On the error rate analysis of dual-hop relaying over composite fading channels using mixture gamma distribution

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Abstract

In this paper, we present the end-to-end performance of a dual-hop amplify-and-forward (AF) relaying system over independent non-identical (non-i.i.d) composite Nakagami-lognormal (NL) fading channels by using mixture gamma (MG) distribution. Novel closed-form expressions for the probability density function (PDF) and the moment-generation function (MGF) of the end-to-end signal-to-noise ratio (SNR) are derived. Moreover, the average error rate and the diversity order are found based on the above new expressions, respectively. These expressions are more simple and accuracy than the previous ones obtained by using generalized-K (KG) distribution. Finally, numerical and simulation results are shown to verify the accuracy of the analytical results. These results show that it is more precise to approximate the composite NL distribution by using the MG distribution than using the KG distribution in the performance analysis of cooperative relaying systems.

Keywords: Dual-hop Relaying, Nakagami-lognormal, Mixture Gamma Distribution, Error Rate Analysis

1 Introduction

Multihop cooperative transmission has emerged as a promising technique for extending coverage, enhancing connectivity, and saving transmitter power in wireless communication networks. In the past decade, the performance analysis of the multihop cooperative system in term of outage probability and average bit/symbol error rate (BER/SER) has been widely studied over various multipath fading models, such as, Rayleigh [1], Nakagami-m [2], Rician [3], Weibull [4] and Generalized Gamma [5].

Recently, as an approximation fading model of composite multipath/shadowing fading channels, the generalized-K (KG) channel model has attracted considerable attention in the performance analysis of the multihop cooperative system. In [6], the performance of a dual-hop relaying system with fixed-gain relays was obtained. In [7], authors studied the error rate performance of multiple dual-hop relaying with maximum ratio combining. In [8], the performance of dual-hop relaying with best relay selection are evaluated. Authors in [9, 10] presented also their analysis of a dual-hop system.

Unfortunately, since their probability density functions (PDF) include modified Bessel functions, their cumulative distribution functions (CDF) and moment-generation functions (MGF) usually include some more complicated special functions, such as Meijer's G functions. To avoid mathematical difficulties, some further approximation has to be used. In [5] and [8], the Padé approximants (PA) method has been employed to obtain the BER/SER. [6-9] adopted minimum SNR approximation model under amplify-and-forward (AF) strategy.

In [11, 12], the authors have developed an alternative approach by using the Mixture Gamma (MG) distribution to approximate the Nakagami-lognormal (NL) distribution. This distribution avoids the above-mentioned problems, and some exact and simple results obtained are possible by adjusting some parameters. To the best of our knowledge, there are few papers in performance analysis of cooperative relaying systems over independent non-identical (non-i.i.d) NL fading channels by using MG distribution.

In this paper, we examine the end-to-end performance of a dual-hop AF relaying system over non-i.i.d MG fading channels. Firstly, some novel closed-form expressions for the PDF and MGF of the end-to-end SNR are derived over MG fading channels, and some approximate results are obtained over KG fading channels for the purpose of comparison. Secondly, these new statistical results are used to evaluate the performance criteria of the dual-hop relay system. Finally, the numerical and simulation results are discussed and compared over MG and KG fading channels, and these results demonstrate the validity of the proposed analysis.

The remainder of this paper is organized as follows. In the next section, three models of composite fading channels are described, respectively. In section 3, a dual-hop relaying system is presented and the statistics of the end-to-end SNR are derived, such as the PDF and the MGF. Section 4 gives several important performance

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criteria. Numerical and simulations results are presented in Section 5. Finally, we conclude our paper in section 6.

2 The Composite Fading Channel Model

2.1 NL FADING CHANNEL MODEL

For the NL channel, the composite NL distribution is a mixture of Nakagami and lognormal shadowing. Let X be the fading amplitude, which is a random variable. Assuming that the transmitted symbol energy is Es and single sided power spectral density of the complex additive white Gaussian noise is N_0, the instantaneous SNR per symbol is $\gamma = X^2\rho$, where $\rho = E_s/N_0$ denotes the un-faded SNR.

