Second order statistics of wireless signals over non-linear LOS fading channel with NLOS interference

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Abstract – In an urban environment, one can frequently encounter a situation where the wireless communication between a user and a wireless stations is impaired by the interfering signals coming from other stations and users. Often the station is in the clear view of the user, but the interfering transmitters are not. Therefore, this kind of wireless channel is interesting to be analysed in more detail. Here we consider a wireless fading channel where useful signal is subject to α-k-μ multipath fading, and co-channel interference is subjected to η-μ multipath fading. We denote the model as (α-k-μ)/(η-μ). This communication channel can be studied as ratio of α-k-μ random process and a η-μ random process. Since the interference is significant in today's wireless networks, the channel model ignores influence of receiver noise on the system performance. Probability density function and cumulative distribution function of (α-k-μ)/(η-μ) distribution are evaluated and level crossing rate of the (α-k-μ)/(η-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)/(η-μ) fading channel are determined. Influence of α-k-μ multipath fading severity and nonlinearity parameters on the level crossing rate is analysed.

Keywords – Level crossing rate, Cumulative distribution function, Average fade duration.

I. Introduction

In this paper, the model of the wireless channel (α-k-μ)/(η-μ) is formulated and estimated. This type of channel contains the desired α-k-μ signal and interference η-μ, and the ratio of this fading and interference itself contains 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, η-μ short term fading nonlinearity parameter and η-μ short term fading severity parameter. The (α-k-μ)/(η-μ) is a general fading channel and multiple known channel models can be derived from (α-k-μ)/(η-μ) fading channel.

There are several papers that discuss the distribution of fading and interference relationships, whose parameters affect the performance of the wireless telecommunication system. In the paper [1], there are first-order statistics for the distribution of η-μ and α-k-μ, eigenvalue functions and cumulative distribution. Using first-order statistics, the moments, the rate of the transient level of random processes α-k-η and η-μ can be calculated. In paper [2], the outage probability of selection combining diversity receiver in the presence of η-μ short term fading and Gama long term fading is evaluated. 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 [3].

In this paper, two random variables and their ratio (α-k-μ)/η-μ) are analyzed, and parameters that affect the performance of a wireless radio system functioning on the principle of a fading channel are evaluated. 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)/(η-μ) random variable. Obtained results can be used in performance analysis of wireless communication system operating over (α-k-μ)/(η-μ) multipath fading channel.

II. Ratio of $\alpha-k-\mu$ and $\eta-\mu$ 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 η-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 a α-k-μ random variable *x* and a η-μ random variable *y* is:

$$z = x/y,\ \ x = zy,\ z = x^{2/\alpha}/y^{2/\alpha},\ z^{\alpha/2} = x/y \qquad (1)$$

Probability density function (PDF) function of variable *x* is [1, eq. (2.14)]:

$$p_x(x) = \frac{2\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}} e^{\mu k} \Omega_1^{\frac{\mu+1}{2}}} x^{\mu} e^{-\frac{\mu(1+k)}{\Omega_1}x^2} I_{\mu-1}\left(2\mu\sqrt{\frac{k(k+1)}{\Omega_1}}x\right) =$$

$$= \frac{2}{e^{\mu k}} \sum_{i_1=0}^{+\infty} \frac{\mu^{2i_1+\mu}(k+1)^{i_1+\mu} k^{i_1} x^{2i_1+2\mu-1}}{\Omega_1^{i_1+\mu}\Gamma(i_1+\mu) i_1!} e^{-\frac{\mu(1+k)}{\Omega_1}x^2} \qquad (2)$$

with Ω=E [R²], denoting average signal power, $I_n(\cdot)$ is the *n*-the order modified Bessel function of the first kind of order *c* by using well-known transformation [6, eq. (17.7.1.1)]:

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$$I_v(x)=\sum_{k=0}^{+\infty}\frac{x^{v+2k}}{2^{v+2k}k!\Gamma(v+k+1)} \tag{3}$$

