Level crossing rate of relay system over LOS multipath fading channel with one and two clusters in the presence of co-channel interference

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Abstract—**Wireless relay mobile communication system with two sections operating over line-of-sight (LOS) short term fading channel in the presence of co-channel interference affected to multipath fading is considered. Desired signal and co-channel interference propagate through environment with no more than two clusters. Probability density function (PDF), cumulative distribution function (CDF) and level crossing rate (LCR) of proposed system output signal are calculated. Derived expressions can be used for calculation of outage probability and average fade duration of relay system. The influence of Rician *k* factor and interference average power on level crossing rate are analyzed and discussed.**

Keywords-level crossing rate (LCR); Rician fading; line-of-sight (LOS); co-channel interference

I. INTRODUCTION

Small scale fading and co-channel interference are presented in wireless communication system resulting in outage probability and average fade duration degradation. Rician distribution can be used to describe signal envelope in short term fading environment with line-of-sight component in the presence of one cluster. This distribution has Rician factor k which can be evaluated as the ratio of desired signal dominant component power and desired signal scattering component power. When parameter k goes to zero, Rician multipath fading channel reduces to Rayleigh multipath fading channel, when Rician factor k goes to infinity Rician multipath fading channel goes to no fading channel [1]-[4]. In this paper Rician distribution is denoted with k-1 while distribution which can describe fading channel with dominant component and two clusters is denoted with k-2. There are more multipath fading channels which can be described by using k-1 and k-2 distributions. By setting for k=0, the k-2 fading channel becomes Nakagami-m channel with two clusters.

In this paper wireless relay mobile communication system with two sections operating over k-1 or k-2 short term multipath fading channel in the presence of co-channel interference also subjected to k-1 or k-2 multipath fading is considered. Under determined conditions, signal envelope at output of relay system with two sections can be written as product of signal envelopes of the first and the second section. In cellular mobile wireless system, the influence of co-channel interference on system performance is significantly higher compared to Gaussian noise, so the Gaussian noise effects can be neglected. In interference limited environment, for the proposed relay model, the ratio of signal to interference (SIR) can be calculated as the ratio of the product of two random variables and one random variable [5]-[8]. In this model, random variables have k-1 or k-2 distributions.

In paper [9], wireless relay communication system operating over Rayleigh short term multipath fading channel is considered. Level crossing rate of output random process is calculated and derived integrals are solved by using Laplace approximation theorem. The wireless relay communication system in the presence of Nakagami-m multipath fading is studied in work [10]. In this paper, signal at output is calculated as the product of signals at sections. In work [11], statistics of the ratio of the product of two random variables and random variable are evaluated. In paper [12], the first order statistical measures by using Maier functions are efficiently calculated.

In this paper, level crossing rate of output signal of considered relay system in the presence of co-channel interference is efficiency calculated. Moreover, the joint probability density function of output signal and the first derivative of output signal is evaluated. Obtained expressions can be used for calculation of average fade duration of proposed relay system with two sections. To the best of author's knowledge, level crossing rate of mobile relay wireless system in the presence of k-1 or k-2 multipath short term fading and k-1 or k-2 co-channel interference is not reported in open technical literature.

II. PDF OF OUTPUT SIR

Wireless relay system with two sections in the presence of short term multipath fading and co-channel interference also subjected to small scale fading is considered. Desired signal output of relay system is expressed as product of two random variables. The ratio of desired signal and interference can be modeled as the ratio of the product of two random variables x and y and random variable z:

$$w = \frac{xy}{z}, \quad x = \frac{wz}{y}. \tag{1}$$

The conditional PDF of w is:

$$p_{w/yz}(w/yz) = \left|\frac{dx}{dw}\right| p_x\left(\frac{wz}{y}\right) \tag{2}$$

where: $\frac{dx}{dw} = \frac{z}{y}$.

