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Comparative Study of Different Modulation Techniques with MRC and SC over Nakagami and Ricean Fading Channel

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***Abstract*—This paper represents the comparative study of different M-ary modulation techniques. To complete this task, we have analyzed the error performance of various M-ary systems with Maximal Ratio Combining (MRC) and Selection Combining (SC) over Nakagami and Ricean Fading Channels. The accuracy of the SER is evaluated by some mathematical expression which is verified through the comparison with the result.**

***Index Terms*—Maximal Ratio Combining, Selection Combining, Nakagami Fading, Ricean Fading.**

I. INTRODUCTION

Fading is a ubiquitous problem in modern digital wireless communication system. To eliminate this problem, various modulation techniques are represented in this paper with MRC and SC over Nakagami and Ricean fading channel. All the performances are measured on the basis of signal error rate (SER). This paper shows that the performance of modulation schemes with maximal ratio combining (MRC) is better than selection combining (SC) in Nakagami-m Fading Channel. We have compared the performance analysis of M-ary modulation techniques with MRC diversity over Ricean fading channel. Then, we have compared various modulation schemes over Nakagami and Ricean fading channel. This comparison has shown that the performance of M-ary systems with MRC fading channel.

Here is manifested that M-ary QAM has been recently proposed for wireless communications because of its smallest SER which is also shown in this paper.

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II. BACKGROUND

The probability density function (pdf) of the instantaneous received SNR per symbol ρ_i on the ith branch of a receiver with diversity combining over Nakagami-m distribution is given by [1], [2]

$$P(\rho_i) = \left(\frac{m}{\Omega}\right)^{L_m} \frac{{\rho_i}^{Lm-1}}{\Gamma(\mathrm{L_m})} exp\left(-\frac{m}{\Omega}\rho_i\right) \quad 2.1$$

Where,

m=the fading severity parameter.
Ω =the average SNR per symbol per branch.
Γ(.) =gamma function.
L_m= number of diversity channel

The instantaneous received SNR per symbol γ at the output of the receiver is given by,

$$\gamma = \sum_{i=1}^{L} \rho_i \qquad \text{for MRC}$$

$$\text{and } \gamma = \max\,(\rho_1, \rho_2 \ldots\ldots \rho_L) \qquad \text{for SC}$$

The probability density function (pdf) of γ for the receiver with MRC diversity reception can be expressed as [1], [3]

$$P_{MRC}(\gamma) = \left(\frac{m}{\Omega}\right)^{L_m} \frac{\gamma^{Lm-1}}{\Gamma(\mathrm{L_m})} exp\left(-\frac{m}{\Omega}\gamma\right) \quad 2.2$$

And the pdf of γ for the case of SC diversity reception is given by [1], [4]

$$P_{SC}(\gamma) = \left(\frac{m}{\Omega}\right)^{m} \frac{l\gamma^{m-1}}{[\Gamma(\mathrm{m})]} \left\{\gamma\left(m, \frac{m\gamma}{\Omega}\right)\right\}^{l-1} exp\left(-\frac{m}{\Omega}\gamma\right)$$

2.3

The average SER at the output of the receiver can be calculated by averaging the conditional probability of error over the PDF of γ [1] i.e,

$$\bar{P} = \int_0^{\infty} P_e(\gamma) P(\gamma)\, d\gamma \quad 2.4$$

In order to find the average SER for the three 16-ary modulations (16-PAM, 16-PSK and 16-QAM), we can use the integral form of (2.4). From the [1], we get the following integral form.

$$I_{MRC}(A) = \int_0^{\infty} erfc(\sqrt{A\gamma})\, P_{MRC}(\gamma) d\gamma \quad 2.5$$

Where, erfc (.) is the complementary error function. After substituting (2.2) into (2.5) and using a relation in [5], $I_{MRC}(A)$ becomes,

$$I_{MRC}(A) = 2\left(\frac{1-\mu_c}{2}\right)^{L_m} \sum_{k=0}^{L_{m-1}} \binom{L_{m-1+k}}{k} \left(\frac{1-\mu_c}{2}\right)^{k} \quad 2.6$$

Where

$$\mu_c = \sqrt{\frac{\Omega/m}{1/A+\Omega/m}}$$

And $I_{SC}(A)$ can be found as [1],

$$I_{SC}(A) = \int_0^{\infty} erfc(\sqrt{A\gamma})\, P_{SC}(\gamma) d\gamma \quad 2.7$$

