THE LCR OF WIRELESS MACRODIVERSITY SSC RECEIVER IN THE PRESENCE OF GAMMA SHADOWED KAPPA-MU FADING

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ABSTRACT

Wireless mobile macrodiversity (MaD) radio system with switch and stay (SSC) receiver and two microdiversity (MiD) selection combining (SC) branches operating over Gamma shadowed Kappa-Mu (k-μ) multipath fading environment is considered. Novel, one-folded integral expression for average level crossing rate (LCR) of MaD SSC receiver output signal envelope is obtained. Numerical results of the proposed model are presented and discussed in relation to the system model parameters.

Key words: LCR, MaD, MiD, multipath, shadowing.

1. INTRODUCTION

Macrodiversity (MaD) system consisting of MaD receiver and two or more microdiversity (MiD) branches is often proposed in the literature ((Shankar, 2009), (Mukherjee & Avidor, 2003), (Basnayaka et al., 2013).

Moreover, multipath fading can be mitigated by MiD receivers at single BSs (base stations) while shadowing can be mitigated by MaD receiver combining signals from two or more BSs. It is important to note that multipath fading is caused by physical phenomena such as reflection, refraction and scattering of radio waves while shadowing is caused by obstacles between transmitter and receiver.

MaD switch and stay (SSC) system with MiD selection combining (SC) as well as MaD SC system with MiD maximal ratio combining (MRC) or SC can be efficiently applied in composite fading environment to improve performances of wireless communication system as shown in((Stefanović, 2015), (Djosic et al., 2016), (Stefanović et al., 2016), (Panić et al., 2011), (Stamenović et al., 2014)).

The Kappa-Mu ($κ$-$μ$) distribution describes signal envelope variation in line-of-sight (LoS) multipath fading channels when signals propagate in the environment with two or more clusters. Parameter k is known as Rician factor and can be calculated as the ratio of dominant components power and scattering components power while parameter $μ$ is related to the number of clusters in the propagation environment. Moreover, kappa-mu is general distribution, which

means that for different values of $κ$ and $μ$, Rayleigh, Rice and Nakagami-m distributions can be derived. Moreover, this distribution fits well with experimental data and is often applied in multipath environment ((Yacoub, 2007), (Paris, 2014), (Stefanović et al., 2015)).

Log-normal distribution and Gamma distribution are used for the purpose of describing shadowing in wireless communication channel.

In this paper, MaD system has been modeled with switch and stay (SSC) receiver at macro level and two dual branch selection combining (SC) at micro level, since its relatively low implementation complexity. Morover, SC and SSC are often considered diversity techniques ((Zhang et al., 2014), (Milic et al., 2016), (Stefanovic et al., 2013), (Zhao et al., 2015)). Gamma distribution is proposed, with the tendency of obtaining closed form solutions due to its mathematical tractability. Moreover, the average level crossing rate (LCR) of MaD SSC receiver output signal envelope in the presence of Gamma shadowed k-$μ$ multipath fading is efficiently calculated in the form of the sum of one-folded integral. Numerical results are presented graphically and the effect of Rician factor, multipath fading severity parameter, shadowing severity parameter, correlation coefficient and threshold of SSC on the proposed MaD model are examined.

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2. SYSTEM MODEL

The MaD system with two MiD SC parts under the influence of Gamma shadowed k-μ multipath fading as shown on Fig. 1. is considered. Operation is the following: when signal envelope average power at the inputs of the first SC, Ω_1 is higher than a specified threshold, Ω_T, MaD SSC selects the first SC to process the signal to the receiver. Contrary, when Ω_1 is lower than Ω_T, SSC selects the second MiD SC to provide the signal path. At the micro level, MiD SC selects the branch with the highest signal envelope power to provide the signal to receiver.

