

Performance Analysis of Hybrid Diversity Technique in TWDP Fading Channel

Dissertation submitted in partial fulfillment of the requirements for the
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Submitted by

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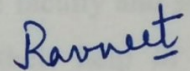
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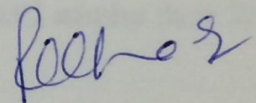


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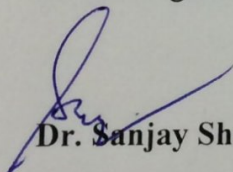


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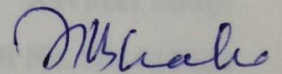
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ABSTRACT

In this technology driven era, tremendous growth in the mobile communication services has made possible for the people to exchange information (data, voice or image) with each other while they are on the move. These wireless systems have brought a revolution in the current market for their high data rates and performance enhanced features. One of the key issues affecting the performance of a wireless channel is the random variations in the signal strength which may be resulted due to some obstructions like buildings, trees, etc. or due to the movement of the mobile user. This leads to stochastic behavior of the radio channel.

This thesis presents the need to obtain a clearer perception of channel characteristics and to model a system for combating fading and improving the system performance. Current wireless scenario where deployment of directional antennas, wide band signals and narrow band receivers is an essential requirement, an environment is formed which is correctly represented by TWDP (Two Wave with Diffuse Power) Fading model other than Rayleigh or Rician Model. It comprises of two LOS components in the presence of other diffusely propagating waves.

A highly faded TWDP environment is discussed along with Hybrid diversity combining i.e. amalgamation of MRC and SC techniques. The effectiveness of this scheme is further evaluated by analyzing the system performance in terms of BER versus SNR. Analytical results are plotted in computer software MATLAB and various mathematical expressions are derived using MATHEMATICA tool to analyze the performance of system model for the same.

Both M i.e. receive antennas and R i.e. number of MRC receivers are varied in a Hybrid diversity system. Comparison is made between both Rayleigh and TWDP channels in terms of BER versus SNR. Modulation schemes such as BPSK and QPSK are applied on this Hybrid system model. The factual statement that TWDP fading forms a link which is worse than the link made by Rayleigh fading is demonstrated with the help of MATLAB simulations. Higher BER is observed considering TWDP channel and the need to consider this model in designing worst case communication scenario is shown in thesis.

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LIST OF ACRONYMS

TWDP	Two Wave Diffuse Power
WSN	Wireless Sensor Network
LOS	Line of Sight
SNR	Signal to Noise Ratio
MISO	Multiple Input Single Output
SIMO	Single Input Multiple Output
SC	Selection Combining
MRC	Maximal Ratio Combining
PDF	Probability Density Function
MATLAB	Matrix Laboratory
BER	Bit Error Rate
BPSK	Binary Phase Shift Keying
QPSK	Quadrature Phase Shift Keying
DQPSK	Differential Quadrature Phase Shift Keying
EGC	Equal Gain Combining
MGF	Moment Generating Function
CSI	Channel State Information
NCFSK	Non-Coherent Frequency Shift Keying
CDMA	Code Division Multiple Access
IR	Impulse Response
MMSE	Minimum mean square error
ZF	Zero forcing
CCI	Co-channel Interference
SIR	Signal to interference ratio
ASEP	Average Symbol Error Probability
SER	Symbol Error rate
DF	Decode and Forward Relaying
AWGN	Additive White Gaussian Noise
AF	Amplitude and Forward Relaying
SSC	Switch and Stay Combining

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CHAPTER 1

INTRODUCTION

Recent years have marked a tremendous growth in wireless communications. Rapid growth in these mobile communication services has enabled people to communicate with each other while they are on the move. Also a huge amount of information which may be in the form of data, voice or image etc can be exchanged. As we are heading forward, wireless technologies are leading the way in which we are communicating. These systems have revolutionized the current market because of their high data rates, high efficiency and improved performance. One of the key issues which adversely affects the performance of wireless channel is the random fluctuations or variations in the signal caused due to obstructions such as buildings, trees, mountains, etc. Another factor affecting the signal fading is the motion of the mobile user. In accordance to these factors, the radio channel exhibits highly stochastic behaviour. The objective of this investigation is to attain a clearer perception of wireless channel characteristics and to model the system which can combat fading and improve the system performance.

1.1 BACKGROUND

Fading and interference are the two major barriers in current wireless communication scenario which deeply deteriorates the performance of any communication system. Hence modeling and simulating a system model that can resist fading and improves system's effectiveness is need of an hour. Different propagation environments have different fading channel characteristics which are completely diverse and complex. Thus designing a fading channel model that properly characterizes a particular channel environment is quite essential.

The most commonly used models characterizing the propagation environments are Rayleigh and Rician models [1]. However, deployment of narrow band receivers, highly directional antennas and wide band signals produce a channel link which does not

correctly match the characteristics of conventional Rayleigh and Rician fading channels. Moreover, recent research depicts that some of the Wireless Sensor Network (WSN) applications in which sensor nodes are used within cavity environment suffer from a type of fading that is highly intense as compared to Rayleigh fading, known as TWDP (Two-Wave with Diffuse Power) fading [2] , [3]. Results discussed in [4] show that TWDP fading produces a worse link when two equal direct waves both having combined power 6 dB higher than the diffused component. Thus it should be considered as the worst case scenario in designing a wireless communication system. A wireless communication environment is depicted in Fig.1.1.

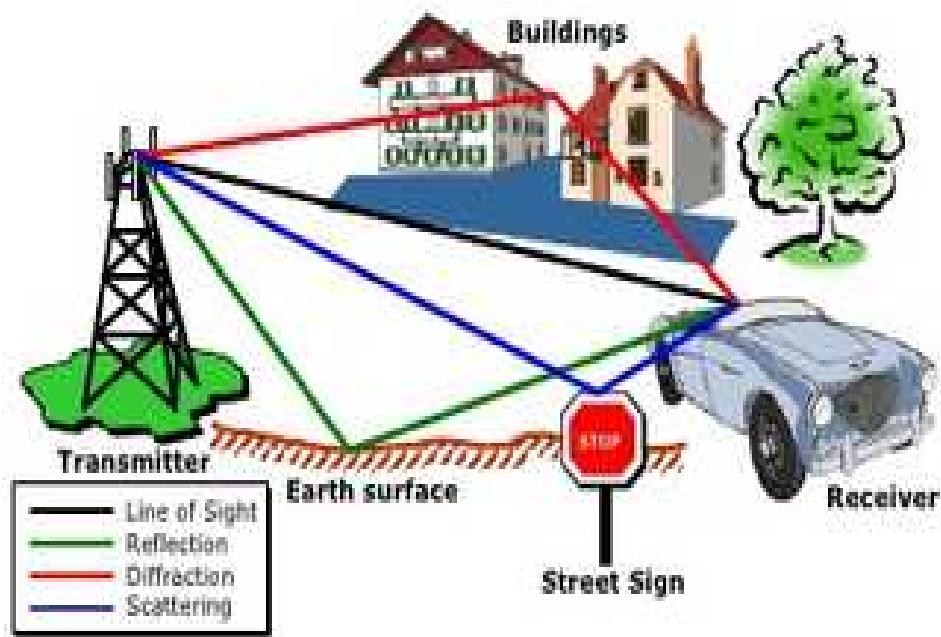


Figure 1.1 Wireless Communication Scenario [5]

1.2 OVERVIEW OF TWDP FADING

Fading is the rapid fluctuation or variation in the amplitude, angular phases or multiple delays of the radio signal over a short span of time or short distance, ignoring other large scale pathloss effects. It is caused by shadowing from obstacles affecting the radio wave propagation or by the interference of multiple copies of the transmitted signal that may add destructively or constructively at the receiver end [1].

In radio communication, signal traverses different paths and reaches the receiver end as a combination of multipath waves with different phases as well as amplitudes. The propagation waves can be decomposed into two main categories: **Specular** and **Diffuse Components**. Specular waves are characterized by one strong LOS (Line of Sight) component plus some reflected components whereas diffuse waves consist of faint waves having random magnitudes and phases commonly known as scattered components [2]. These waves carry lesser power than the total average power carried by the diffuse component. The resultant signal so obtained at the receiver is given by equation (1.1).

$$V_T = \sum_{k=1}^N V_k \exp(j\phi_k) + \sum_{k=1}^M V_k \exp(j\phi_k) \quad (1.1)$$

Eqn 1.1 depicts a received signal comprising of N strong components i.e. specular waves and M diffuse components i.e. diffuse waves. A **Specular Component** is a single term, $\{V_k \exp(j\phi_k)\}$, which represents one arriving multipath wave. The phase ϕ_k is a random term, whereas V_k representing the envelope is a constant. A **Non-Specular Component**, $\sum_{k=1}^M V_k \exp(j\phi_k)$, consisting of many individual waves carrying power which is very small relative to the total average power [2].

Fig.1.2. illustrates the specular and diffuse components in a wireless communication scenario.

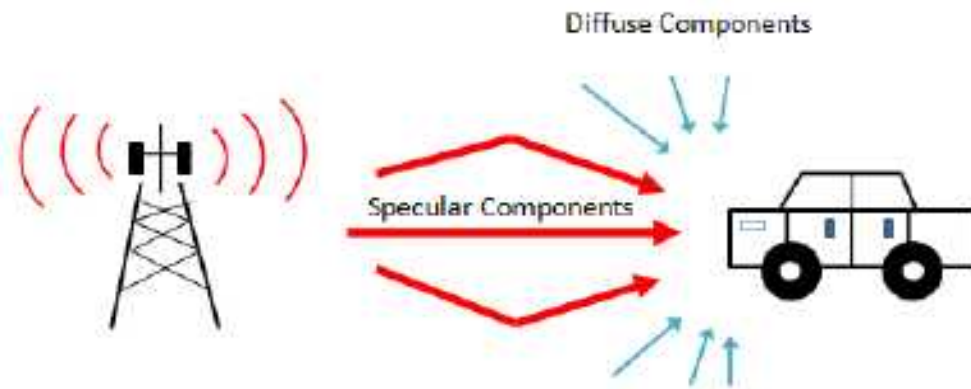


Figure 1.2 Illustration of specular components and diffuse components [5]

The major distinction between the different fading scenarios is the existence of specular components which is given in Table 1.1.

Table 1.1 Fading environment characterized by the specular components

Fading environment	Specular components
Rayleigh fading	Does not exist
Rician fading	1 Specular wave
TWDP fading	2 Specular waves

TWDP term implies Two Wave with Diffuse Power fading. This model comprises of two strong direct, line of sight (LOS) components and numerous faint diffuse components. This fading model has gained attention due to the current wireless scenarios being correctly represented by this model. It has two main parameters K and Δ . K represents the ratio of the specular power to total diffused power and Δ , here depicts the relative power of two specular components and serves as the comparison of two specular component's power level.

$$K = \frac{V_1^2 + V_2^2}{2\sigma^2} \quad \Delta = \frac{2V_1V_2}{V_1^2 + V_2^2} \quad (1.2)$$

Where V_1 and V_2 depicts voltage magnitudes of two specular wave components and $2\sigma^2$ corresponds to the average power of the diffused component [2]. Research work done in [6] proved that TWDP fading when conditioned on the phase difference between the two direct LOS components leads to Rician fading scenario. Hence this model can be used in studying TWDP fading model. The detailed description is given in chapter 3.

1.3 WAYS TO COMBAT FADING

In wireless systems, a well recognized technique called diversity is employed to remove the adverse effect of fading. In a diversity receiver several copies of the same transmitted signal is received through different independent fading paths. All such copies of transmitted signal do not enter the deep fades simultaneously and at the output these can be combined to increase the SNR value. Diversity techniques can improve the system performance without increasing the transmitted power. Higher is the de-correlation among the received signal replicas, higher is the achieved diversity gain. Space diversity

techniques including transmit and receive diversity in which transmitters and receiver are equipped with more than one antenna are shown in Fig 1.3 and 1.4 respectively. A diversity scheme is efficient if and only if signals are uncorrelated i.e. independent.

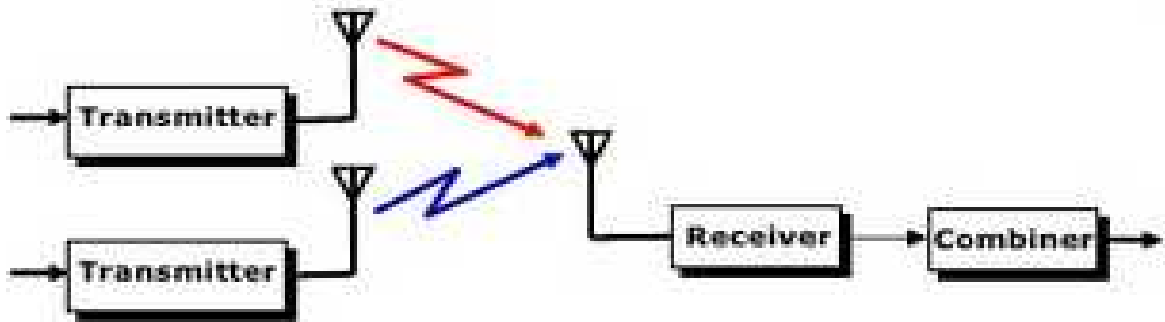


Figure 1.3 Transmit Diversity (MISO) [7]

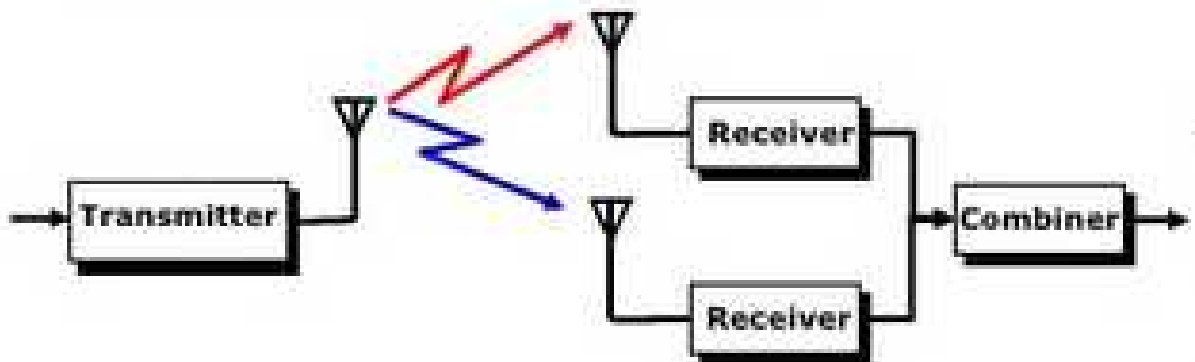


Figure 1.4 Receive Diversity (SIMO) [7]

These signals are further combined using various combining techniques in order to achieve high signal to noise ratio (SNR). Diversity Combining strategies have been of great significance in wireless communication systems so far the performance improvisation is concerned.

There are various combining techniques to combine the signals of diversity reception device into one signal of improved SNR.

-) Selection combining
-) Equal gain combining
-) Maximal ratio combining
-) Hybrid combining

Various techniques can be distinguished as shown in Fig.1.5 in which Selection combiner (SC) is the easiest one to implement and Maximal ratio combiner (MRC) performs optimally [8].

