Hindawi Publishing Corporation
International Journal of Antennas and Propagation
Volume 2012, Article ID 987631, 7 pages
doi:10.1155/2012/987631

Research Article

Positive Effect of Severe Nakagami-*m* Fading on the Performance of Multiuser TAS/MRC Systems with High Selection Gain

Chia-Chun Hung,[1] Ching-Tai Chiang,[2] Rong-Ching Wu,[3] and C. Lee[4]

[1] *Instrument Technology Research Center, National Applied Research Laboratories, 20 R&D VI Road, Hsinchu Science-Based Industrial Park, Hsinchu 300, Taiwan*
[2] *Department of Computer and Communication, National Pingtung Institute of Commerce, 51 Min Sheng E. Road, Pingtung 900, Taiwan*
[3] *Department of Electrical Engineering, I-Shou University, No.1, Section 1, Syuecheng Road, Dashu District, Kaohsiung 84001, Taiwan*
[4] *Department of Mechanical and Automation Engineering, I-Shou University, No.1, Section 1, Syuecheng Road, Dashu District, Kaohsiung 84001, Taiwan*

Correspondence should be addressed to Ching-Tai Chiang, cctai@npic.edu.tw

Received 24 June 2012; Revised 8 November 2012; Accepted 9 November 2012

Academic Editor: Min Zhang

This paper investigates the positive effect of severe Nakagami-*m* fading on the performance of multiuser transmit antenna selection/maximal-ratio combining (TAS/MRC) systems with high selection gain. Both amount of fading (AF) and symbol error rate (SER) of M-QAM are derived as closed-form expressions for integer m. For arbitrary m, the AF and the SER are expressible as a single infinite series of Gamma function and Gauss hypergeometric function, respectively. The analytical results lead to the following observations. First, the SER performance can demonstrate the positive effect of severe Nakagami-*m* fading on multiuser TAS/MRC systems with high selection gain. Second, the AF performance only exhibits the negative impact of severe fading regardless of high selection gain. Last, the benefit of severe fading to the system performance diminishes at high signal-to-noise ratio (SNR).

1. Introduction

Multiple-input multiple-output (MIMO) communications have been considered as suitable ways to improve the performance of wireless communications. Various MIMO transmission schemes have been developed to obtain a high reliability through promised diversity gain and/or high rate transmission via spatial multiplexing (SM) [1–6]. Rectangular quadrature amplitude modulation (QAM) is a general modulation technique which includes important modulation schemes as particular cases, such as binary phase-shift keying (BPSK), pulse amplitude modulation (PAM), or square QAM. Although MIMO maximum-ratio combining (MRC) systems under different conditions have been investigated in the last few years, no results seem to be available for the average symbol error rate (SER) of rectangular QAM in noise-limited environments. In [7], an expression for the bit error rate (BER) of rectangular QAM is derived, yet the result is only valid for Gray code mapping, and no expression for the average SER is provided.

More specifically, the diverse techniques of coherent signal combining were developed depending on the specific treatment of the combined signals' phase and amplitude, which are selection combining (SC), threshold combining, equal-gain combining (EGC) and MRC, as summarized in [8, 9]. Choosing a single transmit antenna, the one that maximizes the total received signal power at the receiver, can substantially reduce the transmitter's hardware and software complexity. Thus, the transmit antenna selection (TAS) has occupied a considerable part of today's communication researches [10]. On the other hand, MRC is an optimal diversity technique with a maximum SNR criterion. To retain the advantages of both TAS and MRC, an integrated TAS scheme with MRC at the receiver, labeled TAS/MRC, was proposed [11]. Besides the antenna diversity, multiuser diversity (MUD) is also utilized to improve performance in point-to-multipoint communication [12]. A proper scheduling algorithm is the key to gain the MUD in the multiuser systems [12]. Moreover, multiuser MIMO systems have recently attracted much attention as the technology enhances the total system capacity by generating a virtual large MIMO channel between a base station and multiple terminal stations [13]. In [14], tight closed-form expressions of outage performance were derived for the multiuser MIMO systems in Rayleigh fading channels. The analytical results demonstrate that users can be viewed as equivalent "*virtual*" transmit antennas [15]. The published papers are mainly focused on flat Rayleigh channels [11, 14, 15]. The closed-form expressions for the average symbol error rate of general rectangular QAM in MIMO MRC systems over Rayleigh fading channels are derived [16].

