Level Crossing Rate of Macrodiversity with Three Microdiversities in the Presence of Long Term Fading and Mixed Short Term Fading

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Abstract: - In this paper, macrodiversity (MAD) reception with MAD selection combining (SC) receiver and three microdiversity (MID) maximal ratio combining (MRC) receivers is analyzed. Received signal in the first MID MRC receiver experiences Gamma long term fading and Nakagami-m short term fading, received signal in the second MID MRC receiver experiences Gamma long term fading and Rician short term fading and received signal in the third MID MRC receiver experiences Gamma long term fading and κ-μ short term fading. Level crossing rates of signals at outputs of MID receivers are calculated and by using these expressions, the level crossing rate (LCR) of MAD SC receiver output signal is evaluated. The influence of Rician factor of κ-μ short term fading, Rician factor of Rician short term fading, severity parameter of Nakagami-m short term fading, severity parameter of Gamma long term fading and correlation coefficient of Gamma long term fading on level crossing rate is studied and discussed.

Key-Words: - macrodiversity reception; microdiversity reception; Gamma fading; κ-μ short term fading; Nakagami-m short term fading; Rician fading; level crossing rate

1 Introduction

Macrodiversity (MAD) reception can be used to reduce long term fading effects and short term fading effects on system performance as outage probability and bit error probability, simultaneously [1][2]. MAD receiver reduces long term fading effects and MID receivers mitigate short term fading effects [3]. In this paper, macrodiversity system with SC receiver and three MRC MID receivers is considered. In the first MID MRC receiver, received signal is subjected to correlated Gamma long term fading and Nakagami-m short term fading, in the second MID MRC receiver, received signal is subjected to correlated Gamma long term fading and Rician short term fading and in the third MID MRC receiver, received signal is affected by correlated Gamma long term fading and κ-μ short term fading.

Nakagami-*m* fading has severity parameter *m* [4] and for m=1, Nakagami-*m* channel becomes Rayleigh channel, for m= 0,5 Nakagami-*m* channel becomes one sided Gaussian channel and when severity parameter goes to infinity, Nakagami-*m* channel becomes no fading channel. Rician distribution has parameter κ known as Rician factor [5], and for κ=0, Rician channel becomes Rayleigh channel and when κ goes to infinity, Rician fading channel becomes goes to no fading channel. κ-μ distribution has two parameters κ and μ [6], where κ is Rician factor and μ is severity parameter. κ-μ channel becomes Nakagami-*m* channel for κ=0, κ-μ channel becomes Rician channel for μ=1, and κ-μ channel becomes Rayleigh channel for κ=0 and μ=1.

The level crossing rate is the second order performance measure of wireless communication system which is defined as the number of crossings of random process at determined level and can be calculated as mean of the first time derivative of random process [3]. Average fade duration is also the second order performance measure of wireless communication system which is defined as average time that signal envelope falls below the determined threshold and can be calculated as ratio of outage probability and level crossing rate. Outage probability is defined as probability that signal envelope fall below the determined threshold and can be evaluated for cumulative distribution [3].

There are more works in open technical literature considering the second order performance measures of wireless mobile communication systems. In paper [7], level crossing rate and average fade duration of output signal of MAD system with MAD SC receiver and two MID MRC receivers operated over Gamma shadowed Nakagami-m short term fading channel are evaluated.

MAD system including MAD SC receiver and two MID SC receivers is considered in [8]. Received signal experiences, simultaneously, both, long term fading and short term fading. MID SC receivers reduce Rayleigh fading effects on system performance and MAD SC receiver mitigates Gamma shadowing effects on the level crossing rate.

MAD system with MAD SC receiver and two MID SC receivers is considered in [9]. Received signal is affected simultaneously to Gamma long term fading and Rician short term fading resulting in system performance degradation. MAD SC receiver reduces Gamma shadowing effects and MID SC receivers reduce multipath fading effects on bit error probability. Closed form expression for average LCR of MAD SC receiver output signal envelope is evaluated.

Level crossing rate and average fade duration of MAD reception in the presence of correlated Gamma long term fading and Rician short term fading are calculated in [10]. In [11], wireless system with MAD reception and three branches MID MRC systems in gamma-shadowed Ricean fading channels is considered. An exact and rapidly converging infinite-series expression for the average level crossing rate (LCR) at the output of the system is provided.

In paper [12], the second-order statistics (LCR and AFD) of SC MAD working over Gamma shadowed Nakagami-*m* fading channels are derived. MAD SC system consists of two MID systems and switching is based on their output signal power values. Each MID is of MRC type with arbitrary number of branches in the presence of correlative Nakagami-*m* fading.