Input signal envelopes for the first MiD path are denoted with y_{11} and y_{12}, while the second MiD input signal envelopes are denoted with y_{21} and y_{22}. Further, the output signal envelopes of the first and second MiD combiners are y_1 and y_2, respectively, while signal envelope at the output of MaD SSC is denoted with y.
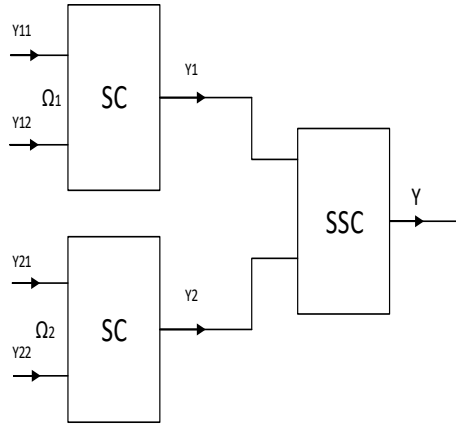

Fig. 1 The MaD system with MaD SSC structure and two MiD SC parts.

Probability density function (PDF) of κ-μ signal envelope at the inputs of the first SC are respectively (Panic et al., 2013):

$$p_{y_{1i}}(y_{1i}) = \frac{2\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}} e^{k\mu} \Omega_1^{\frac{\mu+1}{2}}} y_{1i}{}^{\mu} I_{\mu-1}\left(2\mu\sqrt{\frac{k(k+1)}{\Omega_1}}\right)\cdot$$
$$\cdot e^{-\frac{\mu(k+1)}{\Omega_1}y_{1i}{}^2}, \quad i=1,2. \tag{1}$$

where, κ is Rice factor, μ is fading severity factor, Ω_1 is related to the local mean power of y_{1i} and $I_\nu(\cdot)$ is the modified Bessel function of the first kind and order ν (Stefanovic et al., 2013). The $I_\nu(\cdot)$ can be transformed by utilization (Gradshteyn & Ryzhik,

2000), so that the CDF expression of k-μ signal envelope at the inputs of the first SC can be expressed as (Stüber, 1996):

$$F_{y_{1i}}(y_{1i}) = \int_0^{y_{1i}} p_{y_{1i}}(t)\,dt = \frac{2\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}} e^{k\mu} \Omega_1^{\frac{\mu+1}{2}}}\cdot$$
$$\cdot \sum_{j=1}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_1}}\right)^{2j+\mu-1} \frac{1}{2}\left(\frac{\Omega_1}{\mu(k+1)}\right)^{j+\mu}\cdot \tag{2}$$
$$\cdot \frac{1}{j!\,\Gamma(j+\mu)}\gamma\left(j+\mu,\frac{\mu(k+1)}{\Omega_1}y_{1i}{}^2\right).$$

where Ω_1 is signal envelope average power at input of first micro-diversity SC and $\gamma(m,x)$ is incomplete Gamma function. CDF of the first SC output signal envelope is:

$$F_{y_1}(y_1) = F_{y_{11}}(y_1)F_{y_{12}}(y_1) = \left(\frac{2\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}} e^{k\mu} \Omega_1^{\frac{\mu+1}{2}}}\right)^2\cdot$$
$$\cdot \sum_{i_1=1}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_1}}\right)^{2i_1+\mu-1} \frac{1}{2}\left(\frac{\Omega_1}{\mu(k+1)}\right)^{i_1+\mu} \frac{1}{i_1!\,\Gamma(i_1+\mu)}\cdot$$
$$\cdot \gamma\left(i_1+\mu,\frac{\mu(k+1)}{\Omega_1}y_1{}^2\right)\sum_{i_2=1}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_1}}\right)^{2i_2+\mu-1}\cdot$$
$$\cdot \frac{1}{2}\left(\frac{\Omega_1}{\mu(k+1)}\right)^{i_2+\mu} \frac{1}{i_2!\,\Gamma(i_2+\mu)}\gamma\left(i_2+\mu,\frac{\mu(k+1)}{\Omega_1}y_1{}^2\right).$$
$$\tag{3}$$