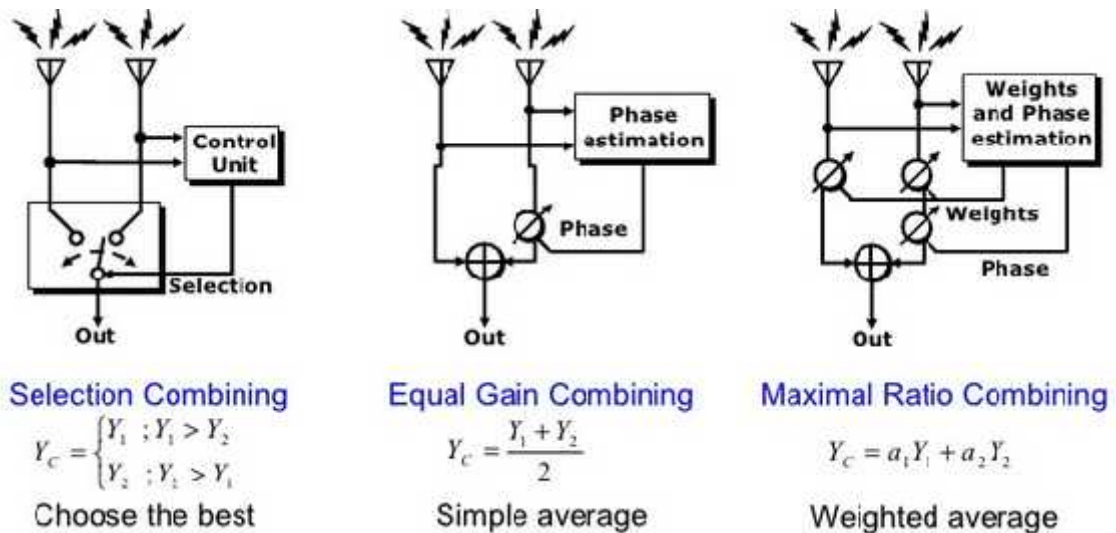


Figure 1.5 Diversity combining techniques [7]

1.4 NEED TO STUDY TWDP FADING SCENARIO

Recent research shown in [4] prove that two LOS components equal in magnitude and opposite in phase when reach the receiver, produces a channel link which is even worse than Rayleigh fading environment. Till now Rayleigh fading model has been considered to be the realistic one and considered to be perfect to design the worst case wireless communication system .But recent studies have proved that use of directional antennas,

wideband signals and typical narrowband receiver operations increases the likelihood of occurrence of TWDP fading [2] and has shown TWDP fading scenario to be more realistic one. In addition to this, TWDP fading occurs when ratio of power of specular component to that of power of diffused one is greater than unity i.e. value of K parameter is extremely high and the same condition occurs when we use highly directional antennas and wideband signals. Highly directional antennas can amplify multipath waves in single particular direction while attenuating the others. Even wide band signal reception perform the same task i.e. task of rejecting multipath components arriving at different times because of different time delays. Thus this reception increases the strength of specular component as comparison to the diffuse waves [3].

Deployment of Wireless Sensor Networks in current wireless systems especially in cavity environments such as airplane hangars, airframes and shipping containers results in an environment which is comparatively static and incapable to fight fades. Thus a new worst case model needs to be studied to correctly characterize this environment [2].

1.5 ISSUES IN TWDP FADING SCENARIO

There are many issues regarding TWDP fading model on which research work can be pursued. An environment which has not been modelled yet has been provided by this model .To deal with the current wireless scenario, it is important to model and simulate a communication system considering this new fading channel. It is the need of an hour to combat fading in order to improve system's effectiveness. Thus designing an efficient model for particular fading scenario is essential.

First and foremost issue is the complex mathematical representation of TWDP PDF which is non-convergent as well as does not support any closed form expression. Thus it is necessary to derive a simple expression for TWDP fading statistics. These simpler expressions will further make the implementation of new communication systems experiencing TWDP fading easy. Researchers and scholars will thus get encouraged to readily implement this fading model in order to evaluate the system's performance. Although some of the authors have provided some simpler expressions which gets converged as the order increases, but there is still a scope for some more improved expressions.

Diversity combining techniques are a better way of using multipath fading as a boon. These techniques have been studied individually as M MRC (Maximal Ratio Combining) or M SC (Selection Combining) over the TWDP fading channel but hybrid techniques involving both SC and MRC receivers have not been covered in any of the papers yet. Various performance measures e.g. capacity analysis over this realistic TWDP fading environment and involving the optimal combining techniques in TWDP fading still needs to be studied. Performance analysis of TWDP fading with soft decision coding such as Convolutional Codes and Viterbi is yet to be studied.

1.6 GOAL OF THESIS

D. Durgin in 2002 proposed a realistic fading model TWDP fading which resulted in worst performance for receivers as compared to Rayleigh fading scenario [2]. After that further studies of various wireless systems in that environment began. A lot of research work in TWDP fading using various conventional diversity combining techniques has been done. This work further offers new areas in which TWDP fading model can be applied which are as follows:-

-) A new hybrid diversity technique considering TWDP channel where R number of MRC receivers and each MRC with M receive antennas are selection combined (SC), has been modelled. This is the main work carried out in this thesis. TWDP consists of two LOS components along with diffusely propagating components. Analytical results are plotted in computer software MATLAB and various mathematical expressions are derived using MATHEMATICA tool to analyze the performance of system model for the same.
-) δ ↓th M i.e. receive antennas and R i.e. number of MRC receivers are varied in order to analyze the performance with reference to Bit Error Rate (BER) in a hybrid diversity communication system.
-) Comparison is made between both Rayleigh and TWDP channels in terms of BER versus SNR.
-) Modulation schemes such as BPSK and QPSK are applied on this Hybrid system model. The factual statement that TWDP fading forms a link which is worse than the link made by Rayleigh fading is demonstrated with the help of MATLAB

simulations. More BER is observed considering TWDP channel and the need to consider this model in designing worst case communication scenario is shown in thesis. |

The objectives defined in this thesis are as follows:-

1. Performance analysis of a hybrid diversity MRC/SC wireless communication system over TWDP fading channel considering both BPSK and QPSK modulation schemes.
2. Performance analysis of a hybrid diversity MRC/SC wireless communication system over Rayleigh fading channel considering both BPSK and QPSK modulation schemes.
3. Performance analysis of a hybrid diversity MRC/SC wireless communication system by varying M receive antennas and keeping number of MRC receivers R constant in Rayleigh and TWDP channel.
4. Performance analysis of a hybrid diversity MRC/SC wireless communication system by keeping M receive antennas constant and varying number of MRC receivers R in Rayleigh and TWDP channel.
5. Comparative analysis of BPSK and QPSK modulation schemes with Hybrid diversity techniques considering both the TWDP and Rayleigh channel.

1.7 OUTLINE OF THESIS

Chapter 1 gives introduction to the Wireless Communication Scenario considering fading, overview of TWDP fading scenario, ways of combating fading, need to study this fading environment, issues related to this fading scenario, goal of thesis and its outline.

Chapter 2 Literature survey gives an overview of Literature review which includes all the research work in the field of TWDP fading done till now in chronological order i.e. starting from the year 2002, when TWDP fading statistics were firstly proposed till now when various conventional diversity schemes are implemented on TWDP channel.

Chapter 3 Small scale fading models gives a detailed description of small scale fading models i.e. Rayleigh, Rician and TWDP model.

Chapter 4 Mathematical analysis of Hybrid MRC/SC receiver in TWDP channel demonstrates a mathematical system model for hybrid MRC/SC diversity system considering BPSK and QPSK modulation schemes in TWDP Channel and provides analytical results for the same.

Chapter 5 Comparative analysis of Hybrid MRC/SC Receiver in TWDP and Rayleigh Channel includes the BER versus SNR analysis of the hybrid system over TWDP channel considering BPSK and QPSK modulation schemes and comparison between the Rayleigh fading and TWDP fading in terms of BER performance analysis.

Chapter 6 Conclusion and Future Scope includes the conclusion of the work done with the future aspects of TWDP fading.

CHAPTER 2

LITERATURE SURVEY

Current mobile wireless communication systems are adversely influenced by propagation impairments caused due to terrain or buildings which cause multipath waves, producing variations in both frequency and amplitude of the received signal-known as fading [2]. Two-wave with diffuse power (TWDP) fading environment was firstly introduced by G.D.Durgin in 2002 as the most realistic fading channel model. Earlier Rayleigh channel was considered as the worst case propagation scenario. But intensive research over the last decades has shown that TWDP fading provides even the worse link than Rayleigh channel in existing environment where highly directional antennas and narrow band receivers are employed. A brief overview of the ways of combating fading by various diversity techniques has been discussed in this chapter in chronological manner.

In **1999 M.S Alouini et al.**, presented the analysis of two hybrid diversity receivers (SC/MRC) over the Nakagami-m fading channels. The authors numerically compared the results with the conventional selection combining (SC) and maximal ratio combining (MRC) schemes. Degradation in the bit error rate (BER) by the use of hybrid diversity techniques instead of conventional one has been shown to be independent of average SNR not considering the severity level of fading. Also as the severity level of fading decreases MRC has shown more improvement than the hybrid SC/MRC scheme [9].

In **2002 D. Durgin et al.**, first introduced TWDP fading scenario. In this paper, received signal strength was represented in the form of probability density function (PDF) curve. PDF's describing the small scale fading observed by narrow band receivers was presented. Novel PDF's describing the small scale fading of two LOS components along with diffuse components were developed. Here propagating waves were decomposed into three categories:

Specular, Non-Specular and Diffuse components. Specular component showing single multipath wave, non-specular component representing more than one multipath waves reaching the receiver and diffuse component coming under the category of non-specular component where each component carries power negligible in comparison to the total average power related to the diffuse component. The authors also summarized various fading envelopes: One-Wave PDF, Two-Wave PDF, Three-Wave PDF, Rayleigh, Rician and TWDP PDF. This paper also described the TWDP fading scenario in which two specular multipath components with other diffuse waves are there. Authors gave the PDF expression that closely approximates the TWDP PDF. A term Order is used in approximating TWDP PDF and thus by increasing this value approximate PDF approaching the exact PDF is shown [2].

In **2002 P.R. Sahu et al.**, presented Nakagami-m slow fading channel as the appropriate channel model for urban multipath environment. They derived closed form expression for BER of a DQPSK system for SC/MRC combined receiver considering the channel to be frequency non selective and for various values of M systems have been analyzed and comparison has been made for SC/MRC and SC/EGC systems [10].

In **2002 A. Annamalai et al.**, examined the weighting error's impact on the output characteristics of hybrid SC/MRC receiver and degraded performance of average symbol error rate. The authors derived expressions for CDF, PDF and MGF of the SC/MRC hybrid receiver in the Rayleigh faded scenario which can be further applied in analyzing simple packet radio combining scheme which enhances the packet radio network's throughput. Impact of weighting errors on average signal to noise ratio and outage probability was investigated. The analytical results showed the tradeoff between the combination losses and diversity gain with the increasing order of diversity [11].

In **2003 Michel T. Ivrlac et al.**, investigated the impact of fading correlation on the wireless communication setup having multiple inputs as well as multiple outputs. Channel knowledge on the transmitter side played an important role in dealing with the fading correlations. In addition to it, time diversity employed in a time selective channel

influenced the performance as well. A new term sample mean outage was introduced to analyze the effect of time selection on capacity and cutoff rate. If transmitter has no CSI, correlated fading proves to be a curse. If it has, it leads to improvement in capacity with respect to uncorrelated fading channel because of very large antenna gain provided in case of correlated. When transmitted power is high fading correlations decrease the performance as capacity gains are higher than antenna gain because of the higher space diversity as well as multi-stream transmission. The authors also showed that semi-correlated fading channels perform well in case of linear modulation techniques if and only if considerable amount of time diversity is available along with pure space diversity. A table 2.1 was presented by the authors depicting the type of correlations in fading as shown [12].

Table 2.1 Types of Fading Correlations [12].

Transmitter side	Receiver side	Type of fading
Uncorrelated	Uncorrelated	Uncorrelated
Correlated	Uncorrelated	Semi-correlated
Uncorrelated	Correlated	Semi-correlated type 2
Correlated	Correlated	Fully-correlated

In **2005 Soon H. Oh et al.**, analyzed the BER of uncoded BPSK system in a two wave with diffused power (TWDP) fading environment. Results simulated using MATLAB are both with and without maximal ratio combining (MRC) technique. Their studies further revealed that this type of fading produced a link which is even worse than that produced by Rayleigh fading when two direct waves which are equal in terms of amplitude strength and have a power greater than 6 dB. These results further stressed on using TWDP fading instead of Rayleigh fading as the worst case while designing the communication systems specifically where highly directional antennas and wideband signals are used. Their studies revealed that when MRC receiver is considered, as the SNR value reaches higher

and higher coherent combining contributes in improving TWDP's performance above the Rayleigh channel. Authors also compared the three types of fading namely Rayleigh, Rician and TWDP fading on the basis of different values of K and α . Their work concluded as value of K tends to infinity and α approaches one TWDP performance becomes poorer than that of Rayleigh channel [4].

In **2007 W. S. Lee et al.**, employed the moment generating function technique in order to obtain a closed form expression for minimum Bit error rate (BER) in case of dual switch-and-stay diversity technique for uncoherent FSK (frequency shift keying) systems. The authors have taken into account two-wave with diffuse power fading channel while calculating optimum switching threshold as well as minimum bit error rate performance on the basis of different values of K and α . Research has shown that results showed by taking into account TWDP fading scenario a considerable improvement in performance using dual switch and stay diversity non coherent FSK systems was shown [13].

In **2007 Soon H. Oh et al.**, presented a paper on the error rate analysis of binary phase shift keying pre-detection MRC systems considering Two wave with diffuse power fading channel. The authors showed that the bit error rate (BER) of MRC receiver system over a TWDP channel environment is equal to the weighted sum of individual bit error rates of the number of MRC receiver systems in case of Rician fading environment. A BER expression in closed form was given by the authors and the methodology used was verified through simulation. Using the bit error rate (BER) expressions in Rician fading the expressions for BER in TWDP were derived. The results shown provided a basis for the further study of mixed mode fading scenario where different channel links in a diversity system experiences different modes of fading [14].

In **2007 Wee Sit Lee** employed the moment generating (MGF) method in order to derive BER expressions in case of post-detection equal gain combining (EGC) un-coherent FSK and DPSK systems in a two wave with diffuse power (TWDP) faded environment. Various curves for plotted for EGC NCFSK and DPSK receiver systems for different values of TWDP parameters. The authors showed that the BER of n-channel post-

detection EGC receiver system in TWDP faded environment equals the weighted sum of bit error rates of $(2M)_n$ post-detection EGC receivers in case of Rician fading environment where M is the approximation order for TWDP PDF [15].

In **2007 J. Frolik** presented a frequency selective fading behavior of channel when the sensors are deployed within the structures as if in in-vehicle wireless applications. The statistics obtained were more severe than that predicted by Rayleigh channel model; hence a new term Hyper-Rayleigh was introduced as worst case in space applications. Author collected the empirical data for the wireless applications exhibited within various cavity structures. Authors even provided empirical fading data for different environments in 2.4GHz band and showed that Rayleigh like fading characterizes majority of the fading environments [3] when the criteria of classification was the statistics for 20 to 30 dB fades. Also Hyper-Rayleigh fading too constituted 10-25% cases and found to be more correctly representing the current wireless scenario as shown in Table 2.2. Hence a two ray, small scale fading model was proposed as the new worst case scenario for wireless sensor applications [16].

Table 2.2 Empirical Data Collected from Different Environments [16].

ENVIRONMENT	CASES	RICIAN CHANNEL	RAYLEIGH CHANNEL	HYPER-RAYLEIGH CHANNEL
Aircraft : MD90	41	22%	52%	22%
Aircraft : 747	44	25%	64%	11%
Bus	100	35%	54%	11%
Wing Aircraft	245	44.9%	30.6%	24.5%

In **2008 J. Frolik** further extended the work on hyper-Rayleigh fading channel by representing it with the most realistic TWDP model. In spite of the fact that Nakagami, log-normal shadowing distribution and Weibull distributions can well characterize the possibility of a severe fading scenario as well as predict infeasible constructive

interference. The author proposed that two wave with diffuse power (TWDP) with $\alpha = 1$ and K lying in the range 0 to ∞ is the one and only model to characterize Hyper-Rayleigh fading scenario. The work also discussed the propagation modeling schemes for wireless sensor networks specifically deployed within metallic cavities [3].

