Level Crossing Rate of MRC Receiver Over *k-μ* Multipath Fading Environment

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***Abstract*—In this paper, the wireless system with maximal ratio combining (MRC) diversity receiver operating over independent identical k-μ multipath fading environment is analyzed. The closed form expression for average level crossing rate of MRC receiver output signal is delivered. The average level crossing rate is calculated as value of the first derivative of MRC receiver output signal envelope. The obtained expression can be used for evaluation of average fade duration of proposed wireless system. Numerical results are presented graphically to show influence of k-μ multipath fading parameters on average level crossing rate (LCR) of considered MRC receiver output signal.**

Keywords- average level crossing rate; MRC receiver; k-μ fading.

I. INTRODUCTION

Multipath fading degrades the system performance and it limits the system capacity. Received signal experiences fading resulting in signal envelope variation. There are more distributions that can be used to describe signal envelope variation in fading channels, which are dependent on propagation environment and communication scenario. The most frequently used statistical models for description of signal envelope variation are Rayleigh, Rician, Nakagami-*m*, *α-μ* and *k-μ* [1] [2].

Rayleigh distribution can be used to describe small scale signal envelope variation in linear non line-of-sight multipath fading channels. In linear line-of-sight multipath fading environments, signal envelope variation can be described with Rician distribution. Rician distribution has Rice factor *k*. The Rice factor *k* is related to the ratio of dominant component's power and scattering component's power. In multipath fading environments with two or more clusters signal envelope variation can be analyzed with Nakagami-*m* distribution. Nakagami-*m* distribution has parameter *m*. The parameter *m* is related to the fading severity and to the number of clusters in multipath fading propagation environment.

By setting *m*=1, Nakagami-*m* distribution reduces to Rayleigh distribution. The one sided Gaussian distribution is obtained from Nakagami-*m* distribution for *m*=0,5. When parameter *m* goes to infinite, Nakagami-*m* fading reduces to no fading case. As parameter *m* decreases, the fading severity increases.

The *α-μ* fading can be applied for analyzing small scale signal envelope variation in nonlinear multipath fading environment [3]. The *α-μ* fading is general fading model. The Rayleigh, Weibull and Nakagami-*m* distributions can be derived from *α-μ* distribution [4].

The Weibull distribution can be obtained from the *α-μ* distribution by setting $\mu = 1$. From the Weibull distribution, by setting $\alpha = 2$, the Rayleigh distribution is obtained; (then the Rayleigh distribution can be obtained from *α-μ* distribution by setting α=2 and μ=1).

For $\alpha = 2$, the *α-μ* distribution reduces to Nakagami-*m* distribution.

Now, from the Nakagami-*m* distribution, by setting μ= 1, the Rayleigh distribution is obtained.

Still from the Nakagami-m distribution, the one-sided Gaussian distribution is obtained using as parameter $\mu = 1/2$.

The *k-μ* distribution can be used to describe small scale signal envelope variation in linear line-of-sight multipath fading propagation environments [5]. The *k-μ* distribution has two parameters. The parameter *k* is related to ratio of dominant component's power and scattering component's power. The parameter *μ* is related to the number of clusters in propagation environments.

The *k-μ* distribution is also general distribution. From *k-μ* distribution the Rayleigh, Rician and Nakagami-*m* distributions can be derived as special cases.

By setting for *k=0*, *k-μ* distribution approximates Nakagami-*m* distribution. For *μ=1*, from *k-μ* distribution can be derived Rician distribution and for *μ=1* and *k=0*, *k-μ* distribution reduces to Rayleigh distribution [6].

There are several combining techniques which can be used to reduce *k-μ* multipath fading effects on level crossing rate of wireless system depend on complexity restriction put on communication system and quality of service required from communication system [7].

The most frequently applied combining techniques are maximal ratio combining (MRC), equal gain combining (EGC) and selection combining (SC). The MRC diversity technique provides the best performance and it is the most complex for practical implementation [1].

In telecommunications, maximal-ratio combining (MRC) is a method of diversity combining in which the signals from each channel are added together, the gain of each channel is made proportional to the root mean square (rms) signal level and inversely proportional to the mean square noise

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level in that channel. The different proportionality constants are used for each channel. It is also known as ratio-squared combining and predetection combining. Actually, with Maximal-ratio combining, the diversity branches are weighted by their respective complex fading gains and combined. The MRC is the optimum combiner for independent AWGN channels. MRC can restore a signal to its original shape [8].