The PDF of γ over NL channel, $f_{\gamma_{NL}}(\gamma)$, is given by [13]:

$$f_{\gamma_{NL}}(\gamma) = \int_0^{\infty} \frac{m^m \gamma^{m-1}\exp(-m\gamma/\rho y)}{\Gamma(m)(\rho y)^m} \frac{1}{\sqrt{2\pi}\lambda y} \exp[-\frac{(\ln y - \mu)^2}{2\lambda^2}]dy \,. \tag{1}$$

where m is fading parameter in Nakagami fading, μ and λ are the mean and the standard deviation of lognormal shadowing, respectively, $\Gamma(\cdot)$ is the gamma function. Since a closed-form expression of (1) is not available in the literature, some approximations or simple forms of (1) have been given a great attention recently, such as, KG and MG distribution.

2.2 KG FADING CHANNEL MODEL

As an approximation of NL distribution, KG distribution is a mixture of Nakagami-m and Gamma distributions, where Gamma distribution approximates lognormal distribution. For KG fading, the PDF of γ, $f_{\gamma_{KG}}(\gamma)$, is given by [14]

$$f_{\gamma_{KG}}(\gamma) = 2\Xi^{(k+m)/2}\gamma^{(k+m)/2-1}K_{k-m}(2\sqrt{\Xi\gamma})/\Gamma(m)\Gamma(k)\,, \tag{2}$$

where k is the distribution shaping parameter reflecting shadowing effect, $\Xi = km/\bar{\gamma}$, $\bar{\gamma} = k\Omega\rho$, Ω is the local mean power, $K_\alpha(\bullet)$ is the second kind modified Bessel function of order α defined in [15].

For integer values of m and arbitrary values of k, The CDF of γ over KG channel, $F_{\gamma_{KG}}(\gamma)$, can be expressed as in [6]:

$$F_{\gamma_{KG}}(\gamma) = 1 - \sum_{i=0}^{m-1} 2(\Xi\gamma)^{(k+i)/2} K_{k-i}(2\sqrt{\Xi\gamma})/\Gamma(k)i!\,. \tag{3}$$

Moreover, the MGF of γ over KG channel is given by [6]:

$$M_{\gamma_{KG}}(s) = G_{2,1}^{1,2}\left(s/\Xi\left|{}^{1-k,1-m}_{0}\right.\right)/\Gamma(m)\Gamma(k)\,, \tag{4}$$

where $G(\bullet)$ is the Meijer's G-function defined in [15].

2.3 MG FADING CHANNEL MODEL

By using Gaussian-Hermite quadrature sum, an alternative approximating approach of (1) is firstly given by [12], named as MG distribution. As in [12], the PDF, CDF and MGF of γ over MG channel can, respectively, be written as:

$$f_{\gamma_{MG}}(\gamma) = \sum_{i=1}^{N} Ca_i\gamma^{m-1}\exp(-\tfrac{b_i}{\rho}\gamma)/2\rho^m\,, \tag{5}$$

$$F_{\gamma_{MG}}(x) = 1 - \sum_{i=1}^{N} Ca_i\Gamma(m, \tfrac{b_i}{\rho}x)/2b_i^m\,, \tag{6}$$

$$M_{\gamma_{MG}}(s) = \sum_{i=1}^{N} C\Gamma(m)a_i/[2\rho^m(s+b_i/\rho)^m]\,, \tag{7}$$

where $a_i = 2m^m w_i \exp[-m(\sqrt{2}\lambda t_i + \mu)]/\sqrt{\pi}\Gamma(m)$, $b_i = m\exp[-(\sqrt{2}\lambda t_i + \mu)]$, C is the normalization factor, defined as $C = \sqrt{\pi}/\sum_{j=1}^{N} w_j$, w_j and t_j are abscissas and weight factors for Gaussian-Hermite integration. w_j and t_j for different N values are available in [16, Table(25.10)] or can be calculated by a simple MATLAB program. $\Gamma(\bullet;\bullet)$ is the incomplete gamma function defined in [15].

For the corresponding relationships between parameters (μ and λ) in NL/MG model and parameters (k and m) in KG model, two approximating expressions can be derived as [17], i.e., $\lambda^2 = \Psi'(k)$, $\mu = \Psi(k) + \ln(\Omega)$, where $\Psi'(\bullet)$ is the first derivative of psi function defined in [15].

