Outage Probability of Two Relay Systems with Two Sections on Selection Combining in the Presence of κ-μ Short Term Fading

DANIJELA ALEKSIĆ*, DRAGANA KRSTIĆ, SINIŠA MINIĆ**, MIHAJLO STEFANOVIĆ, VLADETA MILENKOVIĆ, DJOKO BANDJUR***
Faculty of Electronic Engineering, University of Niš
Aleksandra Medvedeva 14, 18000 Niš
*College of Applied Technical Sciences,
Aleksandra Medvedeva 20, 18000 Niš
**University of Pristina, Kosovska Mitrovica
Faculty of Education in Prizren, Leposavic
*** University of Pristina, Faculty of Technical Sciences
Knjaza Miloša 7, 38220 Kosovska Mitrovica
SERBIA
dragana.krstic@elfak.ni.ac.rs

Abstract: - Two wireless relay communication systems with two sections on selection combining (SC) are considered in this paper. Received signal in sections experiences κ-μ small scale fading. Signal envelope at output of relay systems can be evaluated as product of signal envelopes in sections. Therefore, probability density function (PDF) and cumulative distribution function (CDF) at output of relay system are calculated. SC receiver selects relay system with higher signal envelope. Thus, PDF and CDF of SC receiver signal envelope are calculated by solving integrals in the closed forms by using sums and Bessel function of the second kind. Then, they are graphically presented. The influence of Rician factors of κ-μ short term fading in sections and κ-μ short term fading severity parameters on the outage probability of considered relay system is analyzed and discussed. These results serve to designers of wireless systems to choose optimal system parameters in appropriate fading environment.

Key-Words: - κ-μ short term fading; probability density function (PDF); cumulative distribution function (CDF); outage probability; relay communication system

1 Introduction

A radio transmission system in which intermediate radio stations or radio repeaters receive and retransmit radio signals is known as relay system. Here, two relay systems on selection combining (SC) receiver are considered. Such relay system has two sections. Received signal in each section is subjected to κ-μ short term fading. SC receiver selects relay system with higher signal envelope at output [1]. Signal envelope at output of relay system can be calculated as product of signal envelope in sections or signal envelope at output of relay system can be evaluated as product of two κ-μ random variables. Signal envelope at output of proposed wireless relay system can be evaluated as maximum of two signal envelopes at outputs of relay systems.

The outage probability is important the first order performance measure of wireless communication system which is defined as probability that signal envelope falls below of the specified threshold or can be calculated from cumulative distribution function [2] [3].

The κ-μ distribution can describe small scale signal envelope in fading channel with two or more clusters in the presence of more line of sight components [4]. This distribution is general distribution from witch can be derived Rician, Nakagami-m and Rayleigh distributions as special cases. The κ-μ distribution has two parameters: κ and μ [5]. The parameter κ is Rician factor which can be evaluated as ratio of dominant component power and scattering components power. The κ-μ fading is more sever for lower value of Rician factor. Rician factor has lower values for higher values of scattered components power and lower value of dominant component power. The parameter μ is in relation with the number of clusters and denoted as severity parameter.

There are papers analyzing performance of wireless system in the presence of k-μ multipath fading, shadowing and k-μ cochannel interference

[6], or influence of κ-μ fading on the performance of systems with diversity combining [7]. Also, a few works consider wireless relay communication mobile radio systems with two or more sections, outage and error performance in the presence of long term fading, short term fading and cochannel interference [8]-[11].

In this paper, two wireless relay communication systems with two sections and with SC receiver in the presence of κ-μ short term fading in sections are studied. Signal envelopes at output of relay systems can be written as product of two κ-μ random variables. Therefore, probability density function and cumulative distribution function of product of two κ-μ random variables with different parameters are evaluated. The signal envelope at output of proposed system can be presented as maximum of signal envelopes at outputs of relay systems. Then, probability density function, cumulative distribution function and outage probability of considered system are evaluated and the influence of Rician factors at sections on outage probability is analyzed and discussed. By the authors' knowledge, radio systems consists of two relays with two sections and with SC receivers in the presence of the κ-μ fading are not considered in open technical literature.

This article consists of five sections. After an introduction to the field and description of the papers published in this area, in the second section, the wireless relay communication mobile radio system with SC receiver is presented and the probability density functions and cumulative distribution functions of input and output signals are derived. Then, in third section, CDF of SC receiver output signal is carried out and numerical results are given in the forth one. Some conclusions with described contribution are given in the fifth section.

2 System Model

In this paper, the wireless relay communication mobile radio system with SC receiver is considered. Model of proposed system is shown in Fig. 1.

