# Performance of Wireless System in the Presence of κ-μ Multipath Fading, Gamma Shadowing and κ-μ Cochannel Interference

Dragana Krstic, Mihajlo Stefanovic, Vladeta Milenkovic, Dragan Radenkovic Faculty of Electronic Engineering, University of Nis, Nis, Serbia dragana.krstic@elfak.ni.ac.rs

Abstract—In this paper, wireless communication system working over Gamma shadowed  $\kappa$ - $\mu$  small scale fading channel in the presence of cochannel interference exposed to  $\kappa$ - $\mu$  short term fading is analyzed. For considered model, signal to interference ratio (SIR) at the output can be presented as the ratio of  $\kappa$ - $\mu$  random variable and product of square root of Gamma random variable and  $\kappa$ - $\mu$  random variable. Here, probability density function (PDF) and moments of proposed ratio will be evaluated. By using derived expressions, the outage probability and the bit error probability can be calculated. The influences of Rician factors of desired signal envelope and interference envelope on moments will be discussed and analyzed.

Keywords—cochannel interference; Gamma shadowing;  $\kappa$ - $\mu$  fading; moments; probability density function.

## I. INTRODUCTION

The long term fading, short term fading cochannel interference degrade the outage probability, symbol error probability, system capacity and average fade duration of wireless communication system. Small scale fading causes signal envelope average power variation resulting in system performance degradation [1], [2].

There are more distributions using to express signal envelope variation in multipath fading channels [3], [4]. In this paper, desired signal envelope is described with  $\kappa$ -µ distribution [5], [6]. Cochannel interference propagates in Gamma shadowed  $\kappa$ -µ multipath fading channel. The  $\kappa$ -µ distribution depicts small scale signal envelope variation in line-of-sight multipath fading channel with more clusters [7]. The parameter *k* is Rician factor which can be calculated as the ratio of line of sight components power and scattering components power. System performance is better for higher values of Rician factor. Rician factor increases as dominant components increase, or scattering components power decrease [8].

In [9], the authors performed a characterization of the fading experienced in body to body communications channels for fire and rescue personnel using  $\kappa$ - $\mu$  distribution. A

Hristo Ivanov, Erich Leitgeb Institut für Hochfrequenztechnik, Graz University of Technology, Graz, Austria hristo.ivanov@tugraz.at, erich.leitgeb@tugraz.at

general  $\kappa$ - $\mu$  model with parameters  $\kappa$ =2.31 and  $\mu$ =1.19 was obtained using maximum likelihood estimation and shown to provide a good fit to measured data.

In [10], a generalized Laguerre polynomial expansion for the probability density function and the cumulative distribution function of the sum of independent nonidentically distributed squared  $\kappa$ - $\mu$  random variables is proposed. Based on these statistical results, the performance of maximal-ratiocombining diversity techniques operating over  $\kappa$ - $\mu$  fading channels with arbitrary fading parameters are investigated. Derived formulas are mathematically tractable and include as special cases several results available in the technical literature, namely, those of Rice and Nakagami-m fading channels. The  $\kappa$ - $\mu$  multipath fading channel converts to Nakagami-*m* multipath fading channel for  $\kappa$ =0 and to Rician multipath fading channel for  $\mu$ =1. The  $\kappa$ - $\mu$  distribution reduces to Rayleigh distribution by setting  $\kappa$ =0 and  $\mu$ =1.

Cochannel interference experiences Gamma shadowed  $\kappa$ - $\mu$  multipath fading. For  $\kappa$ =0, Gamma shadowed  $\kappa$ - $\mu$  multipath fading channel becomes Gamma shadowed Nakagami-m channel, and for  $\mu$ =1, Gamma shadowed Rician multipath fading channel appears from Gamma shadowed  $\kappa$ - $\mu$  multipath fading channel. For  $\mu$ =1 and k=0, Gamma shadowed  $\kappa$ - $\mu$  multipath fading channel get Gamma shadowed Rayleigh multipath fading channel. When  $\mu$  or k goes to infinity, Gamma shadowed  $\kappa$ - $\mu$  multipath fading channel and when Gamma shadowing severity parameter c goes to infinity, pure  $\kappa$ - $\mu$  multipath fading channel ensues from Gamma shadowed  $\kappa$ - $\mu$  multipath fading channel ensues from Gamma shadowed  $\kappa$ - $\mu$  multipath fading channel ensues from Gamma shadowed  $\kappa$ - $\mu$  multipath fading channel. When parameters  $\mu$ , k and Gamma severity parameter c go to infinity, Gamma shadowed  $\kappa$ - $\mu$  multipath fading channel becomes no fading channel.

There are many papers in available technical literature, dealing with wireless communication system operating over Gamma shadowed multipath fading channel and wireless system in the presence of short term fading and cochannel interference.

In [11]-[18], wireless communication systems with selection combining diversity receiver in the presence of

fading and cochannel interference are analyzed. Probability density function, cumulative distribution function, outage probability and average symbol error probability are calculated.