Also, in paper [13], MAD system with MAD SC receiver and two MID MRC receivers is considered. Level crossing rate and average fade duration are evaluated for the case when proposed system operating over shadowed κ-μ multipath fading channel.

In this paper, level crossing rate of signal at output of SC receiver operating over Nakagami-m small scale fading channel is evaluated, level crossing rate of signal at output of SC receiver in the presence of Rician fading is calculated and level crossing rate of signal at output of SC receiver subjected to κ-μ short term fading is also evaluated. These expressions for level crossing rate are used for calculation level crossing rate of MAD SC receiver output signal envelope. To the authors' knowledge, level crossing rate of MAD system in the presence of Gamma long term fading, Rician short term fading, Nakagami-m short term fading and κ-μ short term fading is not reported in technical literature.

2 Level Crossing Rate of Output Signals of MID MRC Receivers

MAD system considered in this paper has MAD SC receiver and three MID MRC receivers. Nakagami-m small scale fading and correlated Gamma large scale fading are present at inputs of the first MID MRC receiver, Rician small scale fading and correlated Gamma large scale fading are present at inputs of the second MID MRC receiver and κ-μ small scale fading and correlated Gamma large scale fading are present at inputs of the third MID MRC receiver. Model of proposed wireless system is shown in Fig. 1.

Random variables x_{11} and x_{12} follow Nakagami-m distribution [4]:

$$p_{x_{1i}}(x_{1i}) = \frac{2}{\Gamma(m)} \cdot \left(\frac{m}{\Omega_1}\right)^m x_{1i}^{2m-1} e^{-\frac{m}{\Omega_1}x_{1i}^2},\ x_{1i} \ge 0,\ i = 1,\ 2 \tag{1}$$

where m is severity parameter and Ω_1 is average power of x_{1i}. The first MID MRC output signal envelope x_1 is:

$$x_1^2 = x_{11}^2 + x_{12}^2 \tag{2}$$

and follow distribution:

$$p_{x_1}(x_1) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega_1}\right)^{2m} x_1^{4m-1} e^{-\frac{m}{\Omega_1}x_1^2},\ x_1 \ge 0\,. \tag{3}$$

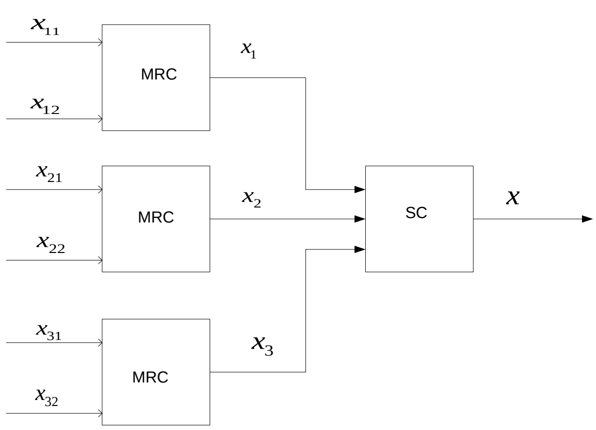

Fig.1. System model

Random variable x_1, also, has Nakagami-m distribution. Joint probability density function of x_1 and $\dot{x}_1$ is:

$$p_{x_1\dot{x}_1}\left(x_1\dot{x}_1\right)=\frac{2}{\Gamma(m)}\left(\frac{m}{\Omega_1}\right)^{2m}x_1^{4m-1}e^{-\frac{m}{\Omega_1}x_1^2}\frac{1}{\sqrt{2\pi}\beta_1}e^{-\frac{\dot{x}_1^2}{2\beta_1^2}}\quad(4)$$

where $\beta_1^2=\pi^2 f_m^2\frac{\Omega_1}{m}$, and f_m is maximal Doppler frequency.

