A COMPARATIVE PERFORMANCE ANALYSIS OF MRC DIVERSITY RECEIVERS IN OFDM SYSTEM

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Abstract

In this paper, the diversity gain of a Maximal Ratio Combiner (MRC) has been investigated for Orthogonal Frequency Division Multiplexing (OFDM) by varying the number of receiving antennas. Different modulation schemes namely 64-PSK, 64-QAM, 16-PSK, 16-QAM and QPSK have been used in OFDM technique. The simulation results show that the performance (SNR) of an OFDM system can be significantly improved by using MRC. We have also derived average Symbol Error Rate (SER) of M-ary Quadrature Amplitude (M-QAM) and M-ary Phase Shift Keying (M-PSK) modulations for N-branch MRC space diversity reception scheme. In this paper, it is shown that M-QAM based OFDM technique outperforms M-PSK based OFDM technique. The comparison of the performances of the Signal-to-Noise Ration (SNR) ofM-PSK and M-QAM based OFDM technique has been presented in this paper. It is also shown that SNR can be improved further if the number of receiving antennasis increased.

Keywords

Rayleigh Fading Channel, OFDM, Maximal-ratio combining (MRC), PSK, QPSK, QAM,Diversity, Multiple Antenna.

1. INTRODUCTION

In modern communication systems, the highest transmission rates in the 20-200 Mb/s range are envisioned for 4G systems [1].However, with the increase of the data rate, the symbol duration reduces and hence the Inter Symbol Interference (ISI) increases. The ISI is caused by the dispersive fading of the wireless channels if single-carrier modulation is used. To reduce this high ISI a multicarrier modulation technique is required that has high spectral efficiency.Orthogonal Frequency Division Multiplexing (OFDM) is a multicarrier modulation technique that is considered as one of the high spectral efficient modulation techniques. OFDM uses minimal densely spaced orthogonal subcarriers. The entire channel is divided into many narrow-band sub channels, which are used in parallel to maintain highdatarate transmission and, at the same time, to increase the symbol duration to combat ISI.Although OFDM plays an important role in wide band transmission schemes, it's performance is degraded by multipath fading that is very common in any wireless communication system [2]. To combat the effects of channel fading and to improve the system performance, various diversity techniquesare used in one form or another.

Diversity can be implemented in three different domains namely time, frequency and space. Coding and interleaving provide time diversity. Spread spectrum signal provides frequency

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diversity. Multiple antenna technique provides space diversity. Space diversity by using multiple antenna configurations is the most widely utilized in communication systems. A base station equipped with multiple antennas in a mobile communication system is an example of space diversity. Multiple antenna based diversity can be classified as receive diversity and transmit diversity.In receive diversitymultiple antennas are used in the receiver. On the other hand in transmit diversity multiple antennasare used in the transmitter. Diversity reception [3] is a conventional technology for communication system that is widely used in advanced mobile communication systems such as W-CDMA [4], MIMO [5] and OFDM [6]. In this investigation we adopted a diversity combining method for receive diversity that is achieved by using multiple receiving antennas. There are basically three kinds of diversity combining schemenamely Selection Combining (SC), Equal Gain Combining (EC) and Maximal Ratio Combining (MRC).In the recently proposed mobile systems MRC scheme shows the best performance and it tends to be the mostly employed among other diversity schemes[7]. In this work we have chosen MRC as the diversity combining scheme to investigate the performance of an OFDM system.

2. RELATED WORK

In one of the early works on diversity scheme Van Wambeck and Rosshavereportedsome experimental results of dual and triple diversity schemes[8]. Kahn derived the combining weights of the optimal linear combiner for dual diversity [9], Brennangeneralized Kahn's results for higher orderdiversity scheme [10]. The technique implemented by Kahn and Brennan is commonly known as Maximal Ratio Combining (MRC). In this investigation we have also focused on other aspects of diversity including non-coherent modulation formats [11-12]and techniques for combining correlated signals [13-14]. A combining technique to mitigate the effects of Inter Symbol Interference (ISI) has been introduced in a more recent work [15]. Acomprehensive investigation of the more commonly used diversity combining techniques can be found in **[16].** However, MRC scheme has the following two major problems.One problem is that it is very complicated to implement the system. Assuming a post detection diversity reception system with *N*branches, MRC scheme needs at least *N* multipliers with two-inputs and one adder with *N*-inputs, all requiring complex arithmetic operations. In a conventional transmission system that usually uses two branches space diversity, the complexity of combining system may not be a serious problem.

However, in an advanced high performance system like W-CDMA, the total number of spaces and the RAKE paths is usually as large as 6-8 [4]. The design complexity is definitely an important issue for the implementation of a mobile unit. The other problem ofMRC is that it minimizes the power attenuation of the received signal in frequency flat fading channels to improve the Bit-Error-Rate (BER) or Symbol-Error-Rate (SER) performance of the system. It meansthat this combining scheme cannot effectively remove the transmission errors introduced by other factors such as ISI in frequency selective fading channels due to multipath delay difference and the co-channel interference (CCI) from other channels. In order to combat these factors, other techniques like equalizer and interference canceller are widely used in modern communication systems.

