FACTA UNIVERSITATIS
Series: **Automatic Control and Robotics** Vol. 14, N° 2, 2015, pp. 99 - 109

LEVEL CROSSING RATE OF MACRODIVERSITY SYSTEM OVER COMPOSITE GAMMA SHADOWED ALPHA-KAPPA-MU MULTIPATH FADING CHANNEL

UDC (621.395.38:621.396.94:517)

Aleksandar V. Marković[1], Zoran H. Perić[1], Danijel B. Đošić[1], Marko M. Smilić[1], Branimir S. Jakšić[2]

[1]University of Niš, Faculty of Electronic Engineering, Department of Telecommunication, Niš, Republic of Serbia
[2] University of Priština, Faculty of Technical Sciences, Department of Electronic and Telecommunications, Kosovska Mitrovica, Republic of Serbia

Abstract. *In this paper macrodiversity system with macrodiversity selection combining (SC) receiver and two microdiversity SC receivers operating over composite shadowed multipath fading environment is considered. Received signal is subjected simultaneously to gamma long term fading and α-κ-μ short term fading resulting in system performance degradation. Macrodiversity SC receiver reduces gamma long term fading effects and microdiversity SC receivers mitigate α-κ-μ short term fading effects. Analitical expression for average level crossing rate of proposed wireless mobile system represented as an infinite series is evaluated. Mathematical and numerical analysis are shown influences of gamma fading severity, α-κ-μ multipath fading severity, and Rician factor on average level crossing rate.*

Key words: *gamma shadowed, level crossing rate, Nakagami-m, macrodiversity, microdiversity*

1. INTRODUCTION

Small scale fading and large scale fading degrade outage probability, bit error probability and channel capacity of wireless communication system. Received signal experiences short term fading resulting in signal envelope variation and long term fading resulting in signal envelope power variation. Reflections and refractions cause multipath propagation and large obstacles between transmitter and receiver cause shadowing. There

Received April 18, 2015
Corresponding author: Aleksandar V. Marković
Faculty of Electronic Engineering, Aleksandra Medvedeva 14, 18000 Niš, Republic of Serbia
E-mail: aleksandar.markovic@pr.ac.rs

are multiple distributions can be used to describe signal envelope in multipath fading channels depending on nonlinearity of line-of-sight component in environment the number clusters in channel, inequality of quadrature components powers and average power variation. Rician distribution can be used to describe small scale signal envelope variation in linear, line-of-sight multipath fading environment. The κ-μ distribution describes short term fading when multiple LOS components exist in environment. The α-κ-μ statistical model can describe signal envelope in nonlinear environments when surfaces are correlated resulting in nonhomogeneous scattering field [1]. Log-normal distribution and gamma distribution can be used to describe signal envelope power variation in shadowing channels. When log-normal distribution is used to describe long term fading, closed form expressions for outage probability and bit error probability of macrodiversity wireless communication system can not be obtained. Theoretical results and measured data have shown that gamma statistical model can well describe signal envelope power variation in fading channel [2][3][4].

Macrodiversity system with macrodiversity SC receiver and two or more microdiversity SC receiver can be used to simultaneously reduce shadowing and multipath fading on system performance. Microdiversity receiver is realized by using multiple antennas on base station. Macrodiversity system is provided by using signals with two or more base stations in cell. Average level crossing rate and average fade duration are second order performance measures of communication system. Average level crossing rate can be calculated as average value of the first derivation of random variable. There are several combining techniques which can be used to reduce long term fading effects and short term fading effects on system performance depend on implementation complexity and diversity gain. The SC diversity techniques has the least complexity due to the processing is performed only on one diversity branch. The SC receiver selects the branch with the highest signal-to-noise ratio. There are more waves considering second order statistics of macrodiversity system in open technical literature [5][6][7][8][10][11].

In paper [9], macrodiversity SC receiver with two microdiversity MRC receivers operating over composite gamma shadowed Nakagami-*m* multipath fading channel is analyzed. Average level crossing rate and average fade duration of proposed system are calculated. Average level crossing rate and average fade duration of macrodiversity system operating over gamma shadowed Rician fading environment are evaluated.

In paper [10], macrodiversiti SC receiver with two SC receivers operating over composite gamma shadowed Rayleigh multipath fading channel is analyzed. Closed form expressions for level crossing rate of microdiversity SC receivers output signals envelopes are calculated.

