Moments of Macrodiversity SC Receiver Output Signal with Two Microdiversity EGC Receivers with Three Branches over Rayleigh Multipath Fading Environment

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***Abstract*–Wireless communication system with macrodiversity reception operating over Gamma shadowed Rayleigh multipath fading channel is considered. Macrodiversity system has macrodiversity selection combining (SC) diversity receiver and two microdiversity equal gain combining (EGC) diversity receivers. Each of EGC microdiversity receivers has three branches. Moments of macrodiversity EGC receivers output signals are calculated. These expressions are used for calculation the closed form expressions for moments of macrodiversity SC receiver output signal envelope. In this paper, the influence of Gamma long term fading parameter severity, shadowing correlation coefficient and Rayleigh short term fading on moments is discussed.** The impact of parameters is **discussed**.

Keywords-long term fading; short term fading degrade outage probability, bit error probability, channel capacity and moments of wireless

I. INTRODUCTION

Long term fading and short term fading degrade the outage probability, the bit error probability, the channel capacity and the moments of wireless communication system with macrodiversity reception. There are a lot of distributions which can be used to describe signal envelope variation in multipath fading channels depend on existence of line of sight component, nonlinearity of propagation environment, the number of clusters in propagation channel, inequality of quadrature components power and signal envelope power variation [1], [2]. Rayleigh distribution is used to describe small scale signal envelope variation in nonlinear, non-line-of-sight multipath fading channel with one cluster and equal power of quadrature component [2].

Large scale signal envelope power variation can be well modeled by using log-normal or Gamma distribution. The expressions for probability density function and cumulative distribution function of macrodiversity receiver output signal cannot be derived in closed form when large scale signal envelope power variation is described by using log normal distribution. When signal envelope power variation is modeled by using Gamma distribution, the expressions for system performance are obtained in closed form [4], [5].

Macrodiversity system is used to reduce simultaneously Gamma long term fading effects and Rayleigh short term fading effects on the outage probability. Macrodiversity SC receiver reduces shadowing effects and microdiversity EGC receivers mitigate multipath fading effects on system performance.

In [6], macrodiversity system with macrodiversity SC receiver and two microdiversity maximal ratio combining (MRC) receivers operating over Gamma shadowed Nakagami–*m* multipath fading channel is considered. The average level crossing rate and the average fade duration of proposed macrodiversity system are calculated in closed form.

In the paper [7], the second-order statistics of wireless communication system with micro and macrodiversity reception in correlated gamma shadowed Nakagami-*m* fading channels is processed. Macrolevel is of selection combining (SC) type and consists of two base stations (dual diversity) while *N*-branch receiver employing MRC is implemented on microlevel. Rapidly converging infinite-series expressions for the level crossing rate (LCR) and the average fade duration (AFD) are derived.

The closed form expressions for the average level crossing rate and the average fade duration of macrodiversity system in the presence of Gamma shadowing and Rician multipath fading are analyzed in [5]. The probability density function, cumulative distribution function and moments of macrodiversity SC receiver output signal envelope are calculated. By using MGF approach, the bit error probability is evaluated and presented graphically to show the influence of fading parameters on the system performance.

An approach to the second order statistics analysis of macrodiversity system operating over Gamma

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shadowed Rayleigh fading channels is presented in [8]. Simultaneous influence of multipath fading and shadowing is alleviated through the usage of macrodiversity system. SC macrodiversity system consisting of two base stations (microdiversity systems) is considered. The cases of MRC and SC diversity with arbitrary number of branches, applied at microlevel over the Rayleigh fading channels are discussed. Selection between macro-combiners is based on output signal power values.

Statistics of macro SC diversity system with two micro EGC diversity systems and Rayleigh fast fading is given in [9]. The probability density function, cumulative distribution function, the first and second order moments of random variable, the amount of fading, channel capacity and bit error rate are calculated and simulated. Macrodiversity SC system with two EGC diversity receivers operating over Gamma shadowed Nakagami-m fading environment is considered in [10]. The received signal is subjected simultaneously to long term fading and short term fading resulting in the signal envelope variation and signal envelope power variation. The moments of macro SC receiver output signal are evaluated.

