

**Performance analysis of differential detection
transmit diversity**

*A Thesis Submitted in partial fulfillment of the
requirements for the award of degree of*

**Master of Engineering
in
Electronics and Communication Engineering**

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JUNE 2006

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Certificate

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Acknowledgement

It is with the deepest sense of gratitude that I am reciprocating the magnanimity, which my guide Mr. Rajesh Khanna, has bestowed on me by providing individual guidance and support throughout the Thesis work.

I am thankful to Dr. R. S. Kaler, Head, Electronics and Communication Engineering Department and also to Dr. A.K. Chatterjee, P.G. Coordinator, Electronics and Communication Engineering Department for their motivation and inspiration that triggered me for my thesis work.

I would also like to thank all the staff members and my co-students who were always there at the need of the hour and provided with all the help and facilities, which I required for the completion of my thesis.

I am also thankful to the authors whose works I have consulted and quoted in this work. Last but not the least I would like to thank God for not letting me down at the time of crisis and showing me the silver lining in the dark clouds.

Ankush Goyal
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Table of Contents

Certificate.....	ii
Acknowledgement	iii
Table of Contents.....	iv
List of Figures.....	Error! Bookmark not defined.
List of Tables	ix
Abstract.....	xii
Chapter 1.....	1
Introduction.....	1
1.1 Introduction.....	1
1.2 Space Time Processing (STP).....	2
1.2.1 Space-time Trellis codes (STTC).....	4
1.2.2 Space-time Block codes (STBC).....	4
1.3 Differential Detection	5
1.4 Objectives of the thesis	6
1.5 Organization of the report.....	7
Chapter 2.....	8
Space Time Processing	8
2.1 Space Time Processing.....	8
2.2 Space-time code	11
2.3 Space-time Communication.....	12
2.3.1 Model of Space-time Communication.....	12
2.4 Diversity.....	16
2.5 Receive diversity.....	17
2.5.1 Macroscopic diversity scheme.....	17
2.5.2 Time Diversity	18
2.5.3 Frequency Diversity.....	19
2.5.4 Polarization Diversity	20
2.5.5 Angle Diversity.....	21

2.6 Transmit Diversity	22
Chapter 3	25
Receive and Transmit Diversity with ML detection.....	25
3.1 Introduction.....	25
3.2 Classical maximal-ratio receive combining (MRRC) scheme.....	26
3.3 The Alamouti's Transmit Diversity Scheme	29
3.4 Simulation details.....	31
3.4.1 Simulation results of BER for BPSK under different fading environments for Alamouti's Scheme.....	32
3.4.2 Simulation results of BER for QPSK under different fading environments for Alamouti's Scheme.....	36
Chapter 4.....	87
Differential Detection transmit diversity	87
4.1 Introduction.....	87
4.2 System Analysis.....	87
4.2.1 Encoding algorithm.....	88
4.2.2 Decoding algorithm	89
4.3 Matlab simulations.....	92
4.3.1 Simulation results of BER for BPSK under different fading environments with Differential Detection Scheme.....	93
4.3.2 Simulation results of BER for DPSK under different fading environments with Differential Detection Scheme	98
4.3.3 Simulation results of BER for QPSK under different fading environments with Differential Detection Scheme.....	103
4.3.4 Comparison of BER of different modulation schemes with Differential Detection Scheme under Rayleigh fading environment	108
4.3.5 Comparison of BER of different modulation schemes with Differential Detection Scheme under Rician fading environment	111
4.3.6 Comparison of BER of different modulation schemes for Differential Detection Scheme under Nakagami fading environment	114

4.3.7 Comparison of Differential Detection Scheme and Alamouti's Scheme using BPSK under Rayleigh fading.....	117
4.3.8 Comparison of Differential Detection Scheme and Alamouti's Scheme using QPSK under Rayleigh fading.....	120
4.3.9 Comparison of Differential Detection Scheme and Alamouti's Scheme using BPSK under Rician fading.....	123
4.3.10 Comparison of Differential Detection Scheme and Alamouti's Scheme using QPSK under Rician fading.....	126
4.3.11 Comparison of Differential Detection Scheme and Alamouti's Scheme using BPSK under Nakagami fading.....	128
4.3.12 Comparison of Differential Detection Scheme and Alamouti's Scheme using QPSK under Nakagami fading.....	131
Chapter 5.....	134
Conclusions and Future Scopes	134
5.1 Conclusions.....	134
5.2 Future Scopes.....	135
References.....	136
List of Publications	91

List of Figures

Fig. 1.1 MIMO System	Error! Bookmark not defined.
Fig. 2.1 MISO System	Error! Bookmark not defined.
Fig. 2.2 SIMO System	Error! Bookmark not defined.
Fig. 2.3 MIMO System	Error! Bookmark not defined.
Fig. 2.4 Time Diversity	Error! Bookmark not defined.
Fig. 2.5 Frequency Diversity	Error! Bookmark not defined.
Fig. 2.6 Polarization Diversity	Error! Bookmark not defined.
Fig. 2.7 Angle Diversity	Error! Bookmark not defined.
Fig. 2.8 – Space Transmit Diversity	Error! Bookmark not defined.
Fig. 3.1 Two-branch MRRC	Error! Bookmark not defined.
Fig. 3.2 Two-branch transmit diversity scheme with one receiver..	Error! Bookmark not defined.
Fig. 3.3: The BER error performance of BPSK for Rayleigh fading	Error! Bookmark not defined.
Fig. 3.4: The BER error performance of BPSK for Rician fading ..	Error! Bookmark not defined.
Fig. 3.5: The BER error performance of BPSK for Nakagami fading ...	Error! Bookmark not defined.
Fig. 3.6: The BER error performance of BPSK for different fading environments ..	Error! Bookmark not defined.
Fig. 3.7: The BER error performance of QPSK for Rayleigh fading	Error! Bookmark not defined.
Fig. 3.8: The BER error performance of QPSK for Rician fading ..	Error! Bookmark not defined.
Fig. 3.9: The BER error performance of QPSK for Nakagami fading ...	Error! Bookmark not defined.
Fig. 3.10: The BER error performance of QPSK under different fading environments	Error! Bookmark not defined.
Fig. 4.1 Encoding scheme for Differential Detection	Error! Bookmark not defined.

Fig. 4.2: The BER error performance of BPSK for Rayleigh fading **Error! Bookmark not defined.**

Fig. 4.3: The BER error performance of BPSK for Rician fading .. **Error! Bookmark not defined.**

Fig. 4.4: The BER error performance of BPSK for Nakagami fading ... **Error! Bookmark not defined.**

Fig. 4.5: The BER error performance of BPSK for Different fading environments . **Error! Bookmark not defined.**

Fig. 4.6: The BER error performance of DPSK for Rayleigh fading **Error! Bookmark not defined.**

Fig. 4.7: The BER error performance of DPSK for Rician fading .. **Error! Bookmark not defined.**

Fig. 4.8: The BER error performance of DPSK for Nakagami fading ... **Error! Bookmark not defined.**

Fig. 4.9: The BER error performance of DPSK for Different fading environments . **Error! Bookmark not defined.**

Fig. 4.10: The BER error performance of QPSK for Rayleigh fading ... **Error! Bookmark not defined.**

Fig. 4.11: The BER error performance of QPSK for Rician fading **Error! Bookmark not defined.**

Fig. 4.12: The BER error performance of QPSK for Nakagami fading . **Error! Bookmark not defined.**

Fig. 4.13: The BER error performance of QPSK for Different fading environments **Error! Bookmark not defined.**

Fig. 4.14: The BER error performance of different modulation schemes under Rayleigh fading **Error! Bookmark not defined.**

Fig. 4.15: The BER error performance of different modulation schemes under RICIAN fading **Error! Bookmark not defined.**

Fig. 4.16: The BER error performance of different modulation schemes under Nakagami fading **Error! Bookmark not defined.**

Fig. 4.17: Comparison of Differential Detection Scheme and Alamouti's Scheme using BPSK under Rayleigh fading.....**Error! Bookmark not defined.**

Fig. 4.18: Comparison of Differential Detection Scheme and Alamouti's Scheme using QPSK under Rayleigh fading.....**Error! Bookmark not defined.**

Fig. 4.19: Comparison of Differential Detection Scheme and Alamouti's Scheme using BPSK under Rician fading.....**Error! Bookmark not defined.**

Fig. 4.20 Comparison of Differential Detection Scheme and Alamouti's Scheme using QPSK under Rician fading.....**Error! Bookmark not defined.**

Fig. 4.21 Comparison of Differential Detection Scheme and Alamouti's Scheme using BPSK under Nakagami fading.....**Error! Bookmark not defined.**

Fig. 4.22 Comparison of Differential Detection Scheme and Alamouti's Scheme using QPSK under Nakagami fading.....**Error! Bookmark not defined.**

List of Tables

Table 3.1 The encoding and transmission sequence for the **Error! Bookmark not defined.**

Two branch transmit diversity scheme **Error! Bookmark not defined.**

Table-4.1: BER performance BPSK under different fading at SNR of 15db. 97

Table-4.2: SNR for BPSK under different fading for BER of 10^{-1} 97

Table-4.3: BER performance DPSK under different fading at SNR of 15db. 102

Table-4.4: SNR for DPSK under different fading for BER of 10^{-1} 102

Table-4.5: BER performance QPSK under different fading at SNR of 12db. 107

Table-4.6: SNR for QPSK under different fading for BER of 10^{-1} 107

Table-4.7: BER performance under Rayleigh fading at SNR of 10db. .. **Error! Bookmark not defined.**

Table-4.8: BER performance under Rayleigh fading at SNR of 15db. .. **Error! Bookmark not defined.**

Table-4.9: SNR under Rayleigh fading for BER of 10^{-1} . .. **Error! Bookmark not defined.**

Table-4.10: SNR under Rayleigh fading for BER of 10^{-2} . **Error! Bookmark not defined.**

Table-4.11: BER performance under Rayleigh fading at SNR of 10db. **Error! Bookmark not defined.**

Table-4.12: BER performance under Rayleigh fading at SNR of 15db. **Error! Bookmark not defined.**

Table-4.13: SNR under Rayleigh fading for BER of 10^{-1} . **Error! Bookmark not defined.**

Table-4.14: SNR under Rayleigh fading for BER of 10^{-2} . **Error! Bookmark not defined.**

Table-4.15: BER performance under Nakagami fading at SNR of 10db. **Error! Bookmark not defined.**

Table-4.16: BER performance under Nakagami fading at SNR of 15db. **Error! Bookmark not defined.**

Table-4.17: SNR under Nakagami fading for BER of 10^{-1} **Error! Bookmark not defined.**

Table-4.18: SNR under Nakagami fading for BER of 10^{-2} **Error! Bookmark not defined.**

Table-4.19: BER performance under Rayleigh fading at SNR of 10db. **Error! Bookmark not defined.**

Table-4.20: BER performance under Rayleigh fading at SNR of 15db. **Error! Bookmark not defined.**

Table-4.21: SNR under Rayleigh fading for BER of 10^{-1} . **Error! Bookmark not defined.**

Table-4.22: SNR under Rayleigh fading for BER of 10^{-2} . **Error! Bookmark not defined.**

Table-4.23: BER performance under Rayleigh fading at SNR of 10db. **Error! Bookmark not defined.**

Table-4.24: BER performance under Rayleigh fading at SNR of 15db. **Error! Bookmark not defined.**

Table-4.25: SNR under Rayleigh fading for BER of 10^{-1} . **Error! Bookmark not defined.**

Table-4.26: SNR under Rayleigh fading for BER of 10^{-2} . **Error! Bookmark not defined.**

Table-4.27: BER performance under Rician fading at SNR of 10db.**Error! Bookmark not defined.**

Table-4.28: BER performance under Rician fading at SNR of 15db.**Error! Bookmark not defined.**

Table-4.29: SNR under Rician fading for BER of 10^{-1}**Error! Bookmark not defined.**

Table-4.30: SNR under Rician fading for BER of 10^{-2}**Error! Bookmark not defined.**

Table-4.31: BER performance under Rician fading at SNR of 5db. **Error! Bookmark not defined.**

Table-4.32: BER performance under Rician fading at SNR of 10db.**Error! Bookmark not defined.**

Table-4.33: BER performance under Nakagami fading at SNR of 8db. **Error! Bookmark not defined.**

Table-4.34: BER performance under Nakagami fading at SNR of 14db. **Error! Bookmark not defined.**

Table-4.35: SNR under Nakagami fading for BER of 10^{-1} **Error! Bookmark not defined.**

Table-4.36: SNR under Nakagami fading for BER of 10^{-2} **Error! Bookmark not defined.**

Table-4.37: BER performance under Nakagami fading at SNR of 8db . **Error! Bookmark not defined.**

Table-4.38: BER performance under Nakagami fading at SNR of 12db. **Error! Bookmark not defined.**

Table-4.39: SNR under Nakagami fading for BER of 10^{-1} **Error! Bookmark not defined.**

Table-4.40: SNR under Nakagami fading for BER of 10^{-2} **Error! Bookmark not defined.**

Mobile communication is going through a constant improvement and it has improved a lot in past few years. It has evolved from the 1G systems of the past to the present phase which is 4G. With the passage of time the demand for improved systems increases and hence there needs for the system to be improved. For improvement in the capacity of the system MIMO systems are employed. Work has been done on a 2x1 transmit diversity system and after that there has been a lot work done in this direction. This is the base for WCDMA systems. Transmit diversity systems increase the diversity gain of the system but it does not waste the bandwidth for it. It uses the spatial parameter for this diversity gain. This 2x1 transmit diversity scheme works well if there is perfect channel information available at the receiver.

In order to estimate the channel pilot symbols are to be transmitted, i.e. the receiver knows the pilot symbols and also the time when the transmitter sends these symbols. The pilot symbols are to be transmitted at regular intervals but even then there are errors in channel approximation. This requires extra hardware at both transmitter and the receiver sides. So in order to remove this limitation differential detection scheme is proposed in which there is no need for channel information.

In order to exploit the advantages of differential detection and transmit diversity a scheme was proposed using BPSK modulation. In this thesis simulation results for BER Vs SNR have been compared using BPSK, DPSK and QPSK modulations for this combined scheme. Comparisons of the BER performance have been done between 2x1 transmit diversity scheme and with the combined scheme. The comparisons have been done under multipath fading.

Chapter 1

Introduction

1.1 Introduction

Wireless communication has been going through constant improvement. The first radiotelephone service was introduced in the US at the end of the 1940s, and was meant to connect mobile users in cars to the public fixed network. In the 1960s, a new system launched by Bell Systems, called "Improved Mobile Telephone Service" (IMTS), brought many improvements like direct dialing and higher bandwidth. The first analog cellular systems were based on IMTS and developed in the late 1960s and early 1970s. The systems were "cellular" because coverage areas were split into smaller areas or "cells", each of which is served by a low power transmitter and receiver.

The advancement in telephone systems is divided into generations. The first generation is linked with digitization of the control link between the mobile unit and the AMPS system is a 1G system [15]. In the 2G digital cellular systems were introduced i.e. voice channel was also digitized in these systems. 3G system came up with additional features like FAX and internet and also introduced roaming. GPRS is also a salient feature which came up in 3G systems. These systems also came up with multimedia features and location based services.

The rapid progress in radio technology has resulted in an increased interest for reliable and largely available wireless networks. Presently the systems are moving from 3G systems to 4G systems [17]. The 4G mobile communication services are expected to provide broadband, large capacity, high speed data transmission, providing users with high quality color video images, 3D graphic animation games, and audio services in 5.1 channels. However, a wireless designer is faced with a number of challenges. These are:

- i) a complex and rapidly varying propagation environment
- ii) limited availability of radio spectrum

- iii) limited energy storage capability of batteries in portable units
- iv) user demands for higher bit rates, voice quality and longer talk times
- v) operator demands for greater coverage of base stations, increased subscriber capacity [3] and
- vi) Lower infrastructure and operating costs.

Such diverse requirements ask for improvement in various areas. These include advanced multiple access techniques, efficient voice and channel coding and improved signal processing. A promising approach to attack the above problems is to use space-time (ST) signal processing [9]. Various studies of mobile radio systems have considered space diversity for combating multi-path fading of the desired signal.

1.2 Space Time Processing (STP)

Space-time processing refers to manipulating signals that are received at or transmitted from an antenna array so as to improve performance. It is basically a step towards using the spatial dimension to improve the performance of an antenna system. The basic module of a space time processing system is MIMO system [11]. STP is about sending the information intelligently over MIMO system so that the spatial dimension can be efficiently exploited. The spatial domain can be used to reduce co-channel interference (CCI), increase diversity gain, improve array gain, and combat inter-symbol interference (ISI). These improvements can have significant impact on the overall performance of a wireless network. Receive STP improves signal to interference ratio through CCI cancellation, mitigates fading through improved receive diversity, offers higher signal-to-noise ratio through array gain and reduces ISI through spatial equalization. Likewise, transmit STP reduces CCI generation, improves transmit diversity and in some cases also reduces ISI generation.

Multi-antenna systems offer potential advantages like–

1. Diversity gain in fading channels.
2. Increased antenna gain.

3. Interference rejection and multi-path rejection.
4. Direction of arrival determination.
5. Spatial multiplexing.

Multi-antenna systems are used for transmit diversity, receive diversity and a combination of both called MIMO [11]. MIMO involves the use of multiple antennas at either end of the wireless link to provide spatial multiplexing. Multiple streams of data are sent between each transmit-receive pair, resulting in increased data transfer. Consider an $M \times N$ system where there are M transmit antennas and N receive antennas, when a symbol leaves a particular antenna it will come across N different channels. These N channels will be independent of each other. Thus the system will have a diversity order of N . The capacity of the MIMO channel is roughly proportional to the number of transmit or receive antenna elements, whichever is smaller. Since demodulation performance can be greatly improved if the receiver obtains a less corrupted version of the original symbol, diversity is a practical method to achieve better system performance in wireless channels.

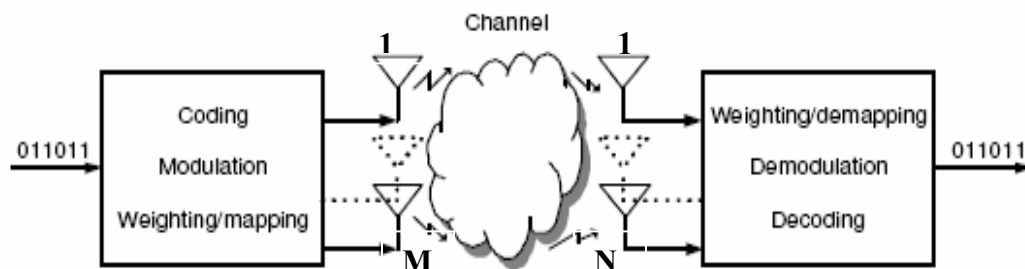


Fig. 1.1 MIMO System

In spite of simply transmitting the same symbol over all the channels the symbols are coded and then sent on different transmit antennas. A particular symbol is to be spread smartly so that it covers almost all the transmit antennas, means the same symbol is not being simply transmitted from all the antennas. Now space-time coding schemes add all this intelligence to the system. There are different kinds of coding schemes for this-

1. Space-time Trellis codes(STTC)
2. Space-time Block codes(STBC)

1.2.1 Space-time Trellis codes (STTC)

STTC is a system where code, modulation and array processing techniques are jointly designed so that the temporal orthogonality criterion may be relaxed. Traditional error correction codes involve adding redundant bits to the bit stream, thus decreasing the bandwidth efficiency of the transmission [18]. In STTC, redundant information is distributed over the space and the time domain, leading to an increased bandwidth efficiency and improved performance for the same transmission rate. The time multiplexing approach used in the delay diversity scheme was a precursor to such a system. In this scheme, delayed replicas of the same symbol are transmitted via different antenna elements so that the flat fading channel becomes a frequency selective fading channel. Tarokh and Calderbank used principles from trellis coded modulation to create STTC. STTC achieves both diversity and coding gain, but suffers from high receiver complexity. The complexity is due to the fact that the space-time maximum likelihood sequence estimator is often implemented as a vector-Viterbi Algorithm. Since this code is in fact a trellis implementation, at the receiver, the trellis path with the minimum distance is chosen.

