Outage Probability of Dual SC Over Correlated Rician Fading Channels in the Presence of Multiple CCIs

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Abstract – **Outage probability is important measure to control the cochannel interference (CCI) level helping the designers of wireless communications systems to readjust the systems operating parameters. The analysis in this paper considers dual selection combining (SC) diversity schemes and it is not limited to a single CCI, but rather assumes the presence of multiple CCIs. Namely, analytical expression for the outage probability for the case of dual signal-to-interference ratio (SIR)-based SC receiver over correlated Rician fading channels experiencing an arbitrary number of Rayleigh CCIs is derived. The various performance evaluation results are graphically presented to show the effect of fading severity, level of correlation and number of CCIs to the system's outage performance.**

Keywords **– SC diversity system, cochannel interference, Rician fading, Rayleigh fading, outage probability.**

I. INTRODUCTION

Transmission in wireless communications systems is subjected to both fading and cochannel interference (CCI). Fading is the result of multipath propagation and CCI is the result of frequency reuse which is essential in increasing system capacity. Diversity combining [1] is one of the most practical, effective and widely employed technique in digital communications receivers for mitigating the effects of fading and CCI in order to improve the offered quality-of-service (QoS) and to increase systems capacity.

Space diversity techniques combine input signals from multiple receive antennas [2]. Over the years, a variety of diversity techniques, such as maximal ratio combining (MRC), equal gain combining (EGC) or selection combining (SC) have evolved. MRC and EGC systems require all or some of the channel state information (fading amplitude, phase and delay) from all received signals. In addition, a separate receiver chain is needed for each diversity branch which increases their complexity. In opposition to MRC and EGC, SC receiver is much simpler for practical realization since it processes only one of the diversity branches. Specifically, in its conventional form, the SC combiner chooses the branch with the highest signal-to-noise ratio (SNR). Efficient cellular system designs are interference-limited [2], i.e. the level of CCI is sufficiently high as compared to the level of thermal noise, so the thermal noise effect may be ignored. In that case, SC receiver selects the branch with the highest signal-to-interference ratio (SIR; SIR-based selection diversity).

There are different models describing the statistical behavior of the multipath fading envelopes depending on the nature of the radio propagation environment. The most frequently used models are Nakagami, Rayleigh, Rician and Weibull. In a microcellular environment, CCIs usually experience significantly deeper fading than the desired signal. Therefore, different fading models are needed to characterize the desired and undesired signals [3]. The desired signal usually experiences Rician fading since a line-of-sight (LoS) path between transmitter and receiver within a microcell may exist [4]. In a microcell environment, an undesired signal from a distant cochannel cell may well be modeled by Rayleigh statistics [5]. Most of the published papers study diversity by considering the effect of only the strongest CCI [6-10] assuming that the remaining CCIs can be ignored. In general, the performance analysis of cellular mobile radio systems should include the influence of multiple CCIs from two or more distant cells [3-5, 11-12].

The performance of dual SC diversity receiver operating over correlated Rician fading channels in the presence of arbitrary number of correlated Rayleigh distributed CCIs is studied in this paper. Actually, the outage probability, as important performance metric, is obtained. The derivation of analytical expressions for the probability density function (PDF) and cumulative distribution function (CDF) of the output SIR has been preceded to assess the influence of various parameters such as fading severity, level of correlation and number of CCIs on SC system performance.

II. SYSTEM AND CHANNEL MODEL

We consider a cellular mobile radio system with dual SIR-based SC receiver. The desired signal envelopes on two diversity branches are assumed to follow the correlated Rician distribution, due to insufficient antennas distance, whose PDF is given by [13]

