Level crossing rate of wireless system over cellular non linear fading channel in the presence of co-channel interference

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Abstract—A **composite fading channel where desired signal is subject to α-k-μ multipath fading, and cochannel interference is subjected to α-μ multipath fading is denoted as α-k-μ/α-μ. This communication channel can be studied as ratio of an α-k-μ random variable and an α-μ random variable. Since the interference is significant, this channel model ignores the influence of Gaussian noise on the system performance. Probability density function and cumulative distribution function of a α-k-μ/α-μ distribution are evaluated and level crossing rate of the α-k-μ/α-μ random process is calculated. By using these results, bit error rate probability, outage probability, and average fade duration of a radio transmission over α-k-μ/α-μ fading channel are analysed. Influence of α-k-μ multipath fading severity parameter and short term fading nonlinearity parameter on the level crossing rate is studied.**

Key Words: 1: outage probability, 2: correlated multipath fading, 3: the cumulative distribution function, 4: the average level crossing rate.

I. INTRODUCTION

This paper formulates and evaluates α-k-μ/α-μ model of a wireless channel. In this type of channel, desired signal experiences α-k-μ short term fading, and co-channel interference α-μ short term fading. The α-k-μ/α-μ distribution has several parameters. These parameters are α-k-μ short term fading nonlinearity parameter, Rician factor of α-k-μ short term fading, α-k-μ short term fading severity parameter, α-μ short term fading nonlinearity parameter and α-μ short term fading severity parameter. The α-k-μ/α-μ is a general fading channel and multiple known channel models can be derived from α-k-μ/α-μ fading channel. For k=1, α-k-μ/α-μ fading channel wiil be α-μ/α-μ fading channel, for α_1=2, and α_2=2, the α-k-μ/α-μ fading channel becomes k-μ/Nakagami-*m* fading channel. For μ_1=1, μ_2=1 the α-k-μ/α-μ fading channel will be α-k/Weibull fading channel, for α_1=2, and α_2=2, k=0, the α-k-μ/α-μ fading channel will become Nakagami-*m*/Nakagami-*m* fading channel. For k_1=0, μ=1, the α-k-μ/α-μ fading channel will be Weibull/Weibull fading channel and for k=0, α_1=2, α_2=2 and μ=1, the α-k-μ/α-μ fading channel becomes Rayleig/Rayleigh multipath fading channel.

There are more papers considering statistics of α-μ and α-k-μ distributions and performance of wireless system operating over α-μ and α-k-μ multipath fading channel. In [1], first-order statistics of α-μ and α-k-μ distribution are derived, namely-probability density function and cumulative distribution. By using these formulas, moments and moment generating function of an α-μ random variable can be derived. Also, level crossing rate of an α-k-μ random process and α-μ random process can be calculated. In paper [2], the outage probability of selection combining diversity receiver in the presence of α-μ short term fading and Gama long term fading is evaluated. In paper [3] product of two Nakagami-*m* random variables is considered and level crossing rate of product of two Nakagami-*m* random processes is calculated. These results can be used in performance analysis of wireless relay comunication system with two sections in Nakagami-*m* multipath fading channel. Statistics of ratio of a random variable and product of two random variables is analysed in paper [4].

In this paper, statistics of an α-k-μ/α-μ random variable are analysed, and performances of wireless radio system operating over α-k-μ/α-μ multipath fading channel are evaluated. The α-k-μ/α-μ distribution can be evaluated as ratio of an α-k-μ random variable and an α-μ random variable. Probability densiy function and cumulative distribution function of α-k-μ/α-μ random variable are calculated. In this paper, we also consider a wireless communication system operating over the proposed fading channel. For this system, level crossing rate of the resulting signal to interference ratio random process is calculated. Probability density function can be used for evaluation of average symbol error probability for the proposed system, and outage probability can be evaluated by using cumulative distribution function of an α-k-μ/α-μ random variable. Obtained results can be used in performance analysis of wireless communication system operating over α-k-μ/α-μ multipath fading channel.