Similarly, CDF of SC output k-μ random variable y_2 is:

$$F_{y_2}(y_2) = F_{y_{21}}(y_2)F_{y_{22}}(y_2) = \left(\frac{2\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}} e^{k\mu} \Omega_2^{\frac{\mu+1}{2}}}\right)^2\cdot$$
$$\cdot \sum_{i_1=1}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_2}}\right)^{2i_1+\mu-1} \frac{1}{2}\left(\frac{\Omega_2}{\mu(k+1)}\right)^{i_1+\mu} \frac{1}{i_1!\,\Gamma(i_1+\mu)}\cdot$$
$$\cdot \gamma\left(i_1+\mu,\frac{\mu(k+1)}{\Omega_2}y_2{}^2\right)\sum_{i_2=1}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_2}}\right)^{2i_2+\mu-1}\cdot$$
$$\cdot \frac{1}{2}\left(\frac{\Omega_2}{\mu(k+1)}\right)^{i_2+\mu} \frac{1}{i_2!\,\Gamma(i_2+\mu)}\gamma\left(i_2+\mu,\frac{\mu(k+1)}{\Omega_2}y_2{}^2\right).$$
$$\tag{4}$$

Signal envelope average power at inputs of two MiD SC structures, Ω_1 and Ω_2 are Gamma distributed ((Xekalaki et al, 2003), (Yue et al., 2001)):

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

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

$$= \frac{1}{\Gamma(c)(1-\rho^2)\rho^{c-1}\Omega_0^{c+1}} \sum_{i=0}^{\infty}\left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i+c-1} \cdot \tag{5}$$

$$\cdot \frac{1}{i!\Gamma(i+c)}\Omega_1^{i+c-1}\Omega_2^{i+c-1}e^{-\frac{\Omega_1+\Omega_2}{\Omega_0(1-\rho^2)}}.$$

where ρ is correlation coefficient of the shadowing process, c is shadowing parameter and Ω_0 is mean value of Ω_1 or Ω_2.

3. LCR OF MaD SSC RECEIVER OUTPUT SIGNAL

LCR of Kappa-Mu random variable y_{1i} is (Panic et al., 2003):

$$N_{y_{1i}} = \int_0^{\infty} \dot{y}\, p_{y_{1i}\dot{y}_{1i}}(y_{1i}\dot{y}_{1i})d\,\dot{y}_{1i} =$$

$$= \frac{\sqrt{2\pi}f_m 2\mu^{\frac{1}{2}}(k+1)^{\frac{\mu}{2}}}{k^{\frac{\mu-1}{2}}e^{k\mu}\Omega_1^{\frac{\mu}{2}}} \sum_{i_1=1}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_1}}\right)^{2i_1+\mu-1} \cdot \tag{6}$$

$$\cdot \frac{1}{i_1!\Gamma(i_1+\mu)} y_{1i}^{2i_1+2\mu-1}e^{-\frac{\mu(k+1)}{\Omega_1}y_{1i}^{2}},\ i=1,2.$$

where $p_{y_{1i}\dot{y}_{1i}}\ y_{1i}\dot{y}_{1i}$ is joint probability density function (JPDF) of y_{1i} and its derivative, f_m is maximal Doppler frequency.

Similarly, LCR of random variable y_{2i} is:

$$N_{y_{2i}} = \frac{\sqrt{2\pi}f_m 2\mu^{\frac{1}{2}}(k+1)^{\frac{\mu}{2}}}{k^{\frac{\mu-1}{2}}e^{k\mu}\Omega_2^{\frac{\mu}{2}}} \sum_{i_1=1}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_2}}\right)^{2i_1+\mu-1} \cdot$$

$$\cdot \frac{1}{i_1!\Gamma(i_1+\mu)} y_{2i}^{2i_1+2\mu-1}e^{-\frac{\mu(k+1)}{\Omega_2}y_{2i}^{2}},\ i=1,2. \tag{7}$$

Since the fading is identical and independent, JPDF of the MiD SC output signal envelope y_1 and its first derivative is:

$$p_{y_1\dot{y}_1}(y_1\dot{y}_1) = p_{y_{11}\dot{y}_{11}}(y_1\dot{y}_1)F_{y_{12}} + p_{y_{12}\dot{y}_{12}}(y_1\dot{y}_1)F_{y_{11}}(y_1) =$$
$$= 2p_{y_{11}\dot{y}_{11}}(y_1\dot{y}_1)F_{y_{12}}(y_1). \tag{8}$$