In **2008 Himal A. Suraweera et al.**, investigated the average BER performance in case of Quadrature Amplitude Modulated (QAM) signal in a two wave with diffuse power (TWDP) fading channel environment. They used the cumulative distribution function (CDF) of TWDP channel for deriving the closed form expressions of bit error rate (BER). These expressions further helped in quantifying the bit error rate (BER) performance analysis of Gray coded Quadrature Amplitude Modulation (QAM) signalling when they are considered in different TWDP fading environments also taking into account Rayleigh and Rician distribution. The authors presented the simulation results in order to showcase the effect of distinct TWDP fading environments on the error rate performance [17].

In **2008 Alyssa Magleby et al.**, presented that the wireless sensor networks (WSN) employed on the aircrafts are more prone to environment which is even worse than the Rayleigh distributed environment. The authors emphasized on giving attention on the type of signals used in wireless transmission in order to overcome severe multipath affects. Hence, the need of analyzing the TWDP fading channel in case of MIMO system was discussed in this work [18].

In **2009 Jiuling Wang et al.**, introduced the RAKE combining receiver that is popularly employed in code division multiple access (CDMA) systems. They obtained the estimates of the transmitting data by the use of linear single carrier equalizers and hence constructed all multipath signals from this starting solution as well as channel impulse response (IR). Various interference cancellation techniques were employed in order to receive the required multipath component and these components were combined together using maximal ratio combining (MRC), and selection combining (SC) so as to achieve temporal diversity gain. The authors showed that the results so produced by the new

combining receiver employing minimum mean square error (MMSE) equalizer and zero forcing (ZF) equalizer were an excellent remark on SNR gain in SUI-5 wireless link but alongside also increased the computational complexity [19].

In **2010 Lei Sun et al.**, analyzed the bit error rate (BER) performance precisely for a binary phase-shift keying system considering the fading channel to be two wave with diffuse power (TWDP) fading channel as well as co-channel interferenced (CCI) environment. The authors derived the precise BER expression utilizing a characteristic expression (CF) approach for perfect coherent detection and BER versus Signal to interference ratio (SIR) is derived by the Chernoff Bound method. The effect of different TWDP fading factors on BER is also presented and results are compared with and without considering the co-channel interference [20].

In **2010 Caijun Zhong et al.**, investigated the ergodic capacity of multiple input multiple output (MIMO) system considering the Nakagami-m fading channel with uniform and non uniform distributed phases. The authors obtained the upper bound capacity and ergodic capacity behavior in low SNR region. They derived the apt expressions for low signal to noise ratio (SNR) capacity metrics and showed the negligible effect of non uniform phase on the ergodic capacity of such channel. They proved that capacity scaling rules are similar for both Rayleigh channel and Nakagami-m channel link [21].

In **2011 Yao Lu et al.**, presented a letter analyzing the average symbol error probability (ASEP) of rectangular M-ary QAM for single and multi channel receiver operations considering both the non diversity environment as well as maximal ratio combining (MRC) receiver diversity system in TWDP faded environment. The derived SEP results were in close agreement with different TWDP fading parameters as well as any number of diversity branches. The authors also compared this QAM scheme among all the three channels TWDP, Rician and Rayleigh fading channel. They showed that by increasing the branches N system performance was improved due to an increment in diversity order and the gap between TWDP and Rayleigh faded scenario became more dominant as N increased in the high SNR region [22].

In **2011 Sasan Haghani** demonstrated the performance analysis of uncoherent M ary FSK with L channelled signal-plus-noise (S+N) selection combiner (SC) over a two-wave with diffused power fading scenario. He assumed the fading to be independent on all the distinct diversity branches but not identically distributed. He examined dual S+N selection combiner structures and derived BER expressions for each. The impact of fading parameters on the performance of SC when both signal plus noise is considered and without noise consideration is compared using Monte Carlo simulations. The results showed that the S+N SC performance is dependent more on channel conditions as compared to conventional SC [23].

In **2011 Beng Soon Tan et al.**, derived the symbol error rate (SER) expressions of SC over Two wave with diffuse power (TWDP) channel by the moment generating function (MGF) approach. TWDP channel comprises of both Rayleigh and Rician channels, both considered as its special cases. The authors used various modulation techniques as BPSK, M ary PSK and MQAM in a TWDP faded scenario considering each branch to be independent but non identically distributed and analyzed SER performance by employing MGF technique and showed that both the analytical and the simulated results were in close proximity to each other. They highlighted that SC receiver can perform worse over the TWDP link even worse than Rayleigh when the value of α is 1 and large value of K is taken [24].

In **2012 Yao Lu et al.**, proposed decode and forward (DF) relaying technique alongwith beam-forming for the multi relay networks in which N_s source antennas communicate with N_d destination antennas through N parallel single antenna relays. Only that relay is selected as transmission link which decodes a signal from the source antenna correctly and the one which has highest instantaneous SNR. Maximal ratio transmission (MRT) is employed by the source to transmit information and MRC is employed by the receiver section i.e. destination side. The authors derived the exact expression of outage probability for non identical but independently distributed TWDP fading channel and asymptotic outage probability characterizing two factors i.e. diversity order and array

gain at very high SNRs. They also derived optimal power allocation factor (OPA) to distribute the total transmission power among the source and relay optimally. They came to a conclusion that TWDP fading parameters did not affect the diversity order but only has impact on array gain. Also when number of source antennas equals destination antennas power allocation solution doesnot dependent on transmission power and also on the number of relays [25].

In **2012 Bhargabjyoti Saikia et al.**, investigated the multiple input multiple output's capacity over the TWDP channel by employing well known water filling algorithm. They presented that the utilization of antenna arrays at both the transmitting and receiving ends of a wireless link (MIMO) increases the capacity two folds than the conventional Single input single output (SISO) systems considering the arbitrary number of antennas. The effect of varying the values of channel parameters i.e. K and α on MIMO capacity is investigated. They concluded that MIMO can not only enhance the spectrum efficiency but also improves the signal quality with the same available bandwidth. Also if transmitter has CSIT i.e. information about the channel at the transmitting end then the system performance can further be improved by implementing water filling algorithm [26].

In **2012 Xiaoxiang Wang et al.**, presented the cooperative networks and considered the Two Wave Diffuse Power fading channels which were assumed to be independent and non-identical. The authors employed opportunistic amplify and forward (AF) Relaying technique and hence derived closed form expressions of symbol error rate and the outage probability in the region of high signal to noise (SNR) ratio [27].

In **2012 Rupaban Subadar et al.**, presented the spectral efficiency for both optimal and sub optimal techniques of adaptive transmission employing un-coded MQAM modulation and considering the TWDP fading channel. The authors made a comparison of spectral efficiencies of TWDP channel in various schemes such as Optimal Power and Rate adaptation (OPRA), CIFR (Channel inversion with fixed rate) and TIFR (Truncated channel inversion with fixed rate) and OPRA is proved to be the best which provided

highest Spectral efficiency. They also derived the PDF of SNR of signal in TWDP channel [28].

In **2013 Dharmendra Dixit et al.**, discussed the performance of QAM modulation techniques i.e. cross QAM (XQAM) and rectangular QAM (RQAM) over TWDP fading environment with the help of exact closed-form expressions of ASER employing moment generating function (MGF) approach. The ASER expressions so obtained were special functions in Appell's ($\Phi_1(\cdot)$) and Lauricella's (Φ_3) form and can be further evaluated easily using integral representation. They also derived the expression for the Nth order moment of received SNR and verified using Monte Carlo simulation [29].

In **2013 Rupaban Subadar et al.**, presented the performance analysis of the simplest form of diversity i.e. selection combiner (SC) over the TWDP environment taking into account non-identical and arbitrary fading parameters. They derived the cumulative distribution function (CDF) expression of SNR for the same channel and then obtained the PDF for the same. They used the PDF expression to derive outage probability expression and BER analysis for both coherent and non coherent modulation techniques and by varying the number of branches and parameters K and α . The method employed by the authors was Monte Carlo simulation [30].

In **2013 Seyed Ali Sabarali** derived two new expressions for TWDP fading CDF and PDF which rapidly converged over the fading parameter's range. They also proposed an algorithm for evaluating the series in which the one and only source of error is the truncation error. The performance analysis was based on integrating TWDP PDF against complementary error function and hence evaluated BER for a BPSK system over this TWDP fading scenario [31].

In **2013 A. Dinamani et al.**, proposed a new diversity technique which is a hybrid of both selection combining (SC) and maximal ratio combining (MRC). They considered the fading environment to be Rayleigh faded. The system model comprised of L number of MRC receivers and M antennas at each receiver. The output of each MRC is sent to SC

and a single output is achieved at the end. They derived the PDF of SNR expression for this hybrid technique and hence the outage probability for the same [8].

In **2014 Milind Rao et al.**, provided a new look to the TWDP fading while observing that when two LOS components differ in phase results in Rician. They showed that any metric which is linearly varying with the TWDP's envelope statistics, can be easily evaluated as its finite integral for the Rice model and hence evaluated amount of fading , level crossing rate (LCR), PDF, MGF and CDF expressions. Employing the moment generating function (MGF) technique, BER was calculated for different modulation schemes [6].

In **2014 A. Dinamani Singh et al.**, derived the PDF expression of output signal to noise ratio of a selection combiner over the TWDP channel and obtained the capacity analysis for different adaptive transmission techniques from that PDF expression. The expressions obtained were in the form of infinite series and contained some special functions like Pochhammer symbol, incomplete gamma function etc. The impact of varying the values of diversity order on the capacity is also presented [32].

In **2014 Rupaban Subadar et al.**, derived a new expression of characteristic function (CF) of output SNR for TWDP channel condition and obtained the PDF expression of SNR for MRC receiver. They also deduced the expressions for outage probability as well as average symbol error rate (ASER) considering both the coherent and non coherent modulation techniques. They analyzed the impact of varying the number of MRC branches on the system performance and verified using the Monte Carlo simulation [33].

In **2015 A. Dinamani Singh et al.**, presented a paper in which characteristic function approach is used to examine average symbol error rate (ASER) and outage probability of single link system over the realistic TWDP channel. They studied the effect of different modulation schemes on the system and evaluated the results numerically using MATHEMATICA tool. The results were verified using Monte Carlo simulation [34].

In **2015 A. Dinamani Singh et al.**, derived the PDF of an output SNR for a dual MRC system in a TWDP environment. They evaluated various measures like outage and average symbol error rate for various non coherent and coherent modulation techniques and compared them with the published results [35].

In **2015 Hima Pradeep V. et al.**, presented a new hybrid scheme of diversity MRC/EGC over the Rayleigh faded environment. The input signal is passed through M maximal ratio combiner branches and L number of branches was there to carry out equal gain combining. Performance analysis was done by evaluating outage probability and ABER and PDF of output SNR was found by convolving L fold times the single PDF using MATLAB software [36].

In **2015 A. Dinamani Singh et al.**, compared the different diversity receivers over the TWDP fading channel and concluded that while evaluating outage probability MRC is the best diversity technique followed by EGC and then SC. But its complexity level constraints practical implementation .So if simplicity is the only requirement of any wireless system SC can prove to be the best. EGC can be used if both performance and simple structure is the prime requirement of any wireless communication system [37].

In **2016 Hima Pradeep V. et al.**, presented a hybrid MRC/EGC model over the AWGN channel and evaluated its performance in terms of average bit error rate (ASER) and outage probability. They concluded that when dual MRC/EGC was taken, by increasing the number of EGC branches L the outage probability improved and when MRC/dual EGC was considered, outage probability improved with increased number of MRC branches M due to the decrease in probability of path being deeply faded. Also SNR requirement decreased with increased diversity branches [38].

Thus from the presented literature review it can be concluded that Hybrid diversity techniques have not been implemented yet with the highly faded TWDP channel. So next chapters include the analysis of system performance using these mixed diversity schemes over the TWDP channel.

CHAPTER 3

SMALL SCALE FADING MODELS

One of the most important issues in wireless communication is the design and analysis of radio propagation models. Thus a realistic communication system can be designed if the characteristics of fading channel are exactly known. Recent research shows that the propagation medium in some of the wireless sensor network applications deployed within some cavity environment shows worse behavior than the Rayleigh fading channel, which is referred to as TWDP fading channel [3]. Thus, modeling of this fading channel is the key issue. Chapter 3 briefly describes the smallscale fading. Modeling of TWDP fading channel is presented further and comparison is made between both conventional small scale fading model and TWDP fading model.

3.1 SMALL SCALE FADING

There are mainly two types of fading scenarios in wireless communication: large scale and small scale fading. Large scale fading is caused by large propagation distance and large sized obstacles e.g. mountains, buildings etc. where signal power gets attenuated with the increase in distance. Other conditions such as the change of climate, also leads to large scale fading. Large scale fading effect is not considered when the communicating area is relatively small. Thus, we mainly focus on studying small scale fading propagation model. Fig.3.1 shows illustration of large scale fading and small scale fading. Wireless communication channel is the most complex channel. Apart from additive white Gaussian noise (AWGN), wireless signal also gets attenuated by many other types of fading and interference. Wireless signal propagates through various paths in the unpredictable and random environment. Line of sight (LOS) waves, reflected waves and scattering waves cause severe distortion of the original information signal.

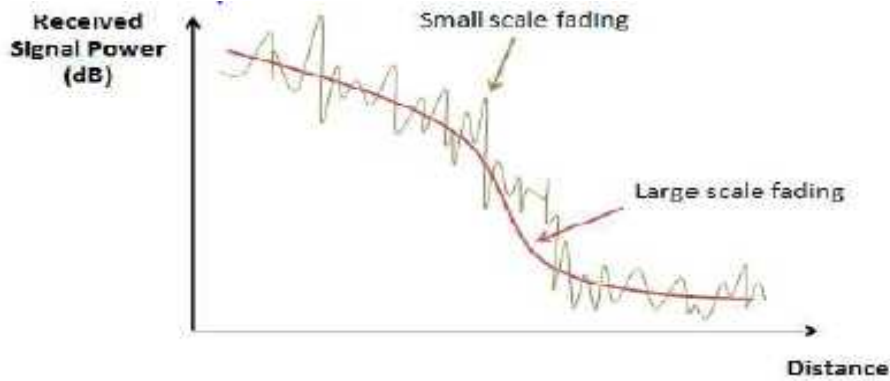


Figure 3.1 Figure demonstrating large scale fading and small scale fading [5]

3.2 TYPICAL SMALL SCALE FADING MODELS

Modeling of radio propagation is crucial for wireless communication systems as it enables the user to adopt some appropriate mean so as to achieve reliable communication and to reduce the signal attenuation and distortion. In this section, two conventional small-scale fading channel models, Rayleigh and Rician are presented before discussing the TWDP model in detail.

3.2.1 Rayleigh Fading Model

Rayleigh fading environment is characterized by numerous multipath components, each having relatively similar signal amplitude along with uniformly distributed phase, i.e. there exists no strong direct line of sight (LOS) path between the transmitting and receiving end. Thus, this scenario is often considered as the worst-case fading scenario for mobile communications within urban environments, ship-to-ship radio links, etc. Besides this Rayleigh distribution is also used by mobile radio to depict the statistical time varying behaviour of the received signal [2]. Fig. 3.2 shows the Rayleigh fading scenario.

It consists of numerous multipath components each with random phase and magnitude. Its PDF is represented by

$$f_R(r) = \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2}\right), r \geq 0 \quad (3.1)$$

Where, the fading amplitude is represented by r , σ represents the RMS value of voltage signal received and σ^2 represents the average power of received signal before signal detection [2].

