Channel Capacity of a System in Shadowed Fading Channels with Micro- and Macrodiversity Reception

Nikola Sekulović[1], Dragan Drača [2], Aleksandra Panajotović [3], Zorica Nikolić[4], Časlav Stefanović[5]

Abstract - **This paper studies wireless communication system following microdiversity to mitigate the effects of short-term fading and macrodiversity processing to reduce shadowing effects. *L*-branch maximal-ratio combining (MRC) is implemented at the micro level (single base station) and selection combining (SC) with two base stations (dual diversity) is implemented at the macro level. This model assumes a Rician density function for the envelope of the received signal and a gamma distribution to model the average power to account for the shadowing. Closed-form expression for the probability density function (PDF) of the signal-to-noise ratio (SNR) after the diversity combining at the micro and macro level is obtained. The derived PDF is applied to study channel capacity of proposed system.**

Keywords - **Shadowing, fading, microdiversity, macrodiversity, channel capacity**

I INTRODUCTION

In wireless communication systems, the received signal can be affected by both short-term fading and long-term fading (shadowing). Short-term fading is the result of multipath propagation while shadowing is the result of large obstacles between transmitter and receiver.

The reliability of communication over the wireless channels can be improved using diversity techniques, such as space diversity [1], [2]. Diversity techniques at single base station (microdiversity) reduce the effects of short-term fading. Impairments due to shadowing can be mitigated using macrodiversity techniques which employ the processing of signals from multiple base stations. The use of composite micro- and macrodiversity has recently received considerable interest due to fact that it simultaneously combats both short-term fading and shadowing. A composite multipath/shadowed fading environment modeled either as Rayleigh-lognormal, Rician-lognormal or Nakagami-lognormal is considered in [3-5].

[1]Nikola Sekulović is with the Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia, E-mail: sekulani@bankerinter.net.

[2]Dragan Drača is with the Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia.

[3]Aleksandra Panajotović is with the Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia.

[4]Zorica Nikolić is with the Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia.

[5]Časlav Stefanović is with the Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia.

The use of lognormal distribution to model the average power which is random variable due to shadowing doesn't lead to a closed form solution for the probability density function (PDF) of the signal-to-noise ratio (SNR) at the receiver. A compound fading model uses a gamma distribution to account for shadowing instead of the lognormal distribution [6], [7]. This model incorporates short-term fading and shadowing and provides an analytical solution for the PDF of the SNR facilitating the analysis of wireless systems.

In this paper, system following micro- and macrodiversity reception in correlated gamma shadowed Rician fading channels is considered. Closed-form expression for the PDF of the SNR is obtained and used to study channel capacity of proposed system.

II SYSTEM MODEL AND CHANNEL CAPACITY

Macrodiversity composed of two geographically distributed microdiversity systems (base stations) per cell operating over gamma shadowed Rician fading channels is analyzed in this paper. *L*-branch maximal-ratio combining (MRC) is implemented at the micro level (single base station) and selection combining (SC) with two base stations (dual diversity) is implemented at the macro level. Signals at antennas in single base station are independent. Because of fact that shadowing has a larger correlation distance, the two base stations are treated to have nonzero correlation.

The instantaneous SNR at the MRC output of the *i*th base station is given by $X_i = \left(E_b / N_0\right)\sum_{j=1}^{L} A_{ij}^2 \quad \left(i = 1,2\right)$, where E_b is the transmitted signal energy per information bit, N_0 is the single-sided power spectral density of the additive white Gaussian noise and A_{ij} are statistically independent envelopes of the faded signals received on the *j*th branch. The PDF of the X_i is given by [4]

$$f_{X_i}\left(X_i \middle| Y_i\right) = \frac{K+1}{Y_i}\exp\left(-\frac{\left(K+1\right)X_i}{Y_i} - KL\right)\left(\frac{\left(K+1\right)X_i}{KLY_i}\right)^{\frac{L-1}{2}} \times I_{L-1}\left(2\sqrt{\frac{KL(K+1)X_i}{Y_i}}\right), \quad i = 1,2 \qquad (1)$$

where Y_i is the average power at the base station, *K* is Rice factor defined as the ratio of the signal power in dominant component over the scattered power and $I_n\left(\cdot\right)$ is modified Bessel function of the first kind and *n*th order. The conditional nature of the PDF in Eq. (1) illustrates the existence of shadowing.