Via the m parameter, Nakagami model is able to cover both severe and weak fadings, which includes the Rayleigh fading ($m = 1$) as a special case. The Nakagami-m distribution also can closely approximate the Hoyt distribution and the Rice distribution [17]. Therefore, the Nakagami-m channels are usually used to model land-mobile, indoor mobile multipath propagation, as well as scintillating ionospheric radio links [17]. The severity of fading can be quantified by the amount of fading (AF) [17]. In [18], a closed-form expression for the AF was derived in a MIMO diversity system with space-time block coding (STBC) in Nakagami-m fading channels. In this paper, we derive the AF of multiuser TAS/MRC systems as a closed-form expression in independent and identically distributed (i.i.d.) Nakagami-m channels with a positive integer m. For arbitrary m, the AF is expressible as a single infinite series of Gamma function. The analytical results show that the AF of multiuser TAS/MRC systems decreases as m increases as expected. The positive effect of severe fading, however, cannot be observed from the standpoint of AF.

Performance analyses, including outage probability, capacity, and symbol error rate (SER), were investigated for the TAS/MRC systems in Nakagami-m fading channels in [19–21]. The performance is improved with the increase of m, that is, in weak fading channels [19–21]. However, the tendency becomes totally different because the paper [22] presented that the higher m causes a negative impact on the capacity of multiuser MIMO systems. In this paper, the performance of TAS/MRC system with MUD in Nakagami-m fading channels is analyzed. We derive a simple closed-form expression for the outage probability of multiuser TAS/MRC systems. Moreover, a closed-form SER of M-*ary* quadrature amplitude modulation (M-QAM) is also derived when m is an integer. For arbitrary m, the SER of M-QAM is expressible as a single infinite series of a Gauss hypergeometric function. The analytical results suggest that the effect of severe fading on the performance becomes beneficial at high selection gain, since a more scattering fading environment enables the selection scheduler to arrange transmissions at higher peaks of channel fading. Thus, the systems with high selection gain perform better in severe fading than in weak fading. However, the high signal-to-noise ratio (SNR) may dilute the function of selection scheduler in transmitters. All the derived expressions are verified by Monte Carlo simulations.

2. Amount of Fading for Nakagami-*m* Models

We consider a TAS/MRC system with a base station serving K users in the downlink. The best transmit antenna out of all L_T transmit candidates, which maximizes the postprocessing SNR at the MRC output of L_R received antennas, is selected to transmit data for the corresponding user. The channels between the transmit antennas and the users experience fading paths which are modeled as i.i.d. Nakagami-m fading channels. The probability density function (PDF) of the instantaneous postprocessing SNR of MRC combiner output for the kth user with respect to the ith transmit antenna is given by

$$f(\gamma_{i,k}) = \left(\frac{m}{\overline{\gamma}}\right)^{mL_R} \frac{\gamma_{i,k}^{mL_R-1}}{\Gamma(mL_R)} \exp\left(-\frac{m\gamma_{i,k}}{\overline{\gamma}}\right), \quad (1)$$

where $\Gamma(\cdot)$ denotes the Gamma function and $\overline{\gamma}$ is the average SNR per symbol per branch. Then, the corresponding cumulative distribution function (CDF) denoted by $F(\gamma_{i,k})$ leads to

$$F(\gamma_{i,k}) = \int_0^{\gamma_{i,k}} f(x)dx = \frac{\gamma(mL_R, (m\gamma_{i,k}/\overline{\gamma}))}{\Gamma(mL_R)}, \quad (2)$$

where $\gamma(y, z)$ is the incomplete Gamma function [23, equation (8.350.1)]. For MUD in the TAS/MRC scheme, which is denoted as a (L_T, L_R, K) multiuser TAS/MRC system, the scheduler at BS collects the MRC output SNR of all users and selects the target user according to the criterion

$$\gamma = \max_{\substack{i=1,2,\ldots,L_T \\ k=1,2,\ldots,K}} \gamma_{i,k}. \quad (3)$$

Then, the selected PDF of effective postprocessing SNR in (3) can be expressed as [19, equation (4)]

$$\begin{aligned} f_I(\gamma) &= KL_T[F(\gamma)]^{KL_T-1} f(\gamma) \\ &= \frac{KL_T}{[\Gamma(mL_R)]^{KL_T}} \left(\frac{m}{\overline{\gamma}}\right)^{mL_R} \gamma^{mL_R-1} \\ &\quad \times \exp\left(-\frac{m\gamma}{\overline{\gamma}}\right) \left[\gamma\left(mL_R, \frac{m\gamma}{\overline{\gamma}}\right)\right]^{KL_T-1}. \end{aligned} \quad (4)$$