Level crossing rate of x_1 random process is [3]:

$$N_{x_1}=\int_0^\infty dx_1\dot{x}_1 p_{x_1\dot{x}_1}\left(x_1\dot{x}_1\right)=$$

$$=\frac{2}{\Gamma(m)}\left(\frac{m}{\Omega_1}\right)^{2m}x_1^{4m-1}e^{-\frac{m}{\Omega_1}x_1^2}\int_0^\infty d\dot{x}_1\dot{x}_1\frac{1}{\sqrt{2\pi}\beta_1}e^{-\frac{\dot{x}_1^2}{2\beta_1^2}}=$$

$$=\frac{\sqrt{2\pi}f_m}{\Gamma(m)}\left(\frac{m}{\Omega_1}\right)^{2m-1/2}x_1^{4m-1}e^{-\frac{m}{\Omega_1}x_1^2}\quad(5)$$

Random signal envelopes x_{21} and x_{22} follow Rician distribution [5]:

$$p_{x_{2i}}\left(x_{2i}\right)=\frac{2(k+1)x_{2i}}{e^k\Omega_2}\cdot e^{-\frac{(k+1)}{\Omega_2}x_{2i}^2}I_0\left(2\sqrt{\frac{k(k+1)}{\Omega_2}}x_{2i}\right),$$

$$x_{2i}\geq 0,\, i=1,\,2\,;\quad(6)$$

here k is Rician factor, Ω_2 is average power of x_{2i}.

PDF of the second MID MRC output signal envelope x_2 is:

$$p_{x_2}\left(x_2\right)=\frac{4(k+1)^{3/2}x_2}{e^{2k}\Omega_2^{3/2}k^{1/2}}\cdot e^{-\frac{2(k+1)}{\Omega_2}x_2^2}I_1\left(4\sqrt{\frac{k(k+1)}{\Omega_2}}x_2\right),\quad(7)$$

where k is Rician factor and Ω_2 is average power of x_2. JPDF of x_2 and $\dot{x}_2$ is:

$$p_{x_2\dot{x}_2}\left(x_2\dot{x}_2\right)=\frac{4(k+1)^{3/2}x_2}{k^{1/2}e^{2k}\Omega_2^{3/2}}\cdot e^{-\frac{2(k+1)}{\Omega_2}x_2^2}$$

$$I_1\left(4\sqrt{\frac{k(k+1)}{\Omega_2}}x_2\right)\frac{1}{\sqrt{2\pi}\beta_2}e^{-\frac{\dot{x}_2^2}{2\beta_2^2}}\quad(8)$$

with $\beta_2^2=\pi^2 f_m^2\frac{\Omega_2}{2(k+1)}$.

Level crossing rate of x_2 random process is:

$$N_{x_2}=\int_0^\infty dx_2\dot{x}_2 p_{x_2\dot{x}_2}\left(x_2\dot{x}_2\right)=$$

$$=\frac{4(k+1)^{3/2}x_2}{k^{1/2}e^{2k}\Omega_2^{3/2}}\cdot e^{-\frac{2(k+1)}{\Omega_2}x_2^2}I_1\left(4\sqrt{\frac{k(k+1)}{\Omega_2}}x_2\right)$$

$$\int_0^\infty d\dot{x}_2\dot{x}_2\frac{1}{\sqrt{2\pi}}\pi f_m\frac{\Omega_2^{1/2}}{2^{1/2}(k+1)^{1/2}}e^{-\frac{\dot{x}_2^2}{2\beta_2^2}}=$$

$$=\frac{2\sqrt{\pi}f_m(k+1)x_2}{k^{1/2}e^{2k}\Omega_2}e^{-\frac{2(k+1)}{\Omega_2}x_2^2}I_1\left(4\sqrt{\frac{k(k+1)}{\Omega_2}}x_2\right).\quad(9)$$

Signal envelopes x_{31} and x_{32} follow κ-μ distribution [6]:

$$p_{x_{3i}}\left(x_{3i}\right)=\frac{2\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}}e^{k\mu}\Omega_3^{\frac{\mu+1}{2}}}x_{3i}^{\mu}\cdot e^{-\frac{\mu(k+1)}{\Omega_3}x_{3i}^2}$$

$$\cdot I_{\mu-1}\left(2\mu\frac{\sqrt{k(k+1)}}{\Omega_3}x_{3i}\right),\ x_{3i}\geq 0,\ i=1,2,\quad(10)$$

where k is Rician factor, Ω_3 is average power of x_{3i} and μ is severity parameter of κ-μ multipath fading.