After substitution and averaging, the PDF of w becomes:

$$p_w(w) = \int_0^\infty dy \int_0^\infty dz \frac{z}{y} p_x\left(\frac{wz}{y}\right) p_y(y) p_z(z). \tag{3}$$

The random variables $p_x(x)$, $p_y(y)$ and $p_z(z)$ have k-1 density probability:

$$p_x(x) = \frac{2(k_1+1)}{e^k \Omega_x} e^{-\frac{(k_1+1)}{\Omega_x}x^2} I_0\left(2\sqrt{\frac{k_1(k_1+1)}{\Omega_x}}\right) = \frac{2(k_1+1)}{e^k \Omega_x} \sum_{i_1=0}^{\infty} \left(\frac{k_1(k_1+1)}{\Omega_x}\right)^{i_1} \frac{1}{(i_1!)^2} x^{2i_1+1} e^{-\frac{(k_1+1)}{\Omega_x}x^2}. \tag{4}$$

$$p_y(y) = \frac{2(k_2+1)}{e^k \Omega_y} \sum_{i_2=0}^{\infty} \left(\frac{k_2(k_2+1)}{\Omega_y}\right)^{i_2} \times \frac{1}{(i_2!)^2} y^{2i_2+1} e^{-\frac{k_2+1}{\Omega_y}y^2}. \tag{5}$$

$$p_z(z) = \frac{2(k_3+1)}{e^k \Omega_z} \sum_{i_3=0}^{\infty} \left(\frac{k_3(k_3+1)}{\Omega_z}\right)^{i_3} \times \frac{1}{(i_3!)^2} z^{2i_3+1} e^{-\frac{k_3+1}{\Omega_z}z^2}. \tag{6}$$

Probability density function of w is:

$$p_w(w) = \frac{2(k_1+1)}{e^k \Omega_x} \sum_{i_1=0}^{\infty} \left(\frac{k_1(k_1+1)}{\Omega_x}\right)^{i_1} \frac{1}{(i_1!)^2} w^{2i_1+1} \times \frac{2(k_2+1)}{e^k \Omega_y} \sum_{i_2=0}^{\infty} \left(\frac{k_2(k_2+1)}{\Omega_y}\right)^{i_2} \frac{1}{(i_2!)^2} \times \frac{2(k_3+1)}{e^k \Omega_z} \sum_{i_3=0}^{\infty} \left(\frac{k_3(k_3+1)}{\Omega_z}\right)^{i_3} \frac{1}{(i_3!)^2} \times \int_0^\infty dy \int_0^\infty dz \frac{z}{y} z^{2i_1+1+2i_3+1} y^{2i_2+1-2i_1-1} \times e^{-\frac{(k_1+1)}{\Omega_x}\frac{w^2 z^2}{y^2} - \frac{(k_2+1)}{\Omega_y}y^2 - \frac{(k_3+1)}{\Omega_z}z^2}. \tag{7}$$

The two-fold integral is:

$$J = \int_0^\infty dy\, y^{2i_2-2i_1-1} e^{-\frac{(k_2+1)}{\Omega_y}y^2} \int_0^\infty dz\, z^{2i_1+2i_2+3} \times e^{-z^2\left(\frac{(k_1+1)}{\Omega_x}\frac{w^2}{y^2} + \frac{(k_3+1)}{\Omega_z}\right)} = \int_0^\infty dy\, y^{2i_2-2i_1-1} \times e^{-\frac{(k_2+1)}{\Omega_y}y^2} \frac{1}{2} \frac{(\Omega_x \Omega_z)^{i_2+i_1+2} y^{2i_2+2i_1+4}}{\left((k_1+1)w^2 + (k_3+1)y^2\right)^{i_2+i_1+2}} = = \frac{1}{2}(\Omega_x\Omega_z)^{i_2+i_1+2} \int_0^\infty dy\, y^{4i_2+3} \times \frac{1}{\left((k_1+1)w^2 + (k_3+1)y^2\right)^{i_2+i_1+2}} e^{-\frac{(k_2+1)}{\Omega_y}y^2}. \tag{8}$$

$$(k_y+1)\Omega_x y^2 = (k_1+1)w^2 s,$$

$$y^2 = \frac{(k_1+1)y^2}{(k_3+1)\Omega_x}s, \quad ydy = \frac{(k_1+1)w^2}{(k_3+1)\Omega_x}ds.$$

After substituting the integral J becomes:

$$J = \frac{1}{2}(\Omega_x\Omega_z)^{i_2+i_1+2} \frac{(k_1+1)w^2}{(k_3+1)\Omega_x} \left(\frac{(k_1+1)w^2}{(k_3+1)\Omega_x}\right)^{2i_2+1} \times \left((k_1+1)w^2\right)^{i_1+i_2+2} \int_0^\infty ds\, s^{2i_2+1} \frac{1}{(1+s)^{i_1+i_2+2}} \times e^{-\frac{(k_1+1)}{\Omega_y}y^2} \frac{(k_1+1)w^2}{(k_3+1)\Omega_x}s. \tag{9}$$

