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RADIO RELAY SYSTEM WITH TWO-SECTION PERFORMANCE IN THE PRESENCE OF NAKAGAMI-M FADING AND RICIAN CO-CHANNEL INTERFERENCE

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Abstract: *Wireless mobile relay communication system with two sections operating over short term fading channel in the presence of co-channel interference subjected to small scale fading has been considered. Desired signal experiences Nakagami-m fading and co-channel interference experiences Rician fading. Desired signal at output of the second section has Nakagami-m*Nakagami-m distribution. The signal-to-interference ratio of product of two Nakagami-m random variables and Rician random variable has been presented. In this paper, closed form expressions for moments of signal-to-interference ratio of considered system are calculated. The influence of Nakagami-m short term fading severity parameter and Rician κ factor on presence is analysed and discussed. Mobile relay communication system with two sections can lead to a more reliable and efficient transmission, which is of great importance in the risky environments.*

Key words: Nakagami-m fading, Rician fading, moment, mobile relay communications system

INTRODUCTION

Wireless mobile relay communication system operating over multipath fading channel in the presence of co-channel interference has been analyzed in this paper. Short term fading and co-channel interference degrade outage probability and bit error probability of wireless system. Reflections, refractions, diffraction and scattering cause multipath propagation resulting in signal envelope variation [1]. There are more distributions which can be used to describe signal envelope variation in fading channels. When line-of-sight dominant component is presented in fading channel, signal envelope can be described by using Rician distribution and when dominant component is not presented signal envelope variation can be modeled by using Nakagami-m distribution. Rician distribution has parameter κ named as Rician factor. Rician factor can be evaluated as a ratio of dominant component power and scattering component power [2]. By setting Rician factor $\kappa=0$, Rayleigh distribution can be derived is Rician distribution. When Rician factor goes to infinity Rician multipath fading channel becomes no fading channel. Nakagami-m distribution can be used to describe small scale signal envelope variation in non line-of-sight short fading channel with more clusters. Nakagami-m distribution is general distribution and Rayleigh and one sided Gaussian distributions can be derived from Nakagami-m distribution. Nakagami-m distribution has parameter m denoted as Nakagami-m multipath fading severity parameter. For parameter $m=1$, Rayleigh distribution can be obtained from Nakagami-m distribution and when parameter $m=1/2$

Nakagami-m distribution becomes one sided Gaussian distribution. When parameter m goes to infinity Nakagami-m short term fading channel becomes no fading channel [3]. Radio relay communication system considered in this paper has two sections. Signal envelopes at outputs from the first and the second section are subjected to Nakagami-m short term fading. Signal envelope variation at output of relay communication system can be described as product of two Nakagami-m distributions. Random variable obtained as product of two Nakagami-m random variables is denoted as Nakagami-m*Nakagami-m. Nakagami-m*Nakagami-m distribution is general distribution. This distribution has two parameters m_1 and m_2 . For $m_1=1$, Nakagami-m* Nakagami-m distribution becomes Rayleigh* Nakagami-m distribution, for $m_1=1$ and $m_2=1$ Nakagami-m*Nakagami-m distribution becomes Rayleigh*Rayleigh distribution and for $m_1=0.5$ and $m_2=0.5$ Nakagami-m*Nakagami-m distribution becomes one sided Gaussian*one sided Gaussian distribution [4], [5], [6], [7].

In considered relay communication system resulting signal to interference ratio can be calculated as the ratio of two Nakagami-m random variables and Rician random variable. This variate can be denoted as Nakagami-m* Nakagami-m/Rician random variable. This variable has three parameters. These parameters are m_1 , m_2 and κ . When $m_1=1$, $m_2=1$ and $\kappa=0$, the Nakagami-m* Nakagami-m/Rician distribution reduces to Rayleigh*Rayleigh/Rayleigh distribution, when $m_1=1$, $m_2=1$ the Nakagami-m*Nakagami-m/Rician distribution becomes Rayleigh*Rayleigh/Rician

distribution, when $\kappa=0$, the Nakagami-m*Nakagami-m/Rician distribution becomes Nakagami-m*Nakagami-m/Rayleigh distribution and for $m_1=1$ the Nakagami-m*Nakagami-m/Rician distribution reduces to Rayleigh*Nakagami-m/Rician distribution [8], [9], [10], [11]. To the best of the authors' knowledge radio relay system with two sections performance analyses in the presence Nakagami-m short term fading and Rician co-channel interference is not reported in open technical literature. Probability density function, cumulative distribution function and moments of signal-to-interference ratio are efficiently evaluated as closed-form expressions. Probability density function can be used for evaluation of average bit error probability, while outage probability can be evaluated by using cumulative distribution function. The important performance measures are the first moment known as average value, the second moment known as average square value and the second central moment known as variance.