The LCR of the first MiD SC output signal envelope y_1 is:

$$N_{y_1} = \int_0^{\infty} \dot{y}_1 p_{y_1\dot{y}_1}(y_1\dot{y}_1)d\,\dot{y}_1 = 2F_{y_{12}}(y_1)N_{y_{11}} =$$

$$= \frac{2\sqrt{2\pi}f_m \mu^{\frac{1}{2}}(k+1)^{\frac{\mu}{2}}}{k^{\frac{\mu-1}{2}}e^{k\mu}\Omega_1^{\frac{\mu}{2}}} \sum_{i_1=1}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_1}}\right)^{2i_1+\mu-1} \cdot$$

$$\cdot \frac{1}{i_1!\Gamma(i_1+\mu)} x_1^{2i_1+2\mu-1}e^{-\frac{\mu(k+1)}{\Omega_1}y_1^2} \frac{\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}}e^{k\mu}\Omega_1^{\frac{\mu+1}{2}}} \cdot \tag{9}$$

$$\cdot \sum_{i_2=1}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_1}}\right)^{2i_2+\mu-1}\left(\frac{\Omega_1}{\mu(k+1)}\right)^{i_2+\mu} \cdot$$

$$\cdot \frac{1}{i_2!\Gamma(i_2+\mu)}\gamma\left(i_2+\mu, \frac{\mu(k+1)}{\Omega_1}y_1^2\right).$$

The average level crossing rate of the second micro-diversity SC output signal is:

$$N_{x_2} = \frac{2\sqrt{2\pi}f_m \mu^{\frac{1}{2}}(k+1)^{\frac{\mu}{2}}}{k^{\frac{\mu-1}{2}}e^{k\mu}\Omega_2^{\frac{\mu}{2}}} \sum_{i_1=1}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_1}}\right)^{2i_1+\mu-1} \cdot$$

$$\cdot \frac{1}{i_1!\Gamma(i_1+\mu)} x_2^{2i_1+2\mu-1}e^{-\frac{\mu(k+1)}{\Omega_2}y_2^2} \frac{\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}}e^{k\mu}\Omega_2^{\frac{\mu+1}{2}}} \cdot \tag{10}$$

$$\cdot \sum_{i_2=1}^{\infty}\left(\mu\sqrt{\frac{k(k+1)}{\Omega_2}}\right)^{2i_2+\mu-1}\left(\frac{\Omega_2}{\mu(k+1)}\right)^{i_2+\mu} \cdot$$

$$\cdot \frac{1}{i_2!\Gamma(i_2+\mu)}\gamma\left(i_2+\mu, \frac{\mu(k+1)}{\Omega_2}y_2^2\right).$$

LCR of MaD SSC output signal envelope is equal to LCR of the first MiD SC output signal envelope when the first MiD SC provides signal to mobile user and the total power at its inputs is higher than predetermined threshold or when the second MiD SC receiver provides signal to the mobile user and the total power at its inputs is lower than the threshold. On the other hand, LCR of MaD SSC output signal envelope is equal to LCR of the second MiD SC output signal envelope when the second MiD SC provides the signal to mobile user and the total power at its inputs is higher than the predetermined threshold or when the first MiD SC provides the mobile user and the total power at its input is lower than the predetermined threshold.

Accordingly, the LCR of MaD SSC output signal envelope is:

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$$N_x = \frac{1}{2}\int\limits_{\Omega_T} d\Omega_1 \int\limits_0^\infty N_{y|\Omega_1} p_{\Omega_1\Omega_2}(\Omega_1\Omega_2)d\Omega_2 +$$

$$+ \frac{1}{2}\int\limits_0^{\Omega_T} d\Omega_1 \int\limits_0^\infty N_{y|\Omega_2} p_{\Omega_1\Omega_2}(\Omega_1\Omega_2)d\Omega_2 +$$

$$+ \frac{1}{2}\int\limits_{\Omega_T} d\Omega_2 \int\limits_0^\infty N_{y|\Omega_2} p_{\Omega_1\Omega_2}(\Omega_1\Omega_2)d\Omega_1 +$$

$$+ \frac{1}{2}\int\limits_0^{\Omega_T} d\Omega_2 \int\limits_0^\infty N_{y|\Omega_1} p_{\Omega_1\Omega_2}(\Omega_1\Omega_2)d\Omega_1 = \qquad (11)$$

