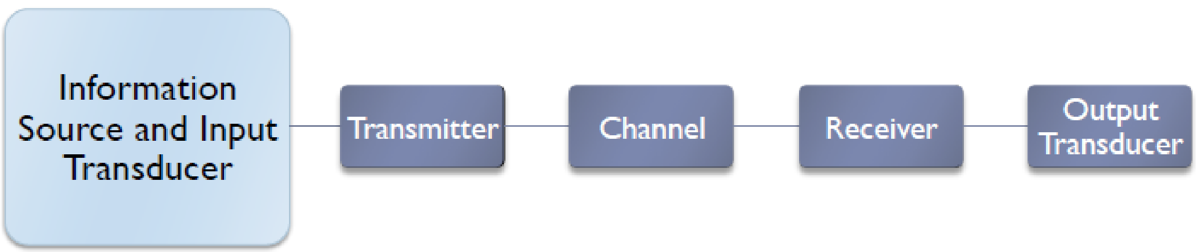

Figure.1.1 Basic elements of communication systems

Three basic elements of every communication system, namely, transmitter, channel and receiver as depicted in Fig.1.1. The transmitter is located at some point in space, the receiver is located at some other point separate from the transmitter, and the channel is the physical medium that connects them. The purpose of the transmitter is to convert the message signal produced by the source of information into a form suitable for the transmission over the channel. However, as the transmitted signal propagates along the channel, is distorted due to channel imperfections. Moreover, noise and interfering signal are added to the channel output, with the result that the received signal is corrupted version of the transmitted signal. The receiver has the task of operating on the received signal so as to reconstruct a recognizable form of the original message signal for the user.

The channel is of two types: Wired and Wireless channel in which the latter is discussed in detail below.

1.2 Wireless communication

Wireless communications is the fastest growing segment of the communications industry. Cellular phones have experienced exponential growth over the last decade, and this growth continues unabated worldwide, with more than a billion worldwide cell phone users projected in the near future. Indeed, cellular phones have become a critical business tool and part of everyday life in most developed countries, and are rapidly supplanting antiquated wire line systems in many developing countries. In addition, wireless local area networks are currently poised to supplement or replace wired networks in many businesses and campuses. Many new applications, including wireless sensor networks, automated highways and factories, smart homes and appliances, and remote telemedicine, are emerging from research ideas to concrete systems. The explosive growth of wireless systems coupled with the proliferation of laptop and palmtop computers indicate a bright future for wireless networks, both as stand-alone systems and as part of the larger networking infrastructure. However, many technical challenges remain in designing robust wireless networks that deliver the performance necessary to support emerging applications.

1.2.1 Technical Challenges

As a signal propagates through a wireless channel, it experiences random fluctuations in time if the transmitter or receiver is moving, due to changing reflections and attenuation. Thus, the characteristics of the channel appear to change randomly with time, which makes it difficult to design reliable systems with guaranteed performance.

The most significant technical challenge in wireless network design is an overhaul of the design process itself. Wired networks are mostly designed according to the layers of the OSI model: each layer is designed independent from the other layers with baseline mechanisms to interface between layers. This methodology greatly simplifies network design, although it leads to some inefficiency and performance loss due to the lack of a global design optimization. However, the large capacity and good reliability of wired network links make it easier to buffer high-level network protocols from the lower level protocols for link transmission and access, and the performance loss resulting from this isolated protocol design is fairly low.

However, the situation is very different in a wireless network. Wireless links can exhibit very poor performance, and this performance along with user connectivity and network topology changes over time. In fact, the very notion of a wireless link is somewhat fuzzy due to the nature of radio propagation. The dynamic nature and poor performance of the underlying wireless communication channel indicates that high-performance wireless networks must be optimized for this channel and must adapt to its variations as well as to user mobility.

1.2.2 Wireless channel

In this section we focus on the wireless channel. Wireless channels make use of radio frequency part of electromagnetic spectrum to operate. Hence, they are also called radio frequency channel. Wireless channel is characterized by its multipath, time varying and broadcast nature. These characteristics are described below.

1.2.3 Multipath nature

Multipath refers to the situation that there are more than one propagation path between a transmitter and a receiver. Multipath are caused by the reflection, diffraction and scattering of the transmitted signal due to the surface of the Earth, buildings, foliage, street signs, lamp posts, peoples walking around etc. Fig.1.2 shows the illustration of multipath.

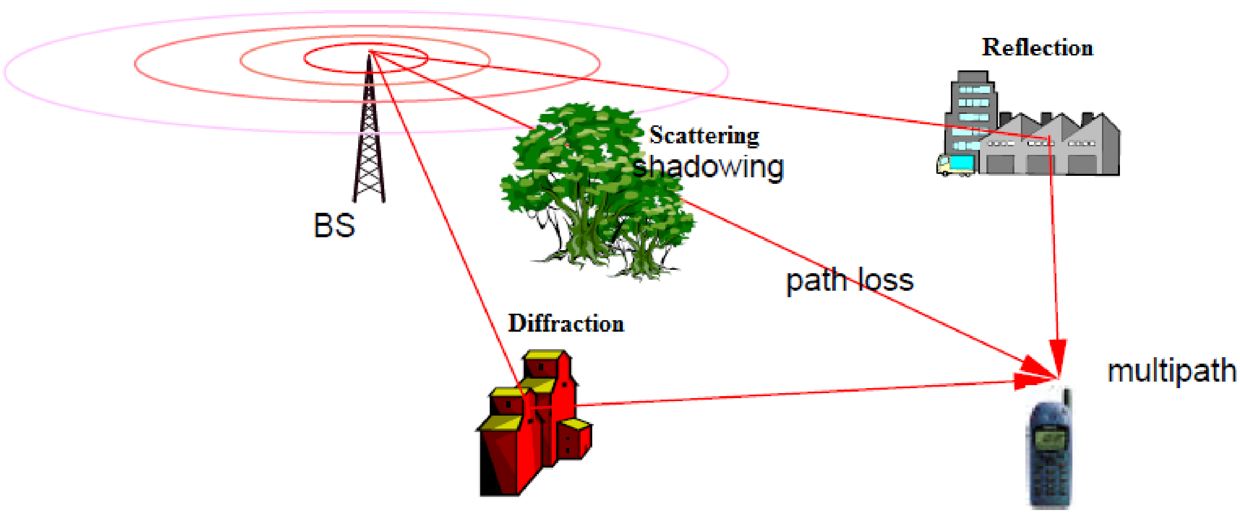

Figure.1.2 Multipath nature

The received signals form multi paths are superimposed with each other. Depending on the phase difference (or path difference) of the multipath, the superposition may be either constructive or destructive. When the superposition is constructive, the received signal will be strong. On the other hand, when the superposition is destructive, the received signal will be weak.

1.2.4 Time varying nature

Time variation of the wireless channel results from the mobility of the transmitter, the receiver or the environment (e.g. obstacle). Hence, the number of multipath, strength of multipath as well as delays of the multipath can be time varying.

1.2.5 Broadcast nature

In a wireless medium when a node transmits, its transmission is overheard by other nodes within its range. But only the recipient node will respond to the transmission. Other nodes treat these overheard signals as interference and the system provides mechanisms to mitigate this interference.

1.3 Channel Model

The simplest wireless channel is the additive white Gaussian noise (AWGN) channel where the output signal from the channel is given by:

$$y = x + n \tag{1.1}$$

where x is the complex modulated signal transmitted through the channel and 'n' is the Additive Gaussian White Noise random variable with zero mean and variance σ^2.In this channel, the received signal is composed of an undistorted transmit signal infected with channel noise. For AWGN the noise variance in terms of noise power spectral density(N_0) is given as:

$$\sigma^2 = N_0/2 \tag{1.2}$$

AWGN channel is quite an accurate model for deep space communication between earth station and satellites. On the other hand, for terrestrial wireless communication, the channel model is much more complicated due to the time varying nature as well as multipath nature of the wireless channel. This introduces distortions in the transmitted signal. To capture different types of distortions we use a three level model.

1.3.1 Large scale path loss model

The first level model is called large scale path loss model. The path loss model focuses on the study of the long term or large scale variations on the average received signal strength due to the variation of distance from the transmitter and the receiver. The path loss indicates how fast the received signal strength drops with respect to change in distance. The simplest path loss model is the free space path loss model where the average received signal strength is inversely proportional to the square of the distance e.g. the received signal strength is reduced by 4 times if we double the distance. But for terrestrial wireless communication the signal strength decreases more quickly. The path loss between transmitter and receiver is characterized by path loss exponent, which depends on environment. For free space or rural area its value is 2, for suburban from 2 to 3, for urban its value is about 4.

The higher the path loss exponent is, the faster the signal strength drops with increasing the distance. In some more composite environments such as irregular terrain the path loss exponent is not deterministic. So some empirical model is used to model the path loss. Examples are Okumura model, Hata model and COST 231 extension to Hata model

1.3.2 Medium Scale Shadowing Model

Shadowing model is the second level model, used to study the medium term variations in the received signal strength when the distance between the transmitter and receiver is fixed. For e.g., a mobile station is circling around a base station, as the mobile moves, one expects some medium term fluctuations in the received signal strength. This signal variation is due to the variations in the terrain profile such as variation in the blockage due to trees, buildings, hills etc. This effect is called shadowing.

1.3.3 Small Scale Fading Model

The third level model which is used to quantify the variation of received signal strength is called small scale fading model. In small scale fading the signal strength fluctuates over 30dB in a very short time scale (i.e. mili or micro seconds). Fading is of two types, namely multipath fading and time varying fading, which are independent of each other.

1.3.3.1 Multipath Fading

To quantify the effects of multipath fading we use either the delay spread or coherence bandwidth. Delay spread is defined as the range of multipath components with significant power when an impulse is transmitted, as depicted in the fig1.3. The graph of received power with delay is called power delay profile (PDP) and is used to measure the delay spread. It is measured in micro seconds.

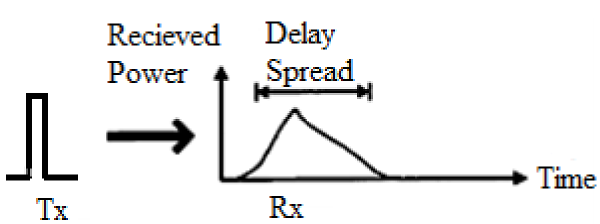

Figure.1.3 Delay spread

Typically, the delay spread in indoor environment is smaller than the outdoor environment because the multi paths are more contained in the indoor environment.

On the other hand, to quantify the multipath fading, an equivalent parameter, called coherence bandwidth, can be used. It is defined as the minimum frequency separation at the transmitter such that uncorrelated fading occur at the receiver. Mathematically,

$$|f1 - f2| > B_c \tag{1.3}$$

where B_c is the coherence bandwidth. This is the bandwidth over which the channel transfer function remains virtually constant. It is related to delay spread as follows:

$$B_c \approx {}^{1}/_{\sigma_\tau} \tag{1.4}$$

1.3.3.2 Flat Fading vs. Frequency Selective fading

Based on the delay spread and the transmitted symbol duration, or equivalently the coherence bandwidth and the transmitted signal bandwidth, the multipath fading can be classified as frequency flat fading or frequency selective fading. A fading channel is said to be frequency flat if $\sigma_\tau < T_s$. Otherwise the fading channel is said to be frequency selective.

When the transmit signal experience flat fading the received signal consists of a single pulse, which is composed of superposition of multipath signals with delays much smaller than the symbol duration, hence the multipath are irresolvable. The effect of flat fading is the flattening of the BER curve.

On the other hand, when a transmit signal experience frequency selective fading, the received signal consists of multipath with delays greater than symbol duration. Hence, the received signal consists of pulses at resolvable delays. The effect of frequency selective fading is flattening of BER curve and mixing of symbols (ISI).

1.3.3.3 Time Varying Fading

To characterize time varying fading effect we can use either the Doppler spread or coherence time. Doppler spread refers to the spread of frequency introduced by the fading channel when we transmit a single narrow pulse as shown in the fig.1.4 below:

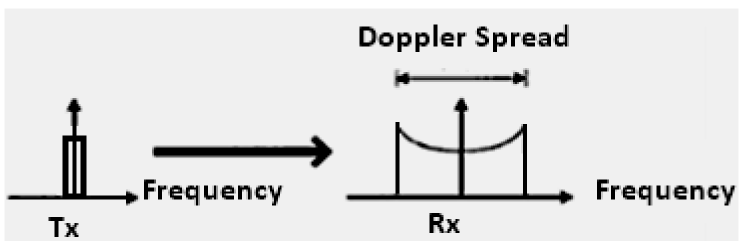

Figure.1.4 Doppler spread

The spread in the frequency is due to the mobility between transmitter and the receiver or the mobility of the surrounding obstacles. The maximum Doppler spread is given by:

$$f_d \approx {}^{v}/_{\lambda} \tag{1.5}$$

On the other hand, coherence time is defined as the minimum time separation at the transmitter in order to have uncorrelated fading at the receiver. Mathematically,

$$|t1 - t2| > T_c \tag{1.6}$$

Coherence time is a measure of the time duration over which the channel impulse response is invariant, and quantifies the similarity of the channel response at different times.

$$T_c \approx {}^{1}\!/_{f_d} \quad (1.7)$$

1.3.3.4 Fast Fading vs. Slow fading

Similarly, based on the Doppler spread and the transmitted bandwidth or equivalently the coherence time and the symbol duration, the time varying fading can be classified as fast fading or slow fading. A fading channel is called a fast fading channel if $T_s > T_c$. Otherwise the fading channel is called as slow fading. In fast fading, the channel impulse response changes rapidly within the symbol duration whereas in slow fading it changes slowly.