After substituting (2.3) into (2.7) and using a relation in [1], [6], $I_{SC}(A)$ becomes,

$$I_{SC}(A) = 2L \sum_{l=0}^{L-1} \sum_{k=0}^{l(m-1)} \sum_{n=0}^{m+k-1} (-1)^l \binom{L-1}{l} \frac{b_k^l}{(l+1)^{m+k}} * \frac{\Gamma(m+n+k)}{\Gamma(m)\Gamma(n+1)} \left(\frac{1-\mu_d}{2}\right)^{m+k} \left(\frac{1+\mu_d}{2}\right)^{n} \quad 2.8$$

Where

$$\mu_d = \sqrt{\frac{\Omega/m(l+1)}{1/A+\Omega/m(l+1)}}$$

Finally, the following integral is considered,
And it can be expressed as [1], [7]

$$I_1(p,q,r) = \left(\frac{1}{p}\right)^r \left\{ \frac{\Gamma(r)}{\left(\frac{q}{p}\right)^r} - \frac{4}{\pi\left(\frac{q}{p}\right)^r} \sum_{k=o}^{r-1} \frac{\Gamma(r)}{2k+1} \left(\frac{q}{p}\right)^k * 2F_1\left(\frac{1}{2}+k, 1+k, \frac{3}{2}+k; -\left(\frac{q}{p}\right)-1\right) \right\}$$

2.9

Where, $2F_1(a,b,c;x)$ is the Gauss hypergeometric function.

III. PERFORMANCE ANALYSIS OF VARIOUS M-ARY MODULATION TECHNIQUES WITH MRC AND SC IN NAKAGAMI FADING CHANNEL

The average SER at the output of the receiver can be calculated by averaging the conditional probability of error over the PDF of γ and the average SER of 16-PSK, 16-PAM and 16-QAM are given by [1], [8]-[10],

$$P_{e,16psk}(\gamma) = erfc\left[\sqrt{\left(\frac{1-Cos(\pi/8)}{2}\right)\gamma}\right] \quad 2.10$$

$$P_M(\gamma_S) = 2\left(1-\frac{1}{M}\right) Q\left(\sqrt{\frac{6}{M^2-1}\gamma_S}\right) \quad 2.11$$

$$P_{e,16QAM}(\gamma) \cong \frac{3}{2} erfc\left(\sqrt{\frac{2}{5}\gamma}\right) - \frac{9}{16} erfc^2\left(\sqrt{\frac{2}{5}\gamma}\right)$$

$$I_{SC}(A) = 2L \sum_{l=0}^{L-1} \sum_{k=0}^{l(m-1)} \sum_{n=0}^{m+k-1} (-1)^l \binom{L-1}{l} \frac{b_k^l}{(l+1)^{m+k}}$$

2.12

2.11 can be represented in error function as

$$P_M(\gamma_S) = \left(1-\frac{1}{M}\right) erfc\left(\sqrt{\frac{6}{M^2-1}\gamma_S}\right)$$

After the substitution of 2.10), (2.11) and (2.12) with (2.2) into (2.4), the average SER of 16-PSK, 16-PAM and 16-QAM with MRC diversity reception over Nakagami-m fading channels can be calculated as,

$$\bar{P}_{MRC,16PSK} = I_{MRC}\left(\frac{1-Cos(\pi/8)}{2}\right) \quad 2.13$$

$$\bar{P}_{MRC,16PAM} = I_{MRC}\left(\sqrt{\frac{6}{M^2-1}}\right) \quad 2.14$$

$$\bar{P}_{MRC,16QAM} = \frac{3}{2} I_{MRC}\left(\frac{2}{5}\right) - \frac{9}{16\Gamma(L_m)} \left(\frac{m}{\Omega}\right)^{L_m} * I_1\left(\frac{2}{5}, \frac{m}{\Omega}, L_m\right)$$

2.15

After the substitution of (2.10), (2.11) and (2.12) with (2.3) into (2.4), the average SER of 16-PSK, 16-PAM and 16-QAM with SC diversity reception over Nakagami-m fading channels can be calculated as,

$$\bar{P}_{SC,16PSK} = I_{SC}\left(\frac{1-Cos(\pi/8)}{2}\right) \quad 2.16$$

$$\bar{P}_{SC,16PAM} = I_{SC}\left(\sqrt{\frac{6}{M^2-1}}\right) \quad 2.17$$

$$\bar{P}_{SC,16QAM} = \frac{3}{2} I_{SC}\left(\frac{2}{5}\right) - \frac{9L}{16\Gamma(m)} \sum_{l=0}^{L-1} \sum_{k=0}^{l(m-1)} (-1)^l * b_k^l \binom{L-1}{l} \left(\frac{m}{\Omega}\right) * I_1\left(\frac{2}{5}, (l+1)\frac{m}{\Omega}, m+k\right)^{m+k}$$

