Further Analysis Performance on the Generalization of SC for the Reception of *M*-ary Signals on Wireless Fading Channels

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Abstract

An alternative solution to the problem of obtaining acceptable performances on a fading channel is the diversity technique, which is widely used to combat the fading effects of time-variant channels. The symbol error probability of *M*-ary DPSK (MDPSK), PSK (MPSK) and QAM (MQAM) systems using 2 branches from the branch with the largest signal-to-noise ratio(SNR) at the output of *L*-branch selection combining(SC), i.e., SC2 in frequency-nonselective slow Nakagami fading channels with an additive white Gaussian noise(AWGN) is derived theoretically. These performance evaluations allow designers to determine *M*-ary modulation methods against Nakagami fading channels.

Key words : SC2, Nakagami Fading, MDPSK, MPSK, MQAM.

Ⅰ. Introduction

In recent years, there have been increased interests in personal communication systems and wireless communications. The statistics for various fading channel models and the resulting communication evaluation have been considerably studied as summarized in [1]. The statistical properties of mobile radio environments can be often specified by the following propagation effects: 1) short-term fading, 2) long-term fading[2]. In short-term fading, the scattering mechanism only results in numerous reflected components[3]. The Rayleigh model is used to characterize this fading in small geographical areas and sometimes does not account for large scale effects like shadowing by building and hills. When the fading index in the Rician model, *K*, goes to 0, the error performances lead to those of Rayleigh fading model. In long-term fading, the change of effective height for mobile communication antenna exists due to the nature of the terrain. Its statistics follow the log-normal distribution. But the Rician model can be obtained from the direct wave and its scattering components, and both waves carry information[4]. In a celluar system, Rayleigh fading is often the feature of large cells, whereas for the cells of smaller field, the envelope fluctuations of a received signal are closer to the Rician fading that is bounded by AWGN perturbations and Rayleigh fading [5]. When *M*-ary signals experience the fading channels, diversity schemes can minimize the effects of these fadings since deep fades simultaneously occur during the same time intervals on two or more paths.

In this paper, to model the disturbances it is assumed that the channel model has independent paths with Nakagami fading statistics. We can represent the average symbol error rate (SER) by SC2 systems in receiving MDPSK, MPSK, and MQAM signals on this fading channel. Especially we evaluate the error performance of coherent MPSK signals over the slow and flat fading channels when AWGN is present, using the approximation, an upper bound on the symbol error probability for large values of *M* signal waveforms. Next we compare the performance of SC2 diversity reception of MDPSK, MPSK, and MQAM signals in slowly frequency-nonselective Nakagami fading channels including an AWGN, based on the previous works of [6]~[8], what is contributed in this paper. Recently, submissions of QPSK have been made to 3GPP(third generation partnership projects), whereas those of 16- QAM have been made to 3GPP2(third generation partnership projects 2)[9],[10].

Ⅱ. System Model with SC2 Diversity Reception

The optimal combination of the received signals is obtained by using maximum ratio combining(MRC) which calls for the increased complexity with respect to other diversity schemes. Anyway, it is frequently considered since its performance can be assumed as the upper bound to compare suboptimal combining rules. On the other hand, among the suboptimal techniques,

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SC is attractive due to implementation simplicity and low cost.

The interest for SC application has been recently increased for the high-capacity mobile radio system. With reference to SC, applied here are the order statistics to select μ branches from the branch with the largest amplitude, or to choose μ branches from the branch with the largest SNR at the L diversity branches, for a data recovery while assuming that the noise power is constant across all branches when the probability density function(PDF) for this combining is analyzed to evaluate the error rate performance of M-ary signals on Nakagami fading channels[11],[12].

Then the statistics of an instantaneous SNR γ are as follows:

$$\gamma=\gamma_L+\gamma_{L-1}+\gamma_{L-2}+\cdots+\gamma_{L-\mu+1},\quad L\geq\mu. \tag{1}$$

It is assumed that the statistical characteristics of diversity branches are independent each other over the Nakagami fading channels.