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$$p_{A_1A_2}(A_1,A_2)=\frac{A_1A_2(K+1)^2}{\beta^2(1-r^2)}\exp\left(-\frac{\left(A_1^2+A_2^2\right)(K+1)+4K\beta(1-r)}{2\beta\left(1-r^2\right)}\right)$$
$$\times\sum_{i=0}^{\infty}\varepsilon_i I_i\left(\frac{A_1A_2r(K+1)}{\beta\left(1-r^2\right)}\right)I_i\left(\frac{A_1}{1+r}\sqrt{\frac{2K(K+1)}{\beta}}\right)I_i\left(\frac{A_2}{1+r}\sqrt{\frac{2K(K+1)}{\beta}}\right), \qquad (1)$$
$$\varepsilon_i=\begin{cases}1, & i=0\\ 2, & i\neq 0\end{cases},$$

where r is the branch correlation coefficient, K is the Rician factor defined as the ratio of the signal power in the dominant component over the scattered power, $2\beta=\overline{A_1^2}=\overline{A_2^2}$ is the average desired signal power and $I_i(\cdot)$ is the modified Bessel function of the first kind and ith order.

The desired signal is corrupted by arbitrary number (n) of Rayleigh distributed CCIs having the same average power, $\Omega=\overline{r_j^2}$, $j=1,2,...,n$. In practice, assumption that CCIs have the same average power is not unreasonable since they originated from approximately the same distance from the receiver [12]. The power sum of CCIs on lth diversity branch is $R_l^2=r_{l,1}^2+r_{l,2}^2+\mathrm{K}+r_{l,n}^2$, $l=1,2$. In that case, the joint PDF of R_1 and R_2 is [14]

$$p_{R_1R_2}(R_1,R_2)=\frac{4(R_1R_2)^n}{\Gamma(n)\left(1-r^2\right)r^{n-1}\Omega^{n+1}}\exp\left(-\frac{R_1^2+R_2^2}{\Omega\left(1-r^2\right)}\right)I_{n-1}\left(\frac{2rR_1R_2}{\Omega\left(1-r^2\right)}\right). \qquad (2)$$

Let $\mu_1=A_1^2/R_1^2$ and $\mu_2=A_2^2/R_2^2$ be the instantaneous SIRs on the two diversity branches of SC receiver. The joint PDF of these random variables can be obtained as

$$p_{\mu_1\mu_2}(\mu_1,\mu_2)=\frac{1}{4\sqrt{\mu_1\mu_2}}\int_0^{\infty}\int_0^{\infty}R_1R_2\,p_{A_1A_2}\left(R_1\sqrt{\mu_1},R_2\sqrt{\mu_2}\right)p_{R_1R_2}(R_1,R_2)\,dR_1dR_2. \qquad (3)$$

Substituting (1) and (2) in (3) and using the infinite-series representation of the modified Bessel function [15]

$$I_i(x)=\sum_{n=0}^{\infty}\frac{x^{2n+i}}{2^{2n+i}n!\Gamma(n+i+1)} \qquad (4)$$

and [16, Eq. (3.326/2)], $p_{\mu_1\mu_2}(\mu_1,\mu_2)$ can be expressed as

$$p_{\mu_1\mu_2}(\mu_1,\mu_2)=\frac{\exp\left(-\frac{2K}{1+r}\right)}{\Gamma(n)}\sum_{i,j,l,s,p=0}^{\infty}\varepsilon_i\frac{r^{i+2(j+p)}\left(1-r^2\right)^{i+l+s+n+1}}{2^{2(i+j+1)+l+s}(1+r)^{2(i+l+s)}}$$
$$\times\frac{K^{i+l+s}(K+1)^{2(i+j+1)+l+s}\,\Omega^{2(i+j+1)+l+s}}{\beta^{2(i+j+1)+l+s}}$$
$$\times\frac{\Gamma(i+j+l+n+p+1)\Gamma(i+j+s+n+p+1)}{j!l!s!p!\Gamma(i+j+1)\Gamma(i+l+1)\Gamma(i+s+1)\Gamma(n+p)} \qquad (5)$$
$$\times\frac{\mu_1^{i+j+l}\mu_2^{i+j+s}}{\left(\frac{(K+1)\mu_1}{\gamma}+1\right)^{i+j+l+n+p+1}\left(\frac{(K+1)\mu_2}{\gamma}+1\right)^{i+j+s+n+p+1}},$$

where γ is the average SIR defined as $\gamma=2\beta/\Omega$.

