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LCR OF SC RECEIVER OUTPUT SIGNAL OVER α-κ-μ MULTIPATH FADING CHANNELS

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Abstract. *Wireless mobile communication system with selection combining (SC) diversity receiver is investigated in this paper. Received signal envelope experiences α-κ-μ short term fading resulting in system performance degradation. Level crossing rate (LCR) and average fade duration (AFD) of SC receiver output signal envelope are obtained as rapidly converging infinite series expressions. Numerically evaluated results are presented graphically, in order to discuss the effects of transmission parameters: multipath fading severity, dominant component power and nonlinearity propagation parameter on observed LCR performance of dual SC.*

Key words: *wireless transmission, α-κ-μ fading selection combining (SC), level crossing rate (LCR), average fade duration (AFD)*

1. INTRODUCTION

Short term fading heavily influences and often degrades transmission quality of wireless communication system and limits channel capacity. There are few statistical models that can be used to describe signal envelope variation in multipath fading channel depending on communication scenario and propagation environment. The α-κ-μ distribution is recently reported in technical literature to describe small scale signal envelope variation in fading channels [1]. The α-κ-μ fading model can describe small scale signal envelope variations in nonlinear line of sight multipath fading environments with two or more clusters, and is presented as a function of three parameters: 1) parameter κ, often called Rician factor, denoting the ratio of dominant components power to the power of scattered components; 2) parameter μ, related to the number of clusters in propagation environment; and 3) parameter α related to the non-linearity of propagation environment. Presented α-κ-μ fading model describes propagation environments with more severe fading when the values of Rician κ factor are lower. The α-κ-μ multipath fading is also more severe for lower values of parameter μ, and when parameter μ tends to

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infinity, *α-κ-μ* fading channel approaches in its characteristics to a channel without fading effects. The *α-κ-μ* distribution is general distribution and *α-μ*, Weibull, Nakagami-*m*, Rician and Rayleigh distributions can be derived from *α-κ-μ* distribution as special cases. By setting $\kappa=0$, the *α-κ-μ* distribution reduces to *α-μ* distribution, and for $\kappa=0$ and $\mu=0$, Weibull distribution can be obtained from *α-κ-μ* distribution. By setting $\mu=1$, and $\alpha=2$, the *α-κ-μ* distribution reduces to Rician distribution, while for $\alpha=2$ and $\kappa=0$ the *α-κ-μ* distribution reduces to Nakagami-*m* distribution, and by setting $\alpha=2$, $\kappa=0$ and $\mu=1$, Rayleigh distribution is derived from the *α-κ-μ* distribution.

There are several space combining techniques (spatial diversity combining), which can be used to mitigate the influence of multipath fading on receiver performance, depending on implementation complexity and quality of service [2,3,4]. Maximal ratio combining (MRC) provides the best diversity gain, while SC enables the lowest implementation complexity. In SC diversity, receiver selects input branch with the highest signal-to-noise ratio, or highest envelope level in observed time instant.

The established second order performance measures of wireless mobile communication system are average level crossing rate (LCR) and average fade duration (AFD) [5]. LCR can be calculated as average value of the first time derivative of random process, while AFD is defined as the average time over which the signal envelope ratio remains below a specified level after crossing that level in a downward direction. The system performs better when the values of average level crossing rate are lower.

A considerable number of research papers consider LCR and AFD of wireless system operating over multipath fading channels. In [6], macro diversity SC receiver with two micro diversity MRC receivers operating over Gamma-shadowed Nakagami-*m* multipath fading channel is considered. Closed form expressions for LCR and AFD are evaluated for the proposed system. LCR and AFD of the wireless system in the presence of long term Gamma fading and Rician short term fading are determined in [7]. In [8], the expressions for the LCR and AFD of SC receiver output signal for cases when Rician, Rayleigh and Nakagami-*m* multipath fading are presented. In [9], an approach to for determining second order statistics over *α-κ-μ* fading channels was proposed.

In this paper, we consider a wireless communication system with SC diversity receiver operating over *α-κ-μ* multipath fading channel. Closed form expressions for LCR and AFD of combiner output system have been efficiently evaluated.