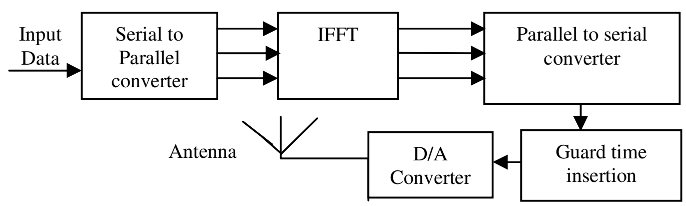
However, the bit-error rate (BER) performance of 16 STAR-QAM in Rayleighfading has been analyzed by Adachi [17] and Chow [18]. Acomparison between 16 STAR-QAM and 16 SQUARE-QAM has been presented in [17], while in [18] an optimum ratio of the two amplitude values is obtained. Chow [19] presented the BER for 16 STAR-QAM in a Rayleigh fading channel, with post detection combining. In [20], the BER calculated under the MRCreceiver diversity schemein case of Nakagami-m fading generated by sum of sinusoidal method using Rayleigh and Ricean channels. Patterh analyzed BER performance of M-QAM over correlated Nakagami-m fading channel [21]. While there are many other excellent papers on the subject of fading channels and diversity reception, with many cases having been thoroughly analyzed; but none of the work has derived average symbol error rate of M-QAM and M-PSK in case of *N*-branch maximum ratio combining (MRC) space diversity reception when the fading channels are modeled as frequency flat slow Rayleigh fading channel corrupted by Additive White Gaussian Noise (AWGN). The approach adopted in this paper results in “clean” derivations for the error probability expressions. This paper containstheperformance investigations of maximal-ratio combiner for OFDM system. Different types of modulation schemes namely QPSK, 64-QAM, 64-PSK, 16-QAM, 16-PSK and QPSK have been used inan OFDM system. The other objective of this paper is to find a suitable modulation technique for OFDM system.

The rest of the paper is organized as follows: In section III, OFDM system and Rayleigh fading channel have been described. In section IV, we have discussed MRC receiver diversity scheme. In section V, simulations results are presented. Finally, we conclude the paper in the last section.

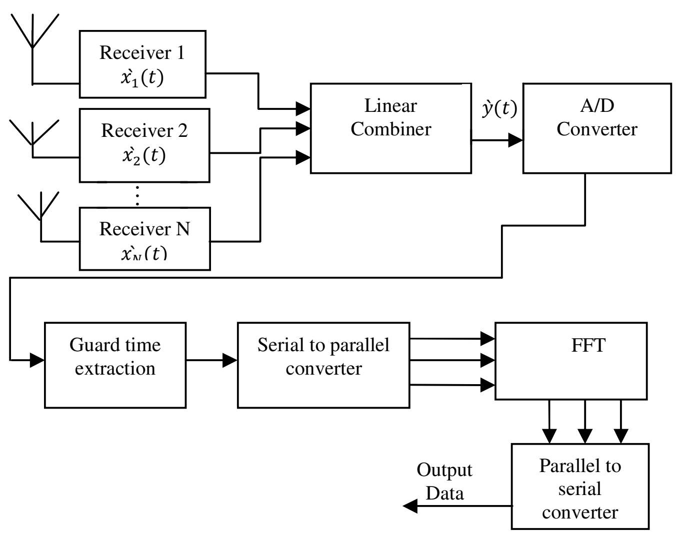
3. SYSTEM MODEL AND CHANNEL MODEL

3.1. OFDM SYSTEM

The architectures of a typical OFDM transmitterand OFDM receiver are shown in Fig.1 (a) and Fig. 1(b)respectively [22]. In the transmitter the incoming modulated serial bits are converted into parallel streams by using a serial to parallel converter.



(a)Transmitter



(b) Receiver

Figure 1. OFDM transmitter and receiver with MRC receiver Diversity

These parallel bit streams are subjected to Inverse Fast Fourier Transform (IFFT) block for baseband OFDM modulation. To prevent overlapping of the data at the receiver Cyclic Prefix (CP) is inserted whose duration is one fourth of the total OFDM symbol duration. The modulated data are sent to the channel through a digital-to-analog converter. At the receiver side, firstly the data is received through N linear receivers followed by a linear combiner. This linear combiner is designed in such a way that the output SNR is maximized at each instant of time. Then this data is converted again to the digital domain by passing it through an analog to digital converter. After removing the cyclic prefix, data is again converted into serial to parallel by a serial-to-parallel converter. These parallel bit streams are demodulated using Fast Fourier Transform (FFT) to get back the original data by converting parallel bit streams into serial bit streams.

