Performance of Wireless System in the Presence of K_G Short Term Fading and Nakagami-m Co-channel Interference

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Abstract: - In this paper, wireless mobile communication system in the presence of short term fading, long term fading and co-channel interference subjected to short term fading is considered. Desired signal experiences Nakagami-m short term fading and Gamma long term fading, and co-channel interference experiences Nakagami-m short term fading. In interference limited wireless fading channel, the ratio of desired signal envelope and co-channel interference envelope is important performance measure. In this paper, the closed form expressions for probability density function (PDF) and cumulative distribution function (CDF) of ratio of desired signal envelope and co-channel interference envelope are calculated. By using these formulas, outage performance of proposed wireless communication mobile system can be evaluated. The influence of Nakagami-m multipath fading severity parameter of desired signal and interference signal, Gamma long term fading severity parameter and Gamma long term fading correlation coefficient on outage probabilities are analyzed and discussed.

Key-Words: - Gamma fading; K_G short term fading; Nakagami-m fading; Outage probability

1 Introduction

Nakagami-m small scale fading, Gamma large scale fading and Nakagami-m co-channel interference degrade outage probability, bit error probability and channel capacity of wireless mobile communication system [1]. Reflections, refractions, defractions and scattering cause Nakagami-m variation of desired signal envelope and co-channel interference envelope. Large obstacles between transmitter and receivers cause Gamma variation of desired signal envelope average power resulting in system performance degradation [1] - [3].

There are a few distributions which are used to describe signal envelope variation in fading channels: Rayleigh, Rician, Nakagami-m, Weibull, α-μ, κ-μ. Nakagami-m distribution can describes small scale signal envelope variation in linear, non line of sight multipath fading channels [4]. This distribution has parameter *m*, known as severity parameter which takes values of 0.5 to infinity. By setting for *m*=1, Nakagami-m distribution reduces to Rayleigh distribution and for *m*=0.5, one sided Gaussian distribution can be derived from Nakagami-m distribution. When parameter *m* goes to infinity, Nakagami-m channel becomes no fading channel. Wireless communication channel with Gamma long term fading and Nakagami-m short term fading is named as Gamma shadowed Nakagami-m channel. Gamma shadowed Nakagami-m channel becomes Nakagami-m short term fading channel when Gamma long term fading severity parameter goes to infinity. Gamma shadowed Nakagami-m channel becomes Gamma long term fading channel when Nakagami-m fading severity parameter goes to infinity. Gamma shadowed Nakagami-m short term fading channel becomes Gamma shadowed Rayleigh channel when Nakagami-m fading severity parameter is one.

K_G distribution is a popular approximation of the Nakagami-lognormal distribution [5]. In the work [6], the authors developed probability density functions for the instantaneous received signal to interference plus noise ratio (SINR) in Nakagami-m fading channels where the target and interfering channels have different fading parameters.

An outage analysis of wireless systems operating in gamma-shadowed Nakagami-faded environment with desired signal suffers co-channel interference is given in [7]. The interference is also subjected to fading and shadowing. The probability density function (PDF) and closed-form expression for the outage probability are obtained based on signal to interference ratio (SIR).

The compound Nakagami-m fading gamma shadowing model was considered by Kostic in [8]. In [9], the effects of simultaneous correlated multipath fading and shadowing on the performances of a signal to interference ratio based dual-branch selection combining diversity receiver is considered. That analysis included the presence of co-channel interference. A generalized fading/shadowing channel model in an interference limited correlated fading environment is modelled by generalized-K distribution. The closed-form expression is derived for the outage probability.

In interference limited environment, the power of co-channel interference is significantly higher in compare to power of Gaussian thermal noise, so that the influence of thermal noise on the outage probability can be ignored. Statistics of signal to interference ratios are important in interference limited channels and the first order performance measures as outage probability, bit error probability and channel capacity can be evaluated.

There are more papers in available literature considering the first order and the second order performance measures of wireless mobile communication systems operating over shadowed multipath fading channel in the presence of co-channel interference.

In [10], wireless communication system with selection combining (SC) diversity receiver in the presence of correlated Weibull short term fading and Weibull co-channel interference is considered. In this paper, probability density function, cumulative distribution function and moments of resulting signal envelope are evaluated. Also, system performance as outage probability, bit error probability and channel capacity are calculated. In [11], the outage probability and bit error probability of wireless system in the presence of Nakagami-m desired signal and Nakagami-m interference are calculated and analyzed.