1.2.2 Space-time Block codes (STBC)

Space-time block code (STBC), which possesses the advantage of possible diversity both spatially and temporally has been given enormous attention in the past few years. Extensive efforts have been made in designing STBC to achieve full rate and full diversity because of its relative simplicity of implementation. However, this is sometimes realized at the expense of channel capacity [19]. STBC involves block encoding an incoming stream of data and simultaneously transmitting the symbols over M transmit antenna elements [13]. This technique was first proposed by Alamouti for $M = 2$ and $N = 1$, where N is the number of receive antenna elements. Alamouti's scheme is a simple

transmit diversity scheme which improves the signal quality at the receiver on one side of the link by simple processing across two transmit antennas on the opposite side.

The diversity obtained with Alamouti's scheme is equal to maximal-ratio receiver combining (MRRC) in which two antennas are at the receiver and one at the transmitter. The scheme may easily be generalized to two transmit antennas and receive antennas to provide a diversity order of $2M$. This is done without any feedback from the receiver to the transmitter and with small computation complexity. The scheme requires no bandwidth expansion, as redundancy is applied in space across multiple antennas, not in time or frequency. Alamouti's code uses a complex orthogonal design, in which the transmission matrix is square and satisfies the conditions for complex orthogonality in both space and time dimensions. Tarokh, Jafarkhani and Calderbank extended Alamouti's code to a generalized complex orthogonal design for $M > 2$ [12]. These generalized codes are non-square, are complex orthogonal only in the temporal domain and suffer a loss in bandwidth efficiency. The STBC receiver linearly processes the received symbols and uses maximum likelihood decoding. The received signal is the linear superposition of the transmitted elements corrupted by fading.

All these systems are still having a limitation that they require a proper or almost approximate knowledge of the channel at the receiver, but in many cases the approximation of the channel is not up to a proper level. So in order to overcome this problem there is need to have differential detection scheme.

1.3 Differential Detection

There can be two types of systems one which has the channel information at the receiver (CSIR) and the other which does not have any channel information at the receiver. In practical systems it is very difficult to have the exact knowledge at the receiver and hence there is supposed to be errors based on these approximations. The channel can be estimated by using training signals emitted by the transmitter. The receiver knows the training sequence and it estimates the channel by comparing it with the received signal. By using differential detection schemes approximation of the

symbols can be done without having the information of the channel at the receiver. Here in this system neither there is any need the information of the channel nor to transmit any pilot or training sequences. This motivates the generalization of differential detection schemes for multiple transmit antennas.

In differential detection transmit diversity the symbols to be sent are mapped with the previous symbols [2]. Here in this thesis study has been done on differential detection system with 2 transmit antennas and one receive antenna using differential detection. In this scheme the performance is worse comparative to two-level diversity combining but the motivation behind this system is that it can work without channel information thus reducing hardware complexity on receiver side. Although differential detection is a suitable demodulation scheme for mobile communications, its bit error rate (BER) performance in an additive white Gaussian noise (AWGN) channel is inferior to that of a coherent detection scheme.

1.4 Objectives of the thesis

The objectives of the thesis are:

- To study the Alamouti's scheme.
- To find out the BER performance of Alamouti's Scheme.
- To improve the performance of Alamouti's scheme for systems where channel is unknown at the receiver, using differential detection.
- To find out the BER performance of differential detection with BPSK under multipath fading environment.
- To find out the BER performance of differential detection with DPSK under multipath fading environment.
- To find out the BER performance of differential detection with QPSK under multipath fading environment.
- Comparison of Differential Detection system with Alamouti's scheme.

1.5 Organization of the report

In Chapter 2 a brief overview of the space-time processing has been given and diversity has also been discussed. Here SIMO, MISO and MIMO systems are discussed. It includes discussion about different types of receive diversity techniques and different type of transmit diversity techniques. In chapter 3 the details of Alamouti's scheme and MRRC scheme have been discussed. The simulation results for Alamouti's scheme of BER using different modulation schemes have been discussed. Chapter 4 gives details of differential detection scheme. The simulations of BER using different modulation schemes and under multipath fading have been compared. Comparison results of BER performance of Differential Detection and Alamouti's scheme have been discussed. Finally chapter 5 includes conclusions and future scopes.

Chapter 2

Space Time Processing

2.1 Space Time Processing

Space-time processing refers to manipulating signals that are received at or transmitted from an antenna array so as to improve performance of the system. Cellular radio signals processing functions include modulation/demodulation, channel coding/decoding, equalization and diversity combining. These functions are performed by the radio modem. Current cellular radio modems do not, however, efficiently exploit the spatial dimension offered by multiple antennas. The spatial domain can be used to reduce co-channel interference (CCI), increase diversity gain, improve array gain, and combat inter-symbol interference (ISI). These improvements can have significant impact on the overall performance of a wireless network.

The systems that operate with multiple antennas in receive and transmit can exploit the spatial domain by performing space-time processing (STP). Receive STP improves signal to interference ratio through CCI cancellation, mitigates fading through improved receive diversity, offers higher signal-to-noise ratio through array gain and reduces ISI through spatial equalization. Likewise, transmit STP reduces CCI generation, improves transmit diversity and in some cases also reduces ISI generation. One classification of STP techniques is based on architecture and covers different design choices for the physical layer of the wireless network. Another classification of STP techniques is based on algorithms and refers to choices of signal processing algorithms and optimizations criteria. Underlying and affecting both these classifications are the characteristics of the physical channel that include angle, delay and Doppler spreads.

Consider the multi-antenna system diagram in Fig. 1.1. A compressed digital source in the form of a binary data stream is fed to a simplified transmitting block encompassing the functions of error control coding and (possibly joined with) mapping to complex modulation symbols. The latter produces several separate symbol streams, which range from independent to partially redundant to fully redundant. Each is then mapped onto one of the multiple Transmit antennas. Mapping may include linear spatial weighting of the antenna elements or linear antenna space–time pre-coding. After upward frequency conversion, filtering and amplification, the signals are launched into the wireless channel. At the receiver, the signals are captured by possibly multiple antennas and demodulation and de-mapping operations are performed to recover the message. The level of intelligence, complexity, and a priori channel knowledge used in selecting the coding and antenna mapping algorithms can vary a great deal depending on the application. This determines the class and performance of the multi-antenna solution that is implemented.

In conventional smart antenna terminology, only the transmitter or the receiver is actually equipped with more than one element, being typically the base station (BTS), where the extra cost and space have been perceived as more easily affordable than on a small phone handset. Traditionally, the intelligence of the multi-antenna system is located in the weight selection algorithm rather than in the coding side although the development of space–time codes (STCs) is transforming this view.

Simple linear antenna array combining can offer a more reliable communications link in the presence of adverse propagation conditions such as multipath fading and interference. A key concept in smart antennas is that of beamforming, by which one can increase the average signal-to-noise ratio (SNR) through focusing energy into desired directions, in either transmit or receiver. Indeed, if one estimates the response of each antenna element to a given desired signal, and possibly to interference signal(s), one can optimally combine the elements with weights selected as a function of each element response. One can then maximize the average desired signal level or minimize the level of other components whether noise or co-channel interference. Another powerful effect of smart antennas lies in the concept of spatial diversity. In the presence of random fading

caused by multipath propagation, the probability of losing the signal vanishes exponentially with the number of de-correlated antenna elements being used. A key concept here is that of diversity order that is defined by the number of de-correlated spatial branches available at the transmitter or receiver. When combined together, leverages of smart antennas are shown to improve the coverage range versus quality tradeoff offered to the wireless user.

As subscriber units (SU) are gradually evolving to become sophisticated wireless Internet access devices rather than just pocket telephones, the stringent size and complexity constraints are becoming somewhat more relaxed. This makes multiple antenna elements transceivers a possibility at both sides of the link, even though pushing much of the processing and cost to the network's side (i.e., BTS) still makes engineering sense. Clearly, in a MIMO link, the benefits of conventional smart antennas are retained since the optimization of the multi-antenna signals is carried out in a larger space, thus providing additional degrees of freedom. In particular, MIMO systems can provide a joint transmit-receive diversity gain, as well as an array gain upon coherent combining of the antenna elements.

Information theory can be used to demonstrate these gains rigorously. However, intuition is perhaps best given by a simple example of such a transmission algorithm over MIMO often referred to in the literature as V-BLAST or more generically called here spatial multiplexing [16]. A high-rate bit stream (left) is decomposed into two independent 1/2-rate bit sequences which are then transmitted simultaneously using multiple antennas, thus consuming one third of the nominal spectrum. The signals are launched and naturally mix together in the wireless channel as they use the same frequency spectrum. At the receiver, after having identified the mixing channel matrix through training symbols, the individual bit streams are separated and estimated. This occurs in the same way, as three unknowns are resolved from a linear system of three equations. This assumes that each pair of transmit receive antennas yields a single scalar channel coefficient, hence flat fading conditions. However, extensions to frequency selective cases are indeed possible using either a straightforward multiple-carrier approach or in the time domain by combining the MIMO space-time detector with an

equalizer. The separation is possible only if the equations are independent which can be interpreted by each antenna “seeing” a sufficiently different channel in which case the bit streams can be detected and merged together to yield the original high rate signal. Iterative versions of this detection algorithm can be used to enhance performance.

2.2 Space-time code

Traditional wireless communication systems almost invariably involve a single transmitter antenna and a single receiver antenna. However, it suffers from the difficulty in supplying high data rate for bad channel environment with the limited power and frequency resources [9]. Multi-input multi-output (MIMO) systems capturing interest of researchers due to its potential to provide high data rate and diversity gain, where diversity can be provided by temporal, frequency, polarization and spatial resources [10]. However, multipath fading arising from multi-antennas in both transmitter and receiver makes it difficult to maintain reliable transmission, especially when fading coefficients are unknown at the transmitter, e.g., in a rapid fading environment. It is difficult to enhance the quality or to reduce the effective error rate in multipath fading channels, due to the additive noise and interference from other users. Effective coding design using typical modulation to reduce bit error probability is thus one important goal sought by engineers nowadays. Space-time block code (STBC) possesses the advantage of possible diversity both spatially and temporally. Extensive efforts have been made in designing STBC to achieve full rate and full diversity because of its relative simplicity of implementation [19]. However, this is sometimes realized at the expense of channel capacity. Linear STBC is a member of STBC family that has relatively simple structures and the ability to achieve high data rate. Most of available linear STBC designs employ maximum-likelihood (ML) detection because ML is theoretically optimal and can provide superior bit error rate (BER) performance to other detectors in practice. However, it involves unacceptably high computational complexity, especially for large number of transmitter antennas, which, on the other hand, is the source of spatial

diversity. The dilemma here demands a new linear STBC scheme which has optimal BER performance and employs relatively simple detectors.

2.3 Space-time Communication

Space-time communication systems will be considered in detail here. First discussion on the MIMO systems has been given, and then based on some assumptions; the model of a space-time communication system will be established [20]. After that, several properties of this model will be presented and the commonly employed methods for MIMO signal detection will be introduced.

2.3.1 Model of Space-time Communication

Traditional communication systems almost invariably involve a single input and a single output (SISO). Since all the data sequences are transmitted through a single antenna here, one problem for such a SISO system is the low transmission data rate, i.e., the number of symbols transmitted per unit time is limited. Another problem for a SISO system is that the transmission is dependent on the channel environment between the single pair of transmitter and receiver antennas.

Let $h(\tau, t)$ be the time varying channel response, if a signal $s(t)$ is transmitted, the received signal $r(t)$ is given by

$$r(t) = h(\tau, t) \otimes s(t) \quad (2.1)$$

Where \otimes denotes the convolution operator. If the channel response h is very low in magnitude, corresponding to the condition of channel fading, then the transmitted signals may not be correctly recovered at the receiver. Moreover, for wireless communication, the quality of a SISO system is often affected by multipath propagation. To increase transmission data rate without the loss of frequency efficiency, a multiple access system is introduced as shown in Fig. 2.1. The common channel here is a general configuration

and may request the uplink of a satellite communication system, or a cable to which a set of terminals that access a central computer are connected.

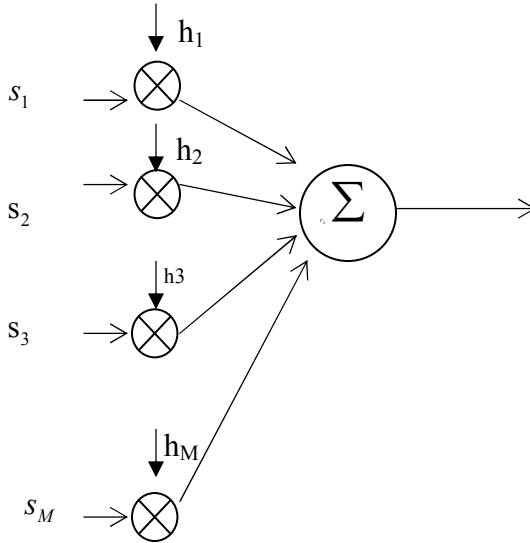


Fig. 2.1 MISO System

The data rate is increased by employing multiple transmitter antenna, each of which transmits a different signal.

Consider a system having M transmit antennas. The MISO channel comprises M different paths. The impulse response between the j^{th} transmit antenna and the receive antenna can be denoted by $h_j(\tau, t)$. Now the channel response for MISO system can be represented by a $1 \times M$ vector

$$h_1(\tau, t) = [h_1(\tau, t) \quad h_2(\tau, t) \quad h_3(\tau, t) \dots \dots \dots h_M(\tau, t)] \quad (2.2)$$

Assuming $s_j(t)$ is the signal transmitted from the j^{th} transmit antenna and $r(t)$ is the received signal then the received signal can be given by

$$r(t) = \sum_{j=1}^M h_j(\tau, t) s_j(t) \quad (2.3)$$

However, since all the transmitted data are received by one single receiver antenna, the transmission efficiency is still influenced by the channel environment and multipath propagation.

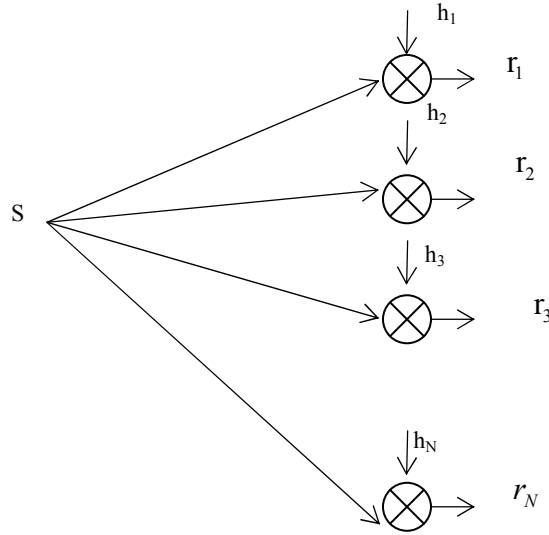


Fig. 2.2 SIMO System

Contrary to the multiple access system, a broadcast network employs a single transmitter to send information to multiple receivers as depicted in Fig.2.2. Now, if all the receiver antennas are applied to one user, then the resulting multipath propagation has positive effect on the transmission efficiency. Due to the existence of multipath, each receiver antenna receives a replica of the transmitted information.

Consider a SIMO system having N receive antennas the impulse response between the transmit antenna and the i^{th} receive antenna can be given by $h_i(\tau, t)$. Now the SIMO channel can be represented by

$$h_r(\tau, t) = [h_1(\tau, t) \quad h_2(\tau, t) \quad h_3(\tau, t) \dots \dots \dots h_M(\tau, t)] \quad (2.4)$$

Now considering signal $s(t)$ to be the transmitted signal the signal received at the i^{th} receiver can be represented by

$$r_i(t) = h_i(\tau, t) \otimes s(t) \quad (2.5)$$

The probability for several paths to have bad fading at the same is low and thus there will normally exist a few paths with high SNR that ensure the correct recovery of

the transmitted information. However, a broadcast network has the same transmission data rate as a SISO system.

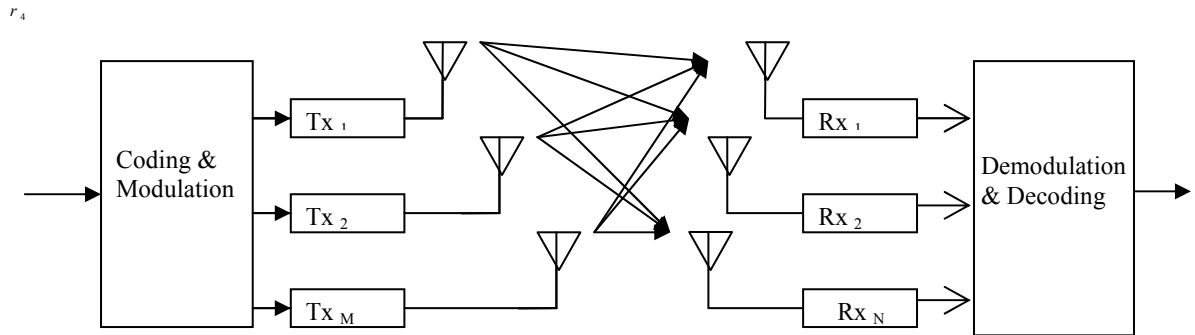


Fig. 2.3 MIMO System

One of the most significant technical breakthroughs in digital communications is the development of the MIMO system that can be explained as follows. The idea behind MIMO is that the signals on the transmitter antennas at one end and the receiver antennas at the other end are combined in such a way that both the transmission data rate and the transmission efficiency will be improved. A core idea in MIMO systems is space-time signal processing in which time (the natural dimension of digital communication data) is complemented with the spatial dimension inherent in the use of multiple spatially distributed antennas [20].

Consider a MIMO communication system with M transmitter and N receiver antennas that operates in a Rayleigh flat fading environment as in Fig.2.3. The word ‘Rayleigh’ here refers to that the amplitude of channel fading coefficients is Rayleigh distributed and ‘flat’ means that the channel frequency response is approximately constant and does not change the spectrum of the transmitted signals much. At time t , each transmitter antenna transmits a symbol s_{tm} , scaled by the power factor P_T/M and the corresponding channel fading coefficient h_{tmn} , $m = 1, 2, \dots, M$, $n = 1, \dots, N$, to all the N receiver antennas. Each receiver antenna receives combined information transmitted from all the M transmitter antennas. The received signals are corrupted by additive noise which is assumed to be identically independent distributed (IID) white Gaussian with zero mean

and unit covariance. Then the received signal at each receiver antenna can be expressed as

$$r_{in} = \sqrt{\frac{\rho}{M}} \sum_{m=1}^M h_{tmn} S_{tm} + w_{tm} \quad t = 1, 2, \dots, T \quad (2.6)$$

The transmitted signal s_{tm} is a symbol assumed to be independently selected from a signal set with the constellation normalized in power. w_{tm} is the noise in the channel. Due to the presence of the power factor $\sqrt{\frac{\rho}{M}}$ in Eq. (2.6), we can normalize s_{tm} has zero mean and unit covariance.

In MIMO systems space diversity is exploited. In diversity the basic aim is to provide the signal with multiple paths and the different paths are to be such that they are least correlated, i.e. if one is experiencing deep fade then the other should be having least probability of being in deep fade.

2.4 Diversity

As discussed above diversity techniques play a vital role in supporting such high-speed connections over radio channels by mitigating the detrimental effects of multi-user interference and multipath fading. It was incorporated to verify improved performance in both the statistical and spatial channel models. Diversity is known to reduce the effect of channel fading and increase the reliability of the transmitted signal. It is assumed that the signals received at the receiver are uncorrelated. Several diversity schemes were available to choose from including space, polarization, angle, frequency, and time. The independent channels in a fading channel environment are often referred to as diversity branches. Having multiple branches available at the receiver decreases the probability that the signals on each branch will all be in a deep fade.

