Outage Probability of Macro-Diversity with Switch-and-Stay Receiver over Gamma-Shadowed Kappa-Mu Multipath Fading Channel

Caslav Stefanovic, Srdjan Jovkovic, Vladeta Milenkovic and Mihajlo Stefanovic

***Abstract*—In this paper, macro-diversity (MaD) system with macro-diversity switch-and-stay combining (SSC) receiver and two dual input micro-diversity (MiD) maximal-ratio-combing (MRC) structures is considered. Received signal is under the influence of kappa-mu (k-μ) multipath fading and correlated Gamma long term fading resulting in the system performance degradation. Cumulative density function (CDF) at the output of SSC MaD receiver is obtained and used for the evaluation of the outage probability (OP) of the proposed system. The influence of k-μ multipath fading severity parameter, line-of-sight (LoS) component, Gamma shadowing severity parameter and shadowing correlation parameter on OP of MaD SSC system are examined and discussed.**

***Index Terms*—MaD, MiD, multipath, outage probability, shadowing.**

I. Introduction

Macro-diversity (MaD) reception with MaD receiver and two or more MiD structures can be efficiently used to diminish simultaneously the effects of short-term fading (multipath) and long-term fading (shadowing) on the system performances [1]-[4]. Moreover, MaD receiver can be applied to reduce shadowing while MiD structures can be applied to reduce multipath on the outage performance.

Although, there are more papers considering first and second order statistics of MaD selection combining (SC) system with maximal-ratio-combining (MRC) at micro structure [5]-[8], there is no paper considering system performances of MaD switch-and-stay combining (SSC) system with MiD MRC receivers. SSC receiver is often discussed and applied diversity technique due to its relatively low implementation complexity [9]-[10]. MaD SSC system with MaD SSC receiver and two MiD MRC receivers selects MiD MRC receiver to provide service to user for the time being signal envelope at the outputs larger than the given threshold. When signal envelope average power falls below the given threshold, SSC MaD selects the other MRC to give service to user. MRC MiD provides signals addition from both inputs at single base station (BS) aiming to face multipath while SSC MaD selects the input from different BSs aiming to face shadowing.

The Kappa-Mu (k-μ) distribution describes signal envelope variation in line-of-sight (LoS) multipath fading channels in the environment with two or more clusters. Parameter k is related to availability of LoS propagation between transmitter and receiver of wireless communication channel and can be calculated as the ratio of dominant components power and scattering components power while parameter μ is related to the number of clusters in the propagation environment. Furthermore, k-μ is general distribution, which means that Rayleigh, Rice and Nakagami-m distributions for different values of k-μ parameters can be derived. This distribution accurately fits with experimental data and is often applied in multipath fading environment [11], [12].

On the other hand, Gamma distribution is efficiently used to describe effect of shadowing in wireless communication channel, since it can be advantageous to the log-normal distribution, another well-known distribution often used to describe the effect of shadowing.

In this paper, the sum of one-folded integrals expression of cumulative distribution function (CDF) of MaD SSC receiver output signal envelope in the presence of correlated Gamma shadowed k-μ multipath fading is obtained and used for derivation of outage probability (OP) of the proposed model. Numerical results are presented graphically and the effect of the system parameters on the proposed MaD model are examined.

II. System Model

The MaD system with two MiD MRC structures routing signal to the MaD SSC receiver is shown on Fig. 1. The system is under the influence of correlated Gamma shadowed k-μ multipath fading.

Random variables $x_{ij},\ i = 1,2;\ j = 1,2;$ follow k-μ distribution [13]:

$$p_{x_{ij}}\left(x_{ij}\right) = \frac{2\mu\left(k+1\right)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}} e^{k\mu} \Omega_i^{\frac{\mu+1}{2}}} x_{ij}^{\ \mu} I_{\mu-1}\left(2\mu\sqrt{\frac{k(k+1)}{\Omega_i}}x\right) \cdot e^{-\frac{\mu(k+1)}{\Omega_i}x_{ij}^{\ 2}}, i = 1,2; j = 1,2; \quad (1)$$

where, μ is fading severity factor, k is Rice factor, Ω_i is related to the local mean power of x_{ij} and $I_v(\cdot)$ is the modified Bessel

Manuscript received April 8, 2016; revised September 17, 2016.

