AVERAGE FADE DURATION FOR DUAL SELECTION DIVERSITY IN CORRELATED RICIAN FADING WITH RAYLEIGH COCHANNEL INTERFERENCE

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The average fade duration (AFD) finds diverse applications in evaluation and design of wireless communication systems. This quantity provides a dynamic representation of the channel and presents the average period of time for which signal stays below a predetermined threshold level. In this paper, an infinite-series expression of AFD for dual selection combining (SC) diversity receiver, operating over correlated Rician fading in the presence of Rayleigh cochannel interference, is derived. The branch selection is based on desired signal power algorithm. Numerical results are presented to illustrate the proposed mathematical analysis and to examine the effects of fading severity and branch correlation on the concerned criterion.

1. INTRODUCTION

In wireless communication systems, various techniques for reducing fading effect and influence of cochannel interference (CCI) are used. Diversity combining [1], which combines multiple replicas of the received signal, is a classical and powerful technique for reducing these deleterious effects. Space diversity reception, which uses multiple antennas at the receiver, is the most common form of diversity reception. Input signals from multiple antennas at the receiver can be combined on various ways and the most popular are maximal ratio combining (MRC), equal gain combining (EGC) and selection combining (SC). Among them, SC is the simplest and most practical diversity technique since the processing is performed only on one of the diversity branches. In general, SC receiver chooses the branch with the highest signal-to-noise ratio (SNR), or equivalently, with the strongest signal assuming equal noise power among the branches. In wireless communication systems, the influence of the thermal noise may be negligible as compared to the influence of CCI. In that case, three different decision algorithms

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can be applied: the desired signal power algorithm, the total power algorithm and the signal-to-interference power ratio (SIR) algorithm. In cellular mobile radio systems with fading, an exact performance analysis is usually quite complicated, and approximations are sometimes used to simplify the analysis, so that some papers study diversity by considering the effect of only the strongest CCI [2–7]. In a microcellular environment, CCI may well be modelled by Rayleigh statistic, but Rayleigh fading may not be a good assumption for desired signal. The desired signal usually experiences Rician fading since a line-of-sight (LoS) path between transmitter and receiver within a microcell may exists [8]. Therefore, in this situation, different fading models for the desired signal and CCI have to be used.

The average level crossing rate (LCR) and average fade duration (AFD) represent the system's second-order statistics and they are used as important performance measures for the proper selection of the transmission symbol rate, interleaver depth, packet length and/or time slot duration [9-10]. Studies focusing on the analysis of the LCR and AFD for SC system with/without presence of CCI can be found in [11-16]. In this paper, we derived an infinite-series expression of the AFD for dual diversity SC receiver which employs the desired signal power algorithm and operates in correlated Rician fading channels exposed to Rayleigh CCI. Numerical results are also presented to show effects of various parameters on the AFD such as the fading severity and level of correlation.

2. AVERAGE FADE DURATION

In this section, we seek to evaluate AFD. It is an important measure to describe how long in average the system remains in the outage status. Actually, in interference-limited environments, the respective AFD at threshold μ is defined as the average time that envelope ratio remains below the level μ after crossing that level in the downward direction. It is given by [13]

$$T_{\mu}(\mu) = F_{\mu}(\mu) / N_{\mu}(\mu), \tag{1}$$

where $F_{\mu}(\mu)$ and $N_{\mu}(\mu)$ denote the cumulative distribution function (CDF) and average LCR of the envelope ratio, respectively. In according to fact that considered dual SC receiver uses desired signal power decision algorithm, instantaneous output envelope ratio is given by $\mu = \sqrt{\max\{r_1^2, r_2^2\}/a^2}$. Due to insufficient antennas distance, desired signal envelopes on two diversity branches, r_1 and r_2, follow correlated Rician probability distribution function (PDF) [5]