3 The Dual-hop AF Relaying System Model

We consider a wireless dual-hop AF relaying system, which the source-destination link is unavailable. The source node (S) communicates with the destination node (D) over a relay node (R). It is assumed that nodes are synchronized and the channel state information is available at the receivers (R and/or D).

Let the instantaneous SNR of each hop link be denoted by γ_i, $i \in \{1,2\}$. Similar as in [1] and [2], the instantaneous equivalent end-to-end SNR of the dual-hop link at the destination node can be expressed as:

$$\gamma_{SRD} = \gamma_1\gamma_2/(\gamma_1 + \gamma_2 + 1)\,, \tag{8}$$

where $\gamma_i = X_i^2\rho$, X_i is the fading amplitude of the i^{th}-hop link. The corresponding average SNR is defined as $\bar{\gamma}_i = \Omega_i\rho$. Due to capture the path-loss effect, $\Omega_i = E[X_i^2] = (d_0/d_i)^{\varepsilon}$, d_i denotes the distance of the i^{th}-hop link, d_0 denotes the distance between S and D, and ε is the path-loss exponent.

In order to simplify the performance analysis of (8) over Nakagami-m, Weibull and KG fading, its upper bound is often adopted in many recent literature as [4, 6-9]:

$$\gamma_{SRD} < \gamma_b = \min(\gamma_1, \gamma_2). \tag{9}$$

This upper bound has been shown to be accurate enough at medium and high SNR values. For the purpose of comparison, we consider some statistics of (9) in this paper.

3.1 STATISTICS OVER MG FADING MODEL

Based on (9), the CDF of γ_b can be expressed as

$$F_{\gamma_b}(\gamma) = F_{\gamma_1}(\gamma) + F_{\gamma_2}(\gamma) - F_{\gamma_1}(\gamma)F_{\gamma_2}(\gamma), \tag{10}$$

where $F_{\gamma_i}(\gamma)$, $i \in \{1,2\}$, is the CDF of the i^{th}-hop link. By substituting (6) into (10) and taking the derivative of (10) with respect to γ, the PDF of γ_b over non-i.i.d MG fading can be found as:

$$f_{\gamma_{b-MG}}(\gamma) = \sum_{i=1}^{N}\sum_{j=1}^{N} \frac{C^2 a_i a_j}{4\rho^{m_1} b_j^{m_2}} \gamma^{m_1-1} \exp(-\frac{b_i}{\rho}\gamma)\Gamma(m_2, \frac{b_j}{\rho}\gamma) + \sum_{i=1}^{N}\sum_{j=1}^{N} \frac{C^2 a_i a_j}{4 b_i^{m_1} \rho^{m_2}} \gamma^{m_2-1} \exp(-\frac{b_j}{\rho}\gamma)\Gamma(m_1, \frac{b_i}{\rho}\gamma), \tag{11}$$

By using (11), the MGF of γ_b can be expressed with the aid of (6.621.3) in [15] as:

$$M_{\gamma_{b-MG}}(s) = \sum_{i=1}^{N}\sum_{j=1}^{N} \frac{C^2 a_i a_j \Gamma(m_1+m_2)}{4m_1(b_i+b_j+\rho s)^{m_1+m_2}} {}_2F_1(1, m_1+m_2; m_1+1; \frac{b_i+\rho s}{b_i+b_j+\rho s}) + \sum_{i=1}^{N}\sum_{j=1}^{N} \frac{C^2 a_i a_j \Gamma(m_1+m_2)}{4m_2(b_i+b_j+\rho s)^{m_1+m_2}} {}_2F_1(1, m_1+m_2; m_2+1; \frac{b_j+\rho s}{b_i+b_j+\rho s}), \tag{12}$$

where ${}_2F_1(a,b;c;z)$ is the hypergeometric function defined in [15].