The signal envelopes x_1 and x_2 follow κ-μ distribution:

$$p_{x_i}(x_i) = \frac{2\mu_{1i}(k_{1i}+1)^{\frac{\mu_{1i}+1}{2}} x_i^{\mu_{1i}}}{k_{1i}^{\frac{\mu_{1i}-1}{2}} e^{k_{1i}\mu_{1i}} \Omega_{1i}^{\frac{\mu_{1i}+1}{2}}} \cdot$$

$$\cdot e^{-\frac{\mu_{1i}(k_{1i}+1)}{\Omega_{1i}}x_i^2} I_{\mu_{1i}-1}\left(2\mu_{1i}\sqrt{\frac{k_{1i}(k_{1i}+1)}{\Omega_{1i}}}x_{1i}\right) \quad (1)$$

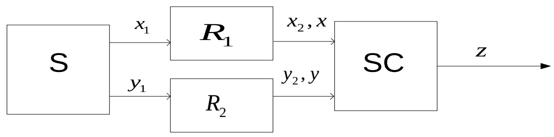

Fig.1. System model

By solving we have:

$$p_{x_i}(x_i) = \frac{2\mu_{1i}(k_{1i}+1)^{\frac{\mu_{1i}+1}{2}}}{k_{1i}^{\frac{\mu_{1i}-1}{2}} e^{k_{1i}\mu_{1i}} \Omega_{1i}^{\frac{\mu_{1i}+1}{2}}} \cdot$$

$$\cdot \sum_{k_1=0}^{\infty}\left(\mu_{1i}\sqrt{\frac{k_{1i}(k_{1i}+1)}{\Omega_{1i}}}\right)^{2k_1+\mu_{1i}-1} \cdot \frac{1}{k_1!\Gamma(k_1+\mu_{1i})} \cdot$$

$$x_i^{2k_1+2\mu_{1i}-1} e^{-\frac{\mu_{1i}(k_{1i}+1)}{\Omega_{1i}}x_i^2}, \; x_i \geq 0, \; i = 1,2 \quad (2)$$

Random variables y_1 and y_2, also, follow κ-μ distribution:

$$p_{y_i}(y_i) = \frac{2\mu_{2i}(k_{2i}+1)^{\frac{\mu_{2i}+1}{2}}}{k_{2i}^{\frac{\mu_{2i}-1}{2}} e^{k_{2i}\mu_{2i}} \Omega_{2i}^{\frac{\mu_{2i}+1}{2}}} \cdot$$

$$\cdot \sum_{k_2=0}^{\infty}\left(\mu_{2i}\sqrt{\frac{k_{2i}(k_{2i}+1)}{\Omega_{2i}}}\right)^{2k_2+\mu_{2i}-1} \cdot \frac{1}{k_2!\Gamma(k_2+\mu_{2i})} \cdot$$

$$y_i^{2k_2+2\mu_{2i}-1} e^{-\frac{\mu_{2i}(k_{2i}+1)}{\Omega_{2i}}x_2^2}, \; y_i \geq 0, \; i = 1,2 \quad (3)$$

Random variable x can be evaluated as product of two κ-μ random variables:

$$x = x_1 \cdot x_2, \quad x_1 = \frac{x}{x_2} \quad (4)$$

PDF of x is [12]:

$$p_x(x) = \int_0^{\infty} dx_2 \cdot \frac{1}{x_2} p_{x_1}\left(\frac{x}{x_2}\right) p_{x_2}(x_2) =$$

$$= \frac{2\mu_{11}(k_{11}+1)^{\frac{\mu_{11}+1}{2}}}{k_{11}^{\frac{\mu_{11}-1}{2}} e^{k_{11}\mu_{11}} \Omega_{11}^{\frac{\mu_{11}+1}{2}}} \cdot$$

$$\cdot \sum_{k_1=0}^{\infty}\left(\mu_{11}\sqrt{\frac{k_{11}(k_{11}+1)}{\Omega_{11}}}\right)^{2k_1+\mu_{11}-1} \cdot \frac{1}{k_1!\Gamma(k_1+\mu_{11})} \cdot$$

$$\cdot x^{2\mu_{11}+2k_1-1} \frac{2\mu_{12}(k_{12}+1)^{\frac{\mu_{12}+1}{2}}}{k_{12}^{\frac{\mu_{12}-1}{2}} e^{k_{12}\mu_{12}} \Omega_{12}^{\frac{\mu_{12}+1}{2}}} \cdot$$

$$\cdot\sum_{k_2=0}^{\infty}\left(\mu_{12}\sqrt{\frac{k_{12}\left(k_{12}+1\right)}{\Omega_{12}}}\right)^{2k_2+\mu_{12}-1}\cdot\frac{1}{k_2!\Gamma\left(k_2+\mu_{12}\right)}\cdot$$

$$\cdot\int_0^{\infty}dx_2\,x_2^{-1-2\mu_{11}-2k_1+1+2\mu_{12}+2k_2-1}\cdot$$

$$\cdot e^{-\left(\frac{\mu_{11}\left(k_{11}+1\right)}{\Omega_{11}}\frac{x^2}{x_2^2}+\frac{\mu_{12}\left(k_{12}+1\right)}{\Omega_{12}}x_2^2\right)}=$$

$$=\frac{2\mu_{11}\left(k_{11}+1\right)^{\frac{\mu_{11}+1}{2}}}{k_{11}^{\frac{\mu_{11}-1}{2}}e^{k_{11}\mu_{11}}\Omega_{11}^{\frac{\mu_{11}+1}{2}}}\cdot$$

$$\cdot\sum_{k_1=0}^{\infty}\left(\mu_{11}\sqrt{\frac{k_{11}\left(k_{11}+1\right)}{\Omega_{11}}}\right)^{2k_1+\mu_{11}-1}\cdot\frac{1}{k_1!\Gamma\left(k_1+\mu_{11}\right)}\cdot$$