$$= \int\limits_{\Omega_T} d\Omega_1 \int\limits_0^\infty N_{y|\Omega_1} p_{\Omega_1\Omega_2}(\Omega_1\Omega_2)d\Omega_2 +$$

$$+ \int\limits_0^{\Omega_T} d\Omega_2 \int\limits_0^\infty N_{y|\Omega_2} p_{\Omega_1\Omega_2}(\Omega_1\Omega_2)d\Omega_1 = I_1 + I_2.$$

where $N_{y|\Omega_1}$ and $N_{y|\Omega_2}$ LCR at the first and second input of SSC obtained in (9) and (10), respectively and $p_{\Omega_1\Omega_2}$ $\Omega_1\Omega_2$ is Gamma distribution already given in (5).

The LCR of MaD system with MaD SSC receiver and two MiD SC branches can be obtained by solving the following integrals (Gradshteyn & Ryzhik, 2000):

$$I_1 = \int\limits_{\Omega_T}^\infty d\Omega_1 \int\limits_0^\infty d\Omega_2 N_{y_1}(y|\Omega_1) p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) =$$

$$= \frac{2\sqrt{2\pi} f_m \mu^{\frac{3}{2}}(k+1)^{\mu+\frac{1}{2}}}{k^{\mu-1}e^{2k\mu}} \sum_{j_1=0}^\infty \mu\sqrt{k(k+1)}^{\,2j_1+\mu-1} \cdot$$

$$\cdot \frac{1}{j_1!\Gamma(j_1+\mu)} y^{2j_1+2\mu-1} \sum_{j_2=0}^\infty \mu\sqrt{k(k+1)}^{\,2j_2+\mu-1} \cdot$$

$$\cdot \frac{1}{j_2!\Gamma(j_2+\mu)}\left(\frac{1}{\mu(k+1)}\right)^{j_2+\mu} \frac{1}{\Gamma(c)(1-\rho^2)\rho^{c-1}\Omega_0^{c+1}} \cdot (12)$$

$$\cdot \sum_{j_3=0}^\infty \left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2j_3+c-1} \frac{1}{j_3!\Gamma(j_3+c)}(\Omega_0(1-\rho^2))^{j_3+c} \cdot$$

$$\cdot \Gamma(i_3+c)\int\limits_{\Omega_T}^\infty \Omega_1^{j_3+c-\frac{1}{2}-\mu-j_1} \gamma\left(j_2+\mu, \frac{\mu(k+1)}{\Omega_1}y^2\right) \cdot$$

$$\cdot e^{-\frac{\mu(k+1)}{\Omega_1}y^2 - \frac{\Omega_1}{\Omega_0(1-\rho^2)}} d\Omega_1.$$

Integral I_2 is (Gradshteyn & Ryzhik, 2000):

$$I_2 = \int\limits_0^{\Omega_T} d\Omega_2 \int\limits_0^\infty d\Omega_1 N_{x_1}(x|\Omega_1) p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) =$$

$$= \frac{2\sqrt{2\pi} f_m \mu^{\frac{3}{2}}(k+1)^{\mu+\frac{1}{2}}}{k^{\mu-1}e^{2k\mu}} \sum_{j_1=0}^\infty \mu\sqrt{k(k+1)}^{\,2j_1+\mu-1} \cdot$$

$$\cdot \frac{1}{j_1!\Gamma(j_1+\mu)} y^{2j_1+2\mu-1} \sum_{j_2=0}^\infty \mu\sqrt{k(k+1)}^{\,2j_2+\mu-1} \cdot$$

$$\cdot \frac{1}{j_2!\Gamma(j_2+\mu)}\left(\frac{1}{\mu(k+1)}\right)^{j_2+\mu} \frac{1}{\Gamma(c)(1-\rho^2)\rho^{c-1}\Omega_0^{c+1}} \cdot$$

$$\cdot \sum_{j_3=0}^\infty \left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2j_3+c-1} \frac{1}{j_3!\Gamma(j_3+c)}(\Omega_0(1-\rho^2))^{j_3+c} \cdot (13)$$

$$\cdot \gamma\left(i_3+c, \frac{\Omega_T}{\Omega_0(1-\rho^2)}\right)\int\limits_{\Omega_T}^\infty \Omega_1^{j_3+c-\frac{1}{2}-\mu-j_1} \cdot$$

$$\cdot \gamma\left(j_2+\mu, \frac{\mu(k+1)}{\Omega_1}y^2\right) e^{-\frac{\mu(k+1)}{\Omega_1}y^2 - \frac{\Omega_1}{\Omega_0(1-\rho^2)}} d\Omega_1.$$