In this paper, the macrodiversity system with one macrodiversity SC receptor and two microdiversity EGC receptors with three branches is observed. The received signal experiences correlated Gamma long term fading and Rayleigh short term fading. Macrodiversity SC receiver reduces Gamma long term fading effects and microdiversity EGC receivers reduce short term fading effects on the system performance. In this work, the moments of macrodiversity SC receiver output signal envelope are calculated. According to the best of authors' knowledge, the moments of macrodiversity SC receiver output signal envelope in the presence of Gamma long term fading and Rayleigh short term fading are not reported in the available technical literature.

II. MOMENTS OF EGC RECEIVER OUTPUT SIGNAL ENVELOPE

Equal gain combining (EGC) diversity receiver from Fig. 1 is considered in this section.

Signal envelopes at the inputs of EGC receiver are denoted with x_1, x_2 and x_3, and EGC receiver output signal is marked with x. Signal envelope at output of EGC receiver is equal to sum of signal envelopes at inputs of EGC receiver:

$$x = x_1 + x_2 + x_3 \tag{1}$$

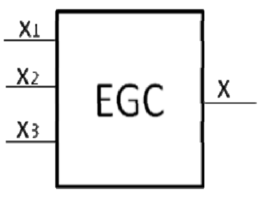

Figure 1. EGC diversity receiver with three branches.

The received signal experiences Rayleigh multipath fading. The moment of n-th order of x_i, i=1,2,3 is:

$$\overline{x^n} = \int_0^\infty dx_i \, x_i^n \, p(x_i) \tag{2}$$

where

$$p(x_i) = \frac{2x_i}{\Omega} e^{-\frac{x_i^2}{\Omega}}, \quad x_i \geq 0 . \tag{3}$$

with x_i being signal envelope average power of Rayleigh random variable x_i. After substituting (3) in (2), the expression for moment of n-th order becomes:

$$\overline{x^n} = \int_0^\infty dx_i \, \frac{2x_i^{k+1}}{\Omega} e^{-\frac{x_i^2}{\Omega}} =$$

$$= \frac{2}{\Omega} \int_0^\infty dx_i \, x_i^{k+1} e^{-\frac{x_i^2}{\Omega}} = \frac{2}{\Omega} \frac{1}{2} \Omega^{1+k/2} \Gamma(1+k/2) =$$

$$= \Omega^{\frac{k}{2}} \Gamma\left(1+\frac{k}{2}\right) \tag{4}$$

Moment of n-th order of EGC receiver output signal envelope is:

$$\overline{x^n} = \overline{(x_1 + x_2 + x_3)^n} =$$

$$= \sum_{i=0}^{n} \sum_{j-0}^{n-i} \frac{n!}{i!\, j!\, (n-i-j)!} \overline{x_1^i} \, \overline{x_2^j} \, \overline{x_3^{n-i-j}} =$$

$$= \sum_{i=0}^{n} \sum_{j-0}^{n-i} \frac{n!}{i!\, j!\, (n-i-j)!} \cdot$$

$$\cdot \Omega^{\frac{i}{2}} \Gamma\left(1+\frac{i}{2}\right) \Omega^{\frac{j}{2}} \Gamma\left(1+\frac{j}{2}\right) \Omega^{\frac{n-i-j}{2}} \Gamma\left(1+\frac{n-i-j}{2}\right) =$$

$$= \Omega^{\frac{n}{2}} \sum_{i=0}^{n} \sum_{j-0}^{n-i} \frac{n!}{i!\, j!\, (n-i-j)!} \cdot$$

$$\cdot \Gamma\left(1+\frac{i}{2}\right) \Gamma\left(1+\frac{j}{2}\right) \Gamma\left(1+\frac{n-i-j}{2}\right) . \tag{5}$$

III. MOMENT OF N-TH ORDER OF MACRODIVERSITY SC RECEIVER OUTPUT SIGNAL ENVELOPE

Macrodiversity system with macrodiversity SC receiver and two EGC microdiversity receivers with three branches is considered. The system model studied in this paper is presented in Fig. 2.

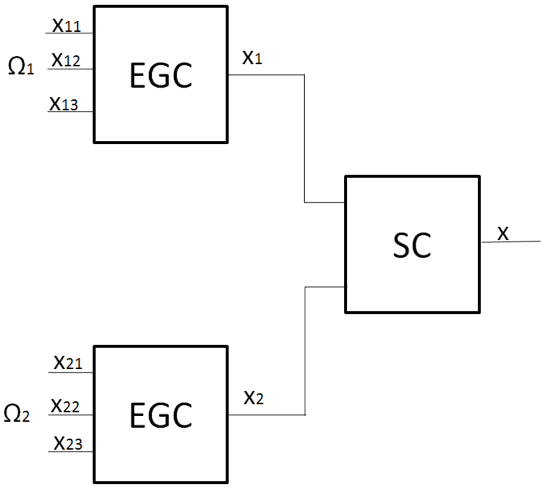

Figure 2. Macrodiversity system model.