II. Ratio of $\alpha - k - \mu$ and $\alpha - \mu$ random variables

The α-k-μ distribution can be used to describe small scale signal envelope variation in nonlinear, line of sight multipath fading environment. The α-μ distribution finds application for description of small scale signal envelope variation in nonlinear, non-line-of-sight multipath fading environments. The ratio z of an α-k-μ random variable x_1 and an α-μ random variable y_1 is:

$$z = \frac{x_1}{y_1},\ x_1 = z y_1,\ z = \frac{x^{\frac{2}{\alpha}}}{y^{\frac{2}{\alpha}}},\ z^{\frac{\alpha}{2}} = \frac{x}{y} \tag{1}$$

where x is k-μ random variables and y is Nakagami-*m* random variable. PDF function of variable x is [1, Eq. (2.14)]:

$$p_x(x) = \frac{2\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}} e^{\mu k} \Omega_1^{\frac{\mu+1}{2}}} x^{\mu} e^{-\frac{\mu(1+k)}{\Omega_1}x^2} I_{\mu-1}\left(2\mu\sqrt{\frac{k(k+1)}{\Omega_1}}x\right) = \\ = \frac{2}{e^{\mu k}} \sum_{i=0}^{\infty} \frac{\mu^{2i+\mu}(k+1)^{i+\mu} k^i x^{2i+2\mu-1}}{\Omega^{i+\mu}\Gamma(i+\mu) i!} e^{-\frac{\mu(1+k)}{\Omega_1}x^2} \tag{2}$$

with Ω=E[R²], denoting average signal power.

The Nakagami-*m* PDF is in essence a central chi-square distribution given by [6, Eq. (11)]:

$$p_y(y) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega_2}\right)^m y^{2m-1} e^{-\frac{m}{\Omega_2}y^2},\ y \ge 0 \tag{3}$$

First derivative of the ratio of α-k-μ and α-μ random variables is:

$$\dot{z} = \frac{2}{\alpha z^{\frac{\alpha}{2}-1}}\left(\frac{\dot{x}}{y} - \frac{x\dot{y}}{y^2}\right) \tag{4}$$

The squared k-μ random variable x^2 is:

$$x^2 = x_{11}^2 + x_{12}^2 + \ldots + x_{12\mu}^2 \tag{5}$$

where x_{1i}, i=1,2,...2μ are independent Gaussian random variables with average values and variances σ_1^2[9]:

$$p_{x_{1i}}(x_{1i}) = \frac{1}{\sqrt{2\pi}\sigma_1} e^{-\frac{(x_{1i}-A)^2}{2\sigma_1^2}},\quad i = 1,2\ldots 2\mu \tag{6}$$

The first derivative of x is:

$$\dot{x} = \frac{1}{x}\left(x_{11}\dot{x}_{11} + x_{12}\dot{x}_{12} + \ldots + x_{12\mu}\dot{x}_{12\mu}\right) \tag{7}$$

The squared Nakagami-*m* random variable y is:

$$y^2 = y_{11}^2 + y_{12}^2 + \ldots + y_{12\mu}^2 \tag{8}$$

where y_{1j}, j=1,2,...2μ are independent zero-mean, Gaussian random variables with variance σ_2^2 [11]:

$$p_{y_{1j}}(y_{1j}) = \frac{1}{\sqrt{2\pi}\sigma_2} e^{-\frac{y_{1j}^2}{2\sigma_2^2}},\quad j = 1,2\ldots,2\mu \tag{9}$$

The first derivate of y is:

$$\dot{y} = \frac{1}{y}\left(y_{11}\dot{y}_{11} + y_{12}\dot{y}_{12} + \ldots + y_{12\mu}\dot{y}_{12\mu}\right) \tag{10}$$

After substituting, the first derivative of the ratio of an α-k-μ random variable and an α-μ random variables is:

$$\dot{z} = \frac{2}{\alpha z^{\frac{\alpha}{2}-1}}\left(\frac{1}{y}\frac{1}{x}\left(x_{11}\dot{x}_{11} + x_{12}\dot{x}_{12} + \ldots + x_{12\mu}\dot{x}_{12\mu}\right) - \\ -\frac{x}{y^2}\frac{1}{y}\left(y_{11}\dot{y}_{11} + y_{12}\dot{y}_{12} + \ldots + y_{12\mu}\dot{y}_{12\mu}\right)\right) \tag{11}$$

The first derivative of a Gaussian random variable is also a Gaussian random variable. The first derivative of z is a linear transformation of a Gaussian random variable. Therefore the first derivative of the ratio of an α-k-μ and α-μ random variables can be viewed as a conditional Gaussian distribution.