Better performance of a mobile radio relay system with two sections allows for a more secure transmission of information from the place where the fire or any other accident occurs to the place where the help center is located.

PDF of the Ratio of Product of Two Nakagami-m Random Variables and Rician Random Variable

Ratio of product of two Nakagami-m random variables and Rician random variable is:

$$w = \frac{x \cdot y}{z}, \quad x = \frac{w \cdot z}{y}, \quad \frac{dx}{dw} = \frac{z}{y}. \quad (1)$$

Random variables x and y follow Nakagami-m distribution:

$$p_x(x) = \frac{2}{\Gamma(m_1)} \left(\frac{m_1}{\Omega_1} \right)^{m_1} x^{2m_1-1} e^{-\frac{m_1}{\Omega_1} x^2}, \quad x \geq 0, \quad (2)$$

$$p_y(y) = \frac{2}{\Gamma(m_2)} \left(\frac{m_2}{\Omega_2} \right)^{m_2} y^{2m_2-1} e^{-\frac{m_2}{\Omega_2} y^2}, \quad y \geq 0, \quad (3)$$

where m_1 is shape parameter of x and m_2 is shape parameter of y , Ω_1 is average power of x and Ω_1 average power of y . Random variable of z has Rician distribution:

$$p_z(z) = \frac{2(k+1)z}{e^k \Omega_3} e^{-\frac{k+1}{\Omega_3} z^2} I_0 \left(2\sqrt{\frac{k(k+1)}{\Omega_3}} z \right) = \frac{2(k+1)}{e^k \Omega_3} \times \sum_{i=0}^{\infty} \left(\frac{k(k+1)}{\Omega_3} \right)^i \frac{1}{(i_1!)^2} \cdot z^{2i+1} e^{-\frac{k+1}{\Omega_3} z^2}, \quad z \geq 0. \quad (4)$$

PDF of w is [10]:

$$p_w(w) = \int_0^{\infty} dy \int_0^{\infty} dz \frac{z}{y} p_x \left(\frac{wz}{y} \right) p_y(y) p_z(z) = \frac{2}{\Gamma(m_1)} \left(\frac{m_1}{\Omega_1} \right)^{m_1} w^{2m_1-1} \frac{2}{\Gamma(m_2)} \left(\frac{m_2}{\Omega_2} \right)^{m_2} \times \frac{2(k+1)}{e^k \Omega_3} \int_0^{\infty} dy y^{2m_2-2m_1-1} e^{-\frac{m_2}{\Omega_2} y^2} \cdot \frac{1}{2} y^{2m_1+2i_1+2} \times (\Omega_1 \Omega_3)^{m_1+i_1+1} \frac{1}{(m_1 \Omega_3 w^2 + (k+1) \Omega_1 y^2)^{m_1+i_1+1}} \quad (5)$$

$$\frac{(k+1) \Omega_1 y^2}{m_1 \Omega_3 w^2} = t, \quad y^2 = \frac{m_1 \Omega_3 w^2}{(k+1) \Omega_1} t, \quad y dy = \frac{1}{2} \frac{m_1 \Omega_3 w^2}{(k+1) \Omega_1} dt.$$

After substituting, the expression for PDF of w becomes:

$$p_w(w) = \frac{2}{\Gamma(m_1)} \left(\frac{m_1}{\Omega_1} \right)^{m_1} w^{2m_1-1} \frac{2}{\Gamma(m_2)} \frac{2(k+1)}{e^k \Omega_3} \times \left(\frac{m_2}{\Omega_2} \right)^{m_2} \frac{1}{2} (\Omega_1 \Omega_3)^{m_1+i_1+1} \frac{1}{(m_1 \Omega_3 w^2)^{m_1+i_1+1}} \times \frac{1}{2} \left(\frac{m_1 \Omega_3 w^2}{(k+1)} \right)^{m_2+m_1+i_1+1} \int_0^{\infty} dt t^{m_2+m_1+i_1} \times e^{-\frac{m_2}{\Omega_2} \frac{m_1 \Omega_3 w^2}{(k+1)} t} \frac{1}{(1+t)^{m_1+i_1+1}}. \quad (6)$$