1.3.4. Rayleigh Fading vs. Rician fading

Rayleigh fading is a type of fading that occurs when there is large number of reflections present. The Rayleigh fading uses a statistical approach to analyze the propagation, and can be used in a number of environments. It operates best under conditions when there is no dominant signal (e.g. direct line of sight signal), and in dense urban environments. Rayleigh fading has a fading envelope in the form of the Rayleigh Probability Density Function (PDF).

The Rician fading is similar to Rayleigh fading, except that in Rician fading a strong dominant component is present. This dominant component can be the line-of-sight signal. Besides the dominant component, there is large number of reflected and scattered waves. This fading characteristic exhibits a Rician PDF (Probability Density Function).

1.4 MIMO Systems

It is well-known that the performance of communication systems degrades greatly when operating in radio-frequency (RF) environments characterized by multipath fading, path loss and shadowing. These impairments can be compensated by various ways such as by increasing transmit power, bandwidth, and/or applying powerful error control coding (ECC). However, power and bandwidth are scarce and expensive radio resources while ECC yields reduced transmission rate. Hence, acquiring a high data rate together with reliable transmission over error-prone wireless channels is a major challenge for a wireless system designer. In conventional direct transmission (DTX), where mobile units directly transmit their information to a common destination, the distant mobile units require more transmit power to provide a comparable quality of service (QoS) to that of the closer ones. Consequently, high aggregate transmit power, which is the sum of all transmit power of individual mobile units, and uneven power distribution among them exist in the network. Diversity techniques like time, frequency, and spatial diversity can be utilized to resolve the above problems.

The multiple-input multiple-output (MIMO) technologies in which communication devices are equipped with multiple transmit and/or multiple receive antennas, can significantly increase communication reliability through the use of spatial diversity. Although MIMO provides spatial diversity to improve communication performance, the use of MIMO technology possesses a number of issues in practical applications. First, the required separation among antennas, usually at least a half of wavelength, makes MIMO unsuitable for low transmit frequencies, which are used to have low free-space path loss and thus a longer battery life. Second, the use of multiple RF chains at a device increases the size and weight of the device and thus limits certain MIMO applications such as those in wireless sensor networks and military hand-held devices.

Figure.1.5 Illustration of MIMO and virtual MIMO systems

To overcome the above drawback, an innovative approach known as cooperative communication has been suggested to exploit MIMO's benefit in a distributed manner. Such a technique is also called a virtual MIMO, since it allows single antenna mobile terminals to reap some of the benefits of MIMO systems. This concept is illustrated in Fig.1.5.

1.5 Cooperative Communication

Cooperative communication makes use of broadcast nature of wireless transmission. Nodes in a network acting as relays can retransmit overheard information to a destination, where the intended information from the source signal and the relay signals is jointly detected. The distributed antennas among the relays are used to provide spatial diversity without the need to use multiple antennas at the source. Various cooperative diversity protocols have been proposed such as decode-and-forward (DAF) and amplify-and-forward (AAF) protocols for cooperative communication are explained.

Cooperative communications often consist of two phases: the source transmission phase and the relay transmission phase. In the first phase, a source broadcasts its information to relays, which then forward the overheard information to the destination in the second phase.

Much research in cooperative communications has focused on simultaneous transmissions from two or more nodes by using frequency-division multiple access (FDMA), code-division multiple access (CDMA), or distributed space-time codes (DSTCs) with an assumption of perfect frequency and timing synchronization. However, such an assumption is difficult to be met in practice due to the asynchronous nature of distributed antennas. The issues of imperfect frequency and timing synchronization prohibit two or more nodes from transmitting at the same time.

1.6 Space Time Network Codes

To overcome these issues, time-division multiple access (TDMA), where each relay node take turn to forward the overheard symbols, would be the most commonly-used technique in many applications. However, TDMA requires large transmission delays, especially for networks with large numbers of source nodes and relay nodes. Therefore, there is an essential need to overcome the issues of imperfect frequency and timing synchronization while maintaining the spatial diversity and reducing the total required time slots.

A novel concept called Wireless Network Cocast (WNC) associated with space-time network codes (STNCs) to achieve the objectives of eliminating the issues of imperfect frequency and timing synchronization while maintaining the full spatial diversity in cooperative communications with low transmission delays. Cocast, an abbreviation of cooperative cast, is a transmission method, in which information from different source nodes are jointly combined within a relay and transmitted to the intended destinations.

Fundamentally, STNC involves combining information from different sources at a relay node, which gives rise to the concept of network coding and transmitting the combined signal in a dedicated time slot, which makes the space–time concept.

Two general cases of multipoint-to-point (M2P) and point-to-multipoint (P2M), where user nodes transmit and receive their information to and from a common base node, respectively, with the assistance from relay nodes in which first case is described. Both DF and AF protocols in cooperative communications are considered. Here, the performance of relay protocol with the direct transmission was compared using space time network codes for M2P communication.

The following chapters are as follows: In the next chapter, literature survey of both cooperative communication and STNC will be discussed followed by the detailed explanation of both in later two chapters. The fifth chapter contains the simulation results followed by conclusion and references in chapter six and seven respectively.

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

This chapter presents the literature surveyed in the area of cooperative communication and space time network coding (STNC). The purpose of this is to choose the appropriate techniques and also calculating different parameters of the system.

[1] In the paper "*User Cooperation Diversity—Part I andPart II"*, they have introduced the cooperative diversity. Mobile users' data rate and quality of service are limited by the fact that, within the duration of any given call, they experience severe variations in signal attenuation, thereby necessitating the use of some type of diversity. In this two-part paper, a new form of spatial diversity, in which diversity gains are achieved via the cooperation of mobile users. Part I describes the user cooperation strategy, while Part II focuses on implementation issues and performance analysis. Results show that, even though the inter user 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.

[2]In this paper *"Cooperative Diversity in Wireless Networks: Efficient Protocols and Outage Behavior",* they have developed and analyzed low-complexity cooperative diversity protocols that combat fading induced by multipath propagation in wireless networks. The techniques exploit space diversity available through cooperating terminals relaying signals for one another. Several strategies employed by the cooperating radios, including fixed relaying schemes

such as amplify-and-forward and decode-and-forward, selection relaying schemes that adapt based upon channel measurements were analyzed. Cooperation with half-duplex operation requires twice the bandwidth of direct transmission for a given rate, and leads to larger effective SNR losses for increasing spectral efficiency Despite these costs, there analysis demonstrates significant performance enhancements, particularly in the low-spectral-efficiency regime.

[3]In this paper, *"Multinode Cooperative Communications in Wireless Networks"* a class of cooperative communication protocols with arbitrary N-relay nodes is proposed for wireless networks, in which each relay coherently combines the signals received from previous relays in addition to the signal from the source. The performance of a simple cooperation scenario in which each relay combines the signals arriving from the previous relay and the source is asymptotically exactly the same as that for the most complicated scenario in which each relay combines the signals arriving from all the previous relays and the source. The analysis also reveals that the proposed protocols achieve full diversity gain in the number of cooperating terminals.

[4] The author of, *"Cooperative communications in wireless networks: performance analysis and optimum power allocation,"* says that they have provided symbol-error-rate (SER) performance analysis and optimum power allocation for uncoded cooperative communications in wireless networks with either DF or AF cooperation protocol, in which source and relay send information to destination through orthogonal channels. In both the DF and AF cooperation systems, it turns out that an equal power strategy is good, but in general not optimum in cooperative communications. The optimum power allocation depends on the channel link quality. It is shown that the performance of systems with the

DF cooperation protocol is better than that with the AF protocol. However, the performance gain varies with different modulation types and channel conditions, and the gain is limited.

[5]In, *"Cooperative Communications with Relay-Selection: When to Cooperate and Whom to Cooperate With?"* a new cooperative communication protocol, achieves higher bandwidth efficiency while guaranteeing the same diversity order as that of the conventional cooperative schemes. The source determines when it needs to cooperate with one relay only, and which relay to cooperate with in case of cooperation. They have defined the optimal relay as the one which has the maximum instantaneous scaled harmonic mean function of its source relay and relay-destination channel gains among the *N* helping relays. For the symmetric scenario, they have presented an approximate expression of the achievable bandwidth efficiency, which decreases with increasing the number of employed relays.

[6]In this work, *"Location-Aware Cooperative Communications utilizing Linear Network Coding"* a location-aware cooperation-based scheme that aims to reduce transmits power of distant mobile units while maintaining a low transmission delay was proposed. The scheme utilizes a linear network coding protocol; where each mobile unit applies linear network coding to a set of transmit symbols that it has received previously. At the base station, multiuser detection is used to decouple the transmit symbols. Both decode-and-forward and amplify-and-forward cooperative protocols are considered and performance analysis was presented, and simulations showed that the proposed scheme can achieve a comparable performance but with a substantial reduction in delay in comparison with the conventional cooperation-based TDMA scheme.

[7]In this paper, *"Wireless Network Cocast: Location-Aware Cooperative Communications with Linear Network Coding"* location-aware cooperation-based schemes namely immediate-neighbor cooperation (INC), maximal cooperation (MAX), and wireless network cocast (WNC) that achieve spatial diversity to reduce aggregate transmit power and even power distribution were considered. In WNC, mobile units acting as relays form unique linearly-coded signals from overheard signals and transmit them to the destination, where a multiuser detector jointly detects the symbols from all received signals. WNC can achieve low aggregate transmit power and even power distribution of MAX with low transmission of INC.

[8]In this work, *"Multipoint to Point and Point to Multipoint Space Time Network Coding"*, space-time network codes (STNCs) that overcome the issue of imperfect synchronization, reduce the large transmission delay, and still provide full spatial diversity in multipoint-to-point (M2P) and point-to-multipoint (P2M) transmissions were proposed. Relays form single linearly-coded signals from the overheard symbols and transmit them to the destination, where multiuser detection is utilized to detect the desired symbol. For a network of N client nodes and a base node, M2P and P2M STNCs result in a diversity order of N for each transmitted symbol with a total of $2N$ time slots, a substantial reduction in comparison with N^2 time slot required in the traditional cooperative communications using TDMA.

[9]In this work, *"Space Time Network Codes"* a framework for cooperative communications is proposed to achieve full spatial diversity with low transmission delay and eliminate the issue of imperfect synchronization. This is realized by the use of space–time network codes (STNCs) associated with a concept of wireless

network cocast. For a network N of client nodes, R relay nodes and a base node, the STNCs provide a diversity order of (R+1) for each symbol with (N+R) time slots, a reduction from 2N time slots in traditional FDMA and CDMA cooperative communications for being usually greater than R and from N(R+1) time slots in traditional TDMA cooperative communications. The STNCs are also applied in networks, where the client nodes located in a cluster act as relays to help one another to improve their transmission performance.

[10]To explore the potential capacity of STNC-based systems, in the paper, *"Space Time Network Coding with overhearing relays"* a new cooperative relaying scheme, termed space-time network coding with overhearing relays (STNC-OR), by allowing each relay to collect the signals transmitted from not only the sources but also its previous relays. Then, some explicit expressions for the outage probability and symbol error rate (SER) for STNCOR with decode-and-forward relaying over independent non-identically distributed (i.n.i.d) Rayleigh fading channels were derived. It is shown that the proposed STNC-OR achieves much lower outage probability and SER than STNC and traditional pure TDMA relaying schemes.

In this chapter we have surveyed about the cooperative diversity, the protocols used in single and multiple relay scenarios, their performance analysis and power allocation. Then, in WNC network M2P and P2M communication is applied and analyzed. Here we have considered the STNC which is applied in M2P cooperative communication scenario.

CHAPTER 3

COOPERATIVE COMMUNICATION

Cooperative communications make use of broadcast nature of wireless transmission with nodes in a network acting as relays retransmitting overheard information to the intended destination. The distributed antennas from the source and the relays form a virtual antenna array, and spatial diversity is achieved without the need to use multiple antennas at the source node.

This idea is particularly attractive in wireless environments due to the diverse channel quality and the limited energy and bandwidth resources. With cooperation, users that experience a deep fade in their link towards the destination can utilize quality channels provided by their partners to achieve the desired QoS. Two features differentiate cooperative transmission schemes from conventional non cooperative systems:

1) The use of the multiple users' resources to transmit the data of a single source.
2) A proper combination of signals from multiple coordinating users at the destination.

