Effects of Imperfect Reference Signal Recovery on Performance of SC and SSC Receivers over Generalized Fading Channels

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Abstract. *This paper presents the study of the effects of imperfect reference signal recovery on the bit error rate (BER) performance of dual-branch switch-and-stay combining (SSC) and multibranch selection combining (SC) receivers in a generalized α-μ fading channel. The average BER of binary and quaternary phase shift keying (BPSK and QPSK) is derived under the assumption that the reference carrier signal is extracted from the received modulated signal. For SSC receiver the optimal switching threshold (in a minimum BER sense) is numerically evaluated. Hereby we determine and discuss the simultaneous influence of the average signal-to-noise ratio (SNR) per bit, fading severity, product phase-locked loop (PLL) bandwidth–bit duration (B_LT_b), switching threshold of SSC and diversity order of SC on BER performance. The influence of B_LT_b in different channel conditions and modulation formats is pointed out. The numerical results are confirmed by computer simulations.*

Keywords

Communication technology, phase shift keying, bit error rate, fading channel, diversity.

1. Introduction

In wireless systems, a variation of instantaneous value of the received signal due to the multipath propagation, i.e. fading, is a very common effect. Fading is one of the main causes of performance degradation in wireless communication systems [1], [2]. Diversity technique, using spatially separated receiver antennas, is certainly one of the most frequently used methods for combating the deleterious effect of channel fading and the increasing of the communication reliability without enlarging either the transmitting power or the bandwidth of the channel. Particular diversity methods and combining techniques are presented in [1], [2]. In [3], the authors described the behavior of dual diversity combining systems over correlated log-normal fading channels. They considered maximal-ratio combining, selection combining, and switch-and-stay combining.

Since the selection combining (SC) and switched-and-stay combining (SSC) do not require signal co-phasing and fading envelope estimation, they are very often used in practice. Selection combining (SC) is a combining technique where the strongest signal is chosen among N branches of diversity system. The criterion for the branch selection is the largest value of instantaneous signal-to-noise ratio (SNR) among the branches [1], [2]. In the case of dual-branch SSC, the first branch stays selected as long as its instantaneous SNR is greater than the predetermined switching threshold, even if the instantaneous SNR in the second branch may have a larger value at that time. The previously published works concerning the performance of SSC receivers are included in [1], [4]-[8]. In [4], [5] the authors consider switching rate of a dual selection combining diversity and dual switch-and-stay combining diversity in fading channels. In [6] the moment generating function (MGF) of the signal power at the output of the dual SSC was derived, valid for several common fading distributions (Rayleigh, Nakagami-*m*, Rician, Nakagami-*q*). Using this approach, the expressions are derived for the bit error rate (BER) of some noncoherent modulations, like noncoherent frequency shift keying (NCFSK), differentially phase shift keying (DPSK), and coherent ones, like *M*-ary phase shift keying (MPSK) and quadrature amplitude modulations (QAM). The BER performance of MPSK and QAM schemes was determined under the assumption of a perfect reference signal recovery. Paper [7] offered generic formulas for the cumulative distribution function (cdf), probability density function (pdf) and MGF of the combined signal power for multibranch switched diversity systems. That paper presented the performance of MPSK coherent signal detection with perfect reference signal recovery. In [8] the authors presented a performance analysis of SSC diversity schemes for MPSK and *M*-ary quadrature-amplitude modulation (MQAM) over a wide variety of fading channels (Rayleigh, Nakagami-*n* and Nakagami-*m*). They determined the optimum threshold and studied the effect of branch unbalance and fading correlation on the performance of SSC diversity systems. The perfect reference signal was used for MPSK and MQAM signal demodulation. Similarly, concerning the detection of PSK and QAM signals in SC receivers, the main assumption in [1], [9], [10] was that reference signal recovery is perfect.

This paper presents the analysis of the reception of binary and quaternary phase-shift keying (BPSK and QPSK) signals, transmitted over the generalized α-μ fading channel. The estimation of the received signal phase is assumed as imperfect. The phase-locked loop (PLL) is used for carrier signal recovery from modulated signal in the receiver. As the receiver is not ideal, a certain phase error appears. The phase error is a difference between the phase of the incoming signal and the phase of the recovered carrier signal in the loop, and this may lead to the serious degradation of system performance. It is a statistical process which follows Tikhonov distribution [11]-[13]. The influence of fading is taken into account in both, that is the decision and PLL circuit. Using the analytical approach, we determine the simultaneous influences of the imperfect reference signal recovery, fading severity and average SNR in the channel on BER performance. The numerical results are confirmed by Monte Carlo simulations.

