On the Performance Analysis of Wireless Receiver with an AFC over Generalized-K Fading Channels in the Presence of Single CCI

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Abstract

The performance of the wireless receiver consisting of an automatic frequency control loop (AFC) over generalized-K fading (KG) channel in the presence of single co-channel interference (CCI) is considered. Novel, closed-form expressions for the average switching rate (ASR) and mean time to loss of lock (MTLL) of an AFC are derived. Obtained results are graphically presented and discussed to show generalization of some previous results, where composite fading environment is not included into consideration.

1. Introduction

Wireless receiver with an automatic frequency control (AFC) loop, implemented in both coherent and non-coherent receivers is an essential part in various digital systems. It is used to control the frequency of the received signal, already shown in [1].

The performance of a wireless receiver with an AFC in the presence of multipath fading and a single co-channel interference (CCI) are analyzed in the literature [2]-[6]. In reference [2], the performance of wireless receiver with an AFC in the presence of multipath fading and CCI is considered. Moreover, it is shown that an AFC will lock on the desired signal if the desired signal envelope is larger than CCI signal envelope. The system outage can occur in the case when CCI envelope is larger than desired signal envelope, causing that an AFC stops its tracking on the desired signal and lock on the CCI. This can happen due to the fact that amplitudes of the received signals depend on different factors such as modulation, multipath fading and shadowing. The average switching rate (ASR), already introduced in [2], and examined in [3]-[6], shows how often are these transitions from the desired signal to the CCI but also from the CCI to the desired signal. The mean time to loss of lock (MTLL), also introduced and investigated in [2]-[6] is another performance measure which gives the average time that such an system remains locked on the desired signal, giving the insight into reliability time of the wireless receiver with an AFC.

In reference [3], the ASR and MTTL of a wireless system with an AFC loop subjected to Rayleigh fading and CCI are obtained. Furthermore, the ASR and the MTTL in Rayleigh, Rician and Nakagami fading environments in the presence of single CCI for different modulated carriers are derived in [4]-[5]. In reference [6], desired signal and CCI signal are considered in different fading environments. Moreover, in [7], the ASR and MTTL of the wireless system with an AFC loop over general α-μ multipath fading channel in the presence of CCI are taken into consideration.

The amplitudes of the received signal besides multipath fading are also affected by shadowing, which causes the mean signal level variation [8]. The composite fading environments are accurately modeled with extended generalized-K (EKG) and generalized-K (KG) distribution, recently reported and used in radar applications as well as in wireless digital communications systems [8]-[10]. This model is a general model, which means that KG includes K-distribution, Nakagami-m and Rayleigh-Lognormal (R-L) distribution as its special cases. In this paper, the closed form expressions for ASR and MTTL of wireless system with an AFC over KG fading channel in the presence of CCI for modulated and unmodulated carriers are derived.

2. ASR of an AFC

The desired signal envelope x_1 and CCI envelope x_2, due to small-scale multipath fading, are modeled by the conditioned Nakagami-m distribution, respectively [8]:

$$p_{x_i|\Omega_i}(x_i|\Omega_i) = \frac{2}{\Gamma(m_i)}\left(\frac{m_i}{\Omega_i}\right)^{m_i} {x_i}^{2m_i-1} e^{-\frac{m_i}{\Omega_i}{x_i}^2}\quad i = 1,2; \qquad (1)$$

where m_i is multipath fading shaping parameter and Ω_i is the average of the local mean power of desired signal and interference respectively. Moreover, the small values of m_i indicate severe multipath conditions and $\Gamma(\cdot)$ is gamma function.

It is already stated that an AFC subjected to fading and CCI will lock on the desired signal if the desired signal envelope is larger than CCI signal envelope, under appropriate conditions, shown in [2]. Accordingly, the difference between two Nakagami-m envelopes is considered:

$$x = s_1 x_1 - s_2 x_2, \qquad (2)$$

where s_1 and s_2 are the amplitudes of the desired signal and CCI, respectively.