3.2 STATISTICS OVER KG FADING MODEL

Similar as (11), and using (2) and (3), the PDF of γ_b over non-i.i.d KG fading channel can be found as:

$$\begin{aligned} f_{\gamma_{b-KG}}(\gamma) &= \sum_{i=0}^{m_2-1} \frac{4\Xi_1^{(k_1+m_1)/2}\Xi_2^{(k_2+i)/2}}{i!\Gamma(m_1)\Gamma(k_1)\Gamma(k_2)} \gamma^{\frac{k_1+m_1}{2}+\frac{k_2+i}{2}-1} K_{k_1-m_1}(2\sqrt{\Xi_1\gamma}) K_{k_2-i}(2\sqrt{\Xi_2\gamma}) \\ &+ \sum_{i=0}^{m_1-1} \frac{4\Xi_2^{(k_2+m_2)/2}\Xi_1^{(k_1+i)/2}}{i!\Gamma(m_2)\Gamma(k_2)\Gamma(k_1)} \gamma^{\frac{k_2+m_2}{2}+\frac{k_1+i}{2}-1} K_{k_2-m_2}(2\sqrt{\Xi_2\gamma}) K_{k_1-i}(2\sqrt{\Xi_1\gamma}). \end{aligned} \tag{13}$$

where k_i (i=1,2) is the distribution shaping parameter of the i-th-hop link, $\Xi_i = k_i m_i / \bar{\gamma}_i$.

In order to reduce the difficulty and complexity in finding the closed-form expression of the MGF of γ_b directly using (13), PA method can be an alternative and efficient way to approximate the MGF. Its main advantage is that due to the form of the produced rational approximation, the error rates can be calculated directly using simple expressions. The PA of the MGF is a rational function of a specified order M for the denominator and L for the nominator, whose power series expansion agrees with the (M+L)-order power expansion of the MGF. Thus, the MGF of γ_b over non-i.i.d KG fading channels can be expressed as:

$$M_{\gamma_{b-KG}}(s) \simeq \frac{\sum_{i=0}^{L} c_i s^i}{1+\sum_{i=0}^{M} b_i s^i} = \sum_{n=0}^{L+M} \frac{\mu_{\gamma_{b-KG}}(n)}{n!} s^n + O(s^{n+1}), \tag{14}$$

where $\mu_{\gamma_{b-KG}}(n)$ is the nth moment of γ_b, the coefficients c_i and b_i are real constants, $O(s^{n+1})$ is the remainder after truncation. In order to obtain an accurate approximation of the MGF, we assume sub-diagonal PA(M=L+1). For (13), by using [18, (03.04.26.0009.01)] and [18, (07.34.21.0011.01)], $\mu_{\gamma_{b-KG}}(n)$ can be expressed as:

$$\mu_{\gamma_{b-KG}}(n) = \sum_{i=0}^{m_2-1} \frac{G_{2,2}^{2,2}[\Xi_2/\Xi_1 \left| {}^{1-k_1-n, 1-m_1-n}_{k_2, \quad i} \right.]}{i!\Gamma(m_1)\Gamma(k_1)\Gamma(k_2)\Xi_1^n} + \sum_{i=0}^{m_1-1} \frac{G_{2,2}^{2,2}[\Xi_1/\Xi_2 \left| {}^{1-k_2-n, 1-m_2-n}_{k_1, \quad i} \right.]}{i!\Gamma(m_2)\Gamma(k_2)\Gamma(k_1)\Xi_2^n}. \tag{15}$$

4 Performance Analysis

In this section, using the previously derived closed-form expressions of the MGF over MG and KG fading channels, the average BER/SER and the diversity order of the dual-hop relaying system are obtained, respectively.

4.1 AVERAGE BER/SER

Using the MGF-based approach, we can obtain the closed-form expression of average BER/SER for the dual-hop relaying system over MG and KG fading channel. For many coherent demodulation schemes, the average SER of M-ary phase-shift keying signals (M-PSK) can be given by [17]:

$$P_{e-MPSK}(s) = \frac{1}{\pi}\int_0^{(M-1)\pi/M} M_\gamma\left(\frac{g_M}{\sin^2\theta}\right)d\theta, \quad (16)$$

where $g_M=\sin^2(\pi/M)$. Similarly, the average SER of other modulations, such as M-ary quadrature amplitude modulation (M-QAM), can also be evaluated, which have to be neglected due to limited space in this paper.

The above BER/SER of the dual-hop relaying system over MG and/or KG fading channels can be numerically evaluated by substituting (12) and/or (14) into (16). This can be done with some elementary numerical integration techniques.

