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LEVEL CROSSING RATE OF MACRODIVERSITY SC RECEIVER WITH TWO MICRODIVERSITY SC RECEIVERS OVER GAMMA SHADOWED MULTIPATH FADING CHANNEL

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Abstract. *In this paper, macrodiversity SC (selection combining) receiver with two microdiversity SC receivers is considered. Received signal experiences Gamma long term fading resulting in signal envelope power variation and short term fading resulting in signal envelope variation. Macrodiversity SC receiver reduces long term fading effects on system performances and microdiversity SC receivers reduce short term fading effects on system performances. Expression level crossing rate of macrodiversity SC receiver output signal envelope is calculated. Mathematical expressions are presented graphically to show the influence of Nakagami-m parameter severity and Gamma parameter severity on level crossing rate of proposed system.*

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

1. INTRODUCTION

Short term fading and long term fading degrade system performances and limit channel capacity of wireless communication systems. Received signal is subjected simultaneously to both large scale fading and small scale fading. Small scale fading causes signal envelope power variation and large scale fading causes signal envelope power variation. There are several distributions that can be used to describe signal envelope variation and signal envelope power variation. Rayleigh and Nakagami-*m* distributions can be used to describe signal envelope variation in linear non-line-of-sight multipath fading channel. In nonlinear, non-line-of-sight multipath fading channel, small scale signal envelope variation can be accurately described by Weibull or α-μ distributions depending on the number of clusters in propagation environment. Signal envelope

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variation in linear line-of-sight environment can be described by using Rician or *k*-μ distributions [1-3]. In long term fading environment, large scale signal envelope power variation can be described with Gamma or log-normal distribution [4]. Nonlinear wireless channels are defined by the parameter nonlinearity α. For linear wireless systems parameter nonlinearity is α=0. Nonlinear wireless channels can be described with α-μ and α-k-μ distributions. There are several combining techniques that can be used to reduce multipath fading effects and shadowing effects on the performance of wireless communication systems. The most frequently used diversity techniques are maximal ratio combining (MRC), equal gain combining (EGC) and selection combining (SC) [5-7].

Diversity techniques can be used to reduce simultaneously the influence of long term fading and short term fading on system performance. Diversity system has macrodiversity receiver and two and more microdiversity receivers. Macrodiversity SC receiver reduces shadowing effects on outage probability and bit error rate and microdiversity receiver reduce multipath fading on outage probability and bit error rate [8, 9]. Second order statistics as average level crossing rate and average fade duration are important performance measures of wireless communication system. Average level crossing rate can be calculated as average value of the first derivative of random variable. Average fade duration of wireless communication system can be evaluated as ratio of outage probability and average level crossing rate [6]. Outage probability is defined as probability that output signal envelope falls below predetermined value [10].

There are more works in open technical literature considering second order statistics of wireless communication systems. In [11], macrodiversity SC receiver with two microdiversity MRC receivers is considered. Received signal is offended to Nakagami-*m* small scale fading and Gamma large scale fading resulting in SC receiver signal envelope variation and signal envelope power variation, respectively. SC receiver mitigates Gamma large scale fading effects on system performance and MRC receiver mitigates small scale fading effects on system performance. Level crossing rate (LCR) and average fade duration are calculated as closed form expressions. In [12], average level crossing rate and average fade duration of macrodiversity SC receiver with two microdiversity MRC receivers are evaluated.

In [13] and [14], average level crossing rate of macrodiversity SC receiver with two microdiversity SC receivers are evaluated. In [13], considered is the case when the received signal is subjected simultaneously to Gamma long term fading and Rayleigh short term fading. In [14], received signal is subjected simultaneously to Gamma long term fading and Rician short term fading.

In this paper macrodiversity SC receiver with two microdiversity SC receivers is considered. Received signal is subjected simultaneously to Gamma long term fading and Nakagami-m short term fading. Signal envelope at output of macrodiversity SC receiver is equal to the signal envelope of the output of the microdiversity structure which has high average power. In this paper we will observe the influence of macrodiversity correlation effects on LCR. Level of macrodiversity correlation depends on the separation between the macrodiversity combiners, on the surrounding terrain, the angle of arrival of the received signals, and various factors, and we will observe how its change affects changes of output signal LCR value.