2. SYSTEM MODEL

The *α-κ-μ* random process can be obtained after transforming:

$$y = x^{\frac{\alpha}{2}} \tag{1}$$

where x denotes the *κ-μ* random process and α is a positive parameter. The *κ-μ* random variable follows probability density function (PDF):

$$p_y(y) = \frac{2\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}} e^{k\mu} \Omega^{\frac{\mu+1}{2}}} y^{\mu} e^{-\frac{\mu(k+1)y^2}{\Omega}} I_{\mu-1}\left(2\mu\sqrt{\frac{(k+1)ky}{\Omega}}\right), \qquad y \geq 0 \tag{2}$$

where κ is Rician factor, μ is fading parameter, Ω is average power of y, and $I_n(x)$ represents modified Bessell function of n-th order. Previous expression can be further written in the following form:

$$p_y(y) = \frac{2\mu(k+1)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}} e^{k\mu} \Omega^{\frac{\mu+1}{2}}} y^{\mu} e^{-\frac{\mu(k+1)}{\Omega}y^2} \sum_{i_1=0}^{\infty} \frac{\left(2\mu\sqrt{\frac{(k+1)ky}{\Omega}}\right)^{2i_1+\mu-1}}{\Gamma(i_1+\mu)i_1!2^{2i_1+\mu-1}} = \sum_{i_1=0}^{\infty} \frac{2\mu^{2i_1+\mu}(k+1)^{i_1+\mu}k^{i_1} y^{\frac{2i_1+3\mu-1}{2}}}{e^{k\mu}\Omega^{i_1+\mu}\Gamma(i_1+\mu)i_1!} e^{-\frac{\mu(k+1)}{\Omega}y^2} \tag{3}$$

Probability density function (PDF) of α-κ-μ random variable now can be obtained after using relations:

$$p_x(x) = \left|\frac{dy}{dx}\right| p_y\left(x^{\frac{\alpha}{2}}\right) \tag{4}$$

and:

$$\frac{dy}{dx} = \frac{\alpha}{2} x^{\frac{\alpha}{2}-1} \tag{5}$$

After substituting (5) and (3) in (4), the expression for PDF for an α-κ-μ random variable becomes, as in [9]:

$$p_x(x) = \frac{\alpha}{2} x^{\frac{\alpha}{2}-1} \sum_{i_1=0}^{\infty} \frac{2\mu^{2i_1+\mu}(k+1)^{i_1+\mu}k^{i_1}\left(x^{\frac{\alpha}{2}}\right)^{\frac{2i_1+3\mu-1}{2}}}{e^{k\mu}\Omega^{i_1+\mu}\Gamma(i_1+\mu)i_1!} e^{-\frac{\mu(k+1)}{\Omega}\left(x^{\frac{\alpha}{2}}\right)^2} = \sum_{i_1=0}^{\infty} \frac{\alpha\mu^{2i_1+\mu}(k+1)^{i_1+\mu}k^{i_1} x^{\frac{2\alpha i_1+3\alpha\mu+\alpha-4}{4}}}{e^{k\mu}\Omega^{i_1+\mu}\Gamma(i_1+\mu)i_1!} e^{-\frac{\mu(k+1)}{\Omega}x^{\alpha}} \tag{6}$$

Now, cumulative distribution function (CDF) of α-κ-μ random variable can be determined as:

$$F_x(x) = \int_0^x p_x(t)dt = \sum_{i_1=0}^{\infty} \frac{\alpha\mu^{2i_1+\mu}(k+1)^{i_1+\mu}k^{i_1}}{e^{k\mu}\Omega^{i_1+\mu}\Gamma(i_1+\mu)i_1!} \int_0^x t^{\frac{2\alpha i_1+3\alpha\mu+\alpha-4}{4}} e^{-\frac{\mu(k+1)}{\Omega}t^{\alpha}} dt = \sum_{i_1=0}^{\infty} \frac{k^{i_1}\Omega^{\frac{\alpha-\alpha\mu-2\alpha i_1}{4\alpha}}(k+1)^{\frac{\alpha\mu+2\alpha i_1-\alpha}{4\alpha}}}{e^{k\mu}\Gamma(i_1+\mu)i_1!\mu^{\frac{\alpha-\alpha\mu-6\alpha i_1}{4\alpha}}} \gamma\left(\frac{2\alpha i_1+3\alpha\mu+\alpha}{4\alpha}, \frac{\mu(k+1)}{\Omega}x^{\alpha}\right) = \sum_{i_1=0}^{\infty}\sum_{j=0}^{\infty} \frac{4\alpha k^{i_1}\mu^{2i_1+\mu+j}(k+1)^{i_1+\mu+j} x^{\frac{2\alpha i_1+3\alpha\mu+4\alpha j+\alpha}{4}}}{\Omega^{i_1+\mu+j}e^{k\mu}\Gamma(i_1+\mu)i_1!(2\alpha i_1+3\alpha\mu+\alpha)\left(\frac{2\alpha i_1+3\alpha\mu+5\alpha}{4\alpha}\right)_{(j)}} e^{-\frac{\mu(k+1)}{\Omega}x^{\alpha}} \tag{7}$$

