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

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Abstract: - In this paper, wireless mobile communication radio system in the presence of long term fading, short term fading and co-channel interference will be analyzed. Desired signal and cochannel interference experiences Nakagami-m short term fading and Gamma long term fading. Probability density function and cumulative distribution function of the ratio of two K_G random variable are obtained as the closed form expressions. Probability density function can be used for calculation the bit error probability and cumulative distribution function can be used for evaluation the outage probability. In interference limited environment, signal to interference ratio is important performance measure of wireless system. The influence of Nakagami-m short term fading severity parameter and Gamma long term fading severity parameter on the outage probability will be examined.

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

1 Introduction

Short term fading causes signal envelope variation and long term fading causes signal envelope average power variation resulting in the outage probability and the bit error probability of wireless system degradation [1] [2]. In cellular communication systems, power of co-channel interference is higher than power of Gaussian noise, so that the ratio of signal envelope to interference envelope is important performance measure. By using statistics of the signal to interference ratio (SIR), the outage probability, the bit error probability and the channel capacity can be evaluated [3].

There are several distributions which can be used to describe signal envelope variation and signal envelope average power variation in fading channels. For describing signal envelope variation, Rayleigh, Rician, Nakagami-*m* and Weibull distributins are used. Nakagami-*m* distribution describes small scale signal envelope variation in linear, non line of sight multipath fading channels [4]. Nakagami-m distribution has parameter *m*, which has values from 0.5 to infinity. For *m*=1, Nakagami-*m* distribution becomes Rayleigh distribution; one sided Gaussian distribution can be obtained from Nakagami-*m* distribution for *m*=0.5; in a situation when parameter *m* goes to infinity, Nakagami-*m* fading channel becomes channel without fading. Parameter *m* is known as severity parameter. As parameter decreases, severity of Nakagami-*m* fading increases.

Gamma distribution can be used to describe signal envelope average power variation in fading channels. Composite Nakagami-Gamma distribution is named K_G distribution. K_G distribution describes signal envelope with Nakagami-*m* distribution and signal envelope average power with Gamma distribution. This distribution has two parameters. The first parameter is Nakagami-*m* short term fading severity parameter and the second parameter is Gamma long term fading severity parameter [5]. When Nakagami-*m* short term fading severity parameter goes to infinity, K_G fading channel becomes Gamma long term fading channel and when Gamma long term fading severity parameter goes to infinity, K_G fading channel becomes Nakagami-*m* short term fading channel. When Nakagami-*m* short term fading severity parameter and Gamma long term fading severity parameter go to infinity, K_G fading channel becomes no fading channel.

Earlier, it was the Nakagami-lognormal distribution the commonly used as composite distribution for modeling multipath fading and shadowing channels. In [6], distribution which can precisely present both, the mutlipath fading and shadowing effects, is shown and accuracy of the mixture distribution compared with K_G distribution, popular approximation of Nakagami-lognormal distribution.

Nowadays, the composite short term fading-Gamma shadowing is more often used to describe fading channels. So, the composite Rayleigh-Gamma and Nakagami-Gamma distributions are considered in [7]; the compound Nakagami-m fading gamma shadowing model was considered in [8]. Because multipath fading and shadowing affect wireless channels together, composite fading model is proposed for modelling the shadowed channels. This resulted in a closed form solution for probability density functions (PDFs) of composite Rayleigh-Gamma and Nakagami-Gamma distributions, known as the K-distribution and K_G-distribution [9]. Later, diversity reception is investigated over generalized-K and K_G fading channels in [10].

There are a certain number of works in available technical literature treated wireless mobile communication radio systems working over short term fading and long term fading channels in the presence of co-channel interference, as in [11]. In [12], the outage probability and the bit error probability of wireless system in the presence of Nakagami-m desired signal and Nakagami-m interference are calculated and analyzed.

An analysis of macrodiversity reception with macrodiversity selection combining (SC) receiver and two microdiversity SC receivers working in Gamma shadowed Weibull small scale fading channel in the presence of cochannel interference subjected to Weibull fading is done in [13]. Level crossing rate (LCR) of the ratio of two Weibull random processes is determined and used for calculation the LCR at the output of MID SC receivers. Finally, the closed form expression for LCR at the MAD SC receiver output is calculated.