2.18

IV. PERFORMANCE ANALYSIS OF M-ARY SYSTEMS WITH MRC OVER RICEAN FADING CHANNEL

The average probability of symbol error for PAM over AWGN is given in [8], [11] as

$$P_M(\gamma_s) = 2\left(1-\frac{1}{M}\right) Q\left(\sqrt{\frac{6}{M^2-1}\gamma_s}\right) \quad 3.1$$

Where, Q (.) is the Gaussian tail function,
We have the probability density function (pdf) of Ricean factor

$$P_{ricean}(\gamma_s) = \frac{\gamma_s}{\sigma^2} \exp\left(-\frac{\gamma_s^2+\mu^2}{2\gamma_s^2}\right) I_0\left(\frac{\gamma_s\mu}{\sigma^2}\right), \gamma_s \geq 0 \quad 3.2$$

By substituting (3.1) and (3.2) into (2.4) we have the average symbol error probability (SEP) of an M-ary PAM system over Ricean fading channels is

$$P_{PAM,ricean,M} = \int_0^{\infty} 2\left(1-\frac{1}{q}\right) Q\left(\sqrt{\frac{6}{q^2-1}\gamma_s}\right) \frac{1}{\overline{\gamma_c^2}\Gamma(L)} \gamma_s^{L-1} e^{\frac{-\gamma_s}{\overline{\gamma_c}}} d\gamma_s$$

3.3

After solving (3.3) we have the closed form symbol error probability for PAM is [11]

$$P_{PAM,ricean,M} = \left(1-\frac{1}{M}\right) \sum_{n=0}^{\infty} \frac{(LK)^n e^{-LK}}{\Gamma(n+1)} * \left[1 - \sum_{i=0}^{L+n-1} \mu \left(\frac{1-\mu^2}{4}\right)^i \binom{2i}{i}\right] \quad 3.4$$

Now the symbol error probability for M-ary PSK for an AWGN channel is given in [11], [12] as

$$P_{PSK,AWGN,M}(\gamma_s) = 2Q\left(\sqrt{2\gamma_s}\sin\frac{\pi}{M}\right) - \frac{1}{\pi} \int_{\frac{\pi}{2}-\frac{\pi}{M}}^{\frac{\pi}{2}} e^{-\gamma_s\left(\frac{\sin\pi/M}{\cos\theta}\right)^2} d\theta$$

3.5

But for large SNR and large values of M

$$\int_{\frac{\pi}{2}-\frac{\pi}{M}}^{\frac{\pi}{2}} e^{-\gamma_s\left(\frac{\sin\pi/M}{\cos\theta}\right)^2} d\theta = 0$$

Details calculation has been shown in Apendix I.
So, the approximation is

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$$P_M(\gamma_s) = 2Q\left(\sqrt{2\gamma_s}\sin\frac{\pi}{M}\right) \quad 3.6$$

Now from (2.4) we have the error probability of the system is

$$P_{M,Ricean} = \int_0^{\infty} P_M(\gamma_s)\, P_{Ricean}(\gamma_s)\, d\gamma_s \quad 3.7$$

Again the probability density function (pdf) of Ricean factor, we have

$$P_{Ricean}(\gamma_s) = \frac{\gamma_s}{\sigma^2}\exp\left(-\frac{\gamma_s^2+\mu^2}{2\gamma_s^2}\right) I_0\left(\frac{\gamma_s\mu}{\sigma^2}\right), \gamma_s \geq 0 \quad 3.8$$

By substituting (3.6) and (3.8) into (3.7) we have the average symbol error probability (SEP) of an M-ary PSK system over Ricean fading channels is

$$P_{PSK,Ricean,M} = \sum_{n=0}^{\infty}\frac{(LK)^n e^{-LK}}{\Gamma(n+1)}\left[1-\sum_{i=0}^{L+n-1}\mu\left(\frac{1-\mu^2}{4}\right)^i \binom{2i}{i}\right]$$