3.2.RAYLEIGH FADING CHANNEL MODEL

In this investigation we assume that the channel is flat fading. In simple terms, it means that the multipath channel has only one tap [23]. Rayleigh channel is modeled with a circularly symmetric complex Gaussian random variable having the following form:

$$h = h_{re} + jh_{im} \quad (1)$$

The real and imaginary parts are zero mean independent and identically distributed (i.i.d) Gaussian random variables with mean 0 and variance σ^2.The probability density function of the magnitude h of complex Gaussian random variable has been definedin [23-24] which is expressed as

$$p(h) = \frac{h}{\delta^2} e^{-\frac{h^2}{2\sigma^2}}, \qquad h \geq 0 \quad (2)$$

The received signal in a Rayleigh fading channel is of the form,

$$y = hx + n, \quad (3)$$

Here y is the received symbol and h isthe complex scaling factor corresponding to Rayleighmultipath channel,x is the transmitted symbol and n is the Additive White Gaussian Noise (AWGN). The channel is randomly varying in time.It means that each transmitted symbol gets multiplied by a randomly varying complex number h. Since h is modeled as Rayleigh channel, the real and imaginary parts are Gaussian distributed having mean 0 and variance ½.

3.3.MRC RECEIVER DIVERSITY

The signals at the output of the receivers are linearly combined in MRC to maximize the instantaneous Signal-to-Noise Ratio (SNR). In the assumed that the complex envelope of the received signal of the i^{th} diversity branch, which is defined by

$$\breve{x_i}(t) = \alpha_i e^{j\theta_i} \breve{s}(t) + \breve{w_i}(t) \qquad 0 \leq t \leq T \quad i = 1,2, \ldots\ldots N \quad (4)$$

,where $\breve{s}(t)$ denote the complex envelope of the modulated signal transmitted during the symbol interval $0 \leq t \leq T$ for the i^{th} diversity branch, the fading is represented by the multiplicative term $\alpha_i e^{j\theta_i}$ and the additive channel noise is denoted by $\breve{w_i}(t)$. Now, at the receiver end the maximal-ratio combiner consists of N linear receivers followed by a linear combiner. Using Eq. (4) the corresponding complex envelope of the linear combiner output is defined by

$$\check{y}(t) = \sum_{i=1}^{N} \alpha_i \, \check{x}_i(t)$$
$$= \check{s}(t) \sum_{i=1}^{N} a_i \, \alpha_i e^{j\theta_i} + \sum_{i=1}^{N} \alpha_i \, \widetilde{w}_i(t) \quad (5)$$

,where the $\boldsymbol{a_i}$ is complex weighting parameters that characterize the linear combiner.

3.3.1. Effective SNR with Maximal Ratio Combining (MRC)

The instantaneous SNR per symbol (γ_i) at the i^{th}receive antenna is given by

$$\gamma_i = \frac{|\alpha_i|^2 E_s}{N_0}. \quad (6)$$

With the N receiving antennaused, the effective output SNR per symbol of the maximal-ratio combiner is,

$$\gamma_{mrc} = \sum_{i=1}^{N} \frac{|\alpha_i|^2 E_s}{N_0} \quad = N\gamma_i (7)$$

So, the effective symbol energy to noise ratio in *N* receiving antennas case is *N* times the symbol energy to noise ratio for single antenna case. This gain is same as the improvement in receive diversity for AWGN case which is shown in Fig. 2.