The wireless communication systems working over Weibull multipath channel with SC receiver in the presence of cochannel interference affected to Weibull multipath fading are evaluated in [11]-[14]. Probability density function, cumulative distribution function, moments, outage probability and bit error probability for several modulation schemes are calculated in these papers. The level crossing rate of dual SC receiver output signal envelope is computed in [13].

Macrodiversity system with macrodiversity SC receiver and two maximal ratio combining (MRC) receivers operating over Gamma shadowed Rician multipath fading channel is analyzed in [17]. The expressions for the PDF, cumulative distribution function (CDF) and moment generating function (MGF) of the output signal-to-noise ratio (SNR) are obtained. Also, the moments of the output SNR and outage probability are analytically derived. Moreover, the average bit error probability (ABEP) for noncoherent binary differential phaseshift keying (BDPSK) is calculated using the MGF based approach while the ABEP for coherent binary phase-shift keying (BPSK) is studied by averaging the conditional bit error probability over the PDF.

The paper [18] treats bit error probability (BEP), symbol error probability (SEP) and outage probability of MRC in the presence of fading. The authors presented fading model, PDF, CDF and PDF, CDF and outage probability of the L-branch MRC output. BEP/SEP is evaluated for broad class of modulation types and for coherent and noncoherent types of detection.

In this work, wireless communication system functioning over multipath fading channel in the presence of to cochannel interference is considered. Desired signal experiences  $\kappa$ - $\mu$ short term fading and cochannel interference experiences Gamma long term fading and  $\kappa$ - $\mu$  short term fading. In interference limited environment, the ratio of desired signal envelope to interference envelope is important performance measure of wireless communication system. For scrutinized case, signal to interference ratio can be calculated as the ratio of the  $\kappa$ - $\mu$  random variable and product of square root of Gamma random variable and the  $\kappa$ - $\mu$  random variable.

In this paper, probability density function and moments of proposed ratio are determined as expressions in closed form. To the best authors' knowledge, the proposed wireless communication system is not reported in open technical literature. The obtained results can be used in performance analysis and designing of wireless communication systems in the presence of long term fading, short term fading and cochannel interference.

# II. PROBABILITY DENSITY FUNCTION OF OUTPUT SIGNAL TO INTERFERENCE RATIO

Signal to interference ratio at the output of wireless communication system is:

$$w = \frac{x}{y \cdot z} \,. \tag{1}$$

(2)

Then, random variable *x* is:

$$x = wyz$$
.

The random variable x follows  $\kappa$ - $\mu$  distribution [5]:

$$p_{x}(x) = \frac{2\mu_{l}(k_{l}+1)^{\frac{\mu_{l}+1}{2}}}{k_{l}^{\frac{\mu_{l}-1}{2}}e^{k_{l}\mu_{l}}\Omega_{l}^{\frac{\mu_{l}+1}{2}}}x^{\mu_{l}} \cdot e^{-\frac{\mu_{l}(k_{l}+1)}{\Omega_{l}}x^{2}} \cdot I_{\mu_{l}-l}\left(2\mu_{l}\frac{\sqrt{k_{l}(k_{l}+1)}}{\Omega_{l}}x^{2}\right) = \\ = \frac{2\mu_{l}(k_{l}+1)^{\frac{\mu_{l}+1}{2}}}{k_{l}^{\frac{\mu_{l}-1}{2}}e^{k_{l}\mu_{l}}\Omega_{l}^{\frac{\mu_{l}+1}{2}}} \cdot \sum_{i=0}^{\infty} \left(\mu_{l}\sqrt{\frac{k_{l}(k_{l}+1)}{\Omega_{l}}}\right)^{2i_{l}+\mu_{l}-1}\frac{1}{i_{l}!\Gamma(i_{l}+\mu_{l})} \cdot \\ \cdot x^{2i_{l}+2\mu_{l}-1} \cdot e^{-\frac{\mu_{l}(k_{l}+1)}{\Omega_{l}}x^{2}} \quad .$$
(3)

where  $k\geq 0$  is the ratio between the total power of the dominant components and the total power of the scattered waves,  $\mu\geq 0$  is given by:

$$\mu = \frac{E^2 \left\{ r^2 \right\}}{\operatorname{var} \left\{ r^2 \right\}} \frac{1 + 2k}{\left( 1 + k \right)^2} ,$$

with *r* is fading signal envelope; and  $I_{\nu}(.)$  is the modified Bessel function of the first kind and arbitrary order v (v real).

Random variable *y* is defined as:

$$y = y_1^{1/2}, y_1 = y^2, \frac{dy_1}{dy} = 2y$$
 (4)

where  $y_1$  is Gamma random variable:

$$p_{y_{1}}(y_{1}) = \frac{1}{\Gamma(c_{1})\beta_{1}^{c_{1}}} y_{1}^{c_{1}-l} e^{-\frac{1}{\beta_{1}}y_{1}}, y_{1} \ge 0$$
(5)

with  $\Gamma(.)$  being gamma function [19], [20].