Previously integral can be solved by using formulae [13]:

$$\int_0^\infty dt\, t^{a-1}\frac{1}{(1+t)^{a+1-b}}e^{-ct} = \Gamma(a)U(a,b,c). \tag{10}$$

$$J=\frac{1}{4}\frac{(\kappa_1+1)w^2}{(\kappa_3+1)\Omega_x}\left(\frac{(\kappa_1+1)w^2}{(\kappa_3+1)\Omega_x}\right)^{2i_2+1}\left((\kappa_1+1)w^2\right)^{i_1+i_2+2}\times$$
$$\times\Gamma(2i_2+2)U\left(2i_2+2, i_2-i_1+1, \frac{(\kappa_1+1)(\kappa_1+1)w^2}{\Omega_x\Omega_y(\kappa_3+1)}\right) \tag{11}$$

III. Level Crossing Rate of Output SIR

The SIR at output of wireless relay communication system is:

$$w=\frac{xy}{z},\quad \frac{x^2}{z^2}=\frac{w^2}{y^2}. \tag{12}$$

The first derivative of w is:

$$\dot w = \frac{\dot x y}{z}+\frac{x\dot y}{z}-\frac{xy\dot z}{z^2}. \tag{13}$$

The first derivative of κ-1 distribution has Gaussian distribution. Also, linear transformation of Gaussian random variables has Gaussian distribution. The mean of $\dot w$ is zero. The variance of $\dot w$ is:

$$\sigma_{\dot w}^2 = \frac{y^2}{z^2}\sigma_{\dot x}^2+\frac{x^2}{z^2}\sigma_{\dot y}^2+\frac{x^2y^2}{z^2}\sigma_{\dot z}^2 \tag{14}$$

when:

$$\sigma_{\dot x}^2=\pi^2 f_m^2\frac{\Omega_x}{\kappa_1+1},\quad \sigma_{\dot y}^2=\pi^2 f_m^2\frac{\Omega_y}{\kappa_2+1},$$
$$\sigma_{\dot z}^2=\pi^2 f_m^2\frac{\Omega_z}{\kappa_3+1}. \tag{15}$$

After substitution the expression for variance of $\dot w$ becomes:

$$\sigma_{\dot w}^2=\pi^2 f_m^2\left(\frac{y^2}{z^2}\frac{\Omega_x}{\kappa_1+1}+\frac{w^2}{y^2}\frac{\Omega_y}{\kappa_2+1}+\frac{w^2}{z^2}\frac{\Omega_z}{\kappa_3+1}\right) \tag{16}$$

The joint PDF of $\dot w wzy$ and y is:

$$p_{\dot w wzy}(\dot w wzy)=p_{\dot w}(\dot w/wzy)p_z(z)p_y(y)p_w(w/zy). \tag{17}$$

where:

$$p_w(w/zy)=\left|\frac{dx}{dw}\right|p_x\left(\frac{wz}{y}\right) \tag{18}$$

where: $\frac{dx}{dw}=\frac{z}{y}$.

By substituting the $p_{w\dot w}(w\dot w)$ is:

$$p_{w\dot w}(w\dot w)=\int_0^\infty dy\int_0^\infty dz\, p_{\dot w}(\dot w/wzy)\frac{z}{y}p_x\left(\frac{wz}{y}\right)p_z(z)p_y(y). \tag{19}$$

LCR of $\dot w$ is:

$$N_w=\int_0^\infty d\dot w\,\dot w\,p_{w\dot w}(w\dot w)=\int_0^\infty dy\int_0^\infty dz\frac{z}{y}p_x\left(\frac{wz}{y}\right)p_z(z)\times$$
$$\times p_y(y)\frac{\sigma_{\dot w}}{\sqrt{2\pi}}\frac{\pi f_m}{\sqrt{2\pi}}\frac{8(\kappa_1+1)(\kappa_3+1)(\kappa_3+1)}{e^{\kappa_1+\kappa_2+\kappa_3}\Omega_x\Omega_y\Omega_z}\times$$
$$\times\sum_{i_1=0}^\infty\left(\frac{\kappa_1(\kappa_1+1)}{\Omega_x}\right)^{i_1}\frac{1}{(i_1!)^2}w^{2i_1+1}\sum_{i_2=0}^\infty\left(\frac{\kappa_2(\kappa_2+1)}{\Omega_y}\right)^{i_2}\times$$
$$\times\frac{1}{(i_2!)^2}\sum_{i_3=0}^\infty\left(\frac{\kappa_3}{\Omega_z}\right)^{i_3}\frac{1}{(i_3!)^2}\int_0^\infty dy\int_0^\infty dz\times \tag{20}$$
$$\times\sqrt{\frac{y^2}{z^2}\frac{\Omega_x}{(\kappa_1+1)}+\frac{w^2}{z^2}\frac{\Omega_y}{(\kappa_2+1)}\frac{w^2}{z^2}\frac{\Omega_z}{(\kappa_3+1)}}\,y^{2i_2-2i_1-1}\times$$
$$\times z^{2i_1+2i_3+3}e^{-\frac{(\kappa_1+1)}{\Omega_x}\frac{w^2z^2}{y^2}-\frac{(\kappa_2+1)}{\Omega_y}y^2-\frac{(\kappa_3+1)}{\Omega_z}z^2}.$$

Previously two-fold integral can be solved by using Laplace approximation formula [13]:

$$\int_0^\infty dx_1\int_0^\infty dx_2\, g(x_1,x_2)e^{-\lambda f(x_1,x_2)}=\frac{2\pi}{\lambda}\frac{g(x_{10},x_{20})}{b(x_{10},x_{20})}e^{-\lambda f(x_{10},x_{20})}. \tag{21}$$

where x_{10} and x_{20} solution of equations:

$$\frac{\partial f(x_{10},x_{20})}{\partial x_{10}}=0,\quad \frac{\partial f(x_{10},x_{20})}{\partial x_{20}}=0. \tag{22}$$

and:

$$b=\begin{vmatrix}\frac{\partial^2 f(x_{10},x_{20})}{\partial x_{10}^2} & \frac{\partial^2 f(x_{10},x_{20})}{\partial x_{10}\partial x_{20}}\\ \frac{\partial f(x_{10},x_{20})}{\partial x_{10}\partial x_{20}} & \frac{\partial^2 f(x_{10},x_{20})}{\partial x_{20}^2}\end{vmatrix}. \tag{23}$$

IV. Level Crossing Rate of Relay System Over κ-2 Multipath Fading Output SIR

The random variables x, y and z follow κ-μ distribution:

$$p_x(x) = \frac{4(k_1+1)^{3/2} x^2}{k_1^{1/2} e^{2k_1} \Omega_x^{3/2}} e^{-\frac{2(k_1+1)}{\Omega_x}x^2} I_0\left(4\sqrt{\frac{k_1(k_1+1)}{\Omega_x}}\,x\right) =$$

$$= \frac{4(k_1+1)^{3/2} x^2}{k_1^{1/2} e^{2k_1} \Omega_x^{3/2}} \sum_{i_1=0}^{\infty}\left(2\sqrt{\frac{k_1(k_1+1)}{\Omega_x}}\right)^{2i_1+1} \times$$

$$\times x^{2i_1+3} e^{-\frac{2(k_1+1)}{\Omega_x}x^2} \frac{1}{i_1!\Gamma(i_1+2)}, \quad x \geq 0.$$

$$p_y(y) = \frac{4(k_2+1)^{3/2}}{k_2^{1/2} e^{2k_2} \Omega_y^{3/2}} \sum_{i_2=0}^{\infty}\left(2\sqrt{\frac{k_2(k_2+1)}{\Omega_y}}\right)^{2i_2+1} \times$$

$$\times y^{2i_2+3} e^{-\frac{2(k_2+1)}{\Omega_y}y^2} \frac{1}{i_2!\Gamma(i_2+2)}.$$

$$p_z(z) = \frac{4(k_3+1)^{3/2}}{k_3^{1/2} e^{2k_3} \Omega_z^{3/2}} \sum_{i_3=0}^{\infty}\left(2\sqrt{\frac{k_3(k_3+1)}{\Omega_3}}\right)^{2i_3+1} \times$$

$$\times z^{2i_3+3} e^{-\frac{2(k_3+1)}{\Omega_z}z^2} \frac{1}{i_3!\Gamma(i_3+2)}. \tag{24}$$