3.9

Where, $\mu = \sqrt{\frac{\sin^2\frac{\pi}{M}\overline{\gamma}_c}{1+\sin^2\frac{\pi}{M}\overline{\gamma}_c}}$

Rectangular QAM signal are equivalent to two PAM signals on quadrature carriers. When K is even, for M-ary, $M=2^K$ the system error probability is given in [11], [13] as

$$P_q = 1-(1-P_{\sqrt{M}})^2 \quad 3.10$$

where

$$P_{\sqrt{M}} = 2\left(1-\frac{1}{\sqrt{M}}\right) Q\left(\sqrt{\frac{3}{M-1}\gamma_s}\right)$$

Substituting (3.8) and (3.10) in (3.7), we have the average symbol error probability (SEP) of an M-ary QAM system over Ricean fading channels [13] is

$$P_{QAM,Ricean,M} = 1-(1-P_{QAM,Ricean,\sqrt{M}})^2 \quad 3.11$$

Where

$$P_{QAM,Ricean,\sqrt{M}} = \left(1-\frac{1}{\sqrt{M}}\right)\sum_{n=0}^{\infty}\frac{(LK)^n e^{-LK}}{\Gamma(n+1)} * \left[1-\sum_{i=0}^{L+n-1}\mu\left(\frac{1-\mu^2}{4}\right)^i \binom{2i}{i}\right]$$

Where, $\mu = \sqrt{\frac{3\overline{\gamma}_c}{M^2-2+3\overline{\gamma}_c}}$

So, we have

$$P_{QAM,Ricean,M} = \lambda\sum_{n=0}^{\infty}\frac{(LK)^n e^{-LK}}{\Gamma(n+1)}\left[1-\sum_{i=0}^{L+n-1}\mu\left(\frac{1-\mu^2}{4}\right)^i \binom{2i}{i}\right] \quad 3.12$$

Where, $\mu = \sqrt{\frac{3\overline{\gamma}_c}{M^2-1+3\overline{\gamma}_c}}$

and $\lambda = \left(1-\frac{1}{M}\right)$

V. NUMERICAL RESULT

For section III, the numerical values of the average symbol error rate (SER) for the three 16-ary modulation techniques with L=2, 3, 4 diversity branches are plotted in Fig 2.1 to Fig 2.3. For the case of 16-PSK in Fig. 2.1, with the fixed value of SNR of 15 dB, symbol error rates are 0.65, 0.20, 0.006 for L=2, 3, 4 MRC diversity receptions. The corresponding values for SC diversity receptions are 0.8, 0.75, and 0.7. The symbol error rates of M-ary with MRC are smaller than SC. So, the M-ary modulation systems with MRC shows better performances than SC .Here is also shown that 16-QAM with MRC shows better performances than other 16- ary modulation techniques because of the lowest symbol error rate (SER)of 16-QAM than others. That is why, M-ary QAM has been recently proposed for wireless communications.

For section IV, The symbol error rate of 16-PAM over Ricean fading channels with different Ricean parameters K and different orders of channel diversity are shown in Fig. 3.1 to Fig. 3.3. For the fixed values of K, with the increasing of the channel diversity L, the symbol error rate is decreasing, thus it shows better performances for the larger value of L. The symbol error probability of 16-PSK over Ricean fading channels with different Ricean parameters K and different orders of channel diversity are shown in Fig. 3.4 to 3.6. PSK also shows better performances for the larger value of L.

With the help of section II and IV, The symbol error probability of 16-PAM and 16-QAM with MRC diversity over Nakagami and Ricean fading channels with the fixed value of m=5 and different orders of channel diversity L=2,3,4 are shown in the Fig. 4.1 to Fig. 4.4. In 16-PAM and 16-QAM, the symbol error probability is decreased with the increasing of the value of L. From Fig. 5.1 and Fig. 5.2, it is shown that for the same value of L, the performance of Nakagami fading channel for 16-PAM and 16-QAM with MRC is better than Ricean fading channel.