The PDF of the third MID MRC output signal envelope x_3 is:

$$p_{x_3}\left(x_3\right)=\frac{4\mu(k+1)^{\frac{2\mu+1}{2}}x_3^{2\mu}}{k^{\frac{2\mu-1}{2}}e^{2k\mu}\Omega_3^{\frac{2\mu+1}{2}}}\cdot$$

$$e^{-\frac{2\mu(k+1)}{2\Omega_3}x_3^2}I_{2\mu-1}\left(4\mu\frac{\sqrt{k(k+1)}}{2\Omega_3}x_3^2\right),\ x_3\geq 0,\quad(11)$$

JPDF of x_3 and $\dot{x}_3$ is:

$$p_{x_3\dot{x}_3}\left(x_3\dot{x}_3\right)=\frac{4\mu(k+1)^{\frac{2\mu+1}{2}}x_3^{2\mu}}{k^{\frac{2\mu-1}{2}}e^{2k\mu}\Omega_3^{\frac{2\mu+1}{2}}}\cdot e^{-\frac{\mu(k+1)}{\Omega_3}x_3^2}$$

$$I_{2\mu-1}\left(4\mu\frac{\sqrt{k(k+1)}}{2\Omega_3}x_3^2\right)\frac{1}{\sqrt{2\pi}\beta_3}e^{-\frac{\dot{x}_3^2}{2\beta_3^2}},\ x_3\geq 0,\quad(12)$$

where $\beta_3^2=\pi^2 f_m^2\frac{\Omega_3}{\mu(k+1)}$.

Level crossing rate of x_3 random process is:

$$N_{x_3}=\int_0^\infty dx_3\dot{x}_3 p_{x_3\dot{x}_3}\left(x_3\dot{x}_3\right)=$$

$$=\frac{4\mu(k+1)^{\frac{2\mu+1}{2}}x_3^{2\mu}}{k^{\frac{2\mu-1}{2}}e^{2k\mu}\Omega_3^{\frac{2\mu+1}{2}}}\cdot$$

$$e^{-\frac{\mu(k+1)}{\Omega_3}x_3^2} I_{2\mu-1}\left(4\mu\frac{\sqrt{k(k+1)}}{2\Omega_3}x_3^2\right)$$

$$\int_0^\infty d\dot{x}_3\dot{x}_3\frac{1}{\sqrt{2\pi}\beta_3}e^{-\frac{\dot{x}_3^2}{2\beta_3^2}}=$$

$$=\frac{4\mu(k+1)^{\frac{2\mu+1}{2}}x_3^{2\mu}}{k^{\frac{2\mu-1}{2}}e^{2k\mu}\Omega_3^{\frac{2\mu+1}{2}}}\cdot e^{-\frac{\mu(k+1)}{\Omega_3}x_3^2}$$

$$I_{2\mu-1}\left(4\mu\frac{\sqrt{k(k+1)}}{2\Omega_3}x_3^2\right)\cdot\frac{1}{\sqrt{2\pi}}\frac{\pi f_m\Omega_3^{1/2}}{\mu^{1/2}(k+1)^{1/2}}=$$

$$=\frac{\sqrt{2\pi}f_m\mu^{1/2}(k+1)^{\mu}x_3^{2\mu}}{k^{2\mu-1/2}e^{2k\mu}\Omega_3^{\mu}}\cdot e^{-\frac{\mu(k+1)}{\Omega_3}x_3^2}$$

$$I_{2\mu-1}\left(4\mu\frac{\sqrt{k(k+1)}}{2\Omega_3}x_3^2\right),\ x_3\geq 0\,. \qquad (13)$$

Signal envelope average powers at inputs of MID MRC receivers Ω_1, Ω_2 and Ω_3 follow JPDF:

$$p_{\Omega_1\Omega_2\Omega_3}(\Omega_1\Omega_2\Omega_3)=\frac{2}{\Gamma(c)\left(1-\rho^2\right)^2\rho^{2(c-1)}\Omega_0^{c+2}}\cdot$$

$$\cdot e^{-\frac{\Omega_1+\left(1+\rho^2\right)\Omega_2+\Omega_3}{2\Omega_0\left(1-\rho^2\right)}}(\Omega_1\Omega_3)^{\frac{c-1}{2}}$$

$$I_{c-1}\left(\frac{2\rho}{\Omega_0\left(1-\rho^2\right)}\Omega_1^{1/2}\Omega_2^{1/2}\right)I_{c-1}\left(\frac{2\rho}{\Omega_0\left(1-\rho^2\right)}\Omega_2^{1/2}\Omega_3^{1/2}\right), \qquad (14)$$

where c is Gamma long term fading severity parameter, Ω_0 is average power of Ω_1, Ω_2 or Ω_3, and ρ is Gamma long term fading correlation coefficient.