Level crossing rate (LCR) of output SIR is:

$$N_w = \frac{\pi f_m}{\sqrt{2\pi}} \frac{4(k_1+1)^{3/2}}{k_1^{1/2} e^{2k_1} \Omega_x^{3/2}} \sum_{i_1=0}^{\infty}\left(2\sqrt{\frac{k_1(k_1+1)}{\Omega_x}}\right)^{2i_1+1} \frac{1}{i_1!\Gamma(i_1+2)} \times$$

$$\times \frac{4(k_2+1)^{3/2}}{k_2^{1/2} e^{2k_2} \Omega_y^{3/2}} \sum_{i_2=0}^{\infty}\left(2\sqrt{\frac{k_2(k_2+1)}{\Omega_y}}\right)^{2i_2+1} \frac{1}{i_2!\Gamma(i_2+2)} \times$$

$$\times \frac{4(k_3+1)^{3/2}}{k_3^{1/2} e^{2k_3} \Omega_z^{3/2}} \sum_{i_3=0}^{\infty}\left(2\sqrt{\frac{k_3(k_3+1)}{\Omega_z}}\right)^{2i_3+1} \frac{1}{i_3!\Gamma(i_3+2)} \times \tag{25}$$

$$\times w^{2i_1+3} \int_0^{\infty} dy \int_0^{\infty} dz \sqrt{\frac{y^2}{z^2}\frac{\Omega_x}{(k_1+1)} + \frac{w^2}{z^2}\frac{\Omega_y}{(k_2+1)} \frac{w^2}{z^2}\frac{\Omega_z}{(k_3+1)}} \times$$

$$\times e^{-\frac{(k_1+1)}{\Omega_x}\frac{w^2 z^2}{y^2} - \frac{(k_2+1)}{\Omega_y}y^2 - \frac{(k_3+1)}{\Omega_z}z^2} \cdot$$

$$\times e^{-(2i_1+2i_3+7)\ln z + (2i_2-2i_1-1)\ln y}.$$

Previously two-fold integral is solved by using Laplace approximation formulae [13].

V. NUMERICAL RESULTS

In figure 1, average level crossing rate of wireless relay mobile communication system with two sections operating over multipath fading channel in the presence of co-channel interference versus signal to interference (SIR) is shown. Considered is case when Rician factor values are 1, 1.2, 1.4 and 1.6 and signal envelopes average powers are constant. Level crossing rate increases as Rician factor increases. The influence of Rician factor on level crossing rate is more dominant for higher values of Rician factor. Moreover, the influence of Rician k factor on level crossing rate is higher for higher values of signal to interference ratio. When SIR increases, average level crossing rate increases, reaches its maximum, than average level crossing rate decreases for higher values of SIR. When Rician factor increases, maximum of curve, slightly goes to higher values of signal to interference ratio.

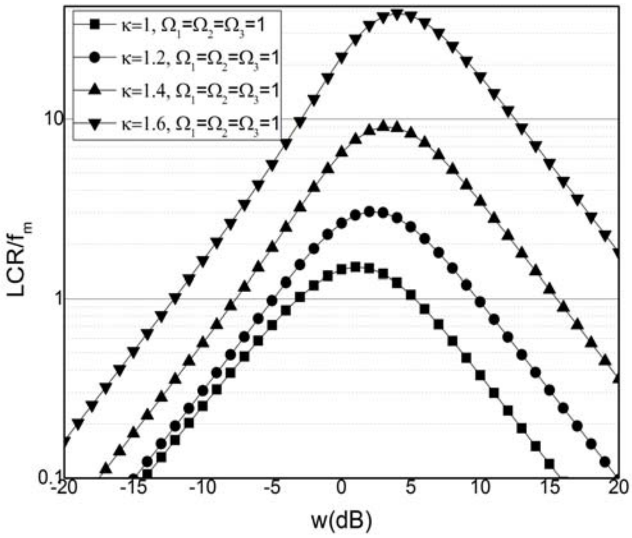

Figure 1. Normalized level crossing rate (LCR), when $\Omega_1 = \Omega_2 = \Omega_3 = 1$ and different values of k.

In figure 2, level crossing rate of wireless system versus signal to interference ratio is shown, for the case when Rician factor is constant and signal envelopes average powers have different values.