The first and second order performance measure can be evaluated for wireless communication system. The first order performance measures are: the outage probability, the bit error probability and the system capacity. The second order performance measures are: the average level crossing rate of output signal envelope and the average fade duration of wireless communication system [9]. The average level crossing rate can be calculated as average value of the first derivative of received output signal and the average fade duration can be obtained as ratio of outage probability and average level crossing rate.

The rest of this paper is organized as follows. In section II, it will be spoken about related works. Section III describes the derivation of level crossing rate of MRC output signal. Numerical results are presented in Section IV. Section V gives last details and concludes the paper.

II. RELATED WORKS

There are more works in open technical literature considering the second order performance measures of wireless communication system operating over multipath fading channels. In [10], wireless communication system with SIR based dual branches SC receiver operating over Rician multipath fading environment in the presence of cochannel interference subjected to Rayleigh multipath fading is considered. The average level crossing rate and the average fade duration are derived for proposed system. The average level crossing rate and average fade duration of SC receiver operating over multipath fading channel are evaluated in [11] and [12] respectively. The performance analysis of selection diversity over exponentially correlated α- μ fading environment is done in [13].

In [6], an exact closed-form expression for the phase-envelope joint distribution of the k-μ fading environment, a general fading model that includes the Rice and the Nakagami-m models as special cases is derived. The derived joint statistics are obtained for both, Rice and Nakagami-m cases.

In paper [14], the ratio of product of two random variables and random variable is considered. The product of two random variables in the numerator of the ratio can represent desired signal envelope subjected to two multipath fading. The random variable in denominator of the ratio can represent cochannel interference signal envelope affected to multipath fading. The results obtained in the paper can be used in performance analysis of wireless communication system operating over multipath fading channels in the presence of cochannel interference which suffer to multipath fading.

The outage performance and symbol error rate analysis of L-Branch MRC for k-μ and η-μ fading are given in [15]. The first order system performance analysis of *L*-branch MRC for k-μ fading is done by Milišić, Hamza and Hadžialić. They made outage performance, outage and Symbol Error Probability performance and BEP/SEP and outage performance analysis in [16], [17] and [18], respectively.

Analysis of channel capacity per unit bandwidth of *L* -branch MRC receiver operating over k-μ fading channels for two adaptive transmission schemes is presented in [19]. Using proposed system model, the optimal power, rate adaptation and constant transmit power policies are analyzed. The expressions for capacity evaluation are derived in the terms of finite sums and the effects of diversity order and fading parameters on the channel capacity for given techniques are considered and numerically presented.

The closed-form expressions for the level crossing rate and average fade duration of k-μ distributed fading signal envelope is presented in [20]. The proposed equations are validated by reduction to known Rice, Rayleigh and Nakagami-*m* distributions as special cases. They are also compared with measured data and shown that provide good agreement.

There are many new studies in the area such as [21]. In this report, a dual-hop decode-amplify-forward (DAF) transmission system over Nakagami-*m* fading channel is studied. The DAF relay system is a hybrid of decode-and-forward and amplify-and-forward relay systems that show the benefits of both decode-and-forward and amplify-and-forward relay systems and is also called hybrid relay system or hybrid DAF relay system. Signal-to-noise ratios and BERs for various system models with varying number of transmit and receive antennas have been discussed.

In this paper, the wireless communication system with MRC diversity receiver operating over multipath fading channel will be analyzed. The received signal is subjected to k-μ multipath fading. MRC diversity receiver is used to reduce multipath fading effects to outage probability and average level crossing rate of proposed system. The closed form expressions for average level crossing rate and average fade duration will be derived. The probability density function and cumulative distribution function of MRC output signal envelope will also be calculated as expressions in closed form. To the best author knowledge the average level crossing rate of MRC output signal envelope in the presence of k-μ multipath fading is not reported in open technical literature. The results obtained in this paper can be used in designing and analyzing of wireless communication system operating over k-μ multipath fading environments.

III. LEVEL CROSSING RATE OF MRC OUTPUT SIGNAL

The wireless communication system with MRC receiver operating over k-μ multipath fading environments is considered. The k-μ multipath fading is presented at the inputs of MRC receiver. The MRC is applied to reduce k-μ fading effects on system performance. The k-μ multipath fading is identical and independent.

