THE α-η-μ RANDOM PROCESS

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Abstract—**In this paper α-η-μ random variable describing signal envelope variation in nonlinear and non line of sight multipath fading channel with two or more clusters, is considered. Closed form expressions for product ratio maximum and minimum probability density functions of two α-η-μ random variables are calculated. Obtained results can be used in performance analysis of wireless communication system which uses diversity technique to reduce fading effects in fading channels. The influence of the α-η-μ fading parameters on system performance is analyzed.**

Key Words: 1; diversity technique 2; probability density functions 3; α-η-μ random variables

I. INTRODUCTION

Short term fading degrades system performance of wireless communication system and limit channel capacity. The α-η-μ random variable can be used to describe small scale signal envelope variation in nonlinear, non line of sight multipath fading environment with two or more clusters and powers of in phase component and quadrature component are different. This distribution has three parameters. Parameter η is equal to the ratio of in phase component power and quadrature component power. The parameter μ is in relation with the number of clusters in propagation environment and parameter α determining non linearity of environment. The α-η-μ distribution is general distribution and distributions as Rayleigh Nakagami-*m*, Nakagami-*q*, α-μ and η-μ can be derived from α-η-μ distribution. By setting α=2 and η=1, the α-η-μ distribution reduces to Nakagami distribution with *m*=μ and setting for α=2 and η=0, the α-η-μ distribution also reduces to Nakagami-*m* distribution but for *m*= μ/2. By setting for α=2, η=1 and μ=1 the α-η-μ distribution reduce, to Rayleigh distribution, the α-μ can be derived from the α-η-μ distribution by setting η=1 and η=0.5 and Weibull distribution can approximate the α-η-μ distribution by setting η=1 and μ=1. In this paper probability density function of product, ratio maximum and minimum of two α-*k*-μ random variables are calculated .

In paper [1], the expressions for probability density function of *k*-μ and η-μ random variables are derived. These expressions can be used for calculation probability density functions for α-*k*-μ and α-η-μ random variables. Also, by using these expressions can be evaluated outage probability and bit error probability of wireless communication system operating over *k*-μ or η-μ multipath fading channel. In work [2], joint probability of envelope and phase of η-μ random process is derived. Average level crossing rate and average fade duration of wireless communication system operating over η-μ short term fading channel are calculated in work.

The probability density function of product of two α-*k*-μ random variables can be used in performance analysis of wireless relay communication system with two sections subjected to α-k-μ multipath fading. By using derived expression for probability density function can be evaluated outage probability and symbol error probability of proposed wireless system. The probability density function of ratio of two the α-η-μ random variables can be used in performance analysis of wireless communication system operating over α-*k*-μ multipath fading environment in the presence of channel interference subjected to α-*k*-μ multipath fading. By using probability density function outage probability and bit error probability can be determined. The probability density function of maximum of two α-η-μ random variables can be used for performance analysis of wireless communication system with dual selection combining diversity receiver operating over α-η-μ multipath fading channel. The selection combining receiver is used to reduce α-η-μ multipath fading effects on system performance. Probability density function of minimum of two α-η-μ random variables can be used in performance analysis of wireless relay communication system with two sections operating over α-*k*-μ multipath fading channel. By using calculated function, outage probability of considered relay system can be calculated [8].

II. THE $\alpha-\eta-\mu$ VARIABLE

Probability density function (PDF) [2] of η-μ random variable *x* is:

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

$$\cdot\frac{\mu^{\mu+\frac{1}{2}}}{H^{\mu-\frac{1}{2}}}\frac{h^{\mu}}{\Omega^{\mu+\frac{1}{2}}}\sum_{i=0}^{\infty}\left(\frac{H\mu}{\Omega}\right)^{2i+\mu-\frac{1}{2}}\frac{1}{i!\Gamma\left(i+\mu+\frac{1}{2}\right)}x^{4i+4\mu-1}e^{-\frac{2\mu h}{\Omega}x^2}=$$