The joint bivariate CDF of μ_1 and μ_2 can be derived as

$$F_{\mu_1\mu_2}(\mu_1,\mu_2)=\int_0^{\mu_1}\int_0^{\mu_2}p_{\mu_1\mu_2}(x_1,x_2)\,dx_1dx_2. \qquad (6)$$

which, by substituting (5) and using [16, Eq. (3.194/1)], yields

$$F_{\mu_1\mu_2}(\mu_1,\mu_2)=\frac{\exp\left(-\frac{2K}{1+r}\right)}{\Gamma(n)}\sum_{i,j,l,s,p=0}^{\infty}\varepsilon_i\frac{r^{i+2(j+p)}\left(1-r^2\right)^{i+l+s+n+1}}{(1+r)^{2(i+l+s)}\gamma^{2(i+j+1)+l+s}}$$
$$\times\frac{K^{i+l+s}(K+1)^{2(i+j+1)+l+s}\mu_1^{i+j+l+1}\mu_2^{i+j+s+1}}{j!l!s!p!}$$
$$\times\frac{\Gamma(i+j+l+n+p+1)\Gamma(i+j+s+n+p+1)}{\Gamma(n+p)\Gamma(i+j+1)\Gamma(i+l+1)\Gamma(i+s+1)(i+j+l+1)(i+j+s+1)} \qquad (7)$$
$$\times{}_2F_1\left(i+j+l+n+p+1,\,i+j+l+1;\,i+j+l+2;\,-\frac{(K+1)\mu_1}{\gamma}\right)$$
$$\times{}_2F_1\left(i+j+s+n+p+1,\,i+j+s+1;\,i+j+s+2;\,-\frac{(K+1)\mu_2}{\gamma}\right),$$

where ${}_2F_1(a,b;c;d)$ is the Gaussian hypergeometric function.

The SC receiver chooses and outputs the branch with the highest SIR, i.e. $\mu_{SC}=\max\{\mu_1,\mu_2\}$. The CDF of μ_{SC} can be derived from (7) by equating arguments.

$$F_{\mu_{SC}}(\mu_{SC})=F_{\mu_1\mu_2}(\mu_{SC},\mu_{SC}). \qquad (8)$$

III. OUTAGE PROBABILITY

The outage probability is important, reliable and widely accepted performance measure for diversity systems operating in fading environments. Therefore, this performance criterion has been thoroughly studied by many researchers. In interference-limited environments, the outage probability is defined as the probability that the output SIR falls below a given outage threshold μ_{th}, also known as a protection ratio, which depends on expected QoS.

$$P_{out}=P_R(\mu<\mu_{th})=\int_0^{\mu_{th}}p_{\mu_{SC}}(\mu)d\mu=F_{\mu_{SC}}(\mu_{th}). \qquad (9)$$

A system planner can use the outage probability calculations to assess the effects of various systems and channels parameters on the QoS provided by the system.

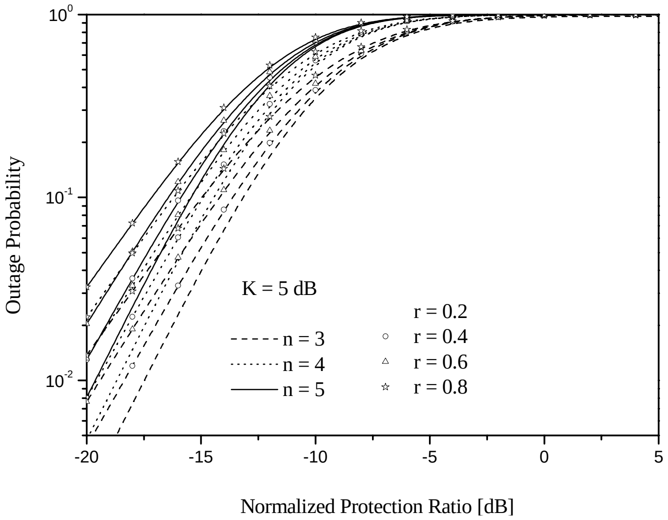

Fig. 1. Outage probability versus the normalized protection ratio for a dual SC receiver for several values of correlation coefficient in the presence of different number of CCIs