The remaining part of the paper is organized as follows. In section 2, we derive the expressions for pdf of phase error and BER in detecting BPSK and QPSK signals at SSC and SC receivers. Section 3 presents numerical and simulation results with appropriate discussions, and section 4 contains some concluding remarks.

2. System Model

We consider BPSK and QPSK signal transmission over the generalized α-μ fading channel. The generalized α-μ fading model was recently proposed in [14], [15] by considering two parameters, non-linearity and clustering. The α-μ distribution is written in terms of physically-based fading parameters, namely $\alpha > 0$ and $\mu > 0$, which describe a non-linearity (α) of propagation medium and a multipath wave clustering (μ). This distribution includes the Rayleigh, Nakagami-*m*, Weibull, and Lognormal distribution as special cases. The pdf of the fading envelope r_i at the *i*-th diversity branch is written as [14], [15]

$$p_{r_i}(r_i) = \frac{\alpha_i \mu_i^{\mu_i} r_i^{\alpha_i \mu_i - 1}}{\hat{r}_i^{\alpha_i \mu_i} \Gamma(\mu_i)} \exp\left(-\mu_i \frac{r_i^{\alpha_i}}{\hat{r}_i^{\alpha_i}}\right) \tag{1}$$

where $\hat{r}_i = \sqrt[\alpha_i]{\mathrm{E}\left(r_i^{\alpha_i}\right)}$, $\mu_i = (\mathrm{E}(r_i^{\alpha_i}))^2/\mathrm{V}(r_i^{\alpha_i})$, $\mathrm{E}(\cdot)$ and $\mathrm{V}(\cdot)$ denote expectation and variance operators, respectively, and $\Gamma(\cdot)$ denotes the Gamma function [16, Eq. (8.310/1)].

After applying the elementary rules for stochastic variable transformation [2], one can obtain the pdf of the instantaneous symbol SNR, denoted by ρ_i, at the *i*-th diversity branch as

$$p_{\rho_i}(\rho_i) = \frac{\alpha_i}{2\Gamma(\mu_i)} \frac{\rho_i^{\alpha_i\mu_i/2-1}}{\left(\overline{\rho_{bi}} \log_2 M\right)^{\alpha_i\mu_i/2}} \left(\frac{\Gamma(\mu_i + 2/\alpha_i)}{\Gamma(\mu_i)}\right)^{\alpha_i\mu_i/2} \times \\ \times \exp\left(-\left(\frac{\Gamma(\mu_i + 2/\alpha_i)}{\Gamma(\mu_i)} \frac{\rho_i}{\overline{\rho_{bi}} \log_2 M}\right)^{\alpha_i/2}\right) \tag{2}$$

where $\overline{\rho_{bi}}$ is an average bit SNR. The number of phase levels is denoted by M and it can take values 2 and 4 for BPSK and QPSK detection, respectively. The logarithm to the base of 2 is represented as $\log_2(\cdot)$.

In the case of SC diversity in the receiver, the pdf of the instantaneous output SNR, denoted by ρ_{SC}, is [1]

$$p_{\rho_{sc}}(\rho) = \sum_{i=1}^{N} p_{\rho i}(\rho) \prod_{\substack{k=1 \\ k \neq i}}^{N} F_k(\rho) = N p_{\rho i}(\rho) F_i^{N-1}(\rho) \tag{3}$$

where N is a number of diversity branches. The cdf is denoted by F_i and defined as

$$F_i(\rho) = \int_0^{\rho} p_{\rho_i}(\rho_i) d\rho_i \,. \tag{4}$$

The pdf of the SSC instantaneous output SNR, denoted by ρ_{SSC}, is [1]

$$p_{\rho_{ssc}}(\rho) = \begin{cases} \dfrac{(1+F_{\tau 1})F_{\tau 2}}{F_{\tau 1}+F_{\tau 2}} p_{\rho_1}(\rho) + \dfrac{(1+F_{\tau 2})F_{\tau 1}}{F_{\tau 1}+F_{\tau 2}} p_{\rho_2}(\rho), \rho > \rho_\tau \\ \dfrac{F_{\tau 1}F_{\tau 2}}{F_{\tau 1}+F_{\tau 2}} \left(p_{\rho_1}(\rho) + p_{\rho_2}(\rho)\right), \rho \le \rho_\tau \end{cases} \tag{5}$$