Previously integral can be solved by using expression [12]:

$$\int_0^{\infty} dt t^{a-1} e^{-ct} \cdot \frac{1}{(t+1)^{a+b}} = \Gamma(a) U(a, b, c). \quad (7)$$

For considered case parameters a , b and c are:

$$a = m_2 + m_1 + i_1 + 1$$

$$b = m_2 + m_1 + i_1 + 1 + 1 - m_1 - i_1 - 1 = m_2 + 1 \quad (8)$$

$$c = \frac{m_2 m_1 \Omega_3}{\Omega_2 (k+1) \Omega_1} w^2$$

After substituting the expression for PDF of w becomes:

$$p_w(w) = \frac{2}{\Gamma(m_1)} \left(\frac{m_1}{\Omega_1} \right)^{m_1} w^{2m_1-1+2m_2} \frac{2}{\Gamma(m_2)} \left(\frac{m_2}{\Omega_2} \right)^{m_2} \times \frac{2(k+1)}{e^k \Omega_3} \cdot \frac{1}{2} (\Omega_1 \Omega_3)^{m_1+i_1+1} \frac{1}{2} \left(\frac{m_1 \Omega_3}{(k+1)} \right)^{m_2+m_1+i_1+1} \times \frac{1}{(m_1 \Omega_3)^{m_1+i_1+1}} \Gamma(m_2+m_1+i_1+1) \times U \left(m_2+m_1+i_1+1, m_2+1, \frac{m_2 m_1 \Omega_3}{\Omega_2 (k+1) \Omega_1} w^2 \right). \quad (9)$$

Moments of Ratio of Product of Two Nakagami-m Random Variables and Rician Random Variable

Moments of random variable w is:

$$m_n = \overline{w^n} = \int_0^\infty dw w^n p_w(w) = \frac{2}{\Gamma(m_1)} \left(\frac{m_1}{\Omega_1} \right)^{m_1} \frac{2}{\Gamma(m_2)} \left(\frac{m_2}{\Omega_2} \right)^{m_2} \frac{2(k+1)}{e^k \Omega_3} \cdot \frac{1}{2} (\Omega_1 \Omega_3)^{m_1+i_1+1} \frac{1}{2} \left(\frac{m_1 \Omega_3}{(k+1)} \right)^{m_2+m_1+i_1+1} \times \frac{1}{(m_1 \Omega_3)^{m_1+i_1+1}} \Gamma(m_2+m_1+i_1+1) \int_0^\infty dw w^{2m_1-1+2m_2+n} \times U \left(m_2+m_1+i_1+1, m_2+1, \frac{m_2 m_1 \Omega_3}{\Omega_2 (k+1) \Omega_1} w^2 \right) \quad (10)$$

Previously integral can be solved by using the formulae [10]:

$$\int_0^\infty dt t^{b-1} U(a, c, t) e^{-st} = \frac{\Gamma(b) \Gamma(b+1-c)}{\Gamma(a+b+1-c)} \times {}_2F_1(b, b+1-c, a+b+1-c, 1-s), \quad (11)$$

$$a = m_2 + m_1 + i_1 + 1,$$

$$v = \frac{m_2 m_1 \Omega_3}{\Omega_2 (k+1) \Omega_1} w^2, \quad w^2 = \frac{\Omega_2 (k+1) \Omega_1}{m_2 m_1 \Omega_3} v,$$

$$w dw = \frac{1}{2} \frac{\Omega_2 (k+1) \Omega_1}{m_2 m_1 \Omega_3} dt.$$

After substituting, the expression for m_n becomes:

$$m_n = \frac{2}{\Gamma(m_1)} \left(\frac{m_1}{\Omega_1} \right)^{m_1} \frac{2}{\Gamma(m_2)} \left(\frac{m_2}{\Omega_2} \right)^{m_2} \frac{2(k+1)}{e^k \Omega_3} \times \frac{1}{2} (\Omega_1 \Omega_3)^{m_1+i_1+1} \frac{1}{2} \left(\frac{m_1 \Omega_3}{(k+1)} \right)^{m_2+m_1+i_1+1} \times \frac{1}{(m_1 \Omega_3)^{m_1+i_1+1}} \Gamma(m_2+m_1+i_1+1) \frac{1}{2} \times \left(\frac{\Omega_2 (k+1) \Omega_1}{m_2 m_1 \Omega_3} \right)^{m_1+m_2+\frac{n}{2}} \int_0^\infty dv v^{m_1+m_2+\frac{n}{2}-1} \times U(m_2+m_1+i_1+1, m_2+1, v). \quad (12)$$