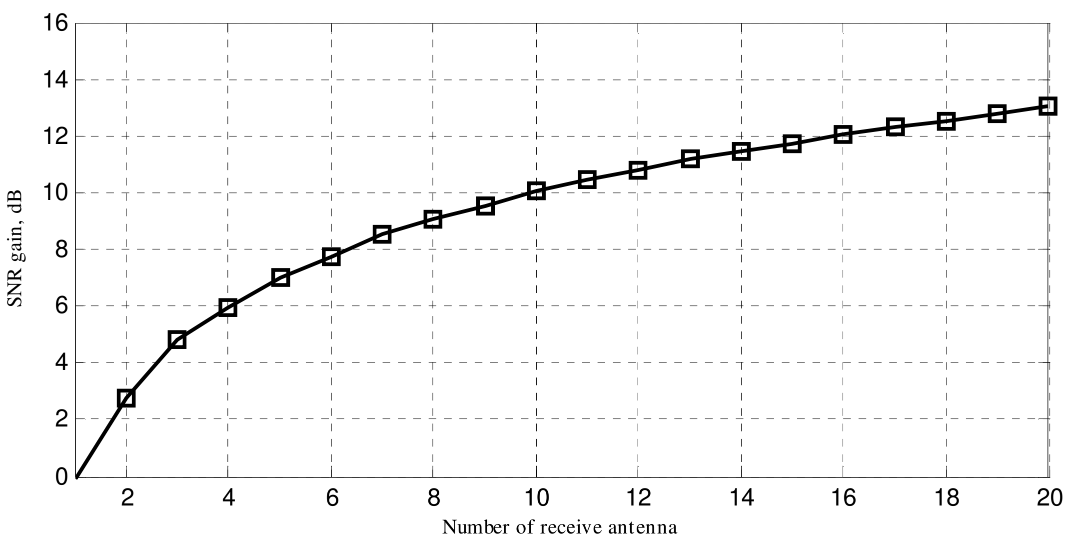


Figure 2:SNR improvement with Maximal Ratio Combining

This figure shows that the SNR gain increases with the number of antennas. It also illustrates that the gain increases at a high rate till eight numbers of antennas. But the gain does not increase significantly if the number of antenna is increased beyond eight. In this investigation we limited the number of receiving antennas till four due to our resource constraint.

3.3.2.Error rate with Maximal Ratio Combining (MRC)

Since the effective symbol energy to noise ratio $\gamma_{mrc}$is the sum of *N* such random variables. From the probability theory, the probability density function of such a sum is known to be Chi-square random variable with *2N*degrees of freedom. That is

$$f_{\Gamma_{mrc}}(\gamma_{mrc}) = \frac{1}{(N-1)!}\frac{\gamma_{mrc}^{N-1}}{\gamma_{av}^{N}}\exp(-\frac{\gamma_{mrc}}{\gamma_{av}})(8)$$

, where γ_{av} is the average signal-to-noise ratio at the output of i^{th} receiver.

Now for maximal-ratio combining, $\frac{E_S}{N_0}$ will be replaced byγ_{mrc}. The instantaneous output signal to noise ratio γ_{mrc} is in fact a random variable. To determine the average probability of symbol error, we must average the conditional probability of error with respect to γ_{mrc} or

$$P_e = E[Prob(error|\gamma_{mrc})](9)$$

This expectation is found by multiplying the conditional probability $Prob(error|\gamma_{mrc})$ by the probability density function of γ_{mrc} and then integrating the product with respect to γ_{mrc}. That is, we write

$$P_e = \int_0^{\infty} Prob(error|\gamma_{mrc})f_{\Gamma}(\gamma_{mrc})\, d\gamma_{mrc}(10)$$

Now, for M-ary PSK (where M= 2^k signal points and k is even)

$$Prob(error|\gamma_{mrc}) = erfc\,[\sqrt{\gamma_{mrc}}\sin(\frac{\pi}{M})]$$

From Eq.(10) we can write by ignoring $\exp(-\frac{\gamma_{mrc}}{\gamma_{av}})$ term,

$$P_e = \frac{1}{(N-1)!}\int_0^{\infty} erfc\left(\sqrt{\gamma_{mrc}}\,c\right)\frac{\gamma_{mrc}^{N-1}}{\gamma_{av}^{N}}\,d\gamma_{mrc}(11)$$

, where c = $\sin(\frac{\pi}{M})$

Let, $x = \frac{\gamma_{mrc}}{\gamma_{av}} \quad \Rightarrow \gamma_{mrc} = x\,\gamma_{av}$

By taking the derivative of *x* we can write, $dx = \frac{1}{\gamma_{av}}d\gamma_{mrc}$

Now, from Eq. (11)

$$P_e = \frac{1}{(N-1)!}\int_0^{\infty} erfc\left(\sqrt{x\,\gamma_{av}}\,c\right)x^{N-1}\,dx \quad (12)$$

Again, $y = x\,\gamma_{av} \Rightarrow x = \frac{y}{\gamma_{av}}$

By taking the derivative of *x* we can write, $dx = \frac{dy}{\gamma_{av}}$

Now, from Eq. (12)

$$P_e = \frac{1}{(N-1)!}\int_0^{\infty} erfc\left(\sqrt{y}\,c\right)\left(\frac{y}{\gamma_{av}}\right)^{N-1}\frac{1}{\gamma_{av}}\quad dy$$

$$= \frac{1}{(\gamma_{av})^N (N-1)!} \int_0^{\infty} erfc\left(\sqrt{y}\, c\right) (y)^{N-1} \quad dy$$

$$= \frac{1}{(\gamma_{av})^N (N-1)!} \times \frac{c}{\sqrt{\pi}\, N} \times \frac{\left(N-\frac{1}{2}\right)!}{(c^2)^{N+\frac{1}{2}}} [\text{Using Integral }, \int_0^{\infty} x^n e^{-ax} dx = \frac{n!}{a^{n+1}}]$$

$$= \frac{c}{\sqrt{\pi}\, (\gamma_{av})^N (c^2)^{N+\frac{1}{2}}} \times \frac{\left(N-\frac{1}{2}\right)!}{N!}$$

$$= \frac{c}{\sqrt{\pi}\, (\gamma_{av})^N (c^2)^{N+\frac{1}{2}}} \times \frac{\sqrt{\pi}\,(2N)!}{2^{2N} (N!)^2}$$