Diversity techniques are employed to produce multiple copies of the transmitted signal, with as low fading correlation as possible, as a means to avoid the effect of the deep fading dips that occur in multipath channels. Even though independency is a desirable property, diversity can still be achieved to some degree as long as the correlation is less than one. Diversity exploits the random nature of radio propagation by finding independent signal paths for communication. In virtually all applications, diversity decisions are made by the receiver, and are unknown to the transmitter. The diversity concept can be explained simply. If one radio path undergoes a deep fade, another independent path may have a strong signal. By having more than one path to select from, both the instantaneous and average SNRs at the receiver may be improved. Now diversity can be of two types

- Receive diversity
- Transmit diversity

2.5 Receive diversity

In receive diversity basically the different combining techniques are important that is how to combine the different signals coming to different diversity branches. It can be classified as follows:

2.5.1 Macroscopic diversity scheme

The Macroscopic diversity scheme is used for combining two or more long-term lognormal signals, which are obtained via independently fading paths received from two or more different antennas at different base-station sites. The local mean strength varies because of variations of terrain between the mobile transmitter and the base station receiver. If only one antenna site is used, the traveling mobile unit may not be able to transmit a signal to the base station at certain geographical locations because of terrain variations such as hills or mountains. Therefore, two separated antenna sites can be used to receive two signals and to combine them to reduce long-term fading. The selective combining technique is recommended in the macroscopic diversity scheme since other

methods require coherent combining that is difficult to achieve when the receivers are some distance apart. Macroscopic diversity is often used in short-wave systems to reduce the effects of fading from the ionosphere. Cellular and PCS system achieve the same effect by handoffs to nearby cell sites when the signal strength becomes weak.

2.5.2 Time Diversity

Time diversity techniques are primarily applicable to the transmission of digital data over a fading channel. In time diversity, the same data are sent over the channel at time intervals of the order of the reciprocal of the baseband fade rate $f_b = 2f_m$. In mobile radio, the reciprocal fade rate can be expressed:

$$\tau \geq \frac{1}{2f_m} = \frac{1}{2\left(\frac{v}{\lambda}\right)} \quad (2.7)$$

where v is the speed of light and λ is the wavelength of the signal.

The time separation increases as the fade rate decreases. Multiple diversity channels can be provided by successively transmitting the signal sample in each time slot. The sampling rate for voice transmission of a single channel is $(2 \times 4 \text{ kHz} = 8\text{kHz})$.

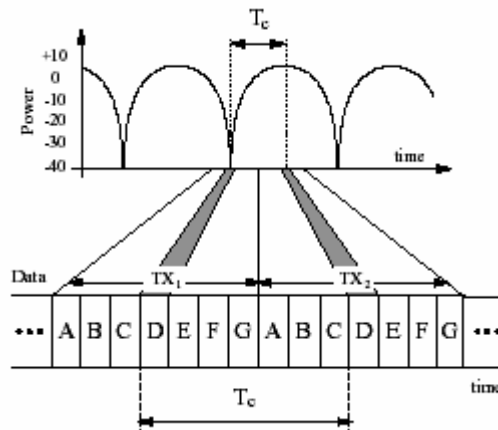


Fig. 2.4 Time Diversity

For N-branch diversity, the sampling rate must be $(N \times 8 \text{ kHz})$, since the transmission delay spread is usually less than $20\mu\text{s}$, which is much less than the inverse of the sampling rate:

$$f_s < \frac{1}{\Delta} \quad (2.8)$$

Hence, the sampling rate f_s is not limited by the time-delay spread. However, the minimum time separation between samples shown in Eq. (2.7) for diversity application may cause a serious problem, since f_m is a Doppler frequency, expressed:

$$f_m = \frac{v}{\lambda} \quad (2.9)$$

When the vehicle is stationary, $v=0$, and thus $f_m=0$. This means that the time separation μ_s is infinite. Therefore, the advantages of time diversity are lost when the vehicle is not moving. This is in sharp contrast to other diversity schemes, in which the branch separation is not a function of vehicle speed and thus the two diversity signals are independent over any value of v .

2.5.3 Frequency Diversity

Frequency diversity is implemented by transmitting information on more than one carrier frequency. The rationale behind this technique is that frequencies separated by more than the coherence bandwidth of the channel will be uncorrelated and will thus not experience the same fades. Theoretically, if the channels are uncorrelated, the probability of simultaneous fading will be product of the individual fading probabilities.

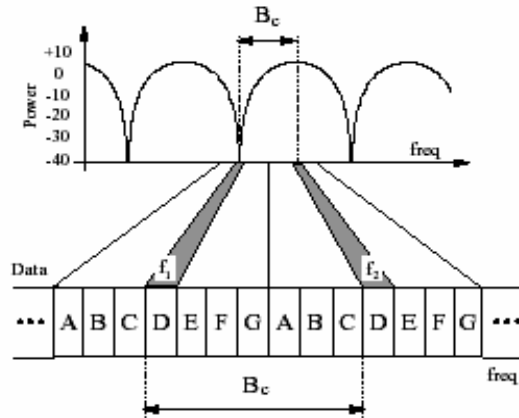


Fig. 2.5 Frequency Diversity

Frequency diversity is often employed in microwave line-of-sight links, which carry several channels in a frequency division multiplex mode (FDM). Due to tropospheric propagation and resulting refraction, deep fading sometimes occurs. This technique has the major disadvantage that it wastes bandwidth.

2.5.4 Polarization Diversity

Signals transmitted in either horizontal or vertical electric fields are uncorrelated at both the mobile and Basestation receivers

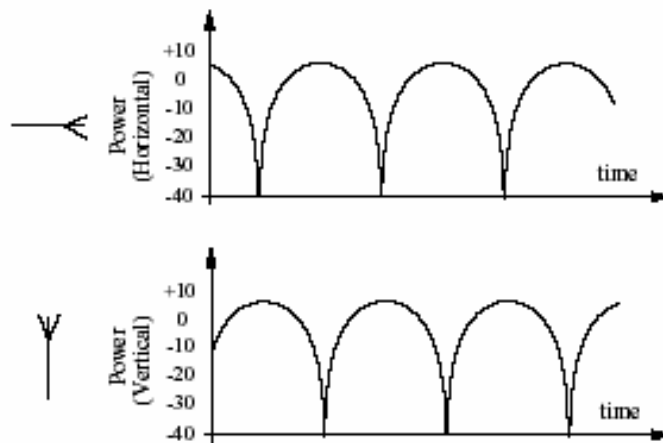


Fig. 2.6 Polarization Diversity

. The horizontal and vertical polarization components, E_x and E_y , transmitted by two polarized antennas at the base station and received by two polarized antennas at the mobile unit, can provide two uncorrelated fading signals. Polarization diversity results in a 3-dB power reduction at the transmitting site since the power must be split into two different polarized antennas. The decorrelation for the signals in each polarization is caused by multiple reflections in the channel between the mobile and base station.

After sufficient random reflections, the polarization state of the signal will be independent of the transmitted polarization. In practice, however, there is some dependence of the received polarization on the transmitted polarization.

2.5.5 Angle Diversity

When the operating frequency is greater than 10 GHz, the scattering of the signals from transmitter to receiver generates received signals from different directions that are uncorrelated with each other.

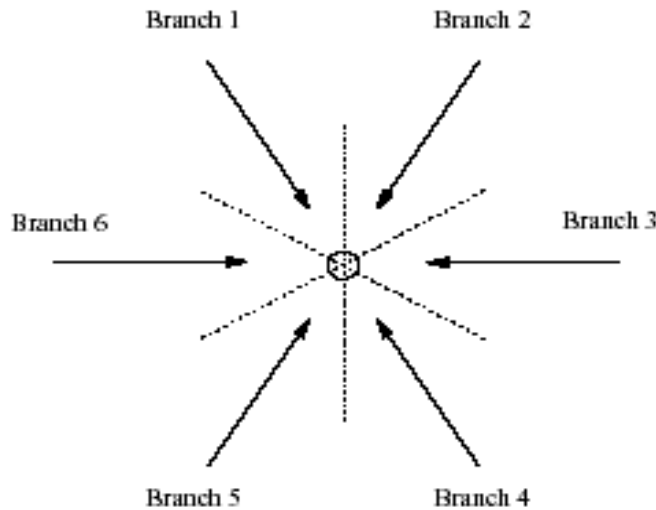


Fig. 2.7 Angle Diversity

Thus, two or more directional antennas can be pointed in different directions at the receiving site and provide signals for a combiner. This scheme is more effective at the mobile unit than at the base station since the scattering is from local buildings and vegetation and is more pronounced at street level than at the height of base station antennas.

2.6 Transmit Diversity

The major problem with using the receive diversity approach is the cost, size, and power of the remote units. The use of multiple antennas and radio frequency (RF) chains (or selection and switching circuits) makes the remote units larger and more expensive. As a result, diversity techniques have almost exclusively been applied to base stations to improve their reception quality. A base station often serves hundreds to thousands of remote units. It is therefore more economical to add equipment to base stations rather than the remote units. For this reason, transmit diversity schemes are very attractive.

The basis for receive diversity is that each element in the receive array receives an independent copy of the same signal. The probability that all signals are in deep fade simultaneously is significantly reduced. In modeling a wireless communication system one can imagine that this capability would be very useful on transmit as well. This is especially true because, at least in the near term, wireless communications will be asymmetric internet traffic. A lot more data would be flowing from the base station to the mobile device that is, say, asking for a webpage. Due to space considerations, it is more likely that the base station antenna comprises multiple elements while the mobile device has only one or two.

In transmit diversity, the diversity is achieved by employing multiple antennas on the transmitter side, which is illustrated in Figure 2.8. Space Diversity, also known as antenna diversity, is one of the most popular forms of diversity used in wireless systems. The antennas are separated physically by a short distance d can provide two signals with low correlation between their fades. The separation d in general varies with antenna height h and with frequency. The higher the frequency, the closer the two antennas can be to each other. Typically a separation of a few wavelengths is enough to obtain uncorrelated signals.

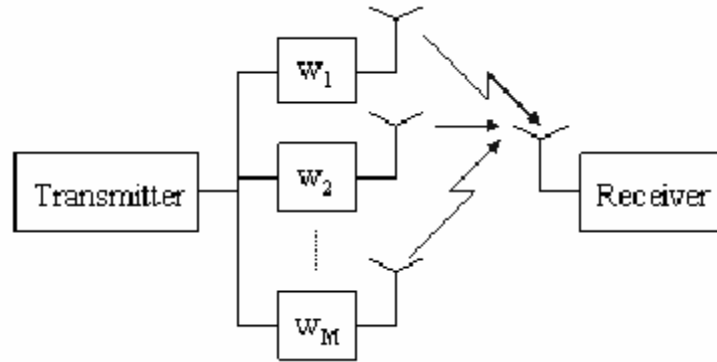


Fig. 2.8 – Space Transmit Diversity

But merely by transmitting the same signal from different positions in space produces no gains. With space diversity in the receiver, the signals arriving at the different receive antennas can be combined in the receiver [8]. But no such option exists with STD, since the different branches inevitably add up in space before they reach the receiver, the same way as the multipath phenomenon appears. This means that with identical transmitted signals from any number of antennas, no diversity gain will be produced. So in order to utilize the potential diversity gains associated with independently propagating signals, the signal is first coded then transmitted and these coding schemes are called Space Time Coding schemes.

A simple way to achieve diversity is to repeat the transmission of the same data symbol (s_0) over M symbol periods, one element at a time. At the receiver, the data from the M received signals from M symbol periods is written as a length- M vector r which is given by

$$r = \sqrt{E_s} h s_0 + n_t \quad (2.10)$$

which has the same form as that for the receive diversity case. This vector is the received signal at a single element over M symbol intervals. The vector h is the length- M vector of the channels from the M transmitting elements to the single receive element. A simple way to achieve diversity with multiple transmit elements is

$$y = h^H x = \sqrt{E_s} \left[\sum_{n=0}^{N-1} |h_n|^2 \right] s_0 + noise \quad (2.11)$$

If the M channels are independent, this transmit scheme achieves diversity of order M. However, this transmit diversity scheme is clearly very inefficient. Within any symbol period, only a single element is used. A single symbol is sent over M periods, i.e. one would need a bandwidth expansion of M to achieve the same data rate. This scheme shows that transmit diversity is possible. It also illustrates another important point that transmit diversity cannot be achieved by focusing on a single symbol period only. Here time dimension must also be involved and this is the basis for space-time coding. Coding, by definition, introduces redundancy and to achieve transmit diversity one must introduce redundancy in both the space and time dimensions.

In the above described diversity schemes the aim is to reduce the effect of channel fading on the signal. But there is another major issue which is the approximation of channel information at the receiver. So there can be two types of systems one in which we have the channel information at the receiver and one which does not have channel information at the receiver. There are different schemes to approximate the channel at the receiver. One of the schemes is by using pilot signal transmission. In this technique a pilot signal means a signal which is known at the receiver is sent prior to sending the message signal and at some regular intervals. In this method we have to waste some of the bandwidth for sending these pilot signals. But even then the channel is not perfectly approximated. Differential detection method can be used in situations where we don't have channel information at the receiver. This technique does not require complex hardware at the receiver and does not require transmitting any pilot signal to approximate the channel.

Before going on to the differential detection transmit diversity scheme first some points about the basic blocks of receive and transmit diversity are to be cleared. So in the next chapter MRRC scheme and Alamouti's 2x1 scheme will be covered.

Chapter 3

Receive and Transmit Diversity with ML detection

3.1 Introduction

An interesting approach for implementing diversity is space–time trellis coding, where symbols are encoded according to the antennas through which they are simultaneously transmitted and are decoded using a maximum likelihood decoder. This scheme is very effective, as it combines the benefits of forward error correction (FEC) coding and diversity transmission to provide considerable performance gains. The cost for this scheme is additional processing, which increases exponentially as a function of bandwidth efficiency (bits/s/Hz) and the required diversity order. Therefore, for some applications it may not be practical or cost-effective.

A simple transmit diversity scheme which improves the signal quality at the receiver on one side of the link by simple processing across two transmit antennas on the opposite side is given by Alamouti [1]. The obtained diversity order is equal to applying maximal-ratio receiver combining (MRRC) with two antennas at the receiver. The scheme may easily be generalized to two transmit antennas and N receive antennas to provide a diversity order of $2N$. This is done without any feedback from the receiver to the transmitter and with small computation complexity. The scheme requires no bandwidth expansion, as redundancy is applied in space across multiple antennas, not in time or frequency.

The new transmit diversity scheme can improve the error performance, data rate, or capacity of wireless communications systems [8]. The decreased sensitivity to fading may allow the use of higher level modulation schemes to increase the effective data rate, or smaller reuse factors in a multi cell environment to increase system capacity. The scheme may also be used to increase the range or the coverage area of wireless systems. In other words, the new scheme is effective in all of the applications where system

capacity is limited by multipath fading and, hence, may be a simple and cost-effective way to address the market demands for quality and efficiency without a complete redesign of existing systems. Furthermore, the scheme seems to be a superb candidate for next-generation wireless systems as it effectively reduces the effect of fading at the remote units using multiple transmit antennas at the base stations.

3.2 Classical maximal-ratio receive combining (MRRC) scheme

At a given time, a signal is sent from the transmitter. The channel including the effects of the transmit chain, the air link, and the receive chain may be modeled by a complex multiplicative distortion composed of a magnitude response and a phase response. The channel between the transmit antenna and the receive antenna zero is denoted by h_0 and between the transmit antenna and the receive antenna one is denoted by h_1 where

$$\begin{aligned}h_0 &= a_0 e^{j\theta_0} \\h_1 &= a_1 e^{j\theta_1}\end{aligned}\tag{3.1}$$

Noise and interference are added at the two receivers. The resulting received baseband signals are

$$\begin{aligned}r_0 &= h_0 s_0 + n_0 \\r_1 &= h_1 s_0 + n_1\end{aligned}\tag{3.2}$$

where n_0 and n_1 represent complex noise and interference.

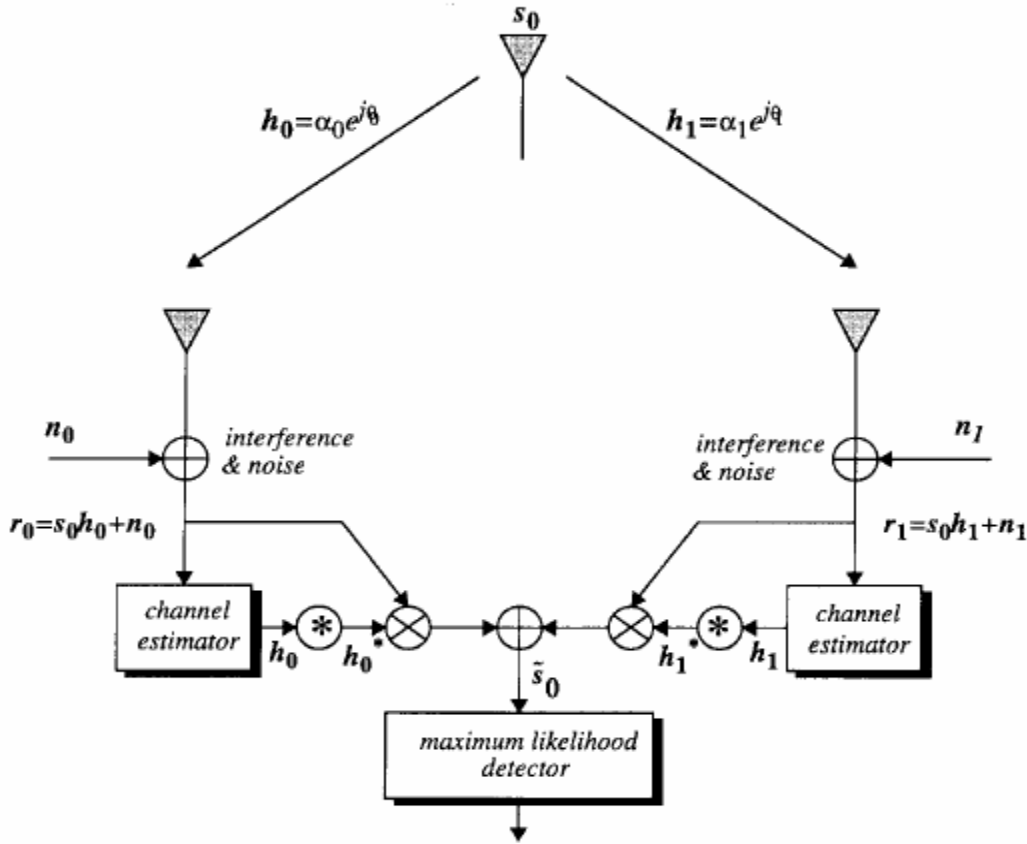


Fig. 3.1 Two-branch MRRC.

Fig.3.1 shows the baseband representation of the classical two-branch MRRC.

Assuming n_0 and n_1 are Gaussian distributed, the maximum likelihood decision rule at the receiver for these received signals is to choose signal if and only if (iff)

$$d^2(r_0, h_0 s_i) + d^2(r_1, h_1 s_i) \leq d^2(r_0, h_0 s_k) + d^2(r_1, h_1 s_k) \quad \forall i \neq k \quad (3.3)$$

where $d^2(x, y)$ is the squared Euclidean distance between signals and calculated by the following expression:

$$d^2(x, y) = (x - y)(x^* - y^*) \quad (3.4)$$

The receiver combining scheme for two-branch MRRC is as follows:

$$\tilde{s}_0 = h_0^* r_0 + h_1^* r_1 \quad (3.5)$$

$$\begin{aligned} &= h_0^* (h_0 s_0 + n_0) + h_1^* (h_1 s_0 + n_1) \\ &= (\alpha_0^2 + \alpha_1^2) s_0 + h_0^* n_0 + h_1^* n_1 \end{aligned} \quad (3.6)$$

Expanding (3.3), (3.4), (3.5) and (3.6) we get, choose s_i iff

$$(\alpha_0^2 + \alpha_1^2) |s_i|^2 - \tilde{s}_0 s_i^* - \tilde{s}_0^* s_i \leq (\alpha_0^2 + \alpha_1^2) |s_k|^2 - \tilde{s}_0 s_k^* - \tilde{s}_0^* s_k \quad \forall i \neq k \quad (3.7)$$

or equivalently, choose s_i iff

$$(\alpha_0^2 + \alpha_1^2 - 1) |s_i|^2 + d^2(\tilde{s}_0, s_i) \leq (\alpha_0^2 + \alpha_1^2 - 1) |s_k|^2 + d^2(\tilde{s}_0, s_k) \quad \forall i \neq k \quad (3.8)$$

for PSK signals(equal energy constellations)

$$|s_i|^2 = |s_k|^2 = E_s \quad \forall i, k \quad (3.9)$$

Where E_s is the energy of the signal. Therefore for PSK signals, the decision rule in (4.2.7) may be simplified to

Choose s_i iff

$$d^2(\tilde{s}_0, s_i) \leq d^2(\tilde{s}_0, s_k) \quad \forall i \neq k \quad (3.10)$$

The maximal-ratio combiner may then construct the signal, as shown in Fig.4.2.1, so that the maximum likelihood detector may produce s_0 , which is a maximum likelihood estimate of s_0 .

