DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

COOPERATIVE COMMUNICATION OVER FADING CHANNEL WITH MULTIPLE RELAYS

by
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İZMİR

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"COOPERATIVE COMMUNICATION OVER FADING CHANNELS WITH MULTIPLE RELAYS"** completed by **CEM SELVİ** under supervision of **ASST. PROF. DR. REYAT YILMAZ** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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COOPERATIVE COMMUNICATION OVER FADING CHANNEL WITH MULTIPLE RELAYS

ABSTRACT

The aim of this thesis is to analyze and develop cooperative communication techniques over fading channel with the aid of multiple relays. The initial research in this study is the performance evaluation of cooperation schemes based one way relaying network for amplify and forward (AF) and decode and forward (DF) methods. For multiple relays, cooperation schemes are analyzed for fading channels. It is shown that cooperation scheme which has multiple relays has better performance than the scheme has single relay.

The second research in this study is the performance evaluation of on the two way relaying network and optimal beamforming schemes based two way relaying network for AF and DF methods. We propose an opportunistic relaying for fading channels and relay selection algorithms for AF and DF methods at the same time. In the proposed schemes, firstly optimal beamforming values are founded and compared with a single best relay selected by different algorithms. Results depict that beamforming achieves a better performance compared to the opportunistic beamforming.

The final research direction is on applying relay stations (RS) with multiple antennas to provide communication between two nodes in the orthogonal frequency division multiplexing (OFDM) based two way relay channel. This scheme entails the channel state information only at RS. In this study, it is aimed to Spatial filtering is implemented at the RS using ZF criterion. Simulations are realized in presence of frequency selective environment. The simulation results show that using of multiple RS is better than using of single RS for DF method.

Keywords: Cooperative communications, two-way relaying, relay selection, beamforming, opportunistic relaying

ÇOKLU RÖLE İLE SÖNÜMLEMELİ KANAL ÜZERİNDE İŞBİRLİKLİ İLETİŞİM

ÖZ

Bu tezin amacı çoklu röle yardımıyla sönümlemeli kanal üzerinde işbirlikli iletişim tekniklerini incelemek ve geliştirmektir. Bu çalışmadaki ilk araştırma kuvvetlendir ilet (AF) and çöz ilet (DF) protokolleri için tek yön röle tabanlı işbirliği şemalarının performans değerlendirmesidir. Çoklu rölelerde sönümlemeli kanallar için işbirliği şemaları analiz edilmiştir. Çoklu röleye sahip işbirliği şemaları tek röleli işbirliği şemalarına göre daha iyi bir performansa sahiptir.

Bu çalışmadaki ikinci araştırma alanı iki yönlü röle ağları ve AF ve DF metotları için iki yönlü röle ağları tabanlı en uygun ışın şekillendiricinin performans değerlendirmeleri üzerinedir. Biz aynı zamanda AF ve DF metotları için röle seçim algoritmaları ve sönümlemeli kanallar için fırsatçı röle şemaları amaçlıyoruz. Amaçladığımız şemalarda, ilk olarak uygun ışın şekillendirme değerleri oluşturuluyor ve farklı algoritmalar tarafından seçilen en iyi röle ile karşılaştırılıyor. Sonuç olarak karşılaştırdığımızda ışın şekillendirme fırsatçı röle ye gore daha iyi bir performansa sahip olduğu görülmektedir.

Son çalışma alanı çoklu antene sahip röle istasyonlarının dikgen frekans bölmeli çoklama (OFDM) tabanlı iki yönlü röle kanalında kaynaklar arasındaki iletişimi sağlamak için uygulanmasıdır. Bu modelde kanal durum bilgisi yalnızca röle istasyonlarında gereklidir. Bu çalışmada ZF kriteri kullanılarak röle istasyonunda uzamsal filtreleme uygulanması amaçlanmıştır. Frekans seçici kanal üzerinde simülasyonlar gerçekleştirilmiştir. Simülasyon sonuçları çoklu röle istasyonu uygulamasının DF metodu için tek röle kullanımına göre daha iyi sonuçlar verdiğini göstermiştir.

Anahtar Sözcükler: İşbirlikli iletişim, iki yönlü röle kanalları, röle seçimi, ışın şekillendirme, fırsatçı röle kanalları

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CHAPTER ONE

INTRODUCTION

Relay assisted communication enables diversity benefits whenever it’s not feasible to equip mobile device with multiple transceiver antennas. The fundamentals of one way relay communication are established in (Cover & El Gamal, 1979), where the authors defined detailed capacity limits for traditional relay channel. The interest in relay based communication has aroused after the introduction of cooperative communication techniques (Sendonaris, Erkip & Aazhang, 2003). In two-way relay channel (TWRC), on the other hand, the sources at the two receiving ends of the communication channel transmit their own information in opposite directions via single or multiple relays. The fundamentals of bi-directional communication are firstly presented in (Shannon, 1961) and achievable rates for full duplex transmission is defined therein. In this context, practical transmission schemes for TWRC are considered in various works. Similar to one way case, two basic forwarding methods applied at the relays in bi-directional two-way transmission schemes are amplify-and-forward (AF) and decode-and-forward (DF) protocols (Popovski & Yomo, 2007). In AF, the received signals at the relay are only amplified without signal processing. This protocol is quite simple to implement however since the noise is also forwarded with the source signals, its performance deteriorates in the low signal-to-noise (SNR) region. In DF protocol on the other hand, the received signals are firstly decoded to be transmitted. For both methods, the transmitted signal from the relay node contains information of all the sources of the bi-directional link.

Beamforming techniques exploit the full or partial channel state information at the transmitter to obtain higher receive SNR for multiple antenna systems. For one way transmission between single pair of transmitter and receiver with multiple relays, the optimal beamforming vector is found analytically in (Jing & Jafarkhani, 2008) for AF network. Additionally, a relay selection method which allows only the relay with highest receive SNR to cooperate is also proposed therein. Network beamforming is shown to outperform both the scheme without beamforming and the scheme that selects the best relay for cooperation.

The application of beamforming techniques for two way relay communication is also considered in various works. Although most of these works apply AF protocol as the forwarding technique at the relays, there also exist beamforming methods proposed for TWRC with DF in the literature. When we overview the AF based solutions, we observe that the solutions are based on calculating the beamforming vector by optimization a figure of merit. In example, the authors obtain the beamforming vectors by either minimizing the total transmit power or minimizing the total relay transmit power or maximizing the smaller of two transceiver SNRs in (Havary-Nassab, Shahbazpanahi & Grami, 2010). In another related work, maximization of summation of individual rate of source nodes is the optimization parameter (Guan, Cai, Liu & Yang, 2010). Linear minimum mean square error based solution for obtaining an optimal beamforming matrix is also presented in the literature for AF protocol (Li, Wang & Zhang, 2011). Similar approaches are also observed at the works that apply DF based TWRC beamforming systems. Specifically, the objective function in (Xu, Yang, Fan, Yi & Lei, 2011) is the received SNR of the worse link under the total transmit power constraint. In another related work (Yi & Kim, 2009) the optimization problem reduces to minimizing the outage probability. When the optimal beamforming vectors in all these works are investigated it can be seen that either the solutions are too complex to implement or even an exact solution cannot be derived. For this reason we search for sub-optimal but practical solution for obtaining a beamforming method for transmission over TWRC for both AF and DF protocols.

The main drawback of the beamforming methods is the excess use of resources, i.e. power, bandwidth, since all the relays are active during the broadcasting phase. A possible improvement is possible by the use of opportunistic transmission techniques in which only a single relay is allowed to forward the signals received from sources. The applications of opportunistic transmission schemes in TWRC for both AF and DF protocols exist in the literature. The relay selection criteria in (Atapattu, Jing, Jiang & Tellambura, 2010) is to maximize the worse of the end-to-end SNRs of the two users for AF systems. On the other hand, for DF based opportunistic TWRC transmission system, the best relay is defined as the one that achieves the maximum value within the set of the minimums of source relay path gains in (Zhou, Li, Lau & Vucetic, 2010). In this work, we apply max-min based opportunistic transmission over TWRC for DF protocol and compare the simulated SER performances with that of the beamforming counterparts.

To mitigate the harmful effects of the channel, there are various techniques like Multiple-Input Multiple-Output (MIMO) are applied (Berger & others, 2009). We extend the approach of MIMO two-way relaying in a frequency selective environment using OFDM. OFDM applied at the nodes transforms the high-rated serial data stream into low-rate sub-streams each of which is modulated onto different orthogonal sub-carriers. The low symbol rate facilitates addition of cyclic prefix (CP) between symbols to eliminate effects of inter-symbol-interference (ISI). Orthogonality among the sub-carrier frequencies does not allow inter-carrier-interference (ICI) and hence OFDM has high spectral efficiency (Soni & others, 2009). Therefore, OFDM is much robust to the frequency selective channel. The spatial filtering using ZF criterion at the RS assist the nodes to detect the information exchanged between each other.

1.1 Outline of Thesis

The thesis is organized as follows: In chapter one, we review previous studies and the organization of thesis is also explained.

In the next chapter, topics of elements of basic communication system and definition of them, digital passband modulation and basic digital modulation schemes, wireless communication, wireless channel models and fading phonemena are discussed to maintain background of thesis.

In chapter three, we firstly summarize cooperative communication. We present coopertaion protocols based on fixed and adaptive cooperation strategies for amplify and forward and decode and forward relaying protocols. We introduce multi-nod cooperative communication for one way relaying system. We propose a cooperation scheme with one relay and evaluate the BER performance of system. Then we propose a cooperation scheme with multiple relays and evaluate the BER performance of system, too. The simulation results are discussed.

In chapter four, we propose cooperative coomunication for two way relay network. We explain beamforming and opportunistic schemes in order to enhance the system performance. We introduce the system diagram and the transmission scheme applying proposed beamforming methods. We present opportunistic transmission techniques. Then simulation result are given and discussed.

In chapter five, we presents Orthogonal Frequency Division Multiplexing (OFDM) based two-way relaying scheme to communicate between two nodes S1 and S2 via MIMO Relay Station (RS) in a frequency selective environment. This scheme relies on two-hop relaying approach which uses two orthogonal channel resources to transmit and receive a signal.

CHAPTER TWO

FUNDAMENTALS OF WIRELESS COMMUNICATION

The purpose of a communication system is to send messages or information from a source to a destination over a communication channel. All of the communication systems have three basic elements, which consist of transmitter, receiver and channel. The transmitter transfoms the message signal produced by an information source into an appropriate form for transmission via a channel. The task of the receiver reconstruct the original version of transmitted signal which is deteriorated because of noise and interference to transmit user destination.

We can subdivide communication systems into analog and digital communication. Digital communication has some advantages with regard to analog communication. In a digital communication system; corruptive effect is less than analog, transmited signals over channel can be regenerated up to certain distance, digital circuits are reliable and cheap, implementation is simple, secrecy of the information is guaranteed, the probability of error is lower, combining of digital signals is simpler and signal jamming can be avoided.

Digital communication system diagram is shown in Fig2.1.

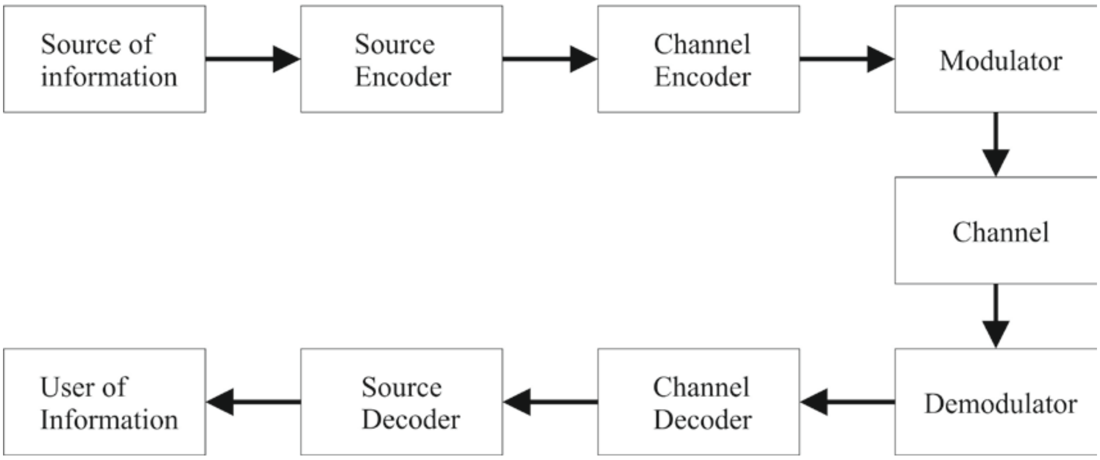


Figure 2.1 Block diagram of a digital communication system

Information sources can have different forms. If we assume radio broadcasting, the information source is usually voice or music and the output of such a source is analog. Therefore, we entitle such sources as analog sources. On the contrary, devices like computer and teletype machine give outputs comprising binary or ASCII characters and they are entitled as digital sources. A digital communication system transmit information in digital form, hence, the output of source must be digital. This process is usually performed by the source encoder.