In this paper expression for average level crossing rate of proposed diversity system is evaluated. To the best authors' knowledge, level crossing rate of macrodiversity SC receiver with two microdiversity SC receivers operating over Gamma shadowed Nakagami-*m* multipath fading environment is not reported in open technical literature. Numerical results are presented graphically to show Nakagami-*m* severity and Gamma severity on level crossing rate of wireless communication system. Obtained results can be applied in performance analysis and designing of wireless communication system in the presence of small scale Nakagami-*m* fading and large scale Gamma fading.

2. NAKAGAMI-M RANDOM VARIABLE LEVEL CROSSING RATE

Squared Nakagami-*m* random variable x can be written as sum of 2μ independent Gaussian random variables [13]. The first derivative of Gaussian random variable ($\dot{x}$) is a Gaussian random variable. Linear transformation of Gaussian random variables is Gaussian random variable. Therefore, the first derivative of Nakagami-*m* random variables is a Gaussian random variable. The mean of $\dot{x}$ is zero [15].

The joint probability density function of Nakagami-*m* random variables and its first derivative is

$$p_{x\dot{x}}(x\dot{x}) = p_{\dot{x}}(\dot{x}/x)\,p_x(x) = p_{\dot{x}}(\dot{x})\,p_x(x)\,, \tag{1}$$

where

$$p_x(x) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega}\right)^m x^{2m-1} e^{-\frac{m}{\Omega}x^2} \tag{2}$$

and

$$p_{\dot{x}}(\dot{x}) = \frac{1}{\sqrt{2\pi}\sigma_{\dot{x}}} e^{-\frac{\dot{x}^2}{2\sigma_{\dot{x}}^2}}\ . \tag{3}$$

The variance of $\dot{x}$ is

$$\sigma_{\dot{x}}^2 = \frac{1}{x^2}\left(x_1^2\sigma_{\dot{x}_1}^2 + x_2^2\sigma_{\dot{x}_2}^2 + \ldots + x_{2\mu}^2\sigma_{\dot{x}_{2\mu}}^2\right), \tag{4}$$

where

$$\sigma_{\dot{x}_1}^2 = \sigma_{\dot{x}_2}^2 = \ldots = \sigma_{\dot{x}_{2\mu}}^2 = 2\sigma^2\pi^2 f_m^2 = \pi^2 f_m^2 \frac{\Omega}{m}\ . \tag{5}$$

After substituting (2) and (3) in (1), the expression for joint probability density function of x and $\dot{x}$ becomes:

$$p_{x\dot{x}}(x\dot{x}) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega}\right)^m x^{2m-1} e^{-\frac{m}{\Omega}x^2} \frac{1}{\sqrt{2\pi}\sigma_{\dot{x}}} e^{-\frac{\dot{x}^2}{2\sigma_{\dot{x}}^2}}\ . \tag{6}$$

The level crossing rate of Nakagami-*m* random variable can be calculated as average value of the first derivative of a Nakagami-*m* random variable:

$$N_x = \int_0^\infty d\dot{x} \cdot \dot{x} \cdot p_{x\dot{x}}(x\dot{x}) =$$
$$= \frac{2}{\Gamma(m)} \left(\frac{m}{\Omega}\right)^m x^{2m-1} e^{-\frac{m}{\Omega}x^2} \int_0^\infty d\dot{x} \cdot \dot{x} \cdot \frac{1}{\sqrt{2\pi}\sigma_{\dot{x}}} e^{-\frac{\dot{x}^2}{2\sigma_{\dot{x}}^2}} = \quad . \tag{7}$$
$$= \frac{f_m \sqrt{2\pi}}{\Gamma(m)} \left(\frac{m}{\Omega}\right)^{m-\frac{1}{2}} x^{2m-1} e^{-\frac{m}{\Omega}x^2}$$

The expression for level crossing rate of Nakagami-*m* random variable can be applied in performance analysis of wireless communication system operating over Nakagami-*m* multipath fading environment.