A canonical example is shown in Figure 3.1, where we have two users transmitting their local messages to destination over independent fading channels. The transmission fails when the channel enters deep fade i.e., when SNR of the received signal falls below a certain threshold. If the two users cooperate by relaying each other's messages and the inter user channel is sufficiently reliable,

then the expected result is obtained. The communication outage occurs only when both the users experience the poor channels simultaneously as a result communication fails.

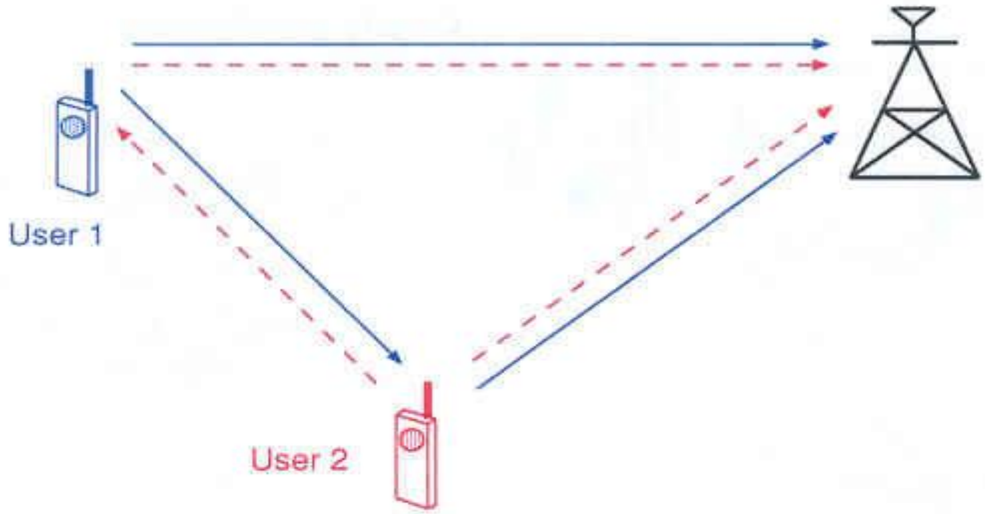

Figure 3.1 Cooperative communications.

3.1 Relay Channels

A relay channel is a three-terminal network consisting of a source, a relay and a destination. The source broadcast to both relay and destination. Also, the relay forwards the received message to the destination.

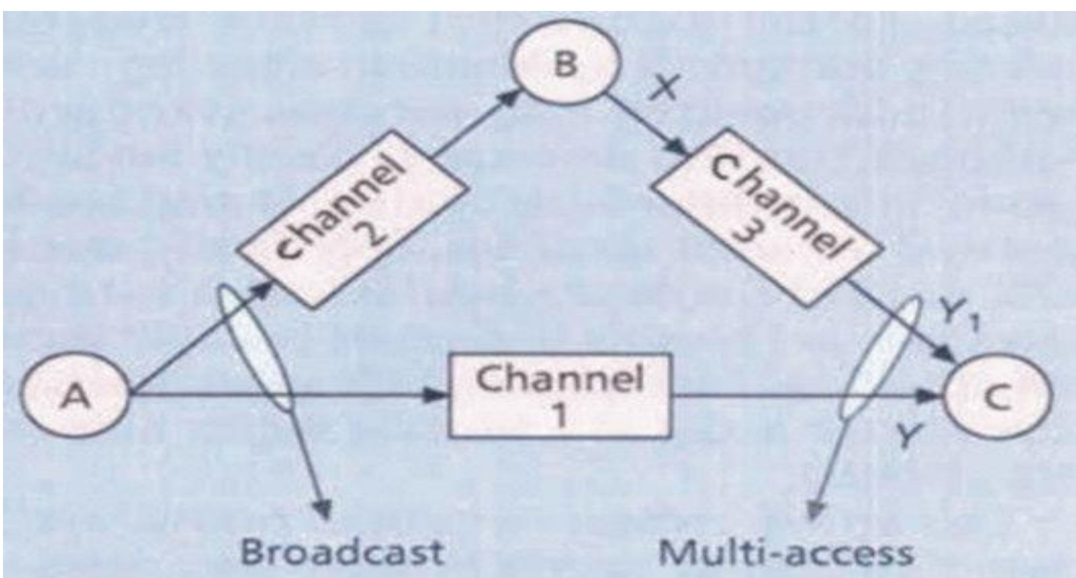

Figure 3.2 Relay channel

Relay systems can achieve distributed spatial diversity in wireless networks of single-antenna devise transmitting over quasi-static fading channel. Relaying can be used to form a *virtual antenna array*. The strategy of cooperative diversity can be exploited by exchanging the role of source and relay.

Coordination is needed in these systems since antennas are not located at a single terminal as in a MIMO system. This may result in system inefficiency, but the cost is often compensated by significant diversity gain at high SNR. Coordination can be achieved by direct inter user communication or by the use of feedback from the destination. Based on the information obtained through coordination, cooperating partners compute and transmit messages so as to reduce the transmission cost or to enhance the detection performance at the receiver in the second phase.

Cooperative communications often consist of two phases: the source transmission phase and the relay transmission phase. In the first phase, a source broadcasts its information to relays, which then forward the overheard information to the destination in the second phase.

The processing of the signal at the relay node which is received from the source is described with the help of cooperative transmission protocols. Different transmission protocols such as Decode and Forward (DF) and Amplify and Forward (AF) were proposed.

3.2 Decode and forward

The most popular method for processing the signal at the relay node is decode and forward, in this technique, the relay detects the source data, decodes and then transmits it to the desired destination. The concept of the Decode and Forward technique is shown in Figure 3.3.

An error correcting code can also be implemented at the relay station. This can help the received bit errors to be corrected at the relay station.

The advantage of DF relaying is that if the relay can successfully decode the received signal, the source-relay link noise effect is canceled out, while in the AF strategy, the relay amplifies also the noise.

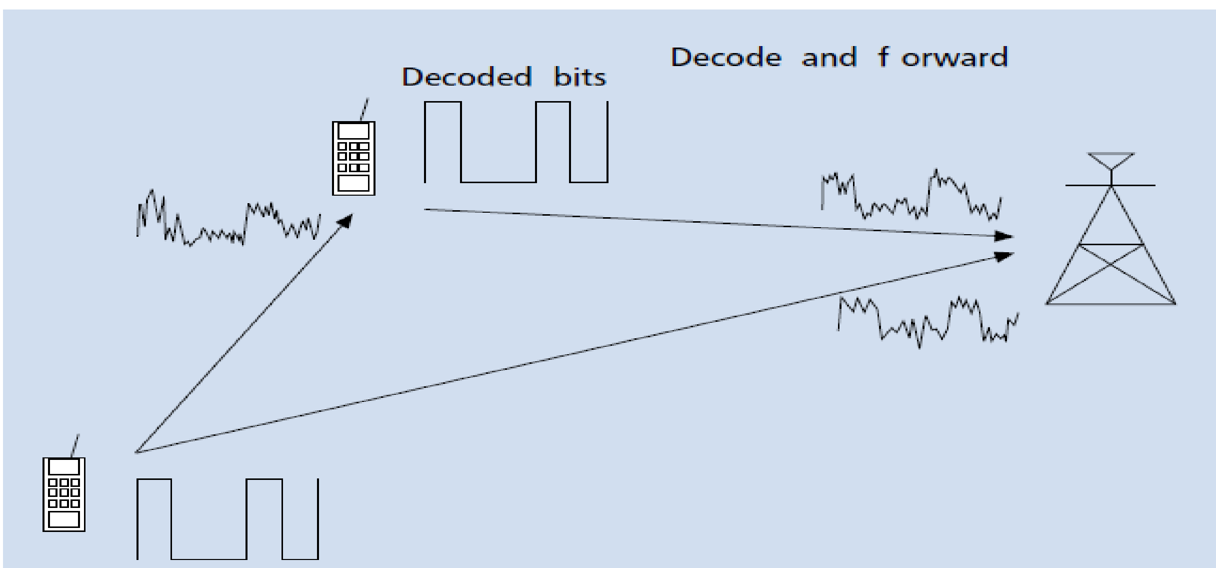

Figure 3.3 Decode and forward

Consider M-PSK containing the following points: $\{\boldsymbol{x1}, \boldsymbol{x2}, \boldsymbol{x3} \ldots \boldsymbol{xM}\}$.
The data received at the relay in the first phase can be written as

$$\boldsymbol{y}_{s,r} = \sqrt{\boldsymbol{P}}\boldsymbol{h}_{s,r}\,\boldsymbol{x} + \boldsymbol{e}_{s,r} \tag{3.1}$$

where $\boldsymbol{h_{s,r}}$is the channel gain between the source and the relay and $\boldsymbol{e_{s,r}}$ is the zero mean complex additive white Gaussian noise (AWGN) with variance $\boldsymbol{N_{s,r}}$.

We can write the data received at the destination in the first phase as follows:

$$\boldsymbol{y_{s,d}} = \sqrt{\boldsymbol{P}}\boldsymbol{h_{s,d}}\,\boldsymbol{x} + \boldsymbol{e_{s,d}} \tag{3.2}$$

where $\boldsymbol{h_{s,d}}$ is the channel gain between the source and the destination and $\boldsymbol{e_{s,d}}$is the zero mean complex AWGN noise with variance $\boldsymbol{N_{s,d}}$.

The decoded signal at the relay may be incorrect. If an incorrect signal is forwarded to the destination, the decoding at the destination is meaningless. It is clear that for such a scheme the diversity achieved is only one, because the performance of the system is limited by the worst link from the source–relay and source–destination.

Although fixed DF relaying has the advantage over AF relaying in reducing the effects of additive noise at the relay, it entails the possibility of forwarding erroneously detected signals to the destination, causing error propagation that can diminish the performance of the system. The mutual information between the source and the destination is limited by the mutual information of the weakest link between the source–relay and the combined channel from the source– destination and relay–destination. The received signal at the destination in Phase 2 in this case can be modelled as

$$\boldsymbol{y_{r,d}} = \sqrt{\widetilde{\boldsymbol{P}}}\boldsymbol{h_{r,d}}\widetilde{\boldsymbol{x}} + \boldsymbol{N_{r,d}} \tag{3.3}$$

where $\widetilde{\boldsymbol{x}}$ is the decoded symbol transmitted by the relay, $\boldsymbol{h_{r,d}}$ is the channel gain between the relay and the destination, and $\boldsymbol{e_{r,d}}$ is a complex zero-mean AWGN noise with variance $\boldsymbol{N_{r,d}}$.

3.3 Amplify and forward

Amplify and Forward technique simply amplifies the signal received by the relay before forwarding it to the destination However, one major drawback of this technique is that the noise in the signal is also amplified at the relay station, and the destination receives two independently faded versions of the signal. Figure 3.4 shows amplify and forward technique.

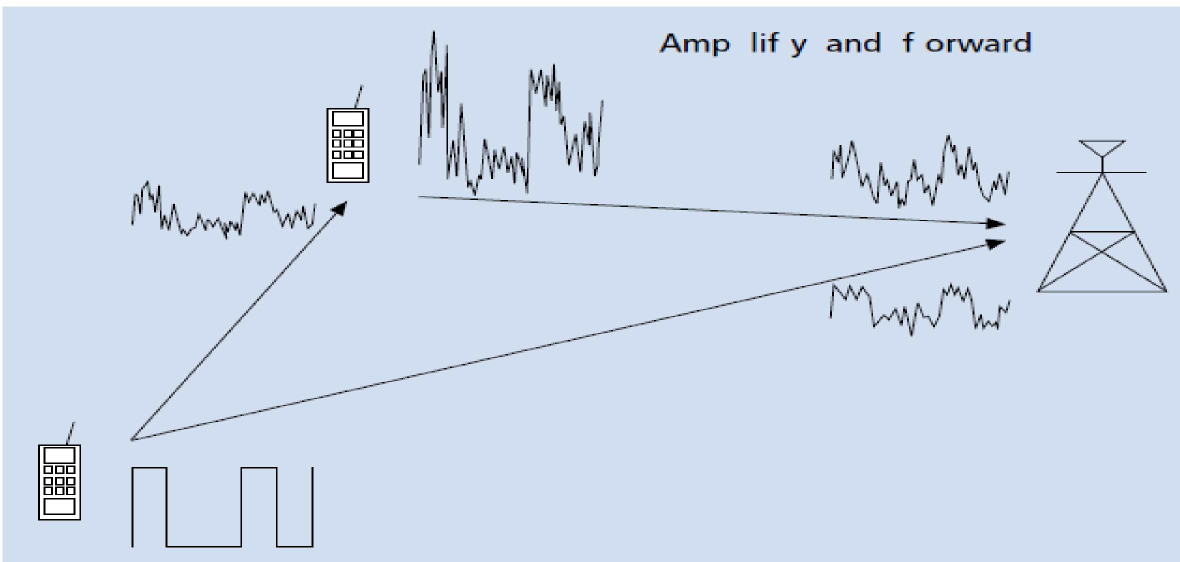

Figure 3.4 Amplify and Forward

Consider M-PSK containing the following points: $\{\boldsymbol{x1}, \boldsymbol{x2}, \boldsymbol{x3} \ldots \boldsymbol{xM}\}$.
The data received at the relay in the first phase can be written as

$$\boldsymbol{y_{s,r}} = \sqrt{\boldsymbol{P}}\, \boldsymbol{h_{s,r}}\, \boldsymbol{x} + \boldsymbol{e_{s,r}} \tag{3.4}$$

where $\boldsymbol{h_{s,r}}$ is the channel gain between the source and the relay and $\boldsymbol{e_{s,r}}$ is the zero mean complex additive white Gaussian noise (AWGN) with variance $\boldsymbol{N_{s,r}}$. We can write the data received at the destination in the first phase as follows:

$$\boldsymbol{y_{s,d}} = \sqrt{\boldsymbol{P}}\boldsymbol{h_{s,d}}\, \boldsymbol{x} + \boldsymbol{e_{s,d}} \tag{3.5}$$

where $\boldsymbol{h_{s,d}}$ is the channel gain between the source and the destination and $\boldsymbol{e_{s,d}}$ is the zero mean complex AWGN noise with variance $\boldsymbol{N_{s,d}}$.