Integrating (4), we can obtain the CDF as

$$F_I(\gamma) = [F(\gamma)]^{KL_T} = \left[\frac{\gamma(mL_R, (m\gamma/\overline{\gamma}))}{\Gamma(mL_R)}\right]^{KL_T}. \quad (5)$$

From (3)–(5), one can see that the effective antenna selection gain is KL_T, since the users can be viewed as equivalent virtual transmit antennas [15]. We propose an expansion of the incomplete Gamma function in (4) by a series development for $\gamma(mL_R, m\gamma/\overline{\gamma})$, namely:

$$\gamma\left(mL_R, \frac{m\gamma}{\overline{\gamma}}\right) = \begin{cases} \exp\left(-\dfrac{m\gamma}{\overline{\gamma}}\right)\displaystyle\sum_{n=0}^{\infty}\frac{\Gamma(mL_R)(m\gamma/\overline{\gamma})^{n+mL_R}}{\Gamma(mL_R+n+1)}, & \text{real } m \geq \dfrac{1}{2}, \\ \Gamma(mL_R)\left[1-\exp\left(-\dfrac{m\gamma}{\overline{\gamma}}\right)\displaystyle\sum_{n=0}^{mL_R-1}\frac{(m\gamma/\overline{\gamma})^n}{n!}\right], & \text{positive integer } m. \end{cases} \tag{6}$$

Next, using (6), we may infer the expansion of $[\gamma(mL_R, m\gamma/\overline{\gamma})]^{KL_T-1}$ by the power series raised to powers [23, equation (0.314)] as follows:

$$\left[\gamma\left(mL_R, \frac{m\gamma}{\overline{\gamma}}\right)\right]^{KL_T-1} = \begin{cases} \displaystyle\sum_{n=0}^{\infty}\alpha_n\left(\frac{m\gamma}{\overline{\gamma}}\right)^{mL_R(KL_T-1)+n} \times\exp\left(-\frac{m\gamma(KL_T-1)}{\overline{\gamma}}\right), & \text{real } m \geq \dfrac{1}{2}, \\ [\Gamma(mL_R)]^{KL_T-1}\displaystyle\sum_{j=0}^{KL_T-1}\binom{KL_T-1}{j}(-1)^j \times\exp\left(-j\frac{m\gamma}{\overline{\gamma}}\right)\sum_{n=0}^{j(mL_R-1)}\beta_n\left(\frac{m\gamma}{\overline{\gamma}}\right)^n, & \text{positive integer } m, \end{cases} \tag{7}$$

where α_n is the coefficient of $(m\gamma/\overline{\gamma})^{mL_R(KL_T-1)+n}$ in the expansion of

$$\left\{\sum_{n=0}^{\infty}\frac{\Gamma(mL_R)(m\gamma/\overline{\gamma})^{mL_R+n}}{\Gamma(mL_R+1+n)}\right\}^{KL_T-1}, \tag{8}$$

and [19, equation (6)]

$$\alpha_0 = \left(\frac{1}{mL_R}\right)^{KL_T-1}, \qquad \alpha_n = \frac{\Gamma(mL_R+1)}{n}\sum_{z=1}^{n}\frac{zKL_T-n}{\Gamma(mL_R+1+z)}\alpha_{n-z}, \quad \text{for } n \geq 1. \tag{9}$$

β_n in (7) is the coefficient of $(m\gamma/\overline{\gamma})^n$ in the expansion of $\{\sum_{n=0}^{mL_R-1} 1/n!(m\gamma/\overline{\gamma})^n\}^j$, and [19, equation (9)]

$$\beta_0 = 1, \qquad \beta_n = \frac{1}{n}\sum_{k=1}^{\min(n,mL_R-1)}\frac{k(j+1)-n}{k!}\beta_{n-k}, \quad \text{for } n \geq 1. \tag{10}$$

Thus, substituting (7) into (4), we can rewrite the PDF of the multiuser TAS/MRC systems as

$$f_I(\gamma) = \begin{cases} \dfrac{KL_T}{[\Gamma(mL_R)]^{KL_T}}\displaystyle\sum_{n=0}^{\infty}\alpha_n\left(\frac{m}{\overline{\gamma}}\right)^{mKL_TL_R+n} \times\gamma^{mKL_TL_R+n-1}\exp\left(-KL_T\frac{m\gamma}{\overline{\gamma}}\right), & \text{real } m \geq \dfrac{1}{2}, \\ \dfrac{KL_T}{\Gamma(mL_R)}\displaystyle\sum_{j=0}^{KL_T-1}\binom{KL_T-1}{j}(-1)^j \times\sum_{n=0}^{j(mL_R-1)}\beta_n\left(\frac{m}{\overline{\gamma}}\right)^{mL_R+n} \times\gamma^{mL_R+n-1}\exp\left(-[j+1]\frac{m\gamma}{\overline{\gamma}}\right), & \text{positive integer } m. \end{cases} \tag{11}$$