PDF of η-μ random variable y is [7]:

$$p_y(y)=\frac{4\sqrt{\pi}\,\mu^{\mu+\frac{1}{2}}h^{\mu}y^{2\mu}}{\Gamma(\mu)H^{\mu-\frac{1}{2}}\Omega^{\mu+\frac{1}{2}}}e^{-\frac{2\mu h}{\Omega}y^2}I_{\mu-\frac{1}{2}}\left(\frac{2H\mu}{\Omega}y^2\right)=$$

$$=\frac{4\sqrt{\pi}\,h^{\mu}}{\Gamma(\mu)}\sum_{i_2=0}^{+\infty}\frac{\mu^{2i_2+2\mu}y^{4i_2+4\mu-1}H^{2i_2}}{i_2!\Gamma\left(i_2+\mu+\frac{1}{2}\right)\Omega_2^{2i_2+2\mu}}e^{-\frac{2\mu h}{\Omega_2}y^2} \tag{4}$$

where Ω= E [R^2], stands for the average power, while Γ(a) denotes Gamma function, H and h are signal parameters, written in the function of parameter η_1 as [1]:

$$H=\frac{\eta_1-\eta_1^{-1}}{4},\ h=\frac{2+\eta_1^{-1}+\eta_1}{4} \tag{5}$$

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

$$\dot{z}=\frac{2}{\alpha z^{\frac{\alpha}{2}-1}}\left(\frac{\dot{x}}{y}-\frac{x\dot{y}}{y^2}\right) \tag{6}$$

The first derivative of the ratio of an α-k-μ and η-μ random variables can be viewed as a conditional Gaussian distribution. The variance of z is [8]:

$$\sigma_{\dot{z}}^{\,2}=\frac{4}{\alpha^2z^{\alpha-2}y^2}\left(f_1^{\,2}+z^{\alpha}f_2^{\,2}\right) \tag{7}$$

where variances involved are:

$$f_1^{\,2}=\pi^2f_m^{\,2}\Omega_1,\ f_2^{\,2}=\pi^2f_m^{\,2}\Omega_2 \tag{8}$$

and f_m is maximal Doppler frequency. Conditional probability density function of $\dot{z}$ is [9]:

$$p_{\dot{z}}(\dot{z}/zy)=\frac{1}{\sqrt{2\pi}\sigma_{\dot{z}}}e^{-\frac{\dot{z}^2}{2\sigma_{\dot{z}}^2}} \tag{9}$$

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

$$p_{z\dot{z}y}(z\dot{z}y)=p_{\dot{z}}(\dot{z}/zy)\,p_{zy}(zy)=$$

$$=p_{\dot{z}}(\dot{z}/zy)\,p_y(y)\,p_z(z/y) \tag{10}$$

Conditional probability density function of z is:

$$p_z(z/y)=\left|\frac{dx}{dz}\right|p_x\left(yz^{\frac{\alpha}{2}}\right)=\frac{\alpha}{2}yz^{\frac{\alpha}{2}-1}p_x\left(yz^{\frac{\alpha}{2}}\right) \tag{11}$$

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

$$p_{z\dot{z}y}(z\dot{z}y)=\frac{\alpha}{2}yz^{\frac{\alpha}{2}-1}p_x\left(yz^{\frac{\alpha}{2}}\right)p_y(y)\,p_{\dot{z}}(\dot{z}/zy) \tag{12}$$

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

$$p_{z\dot{z}}(z\dot{z})=\int_0^{+\infty}p_{z\dot{z}y}(z\dot{z}y)\,dy=\frac{\sqrt{2}\,\alpha^2h^{\mu}}{e^{\mu k}\Gamma(\mu)\left(f_1^{\,2}+z^{\alpha}f_2^{\,2}\right)^{\frac{1}{2}}}\cdot$$

$$\cdot\sum_{i_1=0}^{+\infty}\sum_{i_2=0}^{+\infty}\frac{\mu^{2i_1+2i_2+3\mu}(k+1)^{i_1+\mu}k^{i_1}H^{2i_2}z^{\alpha i_1+\alpha\mu+\frac{\alpha}{2}-2}}{\Omega_1^{\,i_1+\mu}\Omega_2^{\,2i_2+2\mu}\Gamma(i_1+\mu)\Gamma\left(i_2+\mu+\frac{1}{2}\right)i_1!i_2!}\cdot$$

$$\cdot\int_0^{+\infty}y^{2i_1+4i_2+6\mu}e^{-\frac{\mu(1+k)z^{\alpha}\Omega_2+2\mu h\Omega_1}{\Omega_1\Omega_2}y^2}e^{-\frac{\alpha^2z^{\alpha-2}y^2}{8\left(f_1^{\,2}+z^{\alpha}f_2^{\,2}\right)}\dot{z}^2}dy \tag{13}$$