The ASR is equivalent to the zero level crossing rate (LCR) [13] of the difference between desired signal envelope and CCI signal envelope:

$$N = N_x(0) = \int_{-\infty}^{\infty} |\dot{x}|\, f_{X,\dot{X}}(0,x)dx, \qquad (3)$$

where $f_{X,\dot{X}}(x,\dot{x})$ is the joint probability density function (JPDF) of x and its time derivative, $\dot{x}$.

By employment of the modulation $s_1 = ks_2$,where k is a constant, the ASR of an AFC can be expressed as in [5]:

$$N = f_x(0)\int_{-\infty}^{\infty}|\dot{x}|\frac{1}{\sqrt{2\pi\Omega}} e^{\frac{-\dot{x}^2}{2\Omega}} d\dot{x} = f_x(0)\sqrt{\frac{2\Omega}{\pi}}, \qquad (4)$$

where $f_x(0)$is equal to:

$$f_x(0) = \int_0^{\infty}\frac{1}{s_1 s_2} p_{x_1|\Omega_1}\left(\frac{y}{s_1}\right) p_{x_2|\Omega_2}\left(\frac{y}{s_2}\right) dy. \qquad (5)$$

Substituting (1) in (5), $f_x\,(0)$ becomes:

$$f_x\,(0) = \frac{2k^{2m_2-1}}{\Gamma(m_1)\Gamma(m_2)}\left(\frac{m_1}{\Omega_1}\right)^{m_1}\left(\frac{m_2}{\Omega_2}\right)^{m_2}$$
$$\times\frac{(\Omega_1\Omega_2)^{m_1+m_2-\frac{1}{2}}}{(m_2k^2\Omega_1 + m_1\Omega_2)^{m_1+m_2-\frac{1}{2}}}$$
$$\times {\Omega_1}^{m_1-\frac{1}{2}}{\Omega_2}^{m_2-\frac{1}{2}}\,\Gamma\left(m_1 + m_2 - \frac{1}{2}\right). \qquad (6)$$

Equation (6), is obtained by applying the solution of the following integral [12]:

$$\int_0^{\infty} y^{n-1}e^{-\alpha y^2}dy = \frac{1}{2}\left(\frac{1}{\alpha}\right)^{\frac{n}{2}}\Gamma\left(\frac{n}{2}\right). \qquad (7)$$

The variance of $\dot{x}$ in (4), for the case of Nakagami-m multipath fading can be expressed as [8]:

$$\Omega = s_1^2\sigma_{\dot{X}_1}^2 + s_2^2\sigma_{\dot{X}_2}^2$$
$$= \pi^2 f_m^2\frac{(\Omega_1 m_2 + \Omega_2 m_1)}{m_1 m_2}. \qquad (8)$$

It is assumed that $f_{m_1} = f_{m_2} = f_m$, where f_{mi} are the maximal Doppler frequencies of the desired signal and CCI, respectively.

The ASR of an AFC for the case of multipath fading scenario becomes:

$$N = \frac{2k^{2m_2-1}}{\Gamma(m_1)\Gamma(m_2)}\left(\frac{m_1}{\Omega_1}\right)^{m_1}\left(\frac{m_2}{\Omega_2}\right)^{m_2}$$
$$\times\frac{(\Omega_1\Omega_2)^{m_1+m_2-\frac{1}{2}}}{(m_2k^2\Omega_1 + m_1\Omega_2)^{m_1+m_2-\frac{1}{2}}}$$
$$\times {\Omega_1}^{m_1-\frac{1}{2}}{\Omega_2}^{m_2-\frac{1}{2}}\Gamma\left(m_1 + m_2 - \frac{1}{2}\right)$$
$$\times\sqrt{\frac{2}{\pi}}\pi f_m\frac{(\Omega_1 m_2 + \Omega_2 m_1)^{\frac{1}{2}}}{(m_1 m_2)^{\frac{1}{2}}}. \qquad (9)$$

The Gamma density function is proposed to model the local mean power random variations of the desired signal and CCI, respectively, such as [10]:

$$p_{\Omega_i}(\Omega_i) = \frac{1}{\Gamma(c_i)\beta_i^{c_i}}{\Omega_i}^{c_i-1}e^{-\frac{1}{\beta_i}\Omega_i}, i = 1,2; \qquad (10)$$

where $c_i$is shadowing parameter and $\beta_i$is the average of the local mean power of desired signal and CCI, respectively. The parameter c_i points out the severity of shadowing, such that small values of c_i points out severe shadowing conditions.