where ρ_τ is a predetermined switching threshold. It was convenient to denote $F_{\tau i} = F_i(\rho_\tau)$. In our analysis we will assume independent and identically distributed (i.i.d.) average bit SNRs in input branches $\overline{\rho_{bi}} = \overline{\rho_b}$, $i = 1,\ldots,N$ and the fading parameters α_i and μ_i same for all branches $\alpha_i = \alpha$, $\mu_i = \mu$, $i = 1,\ldots,N$. Consequently, the pdf-s and cdf-s of instantaneous symbol SNR are the same in all branches, $p_{\rho i}(\rho_i) = p_\rho(\rho)$, $F_i = F$, $F_{\tau i} = F_\tau$, $i = 1,\ldots,N$.

The conditional BER in the case of BPSK signal detection can be written as [1]

$$P_{eBPSK/\phi_c,\rho} = \frac{1}{2} \mathrm{erfc}\left(\sqrt{\rho} \cos\phi_c\right), \tag{6}$$

and in the case of QPSK as [1]

$$P_{eQPSK/\phi_c,\rho} = \frac{1}{4} \mathrm{erfc}\left(\sqrt{\rho/2}(\cos\phi_c - \sin\phi_c)\right) + \\ + \frac{1}{4} \mathrm{erfc}\left(\sqrt{\rho/2}(\cos\phi_c + \sin\phi_c)\right) \tag{7}$$

where the complementary error function is denoted by erfc $(\cdot)$ [17, Eq. (7.1.2)]. The purpose of the PLL is to estimate the phase of the incoming signal. In ideal case, the estimated phase should be equal to the phase of the incoming signal. However, in practical realizations there is a certain disagreement between the estimated phase $\hat{\delta}$ and the phase δ_i of the incoming signal. This disagreement is a phase error and it is expressed as $\phi_c = \delta_i - \hat{\delta}$. Under the assumption that the reference signal phase is extracted from modulated signal, the conditional pdf of this phase error corresponds to Tikhonov distribution [11]-[13]

$$p_{\phi_c}(\phi_c/\rho) = \frac{M\exp(\rho_{eq}(\rho)\cos(M\phi_c))}{2\pi \mathrm{I}_0(\rho_{eq}(\rho))}$$
$$-\frac{\pi}{M} \le \phi_c < \frac{\pi}{M} \tag{8}$$

where the modified Bessel function of the first kind and order zero is denoted by $\mathrm{I}_0(\cdot)$ [17, Eq. (8.406)]. The equivalent SNR in the PLL circuit is given by [9]

$$\rho_{eq}(\rho) = \frac{\gamma_{PLL}(\rho)S_L(\rho)_{|BPSK\ or\ QPSK}}{M^2} \tag{9}$$

and the SNR in the PLL circuit is

$$\gamma_{PLL}(\rho) = \frac{\rho}{B_L T_b \log_2 M} \tag{10}$$

where $B_L T_b$ denotes the loop bandwidth-bit time product, and $S_L(\rho)|_{BPSK\ or\ QPSK}$ is the squaring loss. In the range of low SNR values, the squaring loss for BPSK modulation, denoted by $S_L(\rho)|_{BPSK}$, is given by [13]

$$S_L(\rho)_{|BPSK} = \frac{2\rho}{1+2\rho} \tag{11}$$

and in the case of QPSK modulation, the squaring loss, denoted by $S_L(\rho)|_{QPSK}$, can be obtained using expression [13]

$$S_L(\rho)_{|QPSK} = \frac{1}{1+\dfrac{9}{2\rho}+\dfrac{3}{2(\rho/2)^2}+\dfrac{3}{16(\rho/2)^3}}. \tag{12}$$

The average BER, as a function of $\overline{\rho_b}$, can be obtained from

$$P_e = \int_0^{+\infty}\int_{-\pi/2}^{\pi/2} P_{eBPSK/\phi_c,\rho}\, p_{\phi_c}(\phi_c/\rho)\, p_{\rho_{SSC,SC}}(\rho)\, d\phi_c d\rho \tag{13}$$