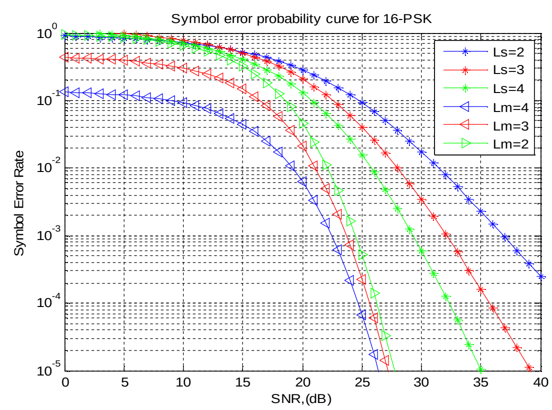

Fig. 2.1 Averages SER Vs SNR of 16-PSK with MRC and SC over Nakagami fading channel

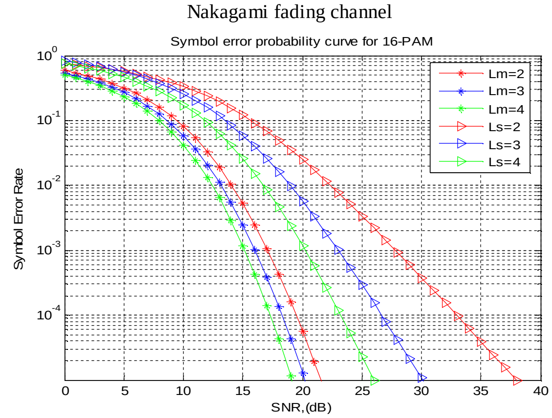

Fig. 2.2 Averages SER Vs SNR of 16-PAM with MRC and SC over Nakagami fading channel

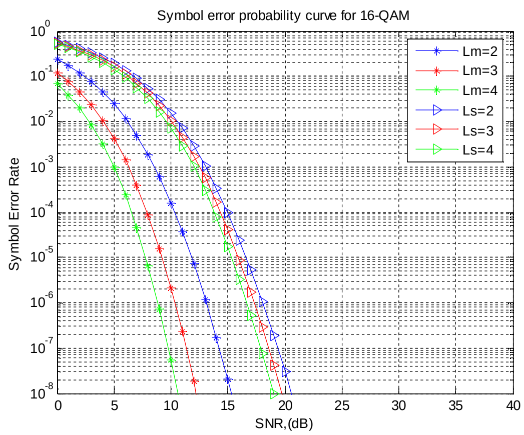

Fig. 2.3 Average SER Vs SNR of 16- QAM with MRC and SC over Nakagami fading channel

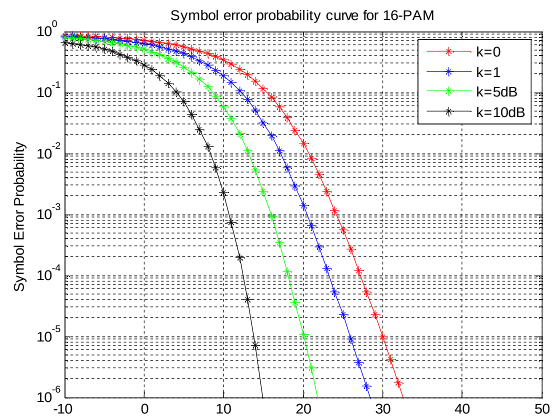

Fig. 3.3 Exact symbol error probability for 16-PAM over Ricean fading channel when L=4

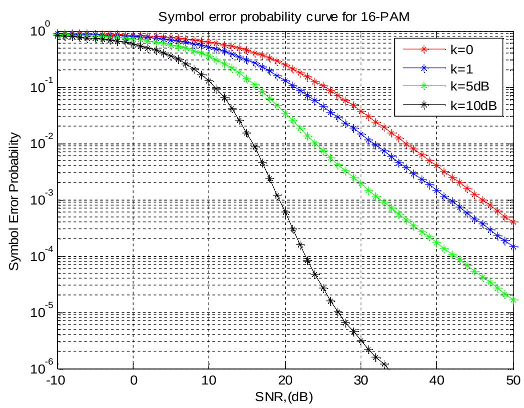

Fig. 3.1 Exact symbol error probability for 16-PAM over Ricean fading channel when L=1

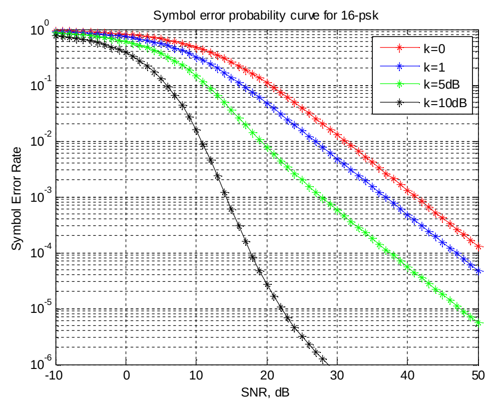

Fig. 3.4 Exact symbol error probability for 16-PSK over Ricean fading channel when L=1