Probability density function of *y* is:

$$p_{y}(y) = \left|\frac{dy_{1}}{dy}\right| p_{y_{1}}(y^{2}) = \frac{2}{\Gamma(c_{1})\beta_{1}^{c_{1}}} y^{2c_{1}-1} e^{-\frac{1}{\beta_{1}}y^{2}}$$
(6)

Random variable *z* has  $\kappa$ - $\mu$  distribution [5]:

$$p_{z}(z) = \frac{2\mu_{2}(k_{2}+1)^{\frac{\mu_{2}+1}{2}}}{k_{2}^{\frac{\mu_{2}-1}{2}}e^{k_{2}\mu_{2}}\Omega_{2}^{\frac{\mu_{2}+1}{2}}} \cdot \sum_{i_{2}=0}^{\infty} \left(\mu_{2}\sqrt{\frac{k_{2}(k_{2}+1)}{\Omega_{2}}}\right)^{2i_{2}+\mu_{2}-1} \frac{1}{i_{2}!\Gamma(i_{2}+\mu_{2})} \cdot \frac{1}{i_{2}!\Gamma$$

The probability density function of *w* is now:

$$\begin{split} p_{w}\left(w\right) &= \int_{0}^{\infty} dy \int_{0}^{\infty} dz \cdot y \cdot z \cdot p_{x}\left(wyz\right) p_{y}\left(y\right) p_{z}\left(z\right) = \\ &= \frac{2\mu_{1}\left(k_{1}+1\right)^{\frac{\mu_{1}+1}{2}}}{k_{1}^{\frac{\mu_{1}-1}{2}} e^{k_{1}\mu_{1}} \Omega_{1}^{\frac{\mu_{1}+1}{2}} \cdot \sum_{i_{1}=0}^{\infty} \left(\mu_{1}\sqrt{\frac{k_{1}\left(k_{1}+1\right)}{\Omega_{1}}}\right)^{2i_{1}+\mu_{1}-1} \frac{1}{i_{1}!\Gamma\left(i_{1}+\mu_{1}\right)} \cdot \\ &\cdot w^{2i_{1}+2\mu_{1}-1} \cdot \frac{2}{\Gamma\left(c_{1}\right)\beta_{1}^{c_{1}}} \cdot \frac{2\mu_{2}\left(k_{2}+1\right)^{\frac{\mu_{2}+1}{2}}}{k_{2}^{\frac{\mu_{2}-1}{2}} e^{k_{2}\mu_{2}} \Omega_{2}^{\frac{\mu_{2}+1}{2}}} \cdot \sum_{i_{2}=0}^{\infty} \left(\mu_{2}\sqrt{\frac{k_{2}\left(k_{2}+1\right)}{\Omega_{2}}}\right)^{2i_{2}+\mu_{2}-1} \frac{1}{i_{2}!\Gamma\left(i_{2}+\mu_{2}\right)} \cdot \end{split}$$

$$\int_{0}^{\infty} dy \ y^{1+2i_{1}+2\mu_{1}-1+2c_{1}-1} e^{-\frac{1}{\beta_{1}}y^{2}} \int_{0}^{\infty} dz \cdot z^{1+2i_{1}+2\mu_{1}-1+2i_{2}+2\mu_{2}-1} \cdot e^{-\frac{\mu_{1}(k_{1}+1)}{\Omega_{1}}w^{2}y^{2}z^{2}\frac{\mu_{2}(k_{2}+1)}{\Omega_{2}}z^{2}}$$
(8)

Let us introduce the integral  $J_1$  as:

$$J_{1} = \int_{0}^{\infty} dy \, y^{2i_{1}+2\mu_{1}+2c_{1}-1} \cdot e^{-\frac{1}{\beta_{1}}y^{2}} \cdot \frac{1}{2} (\Omega_{1}\Omega_{2})^{i_{1}+\mu_{1}+i_{2}+\mu_{2}} \Gamma(i_{1}+\mu_{1}+i_{2}+\mu_{2})$$

$$\cdot \frac{1}{(\mu_{1}(k_{1}+1)\Omega_{2}w^{2}y^{2}+\mu_{2}(k_{2}+1)\Omega_{1})^{i_{1}+\mu_{1}+i_{2}+\mu_{2}}}$$
(9)

Now, let us introduce replacement:

$$\frac{\mu_1(k_1+1)\Omega_2 w^2 y^2}{\mu_2(k_2+1)\Omega_1} = s$$
(10)

In this case, it is valid:

$$y^{2} = \frac{\mu_{2}(k_{2}+1)\Omega_{1}}{\mu_{1}(k_{1}+1)\Omega_{2}w^{2}}s, \quad ydy = \frac{1}{2}\frac{\mu_{2}(k_{2}+1)\Omega_{1}}{\mu_{1}(k_{1}+1)\Omega_{2}w^{2}}ds$$
(11)