3. Level Crossing Rate of SC Receiver Output Signal Envelope

A wireless communication system with dual SC receiver operating over Nakagami-*m* multipath fading channel is considered. Signal envelopes at inputs of SC receiver are denoted with y_1 and y_2 and SC receiver output signal envelope is denoted with y. The joint probability density function of SC receiver output signal envelope and the first derivative of SC receiver output signal envelope for identical and independent fading:

$$p_{y\dot{y}}(y\dot{y}) = p_{y_1\dot{y}_1}(y\dot{y}) F_{y_2}(y) + p_{y_2\dot{y}_2}(y\dot{y}) F_{y_1}(y) = 2 p_{y_1\dot{y}_1}(y\dot{y}) F_{y_2}(y) \ , \tag{8}$$

where $p_{y_1\dot{y}_1}(y\dot{y})$ is given with (7) and $F_{y_2}(y)$ is the cumulative distribution of Nakagami-*m* random variable [6]:

$$F_{y_2}(y) = \frac{1}{\Gamma(m)} \gamma\left(m, \frac{m}{\Omega} y^2\right) \ . \tag{9}$$

Level crossing rate of SC receiver output signal envelope is:

$$N_y = \int_0^\infty p_{y\dot{y}}(y\dot{y}) \dot{y} d\dot{y} =$$
$$= 2F_{y_2}(y) \int_0^\infty p_{y_1\dot{y}_1}(y\dot{y}) \dot{y} d\dot{y} = 2F_{y_2}(y) N_x(y) = \quad . \tag{10}$$
$$= \frac{2 f_m \sqrt{2\pi}}{\Gamma(m)^2} \left(\frac{m}{\Omega}\right)^{m-\frac{1}{2}} y^{2m-1} e^{-\frac{m}{\Omega}y^2} \gamma\left(m, \frac{m}{\Omega} y^2\right)$$

The expression for level crossing rate can be used for evaluation of average fade duration of wireless communication system with dual SC receiver operating over Nakagami-*m* multipath fading environment.

4. MACRODIVERSITY SC RECEIVER WITH TWO MICRODIVERSITY SC RECEIVERS

Level crossing rate of signal at output of macrodiversity SC receiver with two microdiversity dual SC receiver is calculated, short term Nakagami-*m* fading and long term Gamma fading are presented at inputs of microdiversity SC receivers. SC receiver on macro level is used to reduce long term fading effects on system performance and SC receivers on micro level are used to reduce short term fading effects on system performance. Signals envelopes at inputs of the first microdiversity SC receiver are denoted with y_{11} and y_{12}, signals envelope at inputs of the second microdiversity SC receiver are denoted with y_{21} and y_{22}. Signals envelopes at output of the first and the second microdiversity SC receivers are denoted with y_1 and y_2, respectively. Signal at output of macrodiversity SC receiver is denoted with y. The level crossing rate of signal envelope at outputs of receivers on micro level N_{y1} and N_{y2} can be calculated as in (10):

$$N_{y_i} = \frac{2 f_m \sqrt{2\pi}}{\Gamma(m)^2} \left(\frac{m}{\Omega_i}\right)^{m-\frac{1}{2}} y_i^{2m-1} e^{-\frac{m}{\Omega_i} y_i^2} \gamma\left(m, \frac{m}{\Omega_i} y_i^2\right), \tag{11}$$

where Ω_i are powers of signals envelopes at inputs in the first and the second SC receivers on micro level. Gamma long term fading causes signal envelope power variation. Signal envelopes powers at inputs in receivers on micro level are correlated. Signal envelope powers Ω_1 and Ω_2 follow Gama distribution:

$$p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) = \frac{1}{\Gamma(c)(1-\rho^2)\rho^{\frac{c-1}{2}} \Omega_0^{c+1}} (\Omega_1\Omega_2)^{\frac{c-1}{2}} e^{-\frac{\Omega_1+\Omega_2}{\Omega_0(1-\rho^2)}} I_{c-1}\left(\frac{2\rho}{\Omega_0(1-\rho^2)} (\Omega_1\Omega_2)^{\frac{1}{2}}\right) \tag{12}$$

where c is fading severity, ρ is correlation coefficient and Ω_o is average power of Ω_1 and Ω_2.