In [14][15], wireless communication system with selection combining (SC) diversity receiver with two inputs in the presence of Weibull short term fading and co-channel interference is studied. Probability density function, cumulative distribution function (CDF) and moments of SC receiver output signal to interference ratio and the outage probability, the bit error probability and the channel capacity are calculated. Wireless macrodiversity system with macrodiversity SC reception and two microdiversity SC receivers in the presence of long term fading, short term fading and co-channel interference is analyzed.

The analysis of wireless communication radio system where desired signal is subjected to Nakagami-m small scale fading, Gamma large scale fading and cochannel interference suffers only Nakagami-m small scale fading is given in [16]. Under these conditions, PDF and CDF of Gamma shadowed Nakagami-m multipath fading envelope are evaluated and used for calculation PDF and CDF of the ratio of Gamma shadowed Nakagami-m random variable and Nakagami-m random variable.

In this article, wireless communication system in the presence of long term fading, short term fading and co-channel interference is observed. Desired signal experiences Nakagami-m small scale fading and Gamma large scale fading, and co-channel interference is also subjected to Gamma long term fading and Nakagami-m short term fading. In cellular mobile radio systems, the ratio of desired signal envelope to co-channel interference envelope is important performance measure by which the outage probability and the bit error probability can be evaluated. Here, probability density function and cumulative distribution function of ratio of two K_G random variables are calculated. To the best authors' knowledge, wireless communication systems where desired signal experiences Gamma long term fading and Nakagami-m short term fading and co-channel interference experiences also Gamma long term fading and Nakagami-m short term fading is not reported in open technical literature.

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

Conditional probability density function of desired signal is:

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

where Ω_1 follows Gamma distribution:

$$p_{\Omega_1}\left(\Omega_1\right)=\frac{1}{\Gamma(c_1)\beta_1^{c_1}}\cdot\Omega_1^{c_1-1}e^{-\frac{1}{\beta_1}\Omega_1},\ \Omega_1\geq 0 \quad (2)$$

Desired signal follows K_G distribution:

$$p_x(x)=\int_0^\infty d\Omega_1\, p_x\left(x/\Omega_1\right)p_{\Omega_1}\left(\Omega_1\right)=$$

$$=\frac{2}{\Gamma(m)}m^m\frac{1}{\Gamma(c_1)\beta_1^{c}}\cdot x^{2m-1}$$

$$\cdot\int_0^\infty d\Omega_1\,\Omega_1^{c-1-m}e^{-\frac{m}{\Omega_1}x^2-\frac{1}{\beta_1}\Omega_1}=$$

$$=\frac{2}{\Gamma(m)}m^m\frac{1}{\Gamma(c)\beta_1^c}x^{2m-1}\cdot$$

$$\cdot 2\left(mx^2\beta_1\right)^{\frac{c-m}{2}}K_{c-m}\left(\sqrt{\frac{mx^2}{\beta_1}}\right) \quad (3)$$

where $K_\kappa(.)$ is the modified Bessel function of the second kind [17].

Conditional probability density function of interference signal envelope is:

$$p_y\left(y/\Omega_2\right)=\frac{2}{\Gamma(m)}\left(\frac{m}{\Omega_2}\right)^m y^{2m-1}e^{-\frac{m}{\Omega_2}y^2},\ y\geq 0 \quad (4)$$

where Ω_2 follows Gamma distribution:

$$p_{\Omega_2}\left(\Omega_2\right)=\frac{1}{\Gamma(c)\beta_2^c}\cdot\Omega_2^{c-1}e^{-\frac{1}{\beta_2}\Omega_2},\Omega_2\geq 0 \quad (5)$$

Interference signal envelope has distribution:

$$p_y(y)=\int_0^\infty d\Omega_2\, p_y\left(y/\Omega_2\right)p_{\Omega_2}\left(\Omega_2\right)=$$

$$=\frac{2}{\Gamma(m)}m^m\frac{1}{\Gamma(c)\beta_2^c}\cdot y^{2m-1}$$

$$\cdot\int_0^\infty d\Omega_2\,\Omega_2^{c-1-m}\,e^{-\frac{m}{\Omega_2}y^2-\frac{1}{\beta_2}\Omega_2}=$$

$$=\frac{2}{\Gamma(m)}m^m\frac{1}{\Gamma(c)\beta_2^c}y^{2m-1}\cdot$$

$$\cdot 2\left(my^2\beta_2\right)^{\frac{c-m}{2}}K_{c-m}\left(\sqrt{\frac{my^2}{\beta_2}}\right) \quad (6)$$