In our paper, wireless communication system in the presence of Nakagami-m short term fading, Gamma long term fading and co-channel interference affected by Nakagami-m multipath fading is observed. The proposed system operates in interference limited conditions. Probability density function and cumulative distribution function of ratio of Gamma shadowed Nakagami-m random variable and Nakagami-m random variable are evaluated. Outage performance is calculated from cumulative distribution function.

2 Performance of Wireless System in the Presence of K_G Short Term Fading and Nakagami-m Co-channel Interference

The ratio of K_G random variable and Nakagami-m random variable is:

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

Probability density function of x is:

$$p_x\left(x/\Omega\right)=\frac{2}{\Gamma(m)}\left(\frac{m}{\Omega}\right)^m x^{2m-1}e^{-\frac{m}{\Omega}x^2}\,,\ x\geq 0 \tag{2}$$

where Ω has Gamma distribution:

$$p_\Omega\left(\Omega\right)=\frac{1}{\Gamma\left(c_1\right)\beta^{c_1}}\cdot\Omega^{c_1-1}e^{-\frac{1}{\beta}\Omega}\,,\Omega\geq 0 \tag{3}$$

By averaging, $p_x(x)$ becomes:

$$p_x\left(x\right)=\int_0^\infty d\Omega\, p_x\left(x/\Omega\right)p_\Omega\left(\Omega\right)=$$
$$=\frac{2}{\Gamma(m)}\left(\frac{m}{\Omega}\right)^m\frac{1}{\Gamma\left(c_1\right)\beta^{c_1}}\cdot x^{2m-1}$$
$$\cdot\int_0^\infty d\Omega\,\Omega^{c_1-1-m}\,e^{-\frac{mx^2}{\Omega}-\frac{1}{\beta}\Omega}=$$
$$=\frac{2}{\Gamma(m)}m^m x^{2m-1}\frac{1}{\Gamma\left(c_1\right)\beta^{c_1}}\cdot$$
$$\cdot 2\left(\frac{mx^2}{\beta}\right)^{\frac{c_1}{2}-\frac{m}{2}}K_{c-m}\left(\sqrt{mx^2\beta}\right)=$$
$$=\frac{2}{\Gamma(m)}m^m x^{2m-1}\frac{1}{\Gamma\left(c_1\right)\beta^{c_1}}\cdot$$
$$\cdot 2\left(\frac{mx^2}{\beta}\right)^{\frac{c_1}{2}-\frac{m}{2}}\frac{1}{2}G_{0,2}^{2,0}\left(\frac{1}{4}mx^2\beta\left|\begin{matrix}-\\ \frac{1}{2}(c-m),\frac{1}{2}(c-m)\end{matrix}\right.\right) \tag{4}$$

where $K_\kappa(.)$ is the modified Bessel function of the second kind [12]; and $G_{p,q}^{m,n}$ is Meijer G-function [13]. It is very general function which reduces to simpler special functions in many common cases. The Meijer G-function is defined by:

$$G_{p,q}^{m,n}\left(x\left|\begin{matrix}a_1,...,a_p\\ b_1,...,b_q\end{matrix}\right.\right)=$$

$$= \frac{1}{2\pi i} \int_{\gamma L} \frac{\Pi_{j=1}^{m}\Gamma\left(b_j - s\right)\Pi_{j=1}^{n}\Gamma\left(1-a_j+s\right)}{\Pi_{j=n+1}^{p}\Gamma\left(a_j - s\right)\Pi_{j=m+1}^{q}\Gamma\left(1-b_j+s\right)} x^s ds\,,$$

where $\Gamma(.)$ is the gamma function.

Cumulative distribution function of x is:

$$F_x\left(x\right) = \int_0^x dt\, p_x\left(t\right) =$$

$$= \int_0^x dt \frac{2}{\Gamma\left(m\right)} m^m \frac{1}{\Gamma\left(c_1\right)\beta^{c_1}} t^{2m-1}$$

$$\cdot \int_0^\infty d\Omega\,\Omega^{c_1-1-m}\, e^{-\frac{mt^2}{\Omega}-\frac{1}{\beta}\Omega} =$$

$$= \frac{2}{\Gamma\left(m\right)} m^m \frac{1}{\Gamma\left(c_1\right)\beta^{c_1}} \int_0^\infty d\Omega\,\Omega^{c_1-1-m}\, e^{-\frac{1}{\beta}\Omega}$$