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doi: 10.18178/jacn.2016.4.3.226

function of the first kind and order v [14].

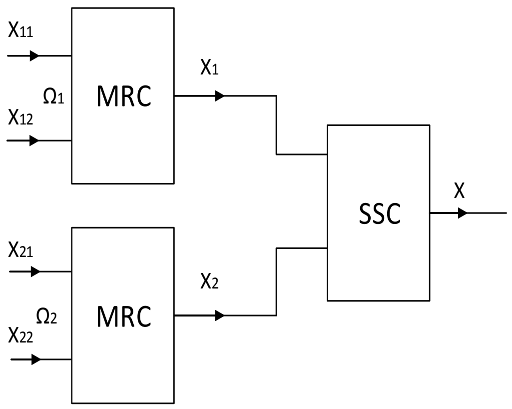

Fig. 1. Block diagram of MaD system with MaD SSC structure and two MiD MRC branches.

The $I_v(\cdot)$ can be transformed by utilization [15], so that the probability density function (PDF) of x_{ij}, $i=1,2;\ j=1,2;$ can be expressed as:

$$p_{x_{ij}}\left(x_{ij}\right)=\frac{2\mu\left(k+1\right)^{\frac{\mu+1}{2}}}{k^{\frac{\mu-1}{2}}e^{k\mu}\Omega_i^{\frac{\mu+1}{2}}}\sum_{i_1=1}^{\infty}\left(\mu\sqrt{\frac{k\left(k+1\right)}{\Omega_i}}\right)^{2i_1+\mu-1}$$

$$\cdot\frac{1}{i_1!\Gamma(i_1+\mu)}x_{ij}^{2i_1+2\mu-1}e^{-\frac{\mu(k+1)}{\Omega_i}x_{ij}^2},i=1,2;j=1,2; \qquad (2)$$

where $\gamma(m,x)$ is incomplete Gamma function [14] and $\Gamma(\cdot)$ is Gamma function [14]. Signal envelopes at outputs of MiD MRC paths are [16]:

$$x_i^2=x_{ij}^2+x_{ij}^2,i=1,2; \qquad (3)$$

Random variables $x_i, i=1,2;$ follow k-μ distribution:

$$p_{x_i}\left(x_i\right)=\frac{4\mu\left(k+1\right)^{\mu+\frac{1}{2}}}{k^{\mu-\frac{1}{2}}e^{2k\mu}\left(2\Omega_i\right)^{\mu+\frac{1}{2}}}\sum_{i_1=1}^{\infty}\left(2\mu\sqrt{\frac{k\left(k+1\right)}{2\Omega_i}}\right)^{2i_1+2\mu-1}$$

$$\cdot\frac{1}{i_1!\Gamma(i_1+2\mu)}x_{ij}^{2i_1+4\mu-1}e^{-\frac{\mu(k+1)}{\Omega_i}x_{ij}^2},i=1,2; \qquad (4)$$

Further, cumulative distribution function (CDF) of $x_i, i=1,2;$ is [16]:

$$F_{x_i}\left(x_i\right)=\int_0^{x_i}p_{x_i}(t)\,dt$$

$$=\frac{4\mu\left(k+1\right)^{\mu+\frac{1}{2}}}{k^{\mu-\frac{1}{2}}e^{2k\mu}\left(2\Omega_i\right)^{\mu+\frac{1}{2}}}\sum_{i_1=1}^{\infty}\left(2\mu\sqrt{\frac{k\left(k+1\right)}{2\Omega_i}}\right)^{2i_1+2\mu-1}$$

$$\cdot\frac{1}{i_1!\Gamma(i_1+2\mu)}\frac{1}{2}\left(\frac{\Omega_i}{\mu(k+1)}\right)^{i_1+2\mu}\gamma\left(i_1+2\mu,\frac{\mu(k+1)}{\Omega_i}x_i^2\right). \qquad (5)$$