The ratio of two K_G random variable x and y is:

$$z=\frac{x}{y},\ \ x=z\cdot y\,. \quad (7)$$

Probability density function of z is:

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

$$=\frac{2}{\Gamma(m)}m^m\frac{1}{\Gamma(c)\beta_1^c}z^{2m-1}\cdot\frac{2}{\Gamma(m)}m^m\frac{1}{\Gamma(c)\beta_2^c}$$

$$\int_0^\infty dy\,y^{1+2m-1+2m-1}\cdot\int_0^\infty d\Omega_1\,\Omega_1^{c-1-m}\,e^{-\frac{m}{\Omega_1}z^2y^2-\frac{1}{\beta_1}\Omega_1}$$

$$\cdot\int_0^\infty d\Omega_2\,\Omega_2^{c-1-m}\,e^{-\frac{m}{\Omega_2}y^2-\frac{1}{\beta_2}\Omega_2}=$$

$$=\frac{2}{\Gamma(m)}m^m\frac{1}{\Gamma(c)\beta_1^c}z^{2m-1}\cdot\frac{2}{\Gamma(m)}m^m\frac{1}{\Gamma(c)\beta_2^c}$$

$$\cdot\int_0^\infty d\Omega_1\,\Omega_1^{c-1-m}\,e^{-\frac{1}{\beta_1}\Omega_1}\cdot\int_0^\infty d\Omega_2\,\Omega_2^{c-1-m}\,e^{-\frac{1}{\beta_2}\Omega_2}$$

$$\int_0^\infty dy\,y^{4m-1}e^{-y^2\left(\frac{mz^2}{\Omega_1}+\frac{m}{\Omega_2}\right)}=$$

$$=\left(\frac{2}{\Gamma(m)}\right)^2 m^{2m}\frac{1}{\left(\Gamma(c)\right)^2\beta_1^c\beta_2^c}z^{2m-1}$$

$$\cdot\int_0^\infty d\Omega_1\,\Omega_1^{c-1-m}\,e^{-\frac{1}{\beta_1}\Omega_1}\cdot\int_0^\infty d\Omega_2\,\Omega_2^{c-1-m}\,e^{-\frac{1}{\beta_2}\Omega_2}$$

$$\frac{1}{2}\left(\Omega_1\Omega_2\right)^{2m}\frac{1}{m^{2m}\left(z^2\Omega_2+\Omega_1\right)^{2m}}=$$

$$=\frac{1}{2}\left(\frac{2}{\Gamma(m)}\right)^2\frac{1}{\left(\Gamma(c)\right)^2\beta_1^c\beta_2^c}z^{2m-1}$$

$$\cdot\int_0^\infty d\Omega_1\,\Omega_1^{c-1-m+2m}\,e^{-\frac{1}{\beta_1}\Omega_1}\cdot\int_0^\infty d\Omega_2\,\Omega_2^{c-1-m+2m}\,e^{-\frac{1}{\beta_2}\Omega_2}$$

$$\frac{1}{\left(z^2\Omega_2+\Omega_1\right)^{2m}}\,. \quad (8)$$

Previous two-fold integral can be solved by using formula [18]:

$$\int_0^\infty d\Omega\,\Omega^{p_1-1}\,e^{-\alpha_1\Omega}\int_0^\infty ds\,s^{p_2-1}\,e^{-\alpha_2 s}\,\frac{1}{\left(a\Omega+bs\right)^n}=$$

$$=\frac{a^{p_1-n}}{b^{p_1}}\frac{\Gamma(p_2)}{\alpha_2^{p_2+p_1-n}}\frac{\Gamma\left(p_1+p_2-n\right)\Gamma(p_1)}{\Gamma\left(p_1+p_2\right)}$$

$$_2F_1\left(p_1+p_2-n,p_1,p_1+p_2;1-\frac{a\alpha_1}{b\alpha_2}\right) \quad (9)$$

where $_2F_1(a;b;c;d)$ is a confluent hypergeometric function of the second kind [19].