Similar to (11), the CDF of (5) can be expanded as

$$F_I(\gamma) = \begin{cases} \displaystyle\sum_{n=0}^{\infty}\eta_n\left(\frac{m\gamma}{\overline{\gamma}}\right)^{mKL_TL_R+n}\exp\left(-KL_T\frac{m\gamma}{\overline{\gamma}}\right), & \text{real } m \geq \dfrac{1}{2} \\ \displaystyle\sum_{j=0}^{KL_T}\binom{KL_T}{j}(-1)^j \times\sum_{n=0}^{j(mL_R-1)}\beta_n\left(\frac{m\gamma}{\overline{\gamma}}\right)^n\exp\left(-j\frac{m\gamma}{\overline{\gamma}}\right), & \text{positive integer } m, \end{cases} \tag{12}$$

where

$$\eta_0 = \left(\frac{1}{\Gamma(mL_R+1)}\right)^{KL_T}, \qquad \eta_n = \frac{\Gamma(mL_R+1)}{n}\sum_{z=1}^{n}\frac{z(KL_T+1)-n}{\Gamma(mL_R+1+z)}\eta_{n-z}, \quad \text{for } n \geq 1. \tag{13}$$

From (11), we can obtain the expectation and the second moment of effective SNR γ by the following expressions [20, equations (7), (8)]:

$$\mu_\gamma = \frac{(\overline{\gamma}/m)}{[\Gamma(mL_R)]^{KL_T}} \times\sum_{n=0}^{\infty}\alpha_n\frac{\Gamma(mKL_TL_R+n+1)}{L_T^{mKL_TL_R+n}}, \quad \text{real } m \geq \frac{1}{2}, \tag{14a}$$

$$\mu_\gamma = \frac{KL_T(\overline{\gamma}/m)}{\Gamma(mL_R)}\sum_{j=0}^{KL_T-1}\binom{KL_T-1}{j}(-1)^j \times\sum_{n=0}^{j(mL_R-1)}\beta_n\frac{\Gamma(mL_R+n+1)}{(j+1)^{mL_R+n+1}}, \quad \text{positive integer } m, \tag{14b}$$

$$E[\gamma^2] = \frac{(\overline{\gamma}/m)^2}{[\Gamma(mL_R)]^{KL_T}} \times \sum_{n=0}^{\infty} \alpha_n \frac{\Gamma(mKL_TL_R+n+2)}{L_T{}^{mKL_TL_R+n+1}}, \quad \text{real } m \geq \frac{1}{2}, \tag{15a}$$

$$E[\gamma^2] = \frac{KL_T(\overline{\gamma}/m)^2}{\Gamma(mL_R)} \sum_{j=0}^{KL_T-1} \binom{KL_T-1}{j} (-1)^j \times \sum_{n=0}^{j(mL_R-1)} \beta_n \frac{\Gamma(mL_R+n+2)}{(j+1)^{mL_R+n+2}}, \quad \text{positive integer } m. \tag{15b}$$

Using (14a), (14b), (15a), and (15b) yields the variance of the effective system SNR:

$$\sigma_\gamma^2 = E[\gamma^2] - \mu_\gamma^2. \tag{16}$$

Accordingly, from (14a)–(16), the quantity of AF for the multiuser TAS/MRC systems can be computed by

$$\text{AF} = \frac{\sigma_\gamma^2}{\mu_\gamma^2}. \tag{17}$$

3. Performance Analysis: Outage Probability and SER

The outage probability is defined as the probability that the instantaneous capacity is less than a given capacity C [19], that is:

$$\begin{aligned} P_{\text{out}}(C, \text{SNR}) &= \Pr\left\{\log_2[1+\text{SNR}(\gamma)] < C\right\} \\ &= \Pr\left\{\text{SNR} < \left(2^C - 1\right)\right\}. \end{aligned} \tag{18}$$

Then, in light of the CDF in (5), we can express the outage probability for the multiuser TAS/MRC systems as

$$\begin{aligned} P_{\text{out}}(C, \text{SNR}) &= F_I\left(2^C - 1\right) \\ &= \left[\frac{\gamma(mL_R, ((2^C-1)m)/\overline{\gamma})}{\Gamma(mL_R)}\right]^{KL_T}. \end{aligned} \tag{19}$$