Signal envelopes average power at inputs of MiD MRC structures, Ω_1 and Ω_2 follow joint correlated Gamma distribution [17], [18]:

$$p_{\Omega_1\Omega_2}\left(\Omega_1\Omega_2\right)=\frac{\left(\Omega_1\Omega_2\right)^{\frac{c-1}{2}}}{\Gamma(c)\left(1-\rho^2\right)\rho^{c-1}\Omega_0^{c+1}}$$

$$\cdot e^{-\frac{\Omega_1+\Omega_2}{\Omega_0(1-\rho^2)}}I_{c-1}\left(\frac{2\rho}{\Omega_0(1-\rho^2)}\left(\Omega_1\Omega_2\right)^{\frac{1}{2}}\right)$$

$$=\frac{1}{\Gamma(c)(1-\rho^2)\rho^{c-1}\Omega_0^{c+1}}\sum_{i=0}^{\infty}\left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i+c-1}$$

$$\cdot\frac{1}{i!\Gamma(i+c)}\Omega_1^{i+c-1}\Omega_2^{i+c-1}e^{-\frac{\Omega_1+\Omega_2}{\Omega_0(1-\rho^2)}}, \qquad (6)$$

where ρ is correlation coefficient of the shadowing process, c is shadowing parameter and Ω_0 is mean value of Ω_1 and Ω_2.

CDF of MaD SSC output signal envelope is equal to the CDF of the first MiD MRC output signal envelope when the first MiD MRC provides signal to mobile user and the total power at its inputs is higher than predetermined threshold or when the second MiD MRC receiver provides signal to the mobile user and the total power at its inputs is lower than the threshold. Contrary, CDF of MaD SSC output signal envelope is equal to CDF of the second MiD MRC output signal envelope when the second MiD MRC provides the signal to mobile user and the total power at its inputs is higher than the predetermined threshold or when the first MiD MRC provides the mobile user and the total power at its input is lower than the predetermined threshold.

Accordingly, CDF of MaD SSC receiver output signal envelope is:

$$F_x(x)=\frac{1}{2}\int_{\Omega_T}^{\infty}d\Omega_1\int_0^{\infty}F_{x_1}\left(X|\Omega_1\right)p_{\Omega_1\Omega_2}\left(\Omega_1\Omega_2\right)d\Omega_2$$

$$+\frac{1}{2}\int_0^{\Omega_T}d\Omega_1\int_0^{\infty}F_{x_2}\left(X|\Omega_2\right)p_{\Omega_1\Omega_2}\left(\Omega_1\Omega_2\right)d\Omega_2$$

$$+\frac{1}{2}\int_{\Omega_T}^{\infty}d\Omega_2\int_0^{\infty}F_{x_2}\left(X|\Omega_2\right)p_{\Omega_1\Omega_2}\left(\Omega_1\Omega_2\right)d\Omega_1$$

$$+\frac{1}{2}\int_0^{\Omega_T}d\Omega_2\int_0^{\infty}F_{x_1}\left(X|\Omega_1\right)p_{\Omega_1\Omega_2}\left(\Omega_1\Omega_2\right)d\Omega_1$$

$$=\int_{\Omega_T}^{\infty}d\Omega_1\int_0^{\infty}d\Omega_2\,F_{x_1}\left(X|\Omega_1\right)p_{\Omega_1\Omega_2}\left(\Omega_1\Omega_2\right)$$

$$+\int_0^{\Omega_T}d\Omega_1\int_0^{\infty}d\Omega_2\,F_{x_2}\left(X|\Omega_2\right)p_{\Omega_1\Omega_2}\left(\Omega_1\Omega_2\right)$$

$$=S_1+S_2. \qquad (7)$$

where $F_{X|\Omega_1}$ is CDF at the first input of SSC and $F_{X|\Omega_2}$ is CDF at the second input of SSC.

Integral of the first sum S_1 is [14]:

$$S_1 = \int_{\Omega_T}^{\infty} d\Omega_1 \int_0^{\infty} F_{x_1}(X|\Omega_1) p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) d\Omega_2 =$$

$$= \frac{4\mu(k+1)^{\mu+\frac{1}{2}}}{k^{\mu-\frac{1}{2}} e^{2k\mu} 2^{\mu+\frac{1}{2}}} \sum_{i_1=1}^{\infty} \left(2\mu\sqrt{\frac{k(k+1)}{2}}\right)^{2i_1+2\mu-1}$$

$$\cdot \frac{1}{i_1!\,\Gamma(i_1+2\mu)} \frac{1}{2} \left(\frac{1}{\mu(k+1)}\right)^{i_1+2\mu} \frac{1}{\Gamma(c)(1-\rho^2)\rho^{c-1}\Omega_0^{\ c+1}}$$