LCR is defined as the rate at which a random process crosses level z in the positive or the negative direction. Using relacions (13), the average level crossing rate (LCR) of the ratio α-k-μ and η-μ random variables is [11]:

$$N_z(z)=\int_0^{+\infty}\dot{z}p_{z\dot{z}}(z\dot{z})\,d\dot{z}=\frac{\alpha^2\sqrt{2}}{e^{\mu k}\Gamma(\mu)\sqrt{f_1^{\,2}+z^{\alpha}f_2^{\,2}}}\cdot$$

$$\cdot\sum_{i_1=0}^{+\infty}\sum_{i_2=0}^{+\infty}\frac{\mu^{2i_1+2i_2+3\mu}k^{i_2}(k+1)^{i_2+\mu}z^{\alpha i_2+\alpha\mu+\frac{\alpha}{2}-2}h^{\mu}H^{2i_1}}{\Omega_1^{\,i_2+\mu}\Omega_2^{\,2i_1+2\mu}\Gamma(i_2+\mu)\Gamma\left(i_1+\mu+\frac{1}{2}\right)i_1!i_2!}\cdot$$

$$\cdot\int_0^{+\infty}y^{4i_1+2i_2+6\mu}dy\,e^{-\frac{\mu(1+k)z^{\alpha}\Omega_2+2\mu h\Omega_1}{\Omega_1\Omega_2}y^2}\int_0^{+\infty}\dot{z}d\dot{z}e^{-\frac{\alpha^2z^{\alpha-2}y^2\dot{z}^2}{8\left(f_1^{\,2}+z^{\alpha}f_2^{\,2}\right)}} \tag{14}$$

Resolving second integral in relacion (14), and using very well term [12]:

$$\Gamma(z)=\int_0^{+\infty}t^{z-1}e^{-t}dt \tag{15}$$

we can writing LCR of z:

$$N_z(z)=\frac{2\sqrt{2}\,h^{\mu}\pi f_m\left(\Omega_1+z^{\alpha}\Omega_2\right)^{\frac{1}{2}}}{e^{\mu k}\Gamma(\mu)}\sum_{i_1=0}^{+\infty}\sum_{i_2=0}^{+\infty}\frac{\mu^{i_1+\frac{1}{2}}(k+1)^{i_1+\mu}}{\Gamma(i_1+\mu)}\cdot$$

$$\cdot\frac{k^{i_1}H^{2i_2}\Omega_1^{\,2i_2+2\mu-\frac{1}{2}}\Omega_2^{\,i_1+\mu-\frac{1}{2}}z^{\alpha i_1+\alpha\mu-\frac{\alpha}{2}}\Gamma\left(i_1+2i_2+3\mu-\frac{1}{2}\right)}{\Gamma\left(i_2+\mu+\frac{1}{2}\right)\left((1+k)z^{\alpha}\Omega_2+2h\Omega_1\right)^{i_1+2i_2+3\mu-\frac{1}{2}}i_1!i_2!} \tag{16}$$

Probability density function of the ratio of a α-k-μ random variable and a η-μ random variable is [8]:

$$p_z(z)=\int_0^{+\infty} dy p_z(z/y)p_y(y)=\frac{2\alpha\sqrt{\pi}\,h^{\mu}}{\Gamma(\mu)e^{\mu k}}\sum_{i_1=0}^{+\infty}\sum_{i_2=0}^{+\infty}\frac{(\mu k)^{i_1}}{i_1!i_2!}\cdot$$

$$\cdot\frac{\Omega_1^{2i_2+2\mu}\left(\Omega_2(k+1)\right)^{i_1+\mu}H^{2i_2}\Gamma(i_1+2i_2+3\mu)z^{\alpha i_1+\alpha\mu-1}}{\Gamma(i_1+\mu)\Gamma\left(i_2+\mu+\frac{1}{2}\right)\left(z^{\alpha}(1+k)\Omega_2+2h\Omega_1\right)^{i_1+2i_2+3\mu}} \quad (17)$$

Cumulative distribution function of the ratio of a α-k-μ random variable and η-μ random variable is [13]:

$$F_z(z)=\int_0^z p_z(t)dt=\frac{2\alpha\sqrt{\pi}\,h^{\mu}}{\Gamma(\mu)e^{\mu k}}\sum_{i_1=0}^{+\infty}\sum_{i_2=0}^{+\infty}\frac{(\mu k)^{i_1}\left(\Omega_2(k+1)\right)^{i_1+\mu}}{i_1!i_2!\Gamma(i_1+\mu)}\cdot$$

$$\cdot\frac{\Omega_1^{2i_2+2\mu}H^{2i_2}\Gamma(i_1+2i_2+3\mu)}{\Gamma\left(i_2+\mu+\frac{1}{2}\right)}\int_0^z\frac{t^{\alpha i_1+\alpha\mu-1}dt}{\left(2h\Omega_1+\Omega_2(1+k)t^{\alpha}\right)^{i_1+2i_2+3\mu}} \quad (18)$$