This fading model is represented using two random variables as follows

$$V_r = \mathbf{X} + j\mathbf{Y} \quad (3.2)$$

Where, \mathbf{X} and \mathbf{Y} represents two random variables having zero mean and σ^2 variance and hence, r_i , the fading amplitude at i -th time instant is given by the following expression:-

$$r_i = \sqrt{x_i^2 + y_i^2} \quad (3.3)$$

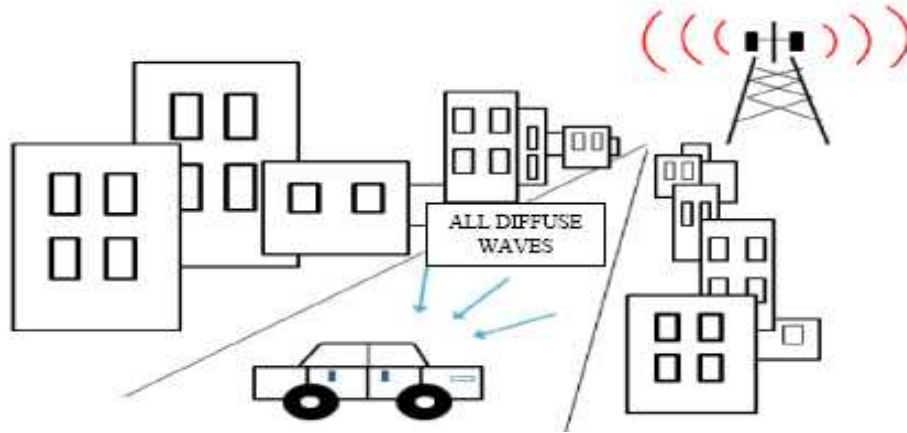


Figure 3.2 Illustration of Rayleigh fading scenario [5]

3.2.2 Rician Fading Model

Rician fading model is the model mainly adopted in pico-cellular indoor, micro-cellular urban and suburban areas, factory environments, etc. [2]. It exists when there is a dominant LOS component and numerous weak diffuse multipath components in propagation environment. Fig. 3.3 illustrates Rician fading scenario.

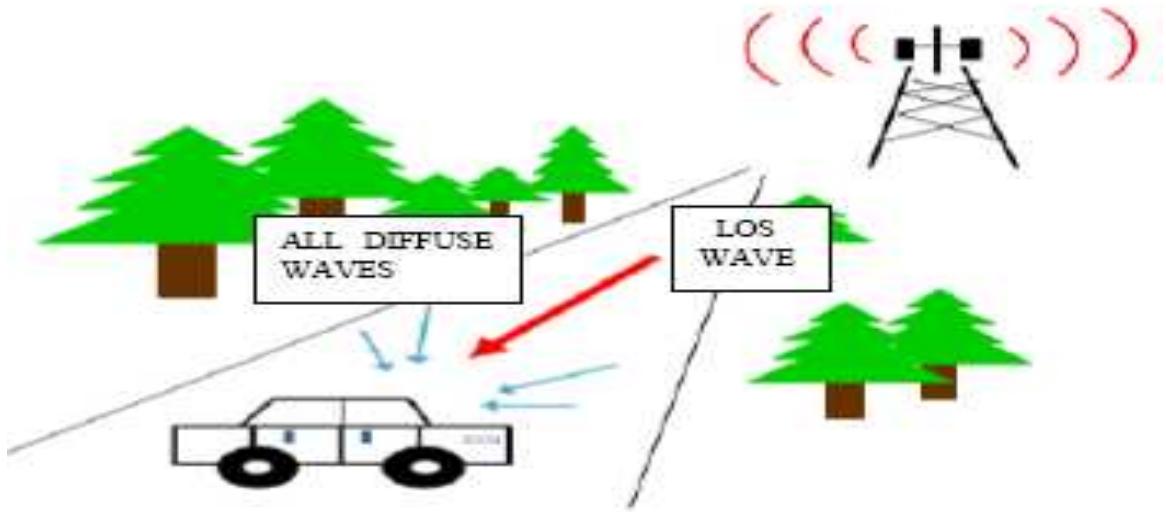


Figure 3.3 Illustration of Rician fading scenario [5]

The fading amplitude r_i at i -th time instant is expressed as

$$r_i = \sqrt{(x_i + V_a)^2 + y_i^2} \quad (3.4)$$

Where V_a represents the maximum magnitude of specular component, x_i and y_i are random variables having zero mean value and σ^2 variance. An important factor used in Rician distribution is K_r factor which implies the ratio of power of specular Component to that of Diffuse Component which is shown as follows:

$$K_r = \frac{s_i}{a} \frac{t \ p_i}{p_i} = \frac{V_a^2}{2\sigma^2} \quad (3.5)$$

K_r factor represents the extent of LOS component in Rician distribution. If the value of this factor tends to infinity (∞), the LOS signal is so strong that that the diffuse waves can be considered as white Gaussian noise (AWGN) i.e. fading behavior will be similar to Gaussian distribution. If value of this factor is 0, this depicts there is no LOS component in the channel of propagation and the behavior will be similar to that of Rayleigh fading. Thus Rician PDF is given by

$$f_R(r) = \frac{r}{\sigma^2} \exp\left(\frac{-r^2 - V_u^2}{2\sigma^2}\right) I_0\left(\frac{rV_u}{\sigma^2}\right), V_u \geq 0, r \geq 0 \quad (3.6)$$

Here $I_0(\cdot)$ refers to the modified Bessel function of the first kind and zero order [2].

Rician fading contains only single LOS component i.e. value of K exists but it is small valued. Hence, value becomes zero as the second LOS component is absent.

3.2.3 TWDP Fading Model

Recently Wireless sensor networks (WSN) have drawn huge interest in the field of monitoring industrial, military and natural environments. Selecting a proper channel model for a particular wireless application has become a critical issue. Mostly these sensor nodes are statically equipped, so small scale fading is considered in some WSN applications. Proper knowledge of fading environment is a pre requisite for an effective wireless communication. Thus, it is important to analyze and design a fading environment which is the realistic one.

Earlier Rayleigh fading model was considered to be perfect to represent small scale fading occurring in WSN environment. But, for some particular applications where deployment of these nodes is within cavity environment, as in airframe and shipping containers, transmitted signal experiences severe multipath fading which is even worse than that predicted by Rayleigh fading model [2] [3]. Thus, a more promising fading model is essential to employ to represent such a scenario, which is termed as two wave with diffuse power (TWDP) fading. Recent researches show that in-vehicle data collection in airframes, buses, etc. depict the propagation behavior to be quite similar as that of TWDP characteristic behavior. Thus this TWDP model is more applicable in WSN applications. TWDP fading model is represented in Fig. 3.4.

TWDP fading model comprises of two strong direct LOS components and numerous diffuse energy components.

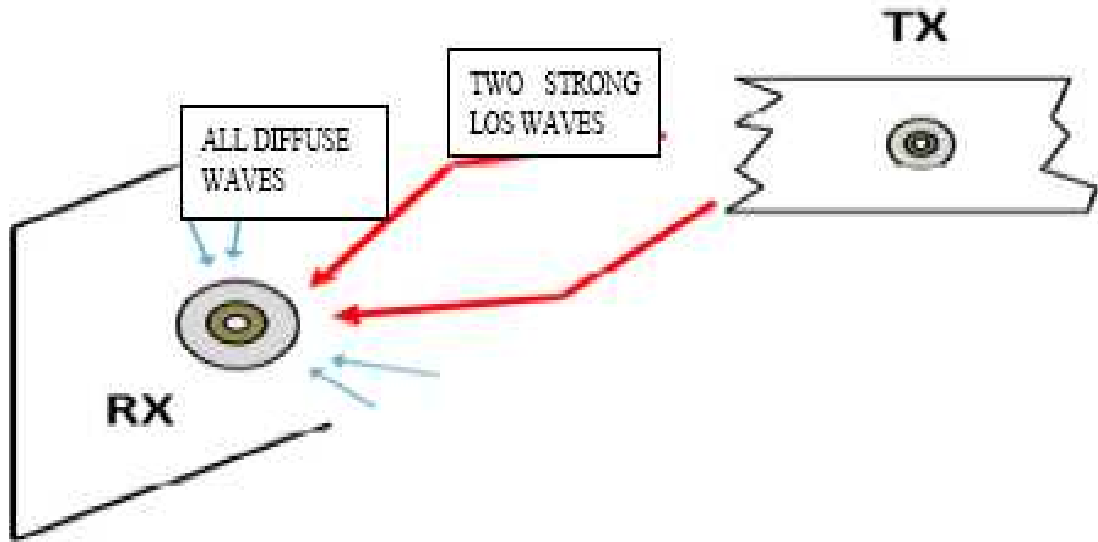


Figure 3.4 Illustration of TWDP fading scenario [5]

It involves two parameters which are K and Δ .

$$K = \frac{V_1^2 + V_2^2}{2\sigma^2} \quad \Delta = \frac{2V_1V_2}{V_1^2 + V_2^2}$$

Here V_1 and V_2 represents the voltage magnitudes of the two specular waves and $2\sigma^2$ denotes the average power of the diffused wave components. K denotes the ratio of the **Specular power to Diffused power**, whereas Δ represents the relative strength of the **Specular Components** [2].

Table 3.1 Classification of Fading on the Basis of Specular strength to that of Diffuse Component [2].

Case	1 st specular Voltage V_1	2 nd specular Voltage V_2	Diffuse RMS Voltage $\sqrt{2\sigma^2}$	Value of K	Value of Δ	Type of fading
1	2 μ V	2 μ V	3 μ V	0.89	1	Rayleigh fading
2	4 μ V	2 μ V	3 μ V	2.22	0.8	Rician fading
3	4 μ V	4 μ V	3 μ V	3.56	1	TWDP fading

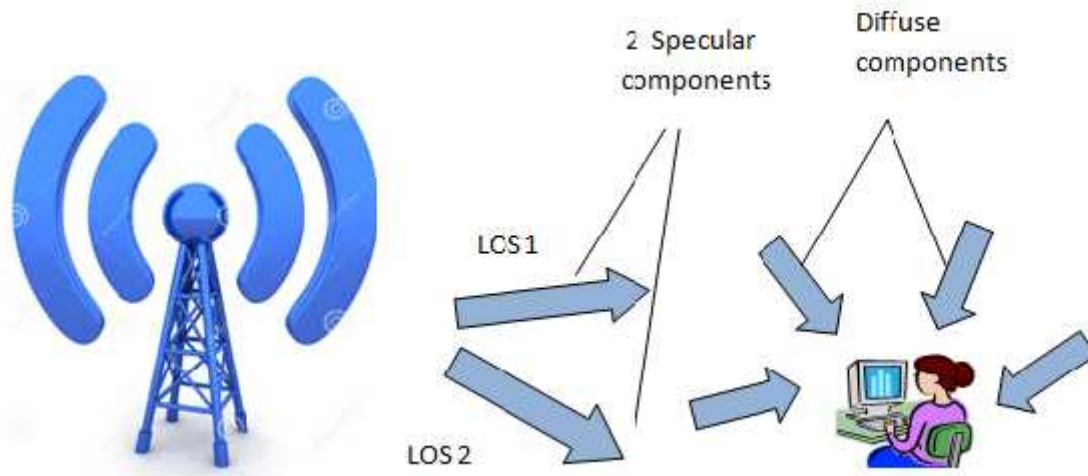


Figure 3.5 Illustration of two Specular Components along with many Diffuse Components in TWDP scenario.

Table 3.2 Range of Values of K and α to distinguish the Fading type [2].

Fading type	Value of K	Value of α
Rayleigh fading	$-\infty$ to 0 dB	Not applicable as it has 0 specular component
Rician fading	1 to 3 dB	$\alpha=0$ as it has 1 specular component
TWDP fading	3 to ∞ dB	lies in between 0 and 1

Mathematically, authors in [2] have expressed TWDP fading PDF as follows:

$$f_R(r) = \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2} - K\right) \sum_{i=1}^M \alpha_i D\left(\frac{r}{\sigma}; K; \Delta \alpha_i \frac{n(i-1)}{2M-1}\right) \quad (3.7)$$

Where

$$D(x; K; \alpha) = \frac{1}{2} \exp(\alpha) I_0(x\sqrt{2K(1-\alpha)}) + \frac{1}{2} \exp(-\alpha) I_0(x\sqrt{2K(1+\alpha)}) \quad (3.8)$$

Here, M denotes the order of the approximate TWDP PDF and by increasing the value of this M, approximate PDF approaches the accurate one. The first five exact $\{\alpha_i\}$

coefficient values are given in table 3.3 [2]. The value of product of K and Δ parameters determines the order M that should follow the condition $M \geq \frac{1}{2}(K\Delta)$ [2].

Table 3.3 Exact Coefficients for First Five Orders to Approximate TWDP Fading PDF. [2].

Order	a1				
1	1	a2			
2	$\frac{1}{4}$	$\frac{3}{4}$	a3		
3	$\frac{19}{144}$	$\frac{25}{48}$	$\frac{25}{72}$	a4	
4	$\frac{751}{8640}$	$\frac{3577}{8640}$	$\frac{49}{320}$	$\frac{2989}{860}$	a5

TWDP fading model comprises of two direct LOS i.e. specular components and many diffuse components as expressed in equation 3.9.

$$\mathbf{V}_r = V_1 \exp(j\phi_1) + V_2 \exp(j\phi_2) + \mathbf{X} + j\mathbf{Y} \quad (3.9)$$

Where, \mathbf{V}_r denotes the received signal amplitude, components 1 and 2 are specular components having phases $\phi_1, \phi_2 \sim U(0, 2\pi)$ and V_1 and V_2 are constants. Diffuse components are given by two random variables \mathbf{X} and \mathbf{Y} , which are Gaussian distributed having zero mean and σ^2 variance [2]. Value of K in TWDP fading almost tends to infinity (∞) which implies it is very high as compared to Rayleigh and Rician fading parameter. Δ almost approaches 1, because of two LOS components having almost equal relative strength in TWDP fading.

3.3 CHAPTER SUMMARY

It can be concluded that different propagation environments exhibit unique fading channel characteristics that are complex and diverse in their own way. So modeling a system model which can resist fading and improves system's performance is a prerequisite. Thus the following chapter 4 deals with a fading channel model that properly characterizes a realistic TWDP channel environment along with diversity combining strategy to achieve higher SNR.

MATHEMATICAL ANALYSIS OF HYBRID MRC/SC RECEIVER IN TWDP CHANNEL

The multiple propagation paths existing between the transmitter and the receiver end results in the copies of signals undergoing different distortions, delays, phase shifts, etc. One way of developing information from various signals traversing different paths is the use of Diversity techniques. It is a simple concept which results in the improvement of both the instantaneous and average SNRs at the receiver as it involves the selection or combination of a signal from various paths. If in one path severe fading is there, another independent path may have a strong signal. Thus combining the signals can result in a signal having higher SNR. Recent research shows that Hybrid diversity techniques involving amalgamation of two or more combination techniques have been of great interest in order to achieve higher diversity gain and improve the performance. This chapter deals with the analysis of Hybrid MRC/SC receiver system in the most realistic fading channel scenario.

4.1 MATHEMATICAL MODEL

Recent years show an abrupt advancement in the research pertaining to the field of diversity combining in wireless communications. These combining strategies are a means to employ multipath fading as a boon as they involve sending the numerous copies of same information signal through different links, hence combining all the copies at the receiver and thereby increasing the overall SNR at the receiver end. These can be categorized into two main types, pure combining and hybrid combining. Pure combining comprises of single combining technique i.e. Selection Combining (SC), Maximal Ratio Combining (MRC), Equal Gain Combining (EGC) and Switch and Stay Combining (SSC) [8]. Hybrid combining consists of combination of two or more pure combining strategies. In case of MRC, the individual signals passing through each link must be aligned in time and co-phased. These are then weighted with their individual fading

amplitudes and are then added. It is a complex natured combining scheme because the pre knowledge related to all the channel fading parameters is necessary in this. Moreover, MRC is known to be the most efficient technique so far the performance evaluation is concerned. SC is just a simple way of selecting that signal from the branch which has the highest signal to noise ratio (SNR) value. The merit of using SC is that there is no need of coherently summing the individual branch signals. There is a need of considering only the single branch and no additional knowledge regarding the phases of signal related to individual branch is needed. Recently employing Hybrid diversity schemes has gained importance because of their lesser complexity, lesser consumed power, fewer electronics involved and higher diversity gain offered. They are employed so as to fulfill the ever increasing needs of emerging wideband communication systems.