In the second phase, the data received in the destination can be written as

$$\boldsymbol{y}_{r,d} = \sqrt{\boldsymbol{P}}\boldsymbol{h}_{r,d}\boldsymbol{G}\boldsymbol{y}_{s,r} + \boldsymbol{N}_{r,d}$$

(3.6)

where G is the amplification factor used by R

$$\boldsymbol{G} = \sqrt{\boldsymbol{P}_R/\boldsymbol{P}_S|\boldsymbol{h}_{sr}|^2 + \boldsymbol{N}_{s,r}}$$

(3.7)

where $\boldsymbol{h}_{sr}$ is the channel gain between the relay and the source, and with variance $\boldsymbol{N}_{s,r}$.

Among many strategies, DF and AF schemes are the most popular ones due to simplicity and intuitive designs. The advantages of relay cooperation often depend on sufficiently reliable inter user channels. For example, in the DF scheme, a node relays the message from the source only if it is able to decode message reliably. Similarly, in the AF scheme, the quality of the relayed signal is limited by the quality of the source-relay link since both the signal and the noise are amplified at relays.

Therefore, relays should be adopted only if the source relay channel is sufficiently reliable. This observation leads to the selective relaying cooperation scheme where relays are selected to retransmit the source message only if the quality of the transmission over the inter user channel meets a certain criterion.

3.4 Multiple relaying schemes

The system is composed of one source node, R relays, and one destination node. Here the transmission is composed of $R + 1$ phase. In the first phase the source broadcasts the message symbols to the relays and destination. In the next R phases, the relays transmit their symbols to the destination one at a time.

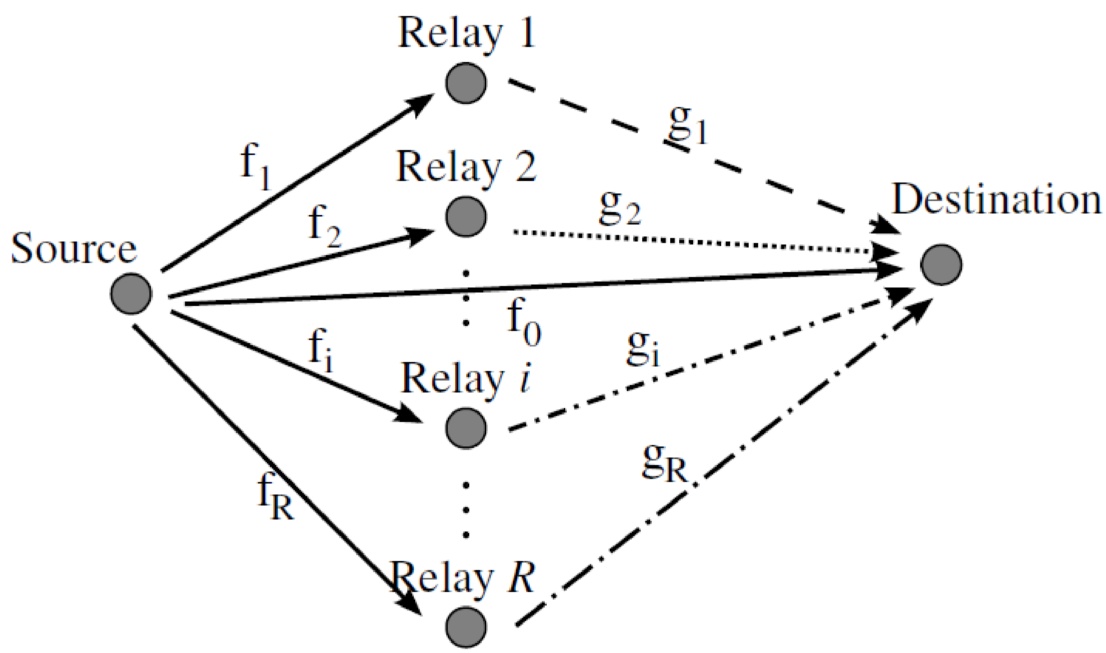

Figure 3.5 System model for multiple relaying scheme

Assuming that all links are i.i.d at fading Rayleigh channels, at the end of the first phase, the received signals by relays and destination are:

$$r_i = \sqrt{E_s}\, f_i\, s + \mathrm{v_i} \qquad i = 1, 2, \ldots\ldots R \tag{3.8}$$

$$y_0 = \sqrt{E_s}\, f_0\, s + \mathrm{v_0} \tag{3.9}$$

where $\mathrm{v_i}$ is the receiver noise. The amplify-and-forward and decode-and-forward strategies can be applied here,

$$t_{iAF} = \sqrt{E_R/E_S|f_{sr}|^2 + W_{s,r}} \tag{3.10}$$

$$t_{iDF} = \sqrt{\tilde{P}}\widetilde{s_i} \tag{3.11}$$

with $\widetilde{s_i}$ decoded symbol at the i^{th} relay

At the end of all phases, the destination receives R more signals from relays:

$$y_i = g_i t_i + w_i \qquad i = 1, 2, \dots \dots R \tag{3.12}$$

with w_i being the AWGN.

For the multiple relay case, as well as the simple cooperative case the destination may use different combination techniques such as SC, EGC, or MRC, in which MRC is used here and explained below.

3.5 Applications of cooperative communication

In a **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 vacate 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 spatially 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.

A **wireless ad hoc network** is an 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, to include commercial and educational use, disaster management, road vehicle network etc.

A **wireless sensor network** can use cooperative relaying to reduce the energy consumption in sensor nodes; hence lifetime of sensor network increases. Due to nature of wireless medium, communication through weaker channels requires 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.

3.6 Advantages of cooperative communication

Reduced Power: If we trade the signal-quality improvement with the transmission power, the total transmission power of cooperative diversity can be reduced to be significantly less than the transmission power of the traditional direct transmission for the same end-to-end SNR or received power levels.

Better Coverage: The extension the signal coverage and communication range to remote users experiencing large path-loss by utilizing the signal-quality improvement (in terms of higher SNR and received power). Also, if the relay locations are carefully chosen, cooperative diversity can overcome large shadowing that may exist in the direct link due to blockage by large objects.

Higher spatial diversity: Compared with direct transmission, the cooperative approach enjoys a higher successful transmission probability. The cooperative communications has the ability to adapt and to mitigate the effects of shadow fading better than MIMO since, unlike MIMO, antenna elements of a cooperative virtual antenna array are separated in space and experience different shadow fading.

Adaptability to network conditions: The cooperative communication paradigm allows wireless terminals to seamlessly adapt to changing channel and interference conditions. The choice of relays, cooperation strategy, and the amount of resources available for cooperation can be opportunistically decided.

Lower interference: The advantage of cooperation also leads to reduced interference when the network is deployed in a cellular fashion to reuse a limited bandwidth. With the improvement of throughput, we can reduce the average channel time used by each station to transfer a certain amount of traffic over the network. Therefore, the signal- to-interference ratio (SIR) between proximal cells using the same channel can be reduced, and a more uniform coverage can be achieved. As wireless network deployments become ever denser, a reduction of SIR will directly lead to a boost in network capacity.

3.7 Disadvantages of cooperative communication

Traditional cooperative communications can greatly improve communication performance. However, transmissions from multiple relay nodes are challenging in practice. Single transmissions using time-division multiple access cause large transmission delay, but simultaneous transmissions from two or more nodes using frequency-division multiple access (FDMA), code-division multiple access (CDMA), or distributed space-time codes are associated with the issues of imperfect frequency and timing synchronization due to the asynchronous nature of cooperation.

For cooperative diversity, the relays need to first acquire the source message before forwarding it to the receiver. However, practical devices are usually subject to half-duplex constraint, i.e., they cannot transmit and receive signals at the same time. As a result, the whole end-to-end data relaying is completed in two phases: data acquiring phase and data forwarding phase. An independent channel is required for each phase and only one message could be delivered across those two phases. For multi-relay systems, such rate loss is even larger if the intermediate relays operate on orthogonal channels. To save channel use for data forwarding phase, the relay can choose to combine different source messages via network coding and forward a single mixed message rather than forward the individual messages separately.

CHAPTER 4
SPACE TIME NETWORK CODES AND WIRELESS NETWORK COCAST

4.1 Wireless Network cocast

Much research in cooperative communication has considered symmetric problems, in which a pair of nodes helps each other in their transmission to a common destination or different source nodes in a network receive assistance from the same group of relays to achieve the same diversity order. However, practical networks are asymmetric in nature. Node distances to a common destination vary based on node locations, and thus some nodes are disadvantageous in their transmission in comparison with others. Therefore, the node locations, which can be obtained using network-aided position techniques, should be taken into consideration to improve network performance.

A number of location-aware cooperation-based schemes that achieve spatial diversity to reduce aggregate transmit power and achieve even power distribution in a network, where mobile units with known locations transmit their information to a common destination were introduced.

The first proposed scheme, namely immediate-neighbour cooperation (INC), utilizes two- user cooperative communication in a network. In INC, each mobile unit, except the closest node to the destination, is assigned a single relay, its immediate neighbour toward the destination, and thus a fixed diversity order of two is achieved. Consequently, INC achieves good reduction in aggregate transmit power with the expense of $(2N - 1)$ time slots for a network of N mobile units.

However, distant users still require more power than the closer ones and power distribution is still uneven as in DTX.

The second proposed scheme, namely maximal cooperation (MAX), provides incremental diversity to a network by means of cooperative communication. Multi-node cooperative communication is utilized in MAX, where each mobile unit is assigned a group of mobile units locating between itself and the destination as relays. Thus the more distant the mobile unit, the higher diversity order to compensate the high required transmit power. Furthermore, the higher transmit power is shared and compensated by the larger group of relaying mobile units. Consequently, MAX with the incremental diversity achieves great reduction of aggregate transmit power and even power distribution. The major drawback in MAX is the large transmission delay since each relay requires a time slot for its transmission.

Therefore, a novel concept of wireless network cocast (WNC) to resolve the weaknesses of INC and MAX is used. Cocast, an analogy to broadcast, unicast, and multicast, is a newly defined transmission method that utilizes linear network coding for a number of nodes to cooperatively transmit their information to the same intended destination. WNC achieves the incremental diversity as in MAX with the low transmission delay of (2*N*-1) time slots as in INC.

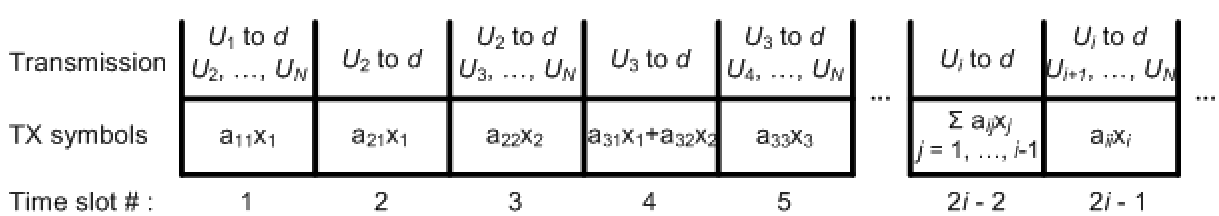

Figure 4.1.Wireless Network Cocast-Transmission Structure

WNC networks and its associated STNCs provide spatial diversity to combat channel fading and thus dramatically reduce the required transmit power in comparison with DTX networks. Here we consider a M2P STNC network which is explained as follows.