Now, to derive the PDF for the instantaneous SNR, it is worth while to note that we introduce the following joint PDF of the statistics γ_L, $\gamma_{L-1},\cdots$, and γ_1, where $0\leq\gamma_1\leq\gamma_2\leq\cdots\leq\gamma_L$[11],[12]:

$$f(\gamma_L,\gamma_{L-1},\cdots,\gamma_1)=f(\gamma_L)f(\gamma_{L-1})\cdots f(\gamma_1). \tag{2}$$

Given each integration interval for the unnecessary random variables(rvs) $\gamma_{L-\mu}$, $\gamma_{L-\mu-1},\cdots$, and γ_1, we can perform the integration of those statistics and yield the marginal joint PDF of γ_L, $\gamma_{L-1},\cdots$, and $\gamma_{L-\mu+1}$.

Next, we can write, after the transform of rvs, the PDF of γ, $\gamma_{L-1},\cdots,\gamma_{L-\mu+2}$, and $\gamma_{L-\mu+1}$ as

$$\begin{aligned} &f(\gamma_L,\cdots,\gamma_{L-\mu+2},\ \gamma_{L-\mu+1})\frac{1}{|J|} \\ &\quad=f(\gamma,\ \gamma_{L-1},\cdots,\gamma_{L-\mu+2},\ \gamma_{L-\mu+1}) \end{aligned} \tag{3}$$

where the Jacobian of the transformation, $|J|=1$ and $0\leq\gamma_{L-\mu+1}\leq\gamma_{L-\mu+2}\leq\cdots\leq\gamma$.

It follows that upon performing the integrations with respect to $\gamma_{L-1},\cdots,\gamma_{L-\mu+2}$, and $\gamma_{L-\mu+1}$, we can obtain the PDF of γ. In a traditional SC to select the branch with the largest SNR from the original diversity branches, it can be shown that $\mu=2$.

If each branch has equal fading parameter m and average SNR γ_0, we can thus express the exact, not recursive, PDF of the received instantaneous SNR by using the binomial theorem in a SC2 diversity system on a Nakagami fading channel as follows[13]:

$$\begin{aligned} f(\gamma)=&\int_0^{\gamma/2}f(\gamma_{L-1},\gamma)d\gamma_{L-1}=\frac{L(L-1)}{[\Gamma(m)]^2}\left(\frac{m}{\gamma_0}\right)^{2m}\cdot \\ &\exp\left(-\frac{m}{\gamma_0}\gamma\right)\sum_{\alpha_1=0}^{m-1}(-1)^{\alpha_1}\cdot\binom{m-1}{\alpha_1}\gamma^{m-\alpha_1-1}\cdot \\ &\left\{\frac{(\gamma/2)^{m+\alpha_1}}{m+\alpha_1}+\sum_{n_0=1}^{L-2}(-1)^{n_0}\binom{L-2}{n_0}\sum_{n_1=0}^{n_0}\sum_{n_2=0}^{n_1}\cdots\sum_{n_{m-1}=0}^{n_{m-2}}\cdot\right. \\ &\left[\prod_{j=1}^{m-1}\binom{n_{j-1}}{n_j}\left(\frac{1}{j!}\right)^{n_j-n_{j+1}}\left(\frac{m}{\gamma_0}\right)^{n_j}\right]\cdot\frac{(m+\alpha_1+n-1)!}{(mn_0/\gamma_0)^{m+\alpha_1+n}}\cdot \\ &\left.\left[1-\exp\left(-\frac{mn_0}{2\gamma_0}\gamma\right)\sum_{p=0}^{m+\alpha_1+n-1}\frac{1}{p!}\left(\frac{mn_0}{2\gamma_0}\gamma\right)^p\right]\right\}. \end{aligned} \tag{4}$$

Ⅲ. Performance Analysis

Once the statistics of the instantaneous SNR are determined as the function of the average SNR, the error performance in the Nakagami fading channels can be evaluated by averaging the conditional probability of error over the PDF, not the moment generating function (MGF), of the output SNR[14],[15].

3-1 Error Probability for MDPSK

When MDPSK signals experience no fading, the expression for the conditional probability of error is given by [5]

$$P_{s,MDPSK}=\frac{\sin\frac{\pi}{M}}{2\pi}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}}\frac{\exp\left[-\gamma\left(1-\cos\frac{\pi}{M}\cos\theta\right)\right]}{1-\cos\frac{\pi}{M}\cos\theta}d\theta. \tag{5}$$

Once the statistics of the instantaneous SNR are determined as the function of the average SNR, we can represent the average SER in receiving MDPSK signals with SC2 diversity branches on Nakagami fading channels by averaging (5) over the PDF of an instantaneous SNR under the effect of Nakagami fading channel as follows:

$$P_{e,MDPSK}=\int_0^{\infty}P_{s,MDPSK}\,f(\gamma)\,d\gamma \tag{6}$$

where $P_{e,MDPSK}$ is the average SER of MDPSK signals under the Nakagami fading model.