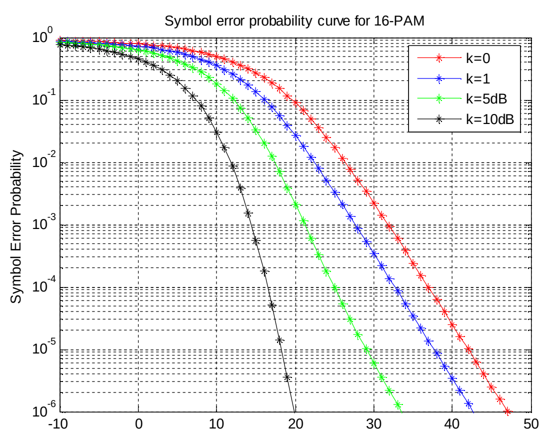

Fig. 3.2 Exact symbol error probability for 16-PAM over Ricean fading channel when L=2

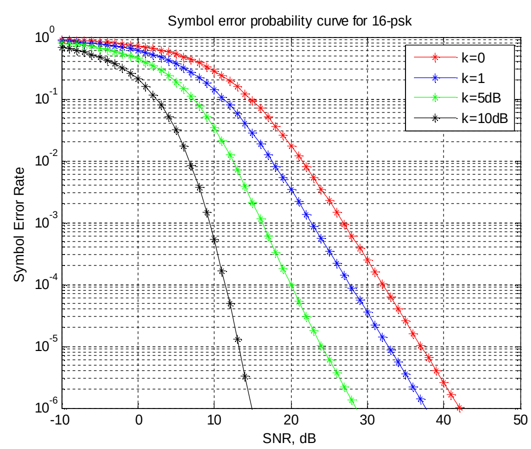

Fig. 3.5 Exact symbol error probability for 16-PSK over Ricean fading channel when L=2

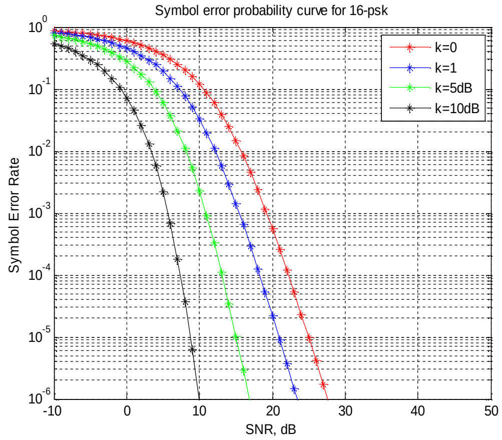

Fig. 3.6 Exact symbol error probability for 16-PSK over Ricean fading channel when L=4

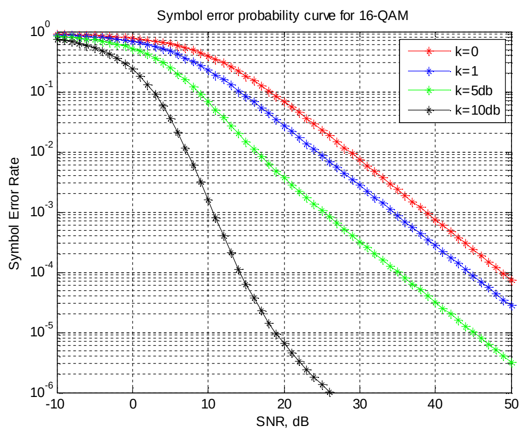

Fig. 3.7 Exact symbol error probability for 16-QAM over Ricean fading channel when L=1

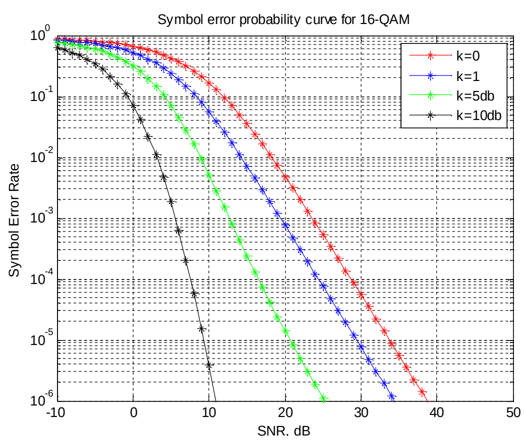

Fig. 3.8 Exact symbol error probability for 16-QAM over Ricean fading channel when L=2.