where $\gamma(a, x)$ is incomplete Gamma function, and $(a)_n$ is Pocchammer symbol [10]. The joint probability density function (JPDF) of κ-μ random variable and its first time derivative is:

$$P_{y\dot{y}}(y\dot{y}) = p(y)p(\dot{y}) = \sum_{i_1=0}^{\infty} \frac{2\mu^{2i_1+\mu}(k+1)^{i_1+\mu}k^{i_1}y^{\frac{2i_1+3\mu-1}{2}}}{e^{k\mu}\Omega^{i_1+\mu}\Gamma(i_1+\mu)i_1!} e^{-\frac{\mu(k+1)}{\Omega}y^2} \frac{1}{\sqrt{2\pi}\beta} e^{-\frac{\dot{y}^2}{2\beta^2}} =$$
$$\sum_{i_1=2}^{\infty} \frac{2\mu^{\frac{4i_1+2\mu+1}{2}}(k+1)^{\frac{2\mu+2i_1+1}{2}}k^{i_1}y^{\frac{2i_1+3\mu-1}{2}}e^{-\frac{\mu(k+1)}{\Omega}y^2}}{\pi\sqrt{2\pi}f_m e^{k\mu}\Omega^{\frac{2\mu+2i_1+1}{2}}\Gamma(i_1+\mu)i_1!} e^{-\frac{\mu(k+1)}{2\pi^2 fm^2\Omega}\dot{y}^2} \tag{8}$$

where β stands for the time derivate process variance and f_m stands for the Doppler frequency. The time derivate of α-κ-μ random process can be determined by using:

$$x = y^{\frac{2}{\alpha}},\quad y = x^{\frac{\alpha}{2}},\quad \dot{x} = \frac{2}{\alpha}y^{\frac{2}{\alpha}-1}\dot{y},\quad \dot{y} = \frac{\alpha}{2}x^{\frac{\alpha}{2}-1}\dot{x} \tag{9}$$

Now, the JPDF of α-κ-μ random process and its first time-derivative is:

$$p_{x\dot{x}}(x\dot{x}) = |J|\, p_{y\dot{y}}\left(x^{\frac{\alpha}{2}}, \frac{\alpha}{2}x^{\frac{\alpha}{2}-1}\dot{x}\right) \tag{10}$$

where Jacobian of transformation can be determined according to:

$$J = \begin{vmatrix} \frac{\partial y}{\partial x} & \frac{\partial y}{\partial \dot{x}} \\ \frac{\partial \dot{y}}{\partial x} & \frac{\partial \dot{y}}{\partial \dot{x}} \end{vmatrix} = \begin{vmatrix} \frac{\alpha}{2}x^{\frac{\alpha}{2}-1} & 0 \\ 0 & \frac{\alpha}{2}x^{\frac{\alpha}{2}-1} \end{vmatrix} = \frac{\alpha^2}{4}x^{\alpha-2} \tag{11}$$