$$p_{r_1r_2}(r_1,r_2)=\frac{r_1r_2(1+K)^2}{\beta^2(1-\rho^2)}\exp\left(-\frac{(r_1^{\,2}+r_2^{\,2})(1+K)+4K\beta(1-\rho)}{2\beta(1-\rho^2)}\right)$$

$$\times\sum_{k=0}^{\infty}\varepsilon_k \mathrm{I}_k\left(\frac{r_1r_2\rho(1+K)}{\beta(1-\rho^2)}\right)\mathrm{I}_k\left(\frac{r_1}{1+\rho}\sqrt{\frac{2K(1+K)}{\beta}}\right)\quad, \tag{2}$$

$$\times\mathrm{I}_k\left(\frac{r_2}{1+\rho}\sqrt{\frac{2K(1+K)}{\beta}}\right),\quad \varepsilon_k=\begin{cases}1, & k=0\\ 2, & k\neq 0\end{cases}$$

where ρ is the branch correlation coefficient, β is the average desired signal power, K is the Rician factor defined as the ratio of the signal power in the dominant component over the scattered power and $\mathrm{I}_k(\cdot)$ is the modified Bessel function of the first kind and k-th order.

The strongest CCI envelope, a, follows Rayleigh PDF [11]

$$p_a(a)=\frac{a}{\sigma_a^{\,2}}\exp\left(-\frac{a^2}{2\sigma_a^{\,2}}\right), \tag{3}$$

where σ_a^2 is the average interference signal power.

The CDF of the output SIR of the proposed SC diversity system, ν, can be obtained using [17]

$$F_\nu(\nu)=1-\int_0^{\infty}\int_0^{R/\nu}p_A(A)p_R(R)\mathrm{d}A\mathrm{d}R\,, \tag{4}$$

where $p_R(R)$ and $p_A(A)$ are the PDFs of desired and interference signal power, respectively.

The PDF of desired signal envelope at considered dual SC receiver output can be obtained as [1, Eq. (9.687)]

$$p_r(r)=\int_0^{r}p_{r_1r_2}(r,r_2)\mathrm{d}r_2+\int_0^{r}p_{r_1r_2}(r_1,r)\mathrm{d}r_1. \tag{5}$$

Substituting (2) in (5) and changing the order of summation and integration, integrals in (5) can be solved with use [18, Eq. (3.351(1))]. The PDF of desired signal power at the SC receiver output is expressed in the form of following infinite-series using [19, Eq. (4.10)]

$$p_R(R)=\sum_{k,p,n,l=0}^{\infty}\varepsilon_k\frac{K^{n+l+k}(1+K)^{p+k+1}R^{p+k}}{n!\,p!\,l!\,\Gamma(n+k+1)\Gamma(p+k+1)\Gamma(l+k+1)}\times$$

$$\times\frac{\rho^{2p+k}}{2^{p+k+1}(1-\rho)^p(1+\rho)^{2k+p+n+l}\beta^{p+k+1}}$$

$$\times\left\{(p+n+k)!(1-\rho)^{n}\left(\frac{(1+K)R}{2\beta(1+\rho)}\right)^{l}\left[\alpha_2-\alpha_1\sum_{i=0}^{p+n+k}\frac{1}{i!}\left(\frac{(1+K)R}{2\beta(1-\rho^2)}\right)^{i}\right]+\right.$$
$$\left.+(p+l+k)!(1-\rho)^{l}\left(\frac{(1+K)R}{2\beta(1+\rho)}\right)^{n}\left[\alpha_2-\alpha_1\sum_{j=0}^{p+l+k}\frac{1}{j!}\left(\frac{(1+K)R}{2\beta(1-\rho^2)}\right)^{j}\right]\right\}, \qquad (6)$$

where $R = \max\{r_1^2, r_2^2\}$, $\Gamma(\cdot)$ is the Gamma function, $\alpha_1=-\frac{R(1+K)}{\beta(1-\rho^2)}-\frac{2K}{1+\rho}$ and $\alpha_2=-\frac{R(1+K)}{2\beta(1-\rho^2)}-\frac{2K}{1+\rho}$.