3 Level Crossing Rate of Signal Envelope at Output of MAD SC Receiver

MAD SC receiver selects MID MRC receiver with the highest signal envelope average power at input. Therefore, level crossing rate of signal envelope at output of MAD SC receiver output signal envelope is:

$$N_x=\int_0^\infty d\Omega_1\int_0^{\Omega_1}d\Omega_2\int_0^{\Omega_1}d\Omega_3 N_{x_1/\Omega_1}p_{\Omega_1\Omega_2\Omega_3}(\Omega_1\Omega_2\Omega_3)+$$

$$+\int_0^\infty d\Omega_2\int_0^{\Omega_2}d\Omega_1\int_0^{\Omega_2}d\Omega_3 N_{x_2/\Omega_2}p_{\Omega_1\Omega_2\Omega_3}(\Omega_1\Omega_2\Omega_3)+$$

$$+\int_0^\infty d\Omega_3\int_0^{\Omega_3}d\Omega_1\int_0^{\Omega_3}d\Omega_2 N_{x_3/\Omega_3}p_{\Omega_1\Omega_2\Omega_3}(\Omega_1\Omega_2\Omega_3)=$$

$$=J_1+J_2+J_3 \qquad (15)$$

The integral J_1 is [14]:

$$J_1=\int_0^\infty d\Omega_1\int_0^{\Omega_1}d\Omega_2\int_0^{\Omega_1}d\Omega_3 N_{x_1/\Omega_1}p_{\Omega_1\Omega_2\Omega_3}(\Omega_1\Omega_2\Omega_3)=$$

$$=\frac{\sqrt{2\pi}f_m}{\Gamma(2m)}m^{2m}x^{4m-1}\cdot\frac{2}{\Gamma(c)\left(1-\rho^2\right)^2\rho^{2(c-1)}\Omega_0^{c+2}}\cdot$$

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

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

$$\left(\frac{\Omega_0\left(1-\rho^2\right)}{1+\rho^2}\right)^{i_1+i_2+c}\Omega_1^{i_1+c-1}\Omega_2^{i_1+i_2+c-1}\Omega_3^{i_2+c-1}\cdot e^{-\frac{\Omega_1+\left(1+\rho^2\right)\Omega_2+\Omega_3}{\Omega_0\left(1-\rho^2\right)}}$$

$$\frac{1}{(i_1+i_2+c)}\left(\frac{1+\rho^2}{\Omega_0\left(1-\rho^2\right)}\right)^{i_1+i_2+c}$$

$$\sum_{j_1=0}^\infty\frac{1}{(i_1+i_2+c+1)(j_1)}\left(\frac{1+\rho^2}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

$$\left(\Omega_0\left(1-\rho^2\right)\right)^{i_2+c}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{i_2+c}\frac{1}{i_2+c}\cdot$$

$$\sum_{j_2=0}^\infty\frac{1}{(i_2+c+1)(j_2)}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_2}$$

$$\int_0^\infty d\Omega_1\Omega_1^{i_1+c-1+i_1+i_2+c+j_1+i_2+c+j_2-2m+1/2}e^{-\frac{m}{\Omega_1}x^2-\frac{\left(3+\rho^2\right)\Omega_1}{\Omega_0\left(1-\rho^2\right)}}=$$

$$=\frac{\sqrt{2\pi}f_m}{\Gamma(2m)}m^{2m}x^{4m-1}\cdot\frac{2}{\Gamma(c)\left(1-\rho^2\right)^2\rho^{2(c-1)}\Omega_0^{c+2}}\cdot$$

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

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

$$\frac{1}{\left(i_1+i_2+c\right)}\sum_{j_1=0}^{\infty}\frac{1}{\left(i_1+i_2+c+1\right)\left(j_1\right)}\left(\frac{1+\rho^2}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

$$\frac{1}{i_2+c}\sum_{j_2=0}^{\infty}\frac{1}{\left(i_2+c+1\right)\left(j_2\right)}\left(\frac{1}{\Omega_0\left(1-\rho^2\right)}\right)^{j_2}$$

$$\left(\frac{mx^2\Omega_0\left(1-\rho^2\right)}{3+\rho^2}\right)^{i_1+i_2+3c/2+j_1/2+j_2/2-m+1/4}$$

$$K_{2i_1+2i_2+3c+j_1+j_2-2m+1/2}\left(2\sqrt{\frac{mx^2\left(3+\rho^2\right)}{\Omega_0\left(1-\rho^2\right)}}\right). \tag{16}$$

$K_n(x)$ denotes the modified Bessel function of the second kind [15], order n and argument x.