After substituting (8) and (11) in (10), the expression for JPDF of α-κ-μ random variable and its first time derivative is:

$$p_{x\dot{x}}(x\dot{x}) = |J|\, p_{y\dot{y}}\left(x^{\frac{\alpha}{2}}, \frac{\alpha}{2}x^{\frac{\alpha}{2}-1}\dot{x}\right) =$$
$$\sum_{i_1=0}^{\infty} \frac{\alpha^2\mu^{\frac{4i_1+2\mu+1}{2}}(k+1)^{\frac{2\mu+2i_1+1}{2}}k^{i_1}x^{\frac{2\alpha i_1+3\alpha\mu+3\alpha-8}{4}}}{2\pi\sqrt{2\pi}f_m e^{k\mu}\Omega^{\frac{2\mu+2i_1+1}{2}}\Gamma(i_1+\mu)i_1!} e^{-\frac{\mu(k+1)}{\Omega}x^{\alpha}} e^{-\frac{\mu(k+1)\alpha^2}{8\pi^2 f_m{}^2\Omega}x^{\alpha-2}\dot{x}^2} \tag{12}$$

LCR of α-κ-μ random process is equal to the average mean value of the time derivative of α-κ-μ random process, namely:

$$N_x(x) = \int_0^{\infty} \dot{x}p_{x\dot{x}}(x\dot{x})d\dot{x} =$$
$$\sum_{i_1=0}^{\infty} \frac{\alpha^2\mu^{\frac{4i_1+2\mu+1}{2}}(k+1)^{\frac{2\mu+2i_1+1}{2}}k^{i_1}x^{\frac{2\alpha i_1+3\alpha\mu+3\alpha-8}{4}}}{2\pi\sqrt{2\pi}f_m e^{k\mu}\Omega^{\frac{2\mu+2i_1+1}{2}}\Gamma(i_1+\mu)i_1!} e^{-\frac{\mu(k+1)}{\Omega}x^{\alpha}} \int_0^{\infty} \dot{x}e^{-\frac{\mu(k+1)\alpha^2}{8\pi^2 f_m{}^2\Omega}x^{\alpha-2}\dot{x}^2} d\dot{x} = \tag{13}$$
$$\sum_{i_1=0}^{\infty} \frac{2\pi f_m\mu^{\frac{4i_1+2\mu-1}{2}}(k+1)^{\frac{2\mu+2i_1-1}{2}}k^{i_1}x^{\frac{2\alpha i_1+3\alpha\mu-\alpha}{4}}}{\sqrt{2\pi}e^{k\mu}\Omega^{\frac{2\mu+2i_1-1}{2}}\Gamma(i_1+\mu)i_1!} e^{-\frac{\mu(k+1)}{\Omega}x^{\alpha}}$$

The expression for LCR of *α-κ-μ* random process can be used to determine AFD of wireless communication systems operating over *α-κ-μ* multipath fading channels. Namely, AFD is equal to ratio of cumulative distribution function and its LCR.

3. Performance Analysis

We further consider a wireless communication system with SC receiver operating over identically distributed independent *α-κ-μ* multipath fading channels. Signal envelopes at inputs of SC receiver are denoted with x_1 and x_2, while the signal envelope at output of SC receiver is denoted by x. The SC receiver selects the branch with higher signal level, therefore PDF of SC receiver output signal envelope is:

$$p_x(x) = p_{x_1}(x)F_{x_2}(x) + p_{x_2}(x)F_{x_1}(x) = 2p_{x_1}(x)F_{x_2}(x) =$$

$$2\sum_{i_1=0}^{\infty}\frac{\alpha\mu^{2i_1+\mu}(k+1)^{i_1+\mu}k^{i_1}x^{\frac{2\alpha i_1+3\alpha\mu+\alpha-4}{4}}}{e^{k\mu}\Omega^{i_1+\mu}\Gamma(i_1+\mu)i_1!}e^{-\frac{\mu(k+1)}{\Omega}x^{\alpha}}$$

$$\sum_{i_2=0}^{\infty}\sum_{j=0}^{\infty}\frac{4\alpha k^{i_2}\mu^{2i_2+\mu+j}(k+1)^{i_2+\mu+j}x^{\frac{2\alpha i_2+3\alpha\mu+4\alpha j+\alpha}{4}}}{\Omega^{i_2+\mu+j}e^{k\mu}\Gamma(i_1+\mu)i_2!(2\alpha i_2+3\alpha\mu+\alpha)\left(\frac{2\alpha i_2+3\alpha\mu+5\alpha}{4\alpha}\right)_{(j)}}e^{-\frac{\mu(k+1)}{\Omega}x^{\alpha}} = \qquad (14)$$