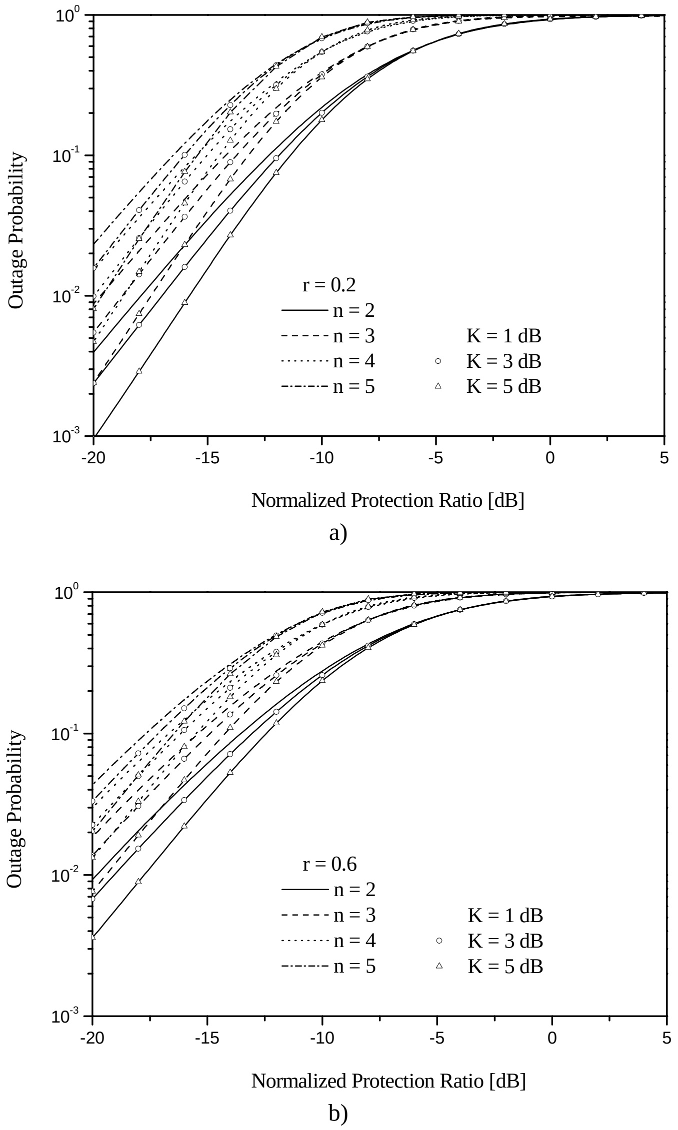

Fig. 2. Outage probability versus the normalized protection ratio for a dual SC receiver for several values of Rician factor in the presence of different number of CCIs a) r=0.2 b) r=0.6

IV. NUMERICAL RESULTS

Using the previous mathematical analysis, the outage probability as a function of the normalized protection ratio μ_{th}/γ for several values of correlation coefficient in the presence of different number of CCIs is plotted in Fig. 1. The obtained results show clearly that outage performance degrades with increase of branch correlation (decrease spatial separation between the received antennas in terminals) and/or number of CCIs. Fig. 2 depicts that the outage probability improves when the Rician factor increases. This happens because a higher value of the Rician factor means that the desired signal contains a large LoS component and a small diffuse-scattered component, i.e. the desired signal suffers less from severe fading. Comparison of Figs. 2*a* and Fig. 2*b* shows greater influence of interferences number *n* on the outage probability in the case of lower correlation coefficient. As an illustration, if the relative deterioration due to increase of number of CCIs is defined as

$$\Delta_{n,n+1} = \left[1 - \frac{P_{out\ n}}{P_{out\ n+1}}\right] \cdot 100\% ,$$

for K = 5 dB and normalized protection ratio of -15 dB, $\Delta_{2,3}$ = 62.1% for r = 0.2 and $\Delta_{2,3}$ =53.27% for r = 0.6.