After substituting, the expression (9) becomes:

$$J_{1} = \frac{1}{2} (\Omega_{1}\Omega_{2})^{i_{1}+\mu_{1}+i_{2}+\mu_{2}} \Gamma(i_{1}+\mu_{1}+i_{2}+\mu_{2}) \cdot \frac{1}{2} \left(\frac{\mu_{2}(k_{2}+1)\Omega_{1}}{\mu_{1}(k_{1}+1)}\right)^{i_{1}+\mu_{1}+c_{1}} \cdot \frac{1}{(\mu_{2}(k_{2}+1)\Omega_{1})^{i_{1}+\mu_{1}+i_{2}+\mu_{2}}} \cdot \frac{1}{(\mu_{2}(k_{2}+1)\Omega_{1})^{i_{1}+\mu_{1}+i_{2}+\mu_{2}}} \cdot \frac{1}{(1+s)^{i_{1}+\mu_{1}+i_{2}+\mu_{2}}}$$
(12)

By using the formula [19]:

$$\int_{0}^{\infty} dt t^{a-1} \cdot e^{-ct} \cdot \frac{1}{\left(t+1\right)^{a+1-b}} = \Gamma(a) U(a,b,c), \qquad (13)$$

in which U(a,b,c) is Tricomi confluent hypergeometric function [21], in integral representation ([19], p. 505), the previous written integral obtains the form:

$$J_{1} = \frac{1}{2} \left( \Omega_{1} \Omega_{2} \right)^{i_{1} + \mu_{1} + i_{2} + \mu_{2}} \Gamma \left( i_{1} + \mu_{1} + i_{2} + \mu_{2} \right) \cdot \frac{1}{2} \left( \frac{\mu_{2} \left( k_{2} + 1 \right) \Omega_{1}}{\mu_{1} \left( k_{1} + 1 \right)} \right)^{i_{1} + \mu_{1} + c_{1}} \cdot \frac{1}{\left( \mu_{2} \left( k_{2} + 1 \right) \Omega_{1} \right)^{i_{1} + \mu_{1} + i_{2} + \mu_{2}}} \cdot \Gamma \left( i_{1} + \mu_{1} + c_{1}, c_{1} + 1 - i_{2} - \mu_{2}, \frac{1}{\beta_{1}} \frac{\mu_{2} \left( k_{2} + 1 \right) \Omega_{1}}{\mu_{1} \left( k_{1} + 1 \right) \Omega_{2} w^{2}} \right).$$
(14)

After substituting, the expression for PDF is:

$$\begin{split} p_w(w) &= \frac{2\mu_1(k_1+1)^{\frac{\mu_1+1}{2}}}{k_1^{\frac{\mu_1-1}{2}}e^{k_1\mu_1}\Omega_1^{\frac{\mu_1+1}{2}}} \cdot \sum_{i_1=0}^{\infty} \left( \mu_1 \sqrt{\frac{k_1(k_1+1)}{\Omega_1}} \right)^{2i_1+\mu_1-1} \frac{1}{i_1!\Gamma(i_1+\mu_1)} \\ & \cdot \frac{2\mu_2(k_2+1)^{\frac{\mu_2+1}{2}}}{k_2^{\frac{\mu_2-1}{2}}e^{k_2\mu_2}\Omega_2^{\frac{\mu_2+1}{2}}} \cdot \sum_{i_2=0}^{\infty} \left( \mu_2 \sqrt{\frac{k_2(k_2+1)}{\Omega_2}} \right)^{2i_2+\mu_2-1} \frac{1}{i_2!\Gamma(i_2+\mu_2)} \cdot \end{split}$$

$$\cdot w^{2i_{1}+2\mu_{1}-1} \cdot \frac{2}{\Gamma(c_{1})\beta_{1}^{c_{1}}} \cdot \frac{1}{2} (\Omega_{1}\Omega_{2})^{i_{1}+\mu_{1}+i_{2}+\mu_{2}} \Gamma(i_{1}+\mu_{1}+i_{2}+\mu_{2}) \cdot \\ \cdot \frac{1}{2} \left( \frac{\mu_{2}(k_{2}+1)\Omega_{1}}{\mu_{1}(k_{1}+1)} \right)^{i_{1}+\mu_{1}+c_{1}} \cdot \frac{1}{(\mu_{2}(k_{2}+1)\Omega_{1})^{i_{1}+\mu_{1}+i_{2}+\mu_{2}}} \cdot \\ \Gamma(i_{1}+\mu_{1}+c_{1})U \left( i_{1}+\mu_{1}+c_{1},c_{1}+1-i_{2}-\mu_{2},\frac{1}{\beta_{1}} \frac{\mu_{2}(k_{2}+1)\Omega_{1}}{\mu_{1}(k_{1}+1)\Omega_{2}w^{2}} \right).$$
(15)