4.2 DIVERSITY ORDER

The diversity order is the magnitude of the slope of the error probability versus SNR curve (log-log scale) in the high SNR region. The array gain measures the shift of error probability curve to the left. The diversity order and the array gain relate to the asymptotic value of the MGF near the infinity, i.e., if the MGF, $M_\gamma(s)$, can be written as

$$|M_\gamma(s)| = a|s|^{-b} + O(|s|^{-(b+1)}), \quad \text{as } s\to\infty, \quad (17)$$

where a and b are defined as the array gain and diversity order in [19], and $O(|s|^{-(b+1)})$ represents the terms of order higher than b.

When $s\to\infty$, using the asymptotic series expansions of Meijer-G function in [18, (07.34.06.0018.01)], the approximate expression of (4) when $k\neq m$ can be given as:

$$|M_{\gamma_{KG}}(s)| \cong \frac{\Gamma(|m-k|)\Xi^k}{\Gamma(m)}|s|^{-k} + \frac{\Gamma(|k-m|)\Xi^m}{\Gamma(k)}|s|^{-m} + O(|s|^{-\min(k,m)-1}). \quad (18)$$

When $k=m$, (4) can be rewritten by using [18, (07.34.03. 0392.01)] as:

$$M_{\gamma_{KG}}(s) = (\Xi/s)^m U(m,1,\Xi/s), \quad (19)$$

where $U(a,b,z)$ is the confluent hypergeometric function defined in [15]. When $s\to\infty$, by using the asymptotic series expansions of $U(a,b,z)$ in [18, (07.33.06.0004.01)], the approximate expression of (4) when $k=m$ can be given as

$$|M_{\gamma_{KG}}(s)| \cong \frac{2\Xi^k}{\Gamma(k)}|s|^{-k} + O(|s|^{-(k+1)}). \quad (20)$$

By using the binomial series expansion in [15, (1.110)], the approximate expression of (7) can be written as in [13]:

$$|M_{\gamma_{MG}}(s)| = \sum_{i=1}^N \frac{a_i C\Gamma(m)}{2\rho^m}\left(s^{-m} + \sum_{k=1}^{\infty}\binom{-m}{k}(b_i/\rho)^k s^{-(m+k)}\right) \cong \sum_{i=1}^N \frac{a_i C\Gamma(m)}{2\rho^m}|s|^{-m} + O(|s|^{-(m+1)}). \quad (21)$$

Since the values of $F_{\gamma_i}(\gamma)$ in (10) range between 0 and 1, the last two terms may be much less than their addition when $\rho\to\infty$. Hence, we can derive an approximating MGF of γ_b by neglecting the product term in (10) over MG fading channel, as:

$$|M_{\gamma_{b-MG}}(s)| \cong \sum_{i=1}^N \frac{C\Gamma(m_1)a_i}{2\rho^{m_1}(s+b_i/\rho)^{m_1}} + \sum_{j=1}^N \frac{C\Gamma(m_2)a_j}{2\rho^{m_2}(s+b_j/\rho)^{m_2}}. \quad (22)$$

Similar as (21), (22) can be further approximated when $s\to\infty$, as:

$$|M_{\gamma_{b-MG}}(s)| \cong \sum_{i=1}^N \frac{C\Gamma(m_1)a_i}{2\rho^{m_1}}|s|^{-m_1} + \sum_{j=1}^N \frac{C\Gamma(m_2)a_j}{2\rho^{m_2}}|s|^{-m_2} + O(|s|^{-\min(m_1,m_2)-1}) \quad (23)$$

By using the same approach as (23), the approximating MGF of γ_b over KG fading channel can be expressed as (24). Based on the difinition of diversity order in (17), the diversity orders of the single-hop and the dual-hop link over KG fading channel are min(k, m) and min(m_1, k_1, m_2, k_2), respectively. For MG fading channel, they are m and min(m_1, m_2), respectively. Note that the diversity order over KG fading channel is determined by the value of m or k, not just the value of m in [12], and the diversity order over MG fading channel is determined only by the value of m as same as that over NL fading channel in [12].