Assuming that thermal noise power is equal among branches, the squared MRC receiver signal envelope can be obtained as sum of squared signal envelopes of inputs of MRC:

$$z^2 = \sum_{i-1}^{L} y_i^2 \tag{1}$$

where y_i is k-μ distributed signal envelope which can be given as

$$y_i^2 = y_{i1}^2 + y_{i2}^2 + \cdots + y_{i2\mu}^2 \tag{2}$$

where y_{ik}, k=1, 2,…,2μ, are Gaussian random variables with average A_{ik} and variance σ^2. The probability density function of y_{ik} is

$$p_{y_{ik}}(y_{ik}) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(y_{ik}-A_{ik})^2}{2\sigma^2}} \tag{3}$$

The first derivative of MRC output signal z is:

$$\dot{z} = \frac{1}{z} \sum_{i-1}^{L} y_i \dot{y}_i \tag{4}$$

where

$$y_i \dot{y}_i = y_{i1}\dot{y}_{i1} + y_{i2}\dot{y}_{i2} + \cdots + y_{i2\mu}\dot{y}_{i2\mu} \tag{5}$$

After substituting expression (5) into (4), the $\dot{z}$ can be written in the form:

$$\dot{z} = \frac{1}{z} \sum_{i-1}^{L} \left(y_{i1}\dot{y}_{i1} + y_{i2}\dot{y}_{i2} + \cdots + y_{i2\mu}\dot{y}_{i2\mu} \right) \tag{6}$$

The first derivative of Gaussian random variable is Gaussian random variable. The linear transformation of Gaussian random variable is also Gaussian random variable. Therefore, random variable $\dot{z}$ has conditional distribution:

$$p_{\dot{z}}(\dot{z}/z, y_{ik}) = \frac{1}{\sqrt{2\pi}\sigma_{\dot{z}}} e^{-\frac{(\dot{z}-\bar{\dot{z}})^2}{2\sigma_{\dot{z}}^2}} \tag{7}$$

where $\bar{\dot{z}}$ and $\sigma_{\dot{z}}$ are average value and variance of $\dot{z}$, respectively.

The average value of $\dot{z}$ is

$$\bar{\dot{z}} = \frac{1}{2} \sum_{i-1}^{L} \left(y_{i1}\dot{y}_{i1} + y_{i2}\dot{y}_{i2} + \cdots + y_{i2\mu}\dot{y}_{i2\mu} \right) = 0 \tag{8}$$

since

$$\bar{\dot{y}}_{i1} = \bar{\dot{y}}_{i2} = \cdots = \bar{\dot{y}}_{i2\mu} = 0 \tag{9}$$

The variance of $\dot{z}$ is

$$\sigma_{\dot{z}}^2 = \frac{1}{z^2} \sum_{i-1}^{L} \left(y_{i1}^2 \sigma_{\dot{y}_{i1}}^2 + y_{i2}^2 \sigma_{\dot{y}_{i2}}^2 + \cdots + y_{i2\mu}^2 \sigma_{\dot{y}_{i2\mu}}^2 \right) \tag{10}$$

$$\sigma_{\dot{y}_{i1}}^2 = \sigma_{\dot{y}_{i2}}^2 = \cdots = \sigma_{\dot{y}_{i2\mu}}^2 = 2\pi^2\sigma^2 f_m^2 = \pi^2 f_m^2 \frac{\Omega}{\mu} \tag{11}$$

where f_m is maximal Dopler frequency, Ω is power of k-μ random variable and μ is severity of k-μ fading.

The variance of the first derivative of $\dot{z}$ becomes

$$\sigma_{\dot{z}}^2 = \frac{1}{z^2}\pi^2 f_m^2 \frac{\Omega}{\mu} \sum_{i-1}^{L} \left(y_{i1}^2 + y_{i2}^2 + \cdots + y_{i2\mu}^2 \right) =$$

$$= \frac{1}{z^2}\pi^2 f_m^2 \frac{\Omega}{\mu} z^2 = \pi^2 f_m^2 \frac{\Omega}{\mu} \tag{12}$$