The PDF of the SNR at the output of a dual-port selection based macrodiversity system is defined as

$$\begin{aligned} f_X(X) &= \int_0^\infty dY_1 \int_0^{Y_1} f_{X_1}(X|Y_1) f_{Y_1Y_2}(Y_1,Y_2)\, dY_2 + \\ &+ \int_0^\infty dY_2 \int_0^{Y_2} f_{X_2}(X|Y_2) f_{Y_1Y_2}(Y_1,Y_2)\, dY_1 = \\ &= 2\int_0^\infty f_{X_1}(X|Y_1) dY_1 \int_0^{Y_1} f_{Y_1Y_2}(Y_1,Y_2)\, dY_2 \end{aligned} \tag{2}$$

The compound PDF fading model uses a gamma distribution for shadowing. In that case, the joint PDF of Y_1 and Y_2 can be expressed as [8], [9]

$$\begin{aligned} f_{Y_1Y_2}(Y_1,Y_2) &= \frac{\rho^{-\frac{c-1}{2}}}{\Gamma(c)(1-\rho)Y_0^{c+1}} (Y_1Y_2)^{\frac{c-1}{2}} \exp\left(-\frac{Y_1+Y_2}{Y_0(1-\rho)}\right) \\ &\times I_{c-1}\left(\frac{\sqrt{4\rho Y_1 Y_2}}{Y_0(1-\rho)}\right) \end{aligned} \tag{3}$$

where ρ is the correlation between Y_1 and Y_2, c is the order of gamma distribution, Y_0 is related to the average power of Y_1 and Y_2, and $\Gamma(\cdot)$ is gamma function. Substituting Eqs. (1) and (3) in Eq. (2) and using [10, Eqs (3.351/1) and (3.471/9)], for integer values of c the following expression is obtained

$$\begin{aligned} f_X(X) &= \frac{4\exp(-KL)}{\Gamma(c)} \\ &\times \sum_{i=0}^{\infty}\sum_{j=0}^{\infty} (K+1)^{\frac{L+c+i+j}{2}} (KL)^i Y_0^{-\frac{c+L+i+j}{2}} X^{\frac{i+j+c+L-2}{2}} \\ &\times \frac{\rho^j}{(1-\rho)^{\frac{L-c+i+j}{2}}} \frac{(c+j-1)!}{i!\,j!\,\Gamma(i+L)\Gamma(j+c)} \\ &\times \left\{ K_{c-L-i+j}\left(2\sqrt{\psi}\right) - \sum_{l=0}^{c+j-1} \frac{1}{2^{\frac{c-L-i+j+l}{2}} l!} \psi^{\frac{l}{2}} K_{c-L-i+j+l}\left(2\sqrt{2\psi}\right) \right\} \end{aligned} \tag{4}$$

where $K_n(\cdot)$ is modified Bessel function of the second kind of order n [10], [11] and $\psi = \dfrac{(K+1)X}{Y_0(1-\rho)}$.

Channel capacity is an important performance measure in design of future digital communications systems since it provides an upper bound of maximum transmission rate. Considering a signals' transmission of bandwidth BW over the additive white Gaussian noise (AWGN) channel, the average channel capacity can be obtained averaging the Shannon capacity over the PDF of X, i.e.,

$$\overline{C} = BW\int_0^\infty \log_2(1+X) f_X(X)\, dX \tag{5}$$

III Numerical Results

In Fig. 1, the normalized average channel capacity is plotted as a function of Y_0 using Eq. (5). As it was expected, C improves with an decrease of correlation coefficient and increase of number of diversity branches at the micro level. The normalized channel capacity of system with no macrodiversity is also plotted. It can be deduced clear conclusion that the combination of micro- and macrodiversity provides significantly performance improvement. In Fig. 2, the normalized average channel capacity is plotted in relation to the Y_0 for several values of Rice factor and order of gamma distribution. We observe here that an increase of K and c leads to an improvement of the system performance.