The source encoder converts the input from its original form to a sequence of bits. It assigns code words to input symbols. The simplest of source coding for discrete sources is representation of each source symbol by a sequence of binary digits, i.e. a source set has letter from the 29 symbol Turkish alphabet can be coded into 5 bit blocks.

The channel coding acomplishes error control coding that is a method to detect errors and corect them if possible. Chanel encoder introduces redundancy to the sequence of bits at the output of source encoder and systematically add bits to the message bits. These redundant bits don’t contain any information or message, but they only use to detect errors in the receiver. Input message bits are divided into blocks that have k message bits. Then each k message bits and (n-k) error control bits compose n bit code word. There are two major codes as block codes and convolutinal codes in channel coding.

Digital modulation is the process of converting an input sequence of bits into a waveform suitable for transmission over the communication channel. Analog wave which modulates input sequence of bits is called carrier. The information is transmitted on carrier via changing amplitude, frequency or phase of the carrier. According to variety of sinussoidal carrier signal, the process of modulation is named as amplitude modulation, frequency modulation or phase modulation. This process is realized in modulator, which is effective to decrease disruptive effect of channel noise.

The communication channel is the physical medium that provides connection between source and destination. There are different communication channels that vary with regard to usage. For example, in wireless communication, media is usually the atmosphere. Some communication system may use different medium. In telephone, medium can be wirelines, fiber optic or wireless. Moreover as well as these, there are channels like coaxial cable, radio channel, satellite channel. Whatever transmition medium is, signal is corrupted because of diverse reasons during transmission. The most extensive distorsion is additive noise, that occurs at receiver and is named termal noise. Another of signal corruption is multipath fading which is seen in radio communication channels. In communication channels, signals are harmed by phase and amplitude distortion, too. Channel have limited bandwith and don’t have ideal frequency responce, also signal power attenuates because of channel’s distortions. In a communacition channel, it is important to know signal to noise power ratio, bandwidth, amplitude and phase responses, noise properties.

Demodulation is the process of converting from a waveform produced by the modulation to an sequence of bits that represent estimates of transmitted message signals. Because of noise and some possible distortions cause some extent in the received signal, the demodulated signal is usually reduced. The most important parameter is type of demodulation in demodulator.

Channel decoder tries to reconstruct orginal information sequence from information of code coming redundancy and channel encoder. It is performed error detection and correction like being in channel encoder. Error control ability, used of which coding, coding efficiency and complicacy are the important parameters in channel decoding.

Source decoder converts the binary output produced by channel decoder into a symbol stream. Source decoding removes redundancy in the transmitiing information. The aim of this is minimizatin of bandwidth for transmission. The output of source decoder is different from orginal message signal, the difference of them is a measure of distortion in digital communication system.

2.1 Digital Passband Modulation

While in baseband transmission, the input sequence is transmitted over low-pass channel, in digital passband transmission, the input stream is modulated on a sinusoidal carrier with limited frequency is result of bandpass channel characteristics.

Passband modulation is a process that converts the information stream to a sinusoidal waveform exchanging phase, amplitude and frequency of a carrier signal, or a combination of these, is varied according to transmitted signal information. There are three basic digital modulation schemes which are named as phase shift keying (PSK), frequency shift keying (FSK) and amplitude shift keying (ASK).

2.1.2 Amplitude Shift Keying (ASK)

In amplitude shift keying, the carrier signal's amplitude have high frequency is set some certain value according to value of input symbol. For example, in binary case, because there are two keying value, on-off keying is used.

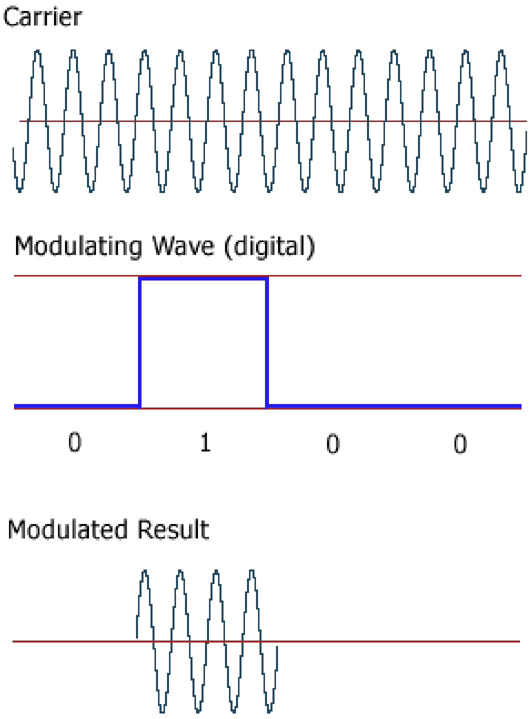


Figure 2.2 Amplitude Shift Keying (WIFI, 2009)

Figure2.2 shows a sample of amplitude shift keying.

ASK waveform can be written as;

$$\phi(t) = \begin{cases} Asin\omega_c t & 0 \leq t \leq T \\ 0 & elsewhere \end{cases} \tag{2.1}$$

For detection of ASK, impulse response of the matched fitler is;

$$h(t) = \phi(T - t) \tag{2.2}$$

The output matched fitler is;

$$y(t) = \phi(t) \otimes h(t)$$

$$= \int_{-\infty}^{\infty} \phi(\tau)\phi(T - t + \tau)d\tau$$

$$= R\phi(T - t) \tag{2.3}$$

where, $R\phi(t)$ is the time auto correlation for $\phi(t)$

for t=T,

$$y(T) = R\phi(0) = E \tag{2.4}$$

The sisnal energy;

$$E = A^2 sin^2 \omega_c tdt = \frac{A^2 T}{2} \tag{2.5}$$

2.1.2 Frequency Shift Keying (FSK)

In frequency shift keying, there are two different carrier frequencies have same amplitude for binary case. FSK can be thought as combination of two ASK signals.

Figure2.3 shows binary FSK waveform.

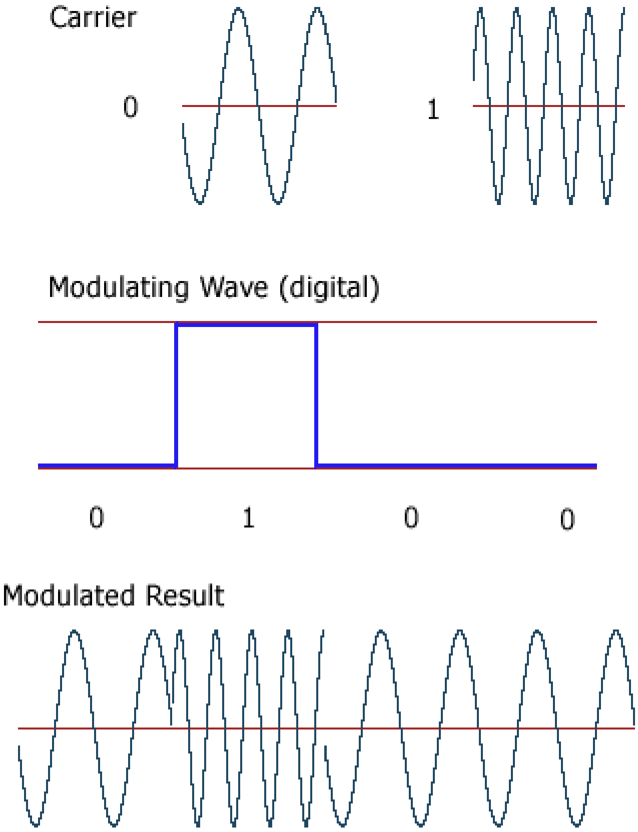


Figure 2.3 Frequency Shift Keying (WIFI, 2009)

A pair of sinusoidal waveform;

$$S_i(t) = \begin{cases} \sqrt{\frac{2E_b}{T_b}} cos 2\pi f_i t & 0 \le t \le T_b \\ 0 & elsewhere \end{cases} \tag{2.6}$$

where Eb is the transmitted energy per bit and i=1,2.

$$f_i = \frac{n_c + i}{T_b} \tag{2.7}$$

where n_c is fixed integer. $S_1(t)$ represent symbol 1 and $S_2(t)$ represent symbol 0. the signals $S_1(t)$ and $S_2(t)$ are orthogonal and the set of orthonormal basis functions is

$$\phi_i(t) = \begin{cases} \sqrt{\frac{2}{T_b}} cos2\pi f_i t & 0 \leq t \leq T_b \\ 0 & elsewhere \end{cases} \tag{2.8}$$

where *i* = 1, 2. The coefficient s_{ij} for *i* = 1, 2, and j = 1, 2. is

$$s_{ij} = \int_0^{T_b} s_i(t)\phi_j(t)dt$$

$$= \int_0^{T_b} \sqrt{\frac{2E_b}{T_b}} cos2\pi f_i t \sqrt{\frac{2}{T_b}} cos2\pi f_i tdt \tag{2.9}$$

$$= \begin{cases} \sqrt{E_b} & i = j \\ 0 & i \neq j \end{cases}$$

$$s_1 = \begin{bmatrix} \sqrt{E_b} \\ 0 \end{bmatrix} \tag{2.10}$$

$$s_2 = \begin{bmatrix} 0 \\ \sqrt{E_b} \end{bmatrix} \tag{2.11}$$

It can be seen that the distance between the two message points is equal $2\sqrt{E_b}$. As x is observation vector has two elements, these are x_1 and x_2.

$$x_1 = \int_0^{T_b} x(t)\phi_1(t)dt \tag{2.12}$$

$$x_2 = \int_0^{T_b} x(t)\phi_2(t)dt \tag{2.13}$$

where $x(t)$ is the received signal,

When x1 > x2, the receiver decides that received symbol is s_1, when x1 < x2, The receiver decides that received symbol is s_2. It may be used scheme shown in Fig2.4 to generate binary FSK and redetect signal being in front of modulator.

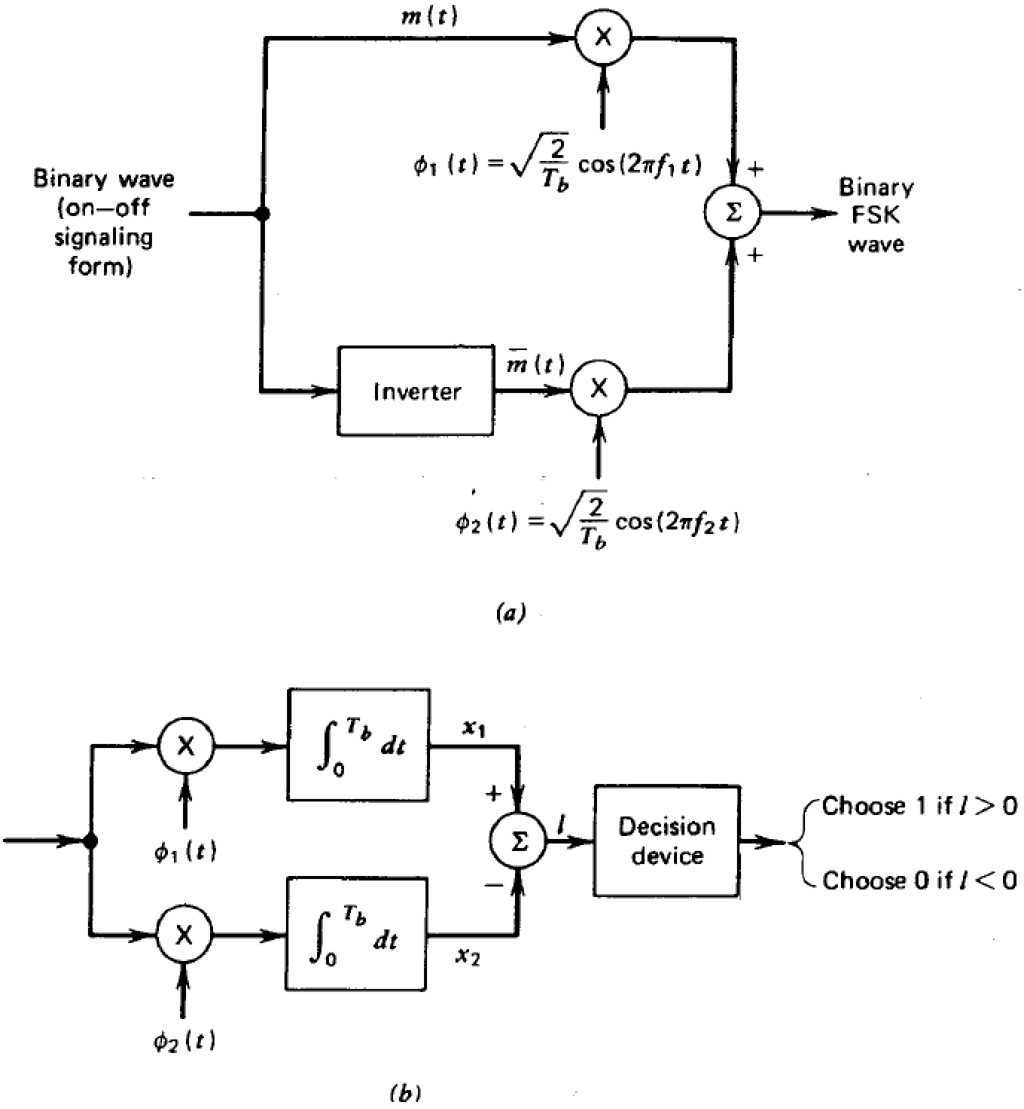


Figure 2.4 Block diagrams of (a) binary FSK transmitter and (b) binary FSK receiver. (Haykin,2000)

2.1.3 Phase Shift Keying (PSK)

PSK is a digital modulation that angle modulated and have constant amplitude. In a coherent binary PSK system, $S_1(t)$ and $S_2(t)$ represent binary symbols “1” and”0”.

$$S_1(t) = \sqrt{\frac{2E_b}{T_b}}cos(2\pi f_c t) \tag{2.14}$$

$$S_2(t) = \sqrt{\frac{2E_b}{T_b}}cos(2\pi f_c t + \pi) = -\sqrt{\frac{2E_b}{T_b}}cos(2\pi f_c t) \tag{2.15}$$

where 0 ≤ t ≤ T_b and E_b is the transmitted signal energy per bit.