In this thesis a hybrid diversity combining technique is discussed and its performance expressions are presented over the TWDP channel.

In this hybrid system, information signal is received by MRC receivers which are R in number and each receiver has M number of diversity branches. The received information signals which are M in number are weighted and combined to achieve maximum SNR. From R such systems, the one which has the highest SNR is chosen/selected using SC having R diversity branches. The system model is shown in Fig.4.1.

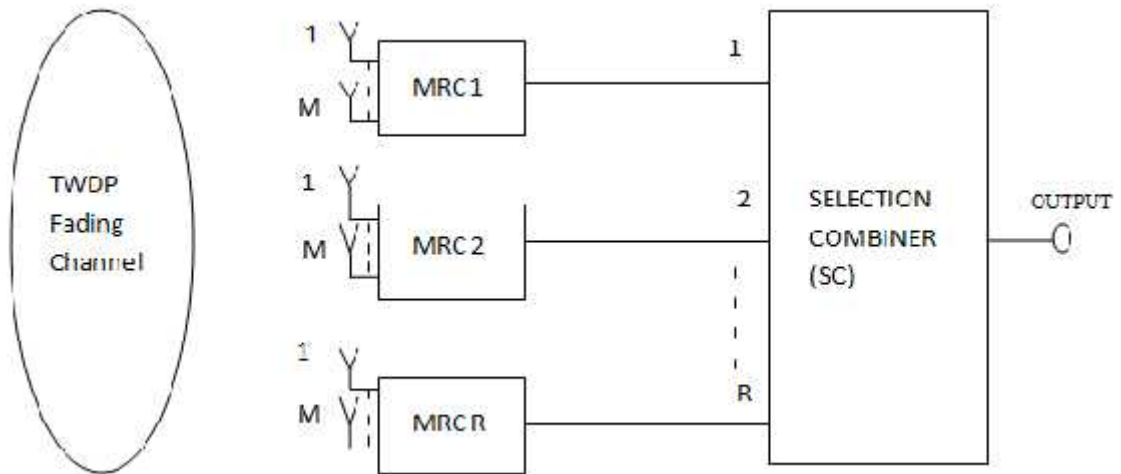


Figure 4.1 Illustration of Hybrid MRC/SC system model in TWDP fading scenario.

Now considering, MRC system having M diversity branches in a TWDP fading channel the output SNR is given by the expression as follows

$$f_{x_{MRC}}(x_{MRC}) = \frac{\eta}{2} \sum_{i_1=1}^M \dots \sum_{i_{L-1}=1}^M \sum_{i_L=1}^M \frac{\{a_{i_j}\}}{\Gamma(M)} \left| e^{-\sum_{i,j} P_{(i,j)} x} \right| e^{-\sum_{i,j} P_{(i,j)} x} x^{M-1} e^{-\sum_{i,j} P_{(i,j)} x} \frac{(x \sum_{i,j} P_{(i,j)})^s}{s! \Gamma(M)_s} \quad (4.1)$$

where, $\eta = \frac{K+1}{\bar{\gamma}}$, $L \geq \frac{1}{2}(K\Delta)$, $P_{(i,j)} = K[1+(-1)^j]$ and L is the order of approximation, K here represents ratio of specular power to diffuse power, η denotes the relative power strength of two specular components, $\bar{\gamma}$ is instantaneous SNR, and $\Gamma(M)$ is Gamma function [35]. When K=0, TWDP PDF becomes Rayleigh PDF as only diffuse waves exist and when K is non zero and η becomes 0, TWDP PDF becomes Rician PDF. TWDP distribution is often used in modelling multipath fading with two direct line-of-sight (LOS) paths and the PDF of the same is given by Durgin in [2] as follows:

$$f_R(r) = \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2} - K\right) \sum_{t=1}^M a_t D\left(\frac{r}{\sigma}; K; \Delta a_t \frac{\pi(t-1)}{2M-1}\right) \quad (4.2)$$

Where

$$D(x; K; \alpha) = \frac{1}{2} \exp(\alpha) I_0(x\sqrt{2K(1-\alpha)}) + \frac{1}{2} \exp(-\alpha) I_0(x\sqrt{2K(1+\alpha)})$$

PDF of output SNR for Hybrid MRC/SC system

The CDF related to the MRC receiver can be calculated using (4.1) as

$$F_{x_{MRC}}(x_{MRC}) = \int_0^{x_{th}} f_{MRC}(x_{MRC}) dx \quad (4.3)$$

Thus putting equation (4.1) in equation (4.3) and on simplifying, we get

$$F_{x_{MRC}}(x_{MRC}) = \prod_{i=1}^M \frac{1}{2} \left(\frac{P_{(i,j_i)}}{s} \right)^s e^{-\frac{x_{MRC}}{s}} g[M \Gamma s, yx] \quad (4.4)$$

Where $g[p,q]$ denotes the lower incomplete gamma function.

In case of selection combining i.e. SC diversity scheme, signal which has the highest value of SNR is sent to the detector. The inputs so provided to the SC system are the outputs of MRC receiver. Thus, the output CDF of RMRC/SC receiver can be expressed

$$\text{as } F_{x_{MRC,SC}}(x) = \prod_{i=1}^R F_{x_i}(x_i)$$

Hence putting equation (4.4) in this we get

$$F_{x_{MRC,SC}}(x) = \prod_{i=1}^R \frac{1}{2} \left(\frac{P_{(i,j_i)}}{s} \right)^s e^{-\frac{x}{s}} g[M \Gamma s, yx] \quad (4.5)$$

Assuming the fading parameters to be identical and approximately equal average SNR achieved in individual branch, thus CDF of the SC output can be expressed as

$$F_{MRC,SC}(x_{MRC,SC}) = \frac{1}{2} \left(\frac{P_{(i,j_i)}}{s} \right)^s e^{-\frac{x_{MRC,SC}}{s}} g[M \Gamma s, yx] \quad (4.6)$$

Thus, outage probability is given by putting value of x_{th} instead of x and we get equation (4.7)

$$P_{OUT(MRC,SC)} X \frac{1}{2} \prod_{i=1}^M \prod_{j=1}^L \left\{ \prod_{i=1}^M a_i \right\} \left| \frac{\left(\prod_{i,j} P_{(i,j)} \right)^s}{s!(M)_s \Gamma(M)} e^{-\sum_{i,j} P_{(i,j)}} g[M \Gamma s, \gamma X_{th}] \right. \quad (4.7)$$

Hence, by differentiating (4.6) with respect to γ , we get the PDF expression of the overall output SNR of Hybrid MRC/SC receiver system in a TWDP fading environment which is as given by equation 4.8.

$$f_{MRC,SC}(X_{MRC,SC}) X \frac{1}{2^M} \prod_{i=1}^M \prod_{j=1}^L \left\{ \prod_{i=1}^M a_i \right\} \left| \frac{\left(\prod_{i,j} P_{(i,j)} \right)^s}{s!(M)_s \Gamma(M)} e^{-\sum_{i,j} P_{(i,j)}} g[M \Gamma s, \gamma X] \right. \quad (4.8)$$

Thus these expressions depict the mathematical model of the new Hybrid system considering the TWDP channel and the BER versus SNR analysis using different modulation schemes is shown in section 4.2.

4.2 MODULATION SCHEMES

In practical wireless communications, transmission of baseband signal cannot be done without applying modulation schemes. Its information is transmitted in such a way that parameter of carrier wave, which is a high frequency wave is varied in accordance with the amplitude or phase of the modulating signal i.e. information signal. In order to design a communication system, proper modulation scheme must be selected. This section presents BPSK and QPSK schemes employed in the Hybrid system.

Binary phase shift keying (BPSK):- Also known as PRK (Phase reversal keying) or 2PSK is a modulation technique which consists of two symbols which are 180° apart and one bit/symbol can be transmitted at a time. Fig. 4.2 depicts the constellation diagram of

BPSK having two constellation points lying entirely on the X axis. There is no projection on the Y axis i.e. there exists only in-phase component and no quadrature component.

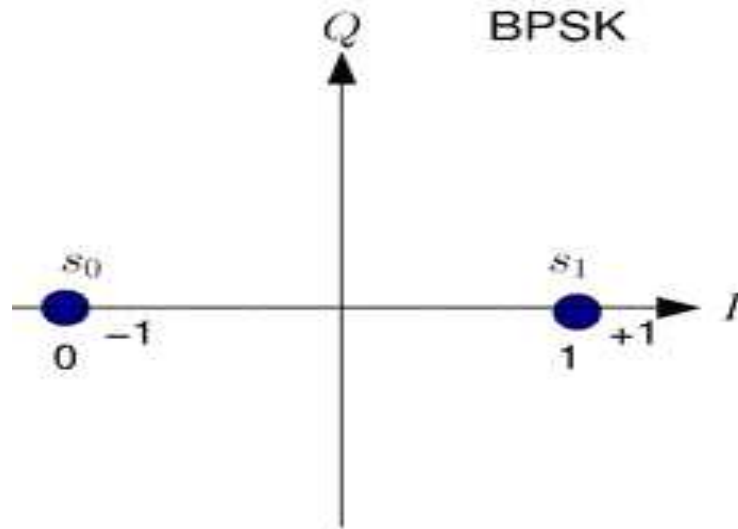


Figure 4.2 BPSK Constellation Diagram [41].

Quadrature phase shift keying (QPSK):- Also known as quadri-phase PSK or 4-PSK. Fig.4.3 depicts constellation diagram having four equi-spaced points. Both in-phase and quadrature phase components exist for this scheme. Two bits/symbol can be transmitted at a time.

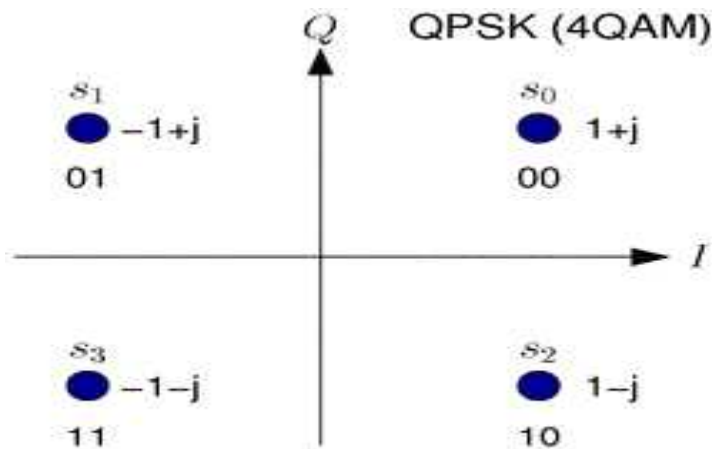


Figure 4.3 QPSK Constellation Diagram [41].

Bit error rate is observed for both these modulation schemes considering the TWDP channel and results are discussed as follows. Here $(M=x,R=y)$ is the notation used

throughout where x represents the number of MRC receive antennas and y represents the SC branches. Fig.4.4 shows the improvement in performance as the number of SC diversity branches ($R=y$) where y increases from 2 to 4 and keeping the number of MRC receive antennas ($M=2$) when simulated using MATLAB software. This is due to the fact that the likelihood of all fading paths entering the deep fade reduces as the number of diversity branches goes on increasing.

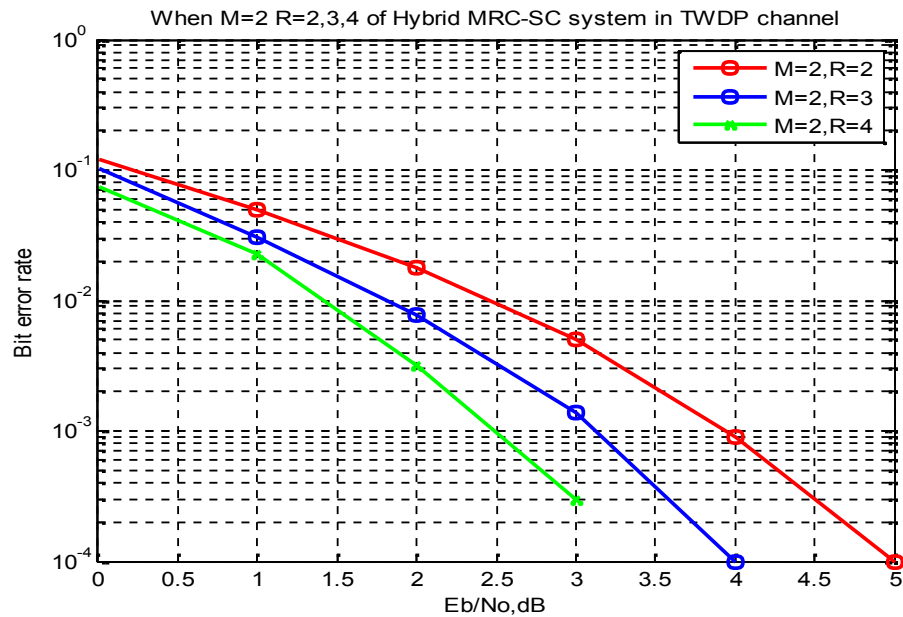


Figure 4.4 BER versus SNR for BPSK Modulation in TWDP channel for different values of R when $M=2$

From the above Fig.4.4 it can be concluded that at 3 dB SNR, minimum BER (3×10^{-4}) found when number of SC branches is higher i.e. 4 and maximum BER (5×10^{-3}) is found when number of SC branches is 2.

Similarly in Fig.4.5, keeping the value of $M=3$, bit error rate reduction is observed with the increase in SC branches. At 3 dB SNR, minimum BER is found when number of SC branches is higher i.e. $R=4$ and maximum BER is found when number of SC branches is $R=2$.

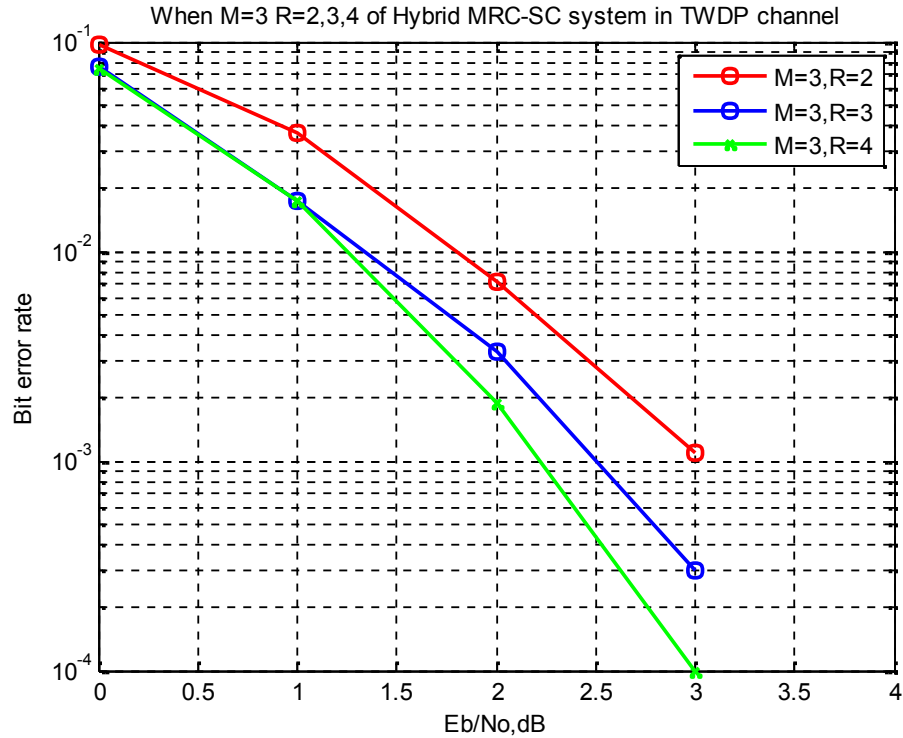


Figure 4.5 BER versus SNR for BPSK Modulation in TWDP channel for different values of R when M=3. BER is observed to be (1×10^{-4}) for M=3, R=4 and for M=3, R=3 BER is depicted as (3×10^{-4}) while for M=3, R=2 maximum BER is observed as (1×10^{-3}) .