The parameters are:

$$p_1=c+m$$

$$p_2=c+m$$

$$\alpha_1=\frac{1}{\beta_1}$$

$$\alpha_2=\frac{1}{\beta_2}$$

$$a = 1$$
$$b = z^2$$
$$p_1 + p_2 = 2c + 2m$$
$$p_1 - n = c + m - 2m = c - m$$
$$p_1 + p_2 - n = 2c + 2m - 2m = 2c$$
$$n = 2m$$

After substituting, the expression for PDF of z becomes:

$$p_z(z) = \frac{1}{2}\left(\frac{2}{\Gamma(m)}\right)^2 \frac{1}{(\Gamma(c))^2 \beta_1^c \beta_2^c} z^{2m-1}$$

$$\cdot \frac{1}{z^{2(c+m)}} \Gamma(c+m) \beta^{2c} \frac{\Gamma(2c)\Gamma(c+m)}{\Gamma(2c+2m)}$$

$${}_2F_1\left(2c, c+m, 2(c+m); 1 - \frac{\beta_2}{\beta_1 z^2}\right) \quad (10)$$

Cumulative distribution function of z is:

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

$$= \left(\frac{2}{\Gamma(m)}\right)^2 m^{2m} \frac{1}{(\Gamma(c))^2 \beta_1^c \beta_2^c}$$

$$\int_0^\infty dy\, y^{4m-1} \cdot \int_0^\infty d\Omega_1\, \Omega_1^{c-1-m} e^{-\frac{1}{\beta_1}\Omega_1}$$

$$\cdot \int_0^\infty d\Omega_2\, \Omega_2^{c-1-m} e^{-\frac{m}{\Omega_2}y^2 - \frac{1}{\beta_2}\Omega_2} \int_0^z dt\, t^{2m-1} e^{-\frac{m}{\Omega_1}y^2 t^2} =$$

$$= \left(\frac{2}{\Gamma(m)}\right)^2 m^{2m} \frac{1}{(\Gamma(c))^2 \beta_1^c \beta_2^c}$$

$$\int_0^\infty dy\, y^{4m-1} \cdot \int_0^\infty d\Omega_1\, \Omega_1^{c-1-m} e^{-\frac{1}{\beta_1}\Omega_1}$$

$$\cdot \int_0^\infty d\Omega_2\, \Omega_2^{c-1-m} e^{-\frac{m}{\Omega_2}y^2 - \frac{1}{\beta_2}\Omega_2}$$

$$\frac{1}{2}\left(\frac{\Omega_1}{my^2}\right)^m \gamma\left(m, \frac{my^2}{\Omega_1} z^2\right) =$$

$$= \left(\frac{2}{\Gamma(m)}\right)^2 m^{2m} \frac{1}{(\Gamma(c))^2 \beta_1^c \beta_2^c}$$

$$\int_0^\infty dy\, y^{4m-1} \cdot \int_0^\infty d\Omega_1\, \Omega_1^{c-1-m} e^{-\frac{1}{\beta_1}\Omega_1}$$

$$\cdot \int_0^\infty d\Omega_2\, \Omega_2^{c-1-m} e^{-\frac{m}{\Omega_2}y^2 - \frac{1}{\beta_2}\Omega_2}$$

$$\frac{1}{2}\left(\frac{\Omega_1}{my^2}\right)^m \frac{1}{m}\left(\frac{my^2}{\Omega_1}\right)^m z^{2m} e^{-\frac{my^2}{\Omega_1}z^2}$$

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

$$= \left(\frac{2}{\Gamma(m)}\right)^2 m^{2m} \frac{1}{(\Gamma(c))^2 \beta_1^c \beta_2^c}$$

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

$$\int_0^\infty dy\, y^{4m-1+2j_1} \cdot \int_0^\infty d\Omega_1\, \Omega_1^{c-1-m-j_1} e^{-\frac{my^2}{\Omega_1}z^2 - \frac{1}{\beta_1}\Omega_1}$$

$$\cdot \int_0^\infty d\Omega_2\, \Omega_2^{c-1-m} e^{-\frac{m}{\Omega_2}y^2 - \frac{1}{\beta_2}\Omega_2} =$$

$$= \left(\frac{2}{\Gamma(m)}\right)^2 m^{2m} \frac{1}{(\Gamma(c))^2 \beta_1^c \beta_2^c}$$