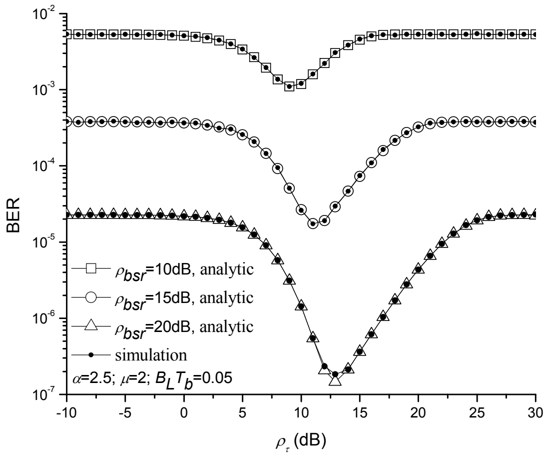
for the case of BPSK detection and for the case of QPSK it is

$$P_e = \int_0^{+\infty}\int_{-\pi/4}^{\pi/4} P_{eQPSK/\phi_c,\rho}\, p_{\phi_c}(\phi_c/\rho)\, p_{\rho_{SSC,SC}}(\rho)\, d\phi_c d\rho\,. \tag{14}$$

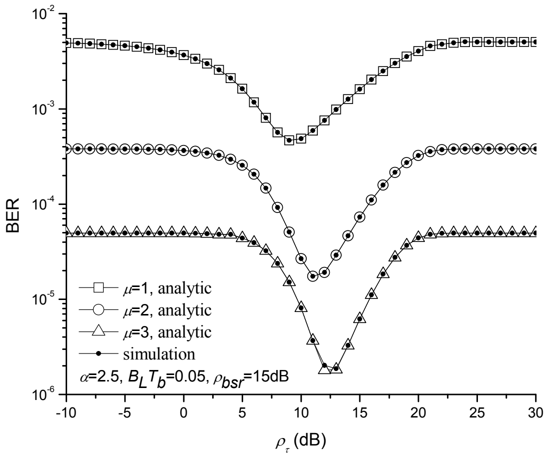
Numerical integration in (13) and (14) was performed by applying Gaussian quadrature formula with 6 precision digits. Independently of the analytical approach, Monte Carlo simulations were performed, too. The BER values are estimated on the basis of $3\cdot 10^3$ bit errors. A minimum number of bits, used to evaluate any BER value, is 10^4 A maximum number of bits, used in simulation, is $2\cdot 10^9$. Based on the results in the next section, one can notice that there is a very good agreement between numerical and simulation results.

3. Numerical Results and Discussion

In this section, we present the numerical results, illustrating the influence of channel and receiver parameters on BER values.



(a)



(b)

Fig. 1. (a) Dependence of BER on switching threshold for different values of average bit SNR in the case of QPSK. (b) Dependence of BER on switching threshold for different values of fading severity in the case of QPSK.

In Fig. 1(a) the influence of the switching threshold (ρ_τ) on the SSC receiver performance is shown. If the switching threshold is too small, the currently used branch is always acceptable. Therefore, there is no branch switching and thus no diversity. If the switching threshold is too high, the receiver will be always switching branches, and this also leads to the no-diversity case. Because of that, there as an optimal switching threshold value that gives the lowest error probability. In [1], the analytical expressions for optimal switching threshold were derived, in case of Rayleigh, Rician, and Nakagami-*m* channels for perfect synchronization at the receiver. However, in case of the generalized α-μ fading channel and the imperfect carrier recovery at the receiver, considered in this paper, the ex pression for the error probability is too complex and the analytical expression for the optimal switching threshold could not be derived. Therefore, numerical optimization of the switching threshold is performed for each combination of parameters. In the cases of ρ_{bsr}= 10 dB and ρ_{bsr}= 20 dB, the corresponding optimum thresholds are 11 dB and 13 dB, respectively. All the other values of the ρ_τ bring worse system performances. Fig. 1(b) illustrates the influence of a fading severity on optimum threshold. The lower the fading severity (the higher the parameter μ value), the higher is the optimum threshold severity. Similar dependence of the average BER on the switching threshold can be seen, for example, in [18].