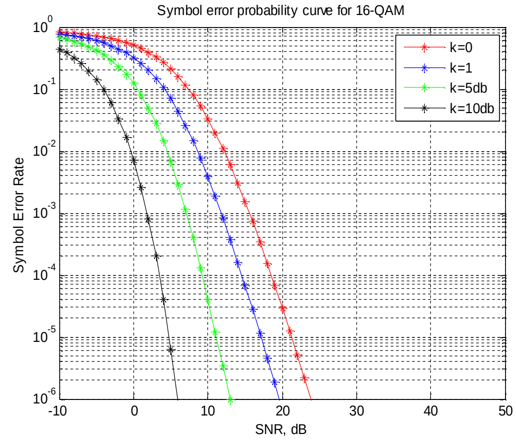

Fig. 3.9 Exact symbol error probability for 16-QAM over Ricean fading channel when L=4.

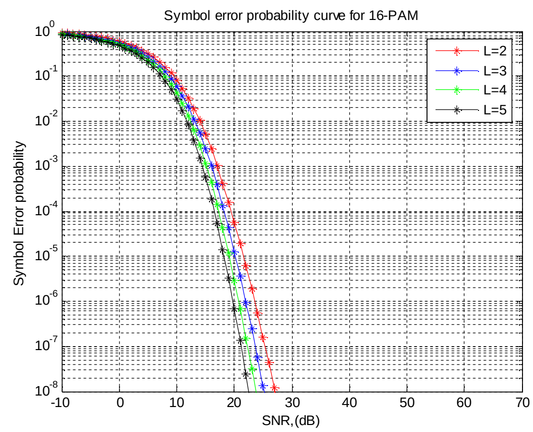

Fig. 4.1 Average SER (Vs SNR) of 16-PAM over Nakagami-m fading channels with m=5.

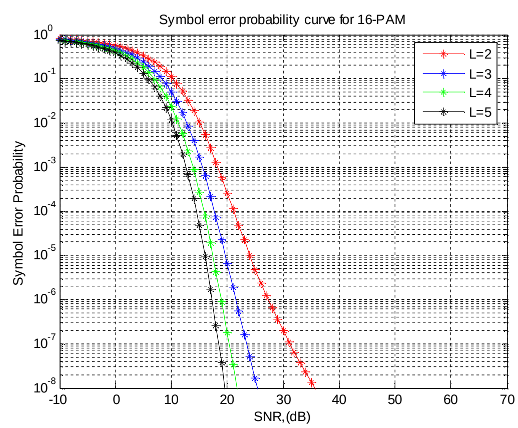

Fig. 4.2 Average SER (Vs SNR) of 16-PAM over Ricean fading channel with k=5.

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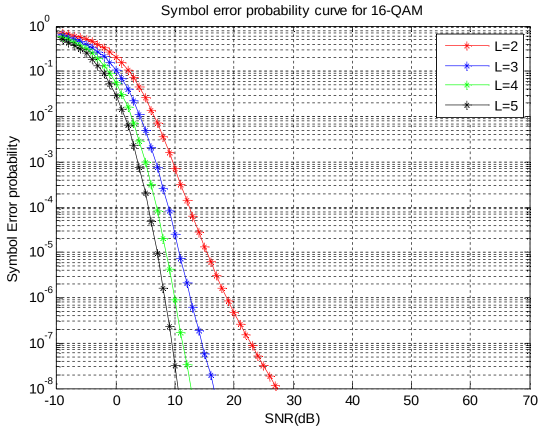

Fig. 4.3 Average SER (Vs SNR) of 16-QAM over Nakagami-m fading channels with m=5.

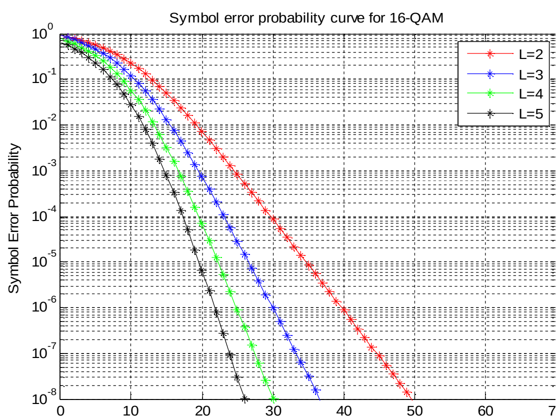

Fig. 4.4 Average SER (Vs SNR) of 16-QAM over Ricean fading channels with k=5.