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

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

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

The α-η-μ random variable is:

$$y=x^{\frac{2}{\alpha}},\quad x=y^{\frac{\alpha}{2}} \tag{3}$$

Probability distribution function (PDF) of y is:

$$p_y(y)=\left|\frac{dx}{dy}\right|p_x\left(y^{\frac{\alpha}{2}}\right)=\frac{2\alpha\sqrt{\pi}h^{\mu}}{\Gamma(\mu)}\sum_{i=0}^{\infty}\frac{\mu^{2i+2\mu}H^{2i}y^{2\alpha i+2\alpha\mu-1}}{i!\Gamma\left(i+\mu+\frac{1}{2}\right)\Omega^{2i+2\mu}}e^{-\frac{2\mu h}{\Omega}y^{\alpha}} \tag{4}$$

Following [3], the cumulative distribution function (CDF) of y can be obtained as:

$$F_y(y)=\int_0^y dtP_y(t)=\frac{\sqrt{\pi}}{\Gamma(\mu)}\sum_{i=0}^{\infty}\frac{H^{2i}}{i!\Gamma\left(i+\mu+\frac{1}{2}\right)2^{2i+2\mu-1}h^{2i+\mu}}\gamma\left(2i+2\mu,\frac{2\mu h}{\Omega}y^{\alpha}\right)=$$

$$=\frac{\sqrt{\pi}}{\Gamma(\mu)}\sum_{i=0}^{\infty}\sum_{j=0}^{\infty}\frac{2^{1+j}\mu^{2i+2\mu+j}H^{2i}h^{\mu+j}y^{2\alpha i+2\alpha\mu+\alpha j}}{i!\Gamma\left(i+\mu+\frac{1}{2}\right)(2i+2\mu)(2i+2\mu+1)_j\,\Omega^{2i+2\mu+j}}e^{-\frac{2\mu h}{\Omega}y^{\alpha}} \tag{5}$$

Function $\gamma(n, x)$ [4] is incomplete Gamma function, and where $(\square)_{(n)}$ denoting the Pocchammer symbol.

III. THE RATIO OF TWO $\alpha-\eta-\mu$ RANDOM VARIABLES

PDF ratio for α-η-μ random variables y_1 and y_2 are [6]:

$$p_{y_1}(y_1)=\frac{2\alpha\sqrt{\pi}h^{\mu}}{\Gamma(\mu)}\sum_{i_1=0}^{\infty}\frac{\mu^{2i_1+2\mu}H^{2i_1}y_1^{2\alpha i_1+2\alpha\mu-1}}{i_1!\Gamma\left(i_1+\mu+\frac{1}{2}\right)\Omega_1^{2i_1+2\mu}}e^{-\frac{2\mu h}{\Omega_1}y_1^{\alpha}} \tag{6}$$

$$p_{y_2}(y_2)=\frac{2\alpha\sqrt{\pi}h^{\mu}}{\Gamma(\mu)}\sum_{i_2=0}^{\infty}\frac{\mu^{2i_2+2\mu}H^{2i_2}y_2^{2\alpha i_2+2\alpha\mu-1}}{i_2!\Gamma\left(i_2+\mu+\frac{1}{2}\right)\Omega_2^{2i_2+2\mu}}e^{\frac{2\mu h}{\Omega_2}y_2^{\alpha}} \tag{7}$$

Ratio of y_1 and y_2 is:

$$\eta=\frac{y_1}{y_2},\quad y_1=\eta y_2 \tag{8}$$

PDF of η [6] is:

$$p_{\eta}(\eta)=\int_0^{\infty}dy_2y_2P_{y_1}(\eta y_2)P_{y_2}(y_2)=\frac{4\alpha^2\pi h^{2\mu}}{\Gamma^2(\mu)}\cdot$$