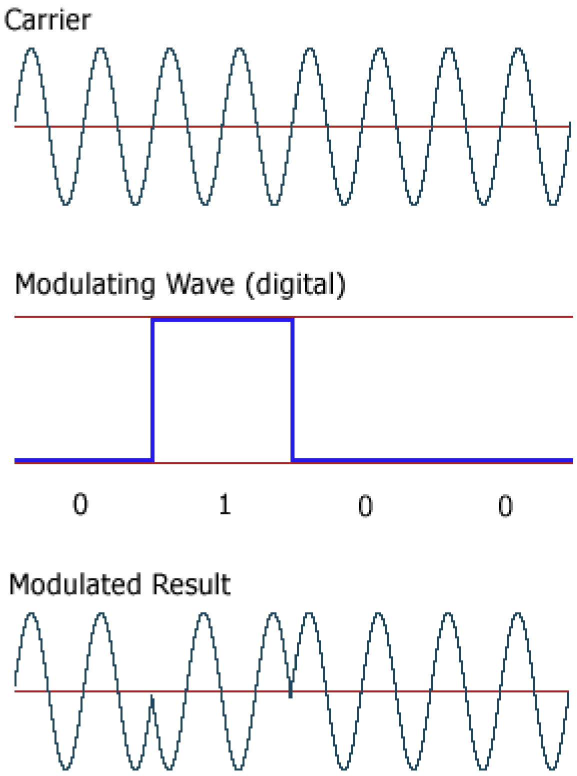


Figure 2.5 Frequency Shift Keying (WIFI, 2009)

There is only one basis function which is,

$$\phi_1(t) = \sqrt{\frac{2}{T_b}} cos(2\pi f_c t) \qquad 0 \leq t \leq T_b \tag{2.16}$$

$$S_1(t) = \sqrt{E_b}\phi_1(t) \qquad 0 \leq t \leq T_b \tag{2.17}$$

$$S_2(t) = -\sqrt{E_b}\phi_1(t) \qquad 0 \leq t \leq T_b \tag{2.18}$$

correlator output, x_1

if $x_1 > 0$, the receiver decides symbol 1.

if $x_1 < 0$, the receiver decides symbol 0.

Figure2.6 shows binary PSK transmitter and coherent binary PSK receiver.

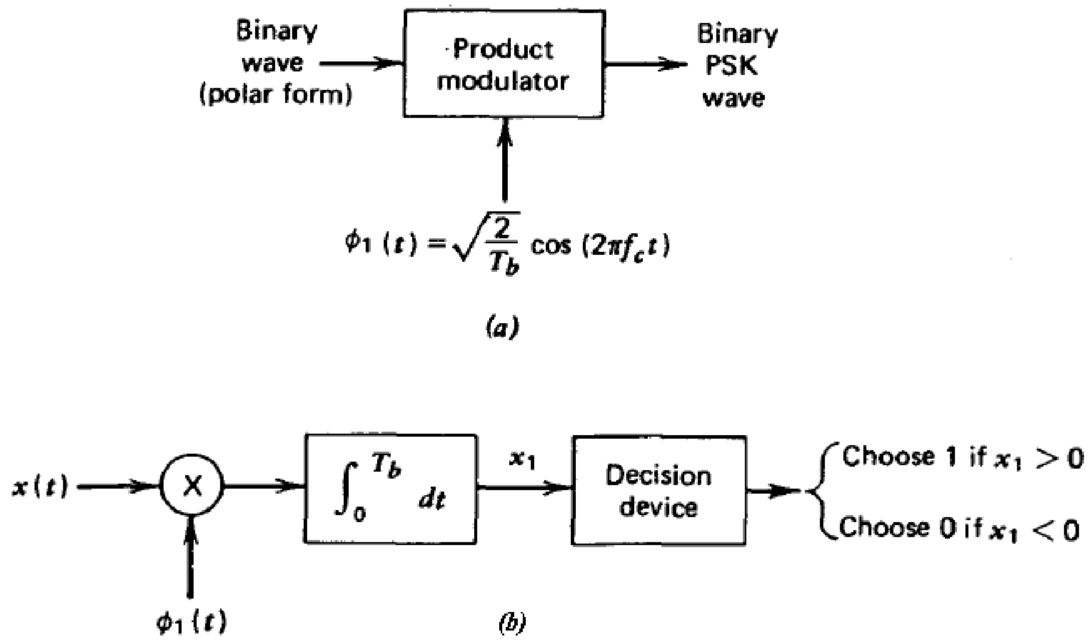


Figure 2.6 (a) binary PSK transmitter (b) coherent binary PSK receiver.(Haykin,2000)

2.1.4 Quadrature Amplitude Modulation (QAM)

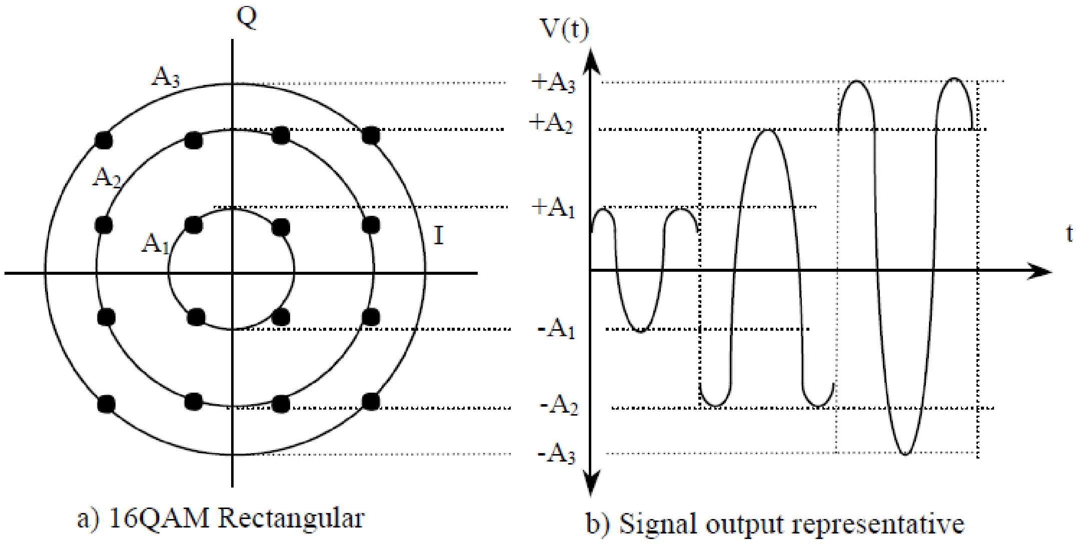
In quadrature amplitude modulation, both the amplitude and phase of carrier signal are varied. The signal amplitude is fixed for all signals, therefore the signal points construct a circular constellation, in M-ary PSK. When this limitation is canceled, the quadrature and in-phase components can be changed independently, modulation is called as quadrature amplitude modulation (QAM).

The QAM signal waveforms can be written as,

$$S_m(t) = \sum_m A_m e^{j\theta_m} \mathrm{g}(t - mT) e^{j2\pi f_c t}$$

$$= A_m \mathrm{g}(t)[\cos(2\pi f_c t + \theta_m) + \sin(2\pi f_c t + \theta_m)] \tag{2.19}$$

If we use M_1 level PAM and M_2 level PSK, we obtain $M=M_1M_2$ level QAM signal constellation. For M=16 there is a way of signal constellation and the output of 16QAM as shown in Figure2.7.



a) 16QAM Rectangular

b) Signal output representative

Figure 2.7 The rectangular constellation of 16 QAM and signal output of 16QAM(Santoso, b.t.)

2.2 Wireless Communication

Information sources send data to a destination. The data is converted into suitable form for transmission and is sent through the channel. The data is corrupted by the disruptive effect of the channel. In wireless channels, the noise sources may be divided into two subdivision as multiplicative and additive effects. The additive noise originates from receiver itself. Thermal noise and shot noise in components, atmospheric effects, cosmic radiation and interference of other transmitters are some example of additive noises. Although some of these interferences exist compulsorily, even so must be carefully controlled. The multiplicative noise results from the various processes crossed by transmitted signal from transmitter to receiver. Some of them can be arranged as the directional characteristics of transceiver antennas, reflection, absorption, scattering, diffraction and refrection.

We can subdivide multiplicative processes into three types of fading. These are entitled as pathloss, shadowing(slow fading) and multipath fading(fast fading). The pathloss cause an overall decrease in signal strength because of distance between transmitter and receiver. This condition occurs because of the outward spreading of waves and blocking effects of obstacles. In pathloss of around 150 dB, variations are formed for a typical system. Shadowing changes more rapidly than pathloss and generally involving variations up to around 20 dB. Shadowing occurs because of tall buildings and dense woods between transmitter and receiver. Fast fading introduces variations as 35-40 dB and involves alteration the scale of a halfwavelength.

2.2.1 Wireless Channel Models

2.2.1.1 Time and Frequency Selectivity

In base-band equivalent continuous time channel model, received signal denoted by y(t) is given in Eq. 2.20.

$$y(t) = \int h(t;\tau)s(t-\tau)d\tau + w(t) \qquad (2.20)$$

where $h(t;\tau)$ denotes the channel response, $s(t-\tau)$ is the transmitted signal, $w(t)$ is additive noise.

This channel is said to be time selective, when we have time invariant impulse response we can talk about time selectivity.

In discrete time channel model, y(n) denotes the received signal, given in Eq. 2.21.

$$y(n) = \sum_k h(n;k)s(n-k) + w(n) \qquad (2.21)$$

where $h(n;k)$ denotes the channel impulse response, $s(n)$ is the transmitted signal, $w(n)$ is additive noise.

This channel is called to be frequency selective. An input-output relationship which is defined as a convolution between impulse response and input is refered by frequency selectivity.

described by a convolution

If $h(t;\tau) = h\delta(\tau)$ and $h(\mathrm{n};\mathrm{k}) = \mathrm{h}\delta(\mathrm{n})$, we obtain a non-time-selective at the same time non-frequency-selective channel.

2.2.1.2 Multipath Propagation and Doppler Effect

Signal power at the receiver suffers from three effects in radio channels. These are the path loss, shadowing loss and fading loss.

The path loss is the signal attentuation born of distance.

2.2.1.3 Fading

The alteration of received signal strength with time is entitled as fading. Fading, because of motion between transmitter and receicer and multipath propagation, cause time-varying attenuation and delay. This delay may create important decrease in system performance.

When the transmitted signal from transmitter is received over N different paths, the signal components combine the received signals. We assume that the receiver be in motion and it has υ velocity, A_i denote the amplitude, θ_i denote the phase and γ_i denote the phase. The received signal is effected Doppler shifts, the shift in carrier frequency;

$$f_i \triangleq f_0 \frac{\upsilon}{c} cos\gamma_i, \qquad i = 1,2,\dots,N \tag{2.22}$$

The received signal may be written,

$$y(t) = \sum_{i=1}^{N} A_i \, exp\, j[2\pi(f_0 - f_i)t + \theta_i] \tag{2.23}$$

The the received signal’s complex envelope,

$$R(t)e^{j\theta(t)} = \sum_{i=1}^{N} A_i e^{-j(2\pi f_i t - \theta_i)}$$

2.2.1.4 Delay Spread and Doppler Frequency Spread

Fading channels may be classified using the definition of coherence bandwidth and coherence time for the physical channel.