The joint probability density function of z and $\dot{z}$ is

$$p_{z\dot{z}}(z\dot{z}) = p_{\dot{z}}(\dot{z}/z) \cdot p_z(z) = p_{\dot{z}}(\dot{z}) \cdot p_z(z) \tag{13}$$

where random variable z follows k-μ distribution

$$p_z(z) = \frac{2\mu L(k+1)^{\frac{L\mu+1}{2}}}{k^{\frac{L\mu-1}{2}} e^{L\mu k} (L\Omega)^{L\mu+1}} z^{L\mu} e^{-\frac{L\mu(k+1)}{L\Omega}z^2} \cdot$$

$$\cdot I_{L\mu-1}\left(\frac{2L\mu\sqrt{k(k+1)}}{L\Omega} \right) =$$

$$= \frac{2\mu L(k+1)^{\frac{L\mu+1}{2}}}{k^{\frac{L\mu-1}{2}} e^{L\mu k} (L\Omega)^{L\mu+1}} z^{L\mu} e^{-\frac{\mu(k+1)}{\Omega}z^2} \cdot$$

$$\cdot I_{L\mu-1}\left(\frac{2\mu\sqrt{k(k+1)}}{\Omega} \right) \tag{14}$$

The level crossing rate of MRC output signal can be evaluated as the average value of the first derivative of MRC output signal:

$$N_2 = \int_0^\infty d\dot{z}\, \dot{z} p_{z\dot{z}}(z\dot{z}) = \int_0^\infty d\dot{z}\, \dot{z} p_{\dot{z}}(\dot{z}) \cdot p_z(z) =$$

$$= p_z(z) \int_0^\infty d\dot{z}\, p_{\dot{z}}(\dot{z}) \cdot \dot{z} = p_z(z) \frac{1}{\sqrt{2\pi}} \sigma_{\dot{z}} =$$

$$= \frac{1}{\sqrt{2\pi}} \frac{2\mu L(k+1)^{\frac{L\mu+1}{2}}}{k^{\frac{L\mu-1}{2}} e^{L\mu k} (L\Omega)^{L\mu+1}} z^{L\mu} e^{-\frac{\mu(k+1)}{\Omega}z^2} \cdot$$

$$\cdot I_{L\mu-1}\left(\frac{2\mu\sqrt{k(k+1)}}{\Omega} z \right) \cdot \pi f_m \left(\frac{\Omega}{\mu} \right)^{1/2} \tag{15}$$

Normalized N_2 is

$$\frac{N_2}{f_m} = \sqrt{\frac{2\pi}{2}} \frac{2L\sqrt{\mu}(k+1)^{\frac{L\mu+1}{2}}}{k^{\frac{L\mu-1}{2}} e^{L\mu k} L^{L\mu+1} \Omega^{L\mu+1/2}} z^{L\mu} \cdot$$

$$\cdot e^{-\frac{\mu(k+1)}{\Omega}z^2} I_{L\mu-1}\left(\frac{2\mu\sqrt{k(k+1)}}{\Omega} z \right) \tag{16}$$

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IV. NUMERICAL RESULTS

In Fig. 1, the level crossing rate of MRC output signal versus MRC output signal envelope is presented for different values of Rice factor *k*, the number of clusters in propagation environment *m*, power of MRC output signal and the number of inputs of MRC combiner.

The level crossing rate of MRC output signal increases as envelope *z* increases for lower values of envelope *z* and the level crossing rate decreases as envelope *z* increases for higher values of *z*. The average level crossing rate decreases as MRC output signal envelope power increases. The power of MRC output signal *z* has greater influence on average level crossing rate for lower values. The influence of parameters on average level crossing rate decreases as signal envelope increases.

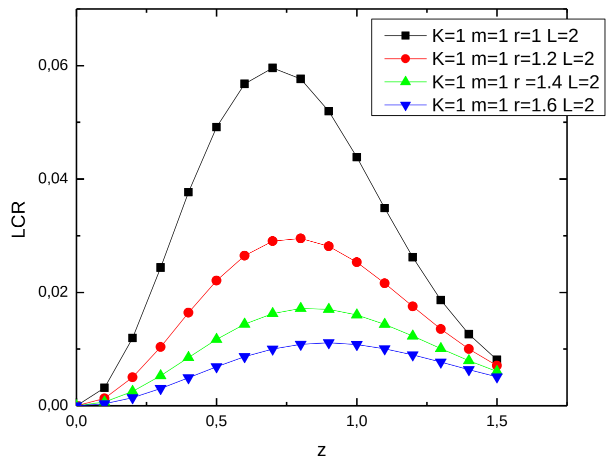

Figure 1. The level crossing rate (LCR) of MRC output signal versus MRC output signal envelope *z*