In Fig. 2 BER is presented as a function of average bit SNR in the case of dual SSC and SC diversity, for different values of parameter B_LT_b. For all the examined values of the parameter B_LT_b, the curves that correspond to SC diversity show better performances. As SSC has a predetermined switching threshold, in the previously mentioned figure two groups of graphs are shown. The first one is related to the fixed switching threshold applied (ρ_τ= 10 dB), and the other one to the optimal threshold, which is calculated for each set of parameters. As expected, the curves with optimal switching threshold show better performances. For B_LT_b= 0.1, in order to reach BER of 10^{-7}, the SC receiver requires 8 dB less ρ_{bsr} than SSC receiver with fixed ρ_τ, and only 2 dB less ρ_{bsr} than SSC receiver with optimum ρ_τ. The influence of B_LT_b is most emphasized in SSC receiver with fixed ρ_τ, and its influence in SSC receiver with optimum ρ_τ and SC receiver is smaller and approximately the same for both diversity schemes.

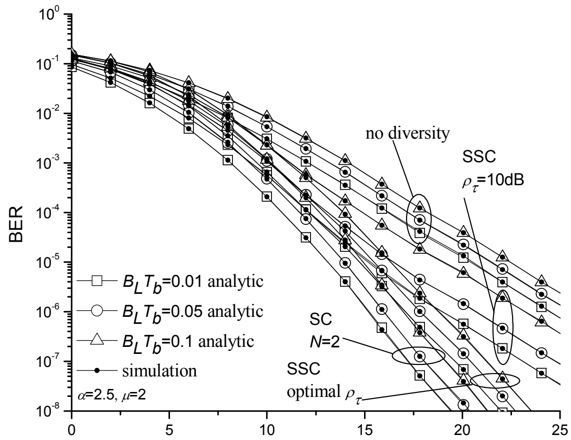


Fig. 2. Dependence of BER on average bit SNR for different values of parameter B_LT_b in the case of QPSK.

In Figs. 3a and 3b the influence of the fading parameters μ and α on the system performances in SSC receiver, respectively, can be observed in more details. Two cases were examined: the one with a fixed switching threshold, and the other with an optimal threshold applied. The difference in BER performance for the optimum switching threshold, in comparison to the case when the fixed switching threshold is applied, is better expressed in the range of high values of ρ_{bsr}. When μ is 2, for ρ_{bsr}= 20 dB, the BER is $9.2\cdot10^{-6}$ for the fixed switching threshold and $1.5\cdot10^{-7}$ for the optimum switching threshold.

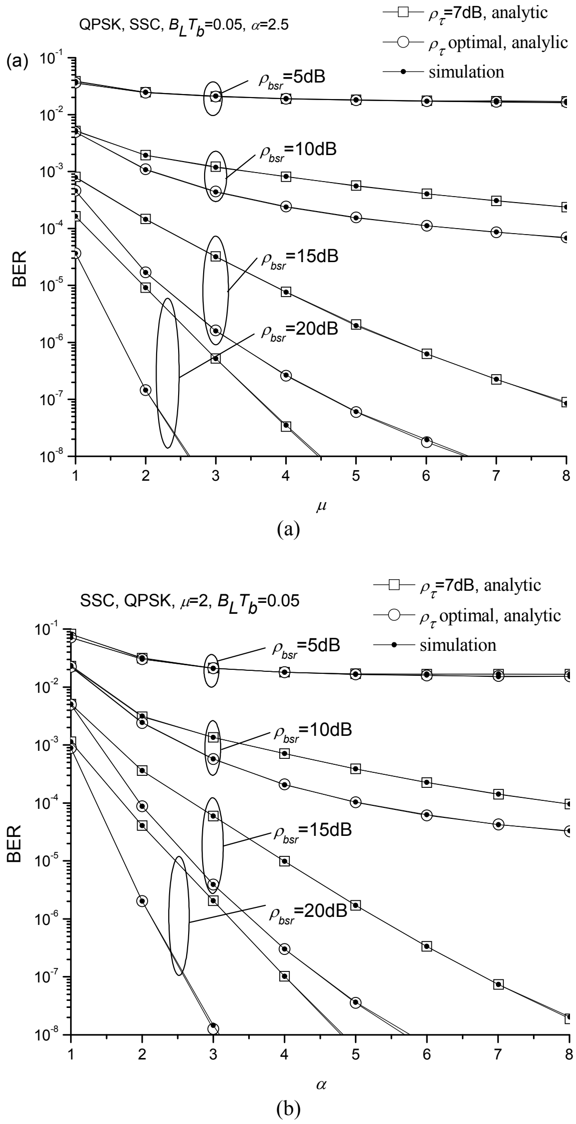


Fig. 3. Dependence of BER on the fading parameter μ (a) and α (b) for different values of the average bit SNR in case of QPSK.