The Doppler effect creates time selective fading and frequency selective fading. In multipath propagation, all of path is classificated by an attenuation and delay. $\tau_i(t)$ denotes i. path's delay and the phase is $2\pi f_0(t - \tau_i(t))$. Assume that significiant changes occur in T_c time at the channel. T_c's order of magnitude is said as the max Doppler shift B_D's inverse between the all of paths. T_c is called the coherence time of the channel.

$$T_c \triangleq \frac{1}{B_D} \tag{2.24}$$

T_x is a transmitted signal's duration. If $T_x \gtrsim T_c$, the channel is time selective. The coherence time defines relation between the channel and time. Coherence bandwidth defines relation between the channel and frequency. Assume that phase difference between i. and j. path is $2\pi f(\tau_i(t) - \tau_j(t))$. T_d is delay spread of the cahannel, then coherence bandwidth of the channel is

$$B_C \triangleq \frac{1}{T_D} \tag{2.25}$$

For a signal, if $B_x \gtrsim B_c$ there is frequency selective fading. When there is not correlation between different frequency components for the transmitted signal, frequency selective fading occurs.

We define useful definition which is called a channel's coherence distance where we use multiple antennas. When the channel response is constant, it means that the maximum spatial seperation of two antennas. If the coherence distance is lower than the separation, the channel is space selective.

2.2.1.5 Fading-Channel Classification

We use two quantities B_c and T_c to define of the channel behaves. If $B_x \ll B_c$, we can say that there is no time dispersion and frequency-selective channel. The channel is flat for frequency because of the channel transfer function is fixed. If $T_x \ll T_c$, we know that time selective fading is absent and in time channel is flat.

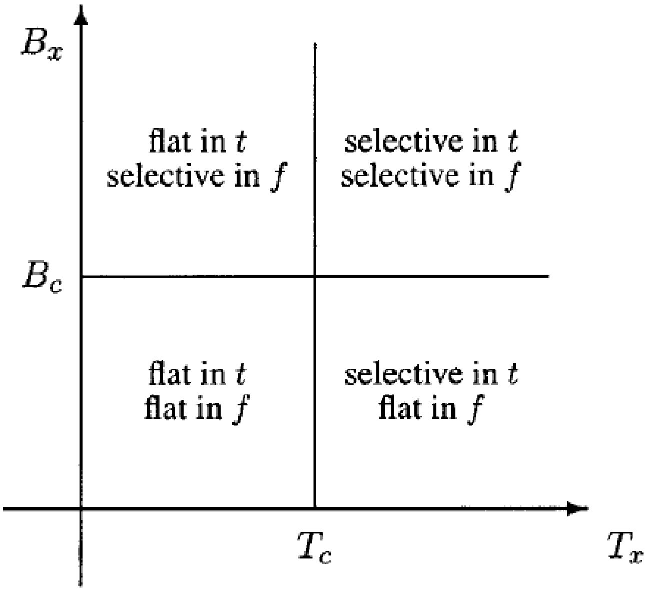
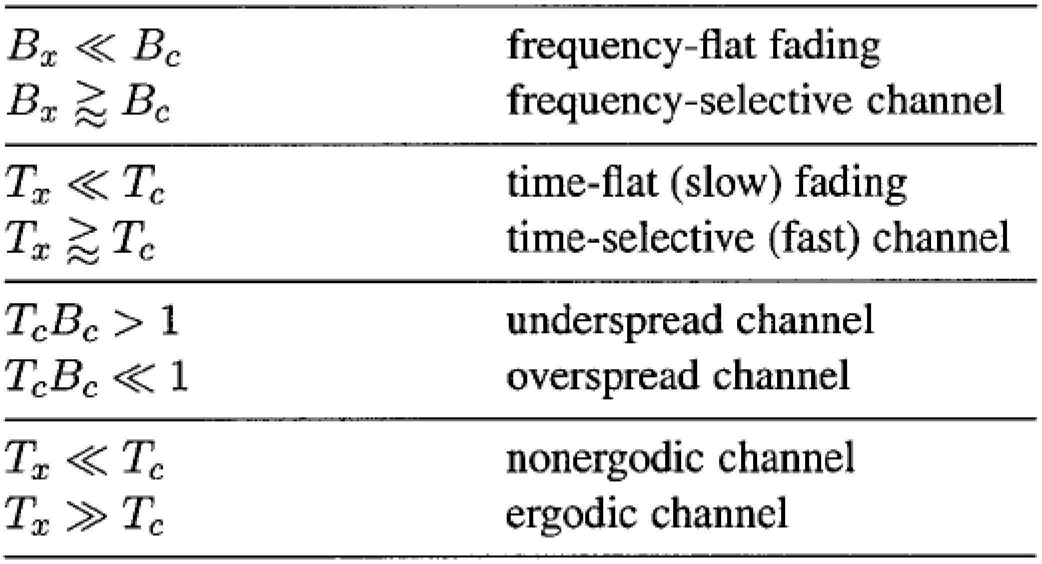


Figure 2.8 Radio-channel classification(Biglieri, 2005)

As shown in Fig2.8, If the channel is flat in f and t, we have not fading both in frequency and time. If the channel is selective in frequency and flat in time, the channel is intersymbol-interference. When the channel is flat, we can use the channel for terrestrial mobile radio. When the channel is selective, we can use the channel for avionic communication.

$T_d B_D = 1/T_c B_c$ is the spread factor of the channel. When$T_d B_D < 1$, the channel is underspread, when $T_d B_D > 1$, the channel is overspread. When the spread factor $\ll 1$, we can measure the channel impulse response. The result of the measrement can be used by receiver and transmitter. An overspppread channel's measurement is difficult and unreliable. Because of that $B_x T_x \gg 1$ and frequency nonselective channel is underspread.

If the signal is long enough, in other words $T_x \gg T_c$, the channel is ergodic. If we want to classificate fading channels we can use B_x, B_c, T_x, T_c terms.



$B_x \ll B_c$	frequency-flat fading
$B_x \gtrapprox B_c$	frequency-selective channel
$T_x \ll T_c$	time-flat (slow) fading
$T_x \gtrapprox T_c$	time-selective (fast) channel
$T_c B_c > 1$	underspread channel
$T_c B_c \ll 1$	overspread channel
$T_x \ll T_c$	nonergodic channel
$T_x \gg T_c$	ergodic channel

Figure 2.9 Classification of fading channels.

CHAPTER THREE
COOPERATIVE COMMUNICATION

Wireless communication have had remarkably technological progress recently. MIMO has the most important role in this progress. MIMO technologies improve the received signal quality and increase the data communication speed. Cooperative communication is a new approach that communication nodes help each other and at the same time it has the same advantages as those found in MIMO systems.

In cooperative communication, independent paths are created between the base station and users through relay channel. The relay channel is an other way that a message reach from source to destination as well as direct channel. In cooperative communaciton process, signal received from the source node is processed by relay. Different processing schemes requires different protocols. Cooperative communication protocols may be classified as fixed relaying schemes and adaptive relaying schemes.

In fixed relaying, source and relay use channel resources in a fixed manner. The procedure used at the relay vary with regard to using protocol. If the relay transmits amplified version of received signal, this relaying scheme is called fixed amplify and forward (AF) relaying protocol. If the relay firstly decodes the received signal then re-encodes it before transmiting, it is called fixed decode and forward (DF) relaying protocol. Fixed relaying has some advantages and disadvantages. While simple implementation is an advantage, low bandwidth efficiency is a disadvantage.

When the channel between source and destination is not very severe, the high percentage of message packets transmitted on this channel. Because of that, relay transmissions become unnecessary. Adaptive relaying is used to overcome this situation. Adaptive relaying can be classified as selective and incremental. In selective relaying, when the SNR of received signal is above a certain threshold, decode and forward is performed on relay. If the source knows that message is not corerctly decoded, source can resend the information to destination or relay transmit information to destination. It is called as incremental relaying.

3.1 Cooperation Protocols

In this part, we assume that there is only one relay to help a source. In cooperation strategy, it can be defined as two orthogonal phases to avoid interference between the two phases in TDMA or FDMA. In phase 1, a source sends information to destination and also sends to relay at the same time. In phase 2, the relay sends the information that the relay received in phase 1 to destination.

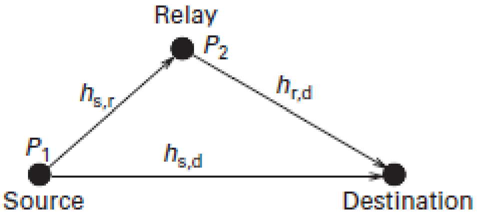


Figure 3.1 a simplified cooperation model
(Su, Sadek, Kwasinski & Liu, 2007).

Figure3.1 shows a general transmission scheme in a relay channel. In this figure, source transmits with power P_1 power and relay transmits with power P_2. We assume that $P_1 = P_2 = P$ and the information is sent to both destination and the relay in phase 1. The received signal in destination is $y_{s,d}$ and the received signal in relay is $y_{s,r}$.

$$y_{s,d} = \sqrt{P} h_{s,d} x + n_{s,d} \tag{4.1}$$

$$y_{s,r} = \sqrt{P} h_{s,r} x + n_{s,r} \tag{4.2}$$

Where x is the transmitted information symbol $n_{s,d}$ and $n_{s,r}$ are additive noises, $h_{s,d}$ and $h_{s,r}$ are channel coefficients which are modeled as zero mean, complex Gaussian random variables with variances $\delta_{s,d}^2$ and $\delta_{s,r}^2$, respectively. $n_{s,d}$ and $n_{s,r}$ depict noise which are modeled as zero mean, complex Gaussian random variables with N_0.

In phase 2, the relay transmits processed information to destination. The received signal in destination to phase 2 is modelled as

$$y_{r,d} = h_{r,d}q(y_{s,r}) + n_{r,d} \tag{4.3}$$

where the function q(.) differ as per implemented process at the relay.

3.1.1 Fixed Cooperation Strategies

3.1.1.1 Fixed Amplify and Forward Relaying Protocol

In fixed amplify and forward relaying protocol, the relay receives the information and transmits an amplified version of it to destination. The relay scales the received signal by a factor of inversely proportional to the received power. The factor is denoted by

$$\beta = \frac{\sqrt{P}}{\sqrt{P\left|h_{s,r}\right|^2 + N_0}} \tag{4.4}$$

The signal transmitted from the relay is $\beta y_{s,r}$ with P power. The SNR from the source link is expressed by

$$\mathrm{SNR_{s,d}} = \Gamma\left|h_{s,d}\right|^2 \tag{4.5}$$

where $\Gamma = \mathrm{P}/N_0$. To calculate received SNR from relay link, the received signal at the destination in phase 2,

$$y_{r,d} = \frac{\sqrt{P}}{\sqrt{P\left|h_{s,r}\right|^2 + N_0}} \quad h_{r,d}y_{s,r} + n_{r,d} \tag{4.6}$$

The destination receives two signal from the source and relay. To combine this two signal, there are different techniques. The optimal technique is the maximal ratio combiner (MRC) for maximizing the overall SNR. MRC combining entails a coherent detector. It must have knowledge of all channel coefficients. At the destination the output of MRC detector is given by

$$y = a1y_{s,d} + a2y_{r,d} \tag{4.7}$$

where a1 and a2 are combining factors and they are used to maximize the combined SNR. To design them, signal space and detection theory principles are used. The noise variance terms should be normalized in received signals and $y_{s,d}\ and\ y_{r,d}$ should be planned the directions $h_{s,d}$ and $h_{r,d}h_{s,r}$. Thus $\mathrm{a}_1$and a_2 can be written as

$$\mathrm{a}_1 = \frac{\sqrt{P}h_{s,d}^{*}}{N_0} \qquad \text{and} \qquad \mathrm{a}_2 = \frac{\sqrt{\frac{P}{P\left|h_{s,r}\right|^2+N_0}}\sqrt{P}h_{s,r}^{*}h_{r,d}^{*}}{\left(\frac{P\left|h_{r,d}\right|^2}{P\left|h_{s,r}\right|^2+N_0}+1\right)N_0} \tag{4.8}$$

Let transmitted symbol x has unit energy, the instantaneous SNR of the MRC output is

$$\gamma = \gamma 1 + \gamma 2 \tag{4.9}$$

$$\gamma 1 = \frac{\left|a1\sqrt{(P)}h_{s,d}\right|^2}{|a1|^2 N_0}$$

$$= P\left|h_{s,d}\right|^2/N_0 \tag{4.10}$$

$$\gamma 2 = \frac{\left|a2\frac{\sqrt{P}}{\sqrt{P\left|h_{s,r}\right|^2+N_0}}\sqrt{P}h_{r,d}h_{s,r}\right|^2}{\left(\frac{P\left|h_{r,d}\right|^2}{P\left|h_{s,r}\right|^2+N_0}+1\right)N_0|a2|^2}$$

$$= \frac{1}{N_0}\frac{P^2\left|h_{s,r}\right|^2\left|h_{r,d}\right|^2}{P\left|h_{s,r}\right|^2+P\left|h_{r,d}\right|^2+N_0} \tag{4.11}$$

The instantaneous mutual information for amplify-and-forward can be written as a function of the fading coefficients as

$$I_{AF} = \frac{1}{2}log\ (1 + \Gamma\left|h_{s,d}\right|^2 + f(\Gamma\left|h_{s,r}\right|^2, \Gamma\left|h_{r,d}\right|^2)) \tag{4.12}$$

The outage probability at high SNR is given by

$$\Pr[I_{AF} < R] \simeq \left(\frac{\sigma_{s,r}^2+\sigma_{r,d}^2}{2\sigma_{s,d}^2\left(\sigma_{s,r}^2\sigma_{r,d}^2\right)}\right)\left(\frac{2^{2R}-1}{\Gamma}\right)^2 \tag{4.13}$$

The outage expression decays as Γ^{-2} , which means that the AF protocol achieves diversity of 2.