$$\cdot x^{2\mu_{11}+2k_1-1}\cdot\frac{2\mu_{12}\left(k_{12}+1\right)^{\frac{\mu_{12}+1}{2}}}{k_{12}^{\frac{\mu_{12}-1}{2}}e^{k_{12}\mu_{12}}\Omega_{12}^{\frac{\mu_{12}+1}{2}}}\cdot$$

$$\cdot\frac{1}{2}\left(\frac{\mu_{11}\left(k_{11}+1\right)x^2}{\Omega_{11}}\frac{\Omega_{12}}{\mu_{12}\left(k_{12}+1\right)}\right)^{\frac{\mu_{12}}{2}+\frac{k_2}{2}-\frac{\mu_{11}}{2}-\frac{k_1}{2}}$$

$$K_{\mu_{12}+k_2-\mu_{11}-k_1}\left(2\sqrt{\frac{\mu_{11}\left(k_{11}+1\right)x^2\mu_{12}\left(k_{12}+1\right)}{\Omega_{11}\Omega_{12}}}\right)\qquad(5)$$

Here, $K_n(x)$ is the modified Bessel function of the second kind with argument x and order n [13].

CDF of x is:

$$F_x(x)=\int_0^x dt\cdot p_x(t)=\frac{2\mu_{11}\left(k_{11}+1\right)^{\frac{\mu_{11}+1}{2}}}{k_{11}^{\frac{\mu_{11}-1}{2}}e^{k_{11}\mu_{11}}\Omega_{11}^{\frac{\mu_{11}+1}{2}}}\cdot$$

$$\cdot\sum_{k_1=0}^{\infty}\left(\mu_{11}\sqrt{\frac{k_{11}\left(k_{11}+1\right)}{\Omega_{11}}}\right)^{2k_1+\mu_{11}-1}\cdot\frac{1}{k_1!\Gamma\left(k_1+\mu_{11}\right)}\cdot$$

$$\cdot\frac{2\mu_{12}\left(k_{12}+1\right)^{\frac{\mu_{12}+1}{2}}}{k_{12}^{\frac{\mu_{12}-1}{2}}e^{k_{12}\mu_{12}}\Omega_{12}^{\frac{\mu_{12}+1}{2}}}\cdot$$

$$\cdot\sum_{k_2=0}^{\infty}\left(\mu_{12}\sqrt{\frac{k_{12}\left(k_{12}+1\right)}{\Omega_{12}}}\right)^{2k_2+\mu_{12}-1}\cdot\frac{1}{k_2!\Gamma\left(k_2+\mu_{12}\right)}\cdot$$

$$\int_0^{\infty}dx_2\,x_2^{2\mu_{12}+2k_2-2\mu_{11}-2k_1-1}e^{-\frac{\mu_{12}\left(k_{12}+1\right)}{\Omega_{12}}x_2^2}$$

$$\int_0^{x}dt\cdot t^{2\mu_{11}+2k_1-1}\cdot e^{-\frac{\mu_{11}\left(k_{11}+1\right)}{\Omega_{11}}\frac{t^2}{x_2^2}}=$$

$$=\frac{2\mu_{11}\left(k_{11}+1\right)^{\frac{\mu_{11}+1}{2}}}{k_{11}^{\frac{\mu_{11}-1}{2}}e^{k_{11}\mu_{11}}\Omega_{11}^{\frac{\mu_{11}+1}{2}}}\cdot$$

$$\cdot\sum_{k_1=0}^{\infty}\left(\mu_{11}\sqrt{\frac{k_{11}\left(k_{11}+1\right)}{\Omega_{11}}}\right)^{2k_1+\mu_{11}-1}\cdot\frac{1}{k_1!\Gamma\left(k_1+\mu_{11}\right)}\cdot$$

$$\cdot\frac{2\mu_{12}\left(k_{12}+1\right)^{\frac{\mu_{12}+1}{2}}}{k_{12}^{\frac{\mu_{12}-1}{2}}e^{k_{12}\mu_{12}}\Omega_{12}^{\frac{\mu_{12}+1}{2}}}\cdot$$

$$\cdot\sum_{k_2=0}^{\infty}\left(\mu_{12}\sqrt{\frac{k_{12}\left(k_{12}+1\right)}{\Omega_{12}}}\right)^{2k_2+\mu_{12}-1}\cdot\frac{1}{k_2!\Gamma\left(k_2+\mu_{12}\right)}\cdot$$

$$\int_0^{\infty}dx_2\,x_2^{2\mu_{12}+2k_2-2\mu_{11}-2k_1-1}e^{-\frac{\mu_{12}\left(k_{12}+1\right)}{\Omega_{12}}x_2^2}$$

$$\cdot\frac{1}{2}\left(\frac{\Omega_{11}x_2^2}{\mu_{11}\left(k_{11}+1\right)}\right)^{\mu_{11}+k_1}$$

$$\cdot\frac{1}{\mu_{11}+k_1}\left(\frac{\mu_{11}\left(k_{11}+1\right)}{\Omega_{11}x_2^2}\right)^{\mu_{11}+k_1}x^{2\left(\mu_{11}+k_1\right)}e^{-\frac{\mu_{11}\left(k_{11}+1\right)x^2}{\Omega_{11}\ \ x_2^2}}\cdot$$