$$\left|M_{\gamma_{b-KG}}(s)\right| \cong \begin{cases} \dfrac{\Gamma(|m_1-k_1|)\Xi_1^{k_1}}{\Gamma(m_1)|s|^{k_1}} + \dfrac{\Gamma(|k_1-m_1|)\Xi_1^{m_1}}{\Gamma(k_1)|s|^{m_1}} + \dfrac{\Gamma(|m_2-k_2|)\Xi_2^{k_2}}{\Gamma(m_2)|s|^{k_2}} + \dfrac{\Gamma(|k_2-m_2|)\Xi_2^{m_2}}{\Gamma(k_2)|s|^{m_2}} + O(|s|^{-\min(m_1,k_1,m_2,k_2)-1})) & k_1 \neq m_1 \\ & k_2 \neq m_2 \\ \dfrac{\Gamma(|m_1-k_1|)\Xi_1^{k_1}}{\Gamma(m_1)|s|^{k_1}} + \dfrac{\Gamma(|k_1-m_1|)\Xi_1^{m_1}}{\Gamma(k_1)|s|^{m_1}} + \dfrac{2\Xi_2^{k_2}}{\Gamma(k_2)|s|^{k_2}} + O(|s|^{-\min(m_1,k_1,k_2)-1})) & k_1 \neq m_1 \\ & k_2 = m_2 \\ \dfrac{\Gamma(|m_2-k_2|)\Xi_2^{k_2}}{\Gamma(m_2)|s|^{k_2}} + \dfrac{\Gamma(|k_2-m_2|)\Xi_2^{m_2}}{\Gamma(k_2)|s|^{m_2}} + \dfrac{2\Xi_1^{k_1}}{\Gamma(k_1)|s|^{k_1}} + O(|s|^{-\min(k_1,m_2,k_2)-1})) & k_1 = m_1 \\ & k_2 \neq m_2 \\ \dfrac{2\Xi_1^{k_1}}{\Gamma(k_1)|s|^{k_1}} + \dfrac{2\Xi_2^{k_2}}{\Gamma(k_2)|s|^{k_2}} + O(|s|^{-\min(k_1,k_2)-1})) & k_1 = m_1 \\ & k_2 = m_2 \end{cases} . \quad (24)$$

5 Numerical and simulation results

In this section, various performance evaluation results derived by numerical and simulation techniques are presented.

Firstly, Figure 1 illustrates the BER of BPSK of single-hop link over NL, KG and MG fading, respectively, where N=10 for MG distribution. It can be seen from Figure1 that the performance over MG fading has almost the same as the one over NL fading. However, from Figure 1(a), it can be seen that the performance over KG fading almost approaches to the one over NL fading as the value of k increases. From Figure 1(b), it can be seen that the former is more deviation from the latter as the value of m increases at high SNR region. Moreover, for discussing their diversity orders, we give the approximate performance over MG and KG fading channel by using (18) and (21) at high SNR, and the case of m=1 and k=1. It can be seen that the diversity order over NL and MG fading is determined by the value of m, and the diversity order over KG fading is determined by the minimum value between k and m.