Under the assumption that the frequency in spectral density function of shadowing is much smaller than f_m, similarly proposed in [11] for the composite fading environments, the ASR of an AFC of the desired signal and CCI over generalized-K fading environment can be obtained by averaging (9):

$$N=\int_0^{\infty} d\Omega_1 \int_0^{\infty} N_{X|\Omega_1\Omega_2}\, p_{\Omega_1}(\Omega_1) p_{\Omega_2}(\Omega_2) d\Omega_2$$

$$=\sqrt{\frac{2}{\pi}}2\pi f_m \frac{2k^{2m_2-1}}{\Gamma(m_1)\Gamma(m_2)}(m_1)^{m_1-\frac{1}{2}}(m_2)^{m_2-\frac{1}{2}}$$

$$\times\Gamma\left(m_1+m_2-\frac{1}{2}\right)\frac{1}{\Gamma(c_1)\Gamma(c_2)\beta_1^{c_1}\beta_2^{c_2}}$$

$$\times\int_0^{\infty} d\Omega_1\, {\Omega_1}^{m_2-\frac{1}{2}+c_1-1} e^{-\frac{1}{\beta_1}\Omega_1}$$

$$\times\int_0^{\infty}\frac{{\Omega_2}^{m_1-\frac{1}{2}+c_2-1}}{(m_2k^2\Omega_1+m_1\Omega_2)^{m_1+m_2-1}} e^{-\frac{1}{\beta_2}\Omega_2}\, d\Omega_2, \qquad (11)$$

where, the integrals in (11), are separately evaluated. The integral J_1 is equal to:

$$J_1=\int_0^{\infty}\frac{{\Omega_2}^{m_1-\frac{1}{2}+c_2-1}}{(m_2k^2\Omega_1+m_1\Omega_2)^{m_1+m_2-1}} e^{-\frac{1}{\beta_2}\Omega_2}\, d\Omega_2=$$

$$\frac{(k^2m_2)^{-m_2+c_2+\frac{1}{2}}}{{m_1}^{m_1+c_2-\frac{1}{2}}}{\Omega_1}^{-m_2+\frac{1}{2}+c_2}\Gamma\left(m_1+c_2-\frac{1}{2}\right)$$

$$\times U\left(m_1+c_2-\frac{1}{2},-m_2+c_2+\frac{3}{2},\frac{m_2\Omega_1}{m_1\beta_2}\right). \qquad (12)$$

The integral J_2 has the following expression:

$$J_2=\int_0^{\infty}{\Omega_1}^{c_1+c_2-1}\, e^{-\frac{1}{\beta_1}\Omega_1}\frac{(k^2m_2)^{-m_2+c_2+\frac{1}{2}}}{{m_1}^{m_1+c_2-\frac{1}{2}}}$$

$$\times\Gamma\left(m_1+c_2-\frac{1}{2}\right)$$

$$\times U\left(m_1+c_2-\frac{1}{2},-m_2+c_2+\frac{3}{2},\frac{m_2k^2\Omega_1}{m_1\beta_2}\right)d\Omega_1$$

$$=\frac{{m_1}^{-m_1+c_1+\frac{1}{2}}}{(k^2m_2)^{m_2+c_1-\frac{1}{2}}}\beta_2^{c_1+c_2}\Gamma\left(m_1+c_2-\frac{1}{2}\right)$$

$$\times\frac{\Gamma(c_1+c_2)\Gamma\left(m_2+c_1-\frac{1}{2}\right)}{\Gamma(m_1+m_2+c_1+c_2-1)}\left(\frac{\beta_2}{\beta_1}\right)^{-2(c_1+c_2)}$$

$${}_2F_1\left(m_1+c_2-\frac{1}{2},c_1+c_2;\ m_1+m_2+c_1+c_2-1;1-\frac{m_2k^2}{m_1}\frac{\beta_1}{\beta_2}\right). (13)$$

The closed form integral J_1 in (12) is evaluated using [12]:

$$U(a,b,z)=1/\Gamma(a)\int_0^{\infty}e^{-zt}t^{a-1}(1+t)^{b-a-1}dt,$$

where $U(a,b,z)$ is the confluent hypergeometric function of the second kind while the closed form integral J_2 in (13) is evaluatedusing [12]:

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

$$\times{}_2F_1(\mathrm{a},\mathrm{b};\mathrm{a}+\mathrm{b}-\mathrm{c}+1,\mathrm{b};1-(s)^{-1}),$$

where ${}_2F_1(a,b;c;z)$is Gauss hypergeometric function.