In Fig 4.6 BER versus SNR plot of BPSK modulated Hybrid MRC/SC system is shown with constant value of (R=2) and varying the number of MRC branches (M=x). Here x is varied from 1 to 4. This plot depicts that in order to maintain BER value below 10^{-3} , for the above system, the required SNR value decreases with an increase in the number of MRC branches. Hence, the SNR required to maintain the BER of 10^{-3} is 6.2 dB for M=1, 3.7 dB for M=2, 2.9 dB for M=3 and 2.2 dB for M=4. Similarly for the Hybrid MRC/SC where R=3, the SNR requirement further reduces with an increase in diversity branches (M=x) i.e. x varying from 1 to 4 so as to maintain BER below 10^{-3} . Thus, the SNR value required to maintain the above BER is 4.8 dB in case of M=1, 3.2 dB in case of M=2 and 2.3 dB in case of M=3 and 1.8 dB in case of M=4 as shown in Fig.4.7.

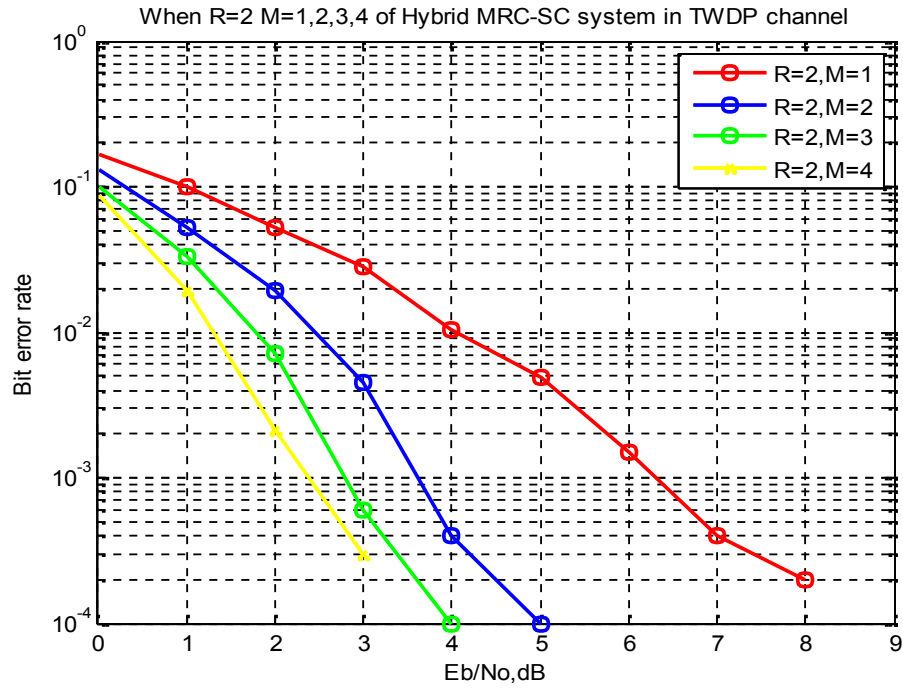


Figure 4.6 BER versus SNR for BPSK Modulation in TWDP channel for different values of M when $R=2$

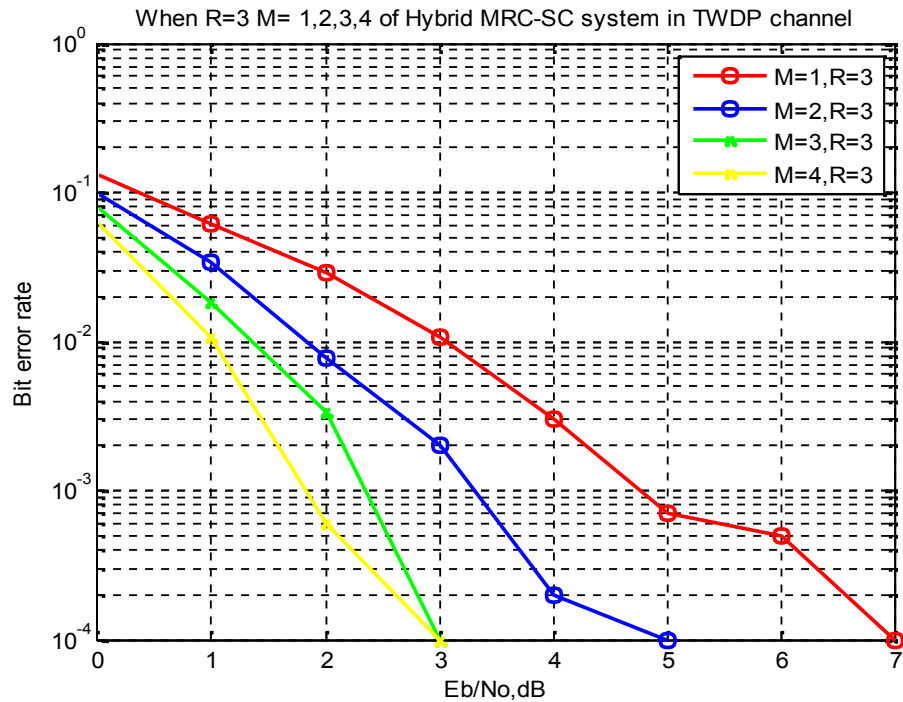


Figure 4.7 BER versus SNR for BPSK Modulation in TWDP channel for different values of M when $R=3$

Fig. 4.8 shown below depicts the BER versus SNR analysis for BPSK modulation in TWDP fading channel by varying the number of MRC antennas (M) and SC receivers (R) simultaneously in MATLAB software. BER performance is improved as the number of diversity branches are increased from 1 to 3. This is on account of the fact that probability of fading paths experiencing the deep fades decreases with increase in order of diversity.

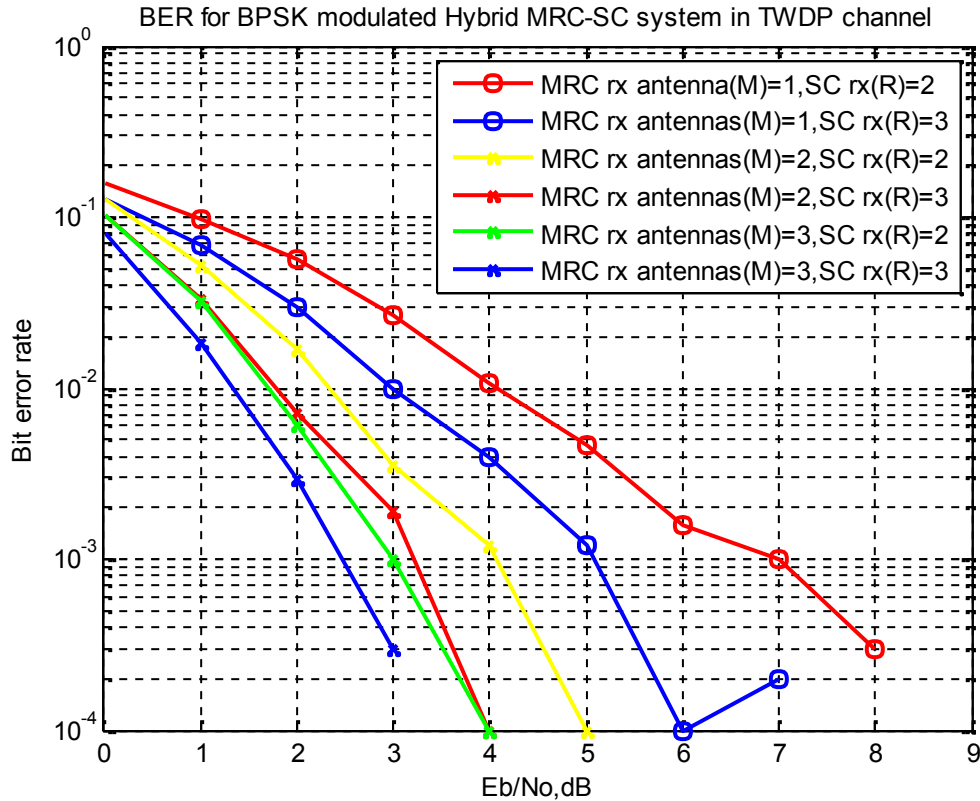


Figure 4.8 BER versus SNR for BPSK Modulation in TWDP channel for different values of M and R

SNR requirement in a hybrid MRC/SC system to maintain BER nearly 10^{-3} when TWDP channel is considered is shown in Table 4.1.

Table 4.1 SNR requirement to maintain BER of BPSK modulation equal to 10^{-3}

Hybrid diversity	M=1R=2	M=1R=3	M=2R=2	M=2R=3	M=2R=3	M=2R=3
MRC/SC SNR (in dB)	7	5.1	4.1	3.2	3	2.5

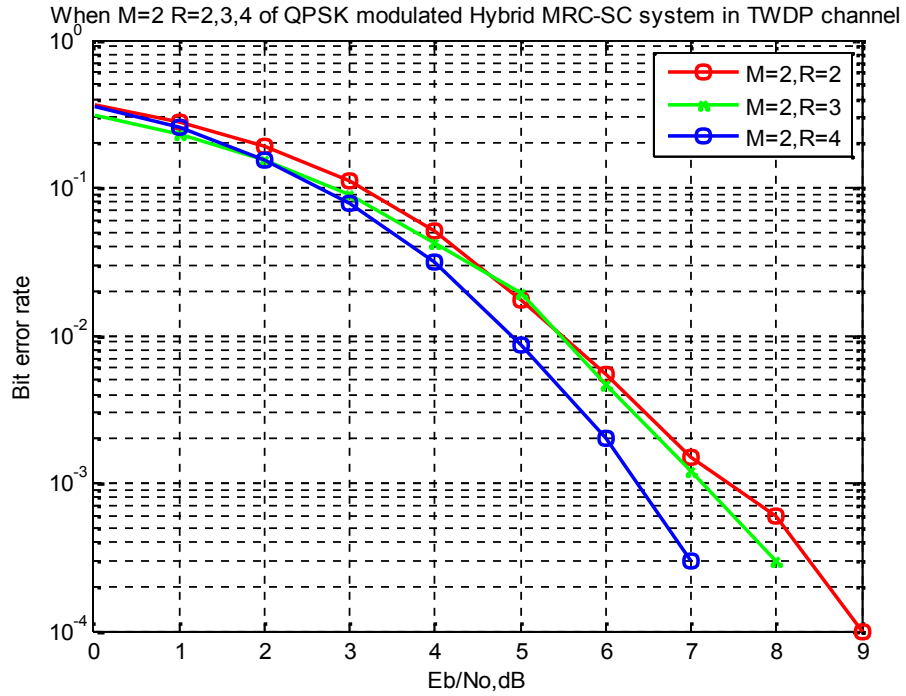


Figure 4.9 BER versus SNR for QPSK Modulation in TWDP channel for different values of R when $M=2$

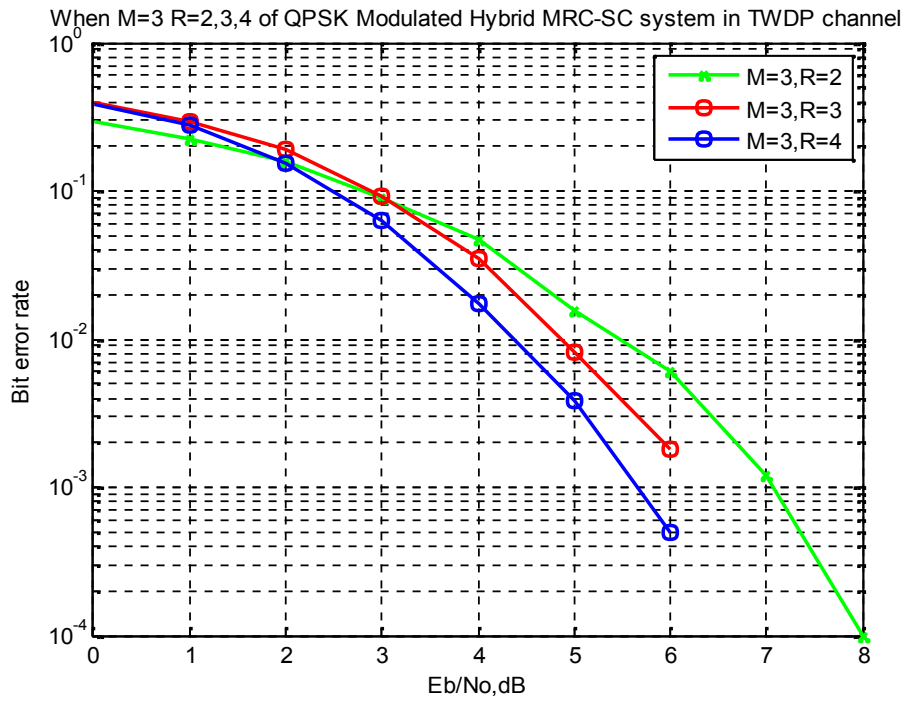


Figure 4.10 BER versus SNR for QPSK Modulation in TWDP channel for different values of R when $M=3$

As we know that as the number of bits to be transmitted in a symbol is more, BER keeps on increasing. Hence, more BER rate is observed in case of QPSK than BPSK as two bits/symbol are transmitted in QPSK. These results are exactly obtained in MATLAB and are discussed as follows.

Fig.4.9 depicts QPSK modulated Hybrid MRC-SC system in a TWDP fading channel. The results so obtained using MATLAB software depict that for a constant $M=2$, performance improvement is observed in terms of BER with the increase in the number of SC branches ($R=y$), y taking the values 2 and 3 as shown because of the decrease in probability of the fading paths to experience the deep fade simultaneously with the increase in order of diversity. From the above Fig.4.9 it can be concluded that at 6 dB SNR, minimum BER (2×10^{-3}) found when number of SC branches is higher i.e. 4 and maximum BER (6×10^{-3}) is found when number of SC branches is 2.

Similarly in Fig.4.10, for $M=3$ bit error rate (BER) reduction is observed with the increase in the order of diversity of SC branches, R . At 6 dB SNR, minimum BER is found when number of SC branches is higher i.e. 4 and maximum BER is found when number of SC branches is 2.

In Fig 4.11, BER versus SNR plot of QPSK modulated Hybrid MRC/SC system is shown. This plot depicts that for maintaining BER below 10^{-3} , in the Hybrid MRC/SC receiver with two branches SC ($R=2$), reduction in the SNR value is observed with an increase in the number of MRC branches. Thus, the SNR required to achieve the above BER is 10 dB for system having receive antennas as $M=1$, 7.2 dB for $M=2$ and 6.4 dB for receive antennas $M=3$.

Similarly for the hybrid MRC/SC where $R=3$, to maintain BER below 10^{-3} , the SNR value requirement further decrements with an increment in number of diversity branches (M). Hence, the SNR requirement is 8 dB for system with $M=1$, 6.2 dB for system with $M=2$ and 5.5 dB for system with $M=3$ so as to maintain the above BER as shown in Fig.4.12.