On the other hand, the SER for M-QAM is given by [24, equation (31)]

$$P_{\text{QAM}}(\gamma) = aQ\left(\sqrt{b\gamma}\right) - cQ^2\left(\sqrt{b\gamma}\right), \tag{20}$$

where $Q(x) = (\sqrt{2\pi})^{-1}\int_x^\infty \exp(-z^2/2)dz$ is the Gaussian Q-function, $(a,b,c) = (4(\sqrt{M}-1)/\sqrt{M}, 3/(M-1), 4(\sqrt{M}-1)^2/M)$. Then, the derivative of (20) is [24, equation (32)]

$$\begin{aligned} P'_{\text{QAM}}(\gamma) &= (c-a)\sqrt{\frac{b}{8\,\pi\,\gamma}}e^{-b\gamma/2} \\ &\quad - \frac{cb}{2\pi}e^{-b\gamma}{}_1F_1\left(1; \frac{3}{2}; \frac{b\gamma}{2}\right), \end{aligned} \tag{21}$$

where ${}_1F_1(\cdot\,;\,\cdot\,;\,\cdot)$ is the confluent hypergeometric function [23, equation (9.210.2)].

Using the integral-by-parts method, the average SER in fading channels is given by

$$P_{\text{SER}} = \int_0^\infty f_I(\gamma)P_{\text{QAM}}(\gamma)d\gamma = -\int_0^\infty F_I(\gamma)P'_{\text{QAM}}(\gamma)d\gamma. \tag{22}$$

Substituting (12) and (21) into (22), we obtain the SER for M-QAM for real $m \geq 1/2$ as

$$\begin{aligned} P_{\text{SER}} = \frac{1}{2}\sum_{n=0}^{\infty}\eta_n \cdot \left(\frac{m}{\overline{\gamma}}\right)^{mKL_TL_R+n} &\times \left\{\sqrt{\frac{b}{2\pi}}\frac{(a-c)\Gamma(mKL_TL_R+n+0.5)}{(mKL_T/\overline{\gamma}+b/2)^{mKL_TL_R+n+0.5}}\right. \\ &+ \frac{bc}{\pi}\frac{\Gamma(mKL_TL_R+n+1)}{(mKL_T/\overline{\gamma}+b)^{mKL_TL_R+n+1}} \\ &\times {}_2F_1\left(mKL_TL_R+n+1, 1; \frac{3}{2};\right. \\ &\left.\left.\frac{b}{2(mKL_T/\overline{\gamma}+b)}\right)\right\}, \\ &\text{real } m \geq \frac{1}{2}, \end{aligned} \tag{23}$$

where we have used the relation [23, equation (7.621.4)]

$$\begin{aligned} &\int_0^\infty \exp(-st)t^{d-1}\ {}_1F_1(f;g;kt)dt \\ &\quad = \frac{\Gamma(d)}{s^d}\ {}_2F_1\left(f, d; g; \frac{k}{s}\right) \end{aligned} \tag{24}$$

and ${}_2F_1(\cdot\,,\cdot\,;\,\cdot)$ is the Gauss hypergeometric function [23, equation (9.14.1)]. Similarly, while the fading parameter m is a positive integer, we obtain a closed form as

$$\begin{aligned} P_{\text{SER}} = \frac{1}{2}\sum_{j=0}^{KL_T}\binom{KL_T}{j}(-1)^j \sum_{n=0}^{j(mL_R-1)}\beta_n \cdot \left(\frac{m}{\overline{\gamma}}\right)^n &\times \left\{\sqrt{\frac{b}{2\pi}}\frac{(a-c)\Gamma(n+0.5)}{(mj/\overline{\gamma}+b/2)^{n+0.5}} + \frac{bc}{\pi}\frac{\Gamma(n+1)}{(mj/\overline{\gamma}+b)^{n+1}}\right. \\ &\left.\times {}_2F_1\left(1, n+1; \frac{3}{2}; \frac{b}{2(mj/\overline{\gamma}+b)}\right)\right\}, \\ &\text{positive integer } m. \end{aligned} \tag{25}$$

4. Numerical and Simulation Results

In this section, we use the MATLAB software to present the numerical and simulation results of performance. The Nakagami-m samples are generated by the square root of