Next, given that v is real number, substituting (4) and (5) into (6) and using the identity [16, p. 310, Eq. (3.351)]

$$\int_0^{\infty}x^n e^{-vx}dx=n!\,v^{-n-1},\qquad Re\ v>0, \tag{7}$$

We find the symbol error probability under the Nakagami fading model to be

$$\begin{aligned} P_{e,MDPSK}=&\frac{\sin\frac{\pi}{M}}{2\pi}\frac{L(L-1)}{[\Gamma(m)]^2}\left(\frac{m}{\gamma_0}\right)^{2m}\sum_{\alpha_1=0}^{m-1}(-1)^{\alpha_1}\cdot \\ &\binom{m-1}{\alpha_1}(A+B-C) \end{aligned} \tag{8}$$

where

$$A=\frac{(1/2)^{m+a_1}}{m+a_1}\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}}\frac{\Gamma(2m)}{1-\cos\frac{\pi}{M}\cos\theta}\cdot\left(\frac{\gamma_0}{m+\gamma_0-\gamma_0\cos\frac{\pi}{M}\cos\theta}\right)^{2m}d\theta, \tag{9}$$

$$B=\sum_{n_0=1}^{L-2}\sum_{n_1=0}^{n_0}\sum_{n_2=0}^{n_1}\cdots\sum_{n_{m-1}=0}^{n_{m-2}}(-1)^{n_0}\binom{L-2}{n_0}\cdot\frac{\Gamma(m+a_1+n)}{(mn_0/\gamma_0)^{m+a_1+n}}\left[\prod_{j=1}^{m-1}\binom{n_{j-1}}{n_j}\left(\frac{1}{j!}\right)^{n_j-n_{j+1}}\left(\frac{m}{\gamma_0}\right)^{n_j}\right]\cdot\int_{-\frac{\pi}{2}}^{-\frac{\pi}{2}}\frac{\Gamma(m-a_1)}{1-\cos\frac{\pi}{M}\cos\theta}\left(\frac{\gamma_0}{m+\gamma_0-\gamma_0\cos\frac{\pi}{M}\cos\theta}\right)^{m-a_1}d\theta, \tag{10}$$

and

$$C=\sum_{n_0=1}^{L-2}\sum_{n_1=0}^{n_0}\sum_{n_2=0}^{n_1}\cdots\sum_{n_{m-1}=0}^{n_{m-2}}(-1)^{n_0}\binom{L-2}{n_0}\cdot\frac{\Gamma(m+a_1+n)}{(mn_0/\gamma_0)^{m+a_1+n}}\left[\prod_{j=1}^{m-1}\binom{n_{j-1}}{n_j}\left(\frac{1}{j!}\right)^{n_j-n_{j+1}}\left(\frac{m}{\gamma_0}\right)^{n_j}\right]\cdot\sum_{p=0}^{m+a_1+n-1}\frac{1}{p!}\left(\frac{mn_0}{2\gamma_0}\right)^p\cdot\int_{-\frac{\pi}{2}}^{+\frac{\pi}{2}}\frac{\Gamma(m+p-a_1)}{1-\cos\frac{\pi}{M}\cos\theta}\cdot\left(\frac{2\gamma_0}{m(2+n_0)+2\gamma_0-2\gamma_0\cos\frac{\pi}{M}\cos\theta}\right)^{m+p-a_1}d\theta \tag{11}$$

which can be written in the integral-form, not in the closed-form.

We can observe that the result of (8) for $L=2$ in Rayleigh fading channel is equivalent to the result of [17, Eq. (5.2.13)] for Nakagami fading index $m=1$.