In this paper macrodiversity system with macrodiversity SC receiver and two microdiversity SC receivers operating over shadowed multipath fading channel is studied. Received signal is affected simultaneously to bout gamma long term fading and α-κ-μ short term fading. Expression for average fade duration of macrodiversity SC receiver output signal envelope represented as an infinite series is calculated. To the best authors knowledge, second order statistics of macrodiversity system operating over gamma shadowed α-κ-μ multipath fading channel is not considered in open technical literature. Obtaining results in this paper can be used in performance analyzes and designing of wireless communication system in composite shadowing multipath fading channels.

2. LEVEL CROSSING RATE OF ALPHA-KAPPA-MU RANDOM VARIABLE

The *α-κ-μ* random variable can be used to describe small scale signal envelope variation in nonlinear, line-of-sight multipath fading environment [12]. This distribution has three parameters. The parameter *α* is related to nonlinearity of propagation environment. The parameter *κ* is Rice factor defined as ratio of dominant components power and scattering components power. The parameter *μ* is associated to the number of clusters in propagation environment. The *α-κ-μ* fading channel is a general channel. For *α*=2, *α-κ-μ* fading channel becomes *α-κ-μ* fading channel. By setting for *κ*=0, *α-κ-μ* distribution becomes *α-μ* distribution and by setting for *α*=2 and *κ*=0 Nakagami-*m* distribution can be derived from *α-κ-μ* distribution. For *μ*=1 and *α*=2, *α-κ-μ* distribution approximates Rician distribution. The *α-κ-μ* random variable *x* is [12]

$$x = y^{\frac{2}{\alpha}}, \; x^{\alpha} = y^2, \; y = x^{\frac{\alpha}{2}}, \tag{1}$$

where *y*=*κ-μ* random variable. Squared *κ-μ* random variable y^2 can be written as sum of 2*μ* independent Gaussian random variables with the same variance

$$x^{\alpha} = y^2 = y_1^2 + y_2^2 + ... + y_{2\mu}^2 . \tag{2}$$

The first derivation of *α-κ-μ* random variable is

$$\dot{x} = \frac{2}{\alpha x^{\alpha-1}} (y_1\dot{y}_1 + y_2\dot{y}_2 + ... + y_{2\mu}\dot{y}_{2\mu}) . \tag{3}$$

The first derivation of Gaussian random variable is Gaussian random variable. This $\dot{y}_1$, $\dot{y}_2$,…, $\dot{y}_{2\mu}$ are independent Gaussian random variables. Linear transform of Gaussian random variables is Gaussian random variable therefore the first derivation of *α-κ-μ* random variable follows conditional Gaussian distribution. The mean of *x* is [13]

$$\bar{\dot{x}} = \frac{2}{\alpha x^{\alpha-1}} (y_1\dot{y}_1 + y_2\dot{y}_2 + ... + y_{2\mu}\dot{y}_{2\mu}) = 0 , \tag{4}$$

where $\dot{y}_1 = \dot{y}_2 = ... = \dot{y}_{2\mu} = 0$.

The variance of *x* is [13]

$$\sigma_{\dot{x}^2} = \frac{4}{\alpha^2 x^{2\alpha-2}} (y_1^2 \sigma_{\dot{y}_1^2} + y_2 \sigma_{\dot{y}_2^2} + ... + y_{2\mu} \sigma_{\dot{y}_{2\mu}^2}) , \tag{5}$$

where

$$\sigma_{\dot{y}_1^2} = \sigma_{\dot{y}_2^2} = ... = \sigma_{\dot{y}_{2\mu}^2} = \pi^2 f_m^2 \frac{\Omega}{(k+1)\mu} . \tag{6}$$

After substituting (6) in (5), the expression for variance of the first derivation of *α-κ-μ* random variable becomes

$$\sigma_{\dot{x}}^2 = \frac{4\pi^2 f_m^2}{\alpha^2 x^{\alpha-2}} \frac{\Omega}{(k+1)\mu} . \tag{7}$$

Joint probability density function of α-κ-μ random variable and the first derivation of α-κ-μ random variable is

$$p_{x\dot{x}}(x\dot{x}) = p_{\dot{x}}(\dot{x}/x)\, p_x(x)\,, \tag{8}$$

where $p_x(x)$ is probability density function of α-κ-μ random variable. The probability density function of α-κ-μ random variable is

$$p_x(x) = \left|\frac{dy}{dx}\right| p_y\left(x^{\frac{\alpha}{2}}\right), \tag{9}$$

where $\dfrac{dy}{dx} = \dfrac{\alpha}{2} x^{\frac{\alpha}{2}-1}$.