The integral J_2 is:

$$J_2=\int_0^{\infty}d\Omega_2\int_0^{\Omega_2}d\Omega_1\int_0^{\Omega_2}d\Omega_3 N_{x_2/\Omega_2}\,p_{\Omega_1\Omega_2\Omega_3}\left(\Omega_1\Omega_2\Omega_3\right)=$$

$$=\frac{2\sqrt{\pi}\,f_m\left(k+1\right)x}{k^{1/2}e^{2k}}\cdot\sum_{i_1=0}^{\infty}\left(2\sqrt{\frac{k\left(k+1\right)}{2}}\right)^{2i_1}\frac{1}{i_1!\Gamma\left(i_1\right)}x^{2i_1}$$

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

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

$$\sum_{i_3=0}^{\infty}\left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_3+c-1}\frac{1}{i_3!\Gamma\left(i_3+c\right)}$$

$$\left(\Omega_0\left(1-\rho^2\right)\right)^{i_2+c}\frac{1}{i_2+c}\frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)^{i_2+c}}\cdot$$

$$\sum_{j_1=0}^{\infty}\frac{1}{\left(i_2+c+1\right)\left(j_1\right)}\frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)^{j_1}}$$

$$\left(\Omega_0\left(1-\rho^2\right)\right)^{i_2+c}\frac{1}{i_3+c}\frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)^{i_2+c}}\cdot$$

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

$$\int_0^{\infty}d\Omega_2\,\Omega_2^{-1+i_1+i_2+i_3+c-1+i_2+c+i_3+c+j_1+j_2}\cdot e^{-\frac{2(k+1)}{\Omega_2}x^2-\frac{\left(3+\rho^2\right)\Omega_2}{\Omega_0\left(1-\rho^2\right)}}=$$

$$=\frac{2\sqrt{\pi}\,f_m\left(k+1\right)x}{k^{1/2}e^{2k}}\cdot\sum_{i_1=0}^{\infty}\left(2\sqrt{\frac{k\left(k+1\right)}{2}}\right)^{2i_1}\frac{1}{i_1!\Gamma\left(i_1\right)}x^{2i_1}$$

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

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

$$\frac{1}{i_2+c}\sum_{j_1=0}^{\infty}\frac{1}{\left(i_2+c+1\right)\left(j_1\right)}\frac{1}{\left(\Omega_0\left(1-\rho^2\right)\right)^{j_1}}$$

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

$$\left(\frac{2\left(k+1\right)x^2\Omega_0\left(1-\rho^2\right)}{3+\rho^2}\right)^{i_1/2+i_2+i_3+3c/2+j_1/2+j_2/2}$$

$$K_{i_1+2i_2+2i_3+3c+j_1+j_2}\left(2\sqrt{\frac{2\left(k+1\right)x^2\left(3+\rho^2\right)}{\Omega_0\left(1-\rho^2\right)}}\right). \tag{17}$$

The integral J_3 is:

$$J_3=\int_0^{\infty}d\Omega_3\int_0^{\Omega_3}d\Omega_1\int_0^{\Omega_3}d\Omega_2 N_{x_3/\Omega_3}\,p_{\Omega_1\Omega_2\Omega_3}\left(\Omega_1\Omega_2\Omega_3\right)=$$

$$=\frac{\sqrt{2\pi}\,f_m\,\mu^{1/2}\left(k+1\right)^{\mu}x^{2\mu}}{k^{\mu-1/2}e^{2k\mu}}$$

$$\sum_{i_1=0}^{\infty}\left(2\mu\sqrt{\frac{k\left(k+1\right)}{2}}x\right)^{2i_1+2\mu-1}\frac{1}{i_1!\Gamma\left(i_1+2\mu\right)}$$

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

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

$$\sum_{i_3=0}^{\infty}\left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_3+c-1}\frac{1}{i_3!\Gamma\left(i_3+c\right)}$$

$$\left(\frac{\Omega_0\left(1-\rho^2\right)}{\left(1+\rho^2\right)}\right)^{i_2+i_3+c}\frac{1}{i_2+i_3+c}\left(\frac{\left(1+\rho^2\right)}{\Omega_0\left(1-\rho^2\right)}\right)^{i_2+i_3+c}.$$

$$\sum_{j_1=0}^{\infty}\frac{1}{\left(i_2+i_3+c+1\right)\left(j_1\right)}\left(\frac{1+\rho^2}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

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

$$\cdot\int_0^{\infty}d\Omega_3\,\Omega_3^{i_3+c-1+i_2+i_3+c+j_1+j_2+i_2+c+\mu-\frac{2i_1+2\mu-1}{2}}$$

$$\cdot e^{-\frac{\mu(k+1)}{\Omega_3}x^2-\frac{\left(3+\rho^2\right)\Omega_3}{\Omega_0\left(1-\rho^2\right)}}=\frac{\sqrt{2\pi}\,f_m\,\mu^{1/2}\left(k+1\right)^{\mu}x^{2\mu}}{k^{\mu-1/2}e^{2k\mu}}$$

$$\sum_{i_1=0}^{\infty}\left(2\mu\sqrt{\frac{k\left(k+1\right)}{2}}x\right)^{2i_1+2\mu-1}\frac{1}{i_1!\Gamma\left(i_1+2\mu\right)}$$