Now by replacing $c = \sin(\frac{\pi}{M})$, the probability of symbol error for M-ary PSK in MRC Receiver Diversity is,

$$P_e = \frac{\sin\left(\frac{\pi}{M}\right)(2N)!}{2^{2N} (\gamma_{av})^N \left[\left\{\sin\left(\frac{\pi}{M}\right)\right\}^2\right]^{N+1/2} (N!)^2} \quad (13)$$

For M-ary QAM (where M= 2^k signal points and k is even)

$$Prob(error|\gamma_{mrc}) = \frac{3}{2}\ erfc\ [\sqrt{\frac{3}{2(M-1)}\gamma_{mrc}}]$$

From Eq.(10) we can write ignoring $\exp(-\frac{\gamma_{mrc}}{\gamma_{av}})$ term,

$$P_e = \frac{3}{2(N-1)!} \int_0^{\infty} erfc\left(\sqrt{\frac{3}{2(M-1)}\gamma_{mrc}}\right) \frac{\gamma_{mrc}^{N-1}}{\gamma_{av}^{N}}\, d\gamma_{mrc} \quad (14)$$

Let, $x = \frac{\gamma_{mrc}}{\gamma_{av}} \quad \Rightarrow \gamma_{mrc} = x\, \gamma_{av}$

By taking the derivative of *x* we can write, $dx = \frac{1}{\gamma_{av}} d\gamma_{mrc}$

Now, from Eq. (14)

$$P_e = \frac{3}{2(N-1)!} \int_0^{\infty} erfc\left(\sqrt{\frac{3}{2(M-1)} x\, \gamma_{av}}\right) x^{N-1}\, dx \quad (15)$$

Again, $y = \frac{3}{2(M-1)} x \gamma_{av} \Rightarrow x = \frac{2(M-1)y}{3\, \gamma_{av}}$, if we consider $c = \frac{2(M-1)}{3}$ then , $x = \frac{cy}{\gamma_{av}}$

By taking the derivative of *x* we can write, $dx = \frac{c\, dy}{\gamma_{av}}$

Now, from Eq. (15)

$$P_e = \frac{3}{2(N-1)!} \int_0^{\infty} erfc\left(\sqrt{y}\right) \left(\frac{cy}{\gamma_{av}}\right)^{N-1} \frac{c}{\gamma_{av}} \quad dy$$

$$= \frac{3}{2\left(\frac{\gamma_{av}}{c}\right)^{N}(N-1)!}\int_{0}^{\infty} erfc\left(\sqrt{y}\right)(y)^{N-1}\ \ dy$$

$$= \frac{3}{2\sqrt{\pi}\left(\frac{\gamma_{av}}{c}\right)^{N}} \times \frac{\left(N-\frac{1}{2}\right)!}{N!}$$

Now by replacing, $c = \frac{2(M-1)}{3}$, the probability of symbol error for M-ary QAM in MRC receiver diversity is,

$$P_e = \frac{3}{2\sqrt{\pi}\left[\frac{3\,\gamma_{av}}{2(M-1)}\right]^{N}} \times \frac{\sqrt{\pi}\,(2N)!}{2^{2N}(N!)^2}$$

$$= \frac{3^{1-N}(2N)!}{2^{1+N}\left(\frac{\gamma_{av}}{M-1}\right)^{N}(N!)^2} \quad (16)$$

4. RESULTS AND DISCUSSIONS

To compare the performance of a maximal ratio combining diversity receiver for different modulation schemes, we conduct MATLAB simulation using the parameters shown in Table-I. These parameters were selected based on the IEEE802.11a standard. The simulation results are presented in Fig. 3. Note that in all the tables and the figures in this paper, the notation *i* is used to denote the number of received antenna for maximal-ratio combiner. Hence *i=1* means that no diversity scheme is used.

TABLE I. SELECTED SIMULATION PARAMETERS

Modulation	64-PSK/64-QAM/16-PSK/16-QAM/QPSK
Bit rate	13Mbps
FFT size nFFT	64
Number of used subcarriers nDSC	52
Pilot subcarrier	4
FFT Sampling frequency	20 MHz
Sub-carrier spacing	312.5 kHz
Cyclic prefix duration, T_{cp}	0.8us
Data symbol duration, T_d	3.2us
Total Symbol duration, T_s	4us