The probability density function of α-κ-μ random variable y is

$$\begin{aligned} p_y(y) &= \frac{2\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}} e^{k\mu} \Omega^{\mu+1}} y^{\mu} e^{-\frac{\mu(k+1)y^2}{\Omega}} I_{\mu-1}\left(2\mu\sqrt{\frac{k(k+1)}{\Omega}}\, y\right) = \\ &= \frac{2\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}} e^{k\mu} \Omega^{\mu+1}} e^{-\frac{\mu(k+1)y^2}{\Omega}} \sum_{i_1=0}^{\infty} \left(\mu\sqrt{\frac{k(k+1)}{\Omega}}\right)^{2i_1+\mu-1} \frac{1}{i_1!\Gamma(i_1+\mu)} y^{2i_1+2\mu-1} \end{aligned}. \tag{10}$$

After substituting (10) in (9), the expression for probability density function of α-κ-μ random variable becomes

$$p_x(x) = \frac{\alpha\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}} e^{k\mu} \Omega^{\mu+1}} e^{-\frac{\mu(k+1)x^{\alpha}}{\Omega}} \sum_{i_1=0}^{\infty} \left(\mu\sqrt{\frac{k(k+1)}{\Omega}}\right)^{2i_1+\mu-1} \frac{x^{\alpha i_1+\alpha\mu-1}}{i_1!\Gamma(i_1+\mu)}\,. \tag{11}$$

The average level crossing rate of α-κ-μ random variable can be evaluated as average value of the first derivation of α-κ-μ random variable

$$\begin{aligned} N_x &= \int_0^{\infty} d\dot{x}\dot{x} p_{x\dot{x}}(x\dot{x}) = \int_0^{\infty} d\dot{x}\dot{x} p_{\dot{x}}(\dot{x}/x)\, p_x(x) = \\ &= \frac{\mu^{\frac{1}{2}}(k+1)^{\frac{\mu}{2}}}{k^{\frac{\mu-1}{2}} e^{k\mu} \Omega^{\mu+\frac{1}{2}}} e^{-\frac{\mu(k+1)}{\Omega}x^{\alpha}} \sum_{i_1=0}^{\infty} \left(\mu\sqrt{\frac{k(k+1)}{\Omega}}\right)^{2i_1+\mu-1} \frac{1}{i_1!\Gamma(i_1+\mu)} x^{\alpha i_1+\alpha\mu+\frac{\alpha}{2}} \end{aligned}. \tag{12}$$

The cumulative distribution function of α-κ-μ random variable

$$\begin{aligned} F_x(x) &= \int_0^{x} dt\, p_x(x) = \frac{\alpha\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}} e^{k\mu} \Omega^{\mu+1}} \sum_{i_1=0}^{\infty} \left(\mu\sqrt{\frac{k(k+1)}{\Omega}}\right)^{2i_1+\mu-1} \\ &\frac{1}{i_1!\Gamma(i_1+\mu)} \frac{1}{\alpha} \left(\frac{\Omega}{\mu(k+1)}\right)^{i_1+\mu} \gamma\left(i_1+\mu, \frac{\mu(k+1)}{\Omega} x^{\alpha}\right) \end{aligned}. \tag{13}$$

The expression for level crossing rate of *α-κ-μ* random variable can be used for evaluation of average fade duration of wireless communication system operating over *α-κ-μ* multipath fading channel.

Level crossing rate of SC receiver output signal envelope dual SC receiver input signal experiences *α-κ-μ* multipath fading independent and identical signal envelopes at inputs of SC receiver are denoted with x_1 and x_2 and SC receiver output signal envelope is denoted with x. Joint probability density function of SC receiver output signal envelope and the first derivation of SC receiver output signal envelope is

$$p_{x\dot{x}}(x\dot{x}) = p_{x_1\dot{x}_1}(x\dot{x})F_{x_2}(x) + p_{x_2\dot{x}_2}(x\dot{x})F_{x_1}(x) = 2p_{x_1\dot{x}_1}(x\dot{x})F_{x_2}(x)\,. \tag{14}$$