$$\cdot \sum_{i_2=0}^{\infty} \left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i_2+c-1} \frac{1}{i_2!\,\Gamma(i_2+c)}$$

$$\cdot \left(\Omega_0(1-\rho^2)\right)^{i_2+c} \Gamma(i_2+c)$$

$$\cdot \int_{\Omega_T}^{\infty} \Omega_1^{\ i_2+c-1} \gamma\left(i_1+2\mu, \frac{\mu(k+1)}{\Omega_1} x^2\right) e^{-\frac{\Omega_1}{\Omega_0(1-\rho^2)}} d\Omega_1 \qquad (8)$$

Integral of the second sum S_2 is [14]:

$$S_2 = \int_0^{\Omega_T} d\Omega_1 \int_0^{\infty} F_{x_2}(X|\Omega_1) p_{\Omega_1\Omega_2}(\Omega_1\Omega_2) d\Omega_2$$

$$= \frac{4\mu(k+1)^{\mu+\frac{1}{2}}}{k^{\mu-\frac{1}{2}} e^{2k\mu} 2^{\mu+\frac{1}{2}}} \sum_{i_1=1}^{\infty} \left(2\mu\sqrt{\frac{k(k+1)}{2}}\right)^{2i_1+2\mu-1}$$

$$\times \frac{1}{i_1!\,\Gamma(i_1+2\mu)} \frac{1}{2} \left(\frac{1}{\mu(k+1)}\right)^{i_1+2\mu} \frac{1}{\Gamma(c)(1-\rho^2)\rho^{c-1}\Omega_0^{\ c+1}}$$

$$\cdot \sum_{i_2=0}^{\infty} \left(\frac{\rho}{\Omega_0(1-\rho^2)}\right)^{2i_2+c-1} \frac{1}{i_2!\,\Gamma(i_2+c)}$$

$$\cdot \left(\Omega_0(1-\rho^2)\right)^{i_2+c} \gamma\left(i_2+c, \frac{\Omega_T}{\Omega_0(1-\rho^2)}\right)$$

$$\cdot \int_0^{\infty} \Omega_2^{\ i_2+c-1} \gamma\left(i_1+2\mu, \frac{\mu(k+1)}{\Omega_2} x^2\right) e^{-\frac{\Omega_2}{\Omega_0(1-\rho^2)}} d\Omega_2. \qquad (9)$$

III. Numerical Results

Outage probability (OP), defined as the probability that the output signal envelope of MaD SSC receiver drops below given outage threshold Ω_T, is given as [16]:

$$P_{out} = \int_0^{\Omega_T} p_X(t)\,dt = F_X(\Omega_T) \qquad (10)$$

After substituting (7) in (10), OP is obtained in the form of the sum of one-folded integrals which are solved using software package mathematica and graphically presented for various system parameters on Fig. 2-Fig. 4.

OP of MaD SSC system for various values of Rice factor k, fading severity parameters μ and shadowing severity parameter c and for constant values of correlation parameter ρ, average power Ω_0 and threshold value Ω_T is presented on Fig. 2. It can been seen that by increasing parameter c, the performances improves, since OP decreases. Moreover, the system performance improvement is also evident by increasing parameters μ and k. It's obvious that parameter c has greater impact on OP then parameter μ and k. Further, the Rice factor has greater impact then the severity of multipath fading.

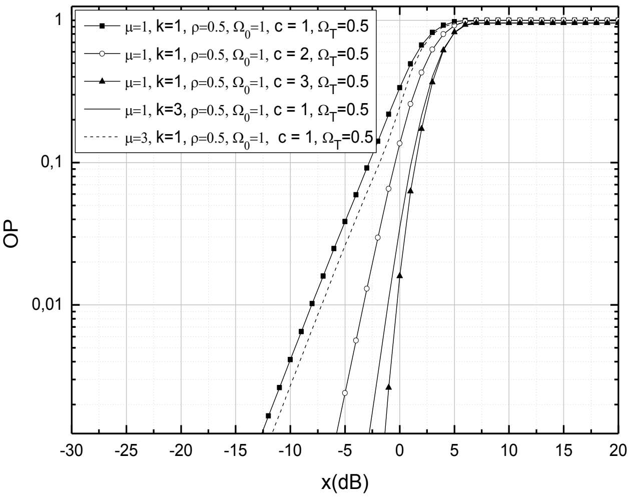

Fig. 2. OP of MaD SSC receiver for different values of parameter ρ and constant values of μ, k, c, Ω_T and Ω_0.