3.1.1.2 Fixed Decode and Forward Relaying Protocol

In fixed decode and forward relaying, the relay node decodes the received signal and re-encodes it, and then transmits it to destination. Let the decoded signal at the relay is $\hat{x}$ which has unit variance, and the output of the relay can be expressed by $\sqrt{P}\hat{x}$. If decoded signal at the relay is incorrect, the decoding at destination is meaningless. For such a situation, the diversity achieved is only one.

DF relaying has some advantages, one of them is that reduce the effects of additive noise at the relay. The mutual information among the source and desitination is defined by the weakest link between relay and direct links. The mutual information for decode-and-forward can be written as

$$I_{DF} = \frac{1}{2} min\left\{log\left(1+\Gamma\left|h_{s,r}\right|^2\right), log\left(1+\Gamma\left|h_{s,d}\right|^2\right)+\Gamma\left|h_{r,d}\right|^2\right\} \tag{4.14}$$

The min operator attentions the fact that the relay only transmits if decoded correctly. Therefore, the weakest link limits the performance between source destination and source relay. In fixed DF, the outage probability is given by $\Pr[I_{DF} < R]$. Because of that log is a monotonic function, the outage event can be expressed by

$$min\left\{\left|h_{s,r}\right|^2, \left|h_{s,d}\right|^2+\left|h_{r,d}\right|^2\right\} < \frac{2^{2R}-1}{\Gamma} \tag{4.15}$$

The outage probability

$$\Pr[I_{DF} < R] = \Pr\left\{\left|h_{s,r}\right|^2 < \frac{2^{2R}-1}{\Gamma}\right\} + \Pr\left\{\left|h_{s,r}\right|^2 > \frac{2^{2R}-1}{\Gamma}\right\}\Pr\left\{\left|h_{s,d}\right|^2+\left|h_{r,d}\right|^2 < \frac{2^{2R}-1}{\Gamma}\right\} \tag{4.16}$$

Since the channel is Rayleigh fading, the above random variables are all exponential with parameter one. At high SNR, the outage probability for DF can be given by

$$\Pr[\mathrm{I}_{\mathrm{DF}} < R] \simeq \frac{1}{\sigma_{\mathrm{s,r}}^{2}} \frac{2^{2R}-1}{\Gamma} \tag{4.17}$$

Although low implemantation complexity is a advantage in fixed relaying, low bandwidth efficiency is a disadvantage. This situation is caused by using half of the channel resources at relay transmission, which reduces the overall rate. If source destination channel is not very severe, a high percentage of transmitted packets by the source can be received at destination. This means that the relay transmission is unnecessary.

3.1.2 Adaptive Cooperation Strategies

To overcome fixed relaying suffering, adaptive relaying protocols can be developed. We mention two strategies as selective DF relaying and incremental relaying.

3.1.2.1 Selective DF Relaying

In a selective DF relaying scheme, if the value of received SNR from source at the relay is above a threshold value, the relay decode and forward received information to destination. If received signal SNR is low because of fading, the relay is idle. Selective relaying has beter performance than fixed DF relaying. Due to inherent problem in fixed DF relaying, threshold is determined at the relay. The selective relaying scheme achieves diversity order two because of that to become a outage, both of two links should be in outage. At high SNR, selective DF and AF have the same diversity gain.

3.1.2.2 Incremental Relaying

In incremental relaying, we asume that there is a feedback channel between destination and relay. If the destination receives the information correctly in phase1, the destination sends an information to the relay and the relay does not transmit to destination. Because the relay does not always transmit, this protocol’s specctral efficiency is the best among others mentioned previously. The incremental relaying scheme achieves diversity order of two similar to selective relaying. Therefore incremental relaying has the best performance.

3.2 Multi-Nod Cooperative Communications

We consider a class of cooperative decode and forward protocols in wireless networks which has a total of N relay and each relay can combine source signal and signal forwarded byprevious relays. We go into the performance copperation and produce symbol error rate statement for quadrature amplitude modulation (QAM) and M-ary phase shifting keying (PSK) signalling. Then, we focus on optimal power allocation for the class of cooperative diversity schemes.

3.2.1 System Model and Protocol Description

In N-relay wireless network, the source transmits an information to destination. The relays can cooperate with source to transmit data to destination. The wireless link among the nodes are modelled as Rayleigh fading narrowband channel and additive white Gaussian noise. We assume that the channel fades are statistically independent. The all additive noises are modelled as zero-mean, complex Gaussian random variables with variance N_0. Channels are assumed as orthogonal, which means that there exist no inter-relay interference.

We consider a selective DF protocol at the relaying nodes as cooperation strategy. We assume that the relay can determine whether the received signal is decoded correctly. When the relays are near the source or the relays operate in high SNR, the channel fading becomes the basic error and for this reason the received SNR become active in evaluating whether the received signal is decoded correctly. In a general cooperative communication scheme $C(\mathrm{m})$,$(1 \leq \mathrm{m} \leq \mathrm{N}-1)$, each relay can combined source signal and the received signal from m previous relay as seen Fig. 3.2.

For general scheme $C(\mathrm{m})$,$(1 \leq \mathrm{m} \leq \mathrm{N}-1)$, relays decode the information after combining. In the cooperation protocol, there are a (N+1) phases. In phase 1, after the source transmits the information, the received signal at the destination is,

$$y_{s,d} = \sqrt{P_0} h_{s,d} x + n_{s,d} \tag{4.18}$$

the received signal at the i-th relay,

$$y_{s,r_i} = \sqrt{P_0} h_{s,r_i} x + n_{s,r_i}, \ 1 \leq i \leq N \tag{4.20}$$

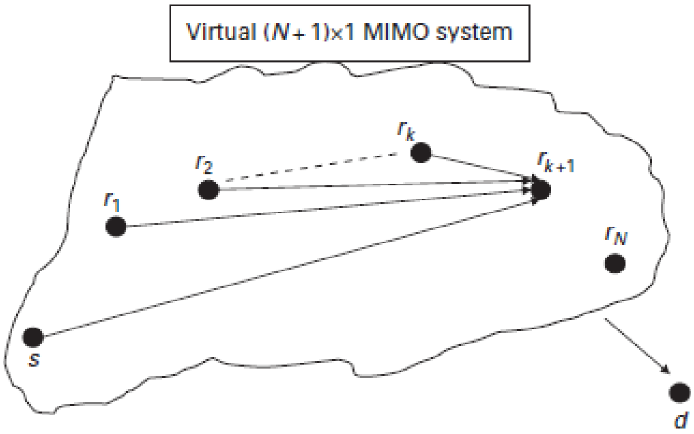


Figure 3.2 C(N − 1): the (k + 1)-th relay combines the signals received from the source and all of the previous relays (Su, Sadek, Kwasinski & Liu, 2007).

where x is the transmitted symbol with unit power, P_0 is the power transmitted at the source, $h_{s,d}$ and $h_{s,r_i}$are the channel fading coefficients between the source and the destination with zero mean and $\delta^2_{\mathrm{s,d}}$ and variances $\delta^2_{\mathrm{s},r_i}$, and i-th relay, respectively. $\mathrm{n_{s,d}}$ and $\mathrm{n_{s,r_i}}$ are the AWGN.

In phase 2, the first relay send the docoded symbol with power $\mathrm{P_1}$if it is doceded correctly. The l-th relay combines the received signals from the previous $min\{m, l -$

$1\}$, $2 \leq l \leq$ N, relays and the source using a maximal-ratio-combiner (MRC) in phase l as seen below

$$y_{r_l} = \sqrt{P_0} h^*_{s,r_l} y_{s,r_l} + \sum_{i=\max(1,l-m)}^{l-1} \sqrt{\widehat{P}_i} h^*_{r_i,r_l} y_{r_i,r_l} \tag{4.21}$$

$$y_{r_i,r_l} = \sqrt{\widehat{P}_i} h_{r_i,r_l} x + n_{r_i,r_l} \tag{4.22}$$

In phase (N + 1),

$$y_d = \sqrt{P_0} h^*_{s,d} y_{s,d} + \sum_{i=1}^{N} \sqrt{\widehat{P}_i} h^*_{r_i,d} y_{r_i,d} \tag{4.23}$$

In Figure3.3, we evaluate the performance of five different system which have different number of relay. As is seen from figure 3.3 when we redound the number of relay, we provide considerable improvement on the system performance in for one way relay channels using AF method.

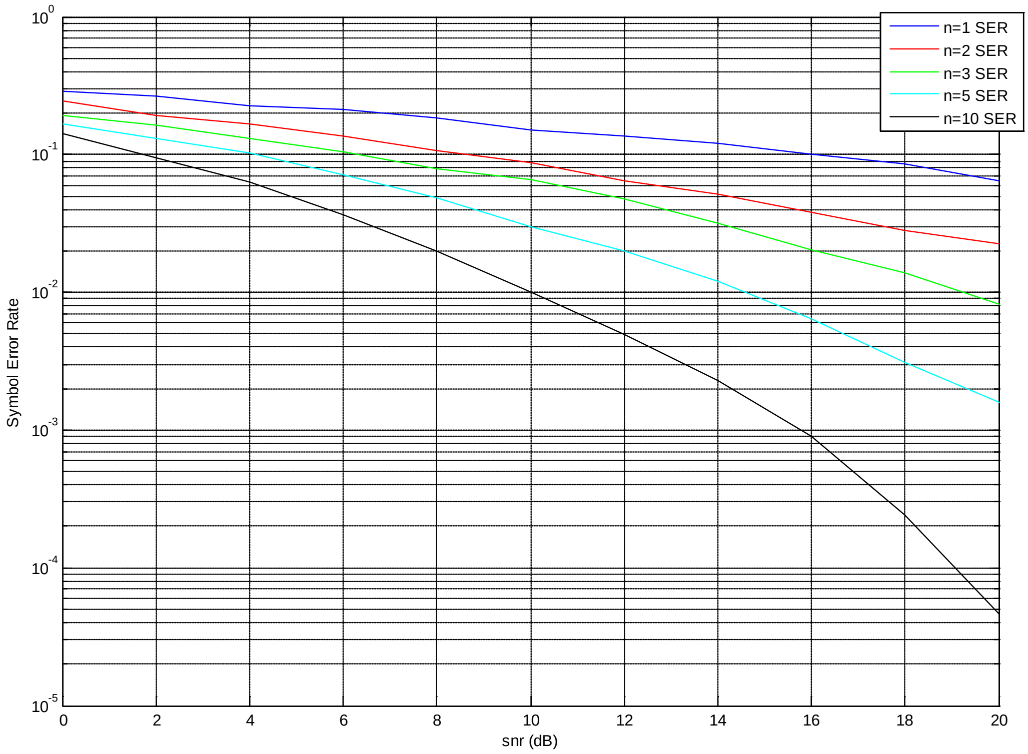


Figure 3.3 The end-to-end error performance of AF based one way relay channel systems

CHAPTER FOUR

TWO-WAY RELAY CHANNELS (TWRC) WİTH MULTIPLE RELAYS

Relay assisted communication enables diversity benefits whenever it’s not feasible to equip mobile device with multiple transceiver antennas. The fundamentals of one way relay communication are established in (Cover & El Gamal, 1979), where the authors defined detailed capacity limits for traditional relay channel. The interest in relay based communication has aroused after the introduction of cooperative communication techniques (Sendonaris, Erkip & Aazhang, 2003). In two-way relay channel (TWRC), on the other hand, the sources at the two receiving ends of the communication channel transmit their own information in opposite directions via single or multiple relays. The fundamentals of bi-directional communication are firstly presented in (Shannon, 1961) and achievable rates for full duplex transmission is defined therein. In this context, practical transmission schemes for TWRC are considered in various works. Similar to one way case, two basic forwarding methods applied at the relays in bi-directional two-way transmission schemes are amplify-and-forward (AF) and decode-and-forward (DF) protocols (Popovski & Yomo, 2007). In AF, the received signals at the relay are only amplified without signal processing. This protocol is quite simple to implement however since the noise is also forwarded with the source signals, its performance deteriorates in the low signal-to-noise (SNR) region. In DF protocol on the other hand, the received signals are firstly decoded to be transmitted. For both methods, the transmitted signal from the relay node contains information of all the sources of the bi-directional link.