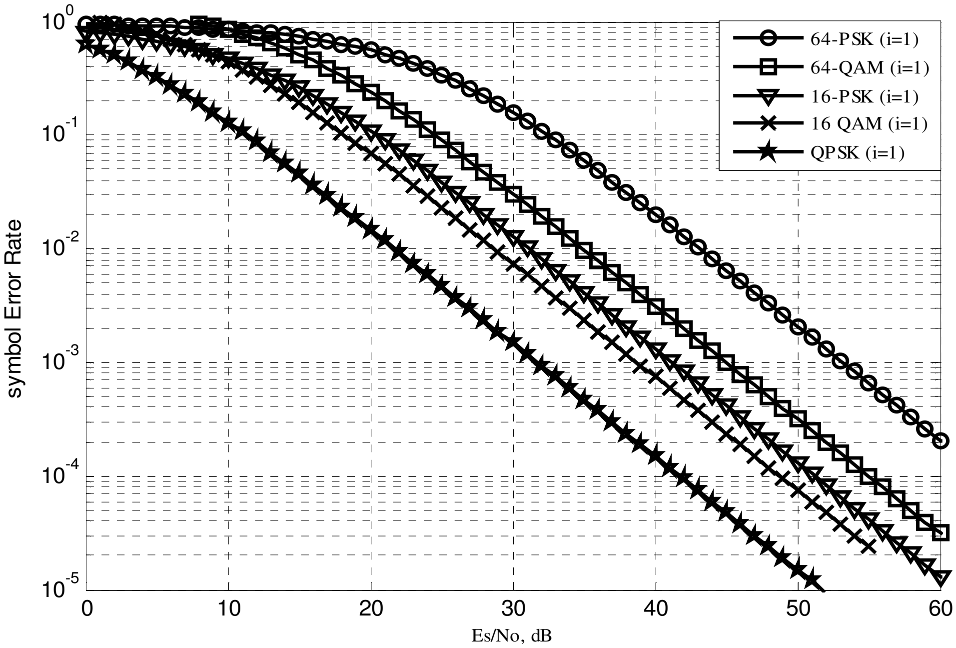


Figure 3. SER comparison in OFDM system with different modulation schemes for single antenna receiver.

The SER comparisons for different modulation schemes namely QPSK, 16-QAM, 16-PSK, 64-QAM, and 64-PSK using OFDM techniques without received diversity scheme are presented in Fig. 3. It is depicted in the figure that to maintain SER at 10^{-3}, QPSK, 64-PSK, 64-QAM, 16-PSK, and 16-QAM should maintain the SNR values at 30dB, 53 dB, 45 dB, 40dB and 38 dB respectively. To send 6 information bits (2^6=64) using one signal point, about 8 dB less SNR is required using 64-QAM scheme in OFDM technique compared to 64-PSK modulation scheme. Whereas only 2 dB less SNR is required for 16-QAM compared to 16-PSK modulation scheme. The QAM scheme shows always better performance compared to PSK modulation scheme in OFDM system. In Fig. 4, the performance of these modulation schemes using two receiving antenna diversity is presented for maximal ratio combining technique in OFDM system. To maintain the SER at 10^{-3}, only 2 dB SNR improvement is found for 64-QAM compared to 64-PSK. The same SNR improvement is also reported for 16-QAM over 16-PSK. In this case, about 10-18 dB diversity gain is found.The reason for this kind of improvement is that a Rayleigh fading channel appears to be an AWGN channel due to maximal ratio combining techniques used in the receiver. Using two antennasreceiving maximal-ratio diversity, 22 dB diversity gains is found for QPSK modulation scheme.

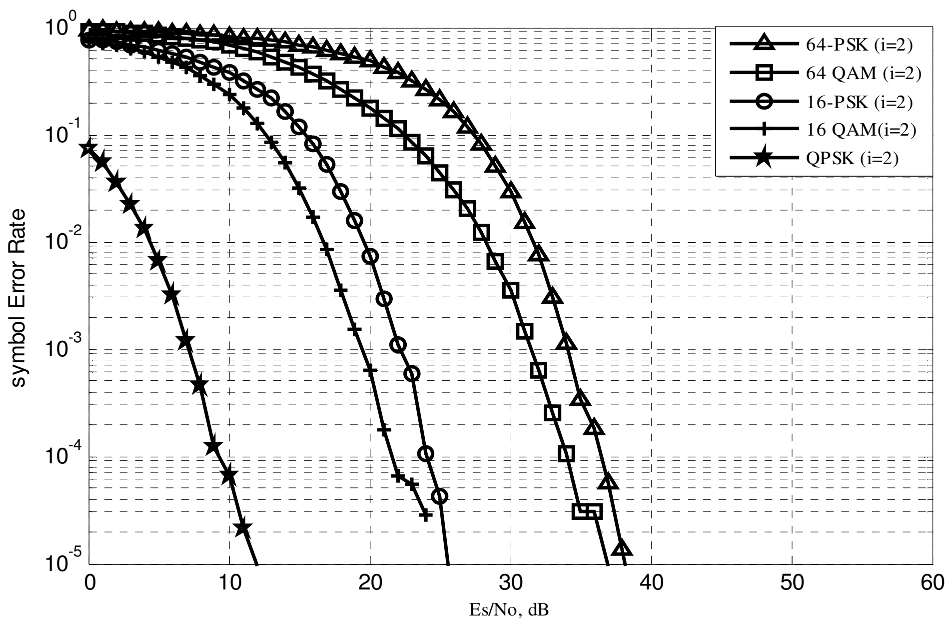


Figure 4. SER comparison in OFDM system with application of MRC diversity for i=2

The performance of the maximal ratio combining scheme by using three antennas is depicted in Fig. 5. For this scenario, the diversity gains for 64-PSK, 64-QAM, 16-PSK, 16-QAM, and QPSK are found respectively 23 dB, 17 dB, 22 dB, 22 dB, and 26 dB.By adding one more receiving antenna the simulations were repeated and the results are presented in Fig. 6.