$$\sum_{i_1=0}^{\infty}\sum_{i_2=0}^{\infty}\frac{\mu^{2i_1+2i_2+4\mu}H^{2i_1+2i_2}\eta^{2\alpha i_1+2\alpha\mu-1}}{i_1!\Gamma\left(i_1+\mu+\frac{1}{2}\right)i_2!\Gamma\left(i_2+\mu+\frac{1}{2}\right)\Omega_1^{2i_1+2\mu}\Omega_2^{2i_2+2\mu}}\cdot$$

$$\int_0^{\infty}dy_2y_2^{2\alpha i_1+2\alpha i_2+4\alpha\mu-1}e^{-2\mu h y_2^{\alpha}\left(\frac{\eta^{\alpha}}{\Omega_1}+\frac{1}{\Omega_2}\right)}=\frac{\alpha\pi}{\Gamma^2(\mu)}\cdot$$

$$\sum_{i_1=0}^{\infty}\sum_{i_2=0}^{\infty}\frac{H^{2i_1+2i_2}\Omega_1^{2i_2+2\mu}\Omega_2^{2i_1+2\mu}\eta^{2\alpha i_1+2\alpha\mu-1}\Gamma(2i_1+2i_2+4\mu)}{i_1!\Gamma\left(i_1+\mu+\frac{1}{2}\right)i_2!\Gamma\left(i_2+\mu+\frac{1}{2}\right)2^{2i_1+2i_2+4\mu-2}h^{2i_1+2i_2+2\mu}\left(\Omega_1+\Omega_2\eta^{\alpha}\right)^{2i_1+2i_2+4\mu}} \tag{9}$$

Random variable which can be calculated or ratio of two α-η-μ random variable is denoted with (α-η-μ)/(α-η-μ). The (α-η-μ)/(α-η-μ) random variable describes signal envelope to interference envelope ratio at output of wireless mobile communication system operating over α-η-μ small scale fading channel in the presence of co channel interference subjected to α-η-μ short form fading. By using the expression for probability density function of (α-η-μ)/(α-η-μ) random variable can be evaluated outage probability, bit error probability moments and channel capacity proposed communication system [7].

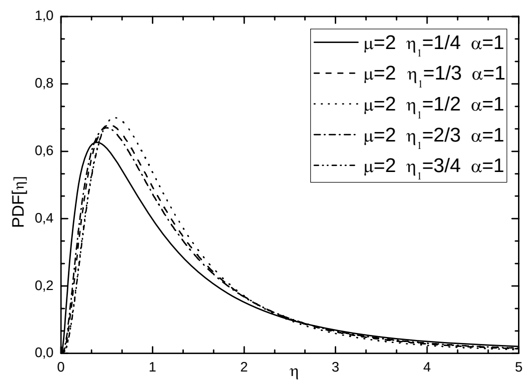

Figure 1. PDF of the ratio of two α-η-μ random variables

IV. THE PRODUCT OF TWO $\alpha-\eta-\mu$ RANDOM VARIABLES

Product of two α-η-μ random variables is:

$$\eta=y_1y_2,\quad y_1=\frac{\eta}{y_2} \tag{10}$$

PDF of η is [9]:

$$p_\eta(\eta) = \int_0^\infty dy_2 \frac{1}{y_2} P_{y_1}\left(\frac{\eta}{y_2}\right) P_{y_2}(y_2) = \frac{4\alpha^2 \pi h^{2\mu}}{\Gamma^2(\mu)} \cdot$$

$$\sum_{i_1=0}^{\infty}\sum_{i_2=0}^{\infty} \frac{\mu^{2i_1+2i_2+4\mu} H^{2i_1+2i_2} \eta^{2\alpha i_1+2\alpha\mu-1}}{i_1!\Gamma\left(i_1+\mu+\frac{1}{2}\right) i_2!\Gamma\left(i_2+\mu+\frac{1}{2}\right) \Omega_1^{2i_1+2\mu} \Omega_2^{2i_2+2\mu}} \cdot$$

$$\int_0^\infty dy_2 y_2^{2\alpha i_2 - 2\alpha i_1 - 1} e^{-\frac{2\mu h \eta^\alpha}{\Omega_1 y_2^\alpha} - \frac{2\mu h}{\Omega_2} y_2^\alpha} \tag{11}$$

$$y_2^\alpha = x, \quad y_2 = x^{\frac{1}{\alpha}}, \quad dy_2 = \frac{1}{\alpha} x^{\frac{1}{\alpha}-1} dx \tag{12}$$