3.3 The Alamouti's Transmit Diversity Scheme

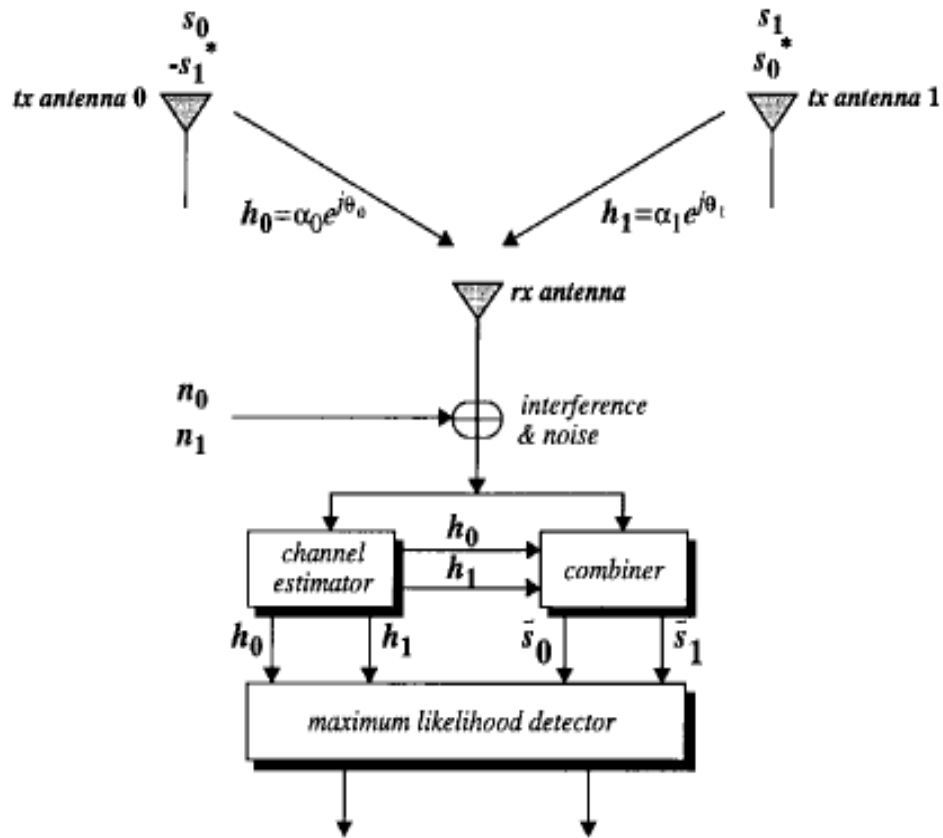


Fig. 3.2 Two-branch transmit diversity scheme with one receiver.

The baseband representation of the two-branch transmit diversity scheme is shown in Fig. 3.2. The scheme uses two transmit antennas and one receive antenna and may be defined by the following three functions:

- The encoding and transmission sequence of information symbols at the transmitter;
- The combining scheme at the receiver;
- The decision rule for maximum likelihood detection.

1) *The Encoding and Transmission Sequence:* At a given symbol period, two signals are simultaneously transmitted from the two antennas. The signal transmitted from antenna zero is denoted by s_0 and from antenna one by s_1 . During the next symbol period signal

$(-s_1^*)$ is transmitted from antenna zero, and signal s_0^* is transmitted from antenna one where * shows the complex conjugate operation. This sequence is shown in Table I.

In Table I, the encoding is done in space and time (space–time coding). The encoding, however, may also be done in space and frequency. Instead of two adjacent symbol periods, two adjacent carriers may be used (space–frequency coding).

Table 3.1 The encoding and transmission sequence for the Two branch transmit diversity scheme

Time ↓	Space →	Antenna 0	Antenna 1
Time t		s_0	s_1
Time t+T		$(-s_1^*)$	s_0^*

The channel at time may be modeled by a complex multiplicative distortion $h_0(t)$ for transmit antenna zero and $h_1(t)$ for transmit antenna one. Assuming that fading is constant across two consecutive symbols, we can write

$$\begin{aligned}
 h_0(t) &= h_0(t+T) = h_0 = a_0 e^{j\theta_0} \\
 h_1(t) &= h_1(t+T) = h_1 = a_1 e^{j\theta_1}
 \end{aligned}
 \tag{3.11}$$

where T is the symbol duration. The received signals can then be expressed as

$$\begin{aligned}
 r_0(t) &= r(t) = h_0 s_0 + h_1 s_1 + n_0 \\
 r_1 &= r_1(t+T) = -h_0 s_1^* + h_1 s_0^* + n_1
 \end{aligned}
 \tag{3.12}$$

where r_0 and r_1 are the received signals at time t and $(t+T)$ and n_0 and n_1 are complex random variables representing receiver noise and interference.

2) *The Combining Scheme*: The combiner shown in Fig. 4.2 builds the following two combined signals that are sent to the maximum likelihood detector:

$$\begin{aligned}\tilde{s}_0 &= h_0^* r_0 + h_1 r_1^* \\ \tilde{s}_1 &= h_1^* r_0 - h_0 r_1^*\end{aligned}\tag{3.13}$$

It is important to note that this combining scheme is different from the MRRRC in (3.6). Substituting (3.11) and (3.12) into (3.13) we get

$$\begin{aligned}\tilde{s}_0 &= (\alpha_0^2 + \alpha_1^2) s_0 + h_0^* n_0 + h_1 n_1^* \\ \tilde{s}_1 &= (\alpha_0^2 + \alpha_1^2) s_1 - h_0 n_1^* + h_1^* n_0\end{aligned}\tag{3.14}$$

3) *The Maximum Likelihood Decision Rule*: These combined signals are then sent to the maximum likelihood detector which, for each of the signals and, uses the decision rule expressed in (3.7) or (3.8) for PSK signals.

The resulting combined signals in (3.14) are equivalent to that obtained from two-branch MRRRC in (3.6). The only difference is phase rotations on the noise components which do not degrade the effective SNR. Therefore, the resulting diversity order from the new two-branch transmit diversity scheme with one receiver is equal to that of two-branch MRRRC.

3.4 Simulation details

Simulations for checking the BER performance have been done on Matlab. Here first random bit stream are generated then correspondingly symbols are generated that are supposed to be transmitted to send the information of the bit stream. Then a channel is modeled for multipath fading environment. The symbols are estimated at the receiver using ML detection. The system performance is checked at different values of SNR and different modulation schemes have been used.

3.4.1 Simulation results of BER for BPSK under different fading environments for Alamouti's Scheme

Modulation Technique: BPSK

Number of Symbols used: 10,000

Bits per symbol: 1

Rayleigh Fading

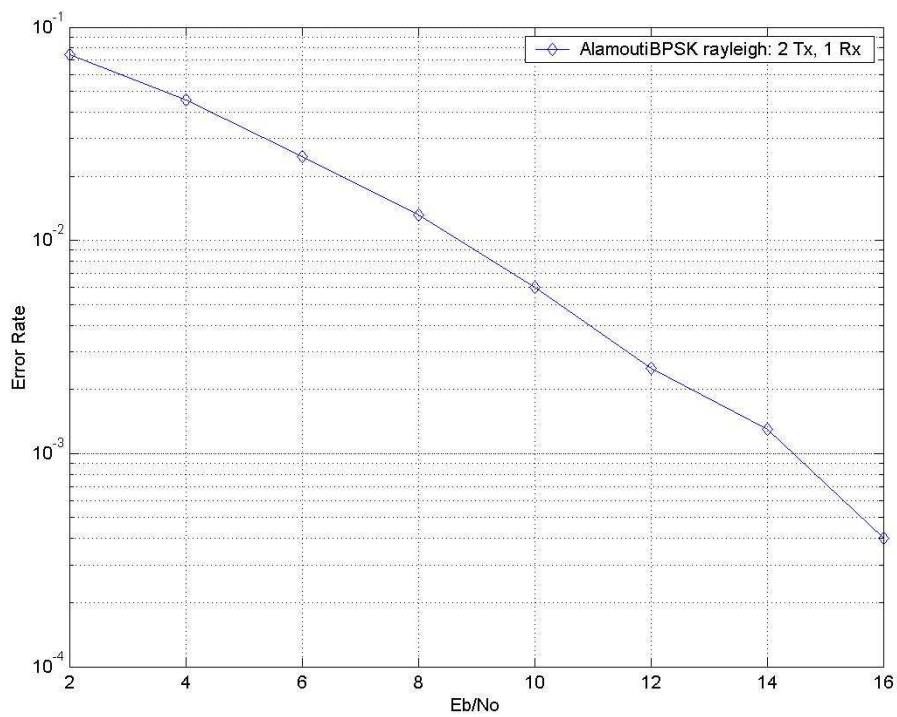


Fig. 3.3: The BER error performance of BPSK for Rayleigh fading

Modulation Technique: BPSK

Number of Symbols used: 10,000

Bits per symbol: 1

Rician Fading

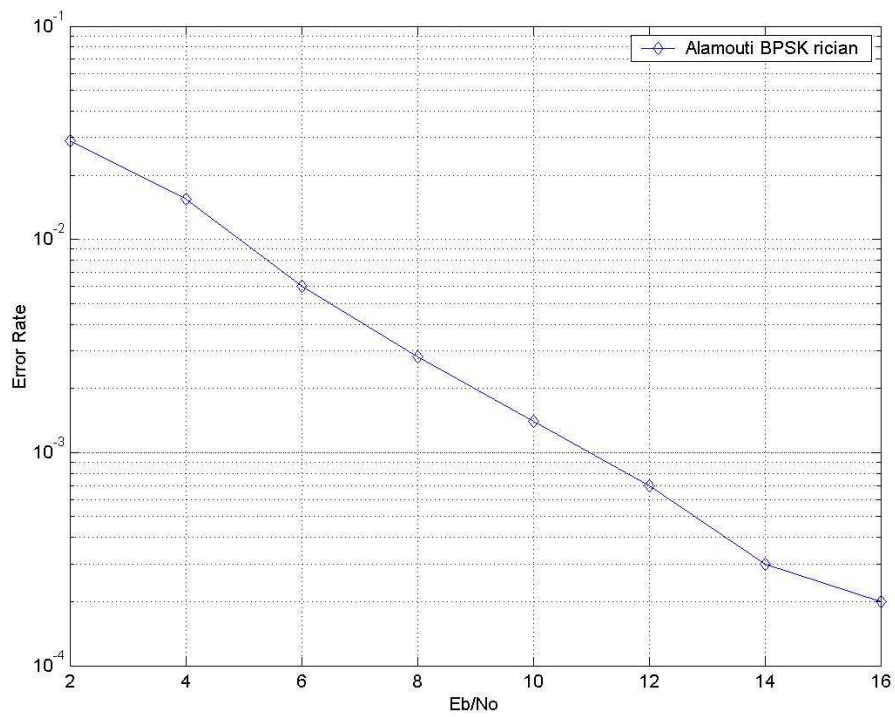


Fig. 3.4: The BER error performance of BPSK for Rician fading

Modulation Technique: BPSK

Number of Symbols used: 10,000

Bits per symbol: 1

Nakagami Fading

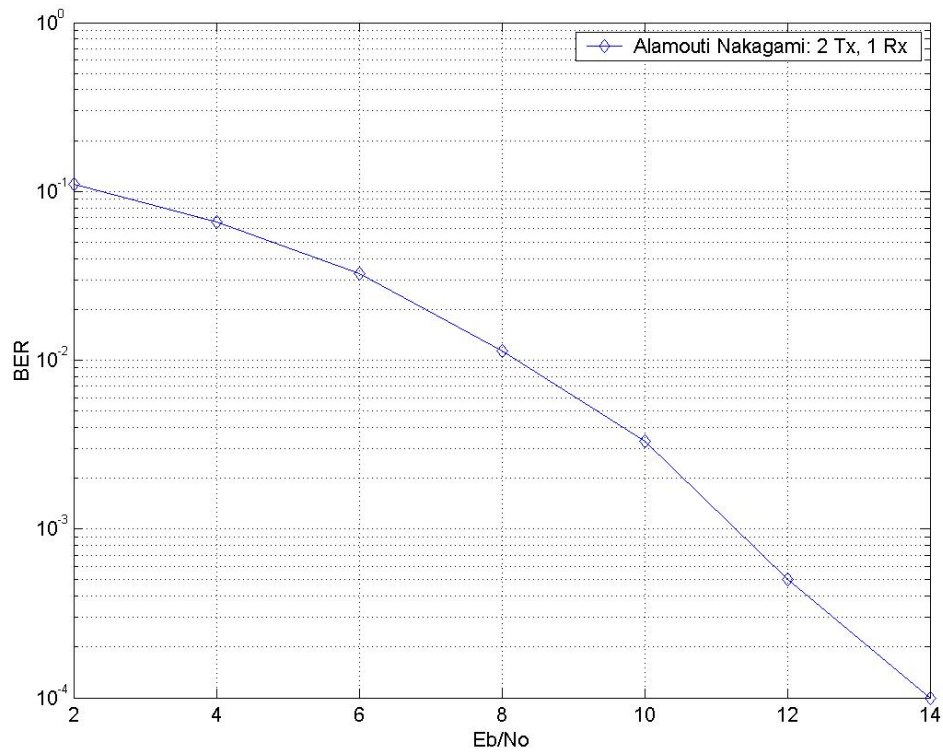


Fig. 3.5: The BER error performance of BPSK for Nakagami fading

Modulation Technique: BPSK

Number of Symbols used: 10,000

Bits per symbol: 1

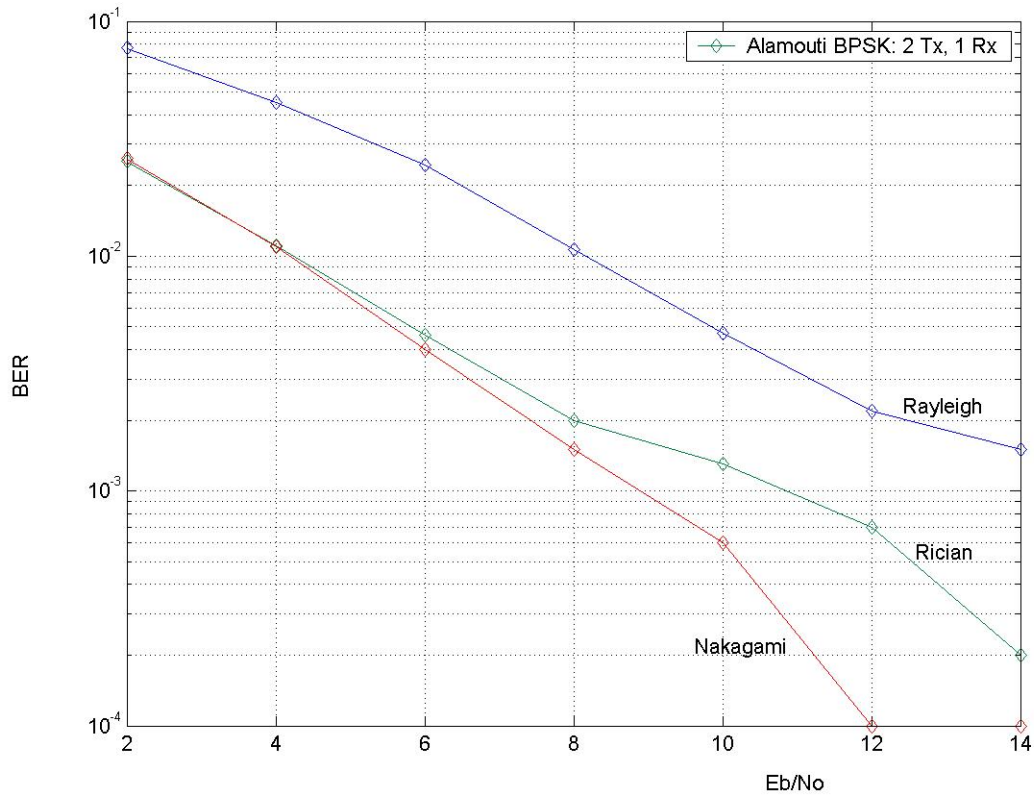


Fig. 3.6: The BER error performance of BPSK for different fading environments

The Fig. 3.4 shows that in case of BPSK modulation scheme, for an error rate of 0.016, Nakagami fading requires approximately 4db less power as compared to Rayleigh fading. For the same error rate Rician fading requires approximately 3db less power as compared to Rayleigh fading. Hence the performance of the system is better in case of Nakagami fading environment.