4.2 Space Time Network Codes

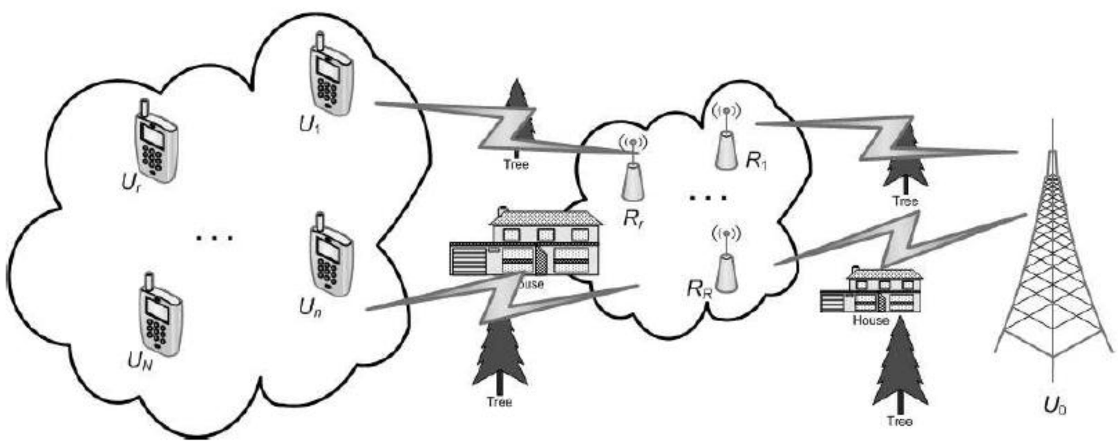

Figure.4.2. A multiuser relay network

Consider a wireless network which contains N client nodes denoted as $\mathrm{U_0, U_1, U_2, \ldots, U_N}$, where $\mathrm{U_0}$ is a base node and $\mathrm{U_1}$, $\mathrm{U_2, \ldots, U_N}$, are client nodes. Assume R relay nodes, denoted as $\mathrm{R_1, R_2, \ldots, R_R}$ which helps to forward the client information as shown in Fig 4.2. The STNC comprises data acquiring phase and data forwarding phase which is represented by matrices given below.

The data acquiring phase, in which the source nodes broadcast their information to N relay nodes which contains a set of overheard symbols, denoted as $x = [x_1, x_2, \ldots, x_N]$. In next phase instead of allowing multiple relay nodes transmitting at the same time as in the traditional cooperative communications, each relay node forms a single signal by encoding the set of overheard symbols, denoted as $f_r(x)$ for the relay node R_r for $r = 1,2,\ldots R$ and transmits it to the desired destination in its allocated time slot.

Each set of encoding functions f_r's, denoted as $\{f_r\}_{r=1}^{R}$, will form a STNC that governs the cooperation and the transmission among the nodes in the network.

$$
\begin{array}{c}
\begin{array}{ccccc} T_1 & \cdots & T_n & \cdots & T_N \end{array} \\
\hline
\begin{array}{c} U_1 \\ \vdots \\ U_n \\ \vdots \\ U_N \end{array}
\begin{bmatrix}
x_1 & \cdots & 0 & \cdots & 0 \\
\vdots & \ddots & \vdots & \cdots & \vdots \\
0 & \cdots & x_n & \cdots & 0 \\
\vdots & \cdots & \vdots & \ddots & \vdots \\
0 & \cdots & 0 & \cdots & x_N
\end{bmatrix}
\end{array}
$$

Data acquiring phase

$$
\begin{array}{c}
\begin{array}{ccccc} T_{N+1} & \cdots & T_{N+r} & \cdots & T_{N+R} \end{array} \\
\hline
\begin{array}{c} R_1 \\ \vdots \\ R_n \\ \vdots \\ R_N \end{array}
\begin{bmatrix}
f_1(x) & \cdots & 0 & \cdots & 0 \\
\vdots & \ddots & \vdots & \cdots & \vdots \\
0 & \cdots & f_r(x) & \cdots & 0 \\
\vdots & \cdots & \vdots & \ddots & \vdots \\
0 & \cdots & 0 & \cdots & f_R(x)
\end{bmatrix}
\end{array}
$$

Data forwarding phase

Figure.4.3. A general framework of STNC

The STNC will provide appropriate spatial diversity with only $(N + R)$ time slots, a reduction from 2N time slots in the traditional CDMA and FDMA cooperative communications.

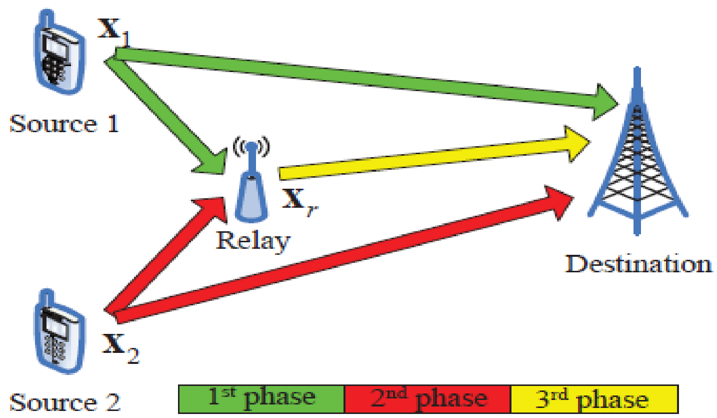

Figure.4.4. Space Time Network Codes

The concept of Space Time Network Codes, shown in Fig.4.4 involves combining information from different source a relay node, which is network coding and transmitting the combined signal in its own dedicated time slot, which is the concept of the space–time. Various traditional combining techniques can be used; still, a major difference is that the combining of symbols from different sources, happens within a transmitter instead of through the air. Each combining technique requires a proper multi-user detection technique to separate the transmitted symbols from single coded-signals.

The general framework in Fig.4.3 is applicable for both M2P and P2M transmissions and here we focus on M2P transmission. In M2P, the N client nodes $U_1, U_2 \ldots, U_N$ transmit their symbols $x_1, x_2, \ldots, x_N$ to the base node U_0. The channels between any two nodes are denoted as h_{uv}, and considered as narrow-band Rayleigh fading with additive white Gaussian noise (AWGN). The channel coefficient between receiver and transmitter is given by $h_{uv} \sim CN(0, \sigma_{uv}^2)$ with zero mean and channel variance σ_{uv}^2. The transmit power P_n associated with transmitted symbol x_n is distributed among the source node and the relay nodes. The power allocation is given as P_n=$P_{nn} + \sum_{\mathrm{r=1}}^{\mathrm{R}} P_{rn}$, where P_{nn} and P_{rn} are the power allocated at the source U_n and the R_r relay, respectively.

In the CDMA-like STNC, each symbol $\mathrm{x_n}$ is associated with a spreading code $s_n(t)$ to protect the symbol against the interference from other symbols. The cross correlation between $s_n(t)$ and $s_m(t)$ and is defined as $\rho_{nm} = \langle s_n(t), s_m(t)\rangle$. Here $\rho_{nm} = ||s_n(t)^2|| = 1$. The assumption here is that the relay nodes know the signature waveforms associated with the client nodes.

4.2.1 Multipoint to Point STNC Transmission

$$
\begin{array}{c} \\ U_1 \\ \vdots \\ U_n \\ \vdots \\ U_N \end{array}
\begin{array}{c}
\begin{array}{ccccc} T_1 & \cdots & T_n & \cdots & T_N \end{array} \\ \hline
\begin{bmatrix} x_1 & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ 0 & \cdots & x_n & \cdots & 0 \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & x_N \end{bmatrix}
\end{array}
$$

Data acquiring phase

$$
\begin{array}{c} R_1 \\ \vdots \\ R_n \\ \vdots \\ R_N \end{array}
\begin{array}{c}
\begin{array}{ccccc} T_{N+1} & \cdots & T_{N+r} & \cdots & T_{N+R} \end{array} \\ \hline
\begin{bmatrix} \sum_{k=1}^{N} a_{1k} x_k & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \cdots & \vdots \\ 0 & \cdots & \sum_{k=1}^{N} a_{rk} x_k & \cdots & 0 \\ \vdots & \cdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & \sum_{k=1}^{N} a_{1k} x_k \end{bmatrix}
\end{array}
$$

Data forwarding phase

Figure.4.5. Multipoint to Point framework

Figure 4.5 depict the transmissions in the source and relay transmission phases of the M2P, in which the N client nodes $U_1, U_2 ..., U_N$ transmit their symbols to the common base node U_0. As shown, the STNC requires $(N + R)$ time slots to complete the transmissions and assures that a single transmission in the network at any given time slot to eliminate the issue of imperfect synchronization in traditional cooperative communications. In the first phase, client node U_n for $n = 1,2, ... N$ is assigned a time slot T_n to broadcast its symbol x_n to the base node and all relay nodes. The signals received at U_0 and R_r are

$$y_{0n}(t) = h_{0n}\sqrt{P_{nn}}\, x_n s_n(t) + w_{0n}(t) \qquad (4.1)$$

and

$$y_{rn}(t) = h_{rn}\sqrt{P_{nn}}\, x_n s_n(t) + w_{rn}(t) \qquad (4.2)$$

respectively, where $w_{0n}(t)$ and $w_{rn}(t)$ are zero-mean and N_0 variance AWGN. At the end of this phase each relay node R_r for $r = 1, 2 ... R$ carries a set of symbols from the client nodes.

4.2.2 Using AF relaying protocol

In the data forwarding phase relays form a single linearly coded signal, a linear combination of these symbols and transmits the signal to the base node in its dedicated time slot T_r. R_r can amplify the signal in (4.2) and combine with others to form the linearly coded signal, the so called Amplify and Forward (AF) protocol. The received signal at U_0 from R_r in the relay transmission phase is

$$y_{0r}(t) = h_{0r} \sum_{k=1}^{N} \sqrt{\widetilde{P_{rk}}}\, x_k s_k(t) + w_{0r}(t) \qquad (4.3)$$

including symbol x_n when $k = n$. In (4.3),

$$\widetilde{P_{rk}} = \frac{P_{rk} P_{kk} |h_{rk}|^2}{P_{kk} |h_{rk}|^2 + N_0} \quad (4.4)$$

for the case of AF and $w_{0r}(t)$ is zero-mean and $N_0 f_{0r}$ -variance AWGN, where

$$f_{0r} = 1 + \sum_{k=1}^{N} \frac{P_{rk} |h_{0r}|^2}{P_{kk} |h_{rk}|^2 + N_0} \quad (4.5)$$

is a factor representing the impact on performance due to the noise amplification at R_r.

4.2.3Using DF relaying protocol

In the second transmission phase relays form a single linearly coded signal, a linear combination of these symbols and transmits the signal to the base node in its dedicated time slot T_r. It can also detect the symbol x_n based on (4.2) and re-encode it in the linearly coded signal if the decoding is successful, the so called DF protocol. A detection state, a success or a failure in detecting a symbol, can be determined based on the amplitude of the estimated channel coefficient or the received signal-to-noise ratio (SNR). This DF scheme is also called the selective-relaying protocol. The received signal at U_0 from R_r in the relay transmission phase is

$$y_{0r}(t) = h_{0r} \sum_{k=1}^{N} \sqrt{\widetilde{P_{rk}}}\, x_k s_k(t) + w_{0r}(t) \quad (4.6)$$

including symbol x_n when $k = n$. In (4.3),

$$\widetilde{\mathrm{P_{rk}}} = \begin{cases} \mathrm{P_{rk}} \text{ if } \mathrm{R_r} \text{ decodes } correctly \\ 0 \qquad\qquad\qquad \text{otherwise} \end{cases} \quad (4.7)$$

for the case of AF and $w_{0r}(t)$ is zero-mean and $N_0 f_{0r}$ -variance AWGN, where

$$f_{0r} = 1 \quad (4.8)$$

In (4.3), U_0 receives a combined signal of multiple transmitted symbols that is formed within a relay node, not through the air as in traditional CDMA or

FDMA schemes, where the symbols are from different relays and hence overcomes the prominent issue of imperfect frequency and timing synchronization.

4.2.4 Diversity

Both Rayleigh fading and log normal shadowing induce a very large power penalty on the performance of modulation over wireless channels. One of the most powerful techniques to mitigate the effects of fading is to use diversity-combining of independently fading signal paths. Diversity combining uses the fact that independent signal paths have a low probability of experiencing deep fades simultaneously. Thus, the idea behind diversity is to send the same data over independent fading paths. These independent paths are combined in some way such that the fading of the resultant signal is reduced. For example, for a system with two antennas that experience independent fading, it is unlikely that both antennas experience deep fades at the same time. By selecting the strongest signal between the two antennas, called selection combining, we will obtain a much better signal than if we just had one antenna.

Diversity techniques that mitigate the effect of multipath fading are called **micro diversity**, and that is the focus of this chapter. Diversity to mitigate the effects of shadowing from buildings and objects is called **macro diversity**. Macro diversity is generally implemented by combining signals received by several base stations or access points.

4.2.5 Maximum ratio combining (MRC)

Here Maximum Combining technique is used since it outperforms other techniques and is explained below:

In maximum ratio combining (MRC) the destination combines yD1 and yD2 with weighting coefficients in order to take into account the SNR of each link. Naturally the link with a stronger signal is more likely to influence the destination's decision on the likeliest transmitted symbol. If MRC is used, the equivalent system SNR is the sum of the signal to noise ratios of both source-relay-destination and source-destination paths.