# III. MOMENTS OF SIGNAL TO INTERFERENCE RATIO AT THE OUTPUT

Moment of n-th order of signal to interference ratio at the output is:

$$m_{n} = \overline{w^{n}} = \int_{0}^{\infty} dw \, w^{n} \cdot p_{w}(w) = B J_{2}$$
(16)

where

$$J_{2} = \int_{0}^{\infty} dw \ w^{2i_{1}+2\mu_{1}-1+n} \cdot U\left(i_{1}+\mu_{1}+c_{1},c_{1}+1-i_{2}-\mu_{2},\frac{1}{\beta_{1}}\frac{\mu_{2}(k_{2}+1)\Omega_{1}}{\mu_{1}(k_{1}+1)\Omega_{2}w^{2}}\right)$$
(17)

with:

$$\frac{1}{\beta_{1}} \frac{\mu_{2}(k_{2}+1)\Omega_{1}}{\mu_{1}(k_{1}+1)\Omega_{2}w^{2}} = u, \qquad w^{2} = \frac{1}{\beta_{1}} \frac{\mu_{2}(k_{2}+1)\Omega_{1}}{\mu_{1}(k_{1}+1)\Omega_{2}} \frac{1}{u}$$
$$w \, dw = -\frac{1}{2} \frac{1}{\beta_{1}} \frac{\mu_{2}(k_{2}+1)\Omega_{1}}{\mu_{1}(k_{1}+1)\Omega_{2}} \cdot \frac{1}{u^{2}} \, du. \qquad (18)$$

After new substitution, the expression for  $J_2$  is obtained as:

$$J_{2} = -\frac{1}{2} \left( \frac{1}{\beta_{1}} \frac{\mu_{2}(k_{2}+1)\Omega_{1}}{\mu_{1}(k_{1}+1)\Omega_{2}} \right)^{t_{1}+\mu_{1}} \cdot \int_{0}^{\infty} du \, u^{-(i_{1}+\mu_{1}+1)+\frac{n}{2}} \cdot \int_{0}^{\infty} du \, u^{-(i_{1}+\mu_{1}+1)+\frac{n}{2}} \cdot U\left(i_{1}+\mu_{1}+c_{1},c_{1}+1-i_{2}-\mu_{2},u\right) \quad (19)$$

By using the integral [19]:

$$\int_{0}^{\infty} dt t^{b-1} \cdot U(a,c,t) e^{-st} = \frac{\Gamma(b)\Gamma(b+1-c)}{\Gamma(a+b+1-c)} {}_{2}F_{1}(b,b+1-c,a+b+1-c,1-s)$$
(20)

the previous integral is:

$$J_{2} = -\frac{1}{2} \left( \frac{1}{\beta_{l}} \frac{\mu_{2}(k_{2}+1)\Omega_{l}}{\mu_{1}(k_{1}+1)\Omega_{2}} \right)^{i_{1}+\mu_{1}+n/2} \cdot \frac{\Gamma(-i_{1}-\mu_{1}+n/2)\Gamma(-i_{1}-\mu_{1}+n/2+1-c_{1}-1+i_{2}+\mu_{2})}{\Gamma(i_{1}+\mu_{1}+c_{1}-i_{1}-\mu_{1}+n/2-c_{1}+i_{2}+\mu_{2})} \\ {}_{2}F_{1}\left( -i_{1}-\mu_{1}+n/2, -i_{1}-\mu_{1}+n/2-c_{1}+i_{2}+\mu_{2}, n/2+i_{2}+\mu_{2}, 1-s \right) .$$
(21)

The function  ${}_{2}F_{1}(a,b;c;x)$  is Gauss's hypergeometric function [22] and it converges if *c* is not a negative integer for all of |z| < 1 and on the unit circle |z| = 1, [23].

Moment of *w* is finaly:

$$m_{n} = \frac{2\mu_{1}(k_{1}+1)^{\frac{\mu_{1}+1}{2}}}{k_{1}^{\frac{\mu_{1}-1}{2}}e^{k_{1}\mu_{1}}\Omega_{1}^{\frac{\mu_{1}+1}{2}}} \cdot \sum_{i=0}^{\infty} \left(\mu_{1}\sqrt{\frac{k_{1}(k_{1}+1)}{\Omega_{1}}}\right)^{2i_{1}+\mu_{1}-1}\frac{1}{i_{1}!\Gamma(i_{1}+\mu_{1})}$$

$$\cdot \frac{2\mu_{2}(k_{2}+1)^{\frac{\mu_{2}+1}{2}}}{k_{2}^{\frac{\mu_{2}-1}{2}}e^{k_{2}\mu_{2}}\Omega_{2}^{\frac{\mu_{2}+1}{2}}} \cdot \sum_{i_{2}=0}^{\infty} \left( \mu_{2}\sqrt{\frac{k_{2}(k_{2}+1)}{\Omega_{2}}} \right)^{2i_{2}+\mu_{2}-1} \frac{1}{i_{2}!\Gamma(i_{2}+\mu_{2})} \cdot w^{2i_{1}+2\mu_{1}-1} \cdot \frac{2}{\Gamma(c_{1})\beta_{1}^{c_{1}}} \cdot \frac{1}{2}(\Omega_{1}\Omega_{2})^{i_{1}+\mu_{1}+i_{2}+\mu_{2}}\Gamma(i_{1}+\mu_{1}+i_{2}+\mu_{2}) \cdot \frac{1}{2}\left(\frac{\mu_{2}(k_{2}+1)\Omega_{1}}{\mu_{1}(k_{1}+1)}\right)^{i_{1}+\mu_{1}+c_{1}} \cdot \frac{1}{(\mu_{2}(k_{2}+1)\Omega_{1})^{i_{1}+\mu_{1}+i_{2}+\mu_{2}}} \cdot \frac{1}{\Gamma(i_{1}+\mu_{1}+c_{1})\left(-\frac{1}{2}\right)\left(\frac{1}{\beta_{1}}\frac{\mu_{2}(k_{2}+1)\Omega_{1}}{\mu_{1}(k_{1}+1)\Omega_{2}}\right)^{i_{1}+\mu_{1}+n/2}} \cdot \frac{\Gamma(-i_{1}-\mu_{1}+n/2)\Gamma(-i_{1}-\mu_{1}+n/2-c_{1}+i_{2}+\mu_{2})}{\Gamma(n/2+i_{2}+\mu_{2})} \\ {}_{2}F_{1}\left(-i_{1}-\mu_{1}+n/2, -i_{1}-\mu_{1}+n/2-c_{1}+i_{2}+\mu_{2}, n/2+i_{2}+\mu_{2}, 1-s\right). \quad (22)$$