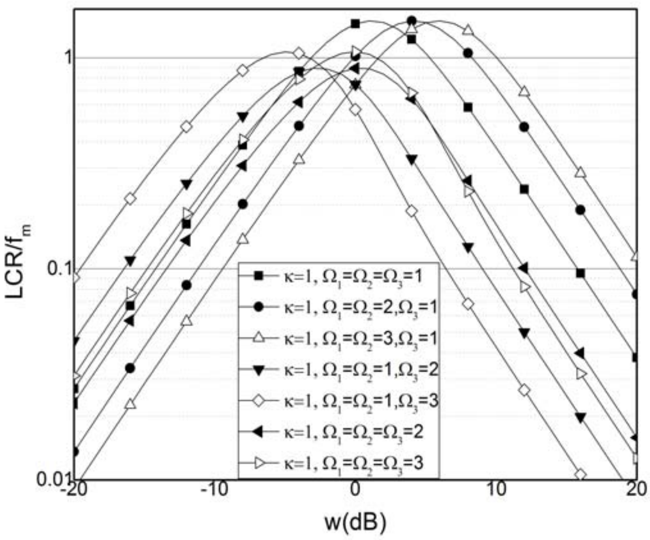

Figure 2. Normalized level crossing rate (LCR) depending on the envelope w, when k=1 and different values Ω_1, Ω_2 and Ω_3.

Similarly, level crossing rate increases for lower values of signal to interference ratio and level crossing rate decreases for higher values of signal to interference ratio. When power of signal envelopes in both sections increase, level crossing rate of relay system increases for higher values of signal to interference ratio while level crossing rate decreases for lower values of signal to interference ratio. When power of interference increases, average level crossing rate increases for lower values of SIR while level crossing rate decreases for higher values of SIR. Moreover, when power of interference increases maximum goes to lower values of SIR.

In figure 3, level crossing rate versus signal to interference ratio is presented for the case when wireless relay system operating over *k*-2 multipath fading channel in the presence of *k*-2 co-channel interference.

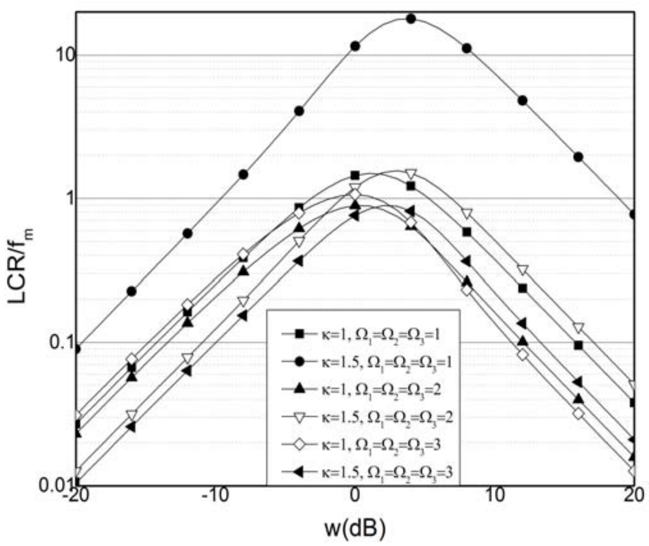

Figure 3. Normalized level crossing rate (LCR) depending on the envelope *w*, for different values *k*, Ω_1, Ω_2 and Ω_3.

CONCLUSION

In this paper wireless relay mobile system with two sections operating over line-of-sight multipath fading channel with one or two clusters in the presence of co-channel interference affected to multipath fading is considered. Signal propagates in the channel with one cluster described with *k*-1 distribution or two clusters described by using *k*-2 distribution. For considered model, signal to interference ratio is presented as ratio of product of two random variables and random variable. The *k*-1 distribution describe signal envelope in channel with line-of-sight components and one cluster and *k*-2 distribution fading channel with two clusters. Closed form expressions for PDF and CDF of ratio of product of two *k*-1 or *k*-2 random variables and *k*-1 or *k*-2 random variable are calculated. Those results can be used for evaluation of outage probability and bit error probability of proposed relay system. Furthermore, average level crossing rate of relay system with two sections in the presence of co-channel interference is calculated. This expression for LCR can be used for calculation of average fade duration of considered relay system. By setting for *k*=0 in expressions for PDF, CDF and LCR can be derived expressions for PDF, CDF and LCR of relay system with two section operating over Rayleigh or Nakagami-*m* short term fading channels in the presence co-channel interference subjected to Rayleigh or Nakagami-*m* short term fading. The influence of Rician factor *k* and average value of signal envelope at level crossing rate is analysed and discussed. Level crossing rate decreases when Rician factor increases.

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