3.4.2 Simulation results of BER for QPSK under different fading environments for Alamouti's Scheme

Modulation Technique: QPSK

Number of Symbols used: 10,000

Bits per symbol: 2

Rayleigh Fading

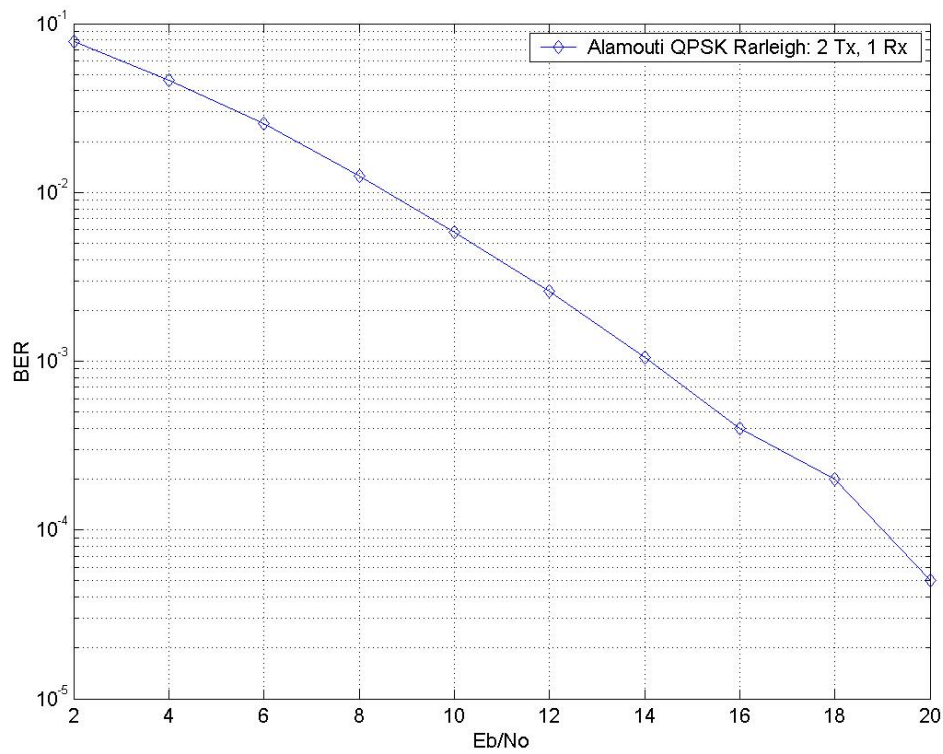


Fig. 3.7: The BER error performance of QPSK for Rayleigh fading

Modulation Technique: QPSK

Number of Symbols used: 10,000

Bits per symbol: 2

Rician Fading

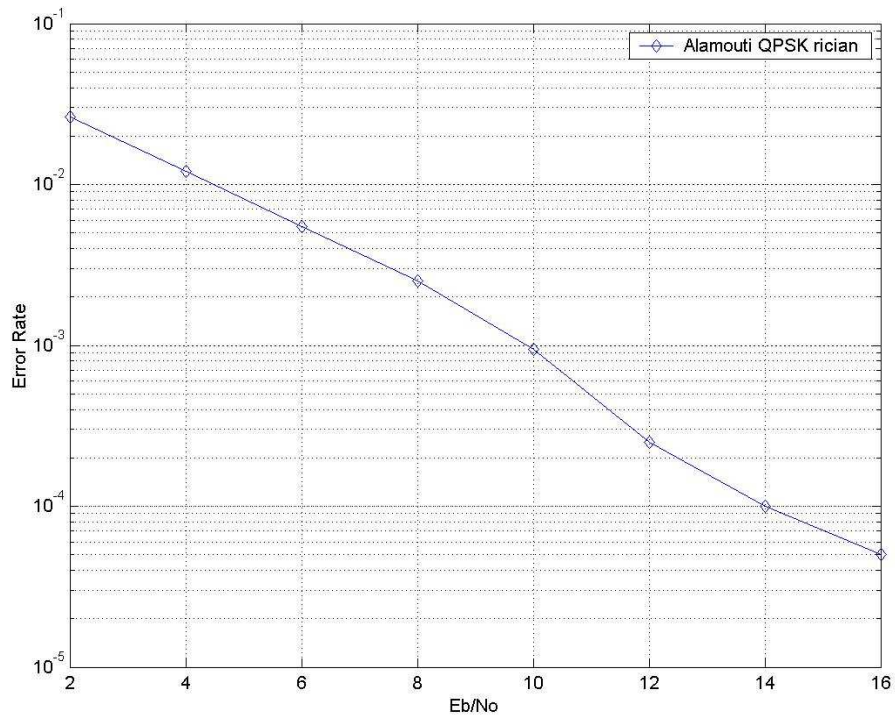


Fig. 3.8: The BER error performance of QPSK for Rician fading

Modulation Technique: QPSK

Number of Symbols used: 10,000

Bits per symbol: 2

Nakagami Fading

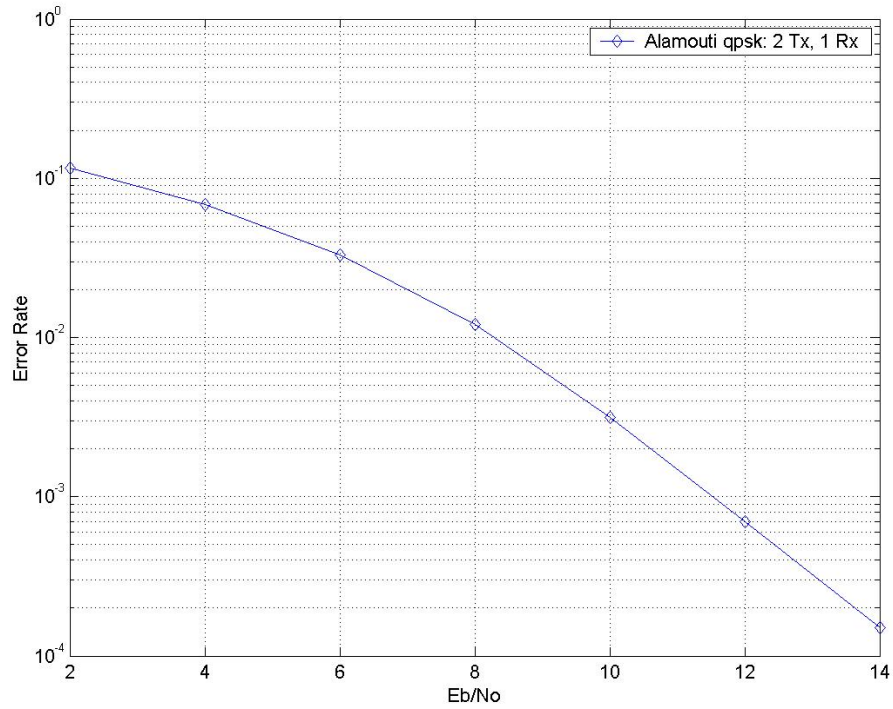


Fig. 3.9: The BER error performance of QPSK for Nakagami fading

Modulation Technique: QPSK

Number of Symbols used: 10,000

Bits per symbol: 2

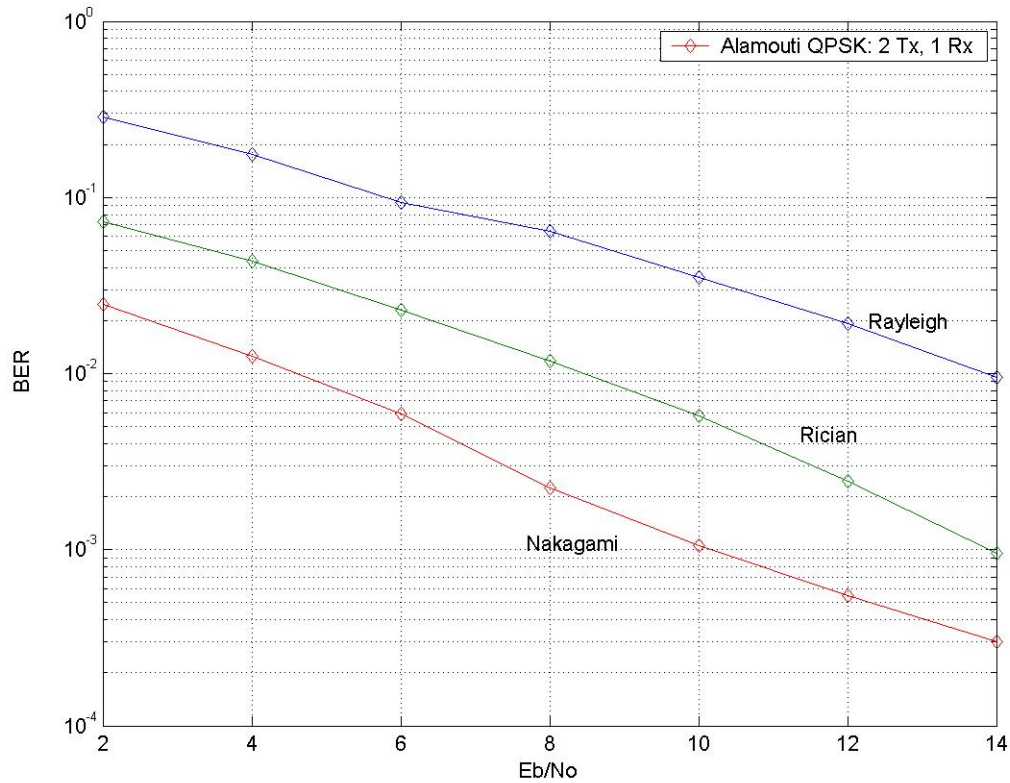


Fig. 3.10: The BER error performance of QPSK under different fading environments.

The figure-3.8 shows that in case of QPSK modulation scheme, for an SNR value of 8dB, under NAKAGAMI fading the system gives a BER of .0013, under Rician fading it gives a BER of .011 and for Rayleigh it gives BER of 0.0394. Hence the performance of the system is better in case of Nakagami fading environment.

Chapter 4

Differential Detection transmit diversity

4.1 Introduction

As discussed in the previous chapters the systems do not work efficiently if there is no channel side information at the receiver. So in order for the system to exploit the array diversity and also be able to work under conditions where there is no channel information, Vahid Tarokh and Hamid Jafarkhani proposed a new scheme which exploits the array diversity and also there is no need for channel information [2, 14]. This system has a low BER performance as compared to the Alamouti's scheme but has the advantage that it has got less complexity at the receiver side and lesser hardware used.

4.2 System Analysis

The system requires transmission of symbols for the information transfer. The set of symbols that we will be using to transmit the data are given by the formula

$$A = \left\{ \frac{e^{2\pi k j / 2^b}}{\sqrt{2}} \mid k = 0, 1, \dots, 2^b - 1 \right\} \quad (4.1)$$

where $j = \sqrt{-1}$ and b gives the number of bits per symbol. This is a generalized formula for MPSK systems where the parameter b depends upon modulation scheme to be used. Given a pair of constellation symbols x_1 and x_2 we observe that complex vectors $(x_1 \ x_2)$ and $(-x_2^* \ x_1^*)$ are orthogonal to each other and have unit lengths. Any two-dimensional vector $\chi = (x_3 \ x_4)$ can be uniquely represented in the orthonormal basis given by these vectors. In other words there exists a unique complex vector $P_\chi = (A_\chi \ B_\chi)$ such that A_χ and B_χ satisfy the equation

$$(x_3 \ x_4) = A_\chi(x_1 \ x_2) + B_\chi(-x_2^* \ x_1^*) \quad (4.2)$$

The coefficients A_χ and B_χ are given by

$$A_\chi = x_3 x_1^* + x_4 x_2^* \quad (4.3)$$

$$B_\chi = -x_3 x_2 + x_4 x_1 \quad (4.4)$$

We define the set V_x to consist of all vectors P_χ $\chi \in A \times A$. The set V_x has the following properties

- 1 property: It has 2^{2b} elements corresponding to the pairs $(x_3 \ x_4)$ of constellation symbols.
- 2 property: All elements of V_x have unit length.

The above properties hold because mapping $\chi \rightarrow P_\chi$ is just change of basis from the standard basis given by vectors $\{(0 \ 1), (1 \ 0)\}$ to orthonormal basis given by $(x_1 \ x_2)$ and $(-x_2^* \ x_1^*)$ which preserves the distance between the two-dimensional complex space.

4.2.1 Encoding algorithm

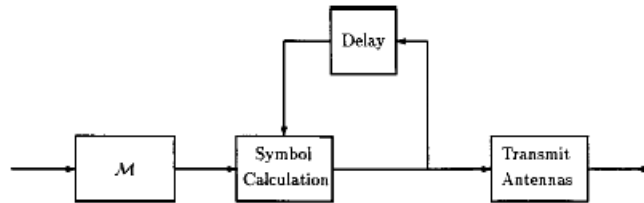


Fig. 4.1 Encoding scheme for Differential Detection

The first part is to choose a set of A and B which satisfy the above properties. We can calculate them by first calculating all possible combinations of $(x_1 \ x_2)$ & $(x_3 \ x_4)$ and then using the equations to calculate A and B. We will get a set of 2^{2b} repeating values for A and B. We then choose mapping bits onto these constellation symbols. Given a block B of 2b bits, the first b bits are mapped into a constellation symbol a_3 and the second bits are mapped into a constellation symbol a_4 using Gray mapping.

The transmitter begins the transmission with sending arbitrary symbols s_1 and s_2 at time 1 and symbols $-s_2^*$ and s_1^* at time 2 unknown to the receiver. These two transmissions do not convey any information. The transmitter subsequently encodes the rest of the data in an inductive manner. At time $2t+1$ a block of $2b$ bits B_{2t+1} arrives at the encoder. The transmitter uses the mapping M and computes $M(B_{2t+1}) = (A(B_{2t+1}) \ B(B_{2t+1}))$. Then it computes

$$(s_{2t+1} \ s_{2t+2}) = A(B_{2t+1})(s_{2t-1} \ s_{2t}) + B(B_{2t+1}) \begin{pmatrix} -s_{2t}^* & s_{2t-1}^* \end{pmatrix} \quad (4.5)$$

4.2.2 Decoding algorithm

Let us assume that signals r_{2t-1} , r_{2t} , r_{2t+1} and r_{2t+2} are received. Let

$$\Lambda(\alpha_1 \ \alpha_2) = \begin{pmatrix} \alpha_1 & \alpha_2^* \\ \alpha_2 & \alpha_1^* \end{pmatrix} \quad (4.6)$$

And

$$N_{2t-1} = \begin{pmatrix} \eta_{2t-1} & \eta_{2t}^* \end{pmatrix} \quad (4.7)$$

The receiver recalls that

$$(r_{2t-1} \ r_{2t}^*) = (s_{2t-1} \ s_{2t}) \Lambda(\alpha_1 \ \alpha_2) + N_{2t-1} \quad (4.8)$$

And

$$(r_{2t+1} \ r_{2t+2}^*) = (s_{2t+1} \ s_{2t+2}) \Lambda(\alpha_1 \ \alpha_2) + N_{2t+1} \quad (4.9)$$

Thus,

$$\begin{aligned} (r_{2t+1} \ r_{2t+2}^*) \bullet (r_{2t-1} \ r_{2t}^*) &= (s_{2t+1} \ s_{2t+2}) \Lambda(\alpha_1 \ \alpha_2) \Lambda^*(\alpha_1 \ \alpha_2) (s_{2t-1}^* \ s_{2t}^*) \\ &\quad + (s_{2t+1} \ s_{2t+2}) \Lambda(\alpha_1 \ \alpha_2) N_{2t-1}^* \\ &\quad + N_{2t+1}^* \Lambda^*(\alpha_1 \ \alpha_2) (s_{2t-1}^* \ s_{2t}^*) + N_{2t+1}^* N_{2t-1}^* \end{aligned} \quad (4.10)$$

It follows that

$$\begin{aligned}
(r_{2t+1} r_{2t-1}^*) + (r_{2t+2} r_{2t}) &= (|\alpha_1|^2 + |\alpha_2|^2)(s_{2t+1} s_{2t-1}^* + s_{2t+2} s_{2t}^*) \\
&+ (s_{2t+1} s_{2t+2}) \Lambda(\alpha_1 \alpha_2) N_{2t-1}^* \\
&+ N_{2t+1} \Lambda^*(\alpha_1 \alpha_2) (s_{2t-1}^* s_{2t}^*) + N_{2t+1} N_{2t-1}^*
\end{aligned} \tag{4.11}$$

For notational simplicity, we let

$$R_1 = (r_{2t+1} r_{2t-1}^*) + (r_{2t+2} r_{2t}) \tag{4.12}$$

$$\begin{aligned}
N_1 &= (s_{2t+1} s_{2t+2}) \Lambda(\alpha_1 \alpha_2) N_{2t-1}^* \\
&+ N_{2t+1} \Lambda^*(\alpha_1 \alpha_2) (s_{2t-1}^* s_{2t}^*) + N_{2t+1} N_{2t-1}^*
\end{aligned} \tag{4.13}$$

Then we have

$$R_1 = (|\alpha_1|^2 + |\alpha_2|^2) A(B_{2t-1}) + N_1 \tag{4.14}$$

Also

$$(r_{2t} - r_{2t-1}^*) = (-s_{2t}^* s_{2t-1}^*) \Lambda(\alpha_1 \alpha_2) + N_{2t} \tag{4.15}$$

It follows that

$$\begin{aligned}
(r_{2t+1} r_{2t+2}^*) \bullet (r_{2t} - r_{2t-1}^*) &= (s_{2t+1} s_{2t+2}) \Lambda(\alpha_1 \alpha_2) \Lambda^*(\alpha_1 \alpha_2) (-s_{2t}^* s_{2t-1}^*) \\
&+ (s_{2t+1} s_{2t+2}) \Lambda(\alpha_1 \alpha_2) N_{2t}^* \\
&+ N_{2t+1}^* \Lambda^*(\alpha_1 \alpha_2) (-s_{2t}^* s_{2t-1}^*) + N_{2t+1} N_{2t-1}^*
\end{aligned} \tag{4.16}$$

Thus,

$$\begin{aligned}
(r_{2t+1} r_{2t}^*) - (r_{2t+2}^* - r_{2t-1}) &= (|\alpha_1|^2 + |\alpha_2|^2) (-s_{2t+1} s_{2t}^* + s_{2t+2} s_{2t-1}^*) \\
&+ (s_{2t+1} s_{2t+2}) \Lambda(\alpha_1 \alpha_2) N_{2t}^* \\
&+ N_{2t+1} \Lambda^*(\alpha_1 \alpha_2) (-s_{2t}^* s_{2t-1}^*) + N_{2t+1} N_{2t-1}^*
\end{aligned} \tag{4.17}$$

For notational simplicity, we let

$$R_2 = (r_{2t+1} \ r_{2t}^*) - (r_{2t+2}^* \ r_{2t-1}) \quad (4.18)$$

$$N_2 = (s_{2t+1} \ s_{2t+2})\Lambda(\alpha_1 \ \alpha_2)N_{2t}^* + N_{2t+1}\Lambda^*(\alpha_1 \ \alpha_2)(s_{2t}^* \ s_{2t-1}^*) + N_{2t+1}N_{2t}^* \quad (4.19)$$

Then we have

$$R_2 = (|\alpha_1|^2 + |\alpha_2|^2)B(B_{2t-1}) + N_2 \quad (4.20)$$

We can thus write

$$(R_1 \ R_2) = (|\alpha_1|^2 + |\alpha_2|^2)(A(B_{2t-1}) \ B(B_{2t-1})) + (N_1 \ N_2) \quad (4.21)$$

Because the elements of V have equal length, to compute $(A(B_{2t-1}) \ B(B_{2t-1}))$, the receiver now computes the closest vector of V to $(R_1 \ R_2)$. Once this vector is computed, the inverse mapping of M is applied and the transmitted bits are recovered.

Here both the sub-channels from the transmit antennas 1 and 2 to the receive antenna must undergo fading. In this light, the decoder suffers from the detrimental effect of fading only if both sub-channels from transmit antennas 1 and 2 to the receive antenna have small path gains. This means that the decoder enjoys a two-level transmit diversity gain.

4.3 Matlab simulations

Simulations for calculating the BER performance have been done on Matlab. Here first a random bit stream is generated. Then signal power level is defined and using the encoding scheme the symbols are generated that are supposed to be transmitted. The encoded symbols are transmitted through multipath faded channel. Here channel is assumed to be flat faded and channel distortion is assumed to be multipath. The channel is generated as $CN(m,N)$ where CN stands for circularly symmetric Gaussian random variable, m is mean and N is variance. The symbols are estimated at the receiver using ML detection. Then AWGN is added in the system which is generated using normally distributed and generated as $N(0,1)$, where N stands for normally distributed RV with 0 mean and variance 1. The system performance is then checked at different values of SNR and for different modulation schemes.

10,000 symbols are generated for each simulation and then the BER Vs SNR curves are plotted. Then comparison is done between different modulation schemes under same fading environment and also performance comparison is done for a single modulation scheme under different fading environments. The system comparison is done between the Alamouti's scheme and the Differential Detection Transmit Diversity.

4.3.1 Simulation results of BER for BPSK under different fading environments with Differential Detection Scheme

Modulation Technique: BPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Rayleigh Fading

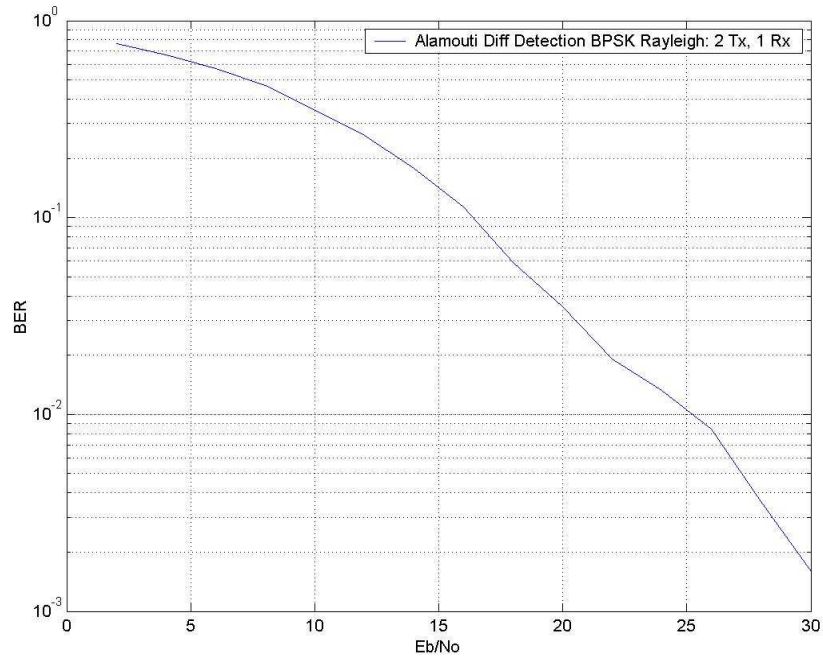


Fig. 4.2: The BER error performance of BPSK for Rayleigh fading

Modulation Technique: BPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Rician Fading

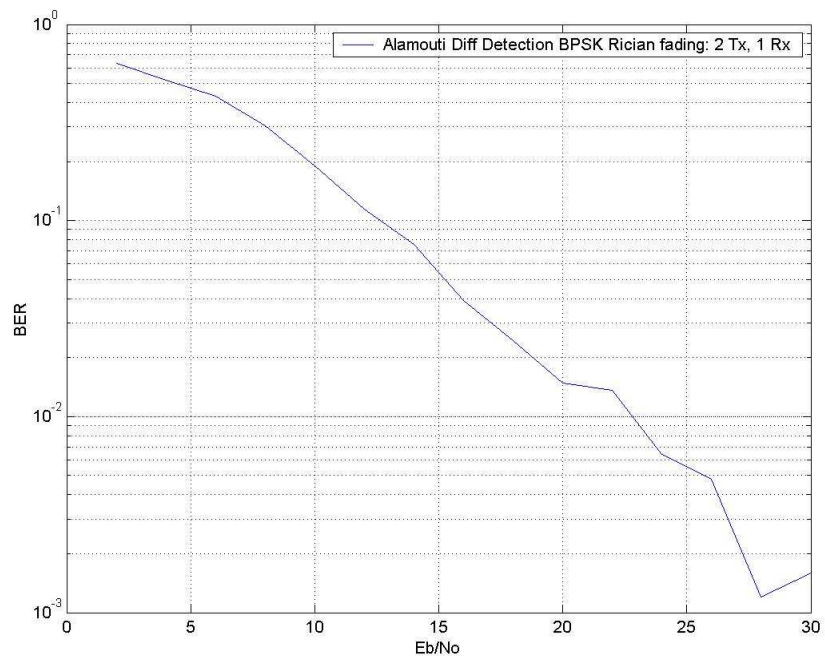


Fig. 4.3: The BER error performance of BPSK for Rician fading

Modulation Technique: BPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Nakagami Fading