After substitution, we obtain:

$$p_\eta(\eta) = \frac{8\alpha\pi h^{2\mu}}{\Gamma^2(\mu)} \sum_{i_1=0}^{\infty}\sum_{i_2=0}^{\infty} \frac{\mu^{2i_1+2i_2+4\mu} H^{2i_1+2i_2} \eta^{\alpha i_1+\alpha i_2+2\alpha\mu-1}}{i_1!\Gamma\left(i_1+\mu+\frac{1}{2}\right) i_2!\Gamma\left(i_2+\mu+\frac{1}{2}\right) \Omega_1^{i_1+i_2+2\mu} \Omega_2^{i_1+i_2+2\mu}} k_{2i_2-2i_1}\left(4\mu h \sqrt{\frac{\eta^\alpha}{\Omega_1\Omega_2}}\right) \tag{13}$$

Where $K_n(y)$ is modified Bessel function of the second kind[4], order α and argument y.

Random variable calculated as product of two α-η-μ random variable is denoted with (α-η-μ)·(α-η-μ). For (α-η-μ)·(α-η-μ) random variable, probability density function, cumulative distribution function moment generating function and moments can be calculated and for (α-η-μ)·(α-η-μ) random process level crossing rate can, also be calculated. The (α-η-μ)·(α-η-μ) random variable describes signal envelope at output wireless relay communication system with two sections operating over α-η-μ multipath fading environment. By using the expressions obtained in this paper the first order performance measured considered relay system can be evaluated.

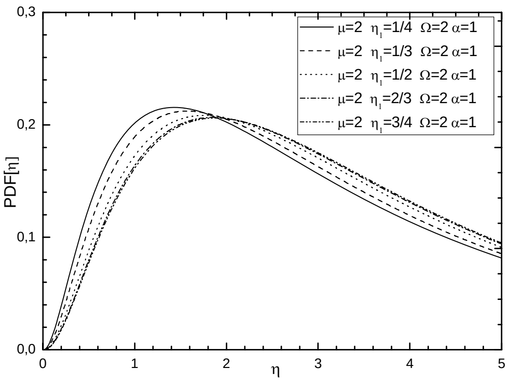

Figure 2. PDF of the product of two α-η-μ random variables

V. THE MAXIMUM OF TWO α−η−μ RANDOM VARIABLES

The maximum of two α-η-μ random variables is:

$$\eta = \max(y_1, y_2) \tag{14}$$

PDF of η is [7]:

$$p_\eta(\eta) = p_{y_1}(\eta) F_{y_2}(\eta) + p_{y_2}(\eta) F_{y_1}(\eta) = 2p_{y_1}(\eta) F_{y_2}(\eta) = \frac{\alpha\pi}{\Gamma^2(\mu)} e^{-2\mu h \eta^\alpha \left(\frac{1}{\Omega_1}+\frac{1}{\Omega_2}\right)}$$

$$\sum_{i_1=0}^{\infty}\sum_{i_2=0}^{\infty}\sum_{j=0}^{\infty} \frac{2^{3+j} \mu^{2i_1+2i_2+j+4\mu} H^{2i_1+2i_2} \eta^{2\alpha i_1+2\alpha i_2+\alpha j+4\alpha\mu-1}}{i_1!\Gamma\left(i_1+\mu+\frac{1}{2}\right) i_2!\Gamma\left(i_2+\mu+\frac{1}{2}\right)(2i_2+2\mu)(2i_2+2\mu+1)_{(j)} \Omega_1^{2i_1+2\mu} \Omega_2^{2i_2+j+2\mu}} \tag{15}$$