3-2 Error Probability for MPSK

The approximation of coherent MPSK signals on the probability of symbol error for larger M under a non-fading channel may be represented as follows[8],[18]:

$$P_{s,MPSK}=erfc\left(\sqrt{\gamma}\sin\frac{\pi}{M}\right) \tag{12}$$

where $erfc(\cdot)$ is the error function defined as

$$erfc(x)=\frac{2}{\sqrt{\pi}}\int_x^{\infty}e^{-t^2}dt. \tag{13}$$

Given that μ, ν, and β are real numbers, using the identity [16, p. 649, Eq. (6.286.1)]

$$\int_0^{\infty}erfc(\beta x)e^{\mu^2x^2}x^{\nu-1}dx=\frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\sqrt{\pi}\nu\beta^{\nu}}\,{}_2F_1\left(\frac{\nu}{2},\frac{\nu+1}{2};\ \frac{\nu}{2}+1;\ \frac{\mu^2}{\beta^2}\right),\quad Re\ \beta^2>Re\ \mu^2, Re\ \nu>0, \tag{14}$$

where

$${}_2F_1(a,b;\ c;\ z)=\frac{\Gamma(c)}{\Gamma(a)\Gamma(b)}\sum_{n=0}^{\infty}\frac{\Gamma(a+n)\Gamma(b+n)}{\Gamma(c+n)}\frac{x^n}{n!}, \tag{15}$$

we can find the approximate performance of MPSK signals under the effect of SC2 diversity in Nakagami fading channels to be (See Appendix.)

$$P_{e,MPSK}=\frac{L(L-1)}{[\Gamma(m)]^2}\left(\frac{m}{\gamma_0}\right)^{2m}\sum_{a_1=0}^{m-1}(-1)^{a_1}\binom{m-1}{a_1}(I+J-K) \tag{16}$$

where

$$I=\frac{(1/2)^{m+a_1+1}}{m+a_1}\frac{\Gamma\left(2m+\frac{1}{2}\right)}{\sqrt{\pi}m\sin^{4m}\frac{\pi}{M}}\,{}_2F_1\left(2m,2m+\frac{1}{2};\ 2m+1;\ -\frac{m}{\gamma_0\sin^2\frac{\pi}{M}}\right) \tag{17}$$

$$J=\sum_{n_0=1}^{L-2}\sum_{n_1=0}^{n_0}\sum_{n_2=0}^{n_1}\cdots\sum_{n_{m-1}=0}^{n_{m-2}}(-1)^{n_0}\binom{L-2}{n_0}\cdot\frac{\Gamma(m+a_1+n)}{(mn_0/\gamma_0)^{m+a_1+n}}\left[\prod_{j=1}^{m-1}\binom{n_{j-1}}{n_j}\left(\frac{1}{j!}\right)^{n_j-n_{j+1}}\left(\frac{m}{\gamma_0}\right)^{n_j}\right]\cdot\frac{\Gamma\left(m-a_1+\frac{1}{2}\right)}{\sqrt{\pi}\ (m-a_1)\sin^{2(m-a_1)}\frac{\pi}{M}}\cdot{}_2F_1\left(m-a_1,m-a_1+\frac{1}{2};\ m-a_1+1;\ -\frac{m}{\gamma_0\sin^2\frac{\pi}{M}}\right) \tag{18}$$

and

$$K=\sum_{n_0=1}^{L-2}\sum_{n_1=0}^{n_0}\sum_{n_2=0}^{n_1}\cdots\sum_{n_{m-1}=0}^{n_{m-2}}(-1)^{n_0}\binom{L-2}{n_0}\frac{\Gamma(m+a_1+n)}{(mn_0/\gamma_0)^{m+a_1+n}}\left[\prod_{j=1}^{m-1}\binom{n_{j-1}}{n_j}\left(\frac{1}{j!}\right)^{n_j-n_{j-1}}\left(\frac{m}{\gamma_0}\right)^{n_j}\right]\cdot\sum_{p=0}^{m+a_1+n-1}\frac{1}{p!}\left(\frac{mn_0}{2\gamma_0}\right)^p\frac{\Gamma\left(m-a_1+p+\frac{1}{2}\right)}{\sqrt{\pi}\ (m-a_1+p)\sin^{2(m-a_1+p)}\frac{\pi}{M}}\cdot{}_2F_1\left(m-a_1+p,m-a_1+p+\frac{1}{2};\ m-a_1+p+1;\ -\frac{m(2+n_0)}{2\gamma_0\sin^2\frac{\pi}{M}}\right). \tag{19}$$

For the special case of Nakagami fading index $m=1$, we can observe that the result of (16) for $L=2$ reduces to the result of [8, Eq. (B.3)] for equal diversity branches in the Rayleigh fading channel.