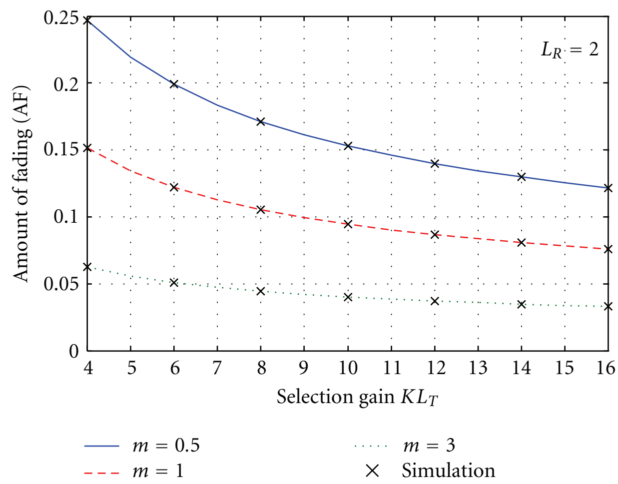

Figure 1: The amount of fading (AF) of multiuser TAS/MRC systems against the selection gain KL_T in various Nakagami-m fading channels when $L_R = 2$ and $\overline{\gamma} = 0$ dB.

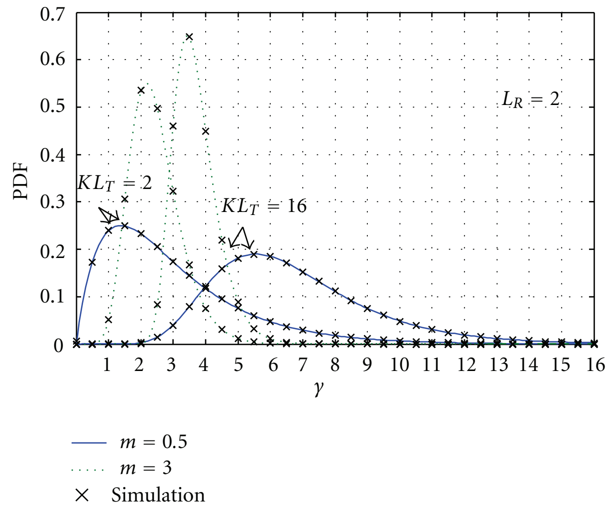

Figure 3: PDF of multiuser TAS/MRC systems with both low and high selection gains when $L_R = 2$ and $\overline{\gamma} = 0$ dB.

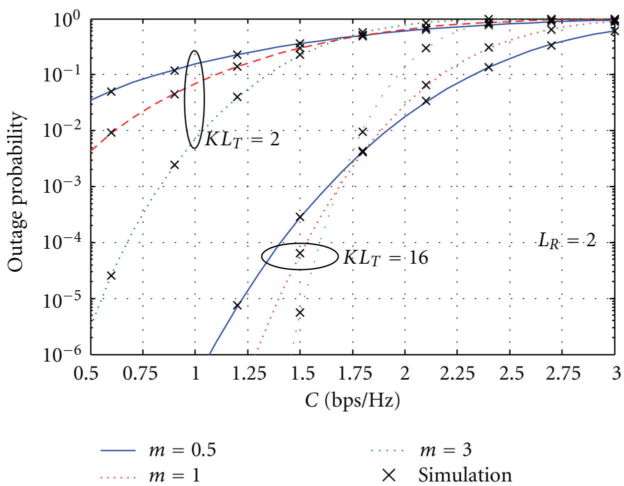

Figure 2: Outage probability against the capacity for both low and high selection gains when $L_R = 2$ and $\overline{\gamma} = 0$ dB.

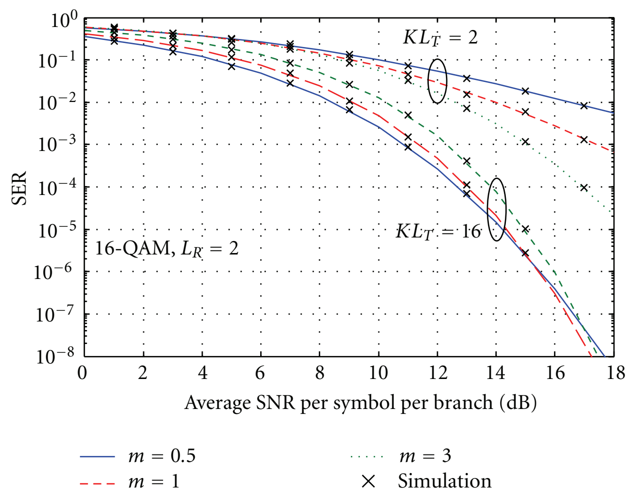

Figure 4: SER of 16-QAM against average SNR per symbol per branch when $L_R = 2$.