#### **IV. NUMERICAL RESULTS**

The first moment of w (mean value  $\overline{w}$ ) is given versus Rician factor of desired signal  $k_1$ , Rician factor of interference signal  $k_2$  and parameter  $\beta$  in the next figures, with different parameters of curves, such as Gamma large scale severity parameter c and parameter  $\mu$ .

In Fig. 1, the main value w versus Rician factor of desired signal  $k_1$  is presented for  $\beta = 0.2$ ,  $\mu = 2$ , Gamma shadowing severity parameter c=2 and variable Rician factor of interference signal  $k_2$ . In Fig. 2, the first moment  $\overline{w}$  is plotted versus Rician factor of desired signal  $k_1$ . The parameters of curves are: Rician factor of interference signal  $k_2=0.2$ ,  $\mu=2$  and c=2. and changeable parameter  $\beta$ . One can see from Fig. 1 that the first moment of w increases when Rician factor of desired signal,  $k_1$ , increases. The first moment also is growing up with waning of Rician factor of interference signal  $k_2$ . An increment of mean value of w is visible from Fig. 2 for reduction of parameter  $\beta$ , whereby the increase is more pronounced for larger values of Rician factor of desired signal  $k_1$ . In order to achieve sufficient accuracy, we took into account a million of terms in (22) for calculation the moment of SIR at the output of wireless communication system.

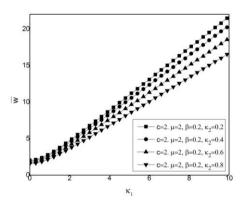


Fig. 1. Mean value  $\overline{w}$  versus Rician factor of desired signal  $k_1$  for  $\beta$ =0.2,  $\mu$ =2, c=2 and variable Rician factor of interference signal  $k_2$ .

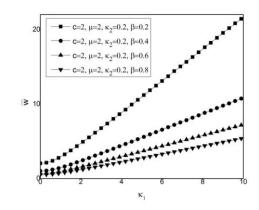


Fig. 2. The first moment of *w* versus Rician factor of desired signal  $k_1$  for c=2,  $\mu=2$ ,  $k_2=0.2$ , and changeable parameter  $\beta$ 

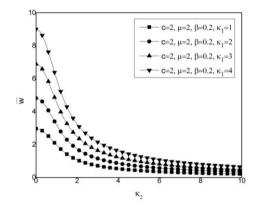


Fig. 3. Mean value *w* versus Rician factor of interference signal  $k_2$  for c=2,  $\mu=2$ ,  $\beta=0.2$  and changeable Rician factor of desired signal  $k_1$ .

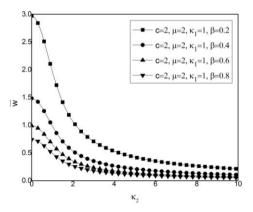


Fig. 4. Mean value  $\overline{w}$  versus Rician factor of interference signal  $k_2$  for c=2,  $\mu=2$ ,  $k_1=1$  and variable parameter  $\beta$ .

Mean value w versus Rician factor of interference signal  $k_2$  is shown in Figs. 3 and 4. In Fig. 3, the parameters of curves are: c=2,  $\mu=2$ ,  $\beta=0.2$  and modifiable Rician factor of desired signal  $k_1$ . In Fig. 4, the curves are drawn for: c=2,  $\mu=2$ ,  $k_1=1$  and variable parameter  $\beta$ . It is evident from these figures that the mean value wanes with increasing of Rician factor of

interference signal  $k_2$ . For small values of Rician factor  $k_2$ , the impact of Rician factor of desired signal  $k_1$  and parameter  $\beta$  is larger. The first moment is getting bigger when Rician factor  $k_1$  is rising and parameter  $\beta$  is decreasing.

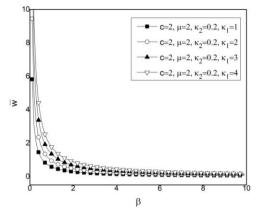


Fig. 5. Mean value *w* versus parameter  $\beta$  for *c*=2,  $\mu$ =2, Rician factor of interference signal  $k_2$ =0.2, and variable Rician factor of desired signal  $k_1$ .