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

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

$$\sum_{i_3=0}^{\infty}\left(\frac{\rho}{\Omega_0\left(1-\rho^2\right)}\right)^{2i_3+c-1}\frac{1}{i_3!\Gamma\left(i_3+c\right)}$$

$$\frac{1}{i_2+i_3+c}\sum_{j_1=0}^{\infty}\frac{1}{\left(i_2+i_3+c+1\right)\left(j_1\right)}\left(\frac{1+\rho^2}{\Omega_0\left(1-\rho^2\right)}\right)^{j_1}$$

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

$$\left(\frac{\mu\left(k+1\right)x^2\Omega_0\left(1-\rho^2\right)}{3+\rho^2}\right)^{i_2+i_3+3c/2-\mu-i_1/2+1/4+j_1/2+j_2/2}$$

$$K_{2i_2+2i_3+3c+j_1+j_2-2\mu-1/2-i_1}\left(2\sqrt{\frac{\mu\left(k+1\right)x^2\left(3+\rho^2\right)}{\Omega_0\left(1-\rho^2\right)}}\right). \quad (18)$$

4 Numerical results

In Fig. 2, level crossing rate versus MAD SC receiver output signal envelope is shown. Parameters are: Rician factor k_1 of Rician feding, Rician factor k_2 of κ-μ fading, Gamma long term fading severity parameter β, Nakagami-m severity parameter and signal envelope average power.

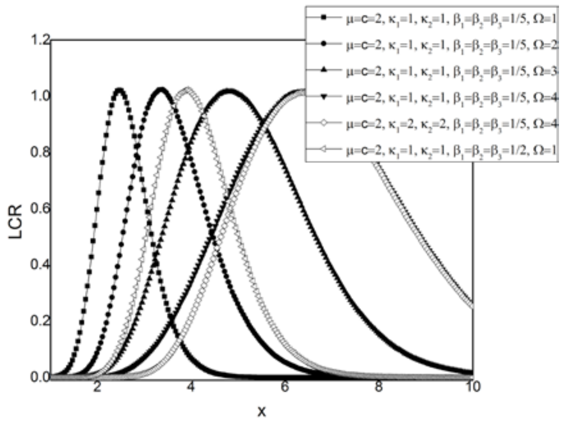

Fig. 2. LCR of MAD SC receiver output signal versus output signal envelope for μ=c=2, variable Gamma fading severity parameter, Rician factors of Rician and κ-μ fading and signal envelope average power.

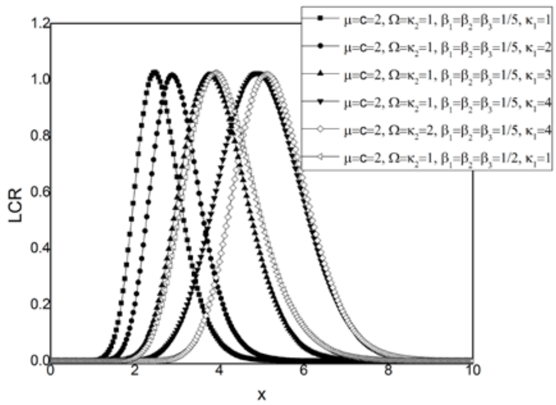

Fig. 3. LCR versus macrodiversity SC receiver output signal envelope for variable Rician factor of Rician fading and Gamma fading severity parameter.

For lower values of output signal amplitude, level crossing rate increases as signal amplitude increases, and for higher values of signal envelope, level crossing rate decreases as signal envelope increases. The influence of signal envelope on level crossing rate is higher for higher values of signal envelope. Signal envelope increases when Nakagami-m short term fading parameter decreases.

The influence of Nakagami-m severity parameter on level crossing rate is higher for lower values of output signal envelope. Maximums of curves go to higher values of signal envelope as Nakagami-m parameter increases. When Gamma severity parameter decreases, LCR increases and outage probability increases also.

Level crossing rate versus output signal envelope for several values of Rician factor of Rician fading, Rician factor of κ-μ fading and Gamma long term fading severity parameter, is presented in Figs. 3 and 4.