The average value of z is:

$$\bar{\dot{z}} = \frac{2}{\alpha z^{\frac{\alpha}{2}-1}}\left(\frac{1}{xy}\left(x_{11}\bar{\dot{x}}_{11} + x_{12}\bar{\dot{x}}_{12} + \ldots + x_{12\mu}\bar{\dot{x}}_{12\mu}\right) - \\ -\frac{x}{y^3}\left(y_{11}\bar{\dot{y}}_{11} + y_{12}\bar{\dot{y}}_{12} + \ldots + y_{12\mu}\bar{\dot{y}}_{12\mu}\right)\right) = 0 \tag{12}$$

Since:

$$\bar{\dot{x}}_{11} = \bar{\dot{x}}_{12} = \ldots = \bar{\dot{x}}_{12\mu} = 0,\ \bar{\dot{y}}_{11} = \bar{\dot{y}}_{12} = \ldots = \bar{\dot{y}}_{12\mu} = 0 \tag{13}$$

the variance of z is [9]:

$$\sigma_{\dot{z}}^2 = \frac{4}{\alpha^2 z^{\alpha-2}}\left(\frac{1}{x^2y^2}\left(x_{11}^2\sigma_{\dot{x}_{11}}^2 + x_{12}^2\sigma_{\dot{x}_{12}}^2 + \ldots + x_{12\mu}^2\sigma_{\dot{x}_{12\mu}}^2\right) + \\ +\frac{x^2}{y^6}\left(y_{11}^2\sigma_{\dot{y}_{11}}^2 + y_{12}^2\sigma_{\dot{y}_{12}}^2 + \ldots + y_{12\mu}^2\sigma_{\dot{y}_{12\mu}}^2\right)\right) \tag{14}$$

where variances involved are:

$$\sigma_{\dot{x}_{11}}^2 = \sigma_{\dot{x}_{12}}^2 = \ldots = \sigma_{\dot{x}_{12\mu}}^2 = \pi^2 f_m^2 \sigma_1^2 = f_1^2, \\ \sigma_{\dot{y}_{11}}^2 = \sigma_{\dot{y}_{12}}^2 = \ldots = \sigma_{\dot{y}_{12\mu}}^2 = \pi^2 f_m^2 \sigma_2^2 = f_2^2 \tag{15}$$

and f_m is maximal Doppler frequency. After substituting, the expression for variance becomes:

$$\sigma_{\dot{z}}^2 = \sigma_{\dot{z}}^2 = \frac{4}{\alpha^2 z^{\alpha-2}}\left(\frac{f_1^2}{x^2y^2}\left(x_{11}^2 + x_{12}^2 + \ldots + x_{12\mu}^2\right) + \frac{x^2 f_2^2}{y^6}\cdot \\ \cdot\left(y_{11}^2 + y_{12}^2 + \ldots + y_{12\mu}^2\right)\right) = \frac{4}{\alpha^2 z^{\alpha-2} y^2}\left(f_1^2 + z^{\alpha} f_2^2\right) \tag{16}$$

Conditional probability density function of $\dot{z}$ is [12]:

$$p_{\dot z}\left(\dot z / zy\right)=\frac{1}{\sqrt{2\pi}\sigma_{\dot z}}e^{-\frac{\dot z^2}{2\sigma_{\dot z}^2}} \tag{17}$$

Joint probability density function of $z, \dot z$ channel y is:

$$\begin{aligned} p_{z\dot z y}\left(z\dot z y\right) &= p_{\dot z}\left(\dot z / zy\right)p_{zy}\left(zy\right)= \\ &= p_{\dot z}\left(\dot z / zy\right)p_{y}\left(y\right)p_{z}\left(z / y\right) \end{aligned} \tag{18}$$

Conditional probability density function of z is:

$$p_z\left(z / y\right)=\left|\frac{dx}{dy}\right|p_x\left(yz^{\frac{\alpha}{2}}\right)=\frac{\alpha}{2}yz^{\frac{\alpha}{2}-1}p_x\left(yz^{\frac{\alpha}{2}}\right) \tag{19}$$

Joint probability density function of $z, \dot z$ and y is therefore:

$$p_{z\dot z y}\left(z\dot z y\right)=\frac{\alpha}{2}yz^{\frac{\alpha}{2}-1}p_x\left(yz^{\frac{\alpha}{2}}\right)p_y\left(y\right)p_{\dot z}\left(\dot z / zy\right) \tag{20}$$