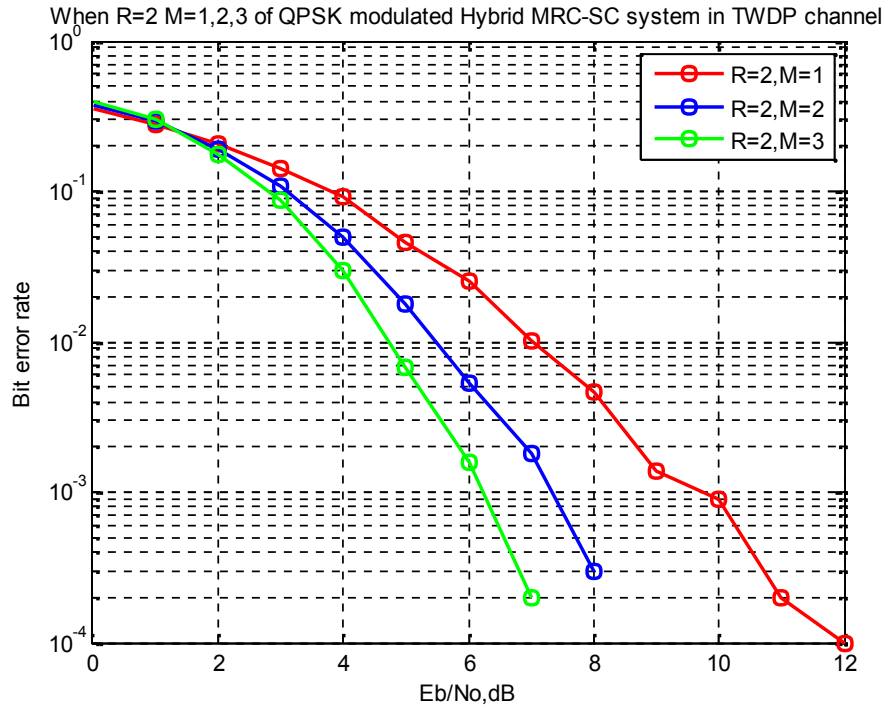


Figure 4.11 BER versus SNR for QPSK Modulation in TWDP channel for different values of M when $R=2$

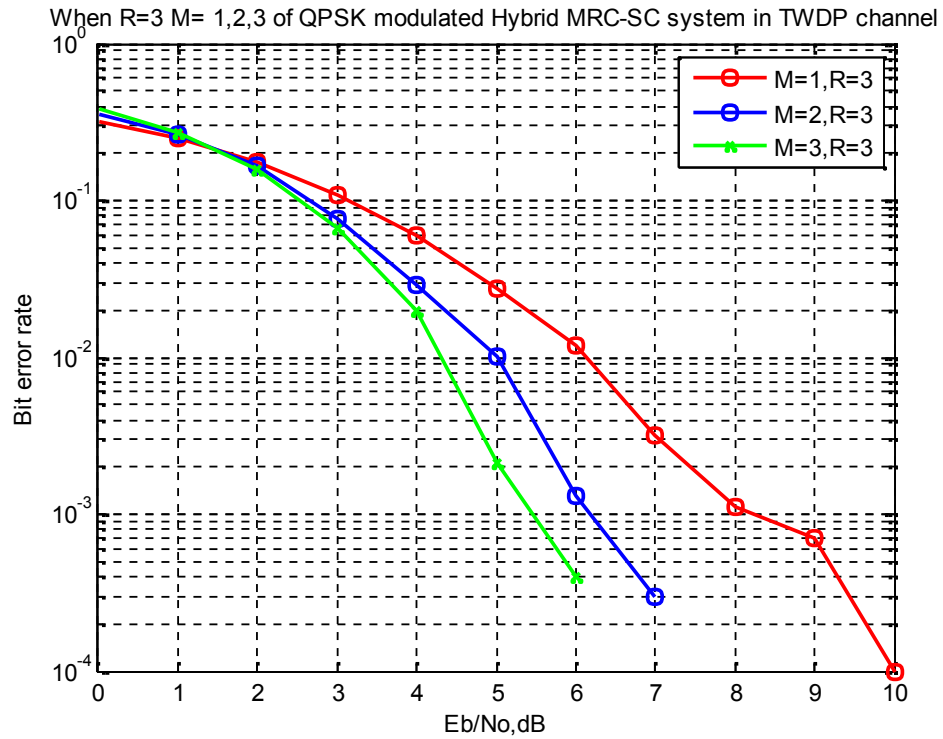


Figure 4.12 BER versus SNR for QPSK Modulation in TWDP channel for different values of M when $R=3$

BER reduction is shown as values of M MRC receive antennas and R SC receivers are increased from 1 to 3 and 2 to 3 respectively. BER achieves minimum value when M=3,R=3 and is highest for M=1,R=2. Also BER is higher in QPSK modulation as compared to that of BPSK modulation which is shown in Fig.4.8.

Table 4.2 SNR requirement to maintain BER of QPSK modulation equal to 10^{-3}

Hybrid technique	M=1 R=2	M=1 R=3	M=2 R=2	M=2 R=3	M=3 R=2	M=3 R=3
MRC/SC	9.1	7.8	6.9	6.5	6.1	5.8
SNR (in dB)						

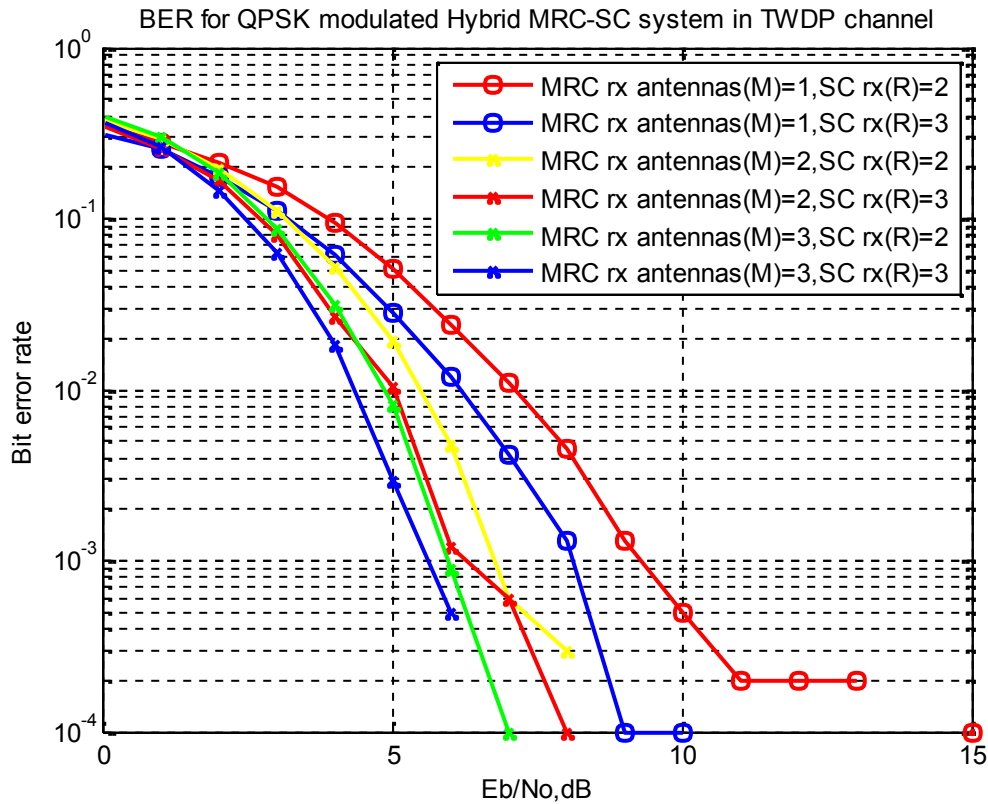


Figure 4.13 BER versus SNR for QPSK Modulation in TWDP channel for different values of M and R

4.3 CHAPTER SUMMARY

The crux of the matter is that for maintaining a particular BER level, SNR requirement reduces with the increase in the diversity order in a hybrid system which is an important aspect for power limited devices designed for communication. However, the cost to achieve this lower SNR requirement results in a more complex receiver. Also in QPSK modulated systems SNR requirement is higher than that achieved by BPSK modulated system as shown above.

COMPARATIVE ANALYSIS OF HYBRID MRC/SC RECEIVER IN TWDP AND RAYLEIGH CHANNEL

5.1 INTRODUCTION

In this chapter comparative analysis has been carried out between the conventional fading channel i.e. Rayleigh channel and the realistic channel model i.e. TWDP (Two wave with diffuse power) fading channel model. The focus of the present research is to analyze the Bit error rates of Hybrid MRC/SC receiver systems using both BPSK and QPSK modulation schemes. A comparison is made on the behalf of the results obtained by taking different number of diversity branches in both channels. BER versus SNR analysis of this hybrid system is also done considering the Rayleigh channel.

5.2 ANALYSIS OF HYBRID MRC/SC SYSTEM IN RAYLEIGH CHANNEL

Consider a BPSK modulated Hybrid diversity system in Rayleigh channel in which information signal is received by MRC receivers which are R in number and each receiver has M diversity branches. These M received information signals are weighted and then combined to achieve maximum value of SNR. From R such systems, the one having the highest SNR is chosen/selected using SC with R diversity branches. This model has been implemented using MATLAB and is clear from Fig. 5.1 and Table 5.1 that to maintain BER equal to 10^{-3} , SNR required is more for lower order diversity and as the diversity branches keep on increasing SNR requirement keeps on reducing. It is on account of the fact that probability of all branches to experience deep fades simultaneously decreases with increase in diversity branches.

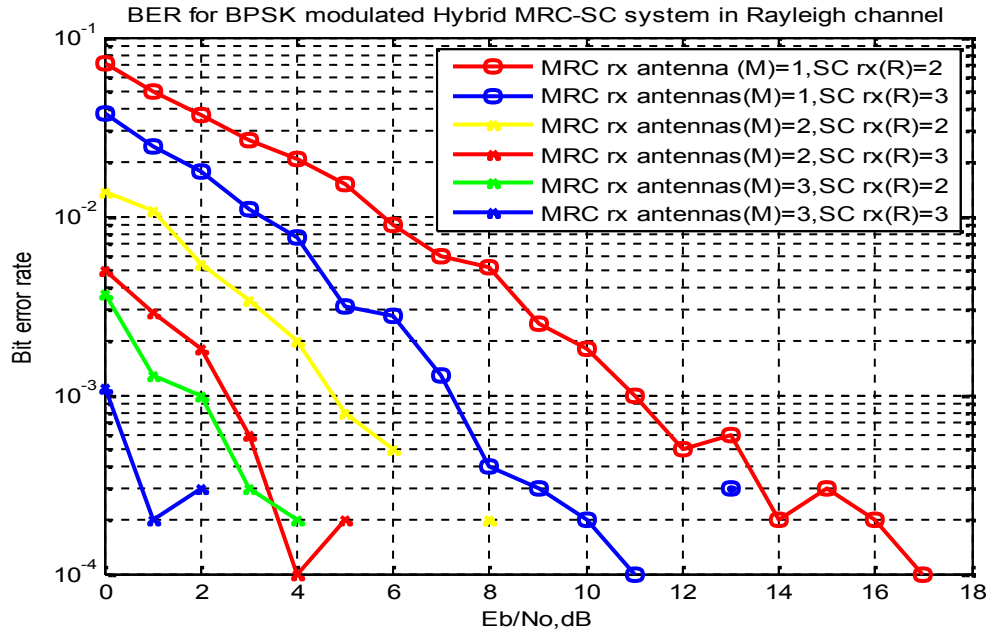


Figure 5.1 BER versus SNR for BPSK Modulation in Rayleigh channel for different values of M and R

Table 5.1 SNR requirement to maintain BER of BPSK modulation equal to 10^{-3}

Hybrid technique	M=1R=2	M=1R=3	M=2R=2	M=2R=3	M=3R=2	M=3R=3
MRC/SC SNR (in dB)	11	7.3	4.9	2.7	2	0.2

Similarly, Fig. 5.2 and Table 5.2 show same system with QPSK modulation scheme applied. Fig 5.2 shows that for higher order diversity scheme, Bit error rate (BER) is minimum at the particular SNR level and for lower order diversity scheme, Bit error rate (BER) is maximum at same SNR level considering the Rayleigh channel.

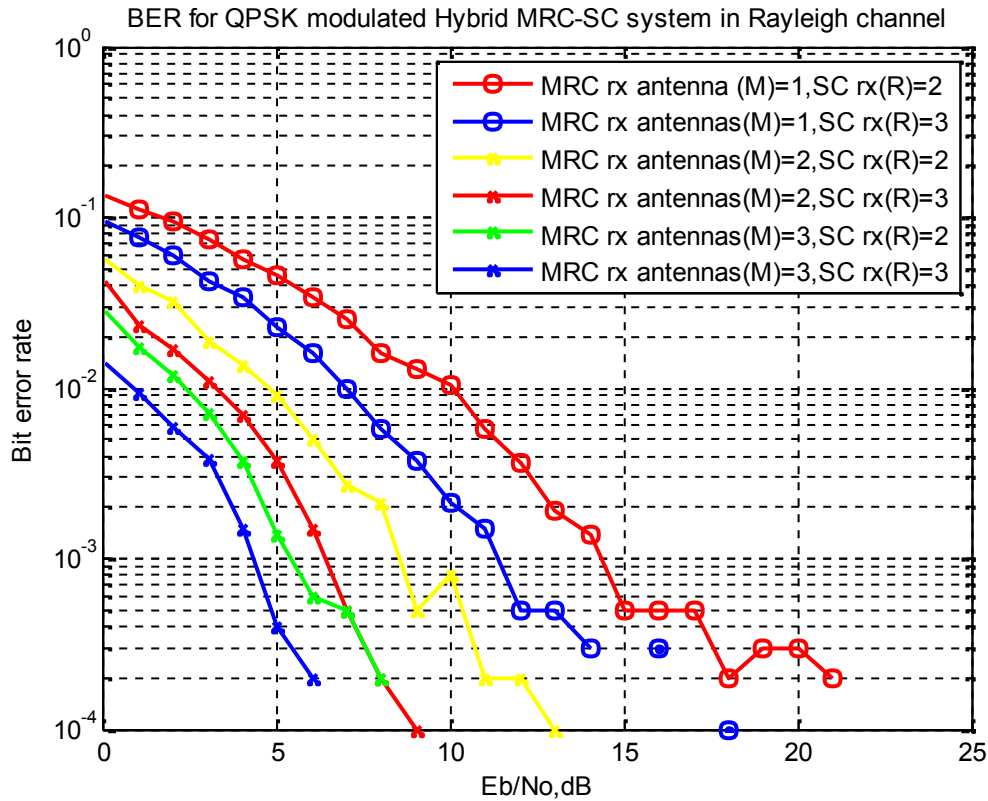


Figure 5.2 BER versus SNR for QPSK Modulation in Rayleigh channel for different values of M and R

Table 5.2 SNR requirement to maintain BER of QPSK modulation equal to 10^{-3}

Hybrid technique	M=1R=2	M=1R=3	M=2R=2	M=2R=3	M=3R=2	M=3R=3
MRC/SC SNR (in dB)	14	11.5	8.4	7	5.2	4.3

5.3 COMPARATIVE STUDY OF HYBRID DIVERSITY MRC/SC SYSTEM CONSIDERING RAYLEIGH AND TWDP FADING CHANNEL

Table 5.3 below depicts as the number of receive antennas (M) increases, SNR requirement decreases in case of both Rayleigh and TWDP fading channels considering the case when BPSK modulation is applied to the system.

Table 5.3 SNR requirement (in dB) to maintain BER of BPSK modulation equal to 10^{-3}

DIVERSITY ORDER	RAYLEIGH CHANNEL	TWDP CHANNEL
M1 R2	6.7	11.8
M1 R3	5	7.4
M2 R2	3.8	4.2
M2 R3	2.9	3.1
M3 R2	1.2	3.2
M3 R3	<0.2	2.2

Table 5.4 shows a comparison of SNR requirement in a Hybrid system in Rayleigh and TWDP channels when QPSK modulation is applied.

Table 5.4 SNR requirement (in dB) of QPSK modulation to maintain BER equal to 10^{-3}

DIVERSITY ORDER	RAYLEIGH CHANNEL	TWDP CHANNEL
M1 R2	10	16
M1 R3	8	12
M2 R2	7.2	9.2
M2 R3	6	6.8
M3 R2	6.2	6.5
M3 R3	4.6	5.6

Table 5.3 and 5.4 also proves that SNR requirement in order to maintain a particular BER when QPSK scheme is employed is higher for TWDP channel rather than Rayleigh channel.