Beamforming techniques exploit the full or partial channel state information at the transmitter to obtain higher receive SNR for multiple antenna systems. For one way transmission between single pair of transmitter and receiver with multiple relays, the optimal beamforming vector is found analytically in (Jing & Jafarkhani, 2008) for AF network. Additionally, a relay selection method which allows only the relay with highest receive SNR to cooperate is also proposed therein. Network beamforming is shown to outperform both the scheme without beamforming and the scheme that selects the best relay for cooperation.

The application of beamforming techniques for two way relay communication is also considered in various works. Although most of these works apply AF protocol as the forwarding technique at the relays, there also exist beamforming methods proposed for TWRC with DF in the literature. When we overview the AF based solutions, we observe that the solutions are based on calculating the beamforming vector by optimization a figure of merit. In example, the authors obtain the beamforming vectors by either minimizing the total transmit power or minimizing the total relay transmit power or maximizing the smaller of two transceiver SNRs in (Havary-Nassab, Shahbazpanahi & Grami, 2010). In another related work, maximization of summation of individual rate of source nodes is the optimization parameter (Guan, Cai, Liu & Yang, 2010). Linear minimum mean square error based solution for obtaining an optimal beamforming matrix is also presented in the literature for AF protocol (Li, Wang & Zhang, 2011). Similar approaches are also observed at the works that apply DF based TWRC beamforming systems. Specifically, the objective function in (Xu, Yang, Fan, Yi & Lei, 2011) is the received SNR of the worse link under the total transmit power constraint. In another related work (Yi & Kim, 2009) the optimization problem reduces to minimizing the outage probability. When the optimal beamforming vectors in all these works are investigated it can be seen that either the solutions are too complex to implement or even an exact solution cannot be derived. For this reason we search for sub-optimal but practical solution for obtaining a beamforming method for transmission over TWRC for both AF and DF protocols.

The main drawback of the beamforming methods is the excess use of resources, i.e. power, bandwidth, since all the relays are active during the broadcasting phase. A possible improvement is possible by the use of opportunistic transmission techniques in which only a single relay is allowed to forward the signals received from sources. The applications of opportunistic transmission schemes in TWRC for both AF and DF protocols exist in the literature. The relay selection criteria in (Atapattu, Jing, Jiang & Tellambura, 2010) is to maximize the worse of the end-to-end SNRs of the two users for AF systems. On the other hand, for DF based opportunistic TWRC transmission system, the best relay is defined as the one that achieves the maximum value within the set of the minimums of source relay path gains in (Zhou, Li, Lau &

Vucetic, 2010). In this work, we apply max-min based opportunistic transmission over TWRC for DF protocol and compare the simulated SER performances with that of the beamforming counterparts.

The chapter is organized as follows: the system diagram and the transmission scheme applying proposed beamforming methods for TWRC. The proposed opportunistic transmission techniques.

4.1 Beamforming Based System Model

In this part, the transmission scheme for bi-directional transmisson via multiple relays that apply beamforming method is given. Two basic forwarding protocols, i.e. AF and DF, are assumed respectively, and the suboptimal but less complex beamforming vectors are given for both protocols. The channel model for both algorithms is given in Fig. 1. Two information sources are labeled as S1 and S2 and bi-directional transmission is achieved through a total of t relays each denoted as Rt. The transmitted signals from the sources S1 and S2 are denoted as s_1 and s_2 respectively and it's assumed that the users transmit their signals through the same channel. The channel coefficients between S1-R$_i$ and S2-R$_i$ are denoted as h_{1i} and h_{2i}, $i = 1, 2, .., t$ respectively. The channel coefficients h_{1i} and h_{2i} are independent complex Gaussian variables with zero mean and unit variance. The channel information is perfectly known at the transceiver and the relay nodes. The beamforming vector, **w**, is formed by individual beamforming coefficients of the relays and can be defined as

$$\mathbf{w} = \left[w_1 \ w_2 \ ... \ w_t \right] \tag{4.1}$$

Based on this notation, the signal received at relay node R$_i$ can be expressed as

$$y_{R_i} = h_{1i} s_1 + h_{2i} s_2 + n_{SR_i} \tag{4.2}$$

where n_{SR_i} is the additive white Gaussian distributed noise term with zero mean and $N_0/2$ variance per dimension.

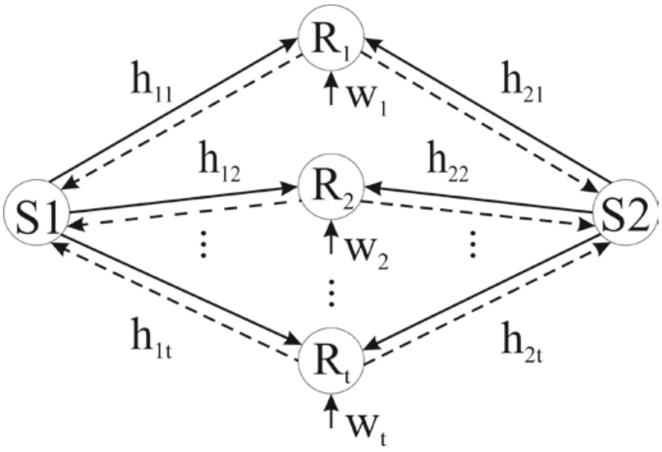


Figure 4.1 A two-way relay network.

In AF protocol, the relay R$_i$ amplifies the received signal using the normalization factor

$$\beta_i = 1 \Big/ \left(E_s \left(|h_{1i}|^2 + |h_{2i}|^2 \right) + N_0 \right) \tag{4.3}$$

and multiplies with the corresponding element (w_i) within the beamforming vector (**w**) before forwarding to both sources. The sources collect all the simultaneous signals from the relays and the received signal at Sm (m=1,2) can be expressed as

$$\begin{aligned} y_{Sm} &= \sum_{i=1}^{t} \left(h_{mi} w_i \beta_i y_{R_i} + n_{R_i Sm} \right) \\ &= \sum_{i=1}^{t} \left(h_{mi} w_i \beta_i h_{1i} s_1 + h_{mi} w_i \beta_i h_{2i} s_2 + h_{mi} w_i \beta_i n_{SR_i} + n_{R_i Sm} \right) \end{aligned} \tag{4.4}$$

The sources remove the self information component from the received signal before decoding the other user's data. Therefore the resultant signal after removing the self information component can be expressed as

$$\tilde{y}_{S1} = \sum_{i=1}^{t} \left(h_{1i} w_i \beta_i h_{2i} s_2 + h_{1i} w_i \beta_i n_{SR_i} + n_{R_i S1} \right) \tag{4.5}$$

and

$$\tilde{y}_{S2} = \sum_{i=1}^{t} \left(h_{2i} w_i \beta_i h_{1i} s_1 + h_{2i} w_i \beta_i n_{SR_i} + n_{R_i S2} \right) \tag{4.6}$$

Observing the individual signals given by ($\tilde{y}_{S1}$) and ($\tilde{y}_{S2}$), we can deduce that the optimal beamforming coefficient can be given as

$$w_i^o = \frac{h_{1i}^* h_{2i}^*}{\left| h_{1i} h_{2i} \right|} \tag{4.7}$$

where $(\ )^*$ denotes the complex conjugate operator. For bi-directional AF networks, end-to-end SNR values can be given as

$$\gamma_{R_i} = \frac{\left| h_{1i} \right|^2 \left| h_{2i} \right|^2}{1 + \left| h_{1i} \right|^2 + \left| h_{2i} \right|^2} \tag{4.8}$$

In DF protocol, on the other hand, the relays decode the received signal and obtains an estimate of each source signal separately before forwarding back to sources. The overall transmission is divided into three time slots in DF protocol. During the first and second time slots, the sources send their information separately. The relays send back a signal obtained by combining individual source signals into a single one. The simple 'XOR' operator is used for this purpose in this work. If we denote the estimated source signals at R$_i$ (i =1,2,…,t) as $\hat{s}_{1i}$ and $\hat{s}_{2i}$, the relay signal transmitted from R$_i$, s_{R_i} , is obtained as

$$s_{R_i} = \hat{s}_{1i} \oplus \hat{s}_{2i} \tag{4.9}$$

The corresponding received signal at Sn (n =1,2) can be expressed as,

$$y_{Sn} = \sum_{i=1}^{t} \left(h_{ni} w_i s_{R_i} + n_{R_i Sn} \right) \tag{4.10}$$

Given these received signals, we apply a suboptimal but simple beamforming vector with elements defined as,

$$w_i^o = \frac{h_1^*}{|h_1|} + \frac{h_2^*}{|h_2|} \tag{4.11}$$

4.2 Opportunistic Transmission for TWRC

Since all the relays take part in beamforming based cooperative two-way transmission scheme given in part II, an inefficient use of power and bandwidth resources arises as a performance criteria. As stated in the introduction part, opportunistic transmission is offered as an alternative to beamforming technique to improve the bandwidth and power efficiency in relay based schemes. For AF based one-way relay schemes, since the relays act only as forwarding the information of the two end users, the relay that achieves the best end-to-end SNR between these two nodes is chosen to assist the information flow. On the other hand, the DF based opportunistic solutions rely on a max-min relay selection method. Specifically, the minimum of the two channel gains between relay and the two end users is found at first for each relay, and the relay that achieves the maximum within these minimums is selected.

For bi-directional AF networks, if only R*ᵢ* is active, the end-end-end SNR values at two end users can be given as,

$$\gamma_{S1R_iS2} = \frac{|h_{1i}\beta_i h_{2i}|^2}{|h_{2i}\beta_i|^2 + N_0\left(\beta_i^2 + 1\right)} \tag{4.12}$$

$$\gamma_{S2R_iS1} = \frac{|h_{2i}\beta_i h_{1i}|^2}{|h_{1i}\beta_i|^2 + N_0\left(\beta_i^2 + 1\right)} \tag{4.13}$$

The relay R$_j$ that achieves the maximum within the set $\min\left\{\gamma_{S1R_iS2}, \gamma_{S2R_iS1}\right\}$, $i \in \{1, 2, ..., t\}$ is selected to assist the bi-directional transmission.

In DF based opportunistic scheme, the possibility of error propogation caused by decoding at the relay, the channel gains should be considered individually and the simple max-min selection algorithm which can be expresses as,

choose R_j such that,

$$j = \max_i \min\left\{|h_{1i}|, |h_{2i}|\right\}$$

is used.

4.3 Simulation Results

In order to obtain the single user SER performances of our proposed beamforming and opportunistic schemes for the two-way relay network, simulations are performed. Assuming quasi-static Rayleigh fading channel and BPSK modulation, five different systems with multiple relays are considered initially. The proposed beamforming and opportunistic transmission for AF networks are applied in the following systems (System1-5). All the systems are composed of a total of 3 relays and defined as,

System1: In this scheme, the proposed beamforming vector given by (w) is applied at all the relays and the total unity power is equally divided between the relays.

Ssytem2: In this scheme, considering that the $|h_{1i}h_{2i}|$ term has impact on performance, it’s calculated for all relays and the relay with the minimum value of this metric is cancelled. The remaini ng relays apply beamforming with unity power.

System3: In this scheme, again beamforming is applied at all the relays, but the power of each relay is distributed in proportion with the end-to-end SNR values given by (γ_{R_i}).

System4: In this scheme, the opportunistic transmission proposed for AF protocol in Part III is applied.

Ssytem5: In this scheme, the power of each relay is unity, i.e., the power dissipated at relays is n times the power dissipated at relays in system1.

The performances of systems1-5 are presented at Figure 4.2. It can be seen that system3 outperforms all remaining ones.