$$\cdot\sum_{j_1=0}^{\infty}\frac{1}{\left(\mu_{11}+k_{11}+1\right)\left(j_1\right)}\left(\frac{\mu_{11}\left(k_{11}+1\right)x^2}{x_2^2}\right)^{j_1}=$$

$$=\frac{2\mu_{11}\left(k_{11}+1\right)^{\frac{\mu_{11}+1}{2}}}{k_{11}^{\frac{\mu_{11}-1}{2}}e^{k_{11}\mu_{11}}\Omega_{11}^{\frac{\mu_{11}+1}{2}}}\cdot$$

$$\cdot\sum_{k_1=0}^{\infty}\left(\mu_{11}\sqrt{\frac{k_{11}\left(k_{11}+1\right)}{\Omega_{11}}}\right)^{2k_1+\mu_{11}-1}\cdot\frac{1}{k_1!\Gamma\left(k_1+\mu_{11}\right)}\cdot$$

$$\cdot\frac{2\mu_{12}\left(k_{12}+1\right)^{\frac{\mu_{12}+1}{2}}}{k_{12}^{\frac{\mu_{12}-1}{2}}e^{k_{12}\mu_{12}}\Omega_{12}^{\frac{\mu_{12}+1}{2}}}\cdot$$

$$\cdot\sum_{k_2=0}^{\infty}\left(\mu_{12}\sqrt{\frac{k_{12}\left(k_{12}+1\right)}{\Omega_{12}}}\right)^{2k_2+\mu_{12}-1}\cdot\frac{1}{k_2!\Gamma\left(k_2+\mu_{12}\right)}\cdot$$

$$\cdot x^{2\left(\mu_{11}+k_1\right)}\frac{1}{\mu_{11}+k_1}\cdot$$

$$\cdot\sum_{j_1=0}^{\infty}\frac{1}{\left(\mu_{11}+k_{11}+1\right)\left(j_1\right)}\left(\mu_{11}\left(k_{11}+1\right)x^2\right)^{j_1}$$

$$\int_0^{\infty}dx_2\,x_2^{2\mu_{12}+2k_2-2\mu_{11}-2k_1-1-2j_1}$$

$$e^{-\frac{\mu_{11}\left(k_{11}+1\right)}{\Omega_{11}}\frac{x^2}{x_2^2}-\frac{\mu_{12}\left(k_{12}+1\right)}{\Omega_{12}}x_2^2}=$$

$$=\frac{2\mu_{11}\left(k_{11}+1\right)^{\frac{\mu_{11}+1}{2}}}{k_{11}^{\frac{\mu_{11}-1}{2}}e^{k_{11}\mu_{11}}\Omega_{11}^{\frac{\mu_{11}+1}{2}}}\cdot$$

$$\cdot\sum_{k_1=0}^{\infty}\left(\mu_{11}\sqrt{\frac{k_{11}\left(k_{11}+1\right)}{\Omega_{11}}}\right)^{2k_1+\mu_{11}-1}\cdot\frac{1}{k_1!\Gamma\left(k_1+\mu_{11}\right)}\cdot$$

$$\cdot \frac{2\mu_{12}\left(k_{12}+1\right)^{\frac{\mu_{12}+1}{2}}}{k_{12}^{\frac{\mu_{12}-1}{2}} e^{k_{12}\mu_{12}} \Omega_{12}^{\frac{\mu_{12}+1}{2}}} \cdot$$

$$\cdot \sum_{k_2=0}^{\infty} \left(\mu_{12}\sqrt{\frac{k_{12}\left(k_{12}+1\right)}{\Omega_{12}}}\right)^{2k_2+\mu_{12}-1} \cdot \frac{1}{k_2!\Gamma\left(k_2+\mu_{12}\right)} \cdot$$

$$\cdot x^{2(\mu_{11}+k_1)} \frac{1}{\mu_{11}+k_1} \cdot$$

$$\cdot \sum_{j_1=0}^{\infty} \frac{1}{\left(\mu_{11}+k_{11}+1\right)\left(j_1\right)} \left(\mu_{11}\left(k_{11}+1\right)\right)^{j_1}$$

$$\cdot \frac{1}{2}\left(\frac{\mu_{11}\left(k_{11}+1\right)\Omega_{12}x^2}{\mu_{12}\left(k_{12}+1\right)\Omega_{11}}\right)^{\frac{\mu_{12}}{2}+\frac{k_2}{2}-\frac{\mu_{11}}{2}-\frac{k_1}{2}-\frac{j_1}{2}}$$

$$K_{\mu_{12}+k_2-\mu_{11}-k_1-j_1}\left(2\sqrt{\frac{\mu_{11}\left(k_{11}+1\right)x^2\mu_{12}\left(k_{12}+1\right)}{\Omega_{11}\Omega_{12}}}\right) \qquad (6)$$