The level crossing rate of SC receiver output signal envelope is

$$N_x = \int_0^\infty d\dot{x}\dot{x}p_{x\dot{x}}(x\dot{x}) = 2F_{x_2}(x)\int_0^\infty d\dot{x}\dot{x}p_{x_1\dot{x}_1}(x\dot{x}) = 2F_{x_2}(x)N_{x_1}\,, \tag{15}$$

where N_{x_1} is given with (12), $F_{x_2}(x)$ is given with (13). Cumulative distribution function of SC receiver output signal envelope can be calculated as product of cumulative distribution functions of signal envelopes at inputs of SC receiver:

$$F_x(x) = F_{x_1}(x)F_{x_2}(x) = (F_{x_1}(x))^2\,. \tag{16}$$

Average fade duration of SC receiver can be calculated as ratio of outage probability and average level crossing rate

$$AFD = \frac{p_0}{N_x} = \frac{(F_{x_1}(x_0))^2}{2F_{x_1}(x_0)N_{x_1}} = \frac{F_{x_1}(x_0)}{2N_{x_1}}\,. \tag{17}$$

Obtained expressions for average level crossing rate and average fade duration can be used for performance analysis of wireless communication system with SC receiver operating over *α-κ-μ* multipath fading environment.

3. Level Crossing Rate of Macrodiversity SC Receiver Output Signal Envelope

Macrodiversity system with macrodiversity SC receiver and two microdiversity SC receiver is considered. Received signal experiences Gamma long term fading resulting in signal envelope power variation and *α-κ-μ* short term fading resulting in signal envelope variation. Gamma shadowing is correlated due two base stations are shadowed by the same obstacle. Signal envelopes at outputs of microdiversity SC receivers are denoted with x and y and macrodiversity SC receiver output signal is denoted with z. Average powers at inputs of microdiversity SC receiver are denoted with Ω_1 and Ω_2. Random variables Ω_1 and Ω_2 follow correlated Gamma distribution:

$$p_{\Omega_1\Omega_2}(\Omega_1\Omega_2)=\frac{1}{\Gamma(c)(1-\rho^2)\rho^{\frac{c-1}{2}}\Omega_0^{c+1}}\sum_{i_2=0}^{\infty}\left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i_2+c-1}$$
$$\frac{1}{i_2!\Gamma(i_2+c)}\Omega_1^{i_2+c-1}\Omega_2^{i_2+c-1}e^{-\frac{\Omega_1+\Omega_2}{\Omega_0(1-\rho^2)}} \tag{18}$$

where c is order of Gamma distribution, ρ is correlation coefficient, Ω_0 is an average power of Ω_1 and Ω_2. Macrodiversity SC receiver selects microdiversity receiver with higher average power. Therefore average level crossing rate of macrodiversity SC receiver output signal envelope is

$$N_z=\int_0^{\infty}d\Omega_1\int_0^{\Omega_1}d\Omega_2\,{N_x}/{\Omega_1}\,p_{\Omega_1\Omega_2}(\Omega_1\Omega_2)+\int_0^{\infty}d\Omega_2\int_0^{\Omega_2}d\Omega_1\,{N_x}/{\Omega_2}\,p_{\Omega_1\Omega_2}(\Omega_1\Omega_2)=$$
$$=2\int_0^{\infty}d\Omega_1\int_0^{\Omega_1}d\Omega_2\,{N_x}/{\Omega_1}\,p_{\Omega_1\Omega_2}(\Omega_1\Omega_2)=$$
$$=4\frac{\alpha\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}}e^{k\mu}}\sum_{i_1=0}^{\infty}\left(\mu\sqrt{k(k+1)}\right)^{2i_1+\mu-1}\frac{1}{i_1!\Gamma(i_1+\mu)}\frac{1}{\alpha}\left(\frac{1}{\mu(k+1)}\right)^{i_1+\mu}$$
$$\frac{\mu^{\frac{1}{2}}(k+1)^{\frac{\mu}{2}}}{k^{\frac{\mu-1}{2}}e^{k\mu}}\sum_{i_2=0}^{\infty}\left(\mu\sqrt{k(k+1)}\right)^{2i_2+\mu-1}\frac{1}{i_2!\Gamma(i_2+\mu)}z^{\alpha i_2+\alpha\mu+\frac{\alpha}{2}} \quad . \tag{19}$$
$$\frac{1}{\Gamma(c)(1-\rho^2)\rho^{\frac{c-1}{2}}\Omega_0^{c+1}}\sum_{i_3=0}^{\infty}\left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i_3+c-1}\frac{1}{i_3!\Gamma(i_3+c)}\cdot(\Omega_0(1-\rho^2))^{i_3+c}$$
$$\int_0^{\infty}d\Omega_1\Omega_1^{-2\mu-3/2-i_2+i_3+c}e^{-\frac{\mu(k+1)z^{\alpha}}{\Omega_1}-\frac{\Omega_1}{\Omega_0(1-\rho^2)}}\gamma\left(i_1+\mu,\frac{\mu(k+1)}{\Omega_1}z^{\alpha}\right)\gamma\left(i_3+\mu,\frac{\Omega_1}{\Omega_0(1-\rho^2)}\right)$$