3-3 Error Probability for MQAM

Next, we analyze the performance of SC2 diversity reception of MQAM signals in Nakagami fading channels. We can derive the integral-form performance exact for $M=2^j$, when j is even, by averaging the conditional probability of error over the PDF of an instantaneous SNR under the effect of Nakagami fading channels.

To derive the integral-form performance in a Nakagami fading channel, given that j is even, we introduce the exact SER in the presence of AWGN channel, represented as [19]

$$P_{s,MQAM}=\frac{4B}{\pi}\int_0^{\frac{\pi}{2}}\exp\left(-\frac{g\gamma}{\sin^2\theta}\right)d\theta - \frac{4B^2}{\pi}\int_0^{\frac{\pi}{4}}\exp\left(-\frac{g\gamma}{\sin^2\theta}\right)d\theta \quad (20)$$

where $g=\frac{3}{2(M-1)}$ and $B=\frac{\sqrt{M}-1}{\sqrt{M}}$.

Average SER for MQAM under the effect of SC2 diversity can be shown to be given by

$$P_{e,MQAM} = \int_0^{\infty} P_{s,MQAM}\, f(\gamma)\, d\gamma = \frac{4B}{\pi}\frac{L(L-1)}{[\Gamma(m)]^2}\left(\frac{m}{\gamma_0}\right)^{2m}\sum_{a_1=0}^{m-1}(-1)^{a_1}\cdot \binom{m-1}{a_1}(L+M-N). \quad (21)$$

L, M, and N can be, respectively, expressed as

$$L=\left(\frac{1}{2}\right)^{m+a_1}\frac{\Gamma(2m)}{m+a_1}\left[\int_0^{\frac{\pi}{2}}\left(\frac{\gamma_0\sin^2\theta}{m\sin^2\theta+g\gamma_0}\right)^{2m}d\theta - B\int_0^{\frac{\pi}{4}}\left(\frac{\gamma_0\sin^2\theta}{m\sin^2\theta+g\gamma_0}\right)^{2m}d\theta\right], \quad (22)$$

$$M=\Gamma(m-a_1)\sum_{n_0=1}^{L-2}\sum_{n_1=0}^{n_0}\sum_{n_2=0}^{n_1}\cdots\sum_{n_{m-1}=0}^{n_{m-2}}(-1)^{n_0}\binom{L-2}{n_0}\cdot\frac{\Gamma(m+a_1+n)}{(mn_0/\gamma_0)^{m+a_1+n}}\left[\prod_{j=1}^{m-1}\binom{n_{j-1}}{n_j}\left(\frac{1}{j!}\right)^{n_j-n_{j+1}}\left(\frac{m}{\gamma_0}\right)^{n_j}\right]\cdot \left[\int_0^{\frac{\pi}{2}}\left(\frac{\gamma_0\sin^2\theta}{m\sin^2\theta+g\gamma_0}\right)^{m-a_1}d\theta - B\int_0^{\frac{\pi}{4}}\left(\frac{\gamma_0\sin^2\theta}{m\sin^2\theta+g\gamma_0}\right)^{m-a_1}d\theta\right], \quad (23)$$

and

$$N=\sum_{n_0=1}^{L-2}\sum_{n_1=0}^{n_0}\sum_{n_2=0}^{n_1}\cdots\sum_{n_{m-1}=0}^{n_{m-2}}(-1)^{n_0}\binom{L-2}{n_0}\cdot\frac{\Gamma(m+a_1+n)}{(mn_0/\gamma_0)^{m+a_1+n}}\left[\prod_{j=1}^{m-1}\binom{n_{j-1}}{n_j}\left(\frac{1}{j!}\right)^{n_j-n_{j+1}}\left(\frac{m}{\gamma_0}\right)^{n_j}\right]\cdot \sum_{p=0}^{m+a_1+n-1}\frac{1}{p!}\left(\frac{mn_0}{2\gamma_0}\right)^p\Gamma(m+p-a_1) \cdot\left[\int_0^{\frac{\pi}{2}}\left(\frac{2\gamma_0\sin^2\theta}{mn_0\sin^2\theta+2m\sin^2\theta++2g\gamma_0}\right)^{m+p-a_1}d\theta - B\int_0^{\frac{\pi}{4}}\left(\frac{2\gamma_0\sin^2\theta}{mn_0\sin^2\theta+2m\sin^2\theta++2g\gamma_0}\right)^{m+p-a_1}d\theta\right]. \quad (24)$$