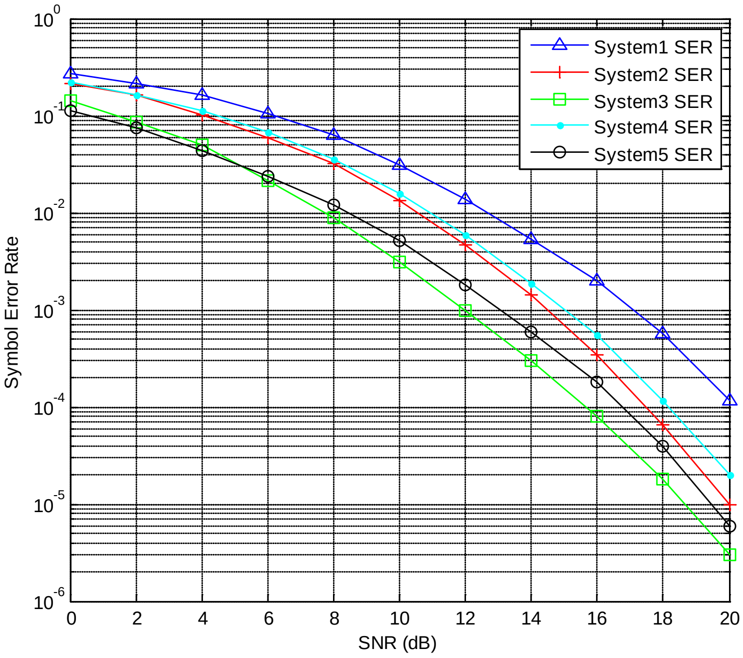


Figure 4.2 The end-to-end error performance of AF based TWRC systems.

The effect of the number of relays is investigated in Figure 4.3. Specifically, total number of relays is varied between 2 and 6, and the performance of system4 is evaluated under these conditions. Observing Figure 4.3, we can deduce that an improvement in SER performance can be ensured when number of relays is increased. At a SER value of 10^{-3} dB, a power improvement about 6 dB can be achieved.

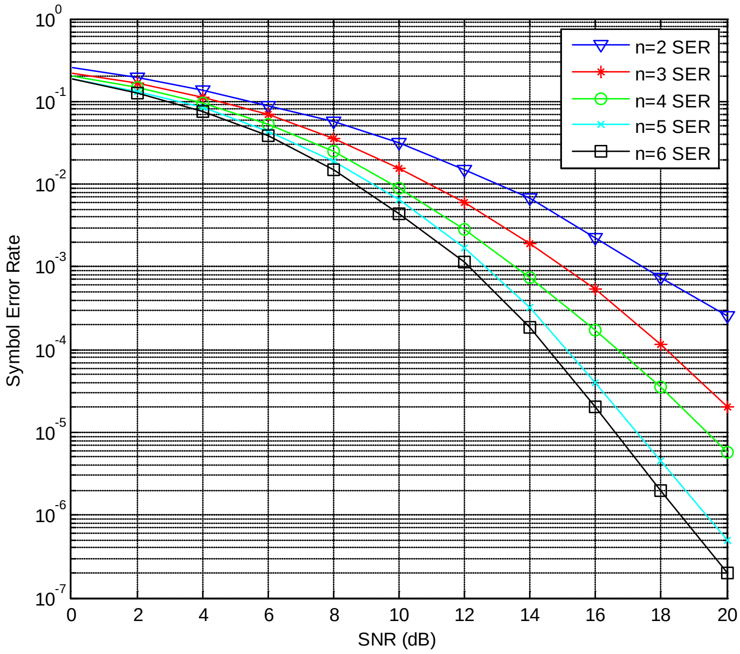


Figure 4.3 The end-to-end error performance of AF for the single transceiver and multiple relays TWRC using system4.

The proposed beamforming and opportunistic transmission schemes for DF protocol is evaluated in Figure 4.4. The single user SER performance of a system employing beamforming vector given by (w) is compared with that of the system employing max-min based opportunistic relay selection algorithm. It can be seen from Figure 4.4 that opportunistic relay selection outperforms beamforming for DF method. Opportunistic transmission improves the performance by 8 dB at SER level of 10^{-3}.

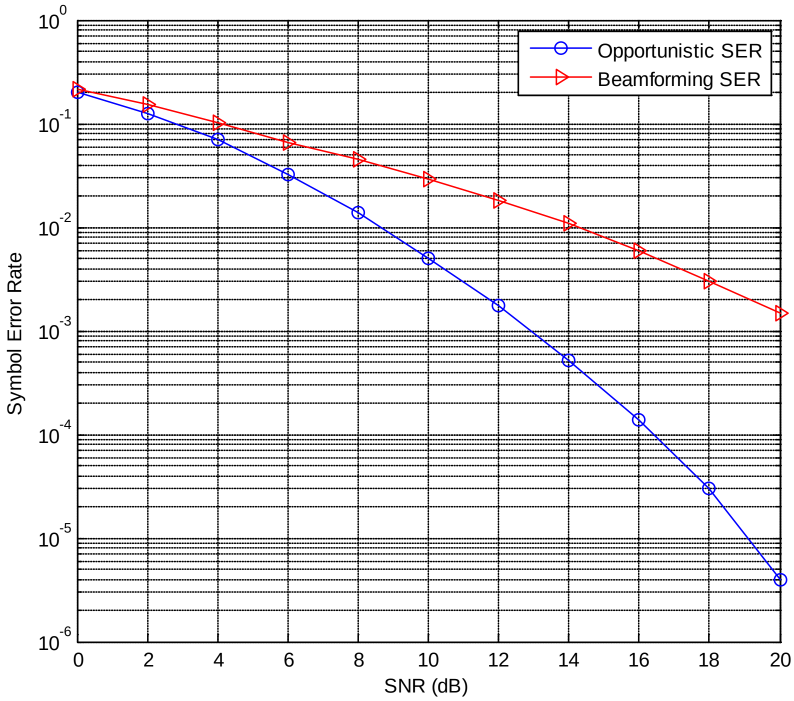


Figure 4.4 The end-to-end error performance of DF for the single-antenna TWRC using opportunistic and beamforming schemes.

CHAPTER FIVE
MIMO TWO WAY RELAYING

5.1 Introduction

There are much continuing work in the field of relay networks. In these works, we heve seen that need for high data rate and high voice quality becomes aleading importance. Because of the fact that communication systems are being located distance range, transmitted signals can be exposed harmful effect of the channels. To mitigate the harmful effects of the channel, we can use Multiple-Input Multiple-Output (MIMO) techniques.

In this study, we discuss about OFDM based two-way relaying case where both the nodes have multiple antennas and the nodes S1 and S2 transmit own data to other node via multiple relay station (RS) when a direct communication among the nodes is not possible.. The relay station (RS) is a MIMO station which requires two orthogonal resources in two hop relaying, one of them is for receiving and other is for transmitting. On a first hop, RS receives a signal and applies signal processing to this signal. On a second hop, RS retransmits processed signal. We assume that bi—directional communication with equal load from S1 to S2, vice versa. The signals received at the MIMO RS are decoded and forwarded.

In MIMO two-way relaying scenario for frequency selective environment using OFDM, nodes can subtract their own data signal from the data received from RS and detect transmission of other nodes which requires CSI at the nodes. Each node S1 and S2 requires CSI from itself to RS and also from other node to RS. Both the nodes S1 and S2 have same number of antennas and RS has minimum of twice the number of antennas that nodes have. The transceive filter at the RS is responsible for the transmit and receive processing and hence CSI at the nodes becomes unnecessary.

OFDM applied at the nodes transforms the high-rated serial data stream into low-rate sub-streams each of which is modulated onto different orthogonal sub-carriers. The low symbol rate facilitates addition of cyclic prefix (CP) between symbols to eliminate effects of inter-symbol-interference (ISI). Orthogonality among the subcarrier frequencies does not allow inter-carrier-interference (ICI) and hence OFDM has high spectral efficiency. Therefore, OFDM is much robust to the frequency selective channel. The spatial filtering using ZF criterion at the RS assist the nodes to detect the information exchanged between each other.

5.1.1 Othogonal Frequency Division Multiplexing (OFDM)

The modulation technique that a transmitter combines multiple low data rate carriers to form a composite high data rate transmission, is called OFDM (Cosby, 2011).In OFDM technique, frequency spectrum is divided into a number of equally spaced frequency bands that each one carries one user data. Each carrier‟s frequency is an integer multiple of a base sinusoid frequency. As opposed to frequency divisionmultiplexing (FDM), there are orthogonal subcarriers in parallel in an OFDM system.

Because of the orthogonality of subcarriers, they do not overlap with each other in time domain and the integral of their product, over one period, is equal to zero. Therefore, OFDM converts a frequency selective fading channel into a flat fading channel by using orthogonal subcarriers.

In practice, discrete Fourier transform (DFT) and inverse DFT (IDFT) processes are useful for implementing the multiple orthogonal subcarrier signals, which are overlapped in spectrum. We can implement DFT and IDFT by using fast Fourier transform (FFT) and inverse fast Fourier transform (IFFT), respectively. In the OFDM transmission system, N-point IFFT is taken for the transmitted symbols. The result is the samples for the sum of orthogonal subcarrier signals. Taking the N-point FFT of the received samples, the noisy version of transmitted symbols can be obtained in the receiver.As all subcarriers are of the finite duration T, the spectrum of the OFDM signal can be considered as the sum of the frequencyshifted sinc functions in the frequency domain.

5.2 System Model

We assume that S1 and S2 can not communicate each other directly, only they communicate via a RS. S1 and S2 have $M^{(1)} = M^{(2)} = M$ antennas and RS has $M_{RS} = 2M$ antennas. Fig 5.1 shows the case of M=1 M_{RS}=2.

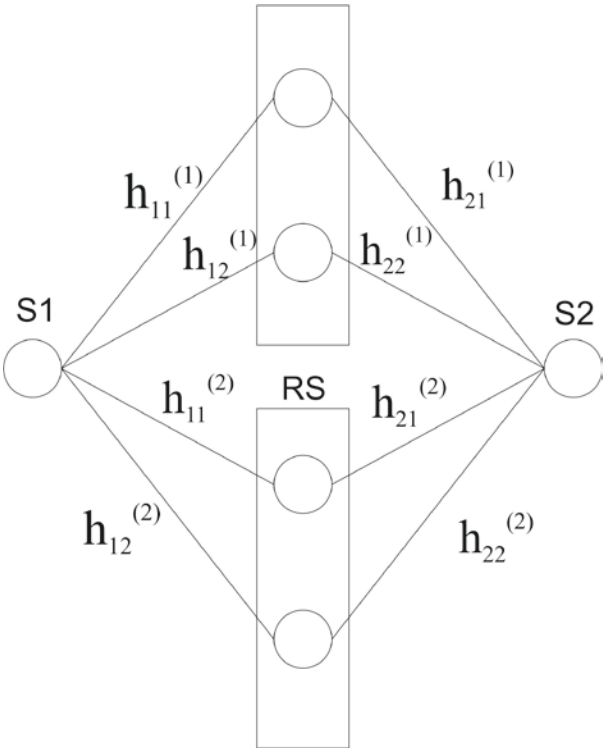


Figure 5.1 relaying scenario

Let data vector from S1 to S2 is $X_1 = [\mathrm{X}_{11,} \mathrm{X}_{12,} \dots, \mathrm{X}_{1\mathrm{M}}]$ and data vector from S2 to S1 is $X_2 = [\mathrm{X}_{21,} \mathrm{X}_{22,} \dots, \mathrm{X}_{2\mathrm{M}}]$, X_1 and X_2 grouped into blocks of length N (number of sub-carriers for OFDM) and then IFFT operation is done giving $x_1 = [\mathrm{x}_{11,} \mathrm{x}_{12,} \dots, \mathrm{x}_{1\mathrm{M}}]$ at S1 $x_2 = [\mathrm{x}_{21,} \mathrm{x}_{22,} \dots, \mathrm{x}_{2\mathrm{M}}]$ at S2. In order to reduce the effect of ISI, CP is added to each block. The resulting OFDM symbols are then arranged serially.