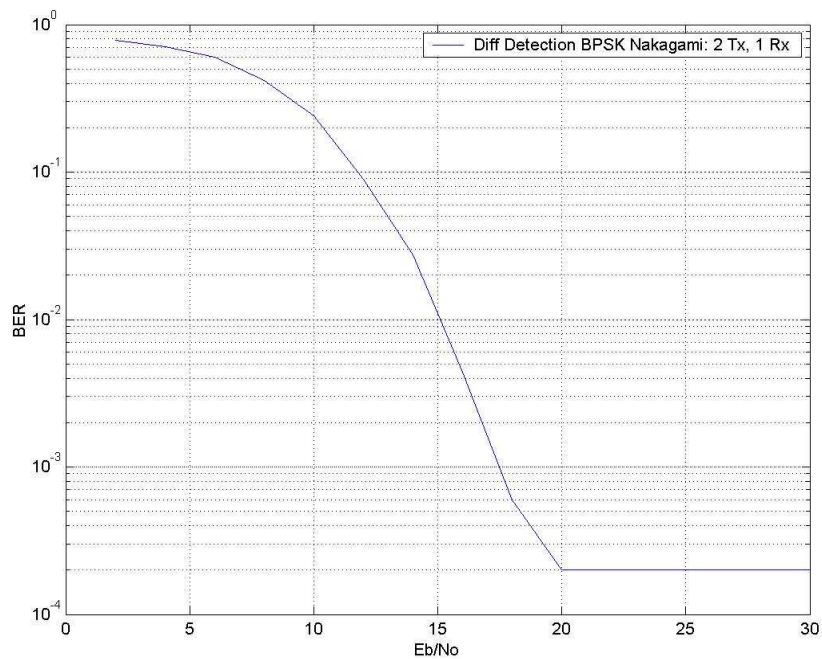


Fig. 4.4: The BER error performance of BPSK for Nakagami fading

Modulation Technique: BPSK
Number of Symbols used: 10,000
Bits per symbol: 1

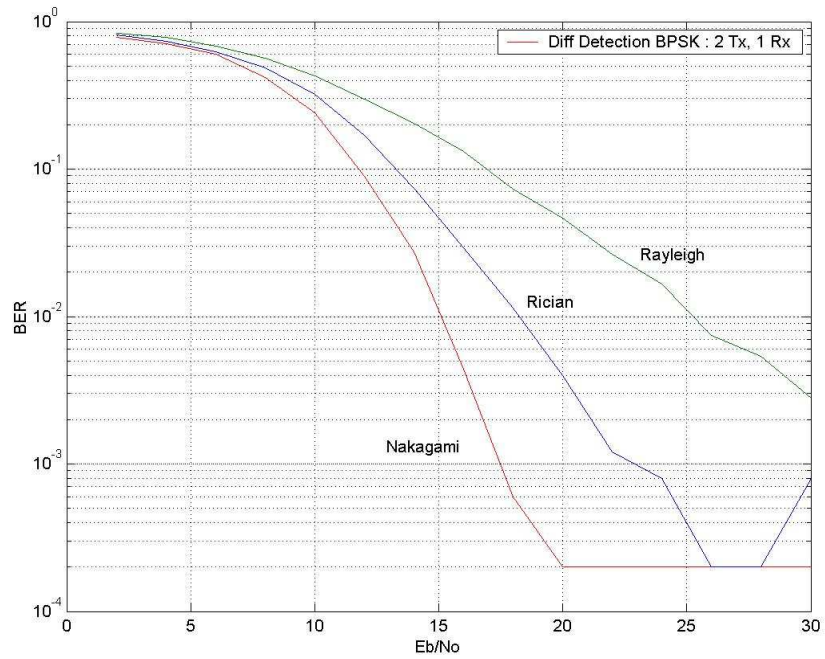


Fig. 4.5: The BER error performance of BPSK for Different fading environments

Table-4.1: BER performance BPSK under different fading at SNR of 15db.

Fading	Bit Error Rate
Rayleigh	0.1208
Rician	0.0251
Nakagami	0.01

Table-4.2: SNR for BPSK under different fading for BER of 10^{-1} .

Fading	SNR(dB)
Rayleigh	17
Rician	13
Nakagami	12

From Fig. 4.2-4.5 and table 4.1-4.2 it is inferred that the system performance using BPSK is best under Nakagami fading. For a BER of 0.01, the system under Nakagami fading requires a SNR of 15dB and under Rician fading it requires a SNR of 18dB and under Rayleigh it requires a SNR of 25dB.

4.3.2 Simulation results of BER for DPSK under different fading environments with Differential Detection Scheme

Modulation Technique: DPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Rayleigh Fading

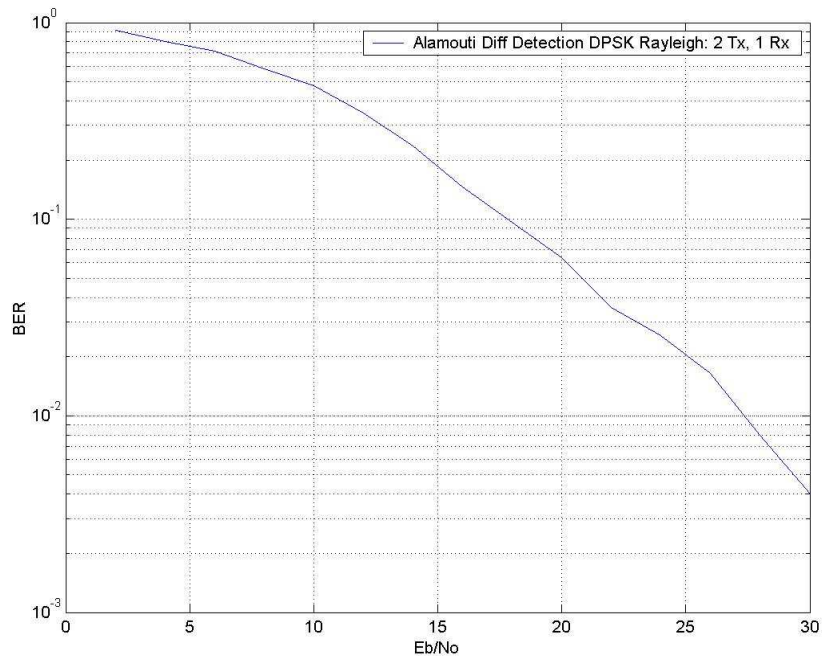


Fig. 4.6: The BER error performance of DPSK for Rayleigh fading

Modulation Technique: DPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Rician Fading

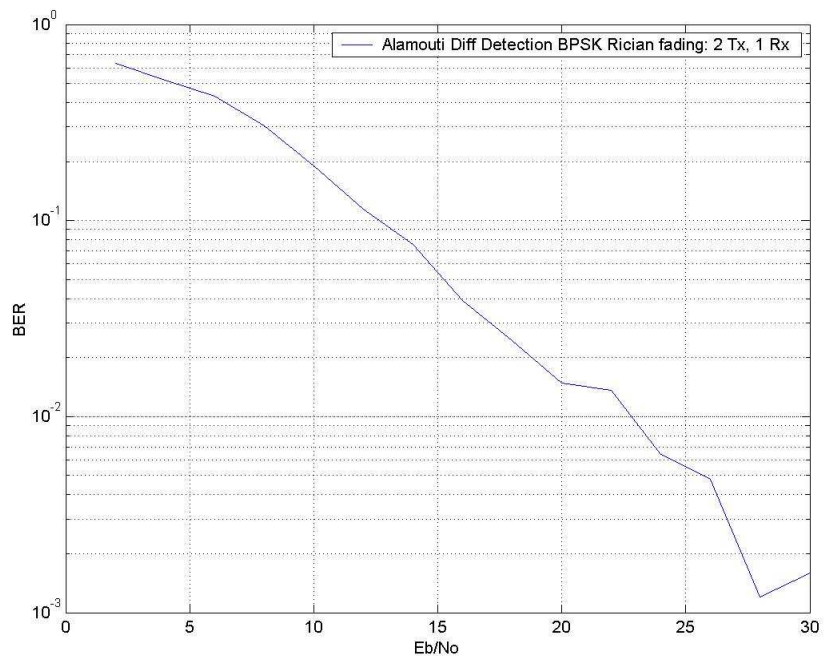


Fig. 4.7: The BER error performance of DPSK for Rician fading

Modulation Technique: DPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Nakagami Fading

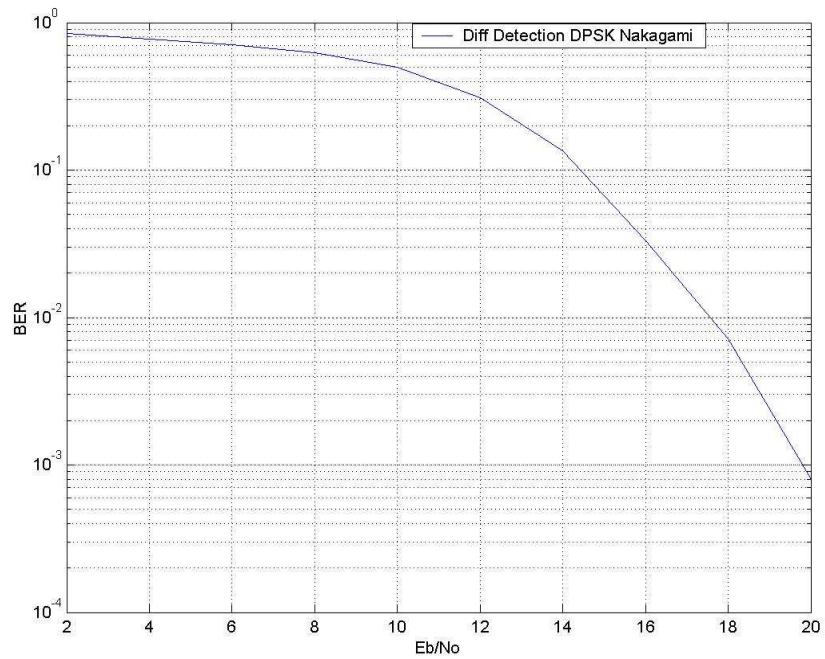


Fig. 4.8: The BER error performance of DPSK for Nakagami fading

Modulation Technique: DPSK
Number of Symbols used: 10,000
Bits per symbol: 1

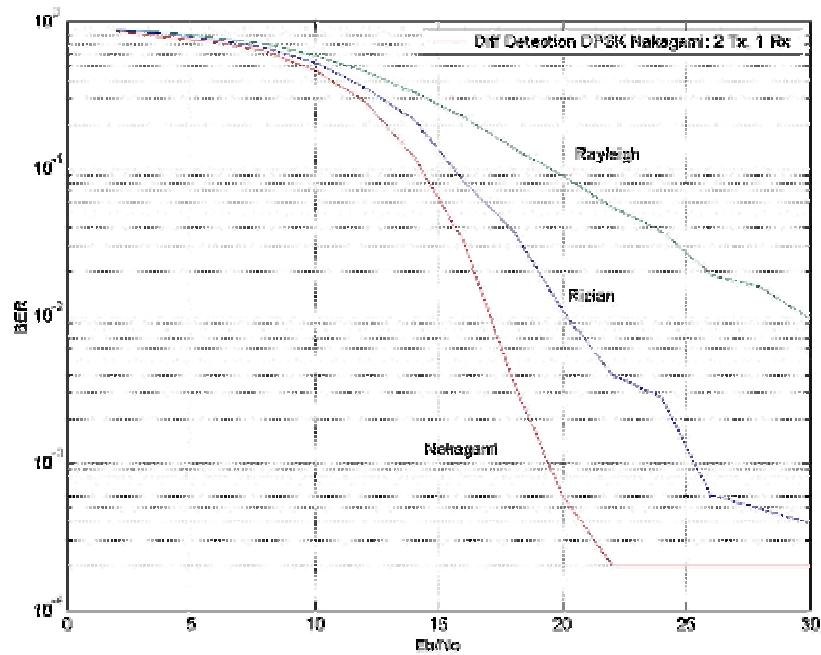


Fig. 4.9: The BER error performance of DPSK for Different fading environments

Table-4.3: BER performance DPSK under different fading at SNR of 15db.

Fading	Bit Error Rate
Rayleigh	0.151
Rician	0.110
Nakagami	0.0316

Table-4.4: SNR for DPSK under different fading for BER of 10^{-1} .

Fading	SNR(dB)
Rayleigh	19
Rician	16
Nakagami	14

From Fig. 4.6-4.9 and table 4.3-4.4 it is inferred that the system performance using BPSK is best under Nakagami fading. For a BER of 0.01, the system under Nakagami fading requires a SNR of 15dB and under Rician fading it requires a SNR of 18dB and under Rayleigh it requires a SNR of 25dB.

4.3.3 Simulation results of BER for QPSK under different fading environments with Differential Detection Scheme

Modulation Technique: QPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Rayleigh Fading

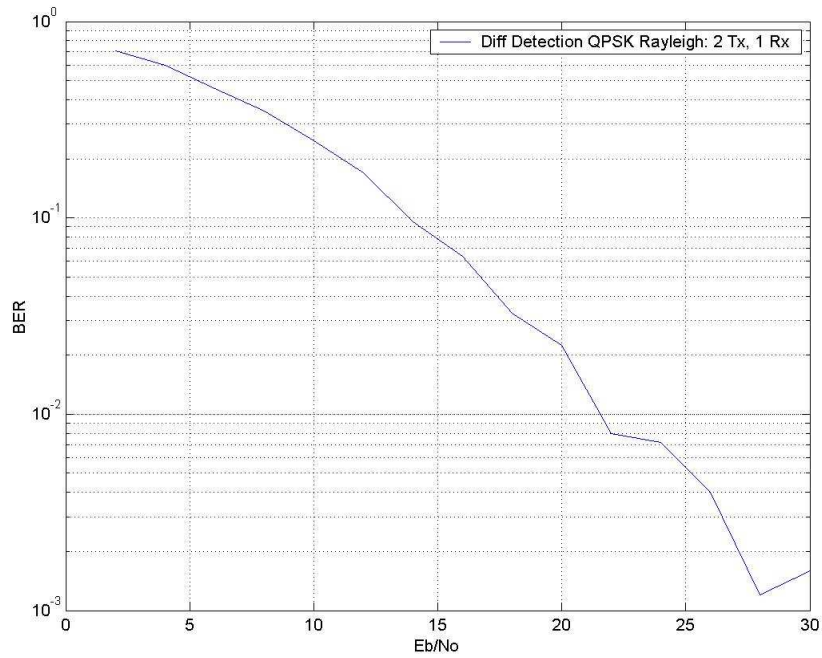


Fig. 4.10: The BER error performance of QPSK for Rayleigh fading

Modulation Technique: QPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Rician Fading

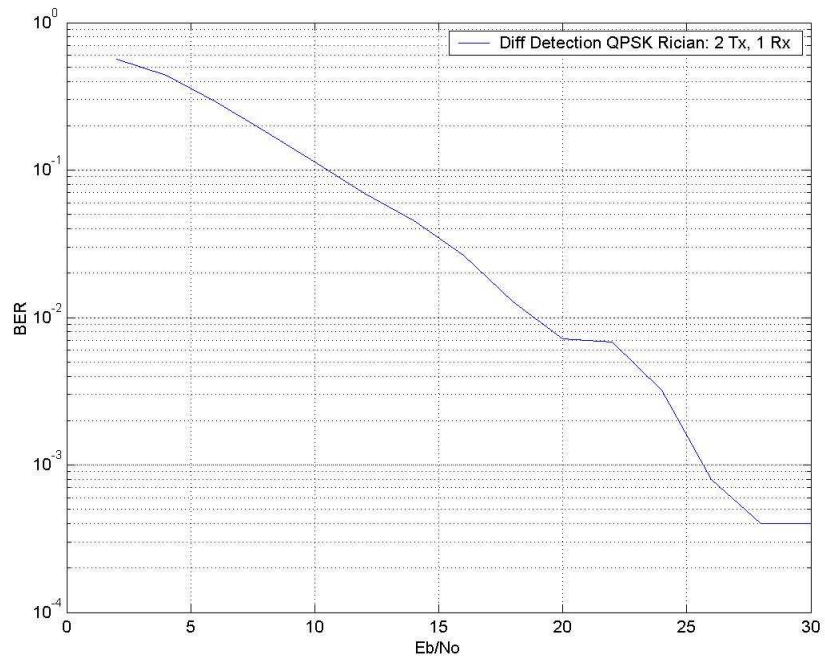


Fig. 4.11: The BER error performance of QPSK for Rician fading

Modulation Technique: QPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Nakagami Fading

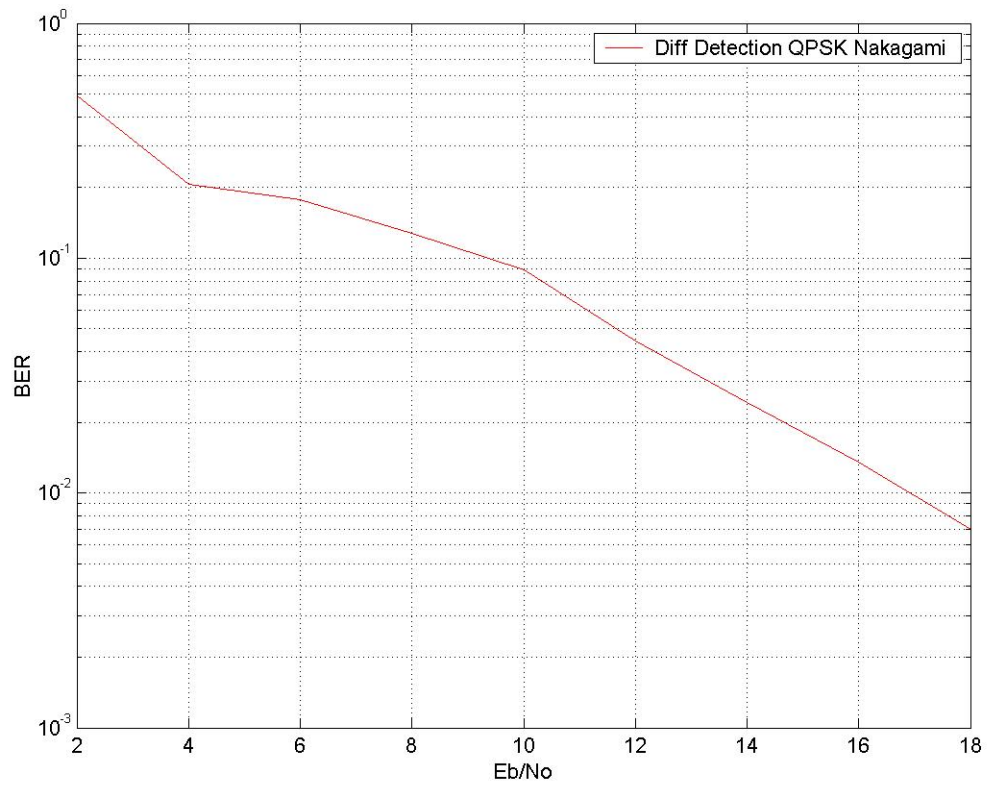


Fig. 4.12: The BER error performance of QPSK for Nakagami fading

Modulation Technique: QPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Nakagami Fading

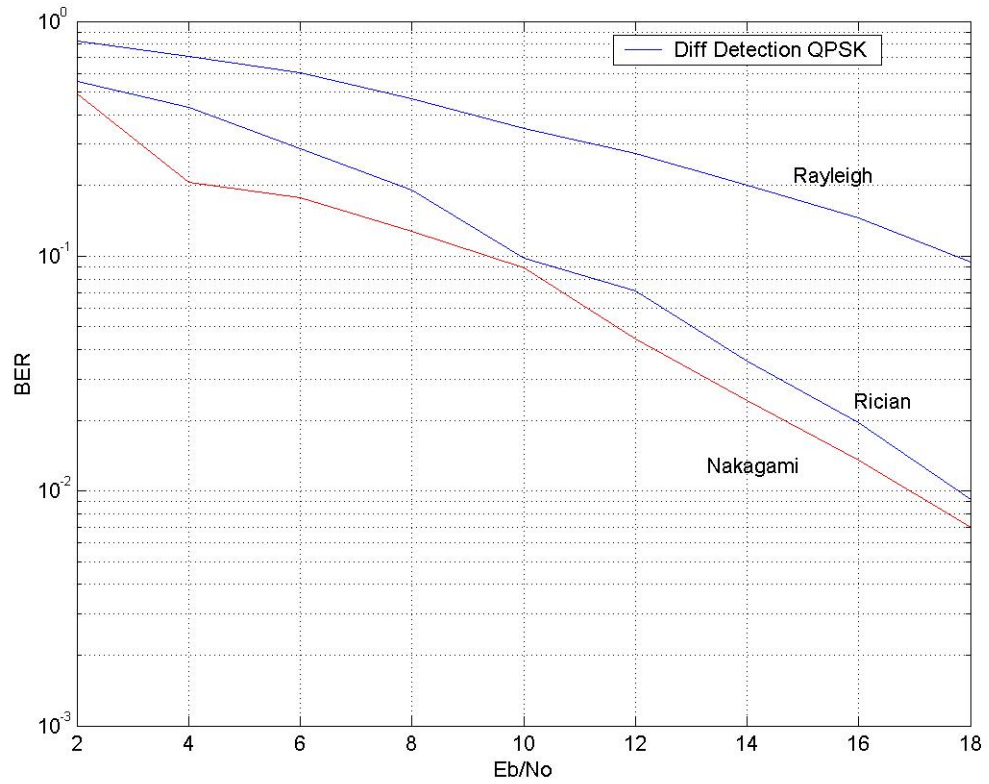


Fig. 4.13: The BER error performance of QPSK for Different fading environments

Table-4.5: BER performance QPSK under different fading at SNR of 12db.