The incomplete Gamma function $\gamma(n,x)$ according to Eq.(8.310/1) from [14] is

$$\gamma(n,x)=\Gamma(n)-\frac{1}{n}x^n e^{-x}\sum_{i=0}^{\infty}\frac{x^i}{(n+1)_i}\,. \tag{20}$$

The integral I is

$$I=\int_0^\infty d\Omega_1\Omega_1^{-2\mu-3/2-i_2+i_3+c}e^{-\frac{\mu(k+1)z^\alpha}{\Omega_1}-\frac{\Omega_1}{\Omega_0(1-\rho^2)}}$$

$$\left(\Gamma(i_1+\mu)-\frac{1}{i_1+\mu}\frac{(\mu(k+1)z^\alpha)^{i_1+\mu}}{\Omega_1^{i_1+\mu}}e^{-\frac{\mu(k+1)z^\alpha}{\Omega_1}}\right.$$

$$\left.\sum_{j_1=0}^\infty\frac{1}{(i_1+\mu+1)_{(j_1)}}\frac{(\mu(k+1)z^\alpha)^{j_1}}{\Omega_1^{j_1}}\right) \tag{21}$$

$$\left(\Gamma(i_3+c)-\frac{1}{i_3+c}\frac{\Omega_1^{i_3+c}}{(\Omega_0(1-\rho^2))^{i_3+c}}e^{-\frac{\Omega_1}{\Omega_0(1-\rho^2)}}\right.$$

$$\left.\sum_{j_2=0}^\infty\frac{1}{(i_3+c+1)_{(j_2)}}\frac{\Omega_1^{j_2}}{(\Omega_0(1-\rho^2))^{j_2}}\right)=I_1+I_2+I_3+I_4$$

The integral I_1 is

$$I_1=\Gamma(i_1+\mu)\Gamma(i_3+c)\int_0^\infty d\Omega_1\Omega_1^{-2\mu-3/2-i_2+i_3+c}e^{-\frac{\mu(k+1)z^\alpha}{\Omega_1}-\frac{\Omega_1}{\Omega_0(1-\rho^2)}}=$$

$$=\Gamma(i_1+\mu)\Gamma(i_3+c)(\mu(k+1)z^\alpha\Omega_0(1-\rho^2))^{-\mu-\frac{1}{4}-\frac{i_2}{2}+\frac{i_3}{2}+\frac{c}{2}} \tag{22}$$

$$\mathrm{K}_{-2\mu-1/2-i_2+i_3+c}\left(2\sqrt{\frac{\mu(k+1)z^\alpha}{\Omega_0(1-\rho^2)}}\right)$$

The integral I_2 is

$$I_2=\int_0^\infty d\Omega_1\Omega_1^{-2\mu-3/2-i_2+i_3+c}e^{-\frac{\mu(k+1)z^\alpha}{\Omega_1}-\frac{\Omega_1}{\Omega_0(1-\rho^2)}}\Gamma(i_1+\mu)\frac{1}{i_3+c}$$

$$\frac{\Omega_1^{i_3+c}}{(\Omega_0(1-\rho^2))^{i_3+c}}e^{-\frac{\Omega_1}{\Omega_0(1-\rho^2)}}\sum_{j_2=0}^\infty\frac{1}{(i_3+c+1)_{(j_2)}}\frac{\Omega_1^{j_2}}{(\Omega_0(1-\rho^2))^{j_2}}=$$

$$=\Gamma(i_1+\mu)\frac{1}{i_3+c}\frac{1}{(\Omega_0(1-\rho^2))^{i_3+c}}\sum_{j_2=0}^\infty\frac{1}{(i_3+c+1)_{(j_2)}}\frac{1}{(\Omega_0(1-\rho^2))^{j_2}} \tag{23}$$

$$\left(\frac{\mu(k+1)z^\alpha\Omega_0(1-\rho^2)}{2}\right)^{-\mu-\frac{1}{4}-\frac{i_2}{2}+i_3+c+\frac{j_2}{2}}$$

$$\mathrm{K}_{-2\mu-1/2-i_2+2i_3+2c+j_2}\left(2\sqrt{\frac{2\mu(k+1)z^\alpha}{\Omega_0(1-\rho^2)}}\right)$$