Ⅳ. Numerical Results

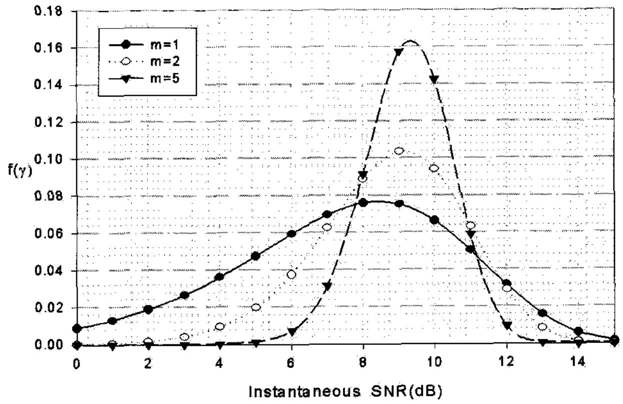

Fig. 1. The PDF of the instantaneous SNR for m=1, 2, 5, L=3, and SNR=6 dB.

It is shown that in Fig. 1 for given diversity branches, the distribution of the instantaneous SNR for the received signal becomes narrower and more peaked as m increases in SC2 diversity reception under the effect of Nakagami fading channels.

Let us assume that the performance of coherent MPSK in the fading channels has, first of all, an approximation. Fig. 2 illustrates the performance of SC2 diversity system in MPSK and MQAM signals for the SNR per symbol with L=3 and M=4. It is clear that given the number of diversity branches, MPSK and MQAM signals for M=4 yield equivalent performance for the same SNR per symbol [4]. Next in Fig. 3 and 4, the average SER performances of MDPSK, MPSK and MQAM signals are, respectively, plotted against average SNR with M=16 and M=64 in a Nakagami fading channel. In each of these figures, we have the single value of diversity branches and different fading environments. The performances of MDPSK and MPSK signals with respect to that of MQAM signals are im-

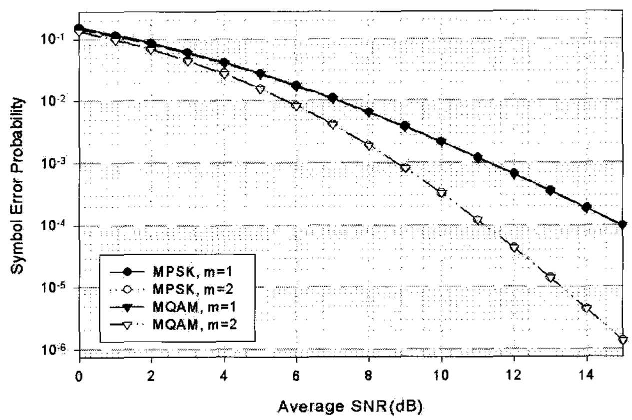

Fig. 2. Error performance comparisons of MPSK and MQAM signals adopting SC2 diversity technique for L=3 and M=4.

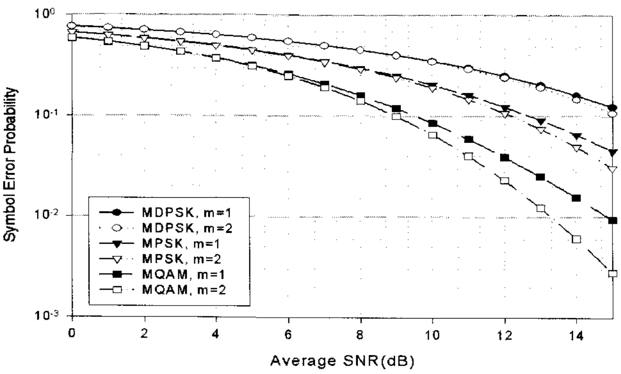

Fig. 3. Error performance comparisons of MDPSK, MPSK, and MQAM signals adopting SC2 diversity technique for L=3 and M=16.