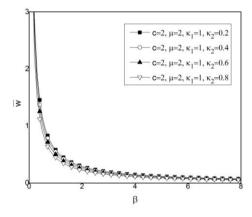


Fig. 6. The first moment of *w* versus parameter  $\beta$  for *c*=2,  $\mu$ =2, Rician factor of desired signal  $k_1$ =1 and changeable Rician factor of interference signal  $k_2$ 

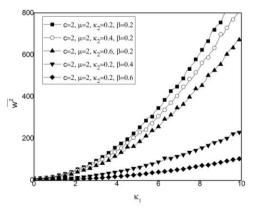


Fig. 7. The second moment of *w* versus Rician factor of desired signal  $k_1$  with parameters c=2 and  $\mu=2$ , and variable Rician factor of interference signal  $k_2$  and parameter  $\beta$ .

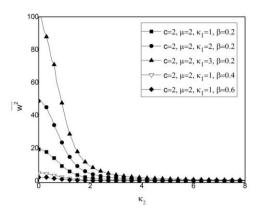


Fig. 8. The squared average value  $w^2$  versus Rician factor of interference signal  $k_2$  for c=2,  $\mu=2$ , and changeable Rician factor of desired signal  $k_1$  and parameter  $\beta$ .

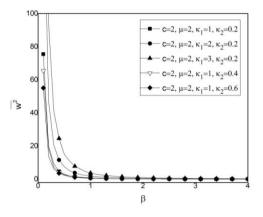


Fig. 9. The second moment  $\overline{w^2}$  versus parameter  $\beta$  for c=2,  $\mu=2$  and mutable Rician factor of desired signal  $k_1$  and Rician factor of interference  $k_2$ .

The first moment of w versus parameter  $\beta$  is displayed in Figs. 5. and 6. Gamma shadowing severity parameter c and  $\kappa$ - $\mu$  distribution parameter  $\mu$  are equal for all presented cases:  $c=2, \mu=2$ . The Rician factor of desired signal  $k_1$  is changeable in Fig. 5. and Rician factor of interference signal  $k_2$  is varying in Fig. 6. It is obvious from these two figures that mean value  $\overline{w}$  is getting smaller with an enlargement of parameter  $\beta$ . One can also see that  $\overline{w}$  declines very fast for small  $\beta$  and has approximately constant value for the remaining values of the parameter  $\beta$ .

The second moment of w (squared average value  $w^2$ ) is given versus Rician factor of desired signal  $k_1$ , Rician factor of interference signal  $k_2$  and parameter  $\beta$  in Figs. 7 to 9, respectively. The parameters of curves are Gamma shadowing severity parameter c and parameter  $\mu$ : c=2,  $\mu=2$ , as well as Rician factor of desired signal  $k_1$ , Rician factor of interference signal  $k_2$  and parameter  $\beta$ . It is obvious from last three figures that: second moment  $\overline{w^2}$  enhances with aggrandizement of Rician factor of desired signal  $k_1$ ; decreases with increasing of Rician factor of interference signal  $k_2$  and parameter  $\beta$ . The greatest impact on increasing of squared average value of w has waning of parameter  $\beta$ . The influence of parameter  $\beta$  is bigger for higher values of Rician factor of desired signal  $k_1$ .

## V. CONCLUSION

In this paper, wireless communication system operating over multipath fading channel in the presence of cochannel interference subjected to shadowed short term fading is considered. Desired signal experiences  $\kappa$ - $\mu$  short term fading and cochannel interference signal experiences Gamma long term fading and  $\kappa$ - $\mu$  short term fading.

For this model, desired signal envelope to cochannel interference envelope ratio can be calculated as the ratio of the  $\kappa$ - $\mu$  random variable and product of square rooted Gamma random variable and the  $\kappa$ - $\mu$  random variable. The closed form expression for probability density function and moments of proposed signal to interference ratio at the output of considered wireless system are calculated. The obtained expressions rapidly converge since ten to fifteen terms need to be summed to achieve accuracy at fifth significant digit for any values of fading parameters. The influence of Rician factors of desired signal and cochannel interference and Gamma long term fading severity parameter on moments are analyzed and discussed.

By using the obtained expressions, moments of SIR for wireless system in the presence of Rician desired signal and Gamma shadowed Rician cochannel interference can be calculated as special case. The system performance is better for higher values of moments. When Rician factor of desired signal increases, the first moment and the second moment also increase. When Gamma long term fading severity parameter decreases, system performance also decreases.

### ACKNOWLEDGMENT

This paper has been partially funded by the Ministry of Education, Science and Technological Development of Republic of Serbia under projects TR-33035 and III-44006.

#### REFERENCES

- M. K. Simon, M. S. Alouini, Digital Communication over Fading Channels. USA: John Wiley & Sons, 2000.
- [2] W.C.Y. Lee, Mobile communications engineering, Mc-Graw-Hill, NewYork, USA, 2003.
- [3] S. Panic, M. Stefanović, J. Anastasov, P. Spalevic, Fading and Interference Mitigation in Wireless Communications. USA: CRC Press, 2013.
- [4] P. M. Shankar, Fading and Shadowing in Wireless Systems, Springer, Dec 7, 2011. DOI 10.1007/978-1-4614-0367-8
- [5] M.D. Yacoub, "The κ-μ distribution", http://www.eletrica.ufpr.br/anais/sbrt/SBrT19/00100000008700059.pdf
- [6] M. D. Yacoub, The α-μ distribution and the κ-μ distribution, IEEE Antennas and Propagation Magazine, 2007, 49, 1, pp. 68-81.