Substituting PDF of interference signal power at the SC receiver output, derived applying [19, Eq. (4.10)] on (3), and (6) into (4), using [18, Eq. (3.351(3))] the CDF of SIR at the output of SC receiver becomes

$$F_{\nu}(\nu)=1-\exp\left(-\frac{2K}{1+\rho}\right)\sum_{k,p,n,l=0}^{\infty}\varepsilon_k\frac{K^{n+l+k}}{\Gamma(n+k+1)\Gamma(p+k+1)\Gamma(l+k+1)}\times$$
$$\times\frac{\rho^{2p+k}(1-\rho)^{n+l+k+1}}{n!p!l!(1+\rho)^{n+l+k-1}}\left\{(p+n+k)!\left[(p+l+k)!\left(1-\frac{1}{\chi^{p+l+k+1}}\right)-\right.\right.$$
$$\left.-\sum_{i=0}^{p+n+k}\frac{(p+l+k+i)!}{i!}\left(\frac{1}{2^{p+l+k+i+1}}-\frac{1}{(1+\chi)^{p+l+k+i+1}}\right)\right]+ \qquad (7)$$
$$+(p+l+k)!\left[(p+n+k)!\left(1-\frac{1}{\chi^{p+n+k+1}}\right)-\right.$$
$$\left.\left.-\sum_{j=0}^{p+l+k}\frac{(p+n+k+j)!}{j!}\left(\frac{1}{2^{p+n+k+j+1}}-\frac{1}{(1+\chi)^{p+n+k+j+1}}\right)\right]\right\},$$

where average input SIR is defined as $S = \beta/\sigma_a^2$ and $\chi=1+\frac{(1-\rho^2)S}{(1+K)\nu}$. Having in mind that $F_\mu(\mu) = F_\nu(\mu^2)$ and using analytical expression for the average LCR of the envelope ratio at threshold μ [7]

$$N_{\mu}(\mu) = f_m \sqrt{2\pi S\left(S + (1+K)\mu^2\right)} \exp\left(-\frac{2K}{1+\rho}\right) \sum_{k,p,n,l=0}^{\infty} Z (1+K)^{p+k+\frac{1}{2}} \times$$

$$\times \rho^{2p+k} \left\{ \left(\frac{(1+K)\mu^2}{1+\rho} \right)^l (p+n+k)!(1-\rho)^n \left[\frac{\left(p+l+k+\frac{1}{2}\right)!}{\left(S + \frac{(1+K)\mu^2}{1-\rho^2}\right)^{p+l+k+\frac{3}{2}}} - \right.\right.$$

$$\left. - \sum_{i=0}^{p+n+k} \left(\frac{(1+K)\mu^2}{1-\rho^2} \right)^i \frac{\left(p+l+k+i+\frac{1}{2}\right)!}{2^{p+l+k+i+\frac{3}{2}} i! \left(\frac{S}{2} + \frac{(1+K)\mu^2}{1-\rho^2} \right)^{p+l+k+i+\frac{3}{2}}} \right] +$$

$$+ \left(\frac{(1+K)\mu^2}{1+\rho} \right)^n (p+l+k)!(1-\rho)^l \left[\frac{\left(p+n+k+\frac{1}{2}\right)!}{\left(S + \frac{(1+K)\mu^2}{1-\rho^2}\right)^{p+n+k+\frac{3}{2}}} - \right. \qquad (8)$$

$$\left.\left. - \sum_{j=0}^{p+l+k} \left(\frac{(1+K)\mu^2}{1-\rho^2} \right)^j \frac{\left(p+n+k+j+\frac{1}{2}\right)!}{2^{p+n+k+j+\frac{3}{2}} j! \left(\frac{S}{2} + \frac{(1+K)\mu^2}{1-\rho^2} \right)^{p+n+k+j+\frac{3}{2}}} \right] \right\},$$

where f_m is the maximum Doppler frequency and

$$Z = \varepsilon_k \frac{\mu^{2p+2k+1} K^{n+l+k}}{n!\,p!\,l!\,\Gamma(p+k+1)\Gamma(l+k+1)\Gamma(n+k+1)(1-\rho)^p (1+\rho)^{p+2k+n+l}},$$

AFD can be easily evaluated by (1).