$$\int_0^x dt\, t^{2m-1} e^{-\frac{mt^2}{\Omega}} =$$

$$= \frac{2}{\Gamma\left(m\right)} m^m \frac{1}{\Gamma\left(c_1\right)\beta^{c_1}} \int_0^\infty d\Omega\,\Omega^{c_1-1-m}\, e^{-\frac{1}{\beta}\Omega}$$

$$\frac{1}{2}\left(\frac{\Omega}{m}\right)^m \gamma\left(m, \frac{m}{\Omega}x^2\right) =$$

$$= \frac{2}{\Gamma\left(m\right)} m^m \frac{1}{\Gamma\left(c_1\right)\beta^{c_1}} \int_0^\infty d\Omega\,\Omega^{c_1-1-m}\, e^{-\frac{1}{\beta}\Omega}$$

$$\frac{1}{2}\left(\frac{\Omega}{m}\right)^m \frac{1}{m}\left(\frac{m}{\Omega}x^2\right)^m e^{-\frac{m}{\Omega}x^2} \sum_{j_1=0}^{\infty} \frac{1}{\left(m+1\right)\left(j_1\right)}\left(\frac{m}{\Omega}x^2\right)^{j_1} =$$

$$= \frac{2}{\Gamma\left(m\right)} m^m \frac{1}{\Gamma\left(c_1\right)\beta^{c_1}}$$

$$\frac{1}{2}\frac{1}{m} x^{2m} e^{-\frac{m}{\Omega}x^2} \sum_{j_1=0}^{\infty} \frac{1}{\left(m+1\right)\left(j_1\right)}\left(mx^2\right)^{j_1}$$

$$\int_0^\infty d\Omega\,\Omega^{c_1-1-m-j_1}\, e^{-\frac{m}{\Omega}x^2-\frac{1}{\beta}\Omega} =$$

$$= \frac{1}{\Gamma\left(m\right)} m^{m-1} \frac{1}{\Gamma\left(c_1\right)\beta^{c_1}}\; x^{2m} \sum_{j_1=0}^{\infty} \frac{1}{\left(m+1\right)\left(j_1\right)}\left(mx^2\right)^{j_1}$$

$$\cdot 2\left(\frac{mx^2}{\beta}\right)^{\frac{c_1}{2}-\frac{m}{2}-\frac{j_1}{2}} K_{c_1-m-j_1}\left(2\sqrt{mx^2\beta}\right). \qquad (5)$$

Probability density function of z is:

$$p_z\left(z\right) = \int_0^\infty dy\, y\, p_x\left(zy\right) p_y\left(y\right) =$$

$$= \int_0^\infty dy\, y \frac{2}{\Gamma\left(m\right)} m^m \frac{1}{\Gamma\left(c_1\right)\beta^{c_1}} \left(zy\right)^{2m-1}$$

$$\cdot \int_0^\infty d\Omega\,\Omega^{c_1-1-m}\, e^{-\frac{mz^2y^2}{\Omega}-\frac{1}{\beta}\Omega}$$

$$\cdot \frac{2}{\Gamma\left(m_1\right)}\left(\frac{m_1}{\Omega_1}\right)^{m_1} y^{2m_1-1} e^{-\frac{m_1}{\Omega_1}y^2} =$$

$$= \frac{2}{\Gamma\left(m\right)} m^m \frac{1}{\Gamma\left(c_1\right)\beta^{c_1}} z^{2m-1} \frac{2}{\Gamma\left(m_1\right)}\left(\frac{m_1}{\Omega_1}\right)^{m_1}$$

$$\cdot \int_0^\infty d\Omega\,\Omega^{c_1-1-m}\, e^{-\frac{1}{\beta}\Omega}$$

$$\cdot \int_0^\infty dy\, y^{1+2m-1+2m_1-1} e^{-y^2\left(\frac{mz^2}{\Omega}+\frac{m_1}{\Omega_1}\right)} =$$

$$= \frac{2}{\Gamma\left(m\right)} m^m \frac{1}{\Gamma\left(c_1\right)\beta^{c_1}} z^{2m-1} \frac{2}{\Gamma\left(m_1\right)}\left(\frac{m_1}{\Omega_1}\right)^{m_1}$$

$$\cdot \int_0^\infty d\Omega\,\Omega^{c_1-1-m}\, e^{-\frac{1}{\beta}\Omega}$$

$$\frac{1}{2}\left(\Omega\Omega_1\right)^{m+m_1} \frac{1}{\left(mz^2\Omega_1+m_1\Omega\right)^{m+m_1}} =$$