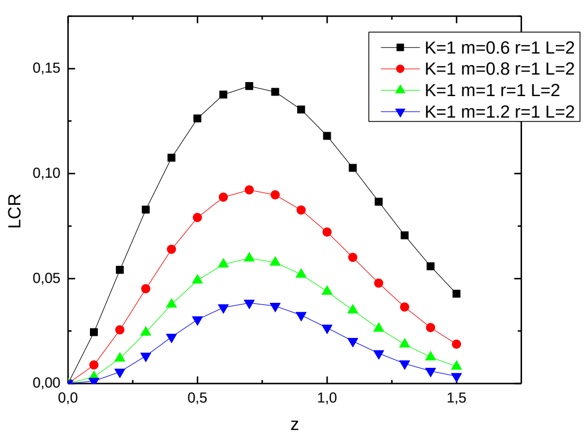

Figure 2. The level crossing rate (LCR) versus MRC output signal envelope *z*

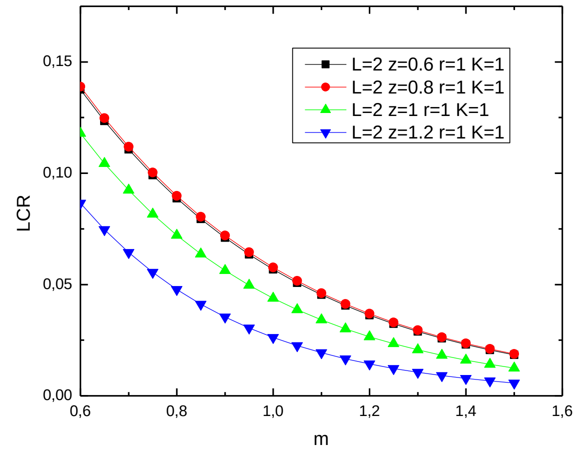

Figure 3. The level crossing rate (LCR) of MRC output signal versus number of clusters in propagation environment, *m*

In Fig. 2, the level crossing rate of MRC output signal versus MRC output signal envelope is presented for different values of parameter *m*. The average level crossing rate decreases as parameter *m* increases. The system performances are better for greater values of parameter *m*.

The level crossing rate of MRC output signal versus number of clusters in propagation environment, *m*, is shown in Fig. 3, for different values of MRC output signal envelope and number of inputs of MRC combiner, power of MRC output signal and Rice factor *k*. The average level crossing rate decreases as parameter *m* increases. The average LCR of MRC output signal envelope also decreases with increasing of MRC output signal envelope *z*. The system performances are better for greater values of parameter *m* and MRC output signal envelope.

The outage probability of wireless system increases as average level crossing rate increases.

V. CONCLUSION

The wireless communication system with MRC diversity receiver operating over multipath fading channel is considered in this paper. Received signal is subjected to k-μ multipath fading environments. The k-μ distribution can be used to describe small scale signal envelope variation in linear non line-of-sight multipath fading environment with two or more clusters. The MRC diversity receiver is used to mitigate k-μ multipath fading effects on system performance. The MRC receiver provides the best performance and has the highest implementation complexity. The closed form expressions for average level crossing rate of MRC receiver output signal and average fade duration of proposed system are evaluated. The average level crossing rate is calculated as the average value of the first derivative of MRC output signal and average fade duration is calculated as the ratio of outage probability and average level crossing rate.

The outage probability and the bit error probability are the first order performance measures and the average level crossing rate of output signal envelope and the average fade duration are the second order performance measures.

Numerical results are presented graphically to show the influence of k-μ multipath fading parameters on level crossing rate. The expression for average level crossing rate of MRC receiver output signal has four parameters. The parameter μ is fading severity. The average level crossing rate decreases as the parameter μ increases. The parameter μ has greater influence on average level crossing rate for lower values of parameter μ. The parameter k is defined as a ratio of dominant components power and scattering components power. The average level crossing rate decreases as the parameter k increases. The influence of parameter k on average level crossing rate is bigger for lower values of parameter μ.

L is the number of branches of MRC receiver. The average level crossing rate decreases as parameter L (number of branches) increases. The parameter Ω is average squared value of signal envelope at the input of the receiver. The average fade duration increases as parameter Ω increases.

The obtained results in this paper can be used for analyzing and designing of wireless communication system with MRC receiver operating over k-μ multipath fading environments.

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