3. **NUMERICAL RESULTS**

We have numerically evaluated AFD for proposed dual SC system and results are shown in Fig. 1. This figure presents plots of the normalized AFD

($T_\mu(\mu)f_m$) in function of the normalized envelope ratio ($\mu_{th}=\mu/\sqrt{S}$) for different values of Rician factor and branch correlation coefficient. As expected, for given value of K and ρ, the AFD is the monotonically increasing function of μ_{th}. Also, Fig. 1 shows that AFD increases when both previous mentioned parameters increase. Moreover, it can be noticed that influence of Rician factor on AFD is negligible for μ_{th} greater than 0 dB. Opposite, the influence of branch correlation is insignificant for μ_{th} less than –20 dB.

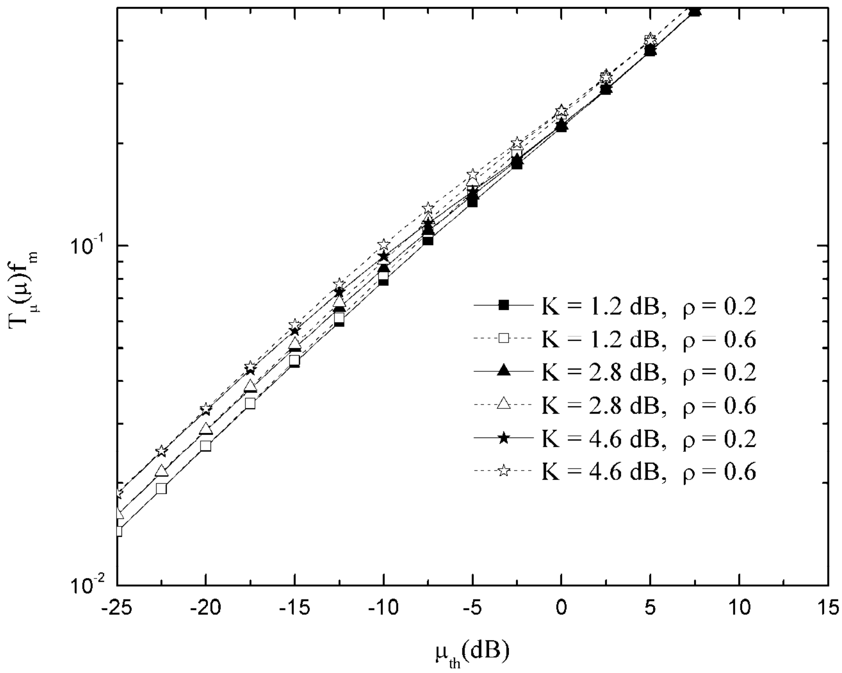

Fig. 1 – Normalized AFD for dual SC receiver for several values of Rician factor and branch correlation coefficient.

4. CONCLUSIONS

In this paper, we determine the analytical solution of AFD at the output of interference-limited SC system in microcell environment employing the desired signal power algorithm. Several numerical results are presented to illustrate the proposed mathematical analysis and to point out the effects of both fading severity and branch correlation to the performance of the dual SC receiver.