- [7] U. S. Dias, M. D. Yacoub, "The κ- μ Phase Envelope joint Distribution, IEEE Transactions on Communications, no. 01, 2010; 58, pp. 40-45. DOI:10.1109/TCOMM.2010.01.080175
- [8] S. L. Cotton, W. G. Scanlon, "Higher-order statistics for  $\kappa$ - $\mu$  distribution", Electronics Letters, 43(22), no 2, 2007, pp. 1215–1217, DOI:10.1049/el:20072372
- [9] S. L. Cotton, W. G. Scanlon, J. Guy, "The \kappa -\mu Distribution Applied to the Analysis of Fading in Body to Body Communication Channels for Fire and Rescue Personnel", IEEE Antennas and Wireless Propagation Letters, Vol.7, 2008, pp. 66-69.
- [10] K. Peppas, "Sum of nonidentical squared variates and applications in the performance analysis of diversity receivers", IEEE Transactions on Vehicular Technology, vol. 61, 1, 2012, pp. 413-419.
- [11] M. C. Stefanovic, D. M. Milovic, A. M. Mitic, M. M. Jakovljevic, "Performance analysis of system with selection combining over correlated Weibull fading channels in the presence of cochannel interference", AEU - International Journal of Electronics and Communications, Vol. 62, Issue 9, October 2008, pp. 695–700.
- [12] H. Stefanovic, I. Petrovic, A. Savic, Z. Popovic, M. Stefanovic, "The outage probability of multibranch selection combining over correlated Weibull fading channel", Revue Roumaine des Sciences Techniques -Serie électrotechnique et énergétique 57(2), April 2012, pp. 192-201
- [13] S. Maricic, D. Krstic, M. Stefanovic, M. Masadeh Bani Yassein, V.Milenkovic, "Performance of SC Receiver over Weibull Multipath Fading Channel", WSEAS Transactions on Communications, Vol. 15, 2016, Art. #14, pp. 114-119.
- [14] D. N. Milic, D. B. Đošic, C. M. Stefanovic, M. M. Smilic, S. N. Suljovic, "Outage performance of multi-branch SC receiver over correlated Weibull channel in the presence of correlated Rayleigh cochannel interference", Facta Universitatis, Series: Automatic Control and Robotics, Vol. 14, No 3, 2015, pp. 183 – 191.
- [15] A. D. Cvetkovic, M. C. Stefanovic, N. M. Sekulovic, D. N. Milic, D. M. Stefanovic, Z.J. Popovic, "Second-order statistics of dual SC macrodiversity system over channels affected by Nakagami-m fading and correlated gamma shadowing", Przegląd Elektrotechniczny (Electrical Review), ISSN 0033-2097, R. 87 NR 6/2011, pp. 284-288.
- [16] A. S. Panajotovic, N. M. Sekulovic, M. C. Stefanovic, D. Lj. Draca, "Average Level Crossing Rate of Dual Selection Diversity over Correlated Unbalanced Nakagami-m Fading Channels in the Presence of Cochannel Interference", IEEE Communications Letters 16(5), 2012, pp. 691-693.
- [17] N.M. Sekulovic, M. Č. Stefanovic, "Performance Analysis of System with Micro- and Macrodiversity Reception in Correlated Gamma Shadowed Rician Fading Channels", Wireless Personal Communications, July 2012, Volume 65, Issue 1, pp 143-156, First online: 12 February 2011, http://www.hindawi.com/journals/ijdmb/2009/573404/
- [18] M. Milisic, M. Hamza, M. Hadzialic, "BEP/SEP and Outage Performance Analysis of L BranchMaximal-Ratio Combiner for κ-μ Fading", International Journal of Digital Multimedia Broadcasting, Vol. 2009, Article I 573404, pp. 1-8. 13.
- [19] M. Abramowitz, I. A. Stegun, Handbook of Mathematical Functions, US Dept. of Commerce, National Bureau of Standards, Applied Mathematics Series, Issued June 1964, Tenth Printing December 1972, with corrections.
- [20] E. W. Weisstein, "Gamma Function." From MathWorld-A Wolfram, http://mathworld.wolfram.com/GammaFunction.html
- [21] E. W. Weisstein, "Confluent Hypergeometric Function of the Second Kind." From MathWorld-A Wolfram, http://mathworld.wolfram.com/ConfluentHypergeometricFunctionofthe SecondKind.html
- [22] E. W. Weisstein, "Hypergeometric Function." From MathWorld-A Wolfram, http://mathworld.wolfram.com/HypergeometricFunction.html
- [23] R. K. S. Hankin, "Numerical evaluation of the Gauss hypergeometric function with the hypergeo package", R Journal; Dec2015, Vol. 7 Issue 2, p81