For considered case is:

$$a = m_1 + m_2 + i_1 + 1$$

$$b = m_1 + m_2 + \frac{n}{2}$$

$$c = m_2 + 1$$

$$b+1-c = m_1 + m_2 + \frac{n}{2} + 1 - m_2 + 1 = m_1 + \frac{n}{2} \quad (13)$$

After substituting, the expression for m_n obtained form:

$$m_n = \frac{2}{\Gamma(m_1)} \left(\frac{m_1}{\Omega_1} \right)^{m_1} \frac{2}{\Gamma(m_2)} \left(\frac{m_2}{\Omega_2} \right)^{m_2} \frac{2(k+1)}{e^k \Omega_3} \times \frac{1}{2} (\Omega_1 \Omega_3)^{m_1+i_1+1} \frac{1}{2} \left(\frac{m_1 \Omega_3}{(k+1)} \right)^{m_2+m_1+i_1+1} \times \frac{1}{(m_1 \Omega_3)^{m_1+i_1+1}} \frac{1}{2} \left(\frac{\Omega_2 (k+1) \Omega_1}{m_2 m_1 \Omega_3} \right)^{m_1+m_2+\frac{n}{2}} \times \Gamma(m_2+m_1+i_1+1) \frac{\Gamma(m_1+m_2+\frac{n}{2}) \Gamma(m_1+\frac{n}{2})}{\Gamma(m_2+2m_1+i_1+1+\frac{n}{2})} \times {}_2F_1 \left(m_1+m_2+\frac{n}{2}, m_1+\frac{n}{2}, m_2+2m_1+i_1+1+\frac{n}{2}, 1 \right) \quad (14)$$

Moment Generating Function of Ratio of Product Two Nakagami-m Random Variables and Rician Random Variable

Moment of generating function of w is:

$$M_w(s) = \overline{e^{ws}} = \int_0^\infty dw e^{ws} p_w(w) = \sum_{j=0}^\infty \frac{s^j}{j!} \int_0^\infty dw w^j p_w(w) = \sum_{j=0}^\infty \frac{s^j}{j!} m_j = \frac{2}{\Gamma(m_1)} \left(\frac{m_1}{\Omega_1} \right)^{m_1} \frac{2}{\Gamma(m_2)} \left(\frac{m_2}{\Omega_2} \right)^{m_2} \frac{2(k+1)}{e^k \Omega_3} \times \frac{1}{2} (\Omega_1 \Omega_3)^{m_1+i_1+1} \frac{1}{2} \left(\frac{m_1 \Omega_3}{(k+1)} \right)^{m_2+m_1+i_1+1} \times \frac{1}{(m_1 \Omega_3)^{m_1+i_1+1}} \frac{1}{2} \left(\frac{\Omega_2 (k+1) \Omega_1}{m_2 m_1 \Omega_3} \right)^{m_1+m_2+\frac{j}{2}} \times \Gamma(m_2+m_1+i_1+1) \frac{\Gamma(m_1+m_2+\frac{j}{2}) \Gamma(m_1+\frac{j}{2})}{\Gamma(m_2+2m_1+i_1+1+\frac{j}{2})} \times {}_2F_1 \left(m_1+m_2+\frac{j}{2}, m_1+\frac{j}{2}, m_2+2m_1+i_1+1+\frac{j}{2}, 1 \right). \quad (15)$$

Numerical results

In Figure 1, the first moment as average value of signal envelope in terms of signal envelope average power in the first section Ω_1 for several values of severity parameters in the first channel and the second channel and Rician factor are shown. The first moment increases when average power Ω_1 increases. The influence of average power Ω_1 on the first derivative is similar for lower and higher values of average power Ω_1 . The first moment takes higher values when the average power of envelope in the second section has higher values. The influence of average power Ω_1 on the first moment is higher for better values of average power Ω_2 . The first moment increases when Rician factor takes lower values. The influence of Rician factor on an average value of the ratio of product of two Nakagami-m random variables is higher for lower values of Rician factor.