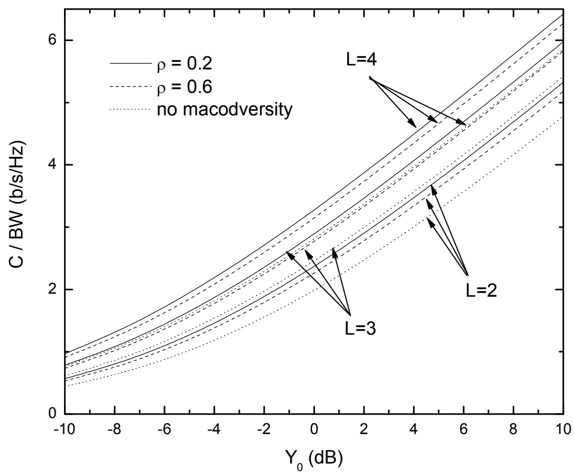

Fig. 1 Normalized average channel capacity versus Y_0 *(dB)* with *K=2.4 dB* and *c=2*

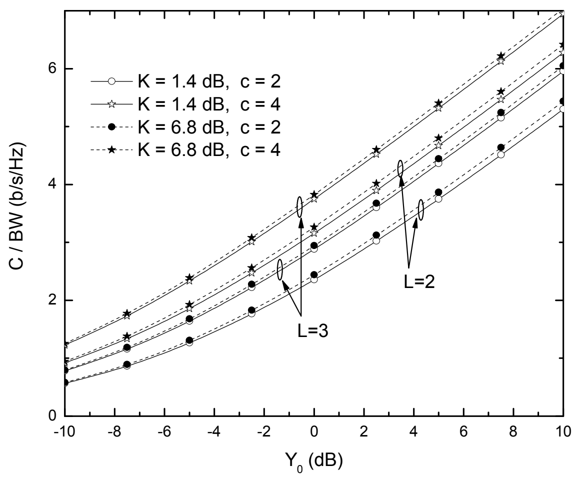

Fig. 2 Normalized average channel capacity versus Y_0 *(dB)* with ρ *=0.2*

IV CONCLUSION

Using a compound PDF model, system with micro- and macrodiversity reception in gamma shadowed Rician fading channels has been analyzed. Closed-form expression for the PDF of the SNR after diversity combining at the micro and macro level is obtained and used to study the average channel capacity in Shannon's sense of proposed system. Numerical results have been graphically presented, showing the effect of number of branches, correlation coefficient, Rice factor and order of gamma distribution on the system performance. It was also shown that composite micro- and macrodiversity provides significantly performance improvement which was the foreground task of this paper.

ACKNOWLEDGEMENT

This work was supported in part by the Ministry of Science of Serbia within the project "Development and realization of new generation software, hardware and services based on software radio for specific purpose applications" (TR-11030).

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 Press, 2005.
[3] F. Hansen and F.I. Mano, "Mobile Fading-Rayleigh and Lognormal Superimposed", IEEE Trans. Vehic. Tech., vol. 26, pp. 332–335, 1977.
[4] J. Zhang and V. Aalo, "Effect of Macrodiversity on Average-Error Probabilities in a Rician Fading Channel with Correlated Lognormal Shadowing", IEEE Trans. Commun. vol. 49, pp. 14-18, 2001.
[5] E. K.Al-Hussaini, A.M. Al-Bassiouni, H. Mourad and H. Al-Shennawy, "Composite Macroscopic and Microscopic Diversity of Sectorized Macrocellular and Microcellular Mobile Radio Systems Employing RAKE Receiver over Nakagami Fading plus Lognormal Shadowing Channel", Wireless Personal Communications, vol. 21, pp. 309–328, 2002.
[6] P. M. Shankar, "Error rates in generalized Shadowed Fading Channels", Wireless Personal Communications, vol. 28, pp. 233-238, 2004
[7] P. M. Shankar, "Analysis of microdiversity and dual channel macrodiversity in shadowed fading channels using a compound fading model", Int. J. Electron. Comm., vol. 62, pp. 445-449, 2007.
[8] S. Yue, TBMJ Ouarda, B. Bobee, "A review of bivariate gamma distributions for hydrological application", J. Hydrol. vol. 246, pp. 1-18, 2001.
[9] E. Xekalaki, J. Panaretos and S. Psarakis, "A Predictive Model Evaluation and Selection Approach - The Correlated Gamma Ratio Distribution" ; STOCHASTIC MUSINGS: PERSPECTIVES FROM THE PIONEERS OF THE LATE 20TH CENTURY, J. Panaretos, ed., Laurence Erlbaum, Publisher, USA, pp. 188-202, 2003. Available at SSRN: http://ssrn.com/abstract=947067]
[10] I. S. Gradshteyn and I. M. Ryzhik, *Table of integrals, series, and products*, Academic, New York, 5th edn., 1994.
[11] M. Abramovitz and I. A. Stegun, *Handbook of mathematical functions with formulas, graphs, and mathematical tables*, Dover publications, New York, 1972.