$$= \frac{2}{\Gamma\left(m\right)} m^m \frac{1}{\Gamma\left(c_1\right)\beta^{c_1}} z^{2m-1} \frac{2}{\Gamma\left(m_1\right)}\left(\frac{m_1}{\Omega_1}\right)^{m_1} \frac{1}{2}\Omega_1^{m+m_1}$$

$$\cdot \int_0^\infty d\Omega\,\Omega^{c_1-1-m+m+m_1}\, e^{-\frac{1}{\beta}\Omega} \frac{1}{\left(mz^2\Omega_1+m_1\Omega\right)^{m+m_1}}. \qquad (6)$$

The next integral J is used to solve the previous one [14]:

$$J = \int_0^\infty d\Omega\,\Omega^{p-1} e^{-\alpha\Omega} \frac{1}{\left(a\Omega+b\right)^n} =$$

$$= \frac{1}{b^n} \int_0^\infty d\Omega\,\Omega^{p-1} e^{-\alpha\Omega} \frac{1}{\left(\frac{a}{b}\Omega+1\right)^n} \qquad (7)$$

Here, the substitution is introduced [15]:

$$\frac{a}{b}\Omega = x, \Omega = \frac{b}{a}x, d\Omega = \frac{b}{a}dx, \tag{8}$$

and integral J obtained in the shape:

$$J = \frac{1}{b^n}\left(\frac{b}{a}\right)^p \int_0^\infty dx\, x^{p-1} e^{-\frac{\alpha b x}{a}} \frac{1}{(x+1)^n} =$$

$$= \frac{1}{b^n}\left(\frac{b}{a}\right)^p \Gamma(p)\, {}_1F_1\left(p, p+1-n, \frac{\alpha b}{a}\right) \tag{9}$$

where ${}_1F_1(a;b;c)$ is confluent hypergeometric function of the first kind [16].

Probability density function of z is now:

$$p_z(z) = \frac{2}{\Gamma(m)} m^m \frac{1}{\Gamma(c_1)\beta^{c_1}} z^{2m-1} \frac{2}{\Gamma(m_1)}\left(\frac{m_1}{\Omega_1}\right)^{m_1} \frac{1}{2}\Omega_1^{m+m_1}$$

$$\cdot \frac{1}{\left(mz^2\Omega_1\right)^{m+m_1+c_1-m_1}} \frac{1}{m_1^{c_1+m_1}}$$

$$\Gamma(c_1+m_1)\, {}_1F_1\left(c_1+m_1, c_1+m_1+1-m-m_1; \frac{1}{\beta}\frac{mz^2\Omega_1}{m_1}\right) \tag{10}$$

Cumulative distribution function of z is:

$$F_z(z) = \int_0^z dt\, p_z(t) =$$

$$= \int_0^z dt \cdot \frac{2}{\Gamma(m)} m^m \frac{1}{\Gamma(c_1)\beta^{c_1}} t^{2m-1} \frac{2}{\Gamma(m_1)}\left(\frac{m_1}{\Omega_1}\right)^{m_1}$$

$$\cdot \int_0^\infty d\Omega\, \Omega^{c_1-1-m} e^{-\frac{1}{\beta}\Omega}$$

$$\cdot \int_0^\infty dy\, y^{2m+2m_1-1} e^{-y^2\left(\frac{mt^2}{\Omega}+\frac{m_1}{\Omega_1}\right)} =$$

$$= \frac{2}{\Gamma(m)} m^m \frac{1}{\Gamma(c_1)\beta^{c_1}} \frac{2}{\Gamma(m_1)}\left(\frac{m_1}{\Omega_1}\right)^{m_1}$$

$$\cdot \int_0^\infty d\Omega\, \Omega^{c_1-1-m} e^{-\frac{1}{\beta}\Omega} \cdot \int_0^\infty dy\, y^{2m+2m_1-1} e^{-\frac{m_1}{\Omega_1}y^2}$$

$$\int_0^z dt \cdot t^{2m-1} e^{-\frac{m}{\Omega}t^2} =$$

$$= \frac{2}{\Gamma(m)} m^m \frac{1}{\Gamma(c_1)\beta^{c_1}} \frac{2}{\Gamma(m_1)}\left(\frac{m_1}{\Omega_1}\right)^{m_1}$$