Gamma distributed samples (i.e., the gamrnd($\cdot$) MATLAB function) [25]. The outage probability and the SER were simulated by the ratios when 10^4 outages and 10^4 symbol errors occurred, respectively. All the simulations, marked by the "$\times$" symbols, agree closely with the analytic curves, validating the theoretical derivation. The number of received antenna L_R is chosen as 2 in all scenarios.

Figure 1 depicts the AF of the multiuser TAS/MRC systems against the selection gain KL_T in various Nakagami-m fading channels. The curves with $\overline{\gamma} = 0$ dB are plotted, using (14a) and (15a) for $m = 0.5$ by truncating the infinite series to 50 terms. It can be seen that the AF decreases as m increases; even the selection gain increases from 4 to 16. In other words, the fading index AF can quantify the severity of channel fading. For the high selection gain, however, the benefit of severe fading cannot be exhibited from the tendency of AF. Figure 2 shows the outage probability with $\overline{\gamma} = 0$ dB against the capacity for both low and high selection gains. The outage probability with the low selection gain ($KL_T = 2$) mostly performs better for the higher values of m, except that the outage probability already exceeds about 50%. On the other hand, the positive effect of severe fading on the performance is clearly demonstrated at the high selection gain ($KL_T = 16$). It is worth noting that the advantage of severe fading occurs in the outage range of practical interest. For example, the outage probability exceeds about 3×10^{-3} when the capacity is required larger than about 1.7 bps/Hz. The positive effect is further illustrated by the PDF values using (11) when $\overline{\gamma} = 0$ dB in Figure 3. As the selection gain increases from 2 to 16, the PDF values for $m = 0.5$ shift to right much more than those for $m = 3$. In the severe fading channel, indeed, the selection gain boosts the probability to distribute the PDF values over a higher instantaneous SNR region and hence demonstrates the positive effect.

In Figure 4, the SERs are plotted for the considered systems with 16-QAM in various fading channels. The SER for $m = 0.5$ is evaluated by (23) with truncation (50 terms) for the infinite series. As expected, the SER performs better in the weak fading channels at low selection gain. However, the tendency becomes contrary for the SERs at high selection gain. It can be seen that the SER for $m = 0.5$ performs best until $\overline{\gamma}$ is higher than about 15 dB, and the SER is smaller than the order of 10^{-5}. Obviously, the signal with high SNR will dilute the character of severe fading even at high selection gain.

5. Conclusions

In general, system performance behaves better in weak fading channels than in severe fading channels. This paper presents a positive impact of severe Nakagami-m fading on the performance of multiuser TAS/MRC systems with high selection gain. The scheduler with high selection gain is the key to arrange the transmission at higher peaks in a more scattering fading channel. Two performance indexes, AF and SER of M-QAM, are derived as closed-form expressions for integer m. For arbitrary m, the AF and the SER are expressible as a single infinite series of Gamma function and Gauss hypergeometric function, respectively. Although the AF is unable to illustrate the benefit of severe fading, from the analytical and numerical results, we validate the favorable effect from the results of PDF, outage probability and SER, occurring in the range of practical interest.

Acknowledgment

The authors thank the anonymous referees for helpful comments. This research was supported by the Instrument Technology Research Center, National Applied Research Laboratories, and NSC 100-2221-E-251-004.

References

[1] V. Tarokh, H. Jafarkhani, and A. R. Calderbank, "Space-time block codes from orthogonal designs," *IEEE Transactions on Information Theory*, vol. 45, no. 5, pp. 1456–1467, 1999.

[2] G. D. Golden, C. J. Foschini, R. A. Valenzuela, and P. W. Wolniansky, "Detection algorithm and initial laboratory results using V-BLAST space-time communication architecture," *Electronics Letters*, vol. 35, no. 1, pp. 14–16, 1999.

[3] S. Sandhu and A. Paulraj, "Space-time block codes: a capacity perspective," *IEEE Communications Letters*, vol. 4, no. 12, pp. 384–386, 2000.

[4] B. Hassibi and B. M. Hochwald, "High-rate codes that are linear in space and time," *IEEE Transactions on Information Theory*, vol. 48, no. 7, pp. 1804–1824, 2002.

[5] X. Ma and G. B. Giannakis, "Full-diversity full-rate complex-field space-time coding," *IEEE Transactions on Signal Processing*, vol. 51, no. 11, pp. 2917–2930, 2003.