Integral in expression (18) resolve by the form [14]:

$$\int_0^{\lambda}\frac{x^m}{(a+bx^n)^p}dx=\frac{a^{-p}}{n}\left(\frac{a}{b}\right)^{\frac{m+1}{n}}B_z\left(\frac{m+1}{n},p-\frac{m+1}{n}\right),$$

$$z=\frac{b\lambda^n}{a+b\lambda^n},a>0,\ b>0,n>0,0<\frac{m+1}{n}<p \quad (19)$$

where $B_z(a, b)$ is the incomplete Beta function, [4, Eq. 8.38]. Using term (19), we can write the expression for $F_z(z)$:

$$F_z(z)=\frac{\sqrt{\pi}}{\Gamma(\mu)e^{\mu k}}\sum_{i_1=0}^{+\infty}\sum_{i_2=0}^{+\infty}\frac{(\mu k)^{i_1}\Gamma(i_1+2i_2+3\mu)}{2^{2i_2+2\mu-1}h^{2i_2+\mu}\Gamma(i_1+\mu)}\cdot$$

$$\cdot\frac{H^{2i_2}}{\Gamma\left(i_2+\mu+\frac{1}{2}\right)i_1!i_2!}B_{\frac{(1+k)\Omega_2z^{\alpha}}{2h\Omega_1+(1+k)\Omega_2z^{\alpha}}}(i_1+\mu,2i_2+2\mu) \quad (20)$$

The average fade duration(AFD)of wireless communication system [5, 8] with dual branch SIR based is:

$$AFD=\frac{F_z(z)}{N_z(z)}=\frac{\sqrt{\pi}\sum_{i_1=0}^{+\infty}\sum_{i_2=0}^{+\infty}\frac{(\mu k)^{i_1}H^{2i_2}}{2^{2i_2+2\mu}h^{2i_2+2\mu}}}{\pi\sqrt{2}\left(\Omega_1+z^{\alpha}\Omega_2\right)^{\frac{1}{2}}\sum_{i_3=0}^{+\infty}\sum_{i_4=0}^{+\infty}\frac{\mu^{i_3+\frac{1}{2}}(k+1)^{i_3+\mu}}{\Gamma(i_3+\mu)}}\cdot$$

$$\cdot\frac{\dfrac{\Gamma(i_1+2i_2+3\mu)B_{\frac{(1+k)\Omega_2z^{\alpha}}{2h\Omega_1+(1+k)\Omega_2z^{\alpha}}}(i_1+\mu,2i_2+2\mu)}{\Gamma(i_1+\mu)\Gamma\left(i_2+\mu+\frac{1}{2}\right)i_1!i_2!}}{\dfrac{k^{i_3}H^{2i_4}z^{\alpha i_3+\alpha\mu-\frac{\alpha}{2}}\Omega_1^{2i_4+2\mu-\frac{1}{2}}\Omega_2^{i_3+\mu-\frac{1}{2}}\Gamma\left(i_3+2i_4+3\mu-\frac{1}{2}\right)}{\Gamma\left(i_4+\mu+\frac{1}{2}\right)\left((1+k)z^{\alpha}\Omega_2+2h\Omega_1\right)^{i_3+2i_4+3\mu-\frac{1}{2}}i_3!i_4!}} \quad (21)$$

III. NUMERICAL RESULTS

Level crossing rate of a (α-k-μ)/(η-μ) random process versus normalized crossing threshold for several values of *k* and α is shown in Fig. 1. Level crossing rate decreases for negative values of *z*, and the system has better performance when the *k* and α parameters increase. This is the consequence of less probable deep fades that cross low thresholds less frequently. For positive values of *z*, parameter *k* has negligible influence on LCR, while the increaseing α decreases LCR. Generally speaking, the system is more sensitive to changes of the non-linear parameter α.

In Fig. 2, cumulative distribution function, or outage probability, versus threshold value is presented, for several values of α-k-μ and η-μ multipath fading parameter. When the parameters *k* and μ increase for negative dB threshold values CDF decreases, while for positive values of *z*[dB], CDF saturates at outage probability of one, thus indicating total loss of connectivity – as expected for very high thresholds.