Finally, ASR of an AFC of the difference of desired signal and CCI over Generalized-K fading environment is derived:

$$N=\frac{2k^{2m_2-1}}{\Gamma(m_1)\Gamma(m_2)}\sqrt{\frac{2}{\pi}}\pi f_m\Gamma\left(m_1+m_2-\frac{1}{2}\right)$$

$$\times(m_1)^{m_1-\frac{1}{2}}(m_2)^{m_2-\frac{1}{2}}\Gamma\left(m_1+m_2-\frac{1}{2}\right)$$

$$\times\frac{1}{\Gamma(c_1)\Gamma(c_2)\beta_1^{c_1}\beta_2^{c_2}}\frac{{m_1}^{-m_1+c_1+\frac{1}{2}}}{(k^2m_2)^{m_2+c_1-\frac{1}{2}}}$$

$$\times\beta_2^{(c_1+c_2)}\Gamma\left(m_1+c_2-\frac{1}{2}\right)$$

$$\times\frac{\Gamma(c_1+c_2)\Gamma\left(m_2+c_1-\frac{1}{2}\right)}{\Gamma(m_1+m_2+c_1+c_2-1)}\left(\frac{m_1\beta_2}{m_2k^2\beta_1}\right)^{-(c_1+c_2)}$$

$${}_2F_1\left(m_1+c_2-\frac{1}{2},c_1+c_2;\ m_1+m_2+c_1+c_2-1;1-\frac{m_2k^2}{m_1}\frac{\beta_1}{\beta_2}\right). (14)$$

3. MTTL of an AFC

The MTTL (T) of an AFC over Generalized-K fading environment can be obtained using [5]:

$$T=\frac{2F}{N}, \qquad (15)$$

where F is the probability that the amplitude of the desired signal is larger than the amplitude of the CCI.

The probability $F_x=F(s_1x_1>s_2x_2)$ for the case of multipath Nakagami-m channel when $s_1=ks_2$, can be expressed as in [5]:

$$F_x=F(s_1x_1>s_2x_2)=$$

$$\int_{q=1}^{\infty}\int_{w=0}^{\infty}\frac{t}{s_1s_2}p_{x_1|\Omega_1}\left(\frac{wq}{s_1}\right)p_{x_2|\Omega_2}\left(\frac{w}{s_2}\right)dw\,dq. \quad (16)$$

Substituting (1) in (16), using the upper incomplete Gamma function [12]:

$$\Gamma(a,x)=x^a e^{-x}U(1,1+a,x).$$

and the following integral solution [12]:

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

$$\times{}_2F_1(b,b-c+1;a+b-c+1;1-s),$$

the probability that the amplitude of the desired signal is larger than the amplitude of the interference for multipath fading scenario becomes:

$$F_x = \frac{k^{2m_2}}{\Gamma(m_1)}\left(\frac{\Omega_1}{\Omega_2}\right)^{m_2}\left(\frac{m_2}{m_1}\right)^{m_2}\frac{\Gamma(m_1+m_2)}{\Gamma(1+m_2)}$$

$$\times {}_2F_1\left(m_1+m_2, m_2; 1+m_2; -\frac{m_2k^2}{m_1}\frac{\Omega_1}{\Omega_2}\right). \quad (17)$$