The integral I_3 is

$$I_3 = \Gamma(i_3+c)\frac{1}{i_1+\mu}\frac{(\mu(k+1)z^\alpha)^{i_1+\mu}}{\Omega_1^{i_1+\mu}}e^{-\frac{\mu(k+1)z^\alpha}{\Omega_1}}$$
$$\sum_{j_1=0}^{\infty}\frac{1}{(i_1+\mu+1)_{(j_1)}}\frac{(\mu(k+1)z^\alpha)^{j_1}}{\Omega_1^{j_1}} =$$
$$\int_0^\infty d\Omega_1 \Omega_1^{-2\mu-3/2-i_2+i_3+c} e^{-\frac{\mu(k+1)z^\alpha}{\Omega_1}-\frac{\Omega_1}{\Omega_0(1-\rho^2)}} = \tag{24}$$
$$= \frac{\Gamma(i_3+c)}{i_1+\mu}(\mu(k+1)z^\alpha)^{i_1+\mu}\sum_{j_1=0}^{\infty}\frac{1}{(i_1+\mu+1)_{(j_1)}}(\mu(k+1)z^\alpha)^{j_1}$$
$$(2\mu(k+1)z^\alpha\Omega_0(1-\rho^2))^{-\frac{3\mu}{2}-\frac{i_1}{2}-\frac{1}{4}-\frac{i_2}{2}+\frac{i_3}{2}+\frac{c}{2}-\frac{j_1}{2}}$$
$$\mathrm{K}_{-3\mu-i_1-1/2-i_2-i_3+c-j_1}\left(2\sqrt{\frac{\mu(k+1)z^\alpha}{\Omega_0(1-\rho^2)}}\right)$$

The integral I_4 is

$$I_4 = \int_0^\infty d\Omega_1 \Omega_1^{-2\mu-3/2-i_2+i_3+c} e^{-\frac{\mu(k+1)z^\alpha}{\Omega_1}-\frac{\Omega_1}{\Omega_0(1-\rho^2)}}$$
$$\frac{1}{i_1+\mu}\frac{(\mu(k+1)z^\alpha)^{i_1+\mu}}{\Omega_1^{i_1+\mu}}e^{-\frac{\mu(k+1)z^\alpha}{\Omega_1}}\sum_{j_1=0}^{\infty}\frac{1}{(i_1+\mu+1)_{(j_1)}}\frac{(\mu(k+1)z^\alpha)^{j_1}}{\Omega_1^{j_1}}$$
$$\frac{1}{i_3+c}\frac{\Omega_1^{i_3+c}}{(\Omega_0(1-\rho^2))^{i_3+c}}e^{-\frac{\Omega_1}{\Omega_0(1-\rho^2)}}\sum_{j_2=0}^{\infty}\frac{1}{(i_3+c+1)_{(j_2)}}\frac{\Omega_1^{j_2}}{(\Omega_0(1-\rho^2))^{j_2}} =$$
$$= \frac{1}{i_1+\mu}(\mu(k+1)z^\alpha)^{i_1+\mu}\sum_{j_1=0}^{\infty}\frac{1}{(i_1+\mu+1)_{(j_1)}}\frac{1}{(\Omega_0(1-\rho^2))^{j_1}} \tag{25}$$
$$\frac{1}{i_3+c}\frac{1}{(\Omega_0(1-\rho^2))^{i_3+c}}\sum_{j_2=0}^{\infty}\frac{1}{(i_3+c+1)_{(j_2)}}\frac{\Omega_1^{j_2}}{(\Omega_0(1-\rho^2))^{j_2}}$$
$$(\mu(k+1)z^\alpha\Omega_0(1-\rho^2))^{-\frac{3\mu}{2}-\frac{i_1}{2}-\frac{i_2}{2}+i_3+c+\frac{j_2}{2}-\frac{j_1}{2}-\frac{1}{4}}$$
$$\mathrm{K}_{-3\mu-i_1-i_2+2i_3+2c+j_2-j_1-1/2}\left(2\sqrt{\frac{4\mu(k+1)z^\alpha}{\Omega_0(1-\rho^2)}}\right)$$

4. Numerical Results

In Fig. 1, normalized average level crossing rate versus normalized macrodiversity SC receiver output signal envelope is plotted for several values of Gamma fading severity c and correlation coefficient ρ. Average level crossing rate decreases as shadowing severity decreases and system performance are better. When order of gamma distribution goes to infinity gamma shadowed α-κ-μ multipath fading channel becomes α-κ-μ multipath fading channel. For lower values of parameter c (order of gamma distribution) long term fading is more severity. For lower values SC receiver output signal envelope, average level crossing rate increases until it reaches the maximum and it decreases as SC receiver output signal envelope increases.