4.2.6 Multiuser detection

To detect a desired symbol, we assume that receivers have a full knowledge of the channel state information. The symbol is first transmitted by the U_n source node in M2P transmission and then forwarded by the relay nodes $R_1, R_2, \dots, R_R$ to the destination node U_0. To achieve a tractable performance analysis, we use a multi-user detection technique that includes a decorrelator and a maximal-ratio combining detector. The detection for an arbitrary symbol x_n is as follows.

After the completion of the two phases, the base node U_0 in M2P receives $(R+1)$ signals that contain symbol x_n. From these signals, it extracts soft symbols and uses a maximal-ratio combiner to detect the symbol. The first soft symbol of x_n comes directly from the source node U_n in the source transmission phase by applying matched-filtering to signal $y_{0n}(t)$ in (4.1) with respect to signature waveform $s_n(t)$ to obtain

$$y_{0nn} = \langle y_{0n}(t)\,, s_n(t)\rangle = h_{0n}\sqrt{P_{nn}}\,x_n + w_{0nn} \qquad (4.9)$$

The remaining R soft symbols are collected from the R relaying signals $y_{0r}(t)$ in (4.3) in the relay transmission phase as follows. For each signal $y_{0r}(t), U_0$ applies a bank of matched-filtering to the signal with respect to signature waveforms $s_m(t)$ for $m = 1,2,\dots,N$ to obtain

$$y_{0rm} = h_{0r} \sum_{k=1}^{N} \sqrt{\widetilde{P_{rk}}}\, x_k\, \rho_{km} + w_{0rm} \quad (4.10)$$

It forms an N×1 vector which consists of y_{0rm} 's as

$$\mathrm{y_{0r}} = h_{0r} \mathrm{RA_r x} + \mathrm{w_{0r}} \quad (4.11)$$

where $\mathrm{y_{0r}} = [y_{0r1}, y_{0r2}, \dots, y_{0rN}]^T$, $\mathrm{A_r} = diag\left\{\sqrt{\widetilde{P_{r1}}}, \sqrt{\widetilde{P_{r2}}}, \dots, \sqrt{\widetilde{P_{rN}}}\right\}$, $\mathrm{x} = [x_1, x_2, \dots, x_N]^T, \mathrm{w_{0r}} = [w_{0r1}, w_{0r2}, \dots, w_{0rN}]^T \sim CN(0,\ N_0 f_{0r}\, R)$ with f_{0r} in (4.5)

$$\mathrm{R}=\begin{bmatrix} 1 & \cdots & \rho N1 \\ \vdots & \ddots & \vdots \\ \rho 1N & \cdots & 1 \end{bmatrix} \quad (4.12)$$

The decorrelating detector (or decorrelator) tries to eliminate all multiple access interference by multiplying output of matched filter by R^{-1}. Assume that R is invertible with the inverse matrix R^{-1}. Since the decorrelator completely eliminates the MAI, it has a near far resistance of 1. A disadvantage of this detector is that it causes noise enhancement, i.e. R^{-1} is always greater than or equal to 1. To get the users decoded bit, take the sign of each of the components of R^{-1}y.This assumption is easy to achieve since the combining of symbol is done within a relay node. The signal vector y_{0r} is then decorrelated to obtain

$$\widetilde{\mathrm{y_{0r}}} = \mathrm{R}^{-1}\mathrm{y_{0r}} = h_{0r}\mathrm{A_r x} + \widetilde{\mathrm{w_{0r}}} \quad (4.13)$$

where $\widetilde{\mathrm{w_{0r}}} \sim CN(0,\ N_0 f_{0r}\, \mathrm{R}^{-1})$.Since $\mathrm{A_r}$ is a diagonal matrix, the soft symbols of x_n from $\mathrm{R_r}$ is

$$\widetilde{y_{0rn}} = h_{0r}\sqrt{\widetilde{P_{rn}}}\, x_n + \widetilde{w_{0rn}} \quad (4.14)$$

where $\widetilde{w_{0r}} \sim CN(0,\ N_0 f_{0r}\, \epsilon_n)$ with ϵ_n being *n*th the diagonal element of matrix R^{-1} associated with symbol x_n. Since there are R relaying signals from R_r's, $r =$

$1,2,\ldots,R,U_0$ obtains R soft symbols of x_n in the above manner. From the soft symbols of in (4.9) and (4.14), forms an (R+1)×1 signal vector

$$\mathrm{y}_{0r} = \mathrm{a}_{0n}\mathrm{x}_n + \mathrm{w}_{0n} \qquad (4.15)$$

where

$\mathrm{a}_{0n} = \left[h_{0n}\sqrt{P_{nn}}, h_{01}\sqrt{\widetilde{P_{1n}}}, \ldots, h_{0r}\sqrt{\widetilde{P_{rn}}}, \ldots, h_{0R}\sqrt{\widetilde{P_{Rn}}}\right]^T$ and $w_{0n}\sim CN(0, \mathrm{K}_{0n})$, $\mathrm{K}_{0n} = diag\{N_0,\ N_0 f_{01}\,\epsilon_n, \ldots,\ N_0 f_{0r}\,\epsilon_n, \ldots,\ N_0 f_{0R}\,\epsilon_n\}$. Let

$$\mathrm{b}_{0n} = \left[h_{0n}\sqrt{P_{nn}}/N_0, h_{01}\sqrt{\widetilde{P_{1n}}}/\ N_0 f_{01}\,\epsilon_n, \ldots, h_{0r}\sqrt{\widetilde{P_{rn}}}\ /\ N_0 f_{0r}\,\epsilon_n, \ldots, h_{0R}\sqrt{\widetilde{P_{Rn}}}\ /\ N_0 f_{0R}\,\epsilon_n\right]^T$$

The desired symbol x_n can be detected by,

$$\widetilde{x_{0n}} \triangleq \mathrm{b}_{0n}^{\mathrm{H}} y_{0n} = a_{0n} x_n + w_{0n} \qquad (4.16)$$

where

$$\mathrm{a}_{0n} \triangleq \mathrm{b}_{0n}^{\mathrm{H}} a_{0n} = \frac{P_{nn}\,|h_{0n}|^2}{N_0} + \sum_{r=1}^{R} \frac{\widetilde{P_{rn}}\,|h_{0r}|^2}{N_0 f_{0R}\,\epsilon_n} \qquad (4.17)$$

and $w_{0n} \triangleq \mathrm{b}_{0n}^{\mathrm{H}}\mathrm{w}_{0n}\sim CN(0,\sigma_{0n}^2)$ with $\sigma_{0n}^2 = \mathrm{a}_{0n}$.

4.2.7 Matched Filter

The simplest approach to demodulate CDMA signals is the single user matched filter (MF). This is the demodulator that was first adopted in CDMA receivers, it is called conventional detector. For the single user CDMA channel, the MF is the optimal receiver. However, in the multiuser CDMA channel, the MF of desired user will suffer from interference from other users: multiple access interference (MAI).

The node receives N direct transmissions. The detection of x_n at the relay node R_r can follow a matched-filtering applied to signal $y_{rn}(t)$ in (4.2) with respect to the signature waveform $s_n(t)$ as

$$y_{rn} = \langle y_{rn}(t), s_n(t) \rangle = h_{rn}\sqrt{P_{nn}}\, x_n + w_{rn} \qquad (4.18)$$

where $\mathrm{w}_{\mathrm{rn}} \sim CN(0, N_0)$.

CHAPTER 5

SIMULATION RESULTS

In this chapter, we have done the simulations to validate the performance analysis of various cooperative diversity protocol schemes and also for M2P STNC cooperative communication. For simulation setup first single relay node is analyzed and then multi relay node is analyzed with BPSK modulation. We assume that relay nodes are placed with equal distance to the source and destination.

5.1 Cooperative communication using single relay

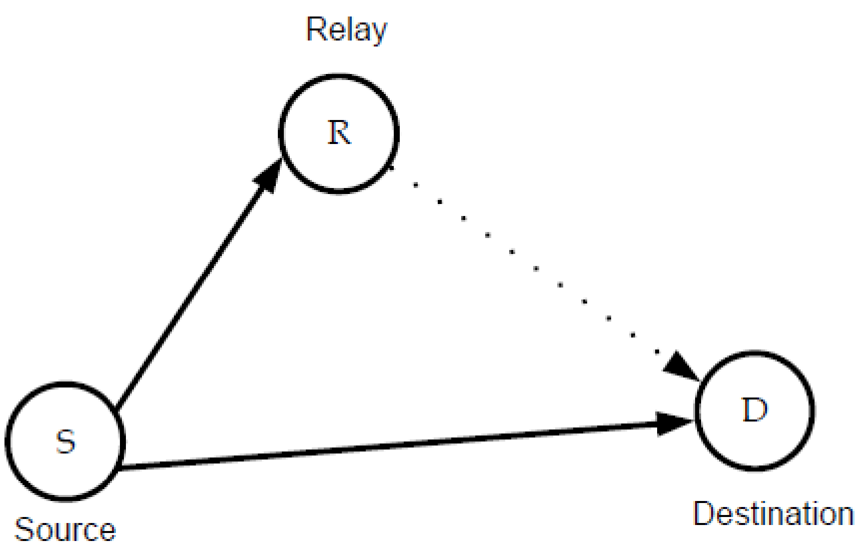

Figure.5.1. Single relay cooperative communication

Figure.5.1. shows the single relay scenario in which the relay forwards the source information. Relaying protocol used here is Amplify and Forward (AF) and Decode and Forward (DF) which is compared with direct transmission shown in the Fig.5.2.

5.1.1 Simulation result for single relay scheme

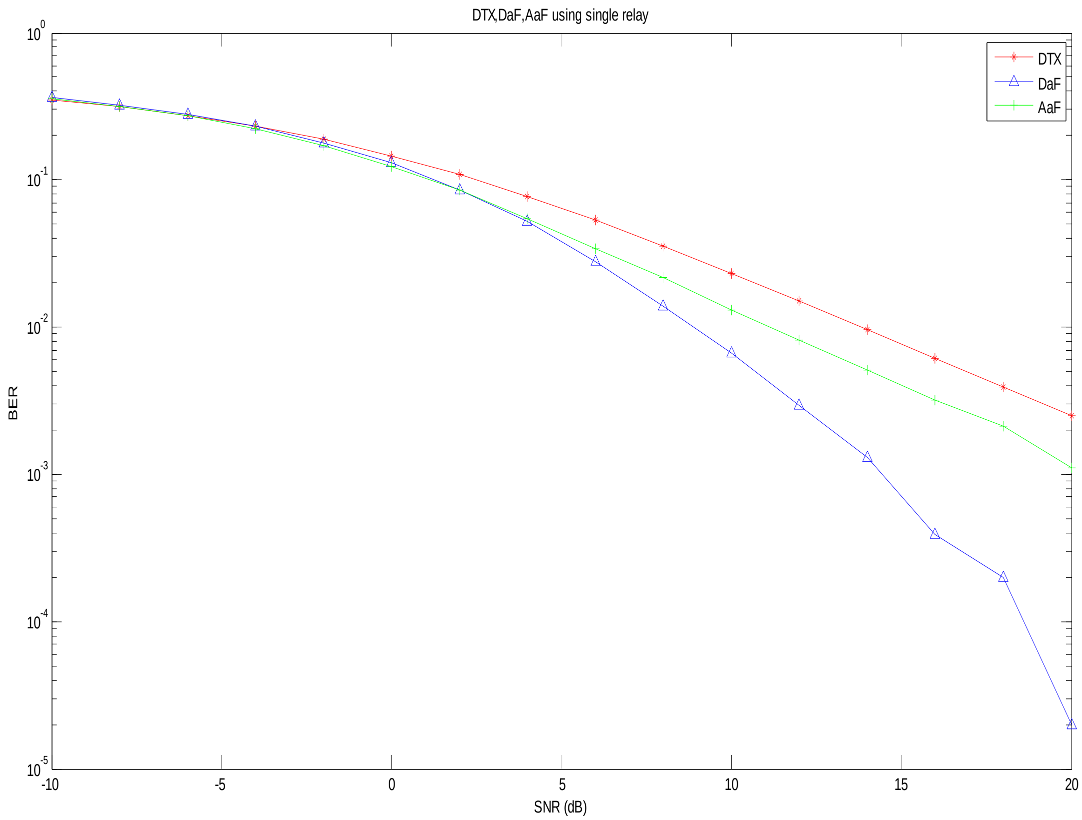

Figure 5.2 Simulation result of DTX, DF, AF using single relay

The figure 5.2 presents BER performance for DF and AF protocol.BER performance of DTX is also displayed for comparision. We infer that gain of relay signal using DF gets improved compared to AF.