Joint probability density function of $z, \dot z$ is [10]:

$$\begin{aligned} p_{z\dot z}\left(z\dot z\right) &= \int_0^\infty p_{z\dot z y}\left(z\dot z y\right)dy=\frac{\alpha}{2}z^{\frac{\alpha}{2}-1}\int_0^\infty dy\, y p_x\left(yz^{\frac{\alpha}{2}}\right)p_y\left(y\right)p_{\dot z}\left(\dot z / zy\right)= \\ &= \frac{\alpha^2 m^m}{\sqrt{2\pi}e^{\mu k}\Gamma\left(m\right)\Omega_2{}^m\sqrt{f_1^2+z^\alpha f_2^2}}\sum_{i=0}^{\infty}\frac{z^{\alpha i+\alpha\mu+\frac{\alpha}{2}-2}\left(k+1\right)^{i+\mu}\mu^{2i+\mu}k^i}{\Omega_1^{i+\mu}\Gamma\left(i+\mu\right)i!}\cdot \\ &\cdot\int_0^\infty dy\, y^{2i+2m+2\mu}e^{-\left(\frac{\mu(1+k)z^\alpha\Omega_2+m\Omega_1}{\Omega_1\Omega_2}+\frac{\dot z^2\alpha^2 z^{\alpha-2}y^2}{8\left(f_1^2+z^\alpha f_2^2\right)}\right)y^2} \end{aligned} \tag{21}$$

LCR is defined as the rate at which a random process crosses level z in the positive or the negative direction. The average level crossing rate (LCR) of the ratio α-k-μ and α-μ random variables is [8]:

$$\begin{aligned} N_z(z) &= \int_0^\infty \dot z p_{z\dot z}\left(z\dot z\right)d\dot z=\frac{\alpha}{2}z^{\frac{\alpha}{2}-1}\int_0^\infty dy\, y p_x\left(yz^{\frac{\alpha}{2}}\right)p_y\left(y\right)\int_0^\infty d\dot z\, \dot z p_{\dot z}\left(\dot z / zy\right)=2m^m\cdot \\ &\cdot\frac{\sqrt{f_1^2+z^\alpha f_2^2}}{\sqrt{2\pi}e^{\mu k}\Gamma\left(m\right)}\sum_{i=0}^{\infty}\frac{\mu^{2i+\mu}k^i\left(k+1\right)^{i+\mu}\Omega_1^{m-\frac{1}{2}}\Omega_2^{i+\mu-\frac{1}{2}}z^{\alpha i+\alpha\mu-\frac{\alpha}{2}}\Gamma\left(i+\mu+m-\frac{1}{2}\right)}{\Gamma\left(i+\mu\right)\left(m\Omega_1+\mu\Omega_2 z^\alpha\left(1+k\right)\right)^{i+\mu+m-\frac{1}{2}}i!} \end{aligned} \tag{22}$$

Probability density function of the ratio of a α-k-μ random variable and a α-μ random variable is:

$$\begin{aligned} p_z\left(z\right) &= \int_0^\infty dy\, p_z\left(z / y\right)p_y\left(y\right)=\frac{\alpha m^m\Omega_1{}^m}{e^{\mu k}\Gamma\left(m\right)}\cdot \\ &\cdot\sum_{i=0}^{\infty}\frac{\mu^{2i+\mu}k^i\left(k+1\right)^{i+\mu}\Omega_2{}^{i+\mu}z^{\alpha i+\alpha\mu-1}\Gamma\left(i+\mu+m\right)}{\Gamma\left(i+\mu\right)\left(m\Omega_1+\mu\left(1+k\right)\Omega_2 z^2\right)^{i+\mu+m}i!} \end{aligned} \tag{23}$$