V. CONCLUSION

In cellular mobile radio systems, the main factors limiting performance are CCIs from neighboring cells and multipath fading. Dual SC receiver operating over correlated Rician fading channels in the presence of arbitrary number of correlated Rayleigh distributed CCIs has been studied in this paper. The outage probability has been derived in form of infinite-series representation. The various graphically presented evaluation results demonstrate that system performance improves when Rician factor increases (fading severity decreases) and/or correlation coefficient decreases. Moreover, the system shows better outage performance for smaller number of CCIs. A system planner can efficiently use the presented expression for the outage probability to simulate different system and channel conditions and to readjust system parameters to provide required QoS.

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REFERENCES

[1] M. K. Simon and M.-S. Alouini, *Digital Communication Over Fading Channels*, 1st ed. New York: Wiley, 2000.
[2] A. Goldsmith, *Wireless communications*, Cambridge University Pres: New York, 2005.
[3] Y.-D. Yao and A. U. H. Sheikh, “Investigations into Cochannel Interference in Microcellular Mobile radio Systems”, IEEE Trans. Veh. Technol., vol. 41, no. 2, pp. 114-123, 1992.
[4] R. J. C. Bultitude and G. K. Bedal, “Propagation characteristics on microcellular urban mobile radio channels at 910 MHz”, IEEE J. Select. Areas Commun., vol. 7, no. 1, pp. 31-39, 1989.
[5] Y.-D. Yao and A. U. H. Sheikh, “Outage probability analysis for microcell mobile radio systems with cochannel interferers in Rician/Rayleigh fading environment”, Electron. Lett., vol. 26, no. 13, pp. 864-866, 1990.
[6] S. Okui, “Effects of SIR selection diversity with two correlated branches in the m-fading channel”, IEEE Trans. Commun., vol. 48, no. 10, pp. 1631-1633, 2000.
[7] G. K. Karagiannidis, “Performance analysis of SIR-based dual selection diversity over correlated Nakagami-m fading channels”, IEEE Trans. Veh. Technol., vol. 52, no. 5, pp. 1207-1216, 2003.
[8] M. Č. Stefanović, D. M. Milović, A. M. Mitić and M. M. Jakovljević, “Performance analysis of system with selection combining over correlated Weibull fading channels in the

presence of cochannel interference", Int. J. AEÜ, vol. 62, no. 9, pp. 695-700, 2008.
[9] A. S. Panajotović, M. Č. Stefanović and D. Lj. Drača, "Performance analysis of system with selection combining over correlated Rician fading channels in the presence of cochannel interference", Int. J. AEÜ, vol. 63, no. 12, pp. 1061-1066, 2009.
[10] M. Č. Stefanović, D. Lj. Drača, A. S. Panajotović and 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., vol. 23, no. 2, pp. 139-150, 2010.
[11] K. W. Sowerby and A. G. Williamson, "Outage probability calculations for a mobile radio system having multiple Rayleigh interferers", Electron. Lett., vol. 23, no. 11, pp. 600-601, 1987.
[12] A. A. Abu-Dayya and N. C. Beaulieu, "Outage probabilities of Cellular Mobile Radio Systems with Multiple Nakagami-m Interferers", IEEE Trans. Veh. Technol., vol. 40, no. 4, pp. 757-768, 1991.
[13] M. K. Simon, "Comments on "Infinite-series representations associated with the bivariate Rician distribution and their applications", IEEE Trans. Commun., vol. 54, no. 8, pp. 1511-1512, 2006.
[14] M. Nakagami, "The m-distribution - A general formula of intensity distribution of rapid fading", in *Statistical Methods in Radio Wave Propagation*, Pergamon Press, Oxford, U.K., pp. 3-36, 1960.
[15] M. Abramovitz and I. A. Stegun, *Handbook of mathematical functions with formulas, graphs, and mathematical tables*, New York: Dover publications Inc., 1970.
[16] I. S. Gradshteyn and I. M. Ryzhik, *Table of Integrals, Series, and Products*, 5th ed. New York: Academic, 1994.