5.2 Cooperative communication using multiple relay

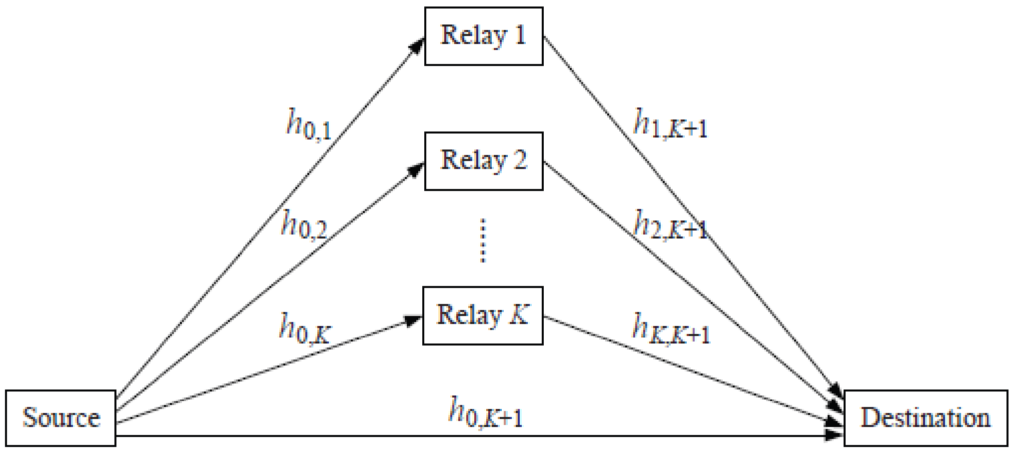

Figure.5.3.Multiple relay cooperative communication

The above figure shows multiple relay scenario. Here three relays are used in the simulation setup with BPSK modulation and Rayleigh fading channel is considerd along with additive white gaussian noise. Assumption is that all the relay nodes know the channel state information and equal power allocation is considered.

Two relaying protocols Decode and Forward (DF) and Amplify and Forward (AF) is simulated. The results show that as the number of relays is increased the error rate gets reduced since diversity is improved.

5.2.1 Simulation result for multi relay scheme using DaF

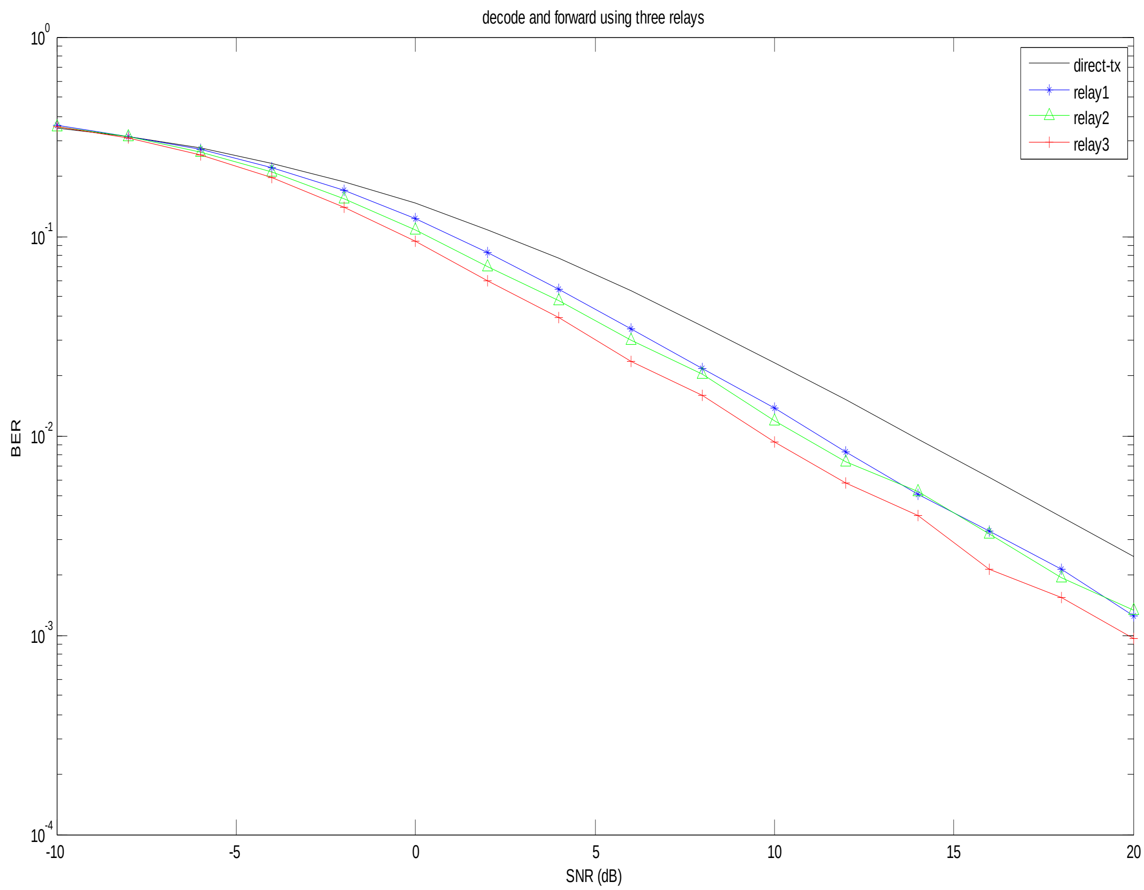

Figure 5.4 Simulation result of DF using three relay nodes and DTX.

The figure 5.4 represents BER performance using DF protocol of the three relay nodes. We infer that as the number of relay increases the diversity increases thereby improving the SNR of the signal.

5.2.2 Simulation result for multi relay scheme using AF

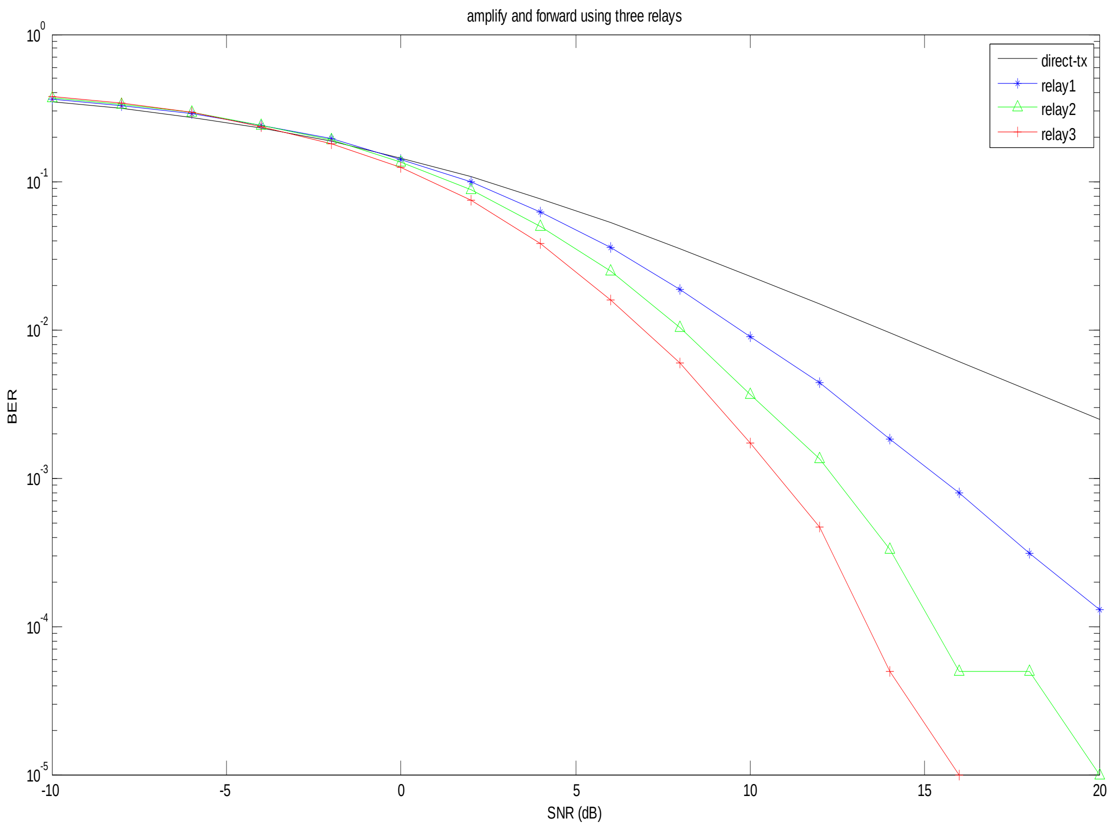

Figure 5.5 Simulation result of AF using three relay nodes and DTX.

The figure 5.5 represents BER performance using AF protocol of the three relay nodes. We infer that as the number of relay increases the diversity increases thereby improving the SNR of the signal.

5.3 Multipoint to Point communication with Space Time Network Codes

The simulation setup for M2P STNCs, four client nodes and two relay nodes with BPSK modulation are considered. Rayleigh channel is considered between the nodes with Additive White Gaussian Noise (AWGN) with zero mean and unit variance N_0. Here a relay node is placed with equal distance to the base node and the client nodes. The transmit power P_n corresponding to x_n is assumed the same for all n and thus denoted as P and the equal power allocation is used, where $P_{nn} = P/2$ and $P_{nr} = P/2R$.

The output shown is the performance associated with x_2 since the performance will be same for the rest of x_n. The output is shown using both relaying protocols that is Amplify and Forward (AF) and Decode and Forward (DF) where CDMA is used in order to avoid the interference between the nodes. It is assumed that the signalling information of each node is known to all the other nodes in the network.

5.3.1 Simulation result for M2P STNC using AF protocol

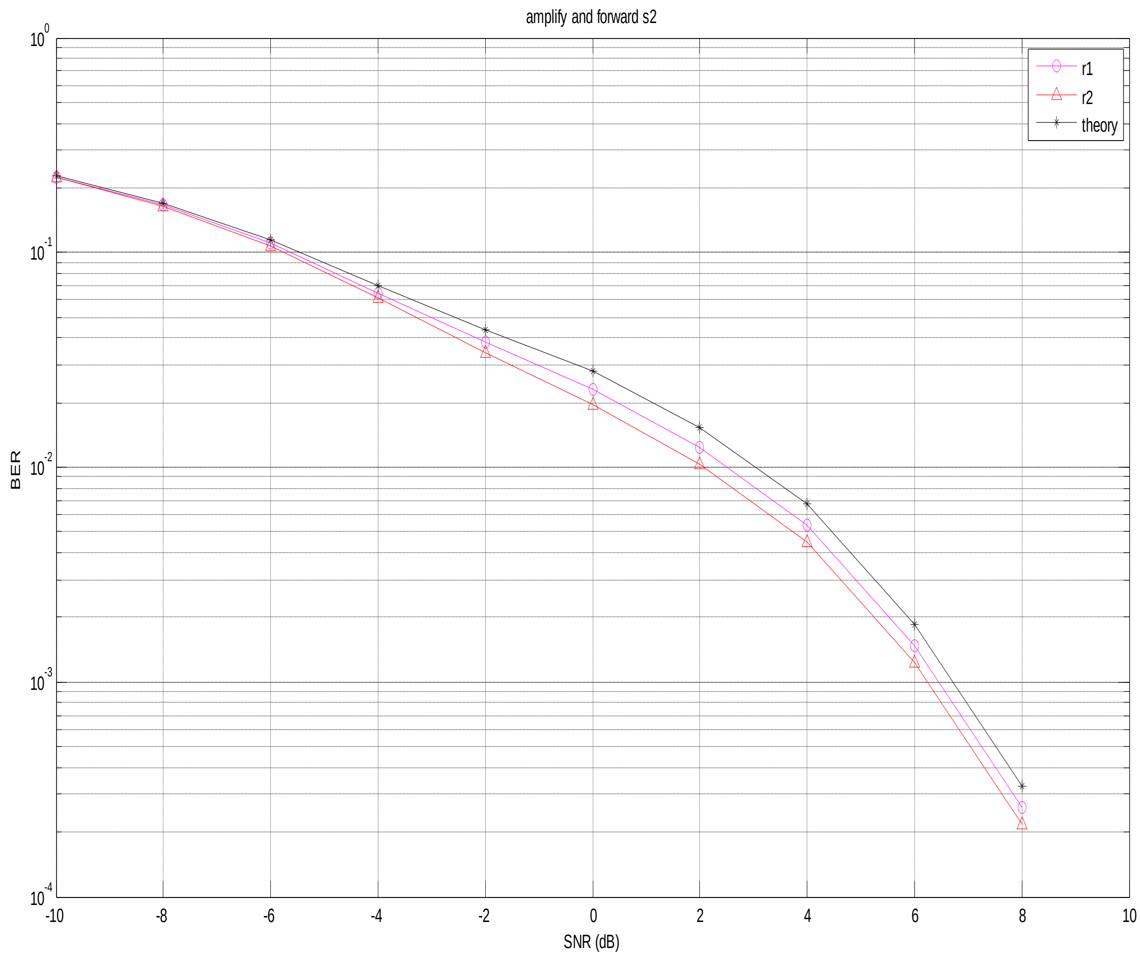

Figure 5.6 Simulation result of M2P STNC using AF protocol for two relay nodes and DTX

The fig 5.6 depicts that the error rate is reduced as the relay nodes is increased. This is obtained using Amplify and Forward protocol which has four client nodes and two relay nodes in which the output has shown only for the user2.