In Fig. 4 the dependence of BER on the average bit SNR is presented for different values of loop bandwidth–bit time product (B_LT_b) and fading parameter μ in the case of SSC diversity reception of QPSK and BPSK signals. It can be seen that the increase of the B_LT_b value leads to the impairments of the receiver performances. With the increasing of the loop bandwidth, the noise power in PLL circuit increases, so the variance of phase error is greater, and consequently the deleterious effect of phase error on BER values is greater, too. It can be concluded that the influence of B_LT_b on the system performance is greater in detecting QPSK than BPSK signals. In the case of BPSK signal detection, the curves overlap almost completely for all values of B_LT_b. The influence of B_LT_b is more expressed in the channel with dipper fading. In order to maintain BER of 10^{-5}, if $B_L T_b$ increases from 0.01 to 0.1, for $\mu = 5$ the penalty of 1.9 dB in ρ_{bsr} should be paid, while for $\mu = 1$ the greater penalty of 5.7 dB should be paid. In addition, higher μ values bring a decrease of the BER.

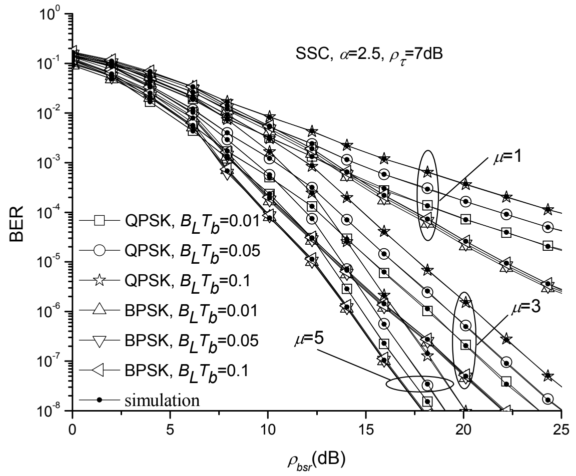


Fig. 4. Dependence of BER on the average bit SNR for different values of $B_L T_b$ and fading parameter μ in the case of QPSK and BPSK.

Fig. 5 shows a BER dependence on diversity order for SC receiver in the case of BPSK and QPSK transmission. Generally, with the increase of the diversity order, performances of the receiver improve in both cases. However, a larger number of diversity branches reduces the additional gain and increases the complexity of the system. Therefore, it is necessary to find a compromise between the quality of the performances and the system complexity (number of diversity branches).

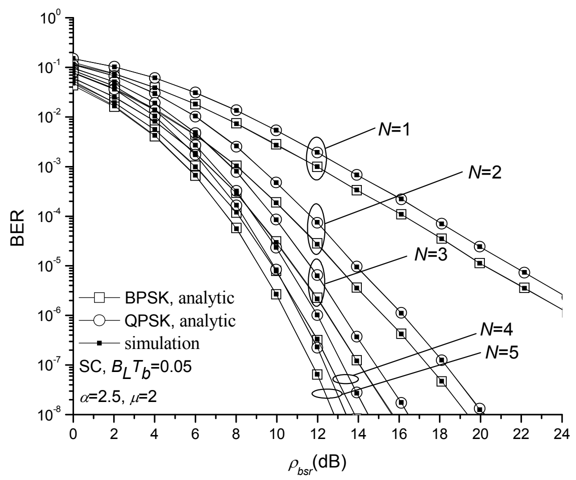


Fig. 5. Influence of diversity order on BPSK and QPSK signal detection.

4. Conclusion

In this paper we analyzed the dual branch SSC and multibranch SC diversity receiver performance for BPSK and QPSK modulation formats and generalized α-μ fading channel, taking the imperfect reference signal recovery into consideration. We derived the relations among BER, average SNR per bit, fading severity and $B_L T_b$, which allow numerical evaluation for the specific cases of interest. All numerical results were confirmed by Monte Carlo simulations.