Cumulative distribution function of the ratio of a α-k-μ random variable and a α-μ random variable is [7]:

$$\begin{aligned} F_z\left(z\right) &= \int_0^z p_z\left(t\right)dt= \\ &= \sum_{i=0}^{\infty}\frac{\alpha m^m\mu^{2i+\mu}k^i\left(k+1\right)^{i+\mu}\Omega_1{}^m\Omega_2{}^{i+\mu}}{e^{\mu k}\Gamma\left(m\right)\Gamma\left(i+\mu\right)i!}\Gamma\left(i+\mu+m\right)\cdot \\ &\cdot\int_0^z dt\frac{t^{\alpha i+\alpha\mu-1}}{\left(m\Omega_1+\mu\left(1+k\right)\Omega_2 z^2\right)^{i+\mu+m}}=\frac{1}{e^{\mu k}\Gamma\left(m\right)}\cdot \\ &\cdot\sum_{i=0}^{\infty}\frac{\mu^i k^i}{\Gamma\left(i+\mu\right)i!}\Gamma\left(i+\mu+m\right)B_{\frac{\mu(1+k)\Omega_2 z^\alpha}{m\Omega_1+\mu(1+k)\Omega_2 z^\alpha}}\left(i+\mu,m\right) \end{aligned} \tag{24}$$

where $B_z(a, b)$ is the incomplete Beta function, [5, Eq. 8.38].

Expressions for average level crossing rate and cumulative distribution function of the ratio of α-k-μ random variable and α-μ random variable can be used for evaluation of the average level crossing rate and average fade duration of wireless communication system with dual branch SIR based SC diversity receiver, operating over interference limited α-k-μ multipath nonlinear fading environment in the presented of co-channel interference subjected to α-μ multipath fading.

The average fade duration(AFD)of wireless communication system with dual branch SIR based, SC diversity receiver operating over interference limited α-k-μ multipath no linear fading environments in the presence of co-channel interference which experiences multipath α-μ fading is [8]:

$$\begin{aligned} AFD &= \frac{F_z(z)}{N_z(z)}= \\ &= \frac{\sqrt{2\pi}\sum\limits_{i=0}^{\infty}\frac{\mu^i k^i}{\Gamma(i+\mu)i!}\Gamma(i+\mu+m)B_{\frac{\mu(1+k)\Omega_2 z^\alpha}{m\Omega_1+\mu(1+k)\Omega_2 z^\alpha}}(i+\mu,m)}{2m^m\Omega_1^{\frac{2m-1}{2}}\sqrt{f_1^2+z^\alpha f_2^2}\sum\limits_{j=0}^{\infty}\frac{\mu^{2j+\mu}(k+1)^{j+\mu}k^j z^{\alpha j+\alpha\mu-\frac{\alpha}{2}}\Omega_2^{j+\mu-\frac{1}{2}}\Gamma\left(j+\mu+m-\frac{1}{2}\right)}{\Gamma(j+\mu)\left(m\Omega_1+\mu\Omega_2 z^\alpha(1+k)\right)^{j+\mu+m-\frac{1}{2}}j!}} \end{aligned} \tag{25}$$

Obtained result for AFD indicates that wireless system with dual SC receiver has only half AFD of a wireless system without SC receiver.

III. NUMERICAL RESULTS

Level crossing rate of a α-k-μ/α-μ random process versus normalized crossing threshold for several values of μ and α is shown in Fig. 1. Level crossing rate increases for lower values of crossing threshold, eventualy reaches maximum value and then decreases for higher threshold values above the average signal envelope. Exact behaviour of the LCR is a complex interplay between the model parameters, but in general we can conclude that the higher values of μ and α parameters are more favorable in terms of system performance. The LCR function tails decrease, and in general, the system will perform better, when parameters α and μ increase, resulting in reduced fading severity.

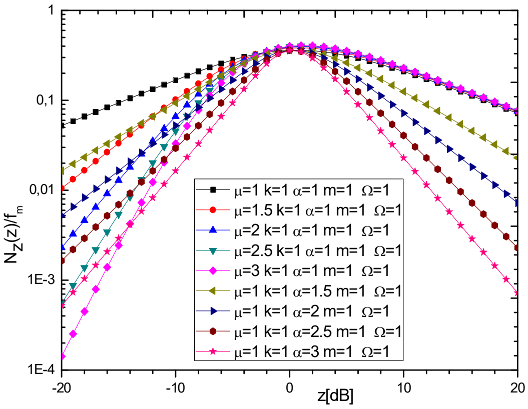

Fig. 1. Average level crossing rate of the ratio of α-k-μ and α-μ random variables

In Fig. 2, cumulative distribution function, or outage probability, versus threshold value, for several values of α-k-μ and α-μ multipath fading parameters is presented. Cumulative distribution function increases as thershold increases, and quickly tends to one as the threshold is increased above the average signal envelope. Outage probability decreases when the threshold is below the average envelope level, with increasing μ and α, as discussed previously.