Signal envelopes at the inputs of the first EGC receiver are x_{11}, x_{12} and x_{13}, and at the inputs of the second EGC receiver signal envelopes are labeled with x_{21}, x_{22} and x_{23}. Signal envelopes at outputs of EGC receiver are x_1 and x_2, and the output signal of the whole system is denoted with x. Signal envelope average power at inputs of the first microdiversity EGC receiver is Ω_1, and at inputs of the second microdiversity EGC receiver is Ω_2.

Macrodiversity SC receiver selects microdiversity EGC receiver with higher signal envelope average power to enable signal to user.

Therefore, moment of n-th order of macrodiversity SC receiver output signal envelope signal is:

$$m_{nx} = \overline{x^n} = \int_0^\infty d\Omega_1 \int_0^{\Omega_1} d\Omega_2 m_{nx_1/\Omega_1} p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) +$$

$$+\int_0^\infty d\Omega_2 \int_0^{\Omega_2} d\Omega_1 m_{nx/\Omega_2} p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) \qquad (6)$$

where m_{nx_1} and m_{nx_2} are given by formula (5).

Random variables Ω_1 and Ω_2 follow correlated Gamma distribution:

$$p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) = \frac{1}{\Gamma(c)(1-\rho^2)\rho^{\frac{c-1}{2}}\Omega_0^{c+1}} (\Omega_1\Omega_2)^{\frac{c-1}{2}} \cdot$$

$$\cdot e^{-\frac{\Omega_1+\Omega_2}{\Omega_0(1-\rho^2)}} I_{c-1}\left(\frac{2\rho}{\Omega_0(1-\rho^2)}\Omega_1^{1/2}\Omega_2^{1/2}\right) =$$

$$= \frac{1}{\Gamma(c)(1-\rho^2)\rho^{\frac{c-1}{2}}\Omega_0^{c+1}} \cdot$$

$$\cdot \sum_{i_1=0}^{\infty} \left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i_1+c-1} \frac{1}{i_1!\,\Gamma(i_1+c)} \cdot$$

$$\cdot \Omega_1^{2i_1+c-1}\Omega_2^{2i_1+c-1} \cdot e^{-\frac{\Omega_1+\Omega_2}{\Omega_0(1-\rho^2)}} \qquad (7)$$

where c is order of Gamma distribution and Ω_0 is related to the power of signal envelope. When c goes to infinity, Gamma shadowed Rayleigh multipath fading channel reduces to Rayleigh multipath fading channel. After substituting (7) into (6), the expressions for moment of n-th order of macrodiversity SC receiver output signal envelope becomes:

$$m_{nx} = 2\int_0^\infty d\Omega_1 \int_0^{\Omega_1} d\Omega_2 m_{nx_1/\Omega_1} p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) =$$

$$= \sum_{i=0}^{n} \sum_{j-0}^{n-i} \frac{n!}{i!\,j!(n-i-j)!} \cdot$$

$$\cdot \Gamma\left(1+\frac{i}{2}\right)\Gamma\left(1+\frac{j}{2}\right)\Gamma\left(1+\frac{n-i-j}{2}\right) \cdot$$

$$\cdot \frac{1}{\Gamma(c)(1-\rho^2)\rho^{\frac{c-1}{2}}\Omega_0^{c+1}} \cdot$$

$$\cdot \sum_{i_1=0}^{\infty} \left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i_1+c-1} \frac{1}{i_1!\,\Gamma(i_1+c)} \cdot$$

$$\cdot \left(\Omega_0(1-\rho^2)\right)^{i_1+c} \cdot \int_0^\infty d\Omega_1 \Omega_1^{\frac{n}{2}+i_1+c-1} \cdot e^{-\frac{\Omega_1}{\Omega_0(1-\rho^2)}} \cdot$$