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

$$\cdot \int_0^\infty d\Omega_1\, \Omega_1^{c-1-m-j_1} e^{-\frac{1}{\beta_1}\Omega_1}$$

$$\cdot \int_0^\infty d\Omega_2\, \Omega_2^{c-1-m} e^{-\frac{1}{\beta_2}\Omega_2}$$

$$\int_0^\infty dy\, y^{4m-1+2j_1} e^{-y^2\left(-\frac{m}{\Omega_1}z^2 - \frac{m}{\Omega_2}\right)} =$$

$$= \left(\frac{2}{\Gamma(m)}\right)^2 m^{2m} \frac{1}{(\Gamma(c))^2 \beta_1^c \beta_2^c}$$

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

$$\cdot\int_0^\infty d\Omega_1\,\Omega_1^{c-1-m-j_1+2m+j_1}\,e^{-\frac{1}{\beta_1}\Omega_1}$$

$$\cdot\int_0^\infty d\Omega_2\,\Omega_2^{c-1-m+2m+j_1}\,e^{-\frac{1}{\beta_2}\Omega_2}$$

$$\frac{1}{\left(z^2\Omega_2+\Omega_1\right)^{2m+j_1}} \qquad (11)$$

For solving the last two-fold integral from (11), the formula (9) is used again. Now, the parameters are:

$$p_1 = c+m$$

$$\alpha_1 = \frac{1}{\beta_1}$$

$$p_2 = c+m+j_1$$

$$\alpha_2 = \frac{1}{\beta_2}$$

$$a = 1$$

$$b = z^2$$

$$n = 2m+j_1$$

$$p_1+p_2 = 2c+2m+j_1$$

$$p_1+p_2-n = 2c+2m+j_1-2m-j_1 = 2c$$

$$p_1-n = c+m-2m-j_1 = c-m-j_1$$

After substituting these parameters into (9), the expression for cumulative distribution function of the ratio of two K_G random variables is:

$$F_z(z) = \left(\frac{2}{\Gamma(m)}\right)^2 \frac{1}{\left(\Gamma(c)\right)^2 \beta_1^c \beta_2^c}$$

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

$$\cdot\frac{1}{z^{2(c+m)}} \Gamma(c+m+j_1)\,\beta_2^{2c}\,\frac{\Gamma(2c)\Gamma(c+m)}{\Gamma(2c+2m+j_1)}$$

$${}_2F_1\left(2c, c+m, 2c+2m+j_1; 1-\frac{\beta_2}{\beta_1 z^2}\right). \qquad (12)$$

The outage probability is probability that the receiver output signal envelope to interference ratio is less than a predefined threshold γ_{th} [20]-[22]. So, mathematically, it can be obtained from cumulative distribution function of the signal to interference ratio as:

$$P_{out}(\gamma_{th}) = F_z(z) = \int_0^{\gamma_{th}} dt\, p_z(t),$$

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

3 Numerical results

In Figs. 1 to 3, the outage probability of wireless communication system versus signal to interference ratio is shown for some values of Nakagami-m short term fading severity parameter of desired signal, Nakagami-m short term fading severity parameter of co-channel interference, Gamma long term fading severity parameter of desired signal, Gamma long term fading severity parameter of co-channel interference signal, signal envelope average power of desired signal and signal envelope average power of co-channel interference. The outage probability increases as SIR increases. The outage probability goes to one when SIR goes to infinity.