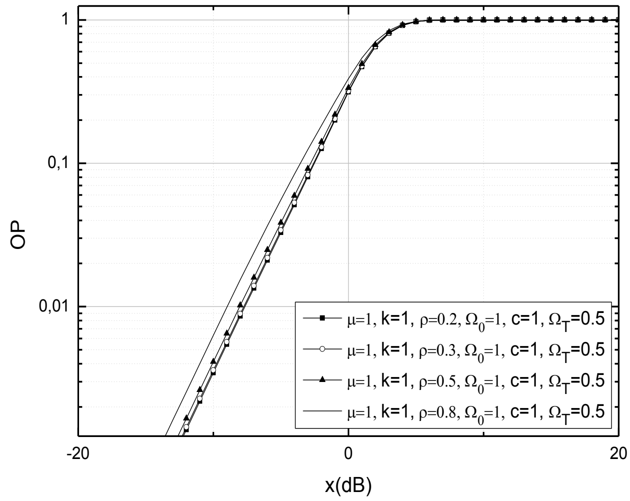

Fig. 3. OP of MaD SSC receiver for different values of parameter ρ and constant values of μ, k, c, Ω_T and Ω_0.

Fig. 3 shows OP of MaD SSC system for constant values k, μ, c, Ω_T and Ω_0 and different values of ρ. Since, there is no correlation for $\rho=0$, the influence of correlation on the MaD SSC system performances increases for higher values of ρ, resulting in system performance degradation, as expected. Since, OP decreases by decreasing parameter ρ influence of correlation on the performances cannot be neglected for higher values of ρ, while it is without significant importance for lower values of ρ.

OP of MaD SSC system for constant values k, μ, c, ρ and Ω_0 and different values of Ω_T is shown on Fig. 4. OP decreases by decreasing parameter Ω_T, which means that for lower values of Ω_T, MaD SSC receiver is more stable since it has less switches between MiD MRC paths.

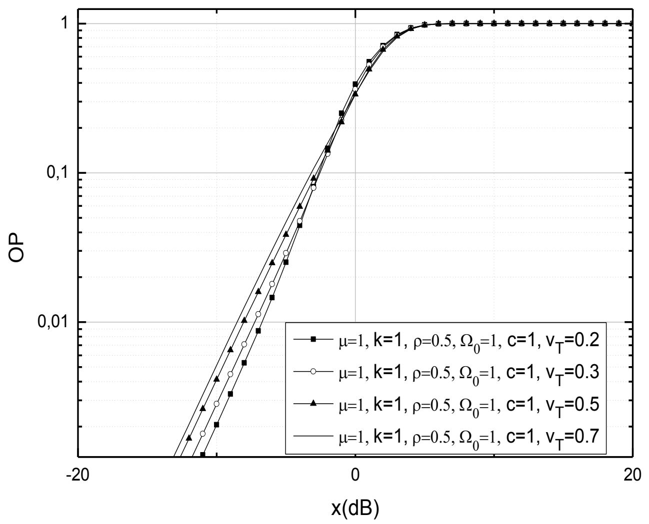

Fig. 4. OP of MaD SSC receiver for different values of parameter Ω_T and constant values of μ, k, c, ρ and Ω_0.

IV. Conclusion

In this paper, MaD technique with MaD switch and stay combining reception and two MiD selection combiners in correlated Gamma shadowed Kappa-Mu multipath fading channel is considered. MaD system with MaD SSC receiver is proposed, since it has lower complexity implementation then other diversity techniques. OP of SSC MaD system in the form of the sum of one-folded integral is obtained and graphically presented in relation to different system model parameters. As expected, the proposed model is theoretically more efficient by modeling with higher values of parameter c, k and μ. Moreover, it can be concluded that parameter c has greater impact on the system performances than parameters μ and k. Moreover, influence of correlation parameter ρ and threshold of SSC receiver Ω_T on the MaD proposed model is also presented and investigated. In general the best possible outcome in theory is achievable by decreasing parameters ρ and Ω_T and by increasing c, k and μ.

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