Cumulative distribution function (CDF) of η can be obtained as:

$$F_\eta(\eta) = F_{y_1}(\eta) F_{y_2}(\eta) = \frac{\pi}{\Gamma^2(\mu)} \sum_{i_1=0}^{\infty}\sum_{j_1=0}^{\infty}\sum_{i_2=0}^{\infty}\sum_{j_2=0}^{\infty} \frac{2^{2+j_1+j_2} \mu^{2i_1+2i_2+j_1+j_2+4\mu} H^{2i_1+2i_2} h^{j_1+j_2+2\mu}}{i_1!\Gamma\left(i_1+\mu+\frac{1}{2}\right) i_2!\Gamma\left(i_2+\mu+\frac{1}{2}\right)} \cdot$$

$$\frac{\eta^{2\alpha i_1+2\alpha i_2+\alpha j_1+\alpha j_2+4\alpha\mu} e^{-2\mu h \eta^\alpha \left(\frac{1}{\Omega_1}+\frac{1}{\Omega_2}\right)}}{(2i_1+2\mu)(2i_1+2\mu+1)_{(j_1)} (2i_2+2\mu)(2i_2+2\mu+1)_{(j_2)} \Omega_1^{2i_1+j_1+2\mu} \Omega_2^{2i_2+j_2+2\mu}} \tag{16}$$

Random variable calculated as maximum of two α-η-μ random variables can be denoted with max (α-η-μ, α-η-μ). Probability density function, cumulative distribution function, moment generating function and moments of max α-η-μ random variable and level crossing rate of max (α-η-μ, α-η-μ) random process have application in performance analysis of wireless communication system. The max (α-η-μ, α-η-μ) random variable describes signal envelope at output of wireless communication system with selection combining diversity receiver with two inputs operating over α-η-μ small scale fading channel. Selection combining diversity receiver is used to reduce α-η-μ fading effects on system performance.

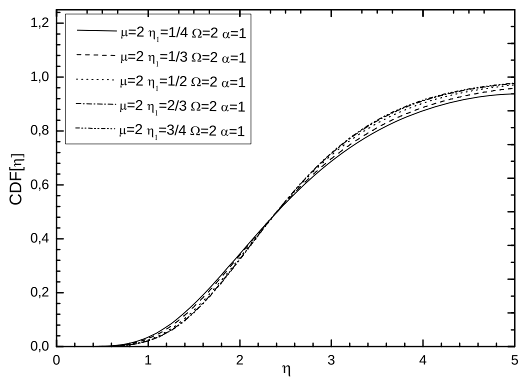

Figure 3. CDF of the maximum of two α-η-μ random variables

VI. THE MINIMUM OF TWO RANDOM α−η−μ VARIABLES

The minimum of two α-η-μ random variables is:

$$\eta = \min(y_1, y_2) \tag{17}$$

PDF of η is [7]:

$$p_{\eta}(\eta)=P_{y_1}(\eta)\left(1-F_{y_2}(\eta)\right)+P_{y_2}(\eta)\left(1-F_{y_1}(\eta)\right)=$$

$$2P_{y_1}(\eta)\left(1-F_{y_2}(\eta)\right)=\frac{4\alpha\sqrt{\pi}h^{\mu}}{\Gamma(\mu)}\sum_{i_1=0}^{\infty}\frac{\mu^{2i_1+2\mu}H^{2i_1}\eta^{2\alpha i_1+2\alpha\mu-1}}{i_1!\Gamma\left(i_1+\mu+\frac{1}{2}\right)\Omega_1^{2i_1+2\mu}}e^{-\frac{2\mu h}{\Omega_1}\eta^{\alpha}}$$

$$\left(1-\frac{\sqrt{\pi}}{\Gamma(\mu)}\sum_{i_2=0}^{\infty}\sum_{j=0}^{\infty}\frac{2^{1+j}\mu^{2i_2+j+2\mu}H^{2i_2}h^{\mu+j}\eta^{2\alpha i_2+2\alpha\mu+\alpha j}}{i_2!\Gamma\left(i_2+\mu+\frac{1}{2}\right)(2i_2+2\mu)(2i_2+2\mu+1)_{(j_2)}\Omega_2^{2i_2+j+2\mu}}e^{-\frac{2\mu h}{\Omega_2}\eta^{\alpha}}\right) \quad (18)$$