$$\cdot \gamma\left(i_1+c, \frac{\Omega_1}{\Omega_0(1-\rho^2)}\right) =$$

$$= \sum_{i=0}^{n} \sum_{j-0}^{n-i} \frac{n!}{i!\,j!(n-i-j)!} \cdot$$

$$\cdot \Gamma\left(1+\frac{i}{2}\right)\Gamma\left(1+\frac{j}{2}\right)\Gamma\left(1+\frac{n-i-j}{2}\right) \cdot$$

$$\cdot \frac{1}{\Gamma(c)(1-\rho^2)\rho^{\frac{c-1}{2}}\Omega_0^{c+1}} \cdot$$

$$\cdot \sum_{i_1=0}^{\infty} \left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i_1+c-1} \frac{1}{i_1!\,\Gamma(i_1+c)} \cdot$$

$$\cdot \left(\Omega_0(1-\rho^2)\right)^{i_1+c} \cdot \frac{1}{i_1+c}\left(\frac{1}{\Omega_0(1-\rho^2)}\right)^{i_1+c} .$$

$$\cdot\sum_{j_1=0}^{\infty}\frac{1}{(i_1+c+1)(j_1)}\frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)j_1}\cdot$$

$$\cdot\int_0^{\infty} d\Omega_1\,\Omega_1^{\frac{n}{2}+i_1+c-1+i_1+c+j_1}\cdot e^{-\frac{2\Omega_1}{\Omega_0\left(1-\rho^2\right)}}=$$

$$=\sum_{i=0}^{n}\sum_{j-0}^{n-i}\frac{n!}{i!\,j!\,(n-i-j)!}\cdot$$

$$\cdot\Gamma\left(1+\frac{i}{2}\right)\Gamma\left(1+\frac{j}{2}\right)\Gamma\left(1+\frac{n-i-j}{2}\right)\cdot$$

$$\cdot\frac{1}{\Gamma(c)\left(1-\rho^2\right)\rho^{\frac{c-1}{2}}\Omega_0^{c+1}}\cdot$$

$$\cdot\sum_{i_1=0}^{\infty}\left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_1+c-1}\frac{1}{i_1!\,\Gamma(i_1+c)}\cdot$$

$$\cdot\left(\Omega_0\left(1-\rho^2\right)\right)^{i_1+c}\cdot\frac{1}{i_1+c}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{i_1+c}\cdot$$

$$\cdot\sum_{j_1=0}^{\infty}\frac{1}{(i_1+c+1)(j_1)}\frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)j_1}\cdot$$

$$\cdot\left(\frac{\Omega_0\left(1-\rho^2\right)}{2}\right)^{\frac{n}{4}+i_1+c+\frac{j_1}{2}}\cdot\Gamma\left(\frac{n}{4}+i_1+c+\frac{j_1}{2}\right)\qquad(8)$$

The obtained expression rapidly converges since 10 till 15 terms should be summed to achieve accuracy at 4^{th} significant digit for all values of Gamma shadowing and Rayleigh fading parameters. When order of Gamma distribution goes to infinity, Gamma shadowed Rayleigh multipath channel becomes Rayleigh multipath channel, and when parameter c decreases, severity of fading increases. As correlation coefficient of Gamma long term fading goes to one, the least signal envelope average power is at both base stations simultaneously, resulting in the system performance degradation.

IV. Numerical Results

Numerical results obtained from previous formulas are presented graphically in Fig. 3 to show the influence of correlation coefficient of shadowing and shadowing severity parameter on the first and second moments.

Moments are important characteristics of a random process. The most important are the mean value, mean square value, mean value and variance cubic. Fading parameters, nature of fading as well as the optimal values of the parameters of the wireless telecommunication system can be determined by using the moments.

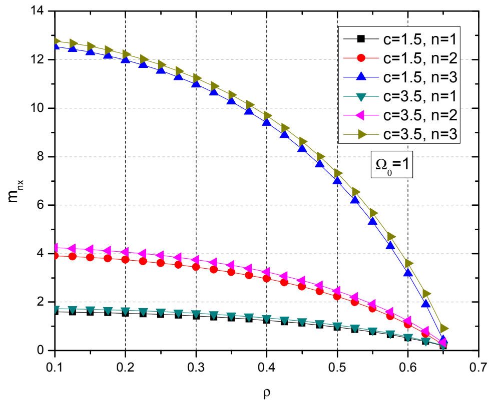

Figure 3. Moments of signal at the output of macrodiversity system versus correlation coefficient ρ for different values of fading severity *c*.