The following Fig.5.3-5.8 depict the comparative analysis of BER versus SNR curves for BPSK and QPSK modulation schemes applied on the Hybrid MRC/SC receiver system considering both the channels Rayleigh and TWDP fading channel.

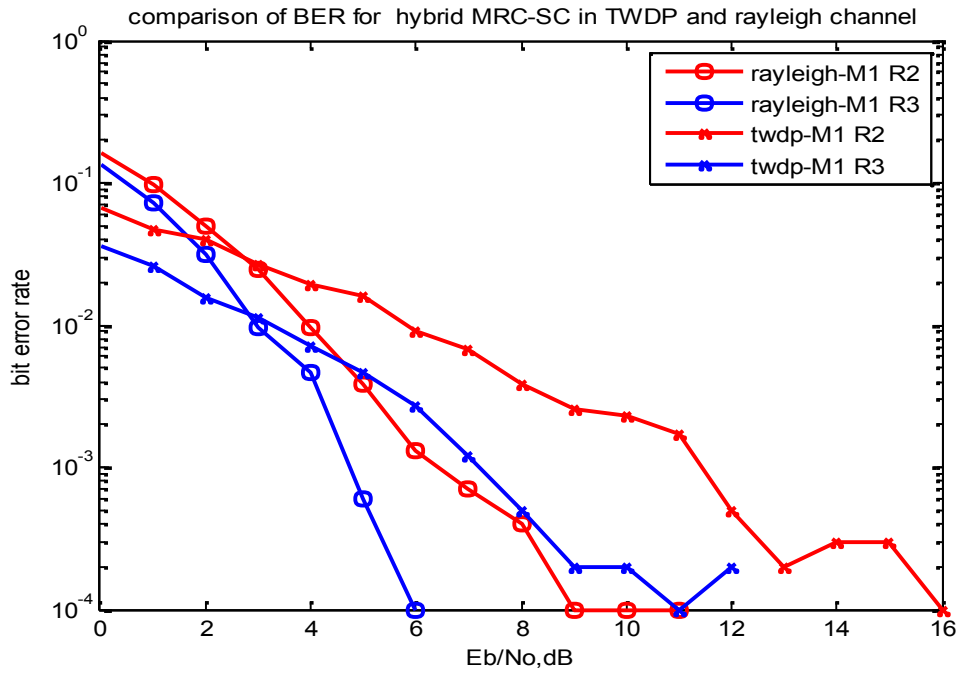


Figure 5.3 BER versus SNR for BPSK Modulation in both channels for M=1 and R=2,3

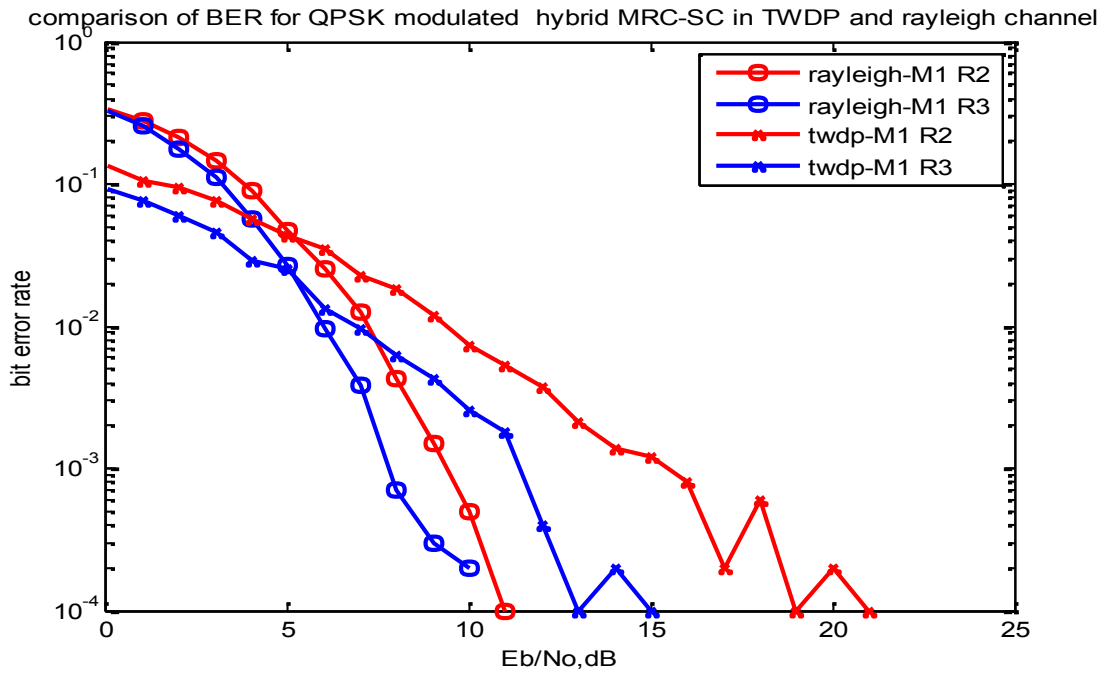


Figure 5.4 BER versus SNR for QPSK Modulation in both channels for M=1 and R=2,3

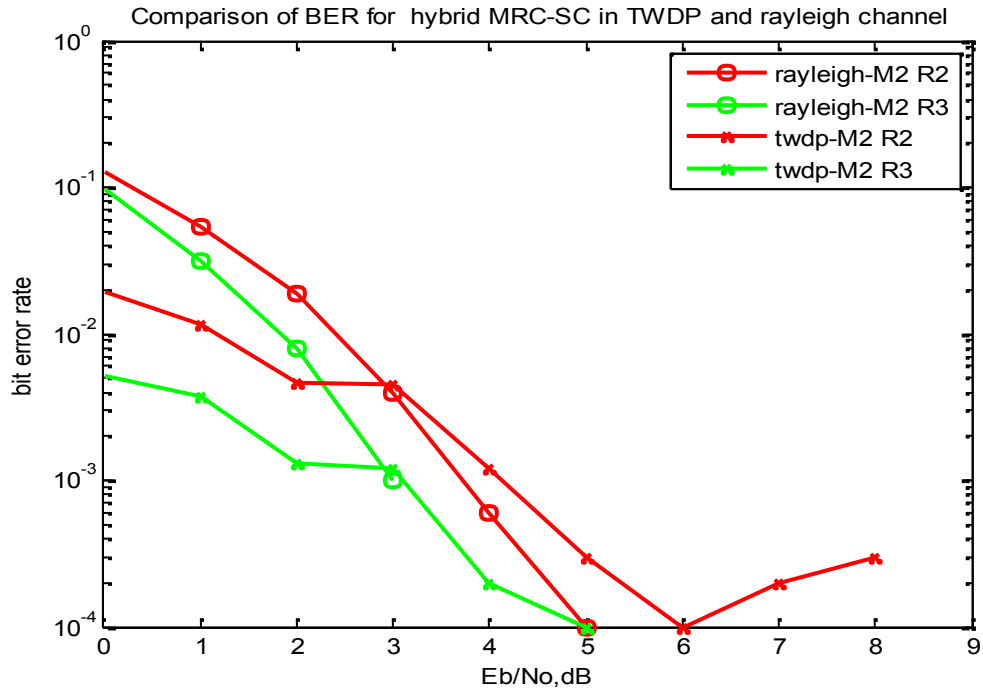


Figure 5.5 BER versus SNR for BPSK Modulation in both channels for M=2 and R=2,3

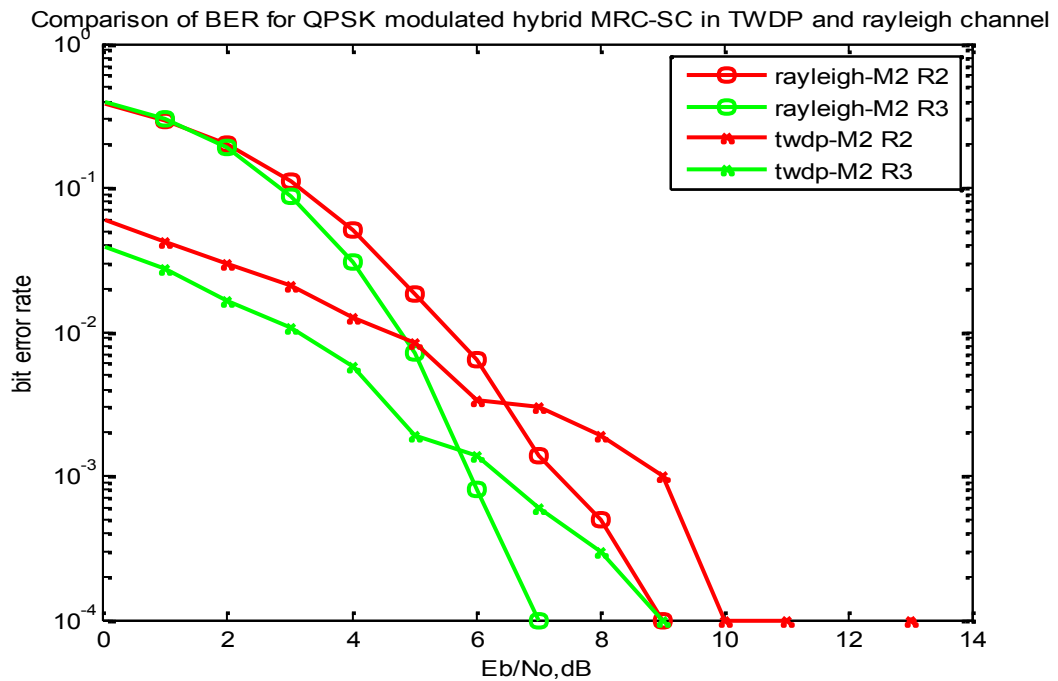


Figure 5.6 BER versus SNR for QPSK Modulation in both channels for M=2 and R=2,3

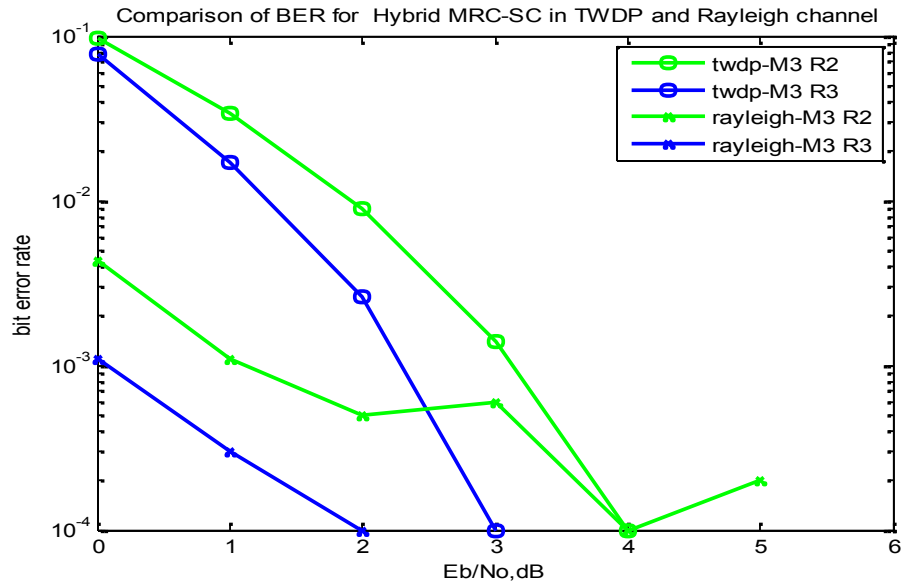


Figure 5.7 BER versus SNR for BPSK Modulation in both channels for M=3 and R=2,3

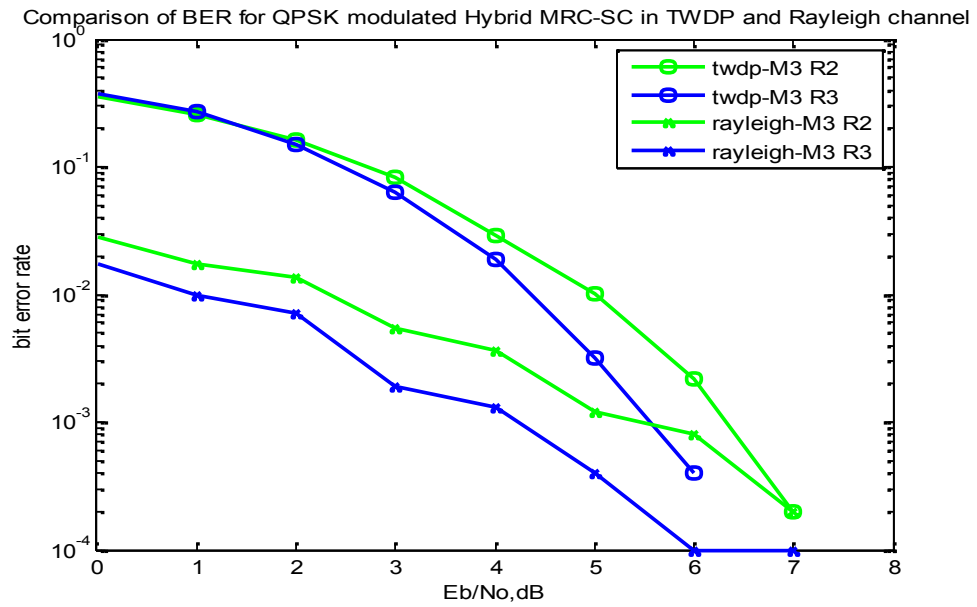


Figure 5.8 BER versus SNR for QPSK Modulation in both channels for M=3 and R=2,3

5.4 CHAPTER SUMMARY

BER versus SNR curves shown in this chapter throw light on the higher BER in case of TWDP channel and more SNR requirement in order to maintain a particular BER. Thereby proving it to be right to consider it when worst case wireless communication system is to be designed.

CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

The objective of this thesis is to explore the BER performance of a Hybrid MRC/SC Receiver system considering a Two Wave with Diffuse Power fading channel model. The same system is also considered under Rayleigh fading, and a comparative analysis is done between the two channels through MATLAB simulation works. Among the different fading channels, TWDP fading behavior is exhibited in Wireless Sensor Network (WSN) applications and it is the one which makes a poorer link as compared to the link formed by the Rayleigh fading model.

BPSK and QPSK Modulation techniques are applied in both Rayleigh and TWDP fading scenarios, and the results are compared. The results so obtained helped to attain a clearer perception of channel characteristics and the statement that TWDP is the worst channel as more BER is observed in a TWDP faded environment. It should be considered as the worst case fading environment due to the cancellation of two LOS components which are equal in strength and opposite in phase. Thus, it should be utilized while designing worst case wireless communication systems. Also, QPSK involves the transmission of two bits/symbol at a time. Hence, more BER is observed in this case as compared to BPSK modulation, which involves one bit/symbol transmission.

In a Hybrid MRC/SC system, varying the number of receive antennas of the MRC system improves the system performance as more diversity branches increase the ability to combat fading. Also, varying the number of SC branches further improves the system's BER performance. In order to maintain a particular BER level, the SNR requirement keeps decreasing on increasing the order of diversity.

6.2 FUTURE SCOPE

Different propagation environments constitute unique fading characteristics which are complex in their own way. So correctly modeling a system which can resist fading, improves system's performance and meeting the current wireless needs is the need of an hour. Deployment of WSN applications further validates the need of designing a realistic channel model.

Above all, future work will focus on the easier mathematical representation of TWDP fading as till now TWDP PDF representation has no closed form expression which makes its implementation a tedious job. Due to the limited time, other performance measures like outage probability and capacity calculation for Hybrid MRC/SC system in TWDP channel was beyond the scope of this thesis. Various performance measures e.g. capacity analysis over this realistic TWDP fading environment and involving the optimal combining techniques in TWDP fading still needs to be studied. Various soft decision coding techniques such as Convolutional Codes and Viterbi algorithm which can further improve the performance by reducing BER have not been implemented yet with this fading.

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