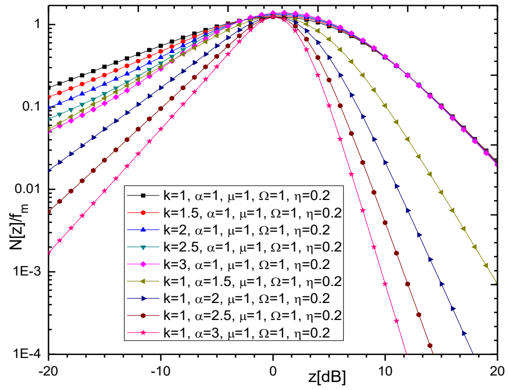

Fig. 1. Average level crossing rate of the ratio of α-k-μ and η-μ random variables

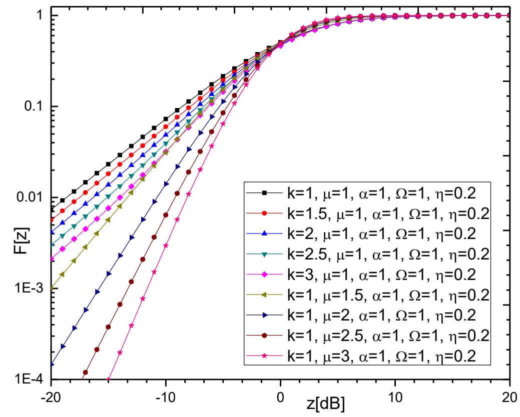

Fig. 2. Cumulative distribution function of the ratio of α-k-μ and η -μ random variables

Obtained expression for cumulative distribution rapidly convergence since 12-15 terms need to be summed in order to rech accracy on 5th significant digit. This is illustrated by the numerical data shown in Table 1.

TABLE 1. NUMBERS OF TERMS THAT SHOULD BE ADDED IN EXPRESSION (10-15) IN ORDER TO REACH ACCURACY AT 5TH SIGNIFICANT DIGIT.

	z=-10 dB	z=0 dB	z=10 dB
k=1, μ=1, α=1, Ω=1, η=0.2	13	13	13
k=1.5, μ=1, α=1, Ω=1, η=0.2	13	14	13
k=2, μ=1, α=1, Ω=1, η=0.2	13	14	14
k=2.5, μ=1, α=1, Ω=1, η=0.2	13	14	14
k=3, μ=1, α=1, Ω=1, η=0.2	13	13	14
k=1, μ=1.5, α=1, Ω=1, η=0.2	14	15	15
k=1, μ=2, α=1, Ω=1, η=0.2	14	17	17
k=1, μ=2.5, α=1, Ω=1, η=0.2	15	17	18
k=1, μ=3, α=1, Ω=1, η=0.2	14	19	20

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

Better performance is expected in cases where the parameter α increases, resulting in lower AFD. Changes to the *k* parameter also affect the change of the AFD function. Due to the increase of the parameter *k*, the AFD function decreases.

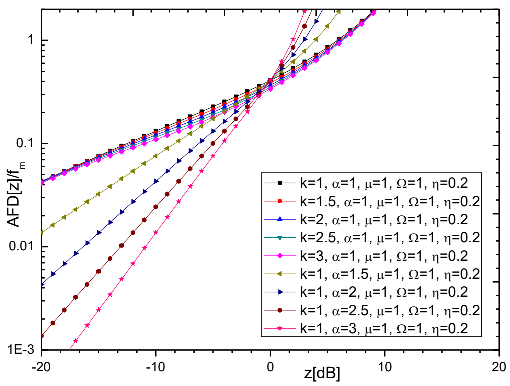

Fig. 3. Average fade duration - AFD of the ratio of α-k-μ and η-μ random variables

IV. CONCLUSION

In this paper, a research on the wireless fading channel was carried out for an environment where multipath fading can be modelled as alpha-k-mu, and interference is modelled as an eta-mu random process. The channel model is denoted as (α-k-μ)/(η-μ). We consider the case where we have fading and interference, as dominating influences, while the influence of Gaussian noise is neglected. Therefore, channel disturbance is considered to be the dominant impairment to the performance of the wireless radio system.

We have derived probability density function and cumulative distribution function of (α-k-μ)/(η-μ) random variable, as well as level crossing rate and average fade duration (of α-k-μ)/(η-μ) random process. By using these results, level crossing rate (LCR) of different, less general random processes can be calculated. The results enable analysis of influence of the α-k-μ fading severity parameter, Rician factor and nonlinearity parameter of the α-k-μ fading, η-μ faded interference nonlinearity parameter and η-μ fading severity parameter on level crossing rate and average fade duration at the wireless receiver.

ACKNOWLEDGEMENT

The paper is supported in part by the projects III44006 and TR32051 funded by Ministry of Education, Science and Technological Development of Republic of Serbia.

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