The performance of the system is better for higher values of the first and the second moments.

The first, second and third moments of signal at the output of the macrodiversity system with three microdiversity EGC receiver versus the correlation coefficient ρ and for different values of the severity of shadowing *c,* are shown graphically in Fig.3.

It can be seen from Fig. 3 that the largest decline is characteristic for the higher moments. If we compare the curves by the parameter c, it can be seen that the higher values of shadowing severity give the higher values of moments.

The first moment increases as the order of Gamma distribution increases and the outage probability decreases. The value of moment decreases as the correlation coefficient increases. The system performance is better for lower values of shadowing correlation coefficient. Correlation between base stations arises due to base stations are shadowed by the same obstacle. The best performances of the system are obtained when the correlation coefficient tends to zero.

V. Conclusion

Macrodiversity system with one macrodiversity SC receiver and two microdiversity EGC receivers operating over correlated Gamma shadowed Rayleigh multipath fading environment is observed. Each equal gain combining receiver has three branches. Macrodiversity SC receiver reduces correlated Gamma long term fading and microdiversity EGC receivers mitigate Rayleigh short term fading influences on system performance. Microdiversity EGC receiver combines signals provided with multiple antennas at base station and macrodiversity SC receiver provides signals from two or more base stations distributed in cell.

The closed form expressions for moments of the n-th order at the output of microdiversity EGC receivers are evaluated and these results are used for calculation of the moment of the n-th order of macrodiversity SC receiver output signal envelope. The numerical results are analyzed and presented graphically to show the influence of correlation coefficient of shadowing and shadowing severity parameter on the first and second moments.

The obtained results can be used in the performance analyzing and designing of wireless communication system using macrodiversity reception to reduce the influence of fast fading and shadow effects on the system performance.

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REFERENCES

[1] A. Goldsmith, Wireless Communications, Cambridge University Press: New York, 2005.

[2] D. Tse and P. Viswanath, Fundamentals of Wireless Communication, Cambrige University Press, 2005.

[3] M. K. Simon and M. S. Alouini, Digital Communication over Fading Channels, Wiley: New York, 2000.

[4] S. Panic, M. Stefanovic, J. Anastasov, P. Spalevic, Fading and Interference Mitigation in Wireless Communications, USA: CRC Press, 2013.

[5] N. Sekulovic and M. Stefanovic, “Performance analysis of system with micro- and macrodiversity reception in corelated gamma shadowed Rician fading channels”, Wireless Personal Communications, (publisher: Springer), vol. 65, no. 1, pp. 143-156, 2012, published online 12. Feb. 2011, doi: 10.1007/s11277-011-0232-8

[6] D. Stefanovic, S. R. Panic, P. Spalevic “Second-order statistics of SC macrodiversity system operating over Gamma shadowed Nakagami-m fading channels,” AEU - International Journal of Electronics and Communications, vo. 65, no. 5, pp. 413–418, 2011.

[7] A. D Cvetkovic, M. Č Stefanovic, N. M Sekulovic, D. N Milic, D. M Stefanovic, Z. J Popovic, “Second-order statistics of dual SC macrodiversity system over channels affected by Nakagami-m fading and correlated gamma shadowing”, Przeglad Elektrotechniczny, 05/2011; 6: pp. 283-287.

[8] M. Stefanovic, B. Miric, P. Spalevic, and S. Panic “Second Order Statistic Analysis of Selection Macro-Diversity Combining over Gama Shadowed Rayleigh Fading Channels”, Scientific Publications of the State University of Novi Pazar, Ser. A: Appl. Math. Inform. and Mech., vol. 1, 1, pp. 1-9, 2009.

[9] B. Milosevic, P. Spalevic, M. Petrovic, D. Vuckovic, S. Milosavljevic, “Statistics of macro SC diversity system with two micro EGC diversity systems and fast fading.”, Electronics and Electrical Engineering. 96, 8, 2009, pp. 55-58.

[10] D. Krstić, D. Radenković, I. Temelkovski, S. Zdravković, S.Maričić, „Performance of Macrodiversity System with two EGC Diversity Receivers in the Presence of Shadowed Multipath Fading“, The 22nd International Conference on Software, Telecommunications and Computer Networks SoftCOM 2014, September 17-19, 2014, Split, Croatia