$$\cdot \int_0^\infty d\Omega\, \Omega^{c_1-1-m} e^{-\frac{1}{\beta}\Omega} \cdot \int_0^\infty dy\, y^{2m+2m_1-1} e^{-\frac{m_1}{\Omega_1}y^2}$$

$$\frac{1}{2}\left(\frac{\Omega}{my^2}\right)^m \gamma\left(m, \frac{my^2}{\Omega}z^2\right) =$$

$$= \frac{2}{\Gamma(m)} m^m \frac{1}{\Gamma(c_1)\beta^{c_1}} \frac{2}{\Gamma(m_1)}\left(\frac{m_1}{\Omega_1}\right)^{m_1}$$

$$\cdot \int_0^\infty d\Omega\, \Omega^{c_1-1-m} e^{-\frac{1}{\beta}\Omega} \cdot \int_0^\infty dy\, y^{2m+2m_1-1} e^{-\frac{m_1}{\Omega_1}y^2}$$

$$\frac{1}{2}\left(\frac{\Omega}{my^2}\right)^m \frac{1}{m}\left(\frac{my^2}{\Omega}\right)^m z^{2m} e^{-\frac{my^2}{\Omega}z^2}$$

$$\sum_{j_1=0}^\infty \frac{1}{(m+1)(j_1)}\left(\frac{my^2z^2}{\Omega}\right)^{j_1} =$$

$$= \frac{2}{\Gamma(m)} m^m \frac{1}{\Gamma(c_1)\beta^{c_1}} \frac{2}{\Gamma(m_1)}\left(\frac{m_1}{\Omega_1}\right)^{m_1}$$

$$\frac{1}{2}\frac{1}{m} x^{2m} \sum_{j_1=0}^\infty \frac{1}{(m+1)(j_1)}\left(mx^2\right)^{j_1}$$

$$\cdot \int_0^\infty d\Omega\, \Omega^{c_1-1-m-j_1} e^{-\frac{1}{\beta}\Omega}$$

$$\cdot \int_0^\infty dy\, y^{2m+2m_1-1+2j_1} e^{-\frac{mx^2}{\Omega}y^2 - \frac{m_1}{\Omega_1}y^2} =$$

$$= \frac{2}{\Gamma(m)} m^m \frac{1}{\Gamma(c_1)\beta^{c_1}} \frac{2}{\Gamma(m_1)}\left(\frac{m_1}{\Omega_1}\right)^{m_1}$$

$$\frac{1}{2}\frac{1}{m} x^{2m} \sum_{j_1=0}^\infty \frac{1}{(m+1)(j_1)}\left(mx^2\right)^{j_1}$$

$$\cdot \int_0^\infty d\Omega\, \Omega^{c_1-1-m-j_1} e^{-\frac{1}{\beta}\Omega}$$

$$\cdot \frac{1}{2}(\Omega\Omega_1)^{m+m_1+j_1} \frac{1}{\left(mx^2\Omega_1+m_1\Omega\right)^{m+m_1+j_1}} =$$

$$= \frac{2}{\Gamma(m)} m^m \frac{1}{\Gamma(c_1)\beta^{c_1}} \frac{2}{\Gamma(m_1)}\left(\frac{m_1}{\Omega_1}\right)^{m_1}$$

$$\frac{1}{2}\frac{1}{m} z^{2m} \sum_{j_1=0}^\infty \frac{1}{(m+1)(j_1)}\left(mz^2\right)^{j_1} \frac{1}{2}\Omega_1^{m+m_1+j_1}$$

$$\cdot \int_0^\infty d\Omega\, \Omega^{c_1-1-m-j_1+m+m_1+j_1} e^{-\frac{1}{\beta}\Omega} \frac{1}{\left(mz^2\Omega_1+m_1\Omega\right)^{m+m_1+j_1}} \tag{11}$$

For solving the last integral in (11), the formula (9) is used. The parameters are:

$$p = c_1 + m_1$$

$$\alpha = \frac{1}{\beta}$$

$$a = m_1$$

$$b = mx^2\Omega_1$$

$$n = m + m_1 + j_1$$

$$n - p = m + m_1 + j_1 - c_1 - m_1$$

$$p + 1 - n = c_1 + m_1 + 1 - m - m_1 - j_1$$

After substituting, the expression for cumulative distribution function of z, $F_z(z)$ from (11) becomes:

$$F_z(z) = \frac{2}{\Gamma(m)} m^m \frac{1}{\Gamma(c_1)\beta^{c_1}} \frac{2}{\Gamma(m_1)} \left(\frac{m_1}{\Omega_1}\right)^{m_1}$$