We showed that an optimum choice of switching threshold in SSC receiver has a considerable effect to the BER performance. This optimum threshold increases with the average bit SNR increasing and fading severity decreasing. We determined how much the QPSK is more sensitive to $B_L T_b$ than BPSK in the observed scenario and illustrated the greater effect of $B_L T_b$ to the BER performance for a higher fading severity. Based on the results related to SC receiver, a compromise between receiver complexity (diversity order) and its performance quality (BER values) can be found.

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References

[1] SIMON, M. K., ALOUINI, M. S. *Digital Communication over Fading Channels: A Unified Approach to Performance Analysis*. 1st ed. New York: John Wiley & Sons, Inc., 2000.

[2] PROAKIS, J. G. *Digital Communications*. 2nd ed. New York: McGraw-Hill, 2000.

[3] ALOUINI, M. S., SIMON, M. K. Dual diversity over correlated log-normal fading channels. *IEEE Transactions on Communications*, 2002, vol. 50, no. 12, p. 1946 - 1959.

[4] BEAULIEU, N. C. Switching rates of dual selection diversity and dual switch-and-stay diversity. *IEEE Transactions on Communications*, 2008, vol. 56, no. 9, p. 1409 - 1413.

[5] WANG, X., BEAULIEU, N. C. Switching rates of dual selection diversity in noisy fading channels. *IEEE Transactions on Communications*, 2009, vol. 57, no. 10, p. 2909 - 2913.

[6] TELLAMBURA, C., ANNAMALAI, A., BHARGAVA, V. K. Unified analysis of switched diversity systems in independent and correlated fading channels. *IEEE Transactions on Communications*, 2001, vol. 49, no. 11, p. 1955 - 1965.

[7] YANG, H. C., ALOUINI, M. S. Performance analysis of multibranch switched diversity systems. *IEEE Transactions on Communications*, 2003, vol. 51, no. 5, p. 782 - 794.

[8] KO, Y. C., ALOUINI, M. S., SIMON, M. K. Analysis and optimization of switched diversity systems. *IEEE Transactions on Vehicular Technology*, 2000, vol. 49, no. 5, p. 1813 - 1831.

[9] SIMON, M. K., ALOUINI, M. S. A unified performance analysis of digital communication with dual selective combining diversity over correlated Rayleigh and Nakagami-*m* fading channels. *IEEE Transactions on Communications*, 1999, vol. 47, no. 1, p. 33 - 43.

[10] CHEN, Y., TELLAMBURA, C. Distribution functions of selection combiner output in equally correlated Rayleigh, Rician, and Naka-

gami-*m* fading channels. *IEEE Transactions on Communications*, 2004, vol. 52, no. 11, p. 1948 - 1956.

[11] LINDSEY, W. C., SIMON, M. K. *Telecommunication Systems Engineering*. New York: Prentice-Hall, Inc., Englewood Cliffs, 1973.

[12] SIMON, M. K. On the bit-error probability of differentially encoded QPSK and offset QPSK in the presence of carrier synchronization. *IEEE Transactions on Communications*, 2006, vol. 54, no. 5, p. 806 - 812.

[13] SIMON, M. K. *Carrier Synchronization of Offset Quadrature Phase-Shift Keying*. Jet Propulsion Lab., Pasadena, CA, TMO Prog. Rep. 42-133, May 15, 1998. 33 pages. [Online] Cited: 2010-01-13. Available at: http://tmo.jpl.nasa.gov/progress_report/42-133/133J. pdf.

[14] YACOUB, M. D. The α-μ distribution: a general fading distribution. In *Proceedings of 13th IEEE Int. Symp. on Personal, Indoor and Mobile Radio Communications.* Lisbon (Portugal), 2002, p. 629 - 633.

[15] YACOUB, M. D. The α-μ distribution: a physical fading model for the Stacy distribution. *IEEE Transactions on Vehicular Technology*, 2007, vol. 56, no. 1, p. 27 - 34.

[16] GRADSTEYN, I. S., RYZHIK, I. M. *Table of Integrals, Series, and Products*. 6th ed. New York: Academic, 2000.

[17] ABRAMOWITZ, M., STEGUN, I. A. *Handbook of Mathematical Functions*. New York: Dover publications, INC., 1972.

[18] YANG, H.-C., ALOUINI, M. S. Markov chains and performance comparison of switched diversity systems. *IEEE Transactions on Communications*, 2004, vol. 52, no. 7, p. 1113 - 1125.

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