The PDF of y is:

$$p_y(y) = \frac{2\mu_{21}\left(k_{21}+1\right)^{\frac{\mu_{21}+1}{2}}}{k_{21}^{\frac{\mu_{21}-1}{2}} e^{k_{21}\mu_{21}} \Omega_{21}^{\frac{\mu_{21}+1}{2}}} \cdot$$

$$\cdot \sum_{k_3=0}^{\infty} \left(\mu_{21}\sqrt{\frac{k_{21}\left(k_{21}+1\right)}{\Omega_{21}}}\right)^{2k_3+\mu_{21}-1} \cdot \frac{1}{k_3!\Gamma\left(k_3+\mu_{21}\right)} \cdot$$

$$\cdot \frac{2\mu_{22}\left(k_{22}+1\right)^{\frac{\mu_{22}+1}{2}}}{k_{22}^{\frac{\mu_{22}-1}{2}} e^{k_{22}\mu_{22}} \Omega_{22}^{\frac{\mu_{22}+1}{2}}} \cdot$$

$$\cdot \sum_{k_4=0}^{\infty} \left(\mu_{22}\sqrt{\frac{k_{22}\left(k_{22}+1\right)}{\Omega_{22}}}\right)^{2k_4+\mu_{22}-1} \cdot \frac{1}{k_4!\Gamma\left(k_4+\mu_{22}\right)} \cdot$$

$$\cdot y^{2k_3+2\mu_{21}-1} \cdot$$

$$\cdot \frac{1}{2}\left(\frac{\mu_{21}\left(k_{21}+1\right)y^2\Omega_{22}}{\Omega_{21}\mu_{22}\left(k_{22}+1\right)}\right)^{\frac{\mu_{22}}{2}+\frac{k_4}{2}-\frac{\mu_{21}}{2}-\frac{k_3}{2}}$$

$$K_{\mu_{22}+k_4-\mu_{21}-k_3}\left(2\sqrt{\frac{\mu_{21}\left(k_{21}+1\right)y^2\mu_{22}\left(k_{22}+1\right)}{\Omega_{21}\Omega_{22}}}\right) \qquad (7)$$

The CDF of y is:

$$F_y(y) = \frac{2\mu_{21}\left(k_{21}+1\right)^{\frac{\mu_{21}+1}{2}}}{k_{21}^{\frac{\mu_{21}-1}{2}} e^{k_{21}\mu_{21}} \Omega_{21}^{\frac{\mu_{21}+1}{2}}} \cdot$$

$$\cdot \sum_{k_3=0}^{\infty} \left(\mu_{21}\sqrt{\frac{k_{21}\left(k_{21}+1\right)}{\Omega_{21}}}\right)^{2k_3+\mu_{21}-1} \cdot \frac{1}{k_3!\Gamma\left(k_3+\mu_{21}\right)} \cdot$$

$$\cdot \frac{2\mu_{22}\left(k_{22}+1\right)^{\frac{\mu_{22}+1}{2}}}{k_{22}^{\frac{\mu_{22}-1}{2}} e^{k_{22}\mu_{22}} \Omega_{22}^{\frac{\mu_{22}+1}{2}}} \cdot$$

$$\cdot \sum_{k_4=0}^{\infty} \left(\mu_{22}\sqrt{\frac{k_{22}\left(k_{22}+1\right)}{\Omega_{22}}}\right)^{2k_4+\mu_{22}-1} \cdot \frac{1}{k_4!\Gamma\left(k_4+\mu_{22}\right)} \cdot$$

$$y^{2(k_3+\mu_{21})} \frac{1}{\mu_{21}+k_3} \sum_{j_2=0}^{\infty} \frac{1}{\left(\mu_{21}+k_{21}+1\right)\left(j_2\right)} \left(\mu_{21}\left(k_{21}+1\right)\right)^{j_2}$$

$$\cdot \frac{1}{2}\left(\frac{\mu_{21}\left(k_{21}+1\right)\Omega_{22}y^2}{\mu_{22}\left(k_{22}+1\right)\Omega_{21}}\right)^{\frac{\mu_{22}}{2}+\frac{k_4}{2}-\frac{\mu_{21}}{2}-\frac{k_3}{2}}$$

$$K_{\mu_{22}+k_4-\mu_{21}-k_3}\left(2\sqrt{\frac{\mu_{21}\left(k_{21}+1\right)y^2\mu_{22}\left(k_{22}+1\right)}{\Omega_{21}\Omega_{22}}}\right). \qquad (8)$$

The outage probability is probability that communication relay system output signal envelope drops below the defined threshold. The outage probability for this case is equal to the CDF of product of signal envelopes at sections.

3 The CDF of SC Receiver Output Signal

The SC receiver output signal is:

$$z = max(x, y) \qquad (9)$$

The CDF of z is:

$$F_z(z) = F_x(z) \cdot F_y(z) =$$

$$= \frac{2\mu_{11}\left(k_{11}+1\right)^{\frac{\mu_{11}+1}{2}}}{k_{11}^{\frac{\mu_{11}-1}{2}} e^{k_{11}\mu_{11}} \Omega_{11}^{\frac{\mu_{11}+1}{2}}} \cdot$$

$$\cdot \sum_{k_1=0}^{\infty} \left(\mu_{11}\sqrt{\frac{k_{11}\left(k_{11}+1\right)}{\Omega_{11}}}\right)^{2k_1+\mu_{11}-1} \cdot \frac{1}{k_1!\Gamma\left(k_1+\mu_{11}\right)} \cdot$$

$$\cdot \frac{2\mu_{12}\left(k_{12}+1\right)^{\frac{\mu_{12}+1}{2}}}{k_{12}^{\frac{\mu_{12}-1}{2}} e^{k_{12}\mu_{12}} \Omega_{12}^{\frac{\mu_{12}+1}{2}}} \cdot$$