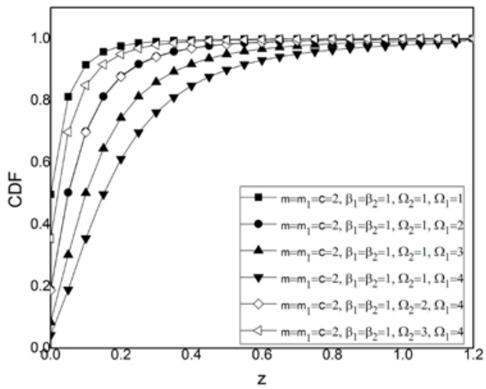

Fig. 1. Outage probability versus output signal to interference ratio *z*

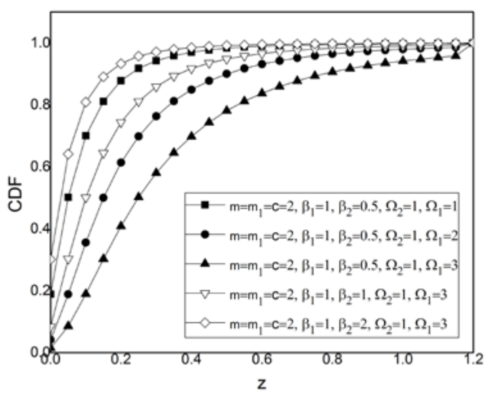

Fig. 2. Outage probability depending on output signal to interference ratio *z*

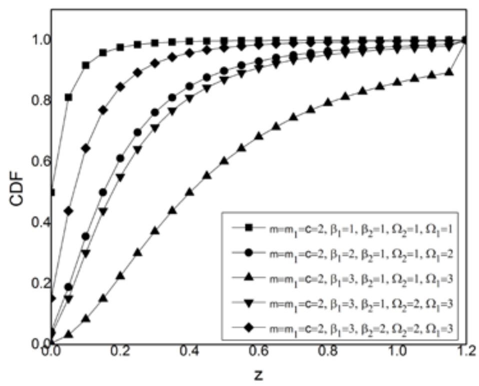

Fig. 3. Outage probability plotted versus output signal to interference ratio

The influence of signal to interference ratio on the outage probability is higher for lower values of SIR. One can see from Fig. 1 that the outage probability lessens with enlargement of signal envelope average power of desired signal. From Fig. 2, it is possible to conclude that the outage probability getting bigger with increasing of the signal envelope average power of co-channel interference and Gamma long term fading severity parameter of co-channel interference. It is visible from Fig. 3 that the outage probability of proposed wireless communication system increases when Gamma severity parameter of desired signal decreases.

Also, the outage probability decreases as Nakagami severity parameter of desired signal increases. The influence of Nakagami severity parameter on the outage probability is higher for lower values of Nakagami severity parameter of desired signal and for lower values of signal to interference ratio.

The influence of Gamma severity parameter of desired signal on the outage probability is higher for lower values of signal to interference ratio and for lower values of Nakagami severity parameter of desired signal and for lower values of Gamma severity parameter of desired signal. System performance is better when the outage probability decreases. The influence of signal to interference ratio on the outage probability is higher for lower values of Nakagami severity parameter of co-channel interference and lower values of Gamma severity parameter of co-channel interference.

4 Conclusion

Wireless communication system operating over interference limited environments in the presence of large scale fading and small scale fading is considered and analyzed in this work. Desired signal experiences Gamma long term fading and co-channel interference experiences also Gamma long term fading and short term fading. In interference limited environment, signal to interference ratio is important performance measure. By using statistics of the signal to interference ratio, the outage probability and the bit error probability of proposed wireless system can be evaluated. K_G distribution can describes Gamma shadowed Nakagami-m multipath fading channels. Composite Gamma distribution and Nakagami-m distribution is known as K_G distribution.

In this paper, probability density function and cumulative distribution function of the ratio of two K_G distributed random variables are determined. Outage probability can be calculated by means cumulative distribution function and bit error probability can be obtained by dint of probability density function. By using derived expressions, outage probability of wireless communication system operating over Gamma shadowed Rayleigh short term fading channel in the presence of co-channel interference could be performed. The influence of Nakagami-*m* short term fading severity parameters of desired and interference signal and Gamma long term fading severity parameters of desired and interference signal on the outage probability is studied. The system performance is better for lower values of the outage probability. The outage probability has lower values when Nakagami-*m* short term fading severity parameter and Gamma long term fading severity parameter go to higher values. The outage probability increases as signal to interference ratio increases. When signal to interference ratio goes to infinity, the outage probability goes to one. The influence of the signal to interference ratio on the outage probability is bigger for small values of the signal to interference ratio.

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