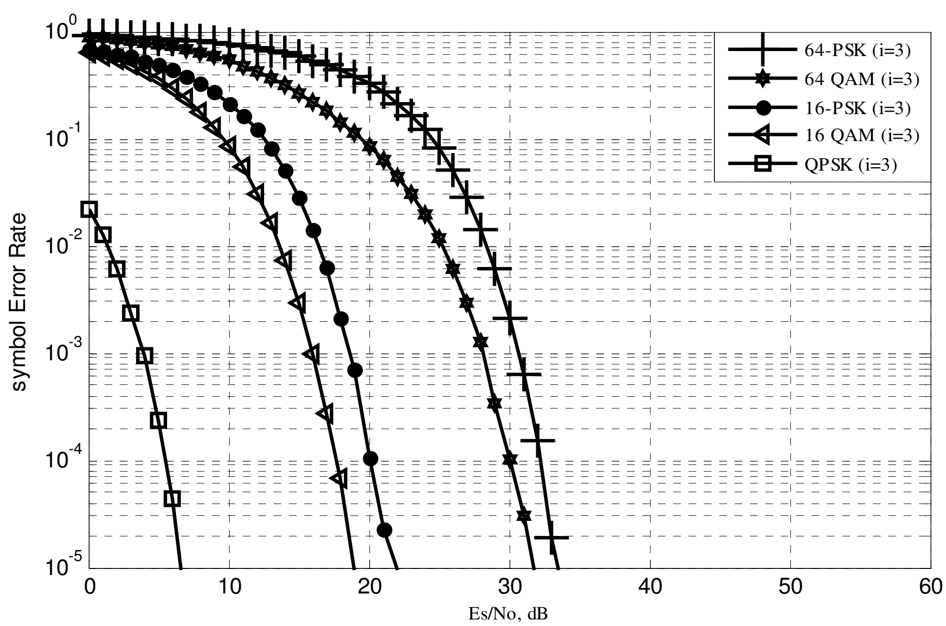


Figure 5. SER comparison in OFDM system with application of MRC diversity for i=3

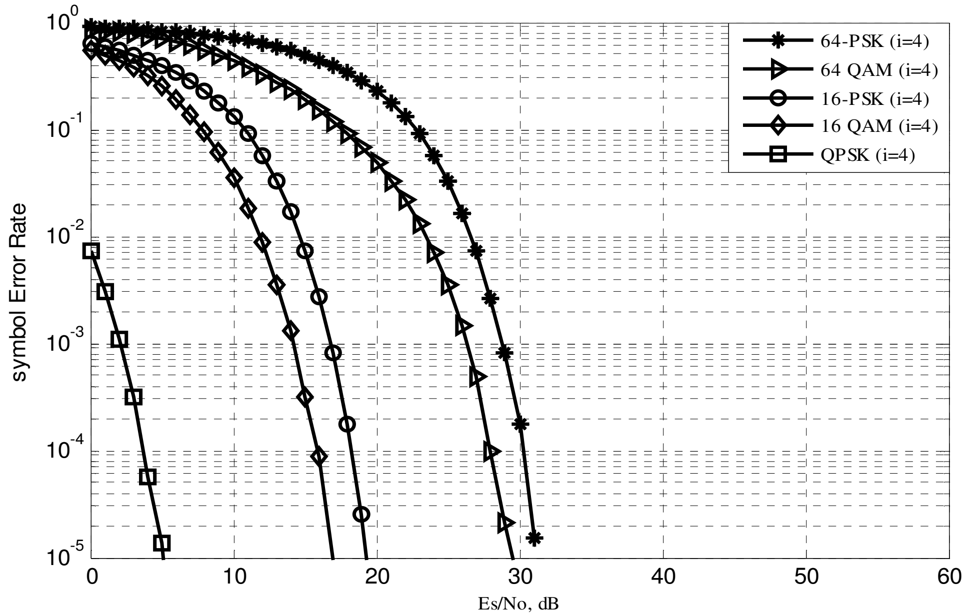


Figure6. SER comparison in OFDM system with application of MRC diversity for i=4.

This figure shows the effect of using four antennas in maximal ratio diversity scheme. Here 1 dB more diversity gain is achieved compared to three antennas receiving diversity found for 64-PSK and 64-QAM and 2 dB more diversity gain is achieved for the rest of the modulation schemes.To summarize different diversity received antennas performance at SER of 10^{-3}, the required SNR is estimated in Table-II for maximal-ratio combiner in an OFDM system.