$$\cdot \sum_{k_2=0}^{\infty} \left(\mu_{12}\sqrt{\frac{k_{12}\left(k_{12}+1\right)}{\Omega_{12}}}\right)^{2k_2+\mu_{12}-1} \cdot \frac{1}{k_2!\Gamma\left(k_2+\mu_{12}\right)} \cdot$$

$$\cdot z^{2(\mu_{11}+k_1)} \frac{1}{\mu_{11}+k_1} \cdot$$

$$\cdot \sum_{j_1=0}^{\infty} \frac{1}{\left(\mu_{11}+k_{11}+1\right)\left(j_1\right)} \left(\mu_{11}\left(k_{11}+1\right)\right)^{j_1}$$

$$\cdot \frac{1}{2}\left(\frac{\mu_{11}\left(k_{11}+1\right)\Omega_{12}z^2}{\mu_{12}\left(k_{12}+1\right)\Omega_{11}}\right)^{\frac{\mu_{12}}{2}+\frac{k_2}{2}-\frac{\mu_{11}}{2}-\frac{k_1}{2}}$$

$$K_{\mu_{12}+k_2-\mu_{11}-k_1}\left(2\sqrt{\frac{\mu_{11}\left(k_{11}+1\right)z^2\mu_{12}\left(k_{12}+1\right)}{\Omega_{11}\Omega_{12}}}\right).$$

$$\cdot\frac{2\mu_{21}\left(k_{21}+1\right)^{\frac{\mu_{21}+1}{2}}}{k_{21}^{\frac{\mu_{21}-1}{2}}e^{k_{21}\mu_{21}}\Omega_{21}^{\frac{\mu_{21}+1}{2}}}\cdot$$

$$\cdot\sum_{k_3=0}^{\infty}\left(\mu_{21}\sqrt{\frac{k_{21}\left(k_{21}+1\right)}{\Omega_{21}}}\right)^{2k_3+\mu_{21}-1}\cdot\frac{1}{k_3!\Gamma\left(k_3+\mu_{21}\right)}\cdot$$

$$\cdot\frac{2\mu_{22}\left(k_{22}+1\right)^{\frac{\mu_{22}+1}{2}}}{k_{22}^{\frac{\mu_{22}-1}{2}}e^{k_{22}\mu_{22}}\Omega_{22}^{\frac{\mu_{22}+1}{2}}}\cdot$$

$$\cdot\sum_{k_4=0}^{\infty}\left(\mu_{22}\sqrt{\frac{k_{22}\left(k_{22}+1\right)}{\Omega_{22}}}\right)^{2k_4+\mu_{22}-1}\cdot\frac{1}{k_4!\Gamma\left(k_4+\mu_{22}\right)}\cdot$$

$$z^{2\left(k_3+\mu_{21}\right)}\frac{1}{\mu_{21}+k_3}\sum_{j_2=0}^{\infty}\frac{1}{\left(\mu_{21}+k_{21}+1\right)\left(j_2\right)}\left(\mu_{21}\left(k_{21}+1\right)\right)^{j_2}$$

$$\cdot\frac{1}{2}\left(\frac{\mu_{21}\left(k_{21}+1\right)\Omega_{22}z^2}{\mu_{22}\left(k_{22}+1\right)\Omega_{21}}\right)^{\frac{\mu_{22}}{2}+\frac{k_4}{2}-\frac{\mu_{21}}{2}-\frac{k_3}{2}}$$

$$K_{\mu_{22}+k_4-\mu_{21}-k_3}\left(2\sqrt{\frac{\mu_{21}\left(k_{21}+1\right)z^2\mu_{22}\left(k_{22}+1\right)}{\Omega_{21}\Omega_{22}}}\right). \quad (10)$$

The outage probability is defined as the probability that the receiver output signal envelope is falling below a given threshold value. Mathematically, the outage probability is the CDF of the signal and is given by [14, eq. (2.23)]:

$$P_{out}\left(\gamma_{th}\right)=P\left(z<\gamma_{th}\right), \quad (11)$$

with γ_{th} being the threshold value.

4 Numerical results

The probability density function of SC receiver output signal envelope is plotted in Figs. 2 and 3. for some values of fading severity parameter μ and Rician factors. In Fig. 2, fading severity parameter μ=2 and Rician factors are k_{ij}=1; *i, j* = 1, 2. In the Fig. 3, fading severity parameter μ=3 and Rician factors are k_{ij}=2; *i, j* = 1, 2. In all figures parameters are assigned as: $k_{11}=k_1$, $k_{12}=k_2$, $k_{21}=k_3$, $k_{22}=k_4$.

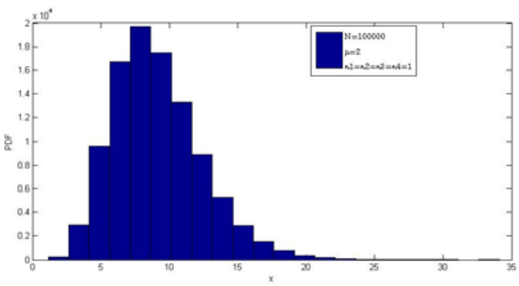

Fig. 2. PDF of *x* for μ=2 and k_{ij}=1.