The level crossing rate of macrodiversity SC receiver output signal envelope is equal to the level crossing rate of signal envelope of the output of the microdiversity structure which has high average power. Therefore, level crossing rate of macrodiversity SC receiver output signal envelope is:

$$\begin{aligned} N_y &= \int_0^\infty d\Omega_1 \int_0^{\Omega_1} d\Omega_2 N_{y_1/\Omega_1} p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) + \int_0^\infty d\Omega_2 \int_0^{\Omega_2} d\Omega_1 N_{y_2/\Omega_2} p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) = \\ &= 2\int_0^\infty d\Omega_1 \int_0^{\Omega_1} d\Omega_2 N_{y_1/\Omega_1} p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) = \\ &= \frac{4 f_m \sqrt{2\pi}}{\Gamma(m)^2} m^{m-\frac{1}{2}} y^{2m-1} \frac{1}{\Gamma(c)(1-\rho^2)\rho^{\frac{c-1}{2}} \Omega_0^{c+1}} \sum_{i=0}^{\infty} \left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{c+2i-1} \times \\ &\times \frac{(\Omega_0(1-\rho^2))^{c+i}}{\Gamma(c+i)i!} \int_0^\infty d\Omega_1 \Omega_1^{-m+c+i-\frac{1}{2}} e^{-\frac{my^2}{\Omega_1} - \frac{\Omega_1}{\Omega_0(1-\rho^2)}} \gamma\left(m, \frac{my^2}{\Omega_1}\right) \gamma\left(c+i, \frac{\Omega_1}{\Omega_0(1-\rho^2)}\right) \end{aligned} \tag{13}$$

The incomplete Gamma function $\gamma(n,x)$ is [16, 17]:

$$\gamma(n,x)=\frac{1}{n}x^{n}e^{-x}\,{}_1F_1(1,n+1,x)=\frac{1}{n}x^{n}e^{-x}\sum_{i=0}^{\infty}\frac{x^{i}}{(n+1)_i}\ . \tag{14}$$

where $(a)_n$ denoting the Pochhammer symbol.

After substituting (14) in (13), the expression for level crossing rate becomes:

$$\begin{aligned}N_y=&\frac{4f_m\sqrt{2\pi}}{\Gamma(m)^2}m^{m-\frac{1}{2}}y^{2m-1}\frac{1}{\Gamma(c)(1-\rho^2)\rho^{\frac{c-1}{2}}\Omega_0^{c+1}}\times\\&\times\sum_{i=0}^{\infty}\left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{c+2i-1}\frac{(\Omega_0(1-\rho^2))^{c+i}}{\Gamma(c+i)i!}\times\\&\times\int_0^{\infty}d\Omega_1\Omega_1^{-m+c+i-\frac{1}{2}}e^{-\frac{my^2}{\Omega_1}-\frac{\Omega_1}{\Omega_0(1-\rho^2)}}\frac{1}{m}\left(\frac{my^2}{\Omega_1}\right)^{m}\times\\&\times e^{-\frac{my^2}{\Omega_1}}\sum_{j=0}^{\infty}\frac{\left(\frac{my^2}{\Omega_1}\right)^{j}}{(m+1)_j}\frac{1}{c+i}\left(\frac{\Omega_1}{\Omega_0(1-\rho^2)}\right)^{c+i}e^{-\frac{\Omega_1}{\Omega_0(1-\rho^2)}}\sum_{k=0}^{\infty}\frac{\left(\frac{\Omega_1}{\Omega_0(1-\rho^2)}\right)^{k}}{(c+i+1)_k}\end{aligned} \tag{15}$$