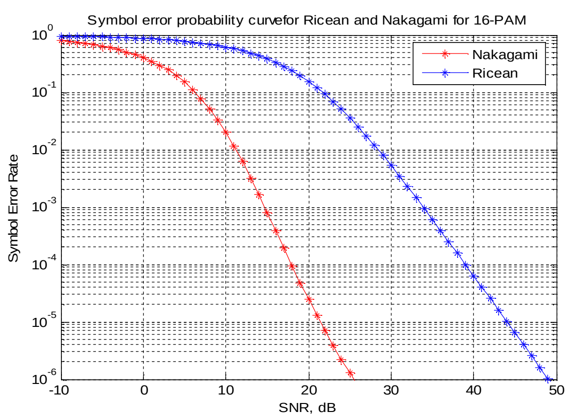

Fig. 5.1 Average SER (Vs SNR) of 16-PAM for Nakagami and Ricean fading channels

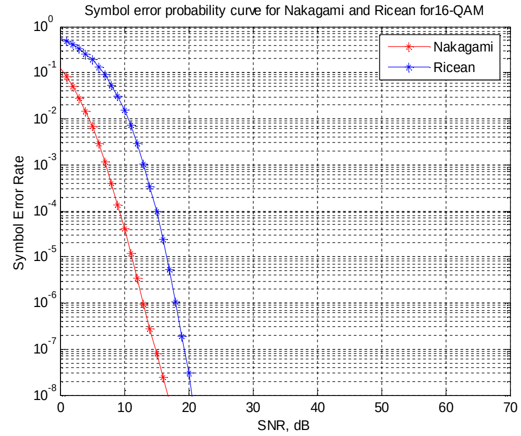

Fig. 5.2 Average SER (Vs SNR) of 16-QAM for Nakagami and Ricean fading channels

VI. CONCLUSION

In this paper, we have studied performance analysis of various modulation systems with MRC and SC over Nakagami and Fading Channel In this analysis, it is shown that modulation techniques with maximal ratio combining (MRC) is better than selection combining (SC) over Nakagami-m fading channel. As, better result is found in the case of MRC so we feel interest to compare the analysis of M-ary systems with MRC diversity between Nakagami and Ricean fading channel. After comparing this analysis, it is seen that M-ary systems with MRC diversity over Nakagami-m fading channel shows better performance than Ricean fading channel. We have also studied performance analysis of symbol error rate (SER) for M-ary systems with different orders of channel diversity and values of K over Ricean fading channel. In this analysis, it is shown that symbol error rates (SER) are decreasing with the increasing of channel diversity L and values of K. So, we can say M-ary systems with larger channel diversity L and values of K gives better performance. Here is also shown that the SER of M-ary QAM is the smallest among other modulation techniques. So, M-ary QAM has been recently proposed for wireless communications.

APPENDIX I

$$P(\gamma) = \int_0^\infty P_M(\gamma_s) P_{Ricean}(\gamma_s)\, d\gamma_s$$

$$= \int_0^\infty \left(-\frac{1}{\pi}\right) \int_{\frac{\pi}{2}-\frac{\pi}{M}}^{\frac{\pi}{2}} e^{-\gamma_s\left(\frac{\sin\pi/_M}{\cos\theta}\right)^2} d\theta * P_{Ricean}(\gamma_s)\, d\gamma_s$$

$$= -\frac{1}{\pi}\int_0^\infty P_{Ricean}(\gamma_s)\left(\int_{\frac{\pi}{2}-\frac{\pi}{M}}^{\frac{\pi}{2}} e^{-\gamma_s \sin^2\frac{\pi}{M}\sec^2\theta} d\theta\right) d\gamma_s$$

$$= -\frac{1}{\pi}\int_0^\infty P_{Ricean}(\gamma_s)\left(\frac{e^{-\gamma_s \sin^2\frac{\pi}{M}\sec^2\theta}}{2\sec^2\theta\tan\theta}\right)_{\frac{\pi}{2}-\frac{\pi}{M}}^{\frac{\pi}{2}} d\gamma_s$$

$$= -\frac{1}{\pi}\int_0^\infty P_{Ricean}(\gamma_s) * (0) d\gamma_s$$

$$= 0$$

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