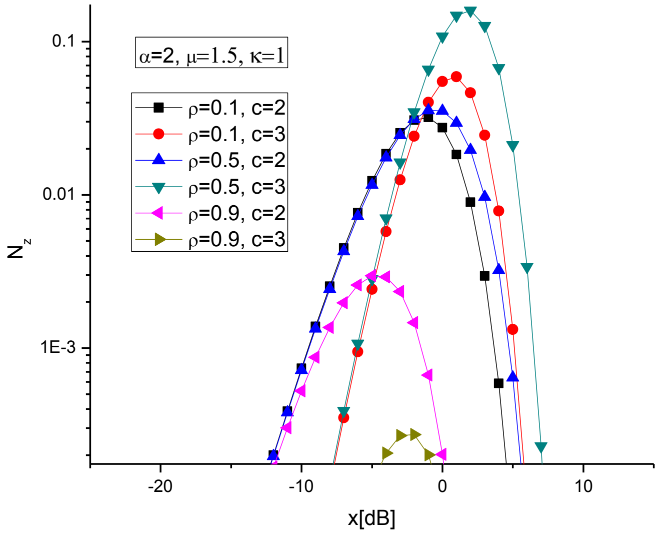

Fig. 1 Normalized average level crossing rate versus normalized macrodiversity SC receiver output signal envelope for several values of parameter c and ρ

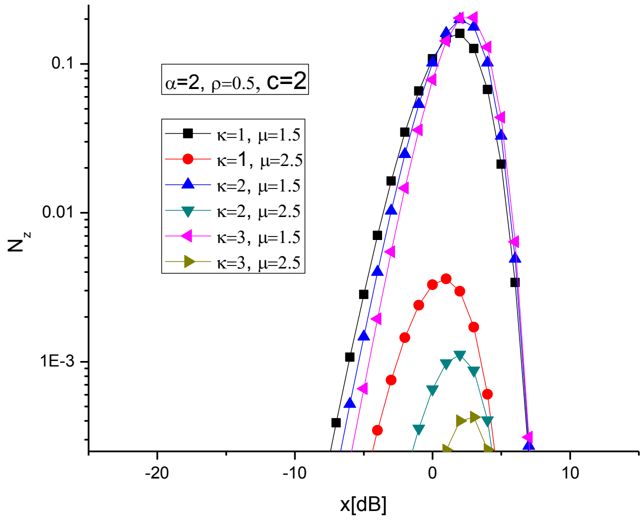

Fig. 2 Normalized average level crossing rate in terms of normalized macrodiversity SC receiver output signal envelope for several values of Rician factor κ and parameter μ

Normalized average level crossing rate in terms of normalized macrodiversity SC receiver output signal envelope is shown in Fig. 2 for several values of Rician factor κ and κ-μ fading severity. Normalized average level crossing rate decreases as Rician factor κ increases. When Rician factor increases multipath fading severity decreases. When Rician factor κ goes to infinity and Gamma parameter c goes to infinity, gamma shadowed Rician multipath fading channel becomes no fading channel. Rician factor κ is equal to the ratio of dominant components power and scattering components power. When average level crossing rate decreases system performances are better. Outage probability obtained lower values for higher values of dominant component power and lower values of scattering components power.

5. CONCLUSION

Macrodiversity system with macrodiversity SC receiver and two microdiversity SC receivers operating over composite gamma shadowed α-κ-μ fading channel is considered. Macrodiversity SC receiver to reduce gamma large scale fading on system performances and microdiversity SC receivers are used to mitigate α-κ-μ small scale fading effects on system performances. Average level crossing rate of macrodiversity SC receiver output signal envelope is evaluated. The α-κ-μ distribution is general distribution. Rician, Nakagami-m, α-μ, κ-μ, Rayleigh, Weibull distributions can be derived from α-κ-μ distribution as special cases.