Level crossing rate of output signal envelope increases when Rician factor of Rician fading and Rician factor of κ-μ fading decrease. The influence of Rician factor of Rician fading on LCR is higher for higher values of Rician factor of κ-μ fading and influence of Rician factor of κ-μ fading on LCR is higher for higher values of Rician factor of Rician fading. Maximum of curve goes to lower values of output signal envelope when Rician factor of Rician fading and Rician factor of κ-μ fading increase.

The influence of Gamma fading parameter β on LCR of MAD SC receiver output signal is shown in Fig. 5. It is visible from this figure that LCR for small signal envelopes is bigger for smaller values of Gamma fading parameter β.

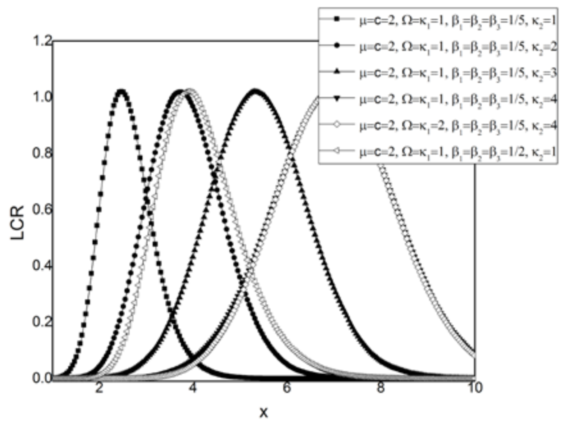

Fig. 4. LCR versus macrodiversity SC receiver output signal envelope.

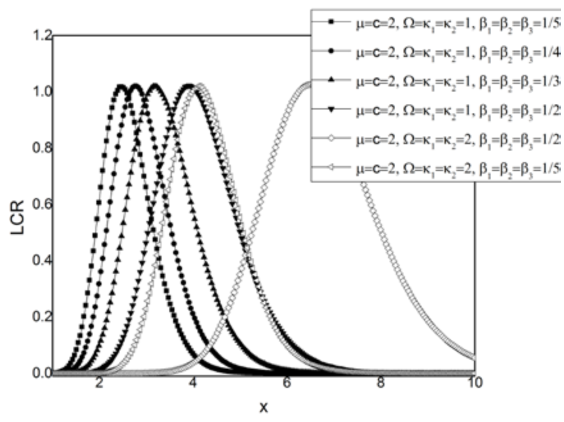

Fig. 5. LCR versus macrodiversity SC receiver output signal envelope for variable Gamma fading severity parameter.

Level crossing rate decreases when Gamma long term fading correlation coefficient goes to one. The influence of Gamma long term fading on level crossing rate is higher for higher values of Nakagami-m short term fading parameter; also, the influence of Nakagami-m severity parameter on level crossing rate is higher for lower values Gamma long term fading correlation coefficient.

5 Conclusion

MAD technique is applied to reduce long term fading and short term fading effects on wireless communication mobile radio performance simultaneously in this paper. Macrodiversity system has MAD selection combining and three MID maximum ratio combinig receptions. At inputs of the first MID receiver, received signal experiences correlated Gamma large scale fading and Nakagami-m small scale fading, at inputs of the second MID reception, received signal experiences correlated Gamma large scale fading and Rician small scale fading and at inputs of the third MID SC receiver, signal envelope experiences correlated Gamma large scale fading and κ-μ small scale fading. The MAD SC receiver reduces Gamma long term fading effects, the first MID MRC receiver reduces Nakagami-m short term fading effects, the second MID MRC receiver reduces Rician short term fading effects, and the third MID MRC reduces Nakagami-m short term fading effects on system performance.

Level crossing rate closed form expressions for MID MRC output signal envelope are calculated in this paper. By using these expressions, in work, average level crossing rate of MAD SC receiver output signal envelope is efficiently evaluated as expression in the closed form. This expression can be used for evaluation average fade duration of proposed radio system as ratio of outage probability and level crossing rate.

The influence of Nakagami-m fading severity parameter, Rician factor, κ-μ fading Rician factor, κ-μ short term fading severity parameter, Gamma long term fading severity parameter and Gamma long term fading correlation coefficient on level crossing rate is analyzed and discussed. Average fade duration decreases when level crossing rate increases. Level crossing rate decreases when of Rician factor of Rician fading, Rician factor of κ-μ fading, Nakagami-m severity parameter and Gamma severity parameter have higher values. When correlation coefficient goes to zero, level crossing rate decreases and when correlation coefficient goes to one, MAD system becomes MID system.

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