After processing and solving integral in (15) [17], expression for normalized level crossing rate of macrodiversity SC receiver output signal envelope becomes:

$$\begin{aligned}N_y=&\frac{4f_m\sqrt{2\pi}}{\Gamma(m)^2}m^{m-\frac{1}{2}}y^{2m-1}\frac{1}{\Gamma(c)(1-\rho^2)\rho^{\frac{c-1}{2}}\Omega_0^{c+1}}\times\\&\times\sum_{i=0}^{\infty}\left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{c+2i-1}\frac{(\Omega_0(1-\rho^2))^{c+i}}{\Gamma(c+i)i!}\times\\&\times\frac{1}{m}\frac{1}{c+i}\sum_{j=0}^{\infty}\frac{(my^2)^{m+j}}{(m+1)_j}\sum_{k=0}^{\infty}\frac{1}{(c+i+1)_k}\frac{1}{(\Omega_0(1-\rho^2))^{c+i+k}}\times\\&\times(my^2\Omega_0(1-\rho^2))^{-m+c+i-\frac{j}{2}+\frac{k}{2}+\frac{1}{4}}K_{-2m+2c+2i-j+k+\frac{1}{2}}\left(2\sqrt{\frac{4my^2}{\Omega_0(1-\rho^2)}}\right)\end{aligned} \tag{16}$$

where $K_n(x)$ is the modified Bessel function of the second kind, order n and argument x.

In Table 1, the number of terms to be summed in order to achieve accuracy at the desired significant digit is depicted. As we can see from the table, how increases the correlation coefficient increases the number of terms to be summed in order to achieve accuracy at the 4th significant digit. For higher values of parameter m, smaller number of terms to achieve accuracy at the 4th significant digit is required.

Table 1 Terms need to be summed in the expression for cumulative distribution function to achieve accuracy at the significant digit presented in the brackets

c=1, y=1, Ω_0=1	m=1 (4th)	m=1.5 (4th)	m=2 (4th)
ρ=0.2	157	143	129
ρ=0.4	161	148	132
ρ=0.6	163	149	134
ρ=0.8	164	150	135

5. Numerical Results

In Fig. 1 and Fig. 2, the normalized level crossing rate of macrodiversity SC receiver output signal envelope is plotted versus macrodiversity SC receiver output signal envelope for several values of Gamma fading severity and several values Gamma fading correlation coefficient. For lower values of SC receiver output signal envelope, level crossing rate increases as SC receiver output signal envelope increases and for higher values of SC receiver output signal envelope, level crossing rate decreases as SC receivers output signal envelope increases. The outage probability of diversity system is better for lower values of level crossing rate.

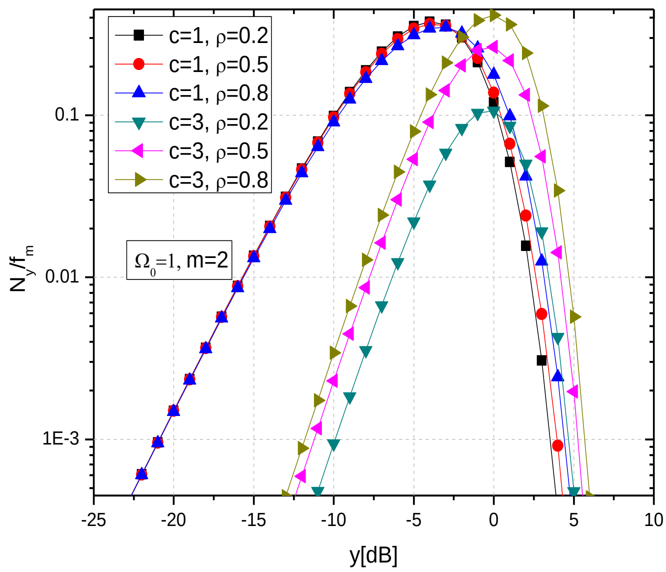

Fig. 1 Level crossing rate of macrodiversity SC receiver output signal envelope for different values of correlation coefficient ρ