5.3.2 Simulation result for M2P STNC using DF protocol

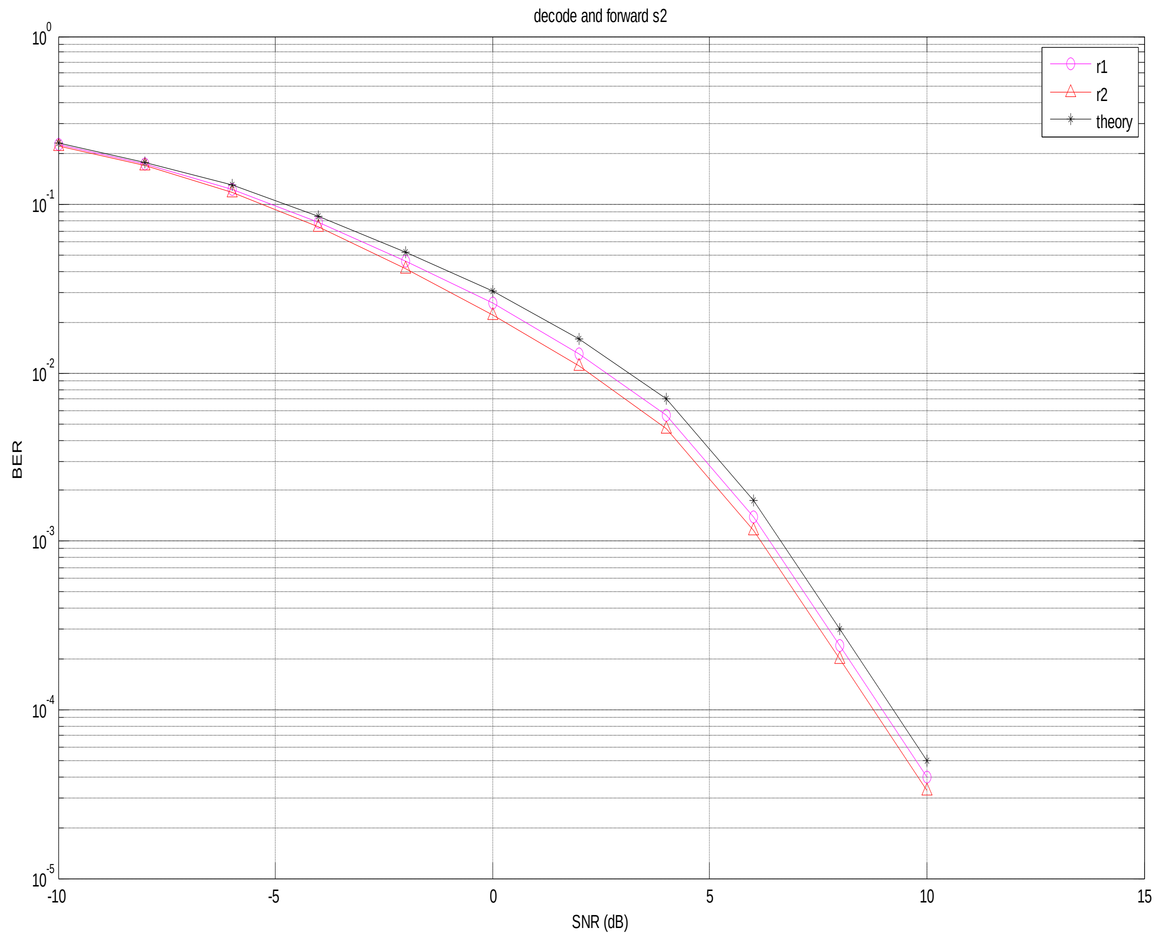

Figure 5.7 Simulation result of M2P STNC using DF protocol for two relay nodes and DTX

The fig 5.7 shows that the error rate is reduced as the relay nodes are increased thereby increasing the diversity. The result is for user2 obtained using Decode and Forward protocol which has the setup of four client nodes and two relay nodes.

5.4 Comparative analysis of Cooperative communication and Multipoint to Point communication with Space Time Network Codes

In this simulation setup for cooperative communication we have used a single relay for both AF and DF relaying protocol. For M2P STNC we have used two client nodes and a single relay node for both AF and DF relaying technique. For both the technique we have used BPSK modulation over Rayleigh fading channel with AWGN.

The result is compared between the cooperative communication and STNCs in which the latter one shows an improved result which is given below.

5.4.1 Simulation result for comparison of cooperative communication and M2P-STNC using AF relaying protocol

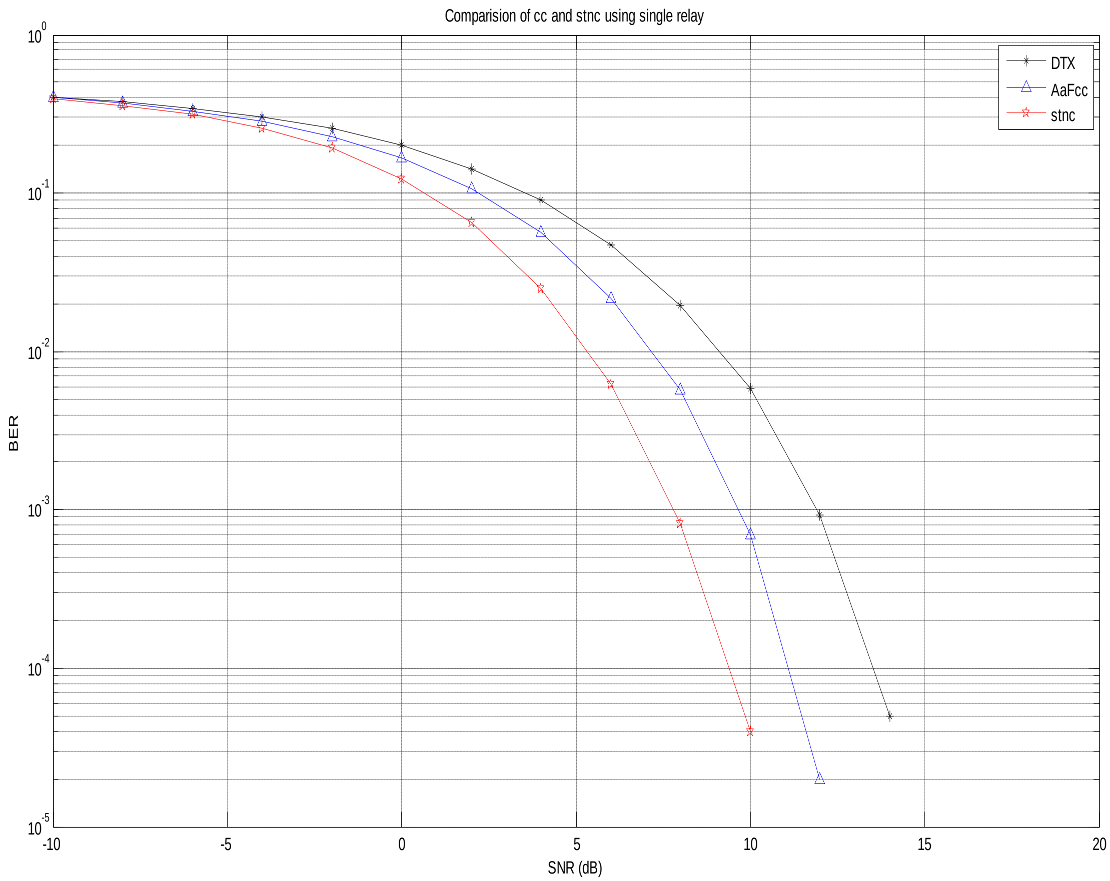

Figure 5.8 Comparative results of CC and M2P STNC using AF protocol for single relay nodes and DTX

The figure 5.8 shows that the M2P STNC gives a better result than the traditional cooperative communication. For comparison the direct transmission is also shown.

5.4.2 Simulation result for comparison of cooperative communication and M2P-STNC using DF relaying protocol

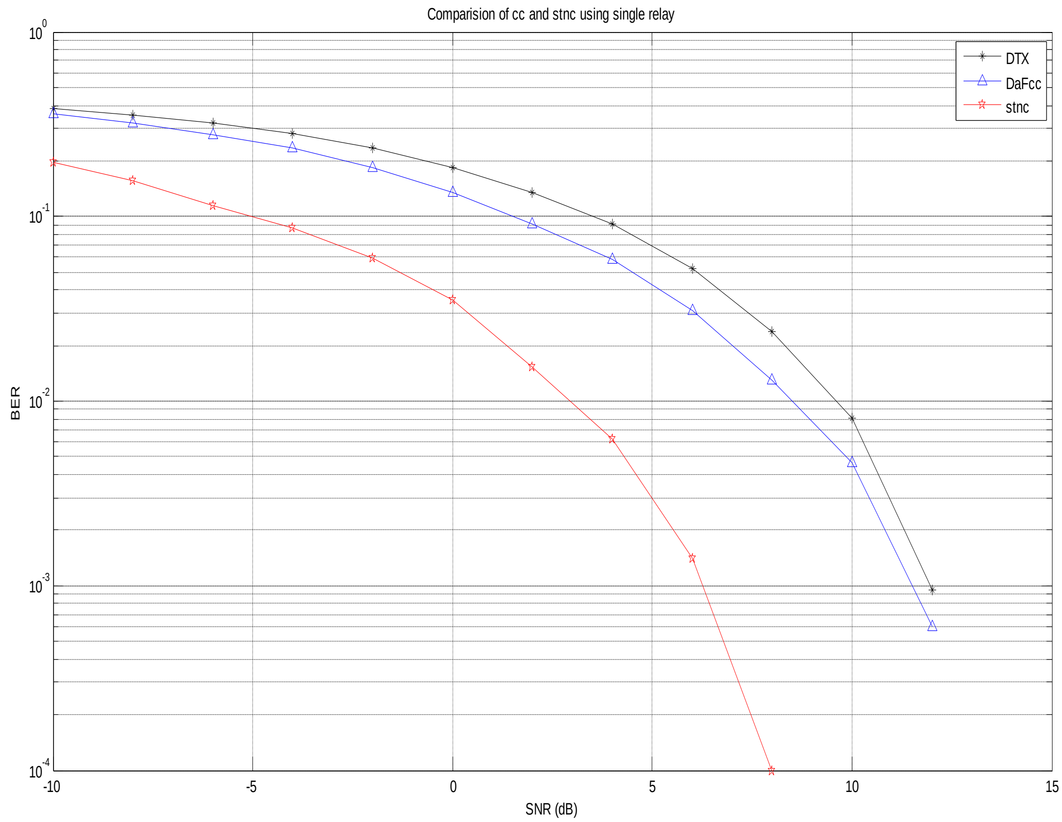

Figure 5.9 Comparative results of CC and M2P STNC using DF protocol for single relay nodes and DTX

The figure 5.8 shows that the M2P STNC gives a better result than the traditional cooperative communication for DF relaying protocol. For comparison the direct transmission is also shown.

CHAPTER 6
CONCLUSION AND FUTURE WORK

In this report, we have analyzed cooperative communication for various relay protocols that reduces the probability of error with better improved performance than the direct transmission. We have proved that for multiple relays with maximum ratio combining scheme gives improved diversity and high gain which is derived for BPSK signaling in flat fading Rayleigh channel.

To efficiently use the channel, the Space Time Network Codes (STNC) has been applied for Multipoint to Point (M2P) cooperative communication using both Amplify and Forward (AF) and Decode and Forward (DF) relaying protocols. The results show that compared to direct transmission the technique, multiple source and multiple relay, used gives a better result for BPSK modulation over Rayleigh channel with AWGN.

Comparative analysis of cooperative communication and M2P-STNC is also done in which latter technique gives an improved performance than the previous one.

The Future work can be further explored in Rician fading channel and frequency selective fading. The same technique can also be applied in case of Point to Multipoint (P2M) communication.

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LIST OF PUBLICATIONS

Conferences

- Presented a paper titled "Cooperative Communication for Multipoint to Point communication with Space Time Network Codes", in 2nd *IEEE International Conference on Innovations in Information, Embedded and Communication Systems* (ICIIECS'15) on 19th & 20th March, 2015, organized by Karpagam College of Engineering, Coimbatore.

- Presented a paper titled "Multipoint to Point communication via Space Time Network Codes", in *IEEE International Conference on Engineering and Technology* (ICETECH'15) on 20th March, 2015, organized by Rathinam Technical Campus, Coimbatore.

Journal

- Paper titled "Cooperative Communication for Multipoint to Point communication with Space Time Network Codes", has been selected for the journal *International Journal of Applied Engineering Research* (IJAER).