4. NUMERICAL RESULTS

Average level crossing rate (LCR) is important second order performance measure of wireless communication system, which determines the number of signal threshold crossings in positive going direction.
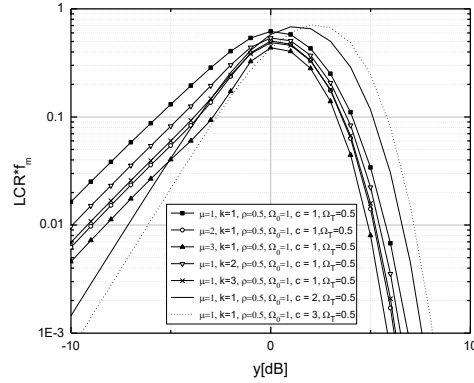

Fig. 2. Normalized LCR of MaD SSC receiver for several values of parameter mu, kappa and c and constant values of ρ, Ω_0, and Ω_T.

Figure 2. presents normalized LCR of MaD SSC system for various values of fading severity parameters μ, Rice factor k shadowing severity c, and constant values of correlation parameter ρ, average power Ω_0 and threshold value Ω_T. It is evident that LCR increases for lower values of y, reaches its maximum, and then decreases for higher values of y. It can been seen that by increasing parameter μ and k, it comes to the improvement of the performances of MaD SSC system, since LCR decreases. For lower values of y, LCR decreases as parameter c increases while for higher values of y, LCR increases as parameter c increases. Moreover, parameter c has greater impact on LCR then parameter μ and k.
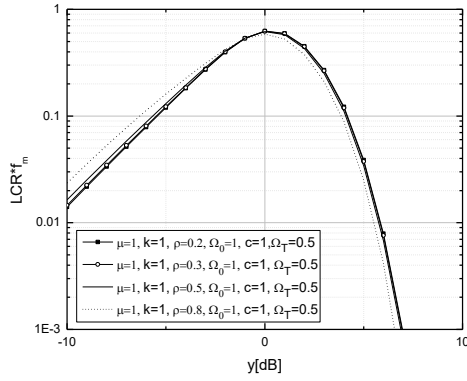
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Fig. 3. Normalized LCR of MaD SSC receiver for constant values of mu, kappa, c, Ω_0 and Ω_T and several values of ρ.
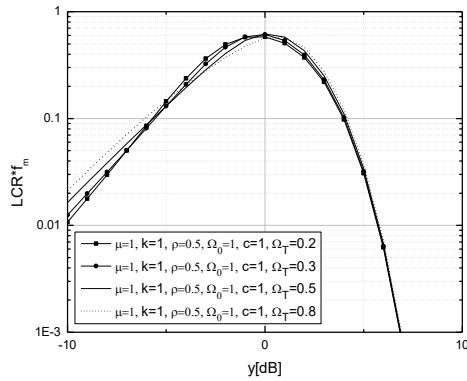
Fig. 4. Normalized LCR of MaD SSC receiver for constant values of mu, kappa, c, Ω_0 and ρ and several values of Ω_T.

Fig. 3. shows normalized average level crossing rate versus y for various values of ρ and constant values of μ, k, c, Ω_0 and Ω_T. Since there is no correlation for ρ=0, the impact of ρ on LCR can be noticed for higher values of ρ.

Fig. 4. shows normalized average level crossing rate versus y for various values of Ω_T and constant values of μ, k, c, Ω_0 and ρ.

5. CONCLUSION

In this paper, MaD technique with MaD switch and stay combining reception and two MiD selection combiners in correlated Gamma shadowed Kappa-Mu multipath fading channel is considered. MaD system with MaD SSC receiver is proposed, since it has lower complexity implementation then other diversity techniques. LCR of SSC MaD receiver output signal envelope in the form the sum of one-folded integrals is

obtained and graphically presented in relation to different system model parameters.

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