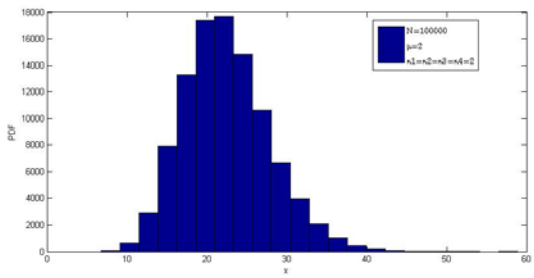

Fig. 3. PDF of *x* for μ=2 and k_{ij}=2.

The cumulative distribution functions of SC receiver output signal envelope are plotted in Figs. 4 to 9. for different quantities of fading severity parameter μ and Rician factors. In Figs. 4 to 7, parameter μ=2, and in Figs. 8 and 9, fading severity parameter μ=3. The CDF is plotted for variable parameters κ.

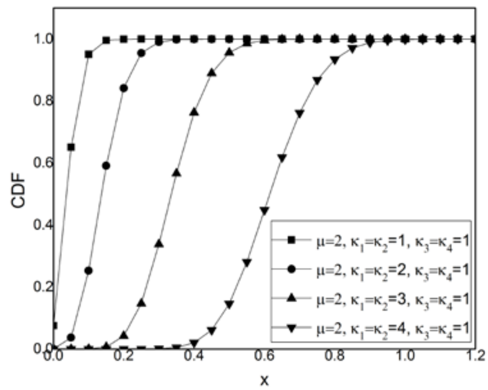

Fig. 4. The cumulative distribution function of SC receiver output signal envelope

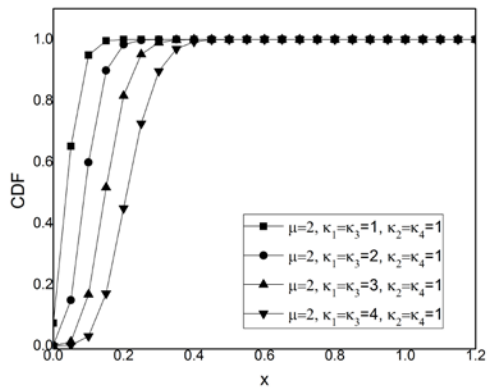

Fig. 5. The cumulative distribution function of SC receiver output signal envelope.

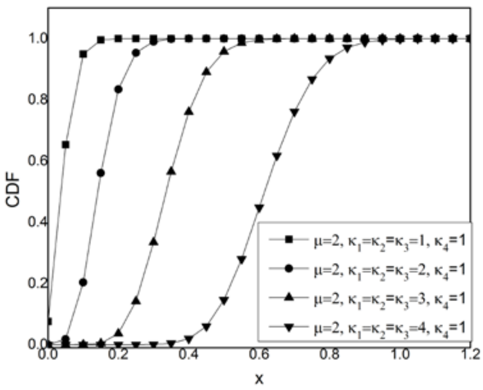

Fig. 6. The cumulative distribution function of SC receiver output signal envelope.

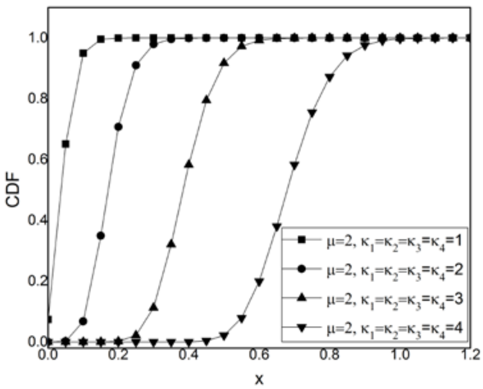

Fig. 7. The cumulative distribution function of SC receiver output signal envelope.

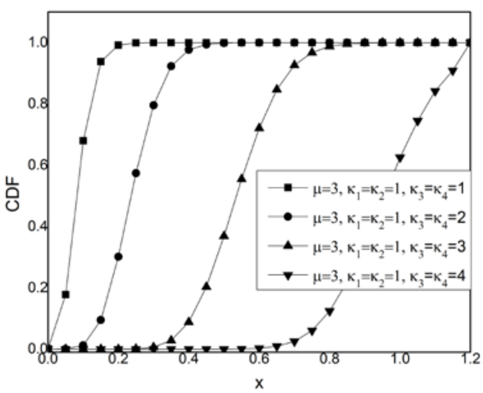

Fig. 8. The cumulative distribution function of SC receiver output signal envelope.

It is visible that CDF increases with increasing of the signal envelope. The cumulative distribution function decreases for larger values of Rician factor κ_{ij}.

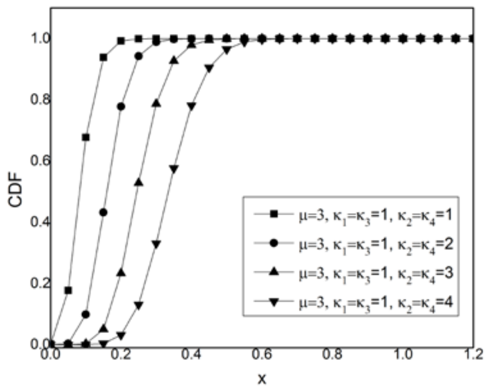

Fig. 9. The The cumulative distribution function of SC receiver output signal envelope.