$$\frac{1}{2m} z^{2m} \sum_{j_1=0}^{\infty} \frac{1}{(m+1)(j_1)} \left(mz^2\right)^{j_1} \frac{1}{2} \Omega_1^{m+m_1+j_1}$$

$$\frac{1}{\left(mz^2\Omega_1\right)^{m+j_1-c_1}} \frac{1}{m_1^{c_1+m_1}}$$

$$\Gamma(c_1 + m_1)\, {}_1F_1\left(c_1 + m_1, c_1 + 1 - m - j_1; \frac{mz^2\Omega_1}{\beta m_1}\right). \tag{12}$$

The outage probability is the probability that the receiver output signal envelope to interference ratio is below a given threshold γ_{th}[17]-[19]. It can be straight calculated as

$$P_{out}(\gamma_{th}) = F_z(z),$$

where $F_z(z)$ is obtained in (12).

4 Numerical results

Outage probability of wireless communication system in the presence of Nakagami-m short term fading, Gamma long term fading and co-channel interference affected by Nakagami-m multipath fading is shown versus receiver output signal to interference ratio in Fig. 1 and 2. This system works in interference limited conditions. Probability density function and cumulative distribution function of ratio of Gamma shadowed Nakagami-m random variable and Nakagami-m random variable are evaluated. Outage performance is calculated from cumulative distribution function.

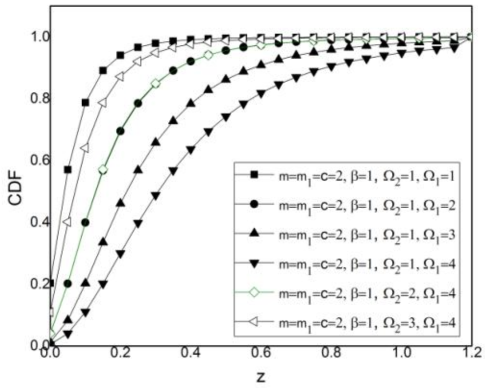

Fig. 1. Outage probability versus output signal to interference ratio z

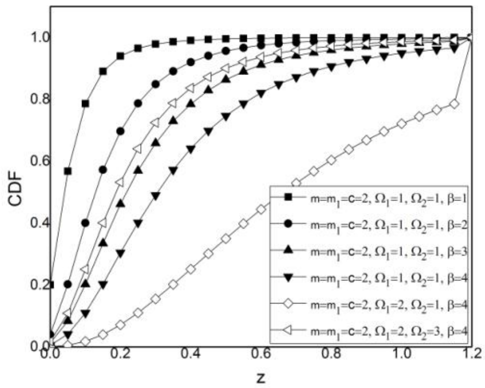

Fig. 2. Outage probability depending on output signal to interference ratio z

When resulting signal to interference ratio increases, the outage probability increases also. The influence of signal to interference ratio at outage probability is higher for lower values of signal to interference ratio. Outage probability decreases when parameter β of Gamma large scale fading increases.

5 Conclusion

In this paper, wireless communication radio system in the presence of small scale fading, large scale fading and co-channel interference is considered. Desired signal is subjected to Nakagami-m small scale fading, Gamma large scale fading and co-channel interference experiences only Nakagami-m small scale fading. Proposed wireless communication system operates over interference limited environment. Under these conditions, ratio of desired signal envelope and co-channel interference signal envelope is important performance measure of wireless system by which outage probability and bit error probability can be calculated. In this paper, probability density function and cumulative distribution function of Gamma shadowed Nakagami-m multipath fading envelope are evaluated and these results are used for evaluation probability density function and cumulative distribution function of ratio of Gamma shadowed Nakagami-m random variable and Nakagami-m random variable are derived.

Outage probability can be calculated by using cumulative distribution function and bit error probability can be evaluated from probability density function. By using obtained expressions, outage performance of wireless communication system in the presence of Gamma long term fading, Rayleigh short term fading and Rayleigh co-channel interference can be calculated. The influence of Gamma long term fading severity parameter, Gamma long term fading correlation coefficient, Nakagami-m short term fading severity parameter of desired signal and co-channel interference on outage probability of proposed wireless communication system is analyzed and studied. Outage probability takes lower values for higher values of Gamma long term fading severity parameter, Nakagami-m short term fading severity parameter of desired signal and Nakagami-m short term fading severity parameter of co-channel interference.

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