By setting for α=2 in obtained expression for average level crossing rate of α-κ-μ random variable can be derived the expression for average fade duration of κ-μ random variable, by setting for α=2 in expression for average level crossing rate of macrodiversity SC receiver output signal operating over gamma shadowed α-κ-μ multipath fading channel can be obtained the expression for level crossing rate of macrodiversity SC receiver output signal operating over gamma shadowed κ-μ multipath fading environment. Obtained results are graphically presented the shown influence Rician factor, gamma shadowing severity nonlinearity parameter and α-κ-μ multipath fading severity on average level crossing rate of considered system. System performances are better for lower values of average level crossing rate. Average level crossing rate decreases as Rician factor increases. Rician factor increases as dominant components power increases on scattering components power decreases. Average level crossing rate is greater for lower values of gamma shadowing fading severity. Average level crossing rate increases as correlation coefficient increases.

When correlation coefficient goes to one, both base station are showed by the same obstacle over the least signal occurs simultaneously on both microdiversity SC receivers resulting in diversity gain degradation. When coefficient of correlation goes on one, the macrodiversity system becomes microdiversity system. The influence of Rician factor on average level crossing rate is higher for lower values of gamma fading severity. When gamma fading severity goes to infinity composite gamma shadowed α-κ-μ multipath fading channel becomes α-κ-μ multipath fading channel.

REFERENCES

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

[2] G. L. Stuber, *Mobile communication*. 2nd ed, Dordrecht: Kluwer Academic Publisher,2003.

[3] M.K. Simon, M.S. Alouini, *Digital Communication over Fading Channels*, New York: John Wiley & Sons, Inc., 2000.

[4] J. Zhang, V. Aalo, "Effect of macrodiversity on average-error probabilities in a Rician fading channel with correlated lognormal shadowing," IEEE Transactions on Communications, vol. 49, no. 1, pp. 14–18, 2001. [Online]. Available: http://dx.doi.org/10.1109/26.898244

[5] N. Sekulovic, M. Stefanovic, "Performance analysis of system with micro- and macrodiversity Reception in correlated gamma shadowed Rician fading channels," Wireless Personal Communications, vol. 65, no. 1, pp. 143–156, 2012. [Online]. Available: http://dx.doi.org/10.1007/s11277-011-0232-8

[6] V. V. Milenkovic, N. M. Sekulovic, M. C. Stefanovic, M. B. Petrovic, "Effect of microdiversity and macrodiversity on average bit error probability in gamma shadowed Rician fading channels," ETRI Journal, vol. 32, no. 3, pp. 464–467, 2010. [Online]. Available: http://dx.doi.org/10.4218/etrij.10.0209.0448

[7] A. S. Panajotovic, M. C. Stefanovic, D .Lj. Draca, "Effect of microdiversity and macrodiversity on average bit error probability in shadowed fading channels in the presence of interference," ETRI Journal, vol. 31, no. 5, pp. 500–505, 2009. [Online]. Available: http://dx.doi.org/10.4218/etrij.09.0109.0011

[8] X. Dong, N. C. Beaulieu, "Average level crossing rate and average fade duration of selection diversity," IEEE Communications Letters, vol. 5, no. 10, pp.396–398, 2001.

[9] D. Stefanovic, S. 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, vol. 65, no. 5, pp. 413–418, 2011. [Online]. Available: http://dx.doi.org/10.1016/j.aeue.2010.05.001

[10] B. Jaksic, D. Stefanovic, M. Stefanovic, P. Spalevic, V. Milenkovic, "Level crossing rate of mMacrodiversity system in the presence of multipath fading and shadowing," Radioengineering, vol. 24, no. 1, pp. 185–191, 2015. [Online]. Available: http://dx.doi.org/10.13164/re.2015.0185

[11] 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, vol. 87, no. 6/2011, 2011.

[12] G. Fraidenraich, M. D. Yacoub, "The α-η-μ and α-κ-μ fading distributions," in *Proceedings IEEE Ninth International Symposium on Spread Spectrum Techniques and Applications*, 28.-31. August, 2006, Manaus-Amazon, Brasil, pp. 16–20, 2006.

[13] M. Bandjur, D. Radenković, V. Milenković, S. Suljević, D. Djosić, "Second order statistics of SC receiver over k-μ multipath fading channel," Serbian Journal of Electrical Engineering, vol. 11, no. 3, pp. 391–401 2014. [Online]. Available: http://dx.doi.org/10.2298/SJEE140303028B

[14] I. S. Gradshteyn, I. M. Ryzhik, *Table of Integrals, Series and Products*. USA San Diego, CA: Academic Press, 2000.