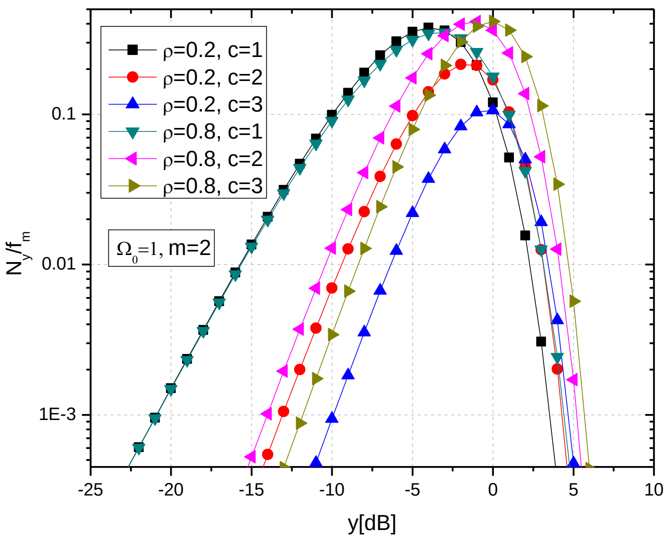

Fig. 2 Level crossing rate of macrodiversity SC receiver output signal envelope for different values of Gamma shadowing severity parameter *c*

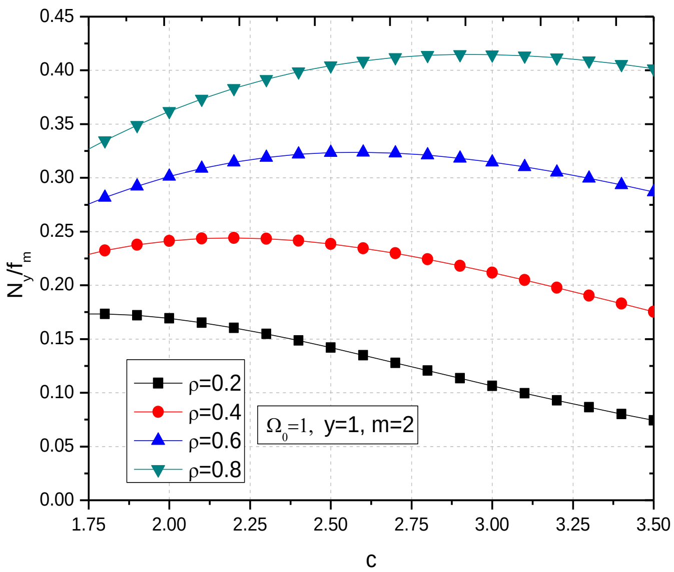

Fig. 3 Level crossing rate of macrodiversity SC receiver output signal envelope versus Gamma shadowing severity parameter *c*

Level crossing rate increases as correlation coefficient increases. Diversity technique provides the best performance when correlation coefficient is zero or when signal envelopes at inputs are independent. Level crossing rate increases as Gamma fading severity increases. The influence of correlation coefficient on level crossing rate is greater for higher values of Gamma fading severity.

Normalized values of average level crossing rate of macrodiversity SC receiver output signal envelope versus Gamma shadowing severity parameter c for several values of correlation coefficient ρ are plotted in Fig. 3. Average level crossing rate decreases as shadowing severity decreases. Shadowing severity has higher effect on average level crossing rate for lower values of correlation coefficient.

In Fig. 4, the normalized level crossing rate versus Nakagami-m parameter m for several values correlation coefficient ρ is plotted. The system performance is better for higher values of parameter m. Average level crossing rate decreases as parameter m decreases. When parameter m goes to infinity, Nakagami-m channel becomes no fading channel.

Normalized average level crossing rate of macro SC receiver output signal envelope as a function of correlation coefficient for several values of shadowing severity is plotted in Fig. 5. Average level crossing rate increases as correlation coefficient increases. When correlation coefficient goes to 1, the same signal occurs at both stations. The system performance is worse when correlation coefficient increases.