Fading	Bit Error Rate
Rayleigh	0.141
Rician	0.0398
Nakagami	0.0224

Table-4.6: SNR for QPSK under different fading for BER of 10^{-1}

Fading	SNR(dB)
Rayleigh	18
Rician	10
Nakagami	9

From Fig. 4.10-4.13 and table 4.5-4.6 it is inferred that the BER performance of the system at an SNR of 12dB for Nakagami is 0.0178, for Rician it is 0.0398 and for Rayleigh it is 0.1585. Hence the performance of the system is comparative under Nakagami and Rician fading schemes.

4.3.4 Comparison of BER of different modulation schemes with Differential Detection Scheme under Rayleigh fading environment

Number of Symbols used per simulation: 10,000

Bits per symbol:

BPSK=1, DPSK=1, QPSK=2

Rayleigh Fading

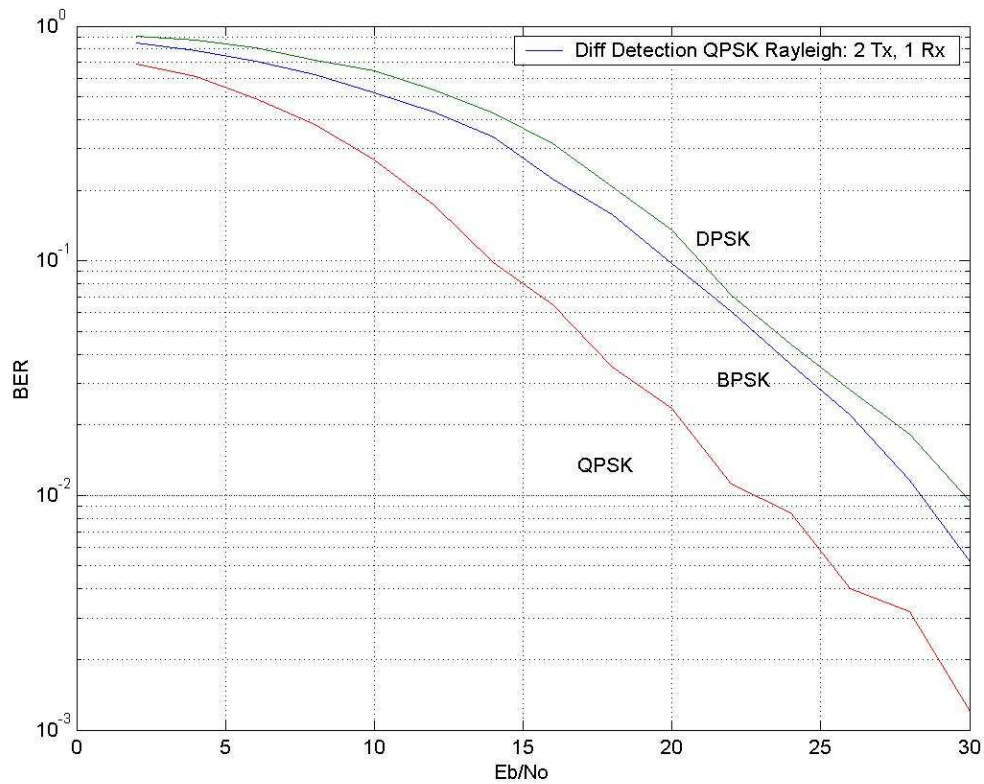


Fig. 4.14: The BER error performance of different modulation schemes under Rayleigh fading

Table-4.7: BER performance under Rayleigh fading at SNR of 10db.

Modulation Technique	Bit Error Rate
DPSK	0.3548
BPSK	0.2512
QPSK	0.1514

Table-4.8: BER performance under Rayleigh fading at SNR of 15db.

Modulation Technique	Bit Error Rate
DPSK	0.1905
BPSK	0.1514
QPSK	0.0631

Table-4.9: SNR under Rayleigh fading for BER of 10^{-1} .

Modulation Technique	SNR(dB)
DPSK	21
BPSK	20
QPSK	14

Table-4.10: SNR under Rayleigh fading for BER of 10^{-2} .

Modulation Technique	SNR(dB)
DPSK	30
BPSK	27
QPSK	22

In Fig. 4.14 and tables 4.7-4.10 the performance comparison of the system is done under Rayleigh fading using different modulation techniques. At a BER of .01 the SNR required by QPSK modulation scheme is 22dB, for BPSK at the same BER the required SNR is 27dB and for DPSK it is 30dB. Hence in order to get same BER performance, QPSK requires the least value of SNR

4.3.5 Comparison of BER of different modulation schemes with Differential Detection Scheme under Rician fading environment

Number of Symbols used per simulation: 10,000

Bits per symbol:

BPSK=1, DPSK=1, QPSK=2

Rician Fading

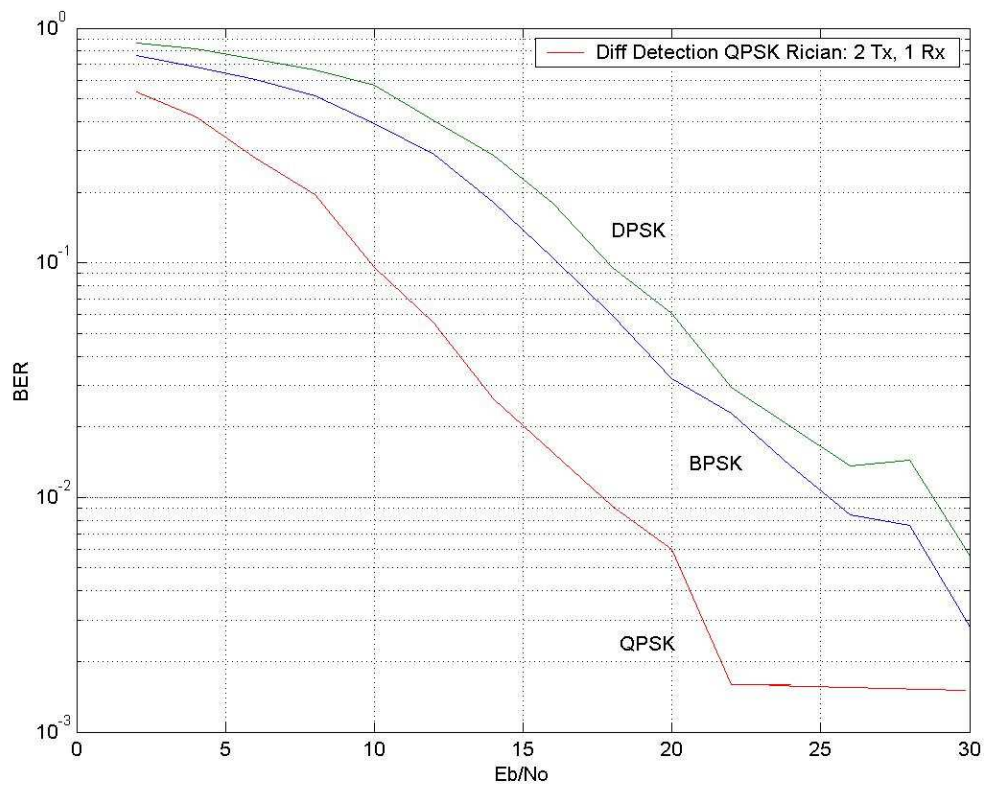


Fig. 4.15: The BER error performance of different modulation schemes under Rician fading

Table-4.11: BER performance under Rayleigh fading at SNR of 10db.

Modulation Technique	Bit Error Rate
DPSK	0.3548
BPSK	0.2512
QPSK	0.1514

Table-4.12: BER performance under Rayleigh fading at SNR of 15db.

Modulation Technique	Bit Error Rate
DPSK	0.1905
BPSK	0.1514
QPSK	0.0126

Table-4.13: SNR under Rayleigh fading for BER of 10^{-1} .

Modulation Technique	SNR(dB)
DPSK	18
BPSK	16
QPSK	10

Table-4.14: SNR under Rayleigh fading for BER of 10^{-2} .

Modulation Technique	SNR(dB)
DPSK	29
BPSK	26
QPSK	18

From Fig. 4.15 and tables 4.11-4.14 it can be observed that at a SNR of 12dB the BER for QPSK scheme is 0.0126, for BPSK it is 0.1514 and for DPSK it is 0.1905. Hence the number of bits in error for this SNR is less for QPSK compared to that of BPSK and DPSK. This means the performance of QPSK is better.

4.3.6 Comparison of BER of different modulation schemes for Differential Detection Scheme under Nakagami fading environment

Number of Symbols used per simulation: 10,000

Bits per symbol:

BPSK=1, DPSK=1, QPSK=2

Nakagami Fading

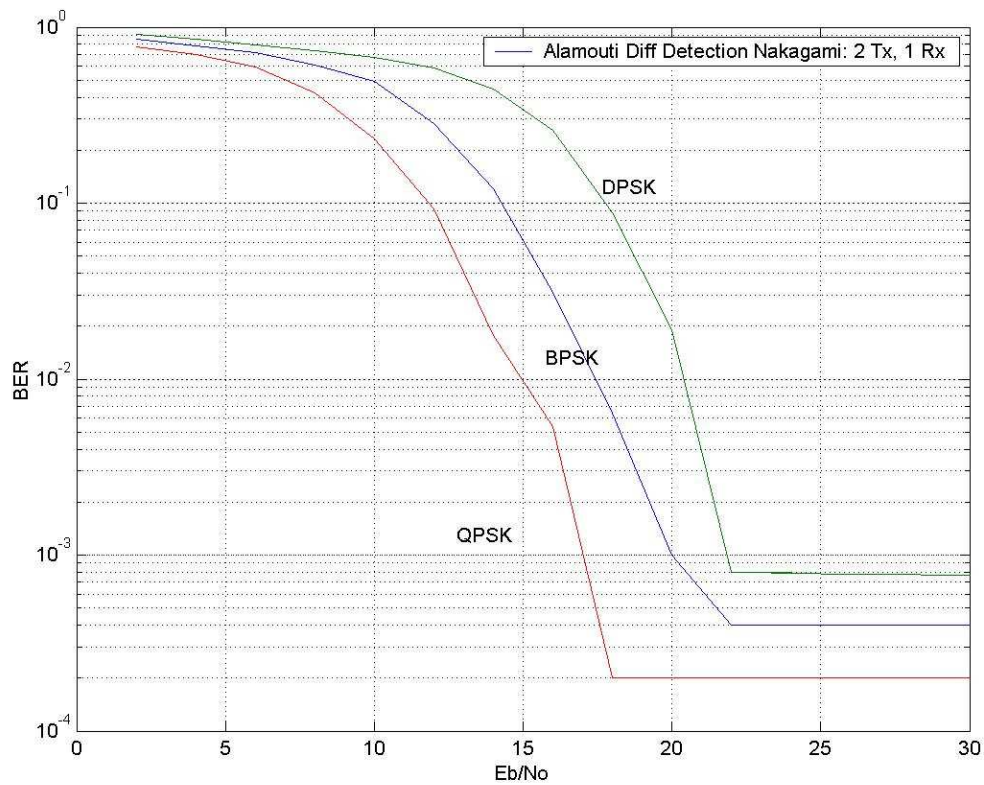


Fig. 4.16: The BER error performance of different modulation schemes under Nakagami fading

Table-4.15: BER performance under Nakagami fading at SNR of 10db.

Modulation Technique	Bit Error Rate
DPSK	0.3981
BPSK	0.2512
QPSK	0.1349

Table-4.16: BER performance under Nakagami fading at SNR of 15db.

Modulation Technique	Bit Error Rate
DPSK	0.1778
BPSK	0.0316
QPSK	0.01

Table-4.17: SNR under Nakagami fading for BER of 10^{-1} .

Modulation Technique	SNR(dB)
DPSK	17
BPSK	14
QPSK	12

Table-4.18: SNR under Nakagami fading for BER of 10^{-2} .

Modulation Technique	SNR(dB)
DPSK	21
BPSK	17
QPSK	15

From Fig. 4.16 and tables 4.15-4.18 it is observed that the performance of the system is better using QPSK scheme compared to BPSK and DPSK schemes. At a BER of .01 the SNR required by QPSK modulation scheme is 15dB, for BPSK at the same BER the required SNR is 17dB and for DPSK it is 21dB. Hence in order to get same BER performance, QPSK requires the least value of SNR.

4.3.7 Comparison of Differential Detection Scheme and Alamouti's Scheme using BPSK under Rayleigh fading

Modulation Technique: BPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Rayleigh Fading

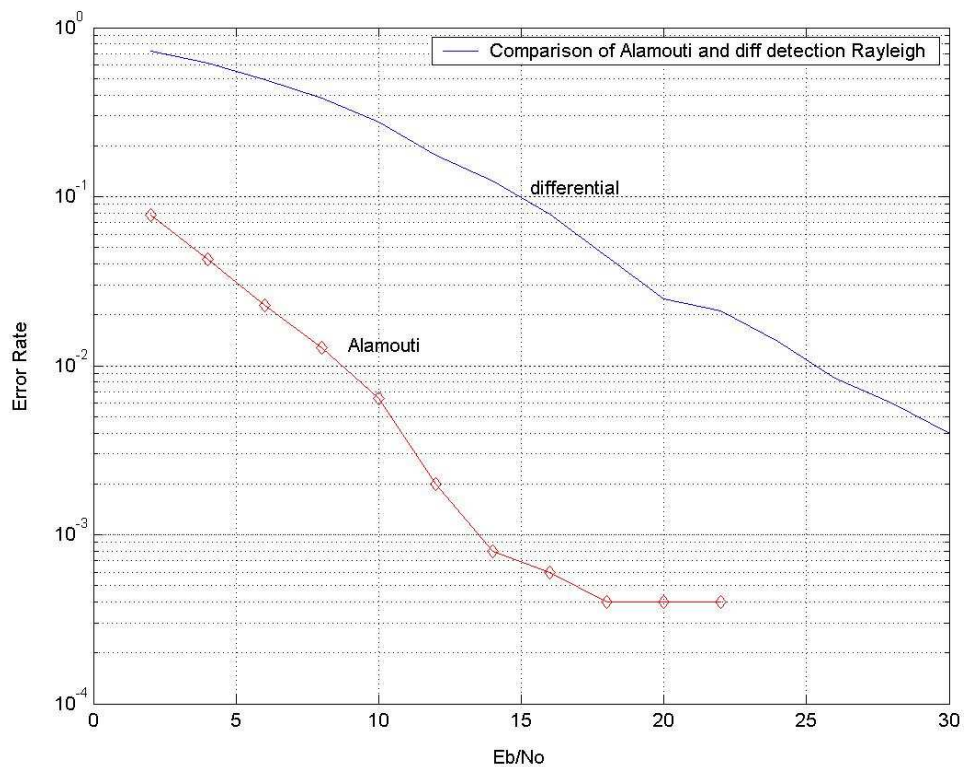


Fig. 4.17: Comparison of Differential Detection Scheme and Alamouti's Scheme using BPSK under Rayleigh fading

Table-4.19: BER performance under Rayleigh fading at SNR of 10db.

Transmission Scheme	Bit Error Rate
Alamouti's scheme	0.0035
Differential Detection	0.1514

Table-4.20: BER performance under Rayleigh fading at SNR of 15db.

Transmission Scheme	Bit Error Rate
Alamouti's scheme	0.0004
Differential Detection	0.1

Table-4.21: SNR under Rayleigh fading for BER of 10^{-1} .

Transmission Scheme	SNR(dB)
Alamouti's scheme	2
Differential Detection	15

Table-4.22: SNR under Rayleigh fading for BER of 10^{-2} .

Transmission Scheme	SNR(dB)
Alamouti's scheme	8
Differential Detection	25

In Fig. 4.17 and tables 4.19-4.22 the performance comparison has been done between Alamouti's scheme and Diff detection transmit diversity technique using BPSK modulation and under Rayleigh fading. For a BER performance of 0.01 the Alamouti's scheme requires a SNR value of 8dB and Diff detection scheme requires a SNR of 25dB.

4.3.8 Comparison of Differential Detection Scheme and Alamouti's Scheme using QPSK under Rayleigh fading

Modulation Technique: QPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Rayleigh Fading

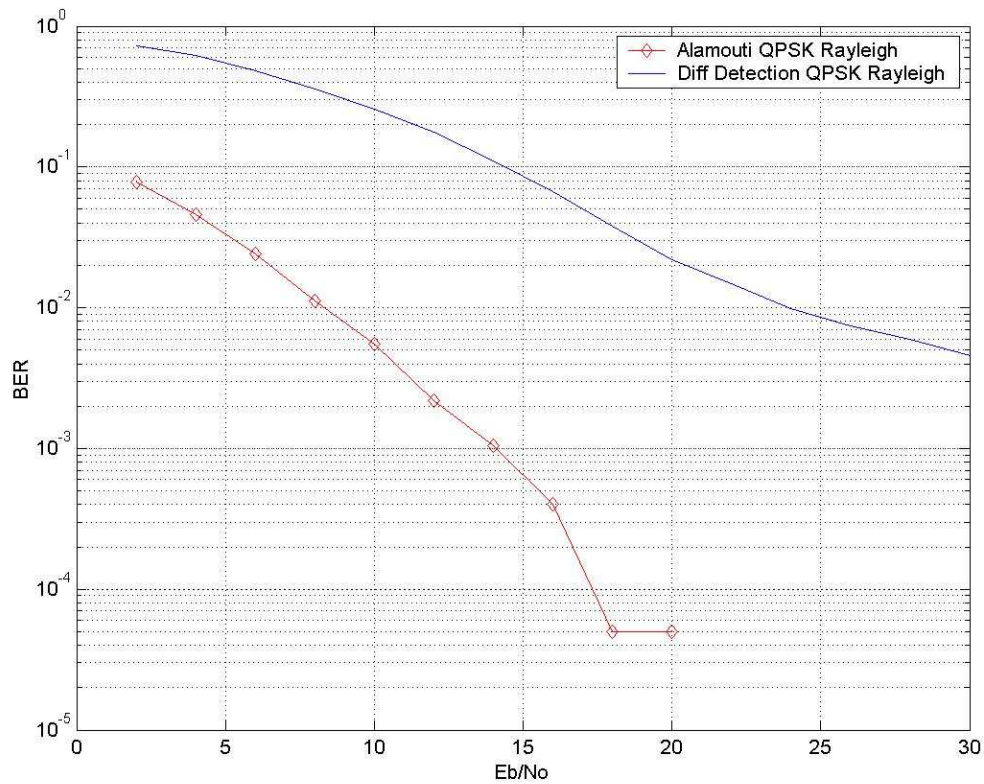


Fig. 4.18: Comparison of Differential Detection Scheme and Alamouti's Scheme using QPSK under Rayleigh fading

Table-4.23: BER performance under Rayleigh fading at SNR of 10db.