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REFERENCES

1. M.K. Simon, M.S. Alouini, *Digital communication over fading channels*, 2nd ed. John Wiley & Sons, Inc., New York, 2005.
2. S. Okui, *Effects of SIR selection diversity with two correlated branches in the m-fading channel*, IEEE Trans. Commun., **48**, *10*, pp. 1631–1633, 2000.
3. G.K. Karagiannidis, *Performance analysis of SIR-based dual selection diversity over correlated Nakagami-m fading channels*, IEEE Trans. Veh. Technol., **52**, *5*, pp. 1207–1216, 2003.
4. M.Č. Stefanović, D.M. Milović, A.M. Mitić, M.M. Jakovljević, *Performance analysis of system with selection combining over correlated Weibull fading channels in the presence of cochannel interference*, Int. J. AEÜ, **62**, *9*, pp. 695–700, 2008.
5. A.S. Panajotović, M.Č. Stefanović, D. Lj. Drača, *Performance analysis of system with selection combining over correlated Rician fading channels in the presence of cochannel interference*, Int. J. AEÜ, **63**, *12*, pp. 1061–1066, 2009.
6. M.Č. Stefanović, D. Lj. Drača, A.S. Panajotović, N.M. Sekulović, *Performance analysis of system with L-branch selection combining over correlated Weibull fading channels in the presence of cochannel interference*, Int. J. Commun. Syst., **23**, *2*, pp. 139–150, 2010.
7. A. Panajotović, M. Stefanović, D. Drača, N. Sekulovć, *Average level crossing rate of dual selection diversity in correlated Rician fading with Rayleigh cochannel interference*, IEEE Commun. Lett., **14**, *7*, pp. 605–607, 2010.
8. R.J.C. Bultitude, G. K. Bedal, *Propagation characteristics on microcellular urban mobile radio channels at 910 MHz*, IEEE J. Sel. Areas in Commun., **7**, *1*, pp. 31–39, 1989.
9. G.L. Stuber, *Principles of mobile communications*, MA: Kluwer, Boston, 1996.
10. L. Yang, M.S. Alouini, *Average outage duration of wireless communication systems* (Ch. 8: "Wireless communications systems and networks"), Springer, US, 2004.
11. X. Dong, N. C. Beaulieu, *Average level crossing rate and average fade duration of selection diversity*, IEEE Commun. Lett., **5**, *10*, pp. 396–398, 2001.
12. F. Adachi, M.T. Feeney, J. D. Parsons, *Effects of correlated fading on level crossing rates and average fade durations with predetection diversity reception*, IEE Proc. Communications, Radar and Signal Processing, **135**, *1*, pp. 11–17, 1988.
13. Z. Hadzi-Velkov, *Level crossing rate and average fade durations of selection diversity with Rician-faded cochannel interferers*, IEEE Commun. Lett., **10**, *9*, pp. 649–651, 2006.
14. N.C. Sagias, D.A. Zogas, G.K. Karagiannidis, *Selection diversity receivers over nonidentical Weibull fading channels*, IEEE Trans. Veh. Technol., **54**, *6*, pp. 2146–2151, 2005.
15. A.S. Panajotović, M.Č. Stefanović, D. Lj. Drača, N.M. Sekulović, I.M. Petrović, *Average fade duration of dual selection diversity over correlated Rician fading channels in the presence of cochannel interferences*, Proc. EUROCON 2011, Lisbon, Portugal, 27–29 April 2011.
16. S.Ž. Stanojčić, M.Č. Stefanović, S.R. Panić, S. Mekić, G. Popović, *Second order statistics of the MIMO κ-μ keywhole fading channels*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **57**, *2*, pp. 183–191, 2012.
17. H. Yang, M.S. Alouini, *Outage probability of dual-branch diversity systems in the presence of cochannel interference*, IEEE Trans. Wireless Commun., **2**, *2*, pp. 310–319, 2003.
18. I.S. Gradshteyn, I.M. Ryzhik, *Table of integrals, series, and products*, 5th ed., Academic Press, CD version 1.0, 1996.
19. D. Zwillinger, S. Kokoska, *Standard probability and statistics tables and formulae*, Chapman&Hall/CRC, Boca Raton, 2000.