[6] B. Song, N. Kim, and H. Park, "A binary space-time code for MIMO systems," *IEEE Transactions on Wireless Communications*, vol. 11, no. 4, pp. 1350–1357, 2012.

[7] M. Li, M. Lin, Z. Q. Gong et al., "Performance analysis of MIMO MRC system," *Electronics Letters*, vol. 43, no. 23, pp. 1297–1298, 2007.

[8] D. G. Brennan, "Linear diversity combining techniques," *Proceedings of the IRE*, vol. 47, no. 6, pp. 1075–1102, 1959.

[9] S. Sugiura, S. Chen, and L. Hanzo, "A universal space-time architecture for multiple-antenna aided systems," *IEEE Communications Surveys and Tutorials*, vol. 14, no. 2, pp. 401–420, 2012.

[10] F. Molish and M. Z. Win, "MIMO systems with antenna selection," *IEEE Microwave Magazine*, vol. 5, no. 1, pp. 46–56, 2004.

[11] S. Thoen, L. van der Perre, B. Gyselinckx, and M. Engels, "Performance analysis of combined transmit-SC/receive-MRC," *IEEE Transactions on Communications*, vol. 49, no. 1, pp. 5–8, 2001.

[12] W. Ajib and D. Haccoun, "An overview of scheduling algorithms in MIMO-based fourth-generation wireless systems," *IEEE Network*, vol. 19, no. 5, pp. 43–48, 2005.

[13] Q. H. Spencer, C. B. Peel, A. L. Swindlehurst, and M. Haardt, "An introduction to the multi-user MIMO downlink," *IEEE Communications Magazine*, vol. 42, no. 10, pp. 60–67, 2004.

[14] X. Zhang, F. Chen, and W. Wang, "Outage probability study of multiuser diversity in MIMO transmit antenna selection systems," *IEEE Signal Processing Letters*, vol. 14, no. 3, pp. 161–164, 2007.

[15] X. Zhang, Z. Lv, and W. Wang, "Performance analysis of multiuser diversity in MIMO systems with antenna selection," *IEEE Transactions on Wireless Communications*, vol. 7, no. 1, pp. 15–21, 2008.

[16] J. M. Romero-Jerez and J. P. Pena-Martin, "ASER of rectangular MQAM in noise-limited and interference-limited MIMO MRC systems," *IEEE Wireless Communications Letters*, vol. 1, no. 1, pp. 1–5, 2012.

[17] M. K. Simon and M. S. Alouini, *Digital Communication in Fading Channels*, John Wiley & Sons, New York, NY, USA, 2nd edition, 2005.

[18] B. Holter and G. E. Øien, "On the amount of fading in MIMO diversity systems," *IEEE Transactions on Wireless Communications*, vol. 4, no. 5, pp. 2498–2507, 2005.

[19] C. C. Hung, C. T. Chiang, N. Y. Yen, and R. C. Wu, "Outage probability of multiuser transmit antenna selection/maximal-ratio combining systems over arbitrary Nakagami-*m* fading channels," *IET Communications*, vol. 4, no. 1, pp. 63–68, 2010.

[20] C. C. Hung, C. T. Chiang, S. N. Lin, and R. C. Wu, "Outage capacity analysis of TAS/MRC systems over arbitrary Nakagami-m fading channels," *IEICE Transactions on Communications*, vol. 93, no. 1, pp. 215–218, 2010.

[21] Z. Chen, Z. Chi, Y. Li, and B. Vucetic, "Error performance of maximal-ratio combining with transmit antenna selection in flat Nakagami-*m* fading channels," *IEEE Transactions on Wireless Communications*, vol. 8, no. 1, pp. 424–431, 2009.

[22] C. J. Chen and L. C. Wang, "A unified capacity analysis for wireless systems with joint multiuser scheduling and antenna diversity in Nakagami fading channels," *IEEE Transactions on Communications*, vol. 54, no. 3, pp. 469–478, 2006.

[23] S. Gradshteyn and I. M. Ryzhik, *Table of Integrals, Series, and Products*, Academic Press, New York, NY, USA, 1995.

[24] J. M. Romero-Jerez and A. J. Goldsmith, "Performance of multichannel reception with transmit antenna selection in arbitrarily distributed Nagakami fading channels," *IEEE*

Transactions on Wireless Communications, vol. 8, no. 4, pp. 2006–2013, 2009.

[25] J. C. S. S. Filho, M. D. Yacoub, and G. A. Fraidenraich, "A simple accurate method for generating autocorrelated Nakagami-*m* envelope sequences," *IEEE Communications Letters*, vol. 11, no. 3, pp. 231–233, 2007.