After taking IFFT and addition of CP, the resultant OFDM data vector becomes $x_1 = [\mathrm{x}_{11,} \mathrm{x}_{12,} \dots, \mathrm{x}_{1\mathrm{M}}]^T$ at S1 $x_2 = [\mathrm{x}_{21,} \mathrm{x}_{22,} \dots, \mathrm{x}_{2\mathrm{M}}]^T$ at S2. The overall data vector is $X = [X_1{}^T, X_2{}^T]^T$ where $[.]^T$denotes the transpose. We apply spatial filtering at the RS, scalar transmit filters $Q1 = q1I_M$ from S1 to S2 and $Q2 = q2I_M$ from S2 to S1, where I_M is identity matrix of size M. We use these filters in order to provide transmit energy constraints. E1 and E2 are the maximum transmit energies of S1 and S2. The transmit energy constraints are described by

$$E\{\|q(k)x(k)\|_2^2\} \leq E(k), \quad k = 1,2 \tag{5.1}$$

where $E\{.\}$ denote the expectation $\|.\|_2^2$ denote Euclidian norm. the overall tranmsit filter is described by

$$\mathrm{Q} = \begin{bmatrix} Q1 & I_M \\ I_M & Q2 \end{bmatrix} \tag{5.2}$$

We assume that the wireless channel is flat fading and channel matrix from S1 to RS is given by

$$\mathrm{H1} = \begin{bmatrix} \mathrm{h}_{11}^{(1)} & \mathrm{h}_{12}^{(1)} \\ \mathrm{h}_{21}^{(1)} & \mathrm{h}_{22}^{(1)} \end{bmatrix} \tag{5.3}$$

channel matrix from S2 to RS is given by

$$\mathrm{H2} = \begin{bmatrix} \mathrm{h}_{11}^{(2)} & \mathrm{h}_{12}^{(2)} \\ \mathrm{h}_{21}^{(2)} & \mathrm{h}_{22}^{(2)} \end{bmatrix} \tag{5.4}$$

The channel matrix from RS to S1 and S2 is transpose of H1 and H2 respectively. From S1 to S2 and S2 to S1, the channel is constant during one transmission cycle. H denotes overall channel matrix and H differ according to relaying protocol at the RS. G is linear transceiver filter. We apply G to received signal at the RS and we obtain $\mathrm{x_{RS}}$ which is the filtered transmit vector. $\mathrm{x_{RS}}$ has to transmit energy constraint before retransmission.

$$E\{\|\mathrm{x_{RS}}\|_2^2\} \leq \mathrm{E_{RS}}, \tag{5.5}$$

where $\mathrm{E_{RS}}$ denotes the maximum transmit energy at the RS. Scalar receive filters are $P1 = p_1 I_M$ at S1 and $P2 = p_2 I_M$ at S2. The overall receive filter P is described by

$$\mathrm{P} = \begin{bmatrix} P1 & I_M \\ I_M & P2 \end{bmatrix} \quad 5.6$$

$\widehat{x_1}$ is the estimate for data vector x_2 at S1 and $\widehat{x_2}$ is the estimate for data vector x_1 at S2. The overall estimated data vector is given by $\hat{x} = [\widehat{x_1}^T, \widehat{x_2}^T]^T$ and the output of scaler receive filter is described by

$$\hat{x} = P(H^T GHQx + H^T G n_{RS} + n_R) \quad 5.7$$

n_{RS} and n_R are additive noise vectors. $n_R = [{n_{R1}}^T, {n_{R2}}^T]^T$, n_{R1} and n_{R2} is the noise vectors at S1 and S2, respectively.

5.2.1 Maximum Ratio Combining at the RS

In one way relaying, we need four orthogonal time slots for bi-directional communication between S1 and S2. S1 sends x_1 to RS during the first time slot. Firstly, we apply receive vector to receive MRC at the RS. The receive filter is shown

$$\mathrm{G_{R1}} = \frac{\mathrm{H1}^T}{\|\mathrm{H1}^T\|_2^2} \quad 5.8$$

Secondly, we apply transmit MRC, the transmit filter is given by

$$\mathrm{G_{T2}} = \mathrm{c_{T2}}\ \mathrm{H_2}^T \quad 5.9$$

$\mathrm{c_{T2}}$ is used to meet the transmit energy constraint at the RS. The overall transceiver filter from S1 to S2 is described by

$$\mathrm{G_1} = \mathrm{G_{R1}} \mathrm{G_{T2}} \quad 5.10$$

In the second time slot, the filtered vector is retransmitted to S2 by RS, the estimate for data vector x_1

$$\widehat{x_2} = P2({H_2}^T G_1\, H_1\, Q_1\, x_1 + {H_2}^T G_1\, n_{RS} + n_{R2}) \quad 5.11$$

In the third time slot, x_2 is transmitted to RS by S2. The receive vector at the RS pass the overall transceiver filter is denoted by

$$\mathrm{G}_2 = \mathrm{G}_{\mathrm{R2}}\mathrm{G}_{\mathrm{T1}} \qquad 5.12$$

In the fourth time slot, the filtered vector is retransmitted to S1 leading to the estimate

$$\widehat{x_2} = P2({H_1}^T G_2\, H_2\, Q_2\, x_2 + {H_1}^T G_2\, n_{RS} + n_{R1}) \qquad 5.13$$

5.2.2 MIMO Two-Way Relaying

In MIMO two-way relaying, we need three orthogonal time slot between S1 and S2 for bi-directional communication. For the first time slot, S1 transmit x1 to RS and S2 transmit x_2 to RS, simultaneously. Firstly, we apply a linear receive filter is described asG_{R}. Secondly, we apply RS mapping matrix

$$\mathrm{G}_{\mathrm{II}} = \begin{bmatrix} \emptyset & I \\ I & \emptyset \end{bmatrix} \qquad 5.14$$

Thirdly, we apply a linear transmit filter G_{T} which seperates the vectors esignated for S1 and S2. In the second time slot, the filtered vector is retransmitted to S1 and S2 simultaneously.

5.3 Sum Rate of Two-Way Relaying

We define sum rate of a system as the sum of the mutual information values for bi-directional communication. We can rewrite Eq. 5.7 concerning the sum rate of the MRC one-way relaying approach and the MIMO two-way relaying approach and the MIMO two-way relaying approach.

$$\hat{x} = Ax + [D\ P]\, n$$

$$= \begin{bmatrix} A1 \\ A2 \end{bmatrix} x + \begin{bmatrix} B1 \\ B2 \end{bmatrix}\, n \qquad 5.15$$

$$A = PH^T GHQ \qquad 5.16$$

$D = PH^T G$ 5.17

$n = [n_{RS}{}^T, n_R{}^T]^T$ 5.18

The two estimates at nodes,

$\widehat{x_k} = A_k\, x + B_k\, n$, for k=1,2 5.19

We can show that the mutual information among receive node k and corresponding transmit node,

$C_k = \log_2 \left(det \left[I_M + \frac{A_k\, R_x\, A_k{}^H}{B_k\, R_n\, B_k{}^H} \right] \right)\ for\ k = 1{,}2$ 5.20

R_x is the overall transmit vector and R_n is the overall receive noise vector covariance matrices. $[.]^{\mathrm{H}}$ denotes the conjugate complex transpose.

In MRC one way relaying, we can separate the transmission four orthogonal channel resources. The overall sum rate of MRC one way relaying is shown as

$\mathrm{C_{ow}} = \frac{1}{4}(\mathrm{C_{ow1}} + \mathrm{C_{ow2}})$ 5.21

$\mathrm{C_{ow1}}$ denotes the mutual information for the transmission from S2 to S1, $\mathrm{C_{ow2}}$ denotes the mutual information for the transmission from S1 to S2. The factor ¼ expresses the number of required channel resources for the bi-directional communication.

In MIMO two-way relaying, we use three orthogonal channel resources. The sum rate of MIMO two-way realying is described by

$\mathrm{C_{tw}} = \frac{1}{2}(\mathrm{C_{tw1}} + \mathrm{C_{tw2}})$ 5.22

$\mathrm{C_{tw1}}$ denotes the mutual information for the transmission from S2 to S1, $\mathrm{C_{tw2}}$ denotes the mutual information for the transmission from S1 to S2. The factor 1/2 expresses the number of required channel resources for the bi-directional communication.

5.4 Simulation and Results

In this section, BER performances of the linear ZF transceive filters are evaluated considering frequency selective environments. The number of antennas at the nodes S1 and S2 are taken to be 1 (M = 1) and number of antennas at the MIMO RS is taken as 2 (2M). BPSK modulation is performed on the data to be transmitted by both nodes to RS. The number of sub-carriers N in OFDM are taken as 128 and CP length is taken as 5.

In Figure 5.2, BER performance at node S1 is computed for ZF transceive filter considering a frequency selective channel using OFDM. We can infer that when we use OFDM, it can be ensured high performance values at high SNRs. It can be clearly seen from the figure that the BER performance of system having two RS has better performance,if it is compared with the system having one RS.

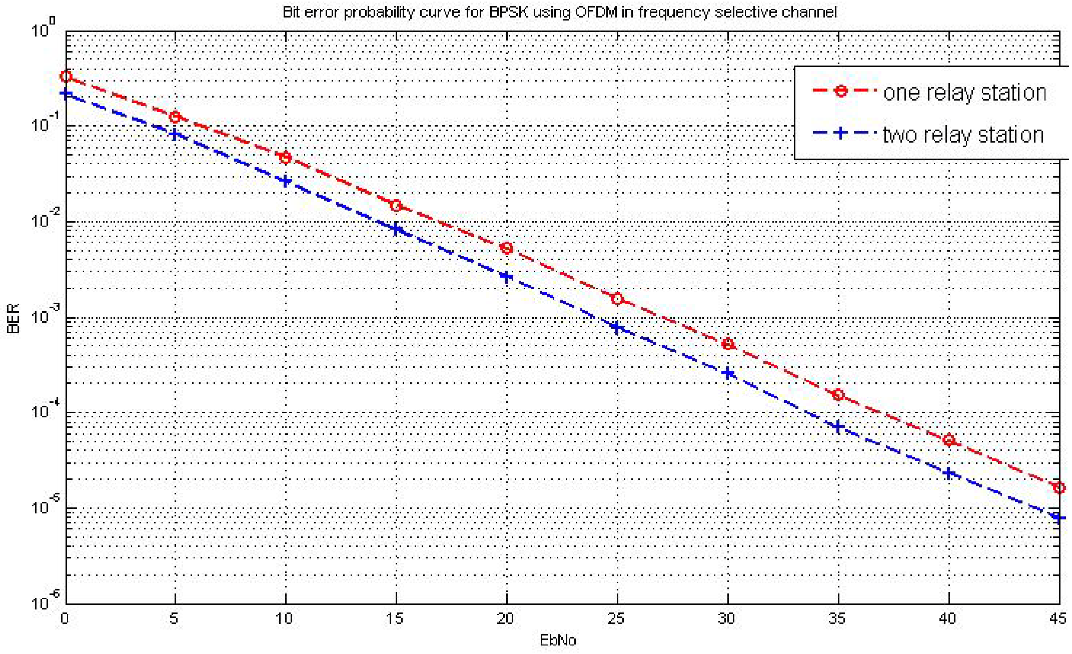


Figure 5.2 The end-to-end error performance of DF for the MIMO antenna TWRC using OFDM.

CHAPTER SIX

CONCLUSION

In this thesis, we have investigated cooperative communication techniques. Initially, we have focused on one way relaying system which has single and multiple relays for amplify and forward (AF) and decode and forward (DF) cooperation techniques. For both techniques, we have seen that rising of number of relay cause improvement on the system Bit Error Rate (BER) performance. Then, we have considered two way relay channels for cooperation. In a two way relay channel scenario, the performance of optimal beamforming schemes have been investigated for AF and DF strategies. At the same time, we have proposed an opportunistic relaying for fading channels and optimal relay selection algorithms.

In order to obtain the single user SER performances of our proposed beamforming and opportunistic schemes for the two-way relay network, simulations have been performed. Assuming quasi-static Rayleigh fading channel and BPSK modulation, five different systems with multiple relays have been considered initially. The proposed beamforming and opportunistic transmission for AF networks have been applied in the systems which mentioned in chapter four. All the systems are composed of a total of 3 relays.

The effect of the number of relays has been investigated. Specifically, total number of relays has been varied between 2 and 6, and the performance of system4 has been evaluated under these conditions. We can deduce that an improvement in SER performance can be ensured when number of relays is increased. At a SER value of 10-3 dB, a power improvement about 6 dB can be achieved.

The proposed beamforming and opportunistic transmission schemes for DF protocol has been evaluated. The single user SER performance of a system employing beamforming vector has been compared with that of the system employing max-min based opportunistic relay selection algorithm. It can be seen that opportunistic relay selection outperforms beamforming for DF method. Opportunistic transmission improves the performance by 8 dB at SER level of 10^{-3}.

MIMO two-way relaying scenario is considered for frequency selective environment using OFDM where two nodes S1 and S2 communicate via an intermediate MIMO RS. For two-way relaying, the utilization of spatial filtering only at RS eliminates the CSI signaling overhead at nodes S1 and S2. It is evident from the simulation results that SNR value of one channel affects the BER performance at frequency selective environments. The BER performance of the ZF transceive filter outperforms frequency selective environments. OFDM mitigates the effects of the frequency selective channel and plays a critical role in reducing the BER. The BER performance of system having two RS is better than the system having one RS.

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