Figure 1. Average signal value on output versus Ω_1 for various parameters κ and Ω_2 .

Figure 2. Average signal value on output versus Ω_2 for various parameters κ and Ω_1 .

Figure 3. Average signal value on output versus κ for various parameters Ω_2 and Ω_1 .

In Figure 2, the first moment of the ratio product of two Nakagami-m random variables and Rician random variable versus average power of signal envelope in the second channel is presented for several values of Rician factor and average powers of signal envelopes in the first section and the second section. The first power increases as signal envelope average power in the second channel increases. The effect of signal envelope average power on the first moment is same for lower and higher values of signal envelope average power.

In Figure 3, the first moment of signal to interference ration of considered system versus Rician κ factor of Rician short term fading interference is shown for several values of signal envelope average power in the second section and signal interference envelope average power. The first moment decreases as Rician κ factor increases. The influence of Rician factor on the first moment is higher for lower values of Rician factor. For higher values of Rician factor the first moment goes to constant. The first moment has higher values for higher values of the average power of signal envelope in the second section.

CONCLUSION

Wireless communication relay system with two sections, in the presence of multipath fading and co-channel interference affected to short term fading, is considered and analyzed in this paper. The desired signal in the first section suffers Nakagami-m small scale fading, the desired signal in the second section, also, is subjected to Nakagami-m multipath fading and co-channel interference envelope can be well described by using Rician distribution. Desired signal at output of radio relay system is equal to products of two Nakagami-m random variables. Nakagami-m distribution well modeled signal envelope in no line-of-sight fading environment and Rician distribution well describe the signal envelope in line-of-sight fading environment. In interference limited environment, where interference envelope average power is significantly higher from Gaussian noise power so that the effects of Gaussian noise on outage probability and bit error probability can be ignored, the important

performance measure is signal to noise ratio. In proposed relay system, signal to interference ratio is equal to the ratio of products of two Nakagami-m random variables and Rician random variable. The expression for probability density function, cumulative distribution function and moments of the ratio of two Nakagami-m random variables product and Rician random variable are derived. By using obtained expressions, outage probability, bit error probability and system capacity of wireless communication radio system in the presence of Nakagami-m fading and Rician co-channel interference can be evaluated. Also, using derived formulas, outage probability and bit error probability of wireless relay communication system in the presence Rayleigh short term fading and Rayleigh co-channel interference can be evaluated. The effects of Rician factor and Nakagami-m severity parameters m_1 and m_2 on the first moment are analyzed. Considered mobile relay communication system with two sections can lead to a more reliable and efficient transmission, which is of great importance in the risky environments.

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BIOGRAPHY

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PERFORMANSE RADIO RELEJNOG SISTEMA SA DVE DEONICE U PRISUSTVU NAKAGAMI-M FEDINGA I RAJSOVE MEĐUKANALNE INTERFERENCIJE

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Rezime. Posmatran je bežični mobilni relejni sistem sa dve deonice koji je izložen uticaju fedinga u kratkoročnom feding kanalu u prisustvu međukanalne interferencije. Korisni signal je izložen uticaju Nakagami-m fedinga, a međukanalna interferencija je izložena uticaju Rajsovog fedinga. Korisni signal na kraju druge deonice ima Nakagami-m*Nakagami-m raspodelu. Odnos korisnog signala i međukanalne interferencije je predstavljen količnikom proizvoda dve Nakagami-m slučajne promenljive i Rajsove slučajne promenljive. U ovom radu su za posmatrani sistem dobijeni izrazi u zatvorenom obliku za momente odnosa korisnog signala i interferencije. Uticaj parametara kratkoročnog Nakagami-m fedinga i Rajsovog κ faktora je analiziran i diskutovan. Mobilni relejni sistem sa dve deonice može dovesti do pouzdanijeg i efikasnijeg prenosa signala, što je od ogromnog značaja u rizičnim okruženjima.

Ključne reči: Nakagami-m feding, Rajsov feding, momenti, mobilni relejni komunikacioni sistem.