In order to obtain the probability that the amplitude of the desired signal is larger than the amplitude of the CCI over generalized KG fading environment it is necessary first to apply the fundamental transformation:

$$p_x(x|\Omega_2) = \left|\frac{d\Omega_1}{dx}\right| p_{\Omega_1}\left(\frac{m_1}{m_2k^2}x\Omega_2\right), \quad (18)$$

where the substitution, $x = \frac{m_2k^2}{m_1}\frac{\Omega_1}{\Omega_2}$ is used and $p_{\Omega_i}(\Omega_i)$ are the gamma distributions of the signal and CCI, respectively, given in (10). After some additional mathematical manipulations, we have:

$$p_x(x) = \frac{1}{\Gamma(c_1)\beta_1^{c_1}}\frac{1}{\Gamma(c2)\beta_2^{c_2}}\left(\frac{m_1}{k^2m_2}\right)^{c_1}(x)^{c_1-1}$$

$$\times \frac{(m_2k^2\beta_1\beta_1)^{c_1+c_2}}{(m_1\beta_2x+m_2k^2\beta_1)^{c_1+c_2}}\Gamma(c_1+c_2). \quad (19)$$

Finally, the probability that the desired amplitude is larger than interferer of an AFC over generalized-K fading environment is:

$$F = \int_0^\infty F_x p_x(x)dx$$

$$= \frac{1}{\Gamma(c_1)}\frac{\Gamma(c_1+c_2)}{\Gamma(c_2)}\left(\frac{m_1}{k^2m_2}\right)^{c1}\left(\frac{\beta_1}{\beta_2}\right)^{c_2}$$

$$\times (m_2k^2)^{c_1+c_2}{m_1}^{-c_1-c_2}\frac{\Gamma(m_1+m_2)}{\Gamma(1+m_2)\Gamma(m_1)}$$

$$\times \frac{\Gamma(1+m_2)\Gamma(m_1-1+c_1+c_2)\Gamma(c_1+c_2-1)}{\Gamma(c_1+c_2)\Gamma(m_1+m_2-1+c_1+c_2)}$$

$$\times {}_2F_1\left(m_1-1+c_1+c_2, c_1+c_2-1, m_1+m_2-1+c_1+c_2; 1-\frac{\beta_1}{\beta_2}\frac{k^2m_2}{m_1}\right). \quad (20)$$

where the following integral solution is used [12]:

$$\int_0^\infty x^{\gamma-1}(x+z)^{-\delta}{}_2F_1(a,b;\gamma;-x)dx =$$

$$= \frac{\Gamma(\gamma)\Gamma(a-\gamma+\delta)\Gamma(b-\gamma+\delta)}{\Gamma(\delta)\Gamma(a+b-\gamma+\delta)}$$

$$\times {}_2F_1(a-\gamma+\delta, b-\gamma+\delta, a+b-\gamma+\delta; 1-z).$$

4. Numerical results

Figures 1-2 show the normalized ASR of wireless receiver with an AFC versus the signal-to-interference ratio (SIR) over Generalized-K fading channel for different multipath and shadowing severity parameters. The SIR is given as the ratio of β_1 and β_2 in dB. The ASR is normalized to $f_m$and the signals are assumed to be unmodulated, $s_1 = s_2 = 1$.

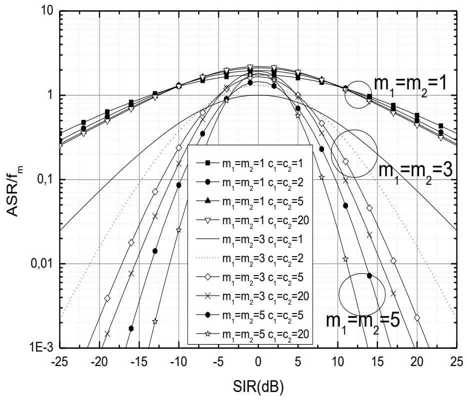

Figure 1. The normalized ASR versus SIR of an AFC over Generalized K fading for different system model parameters.

Figure 1. shows that multipath fading severity parameters have greater influence on ASR than shadowing severity parameters. By increasing parameters $c_1$and c_2, for the same values of parameters m_1 and m_2, the ASR decreases in the boundary region while the ASR reaches its maximum when the signals have similar powers. Moreover, by increasing the parameters $m_1$and m_2, the ASR also decreases, what is already shown and thoroughly explained in [4]-[5].Note that for the special case, when $c_1$and $c_2$take higher values ($c_1 = c_2 \to \infty$) generalized-K distribution approximates Nakagami-m distribution. In the particular case, when $c_1 = c_2 = 20$ the ASR of an AFC indicate similar outcomes as the results previously shown in [4]-[5], as expected.