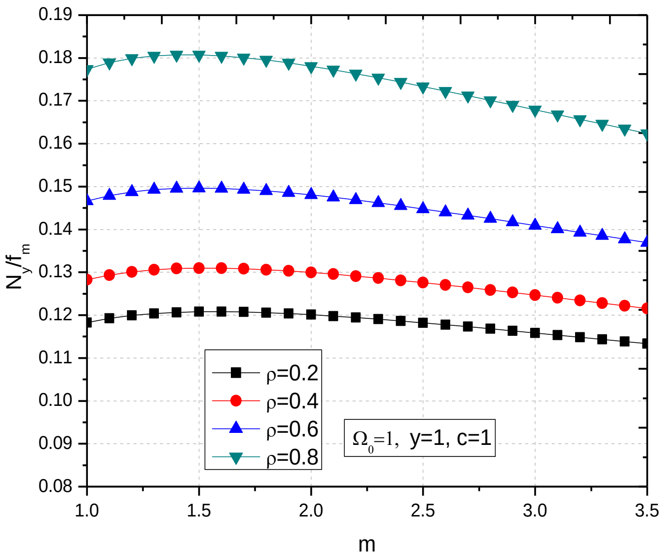

Fig. 4 Level crossing rate of macrodiversity SC receiver output signal envelope versus parameter *m*

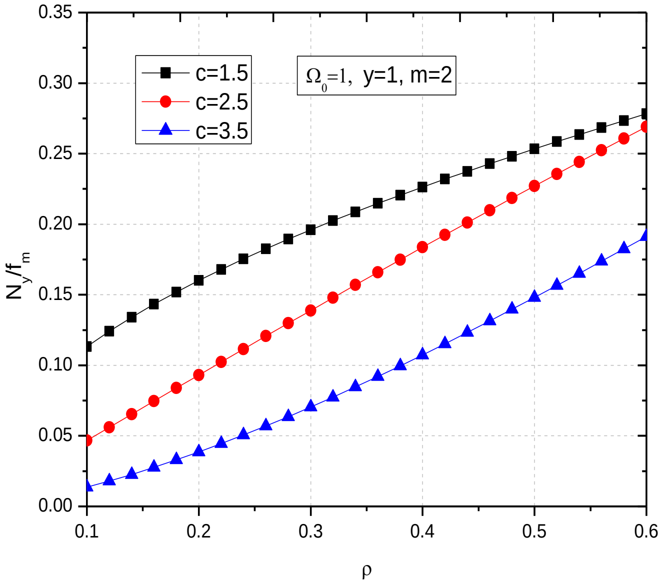

Fig. 5 Level crossing rate of macrodiversity SC receiver output signal envelope versus correlation coefficient ρ

The average level crossing rate (LCR) is measure that clearly reflect the performances of fading affected system and is used for modeling of wireless communication systems. LCR is related to criterion used to assess error probability of packets of distinct length, and to determinate parameters of equivalent channel, modeled by a *Markov chain* with defined number of states. LCR is used for determining of the rate at which the envelope of the received signal crosses a specified defined level [13].

6. Conclusion

Macrodiversity SC receiver with two microdiversity SC receivers is considered. Received signal experiences Nakagami-m short term fading and Gamma long term fading resulting in system performance degradation. Small scale fading causes signal envelope variation and large scale fading causes signal envelope power variation. SC receivers on micro level reduce Nakagami-m short term fading on system performances. SC receivers on macro level reduce long term fading effects on system performance. There are other distributions can be used to describe signal envelope variation and signal envelope power variation in fading channel.

In this paper, signal envelope variation is described by using Nakagami-m distribution and long scale signal envelope power variation is described by using Gamma distribution. Second order statistics performance measures are average level crossing rate and average fade duration of wireless communication system. In this paper, level crossing rate of macrodiversity SC receiver output signal envelope is evaluated. Level crossing rate of macrodiversity SC receiver output signal envelope is calculated as average value of the first derivative of macrodiversity SC receiver output signal envelope.

By using m=1 in obtained expression for level crossing rate of signal envelope can be described the expression for level crossing rate of signal envelope at output diversity system operating over Gamma shadowed Rayleigh multipath fading environment. Numerical expression is plotted to show Nakagami-*m* severity parameter effects and Gamma severity parameter effects on level crossing rate. System performance is better for lower values of level crossing rate. Level crossing rate increases as Nakagami-*m* severity parameter decreases. For lower values of macrodiversity SC receiver output signal envelope, level crossing rate increases as macrodiversity SC receiver output signal envelope increases. For higher values of macrodiversity SC receiver output signal envelope level crossing rate decreases as SC receiver output signal envelope increases.

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