Also, one can see from these figures that CDF is smaller for bigger values of fading severity parameter μ.

System performances are better for lower values of the outage probability. Because the outage probability is mathematically the CDF, previous few figures for CDF are drawn curves for the outage probability versus signal envelope. From them, the influence of different fading parameters can be seen.

5 Conclusion

In this paper, wireless system with two relay communication systems, both with two sections, whose outputs are inputs in SC receiver, in the presence of κ-μ short term fading in sections, is studied. Signal envelopes at output of relay systems are products of two κ-μ random variables. The probability density function and cumulative distribution function of products of two κ-μ random variables with different parameters are evaluated.

The signal envelope at output of proposed system is presented as maximum of signal envelopes at outputs of relay systems. Then, probability density function, cumulative distribution function and outage probability of considered system are determined and the influence of Rician factors at sections on outage probability is analyzed and discussed.

System performance is better for lower values of the outage probability. This can be achieved by larger values of Rician factor κ_{ij} when cumulative distribution function decreases. Also, the CDF is smaller for bigger values of fading severity parameter μ.

Presented figures for the outage probability versus signal envelope are given to show the influence of fading parameters what contributes to the wireless system designers to choose optimal system parameters.

Acknowledgment

This paper is partially financed within the projects TR-33035 and III-44006 by the Ministry of Education, Science and Technological Development of Republic of Serbia.

References:

[1] S. Panic, M. Stefanovic, J. Anastasov, P. Spalevic, *Fading and Interference Mitigation in Wireless Communications*. CRC Press, USA, 2013.

[2] M. K. Simon, M. S. Alouini, *Digital Communication over Fading Channels*, USA: John Wiley & Sons. 2000.

[3] W.C.Y. Lee, *Mobile communications engineering*, Mc-Graw-Hill, NewYork, USA, 2003.

[4] M. D. Yacoub, "The κ-μ Distribution: A General Fading Distribution", IEEE Atlantic City Fall Vehicular Technology Conference 2001, Atlantic City, USA, Oct. 2001.

[5] D. Krstić, Z. Jovanović, R. Gerov, D.Radenković, V. Milenković, "Statistics of k-μ Random Variable", Proc. of the 18th Intrnational Conference on Mathematical Methods, Computational Techniques and Intelligent Systems (MAMECTIS 16), ISSN: 2227-4588, ISBN: 978-1-61804-360-3, Venice, Italy, January 29-31, 2016, pp. 163-171.

[6] S. R. Panic, D. M. Stefanovic, I. M. Petrovic, M. C. Stefanovic, J. A. Anastasov, D. S. Krstic, "Second order statistics of selection macro-diversity system operating over Gamma shadowed k-μ fading channels", *EURASIP Journal on Wireless Communications and Networking,* 2011, 2011:151, Article ID 631204, doi:10.1186/1687-1499-2011-151.

[7] D. Krstic, M. Stefanovic, V. Milenkovic, D. Radenkovic, H. Ivanov, E. Leitgeb, „Performance of Wireless System in the Presence of k-μ Multipath Fading, Gamma Shadowing and k-μ Cochannel Interference", IEICE Information and Communication Technology Forum 2016, The 2016 IEICE ICTF Patras, Greece, 6th of July- 8th of July 2016.

[8] D. Aleksić, D. Krstić, Z. Popović, V.Milenković, M. Stefanović, "The Analysis of Wireless Relay Communication System in the Presence of Nakagami-m Fading", accepted for printing in *WSEAS Transactions on Computer Research*, Print ISSN: 1991-8755, E-ISSN: 2415-1521, Vol. 4, 2016.

[9] D. Krstic, M. Stefanovic, R. Gerov, Z. Popovic, "Wireless Relay System with Two Sections in κ-μ Short Term Fading Channel", The Twelfth International Conference on Wireless and Mobile Communications, ICWMC 2016, Barcelona, Spain, November 13 - 17, 2016.

[10] D. Krstic, M. Stefanovic, V. Milenkovic, M.M.B. Yassein, S. Aljawarneh, Z. Popovic, „Wireless Relay System with Two Sections in the Presence of κ-μ and η-μ Multipath Fading", IEEE International Conference on Internet of Things and Pervasive Systems (IoT-SP-2016), 22-24 September 2016, Agadir, Morocco

[11] D. Aleksić, D. Krstic, Z. Popovic, I. Dinić, M. Stefanović, "Outage Probability of Wireless Relay Communication System with Three Sections in the Presence of Nakagami-m Short Term Fading", *International Journal of Communications,* ISSN: 2367-8887, vol. 1, 2016, pp. 199-204.

[12] I. S. Gradshteyn, I. M. Ryzhik, *Table of Integrals, Series and Products*. Academic Press, USA San Diego, 2000.

[13] G. Arfken, "Neumann Functions, Bessel Functions of the Second Kind, $N_\nu(x)$", 11.3 in Mathematical Methods for Physicists, 3rd ed., Orlando, FL: Academic Press, 1985, pp. 596-604.

[14] D. Ben Cheikh Battikh, "Outage probability formulas for cellular networks: contributions for MIMO, CoMP and time reversal features", Telecom ParisTech, 2012. English. https://tel.archives-ouvertes.fr/pastel-00790614/document