TABLE II. SNR FOR DIFFERENT MODULATION SCHEME FOR i=1, 2, 3,4

ModulationScheme	**SNR for i=1 at SER 10^{-3}**	**SNR for i=2 at SER 10^{-3}**	**SNR for i=3 at SER 10^{-3}**	**SNR for i=4 at SER 10^{-3}**
64-PSK	53 dB	34 dB	30 dB	29 dB
64-QAM	45 dB	32 dB	28 dB	27 dB
16-PSK	40 dB	22 dB	18 dB	16 dB
16- QAM	38 dB	20 dB	16 dB	14 dB
QPSK	30 dB	8 dB	4 dB	2 dB

The reasons of why more diversity gain is found for increased received antennas are illustrated in Fig. 7[25]. In this figure, the outage probability of maximal-ratio combining is computed for varying received antennas. The outage probability of a diversity combiner is defined as the percentage of time the instantaneous output signal-to-noise ratio of the combiner is below some prescribed level for a specified number of branches.

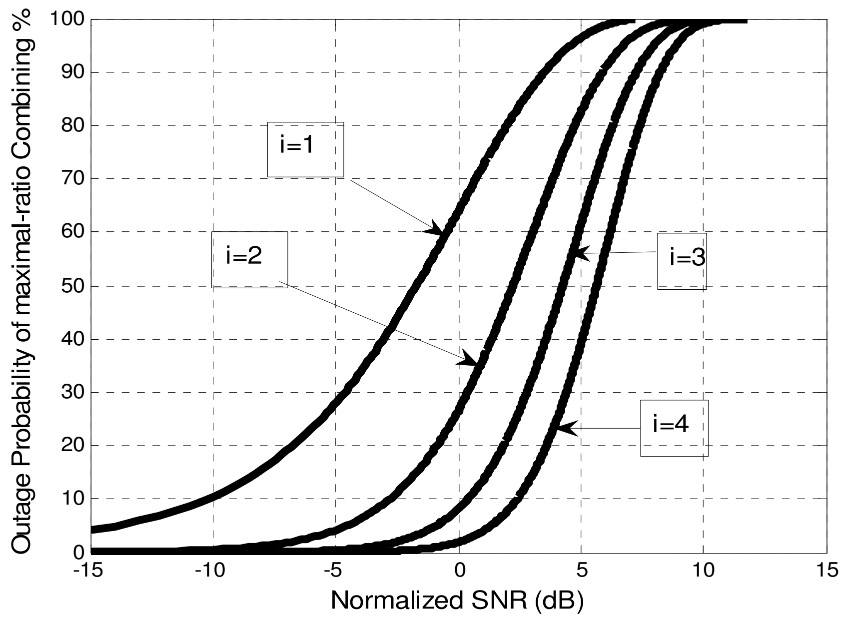


Figure 7. Outage probability of maximal-ratio combiner for a varying number *i* of received antennas.

Using cumulative distribution function plotted in Fig. 7we can conclude that more diversity gain is found for varying received antenna for maximal-ratio combining technique. For example, at SNR of 5dB, the outage probabilities for *i*=1, 2, 3 and 4 are found 95%, 82%, 60%, and 40% respectively.

5. CONCLUSION

In this paper, the diversity gain is mathematically computed and simulated by varying the number of receiving antennas using maximal-ratio combining technique in an OFDM system. It is shown in this paper that aRayleigh fading channel acts as an AWGN channel in the receiving antenna if diversity combining technique is used. The diversity gains found in maximal-ratio diversity combiner technique for different number of antennas is listed in Table-III.

TABLEIII. DIVERSITY GAIN FOR DIFFERENT MODULATION SCHEME FOR i=1, 2, 3, 4

ModulationScheme	**Diversity Gain for i=2 at SER 10^{-3}**	**Diversity Gain for i=3 at SER 10^{-3}**	**Diversity Gain for i=4 at SER 10^{-3}**
64-PSK	19dB	23 dB	24 dB
64 -QAM	13 dB	17dB	18 dB
16-PSK	18 dB	22 dB	24 dB
16- QAM	18 dB	22 dB	24 dB
QPSK	22 dB	26 dB	28 dB

The diversity gain comparisons for QPSK, 16-QAM, 16-PSK, 64-QAM, and 64-PSK modulation schemes using OFDM techniques with received diversity scheme are presented in Table-III. Based on the findings listed in the table we can conclude that as the number of antenna increases, the diversity gain also increases for the same modulation scheme. It is also clearly shown in the same table that M-QAM based OFDM technique always shows better performance compared to M-PSK based OFDM technique.

FURTHER WORK

In future, we can mathematically analyze and simulate the performance of MIMO system in OFDM with MRC diversity scheme. And, also we want to compare this system in advanced communication system like in IEEE 802.11 b/g/n, IEEE 802.16 e/d/g standard.

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