$$\sum_{i_1=0}^{\infty}\sum_{i_2=0}^{\infty}\sum_{j=0}^{\infty}\frac{8\alpha^2\mu^{2i_1+2i_2+2\mu+j}(k+1)^{i_1+i_2+2\mu+j}k^{i_1+i_2}x^{\frac{\alpha i_1+\alpha i_2+3\alpha\mu+\alpha+2\alpha j-2}{2}}}{e^{2k\mu}\Omega^{i_1+i_2+2\mu+j}\Gamma(i_1+\mu)i_1!\Gamma(i_2+\mu)i_2!(2\alpha i_2+3\alpha\mu+\alpha)\left(\frac{2i_2+3\mu+5}{4}\right)_{(j)}}e^{-\frac{2\mu(k+1)}{\Omega}x^{\alpha}}$$

Now, CDF of SC receiver output signal envelope is obtained as:

$$F_x(x) = F_{x_1}(x)F_{x_2}(x) = (F_{x_1}(x))^2 =$$

$$\sum_{i_1=0}^{\infty}\sum_{j=0}^{\infty}\frac{4\alpha k^{i_1}\mu^{2i_1+\mu+j}(k+1)^{i_1+\mu+j}x^{\frac{2\alpha i_1+3\alpha\mu+4\alpha j+\alpha}{4}}}{\Omega^{i_1+\mu+j}e^{k\mu}\Gamma(i_1+\mu)i_1!(2\alpha i_1+3\alpha\mu+\alpha)\left(\frac{2i_1+3\mu+5}{4}\right)_{(j)}}e^{-\frac{\mu(k+1)}{\Omega}x^{\alpha}} \qquad (15)$$

Further, JPDF of SC receiver output signal and its first time derivative can be obtained as:

$$p_{x\dot{x}}(x\dot{x}) = p_{x_1\dot{x}_1}(x\dot{x})F_{x_2}(x) + p_{x_2\dot{x}_2}(x\dot{x})F_{x_1}(x) = 2p_{x_1\dot{x}_1}(x\dot{x})F_{x_2}(x) \qquad (16)$$

After substituting (7) and (13) in (17), the expression for LCR can be expressed as:

$$N_x(x) = \int_0^{\infty}\dot{x}p_{x\dot{x}}(x\dot{x})d\dot{x} = 2F_{x_2}(x)\int_0^{\infty}\dot{x}p_{x_1\dot{x}_1}(x\dot{x})d\dot{x} = 2F_{x_2}(x)N_{x_1}(x) =$$

$$\sum_{i_1=0}^{\infty}\sum_{i_2=0}^{\infty}\sum_{j=0}^{\infty}\frac{16\alpha\pi f_m k^{i_1+i_2}\mu^{\frac{4i_1+4i_2+4\mu+2j-1}{2}}(k+1)^{\frac{2i_1+2i_2+4\mu+2j-1}{2}}x^{\frac{\alpha i_1+\alpha i_2+3\alpha\mu+2\alpha j}{2}}e^{-\frac{2\mu(k+1)}{\Omega}x^{\alpha}}}{\sqrt{2\pi}e^{2k\mu}\Omega^{\frac{2i_1+2i_2+4\mu+2j-1}{2}}\Gamma(i_1+\mu)i_1!\Gamma(i_2+\mu)i_2!(2\alpha i_2+3\alpha\mu+\alpha)\left(\frac{2i_2+3\mu+5}{4}\right)_{(j)}} \qquad (17)$$

where $N_{x_1}(x)$ is given by (13).

The AFD of SC receiver can now be determined as [2, Eq.4.14]:

$$T=\frac{F_x(x)}{N_x(x)}=\frac{(F_{x_2}(x))^2}{2F_{x_2}(x)N_{x_1}(x)}=\frac{F_{x_2}(x)}{2N_{x_1}(x)}=$$
$$=\frac{\sum_{i_2=0}^{\infty}\sum_{j=0}^{\infty}\frac{\alpha k^{i_2}(k+1)^{i_2+j+\mu}\mu^{2i_2+j+\mu}x^{\frac{2\alpha i_2+4\alpha j+3\alpha\mu+\alpha}{4}}}{\Omega^{i_2+j+\mu}\Gamma(i_2+\mu)i_2!(2\alpha i_2+3\alpha\mu+\alpha)\left(\frac{2\alpha i_2+3\alpha\mu+5\alpha}{4\alpha}\right)_{(j)}}}{\sum_{i_1=0}^{\infty}\frac{\pi f_m\mu^{\frac{4i_1+2\mu-1}{2}}(k+1)^{\frac{2i_1+2\mu-1}{2}}k^{i_1}x^{\frac{2\alpha i_1+3\alpha\mu-\alpha}{4}}}{\sqrt{2\pi}\Omega^{\frac{2i_1+2\mu-1}{2}}\Gamma(i_1+\mu)i_1!}} \tag{18}$$