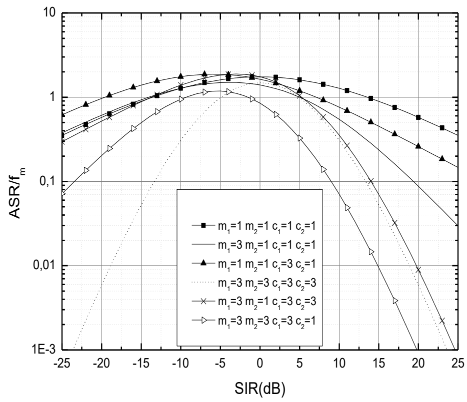

Figure 2.The normalized ASR versus SIR of an AFC over Generalized K fading scenario for different system model parameters.

The Figure 2. shows that by increasing parameter c_1, while keeping constant parameter c_2 causes the ASR to decrease for higher values of SIR while the ASR increases for lower values of SIR while keeping constant parameter

m_2.On the other hand, the ASR is not significantly influenced for lower values of the SIR by such modelling of multipath fading severity parameters.

Figures 3-4 show the mean time to lose of lock of wireless receiver with an AFC over Generalized K fading channel or different multipath fading severity parameters and shadowing severity parameters. The MTLL is multiplied by f_m and the figures are represented versus SIR. Figure 3. shows that the multipath fading severity parameters have greater impact on MTTL than multipath shadowing parameters. Moreover, it shows that if the channel is modeled by larger values of c_1 and c_2, the performances improves in the sense that MTLL of an AFC increases. The same impact on the MTTL can be concluded for multipath fading severity parameters which is also in accordance with the expected results, previously shown in [4]-[5].

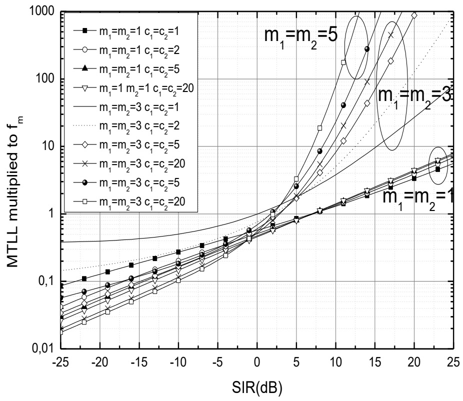

Figure 3. The MTLL of the AFC over Generalized-K fading scenario for different values of multipath fading and shadowing severity parameters.

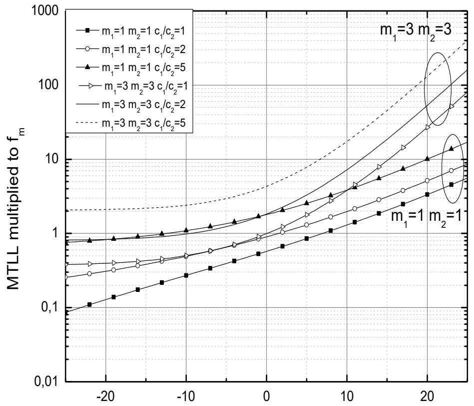

Figure 4. The MTLL of the AFC over Generalized-K fading scenario for different values of and of different values of the ratio of shadowing fading severity parameters.

Fig 4. shows the MTTL of an AFC for constant multipath fading severity parameters m_1 and m_2 and the ratio of shadowing severity parameters, c_1/c_2. By comparing presented curves, the best possible model in theory is achived when the channel is modeled with higher values of parameters m_1, m_2 and parameter $c_1$while keeping parameter c_2 constant.

Conclusion

In this paper, closed form expressions for ASR and the MTLL of an AFC over generalized-K fading are obtained. The special cases are investigated and compared to the previous results in the literature when applicable. Numerical results are provided and discussed to show the effect of the interference, multipath fading and shadowing on the performance of an AFC. For the first time, Generalized-K distribution is considered, to show the influence of composite fading environment on the performance of an AFC.

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