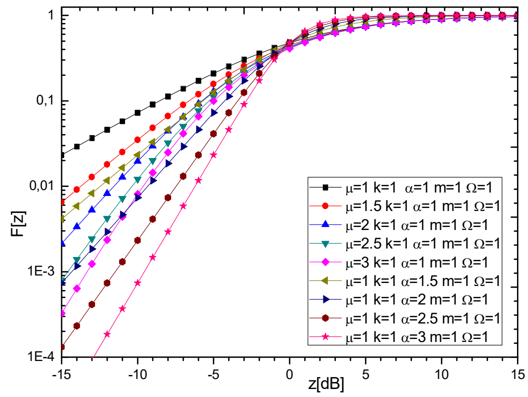

Fig. 2. Cumulative distribution function of the ratio of α-k-μ and α -μ random variables

Obtained expression for cumulative distribution rapidly convergence since 10-12 terms need summed in order to rech accracly on 6th significant digit. This is illustrated by the data shown in Table 1.

TABLE 1. NUMBERS OF TERMS THAT SHOULD BE ADDED IN EXPRESSION (10-12) IN ORDER TO REACH ACCURACY AT 6TH SIGNIFICANT DIGIT.

	z=-10 dB	z=0 dB	z=10 dB
μ=1,k=1,α=1, m=1, Ω=1	5	8	8
μ=1.5,k=1,α=1, m=1, Ω=1	6	9	10
μ=2,k=1,α=1, m=1, Ω=1	6	11	12
μ=2.5,k=1,α=1, m=1, Ω=1	6	12	13
μ=3,k=1,α=1, m=1, Ω=1	8	14	15
μ=1,k=1,α=1.5, m=1, Ω=1	5	8	9
μ=1,k=1,α=2, m=1, Ω=1	5	8	9
μ=1,k=1,α=2.5, m=1, Ω=1	5	8	9
μ=1,k=1,α=3, m=1, Ω=1	5	8	9

In Fig. 3, AFD of the ratio α-k-μ and α-μ random variables is presented, when μ and α change. Conclusions about system performance are more obvious in Fig. 3, since the lower values of fade duration are better. This situation has sense when the threshold is set below the average signal envelope.

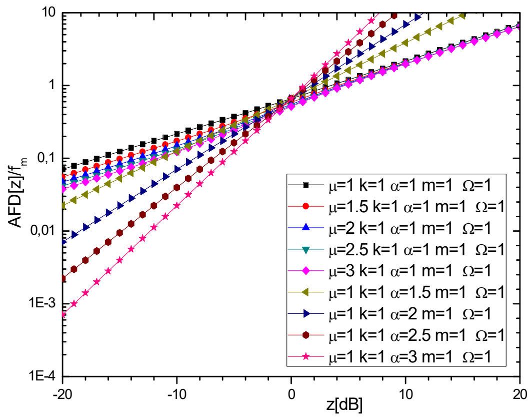

Fig. 3. Average fade duration - AFD of the ratio of α-k-μ and α-μ random variables

CONCLUSION

In this paper, wireless fading channel where desired signal experiences α-k-μ short term fading and co-channel interference α-μ multipath fading is studied. This fading channel model is denoted as α-k-μ/α-μ. In this particular case of the multipath fading channel model the influence of Gaussian noise on outage probability is ignored, since the co-channel interference is considered dominant performance impairment. The α-k-μ/α-μ random variable is defined straight forwardly as ratio of α-k-μ random variable and α-μ random variable. Performance of a radio system operating over α-k-μ/α-μ multipath fading channel can be evaluated by using statistics of α-k-μ/α-μ random variable.

In this paper we have derived probability density function and cumulative distribution function of α-k-μ/α-μ random variable, as well as level crossing rate and average fade duration of α-k-μ/α-μ random process. By using these results, level crossing rate (LCR) of Weibull/Weibull, Nakagami-*m*/Nakagami-*m*, Rayleigh/Rayleigh, Weibull/Nakagami-*m* and Rayleigh/α-μ random processes can be calculated. The results enable analysis of influence of the α-k-μ short term fading severity parameter, Rician factor of α-k-μ short term fading, α-k-μ short term fading non-linearity parameter, α-μ short term fading nonlinearity parameter and α-μ short term fading, severity parameter on level crossing rate and average fade duration.

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