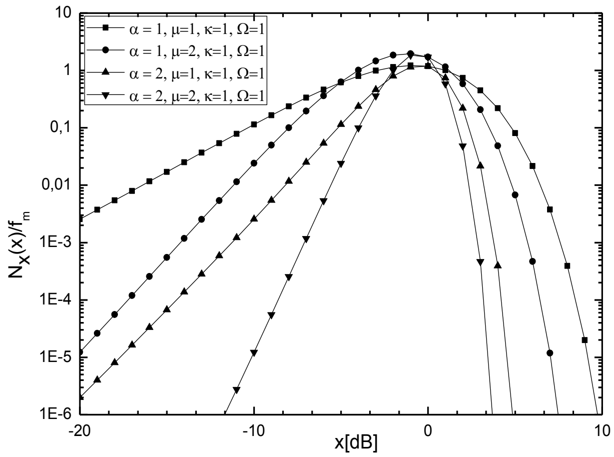

Fig. 1 LCR for different system parameters

4. NUMERICAL RESULTS

In figure 1, normalized LCR values at the SC receiver output signal envelope, versus SC receiver output signal envelope for several values of fading severity and nonlinearity parameter are presented. First, we consider level crossing for the fixed level *x*, set below the average signal level. In this scenario, it is expected that the signal is going to be above level *x* most of the time, and the LCR is going to be relatively low. As the level *x* increases, and comes closer to average signal level, the LCR also increases. The LCR values decrease, and in general, the system will perform better, when parameter μ increases, resulting in reduced fading severity. Also, it is obvious that LCR values decrease as nonlinearity parameter α increases. When the crossing level is above the average signal level, the LCR will start to decrease with increase of level *x*. Again, this is an expected effect, as the signal excursions above its average value will quickly become less likely. The parameters α and μ generally have similar effects as in the previous scenario.

Normalized AFD are presented for different system parameters in Fig. 2. When the crossing threshold *x* is below the average signal level, AFD is low, and this is generally the regime in which the system normally operates. Better performances are expected in the cases when Rician κ factor increases, resulting in lower AFD. Rician κ factor increases when dominant LOS (line-of-sight) component power increases or the power of scattering components decreases, thus making the fading less severe. Performance improvement is expected in less severe environments.

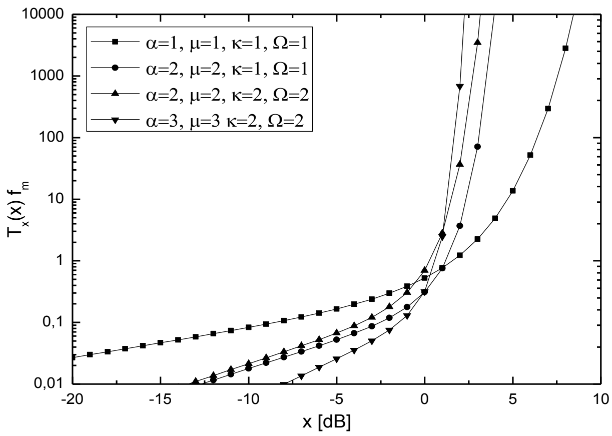

Fig. 2 AFD for different system parameters

5. Conclusion

In this paper, wireless communication system with dual selection combining (SC) diversity receiver operating over *α-κ-μ* multipath fading channel is considered. Main contribution is generality of the analysis, since from *α-κ-μ* distribution model other models can be derived as special cases. Closed form expressions for LCR and AFD of SC receiver output signal envelope are efficiently evaluated and discussed in the function of system parameters. In order to point out the influence of propagation nonlinearity, fading severity and Rician κ factor on observed performances, results are presented graphically.

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