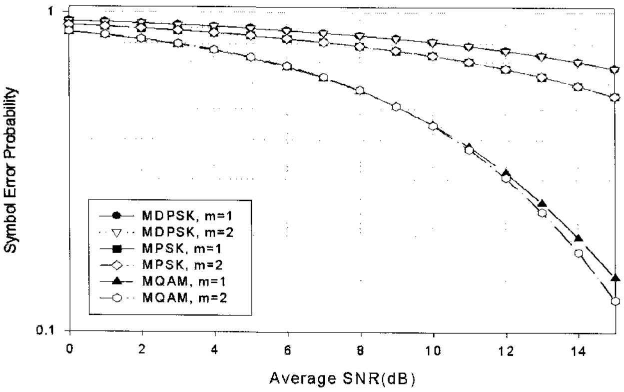

Fig. 4. Error performance comparisons of MDPSK, MPSK, and MQAM signals adopting SC2 diversity technique for L=3 and M=64.

proved very restrictedly with increasing the fading index for the single value of M. It is expected result as the fading index m increase, the fading depth decreases. However, the effective improvement in a fading parameter does not improve the error performance in proportion to increasing M.

V. Conclusion

The performances for MDPSK, MPSK and MQAM signals under the effect of SC2 have been evaluated in Nakagami fading channels. The approximation to a symbol error probability for coherent MPSK in the fading channel has especially been derived not employing the exact SER under a nonfading channel[5].

We can find that for the given number of the diversity branches, L, the restricted performance gain is achievable with increasing the fading index m. The actual evaluation with increasing M does not have the important effect on the performance of M-ary signals in SC2 diversity system.

The results of the present works are sufficiently general in offering a convenient method to evaluate the performance of several current M-ary modulation systems that operate on channels with a wide variety of fading conditions in wireless personal communications.

Appendix: The Finite-series Representation of ${}_2F_1(\cdot)$ in (19)

Given that n is real number more than $1/2$, we assume that $G(z)$ is given by [20]

$$G(z)=z^n\,{}_2F_1\left(n,n+\frac{1}{2};\ n+1;\ -z\right)$$
$$=\sum_{i=0}^{\infty}\frac{n}{n+i}\,\frac{(2n-1+2i)!!}{2^i(2n-1)!!}\,\frac{(-1)^i}{i!}\,z^{n+i},\quad Re\ n>\frac{1}{2} \tag{A.1}$$

where

$$(2n-1)!!=(2n-1)(2n-3)\cdots 3\cdot 1. \tag{A.2}$$

We note that since n is more than $1/2$, $G(0)$ is 0. Then, (A.1) can be represented as follows:

$$G(z)=n\int_0^z x^{n-1}\left[\sum_{i=0}^{\infty}\frac{(2n-1+2i)!!}{2^i(2n-1)!!}\,\frac{(-x)^i}{i!}\right]dx+G(0). \tag{A.3}$$

The infinite-series formula of (A.3) becomes

$$\sum_{i=0}^{\infty}\frac{(2n-1+2i)!!}{2^i(2n-1)!!}\,\frac{(-x)^i}{i!}=(x+1)^{-n-\frac{1}{2}}. \tag{A.4}$$

Hence, (A.3) can be expressed as

$$G(z)=\int_0^z nx^{n-1}(x+1)^{-\frac{2n+1}{2}}dx. \tag{A.5}$$

Consequently, (A.5) may be presented as follows [16, p. 73, Eq. (2.221)]:

$$G(z)=-n\sum_{i=1}^{n-1}\frac{(-1)^i}{i+\frac{1}{2}}\binom{n-1}{i}\left[(z+1)^{-i-\frac{1}{2}}-1\right]$$
$$=-\sum_{i=0}^{n-1}\frac{(-1)^i}{i+\frac{1}{2}}\,\frac{\Gamma(n+1)}{\Gamma(i+1)\Gamma(n-i)}\left[(z+1)^{-i-\frac{1}{2}}-1\right]. \tag{A.6}$$

Finally, ${}_2F_1(\cdot)$ in (A.1) can be written as

$${}_2F_1(n,n+\frac{1}{2};\ n+1;\ -z)$$
$$=-z^{-n}\sum_{i=0}^{n-1}\frac{(-1)^i}{i+\frac{1}{2}}\,\frac{\Gamma(n+1)}{\Gamma(i+1)\Gamma(n-i)}\left[(z+1)^{-i-\frac{1}{2}}-1\right]. \tag{A.7}$$

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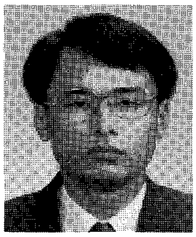

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