CDF of η is:

$$F_{\eta}(\eta)=1-\left(1-F_{y_1}(\eta)\right)\left(1-F_{y_2}(\eta)\right)=1-$$

$$\left(1-\frac{\sqrt{\pi}}{\Gamma(\mu)}\sum_{i_1=0}^{\infty}\sum_{j_1=0}^{\infty}\frac{2^{1+j_1}\mu^{2i_1+j_1+2\mu}H^{2i_1}h^{\mu+j_1}\eta^{2\alpha i_1+2\alpha\mu+\alpha j_1}}{i_1!\Gamma\left(i_1+\mu+\frac{1}{2}\right)(2i_1+2\mu)(2i_1+2\mu+1)_{(j_1)}\Omega_1^{2i_1+j_1+2\mu}}e^{-\frac{2\mu h}{\Omega_1}\eta^{\alpha}}\right)\cdot$$

$$\left(1-\frac{\sqrt{\pi}}{\Gamma(\mu)}\sum_{i_2=0}^{\infty}\sum_{j_2=0}^{\infty}\frac{2^{1+j_2}\mu^{2i_2+j_2+2\mu}H^{2i_2}h^{\mu+j_2}\eta^{2\alpha i_2+2\alpha\mu+\alpha j_2}}{i_2!\Gamma\left(i_2+\mu+\frac{1}{2}\right)(2i_2+2\mu)(2i_2+2\mu+1)_{(j_2)}\Omega_2^{2i_2+j_2+2\mu}}e^{-\frac{2\mu h}{\Omega_2}\eta^{\alpha}}\right) \quad (19)$$

Random variable calculated as minimum of two α-η-μ random variable can be denoted with min (α-η-μ, α-η-μ) and for this random variable can be calculated the first order statistical measures. The second order statistical measures of the min (α-η-μ, α-η-μ) random variable can be used for evaluation of outage probability and average fade duration of wireless relay communication system with two section operating over α-η-μ short term fading environment.

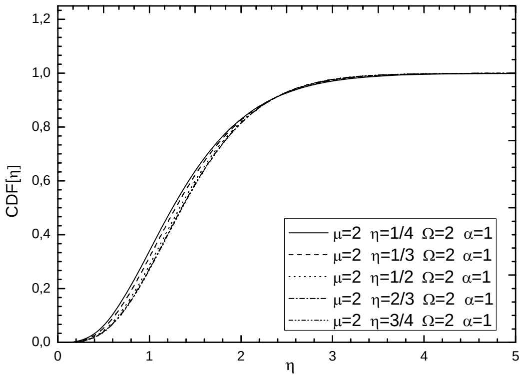

Figure 4. CDF of the minimum of two α-η-μ random variables

CONCLUSION

In this paper, α-η-μ random process is considered. The samples of α-η-μ random process can be calculated as nonlinear transformation of samples of η-μ random process. The α-η-μ random variable can be used to describe signal envelope variation in nonlinear and non line of sight short term fading channels with two or more clusters and in phase component and quadrature component have different powers. In this paper, closed form expressions for probability density functions of product of two α-η-μ random variables, ratio of two α-η-μ random variables, maximum of two α-η-μ random variables and minimum of two α-η-μ random variables are calculated. Since the α-η-μ random variable is general random variable, probability density functions of product, ratio, maximum and minimum for two Nakagami-*m*, Nakagami-*q* and Veibull random variables can be derived from obtained expressions as special cases. By using obtained formulas, can be calculated cumulative distribution functions, moment generates functions and moments of product of two α-η-μ random variables, ratio of two α-η-μ random variables, maximum of two α-η-μ random variables and minimum of two α-η-μ random variables.

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