Transmission Scheme	Bit Error Rate
Alamouti's scheme	0.0032
Differential Detection	0.1413

Table-4.24: BER performance under Rayleigh fading at SNR of 15db.

Transmission Scheme	Bit Error Rate
Alamouti's scheme	0.0004
Differential Detection	0.0501

Table-4.25: SNR under Rayleigh fading for BER of 10^{-1} .

Transmission Scheme	SNR(dB)
Alamouti's scheme	2
Differential Detection	14

Table-4.26: SNR under Rayleigh fading for BER of 10^{-2} .

Transmission Scheme	SNR(dB)
Alamouti's scheme	8
Differential Detection	23

In Fig. 4.18 and tables 4.23-4.26 the performance comparison has been done between Alamouti's scheme and Diff detection transmit diversity technique using QPSK modulation and under Rayleigh fading. For the system to have a BER performance of 0.1 the Alamouti's scheme requires a SNR value of 2dB and Diff detection scheme requires a SNR of 14dB.

4.3.9 Comparison of Differential Detection Scheme and Alamouti's Scheme using BPSK under Rician fading

Modulation Technique: BPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Rician Fading

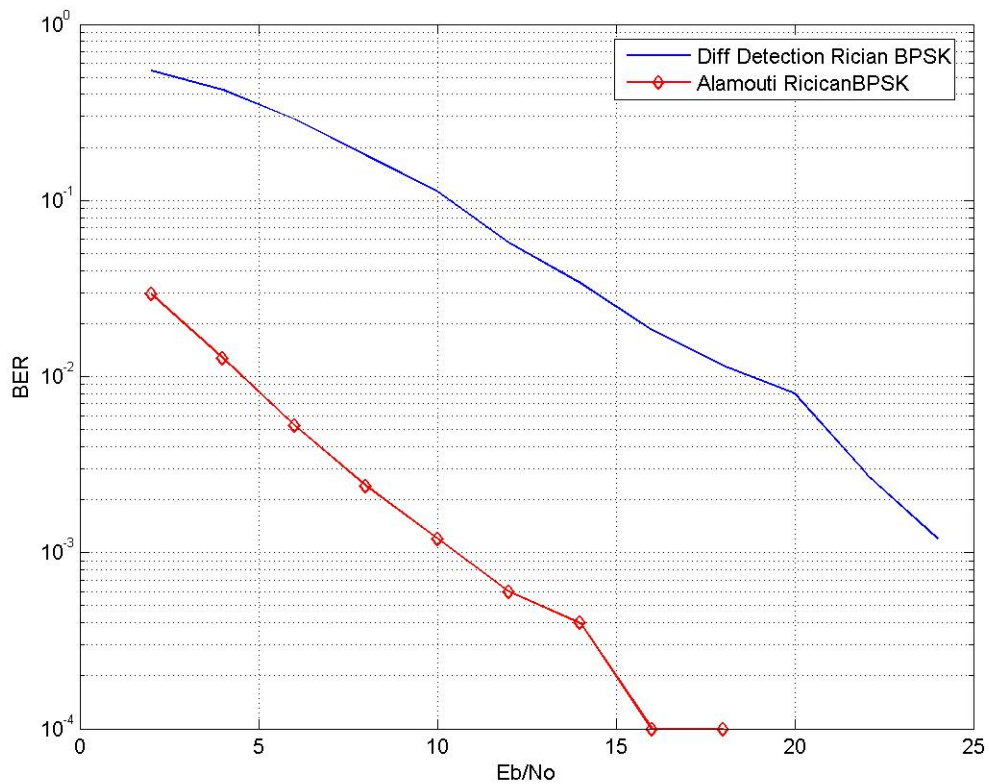


Fig. 4.19: Comparison of Differential Detection Scheme and Alamouti's Scheme using BPSK under Rician fading

Table-4.27: BER performance under Rician fading at SNR of 10db.

Transmission Scheme	Bit Error Rate
Alamouti's scheme	0.0032
Differential Detection	0.1413

Table-4.28: BER performance under Rician fading at SNR of 15db.

Transmission Scheme	Bit Error Rate
Alamouti's scheme	0.0004
Differential Detection	0.0501

Table-4.29: SNR under Rician fading for BER of 10^{-1} .

Transmission Scheme	SNR(dB)
Alamouti's scheme	2
Differential Detection	14

Table-4.30: SNR under Rician fading for BER of 10^{-2} .

Transmission Scheme	SNR(dB)
Alamouti's scheme	8
Differential Detection	23

In Fig. 4.19 and tables 4.27-4.30 the performance comparison has been done between Alamouti's scheme and Diff detection transmit diversity technique using BPSK modulation and under Rician fading. For a SNR of 15dB the Alamouti's scheme gives a BER of .0004 and for the same value of SNR the Diff detection scheme gives a BER of 0.0501.

4.3.10 Comparison of Differential Detection Scheme and Alamouti's Scheme using QPSK under Rician fading

Modulation Technique: QPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Rician Fading

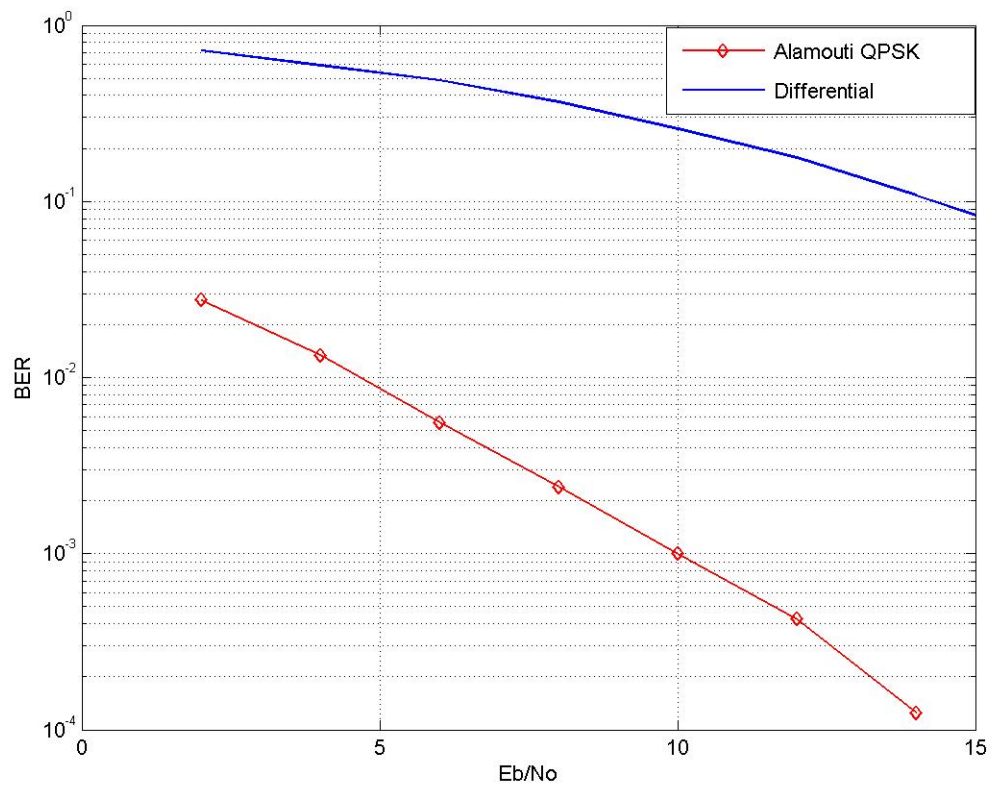


Fig. 4.20 Comparison of Differential Detection Scheme and Alamouti's Scheme using QPSK under Rician fading

Table-4.31: BER performance under Rician fading at SNR of 5db.

Transmission Scheme	Bit Error Rate
Alamouti's scheme	0.0032
Differential Detection	0.1413

Table-4.32: BER performance under Rician fading at SNR of 10db.

Transmission Scheme	Bit Error Rate
Alamouti's scheme	0.0004
Differential Detection	0.0501

In Fig. 4.20 and tables 4.31-4.32 the performance comparison has been done between Alamouti's scheme and Diff detection transmit diversity technique using QPSK modulation and under Rician fading. For a SNR of 5dB the Alamouti's scheme gives a BER of .0032 and for the same value of SNR the Diff detection scheme gives a BER of 0.1413.

4.3.11 Comparison of Differential Detection Scheme and Alamouti's Scheme using BPSK under Nakagami fading

Modulation Technique: BPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Nakagami Fading

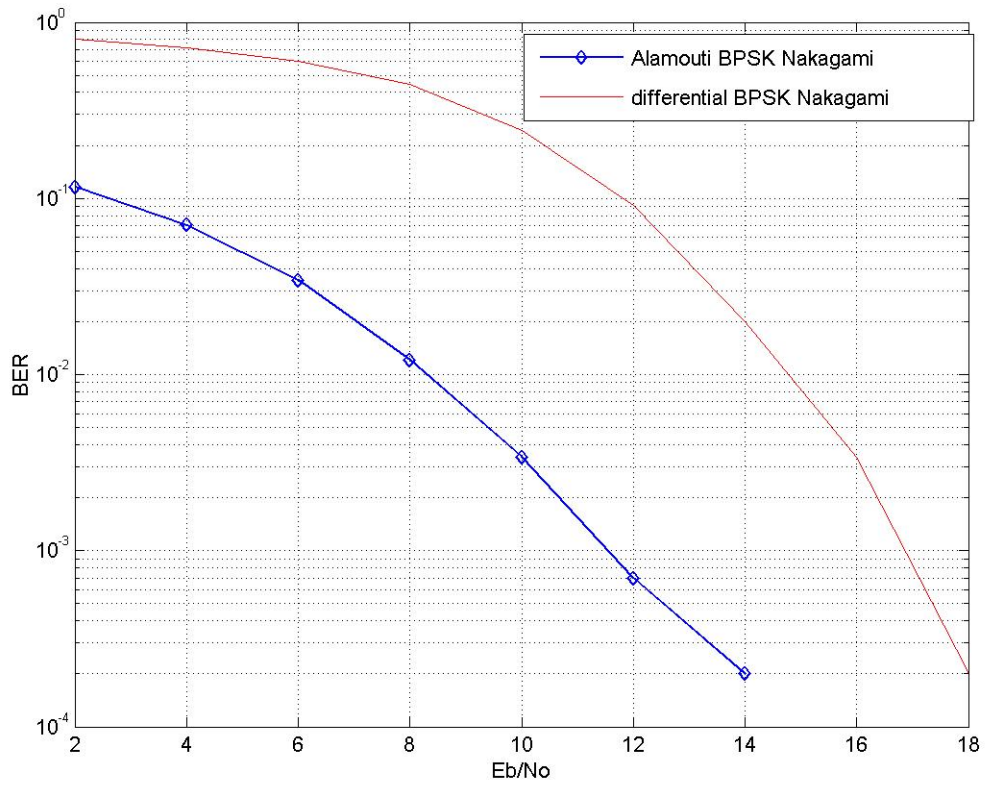


Fig. 4.21 Comparison of Differential Detection Scheme and Alamouti's Scheme using BPSK under Nakagami fading

Table-4.33: BER performance under Nakagami fading at SNR of 8db.

Transmission Scheme	Bit Error Rate
Alamouti's scheme	0.0110
Differential Detection	0.1413

Table-4.34: BER performance under Nakagami fading at SNR of 14db.

Transmission Scheme	Bit Error Rate
Alamouti's scheme	0.0004
Differential Detection	0.0501

Table-4.35: SNR under Nakagami fading for BER of 10^{-1} .

Transmission Scheme	SNR(dB)
Alamouti's scheme	3
Differential Detection	12

Table-4.36: SNR under Nakagami fading for BER of 10^{-2} .

Transmission Scheme	SNR(dB)
Alamouti's scheme	8
Differential Detection	15

In Fig. 4.21 and tables 4.33-4.36 the performance comparison has been done between Alamouti's scheme and Diff detection transmit diversity technique using BPSK modulation and under Nakagami fading. For a BER value of 0.01 the Alamouti's scheme requires a SNR value of 8dB and the Diff detection scheme requires a value of 15dB.

4.3.12 Comparison of Differential Detection Scheme and Alamouti's Scheme using QPSK under Nakagami fading

Modulation Technique: QPSK
Number of Symbols used: 10,000
Bits per symbol: 1
Nakagami Fading

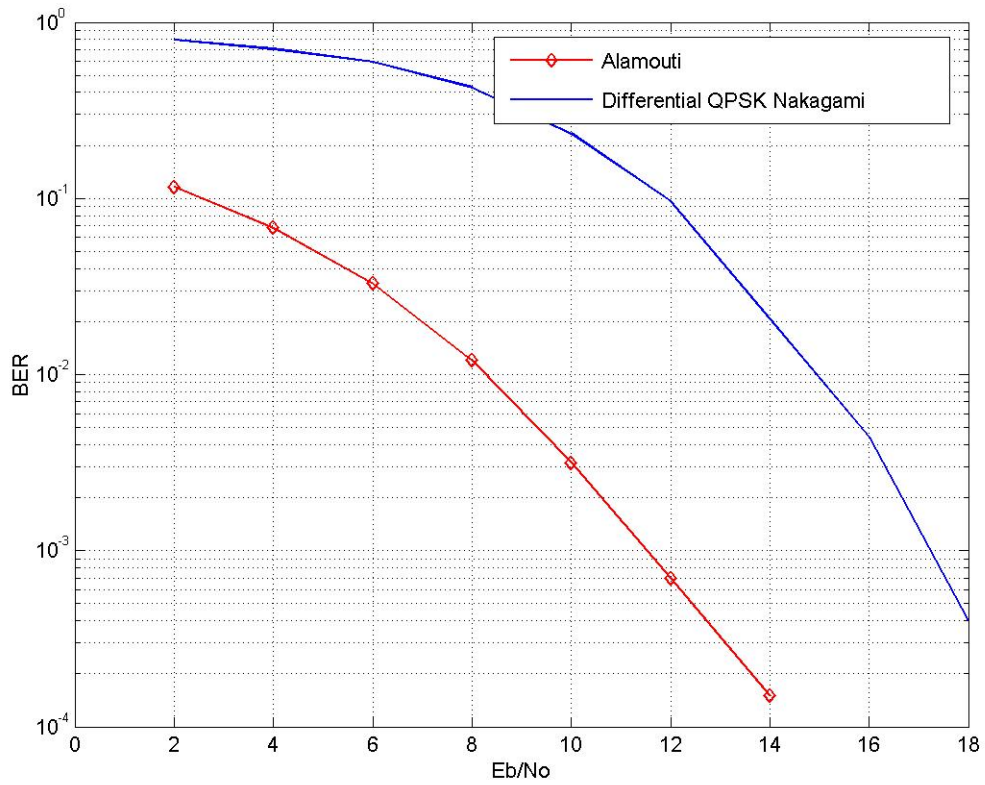


Fig. 4.22 Comparison of Differential Detection Scheme and Alamouti's Scheme using QPSK under Nakagami fading

Table-4.37: BER performance under Nakagami fading at SNR of 8db.

Transmission Scheme	Bit Error Rate
Alamouti's scheme	0.0120
Differential Detection	0.3102

Table-4.38: BER performance under Nakagami fading at SNR of 12db.

Transmission Scheme	Bit Error Rate
Alamouti's scheme	.00031
Differential Detection	.1

Table-4.39: SNR under Nakagami fading for BER of 10^{-1} .

Transmission Scheme	SNR(dB)
Alamouti's scheme	3
Differential Detection	12

Table-4.40: SNR under Nakagami fading for BER of 10^{-2} .

Transmission Scheme	SNR(dB)
Alamouti's scheme	8
Differential Detection	15

In Fig. 4.22 and tables 4.37-4.40 the performance comparison has been done between Alamouti's scheme and Diff detection transmit diversity technique using QPSK modulation and under Nakagami fading. For a BER value of 0.01 the Alamouti's scheme requires a SNR value of 8dB and the Diff detection scheme requires a value of 15dB.

Chapter 5

Conclusions and Future Scopes

5.1 Conclusions

In this thesis comparative study has been carried on the simulation performance of differential detection transmit diversity and Alamouti's scheme using different modulation schemes under different fading environments. Here in the simulation 2 transmit antennas and 1 receive antenna system is used. It is found that the BER performance of Alamouti's scheme is better as compared to differential Detection transmit diversity but the advantage with using differential detection is that there is no need to have the channel information at the receiver or transmitter side. Moreover the system complexity with using a differential scheme is less as compared to Alamouti's scheme. So differential detection method should be preferred where there is no need for a higher BER performance as it will reduce system complexity.

The simulation results show that the performance of a QPSK system is better as compared to BPSK and DPSK modulation techniques. Also it is found that Nakagami fading gives best approximation for the channel as it gives the best performance among all the fadings considered. The DPSK gives the least BER but it has the advantage that the system does not require any channel information at the transmitter for DPSK systems.

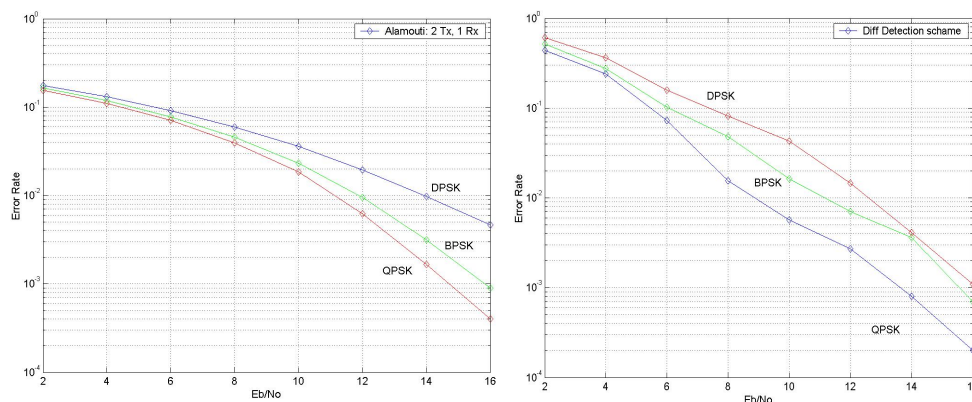


Fig. 5.1: BER Vs SNR for (a) Alamouti's scheme (b) Diff detection 2x1 system.

The performance of the Alamouti's system using QPSK modulation under Nakagami fading gives BER performance of 0.0120 at a SNR of 15dB and the Differential Detection Transmit Diversity scheme gives a BER performance of 0.302. The simulation results show that the BER performance of the Alamouti's scheme is better but the advantage with using the Differential Detection Transmit diversity scheme is that in this scheme there is no need for channel estimation in the second scheme. This reduces the system complexity as there is no need for extra hardware to estimate the channel.

5.2 Future Scopes

Future scope of this system is that further work can be done by increasing the number of transmit and receive antennas as the work in this thesis is on 2x1 system. In that way the spatial diversity would be exploited in a better way. Further work can be carried on higher order MPSK systems. The practical implementation of Differential Detection Transmit Diversity scheme can be taken up for further study. The result obtained through simulations can be verified with practical results obtained.

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List of Publications

- Submitted a paper on “**COMPARISON OF DIFFERENT TRANSMIT DIVERSITY SCHEMES**” in conference on **NATIONAL CONFERENCE ON WIRELESS NETWORKS AND EMBEDDED SYSTEMS AT CHITKARA INSTITUTE OF ENGG & TECH, CHANDIGARH** in June 2006.
- Presented a paper on “**WAP TECHNOLOGY AND ITS APPLICATIONS**” in conference on **INFORMATION & COMMUNICATION TECHNOLOGY** at **JMIT, RADAUR** in February 2006.
- Presented a paper on “**Network Security: Issues and Research Directions**” in conference on **BIOINFORMATICS** at **THAPAR INSTITUTE OF ENGG. & TECH., PATIALA** in February 2005.