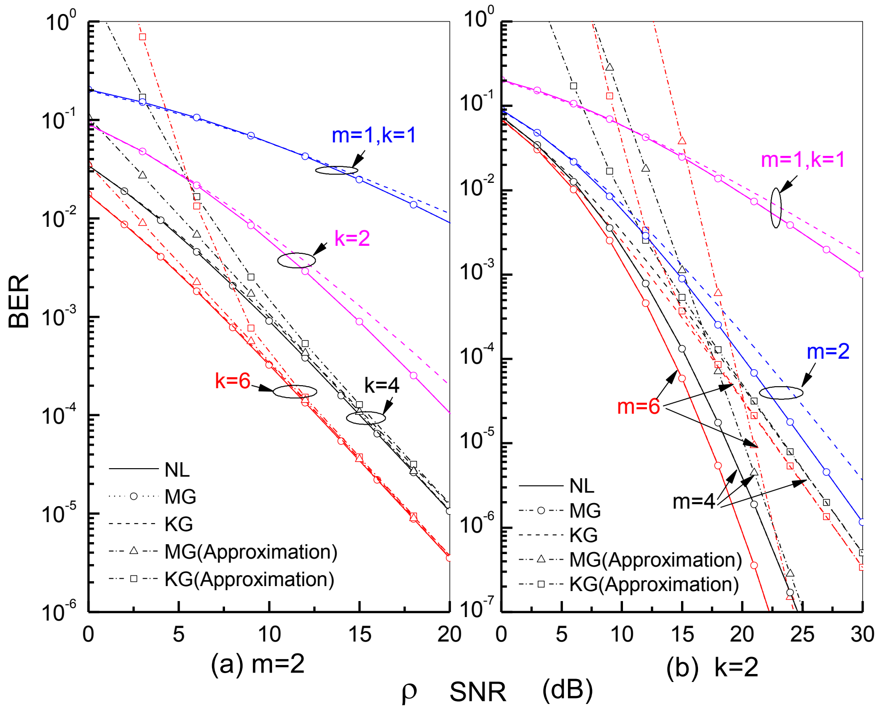

FIGURE 1 Average BER of BPSK for the single-hop link versus un-faded SNR (ρ)

In Figure 2, we give the average SER of 16PSK over i.i.d fading channels. In this case, an symmetric network geometry is assumed where R is located at the middle of a straight line between S and D, and d_0=1, $\varepsilon = 2$. Each hop has the same fading parameters (*k* and *m*), N =10 for MG distribution. From Figure 2, it is evident that the performance of the dual-hop link (dash line) is improved with an increase of *m* and/or *k* over MG fading.

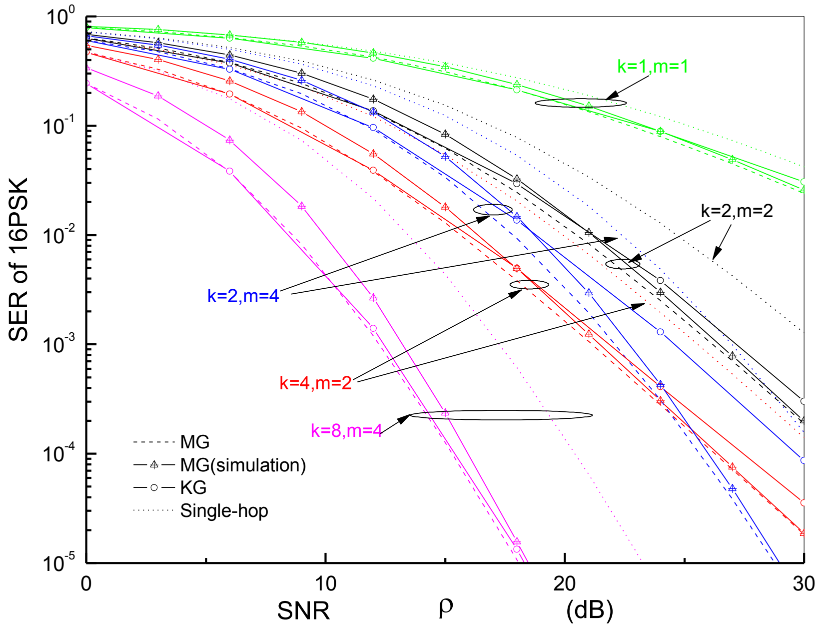

FIGURE 2 Average SER of 16PSK for the dual-hop link versus unfaded SNR (ρ) over i.i.d fading channels

They outperform the performance of the single-hop (dot line) due to the path loss reduction, and the difference become more evident as the value of *m* (or *k*) increases. For the difference between MG (dash line) and KG (line with circle mark) fading, it can be found that they have almost similar performance when *k* is more than *m* and/or at low SNR region, but they show more deviation when *k* is not more than *m* at medium and high SNR region. Moreover, for the diversity order, it can be seen that the diversity orders over MG fading depend on the value of *m*. However, the diversity orders over KG fading depend on the minimum value between *k* and *m*. At the same time, the simulation results of the dual-hop link (line with triangle mark) show agreement with the analytical results (dash line) at medium and high SNR region, and verify the mathematical accuracy.

Finally, Figure 3 shows the average SER of 16PSK of the dual-hop link over non-i.i.d MG and KG fading channels, where each hop has different channel parameters, N=10 for MG distribution.

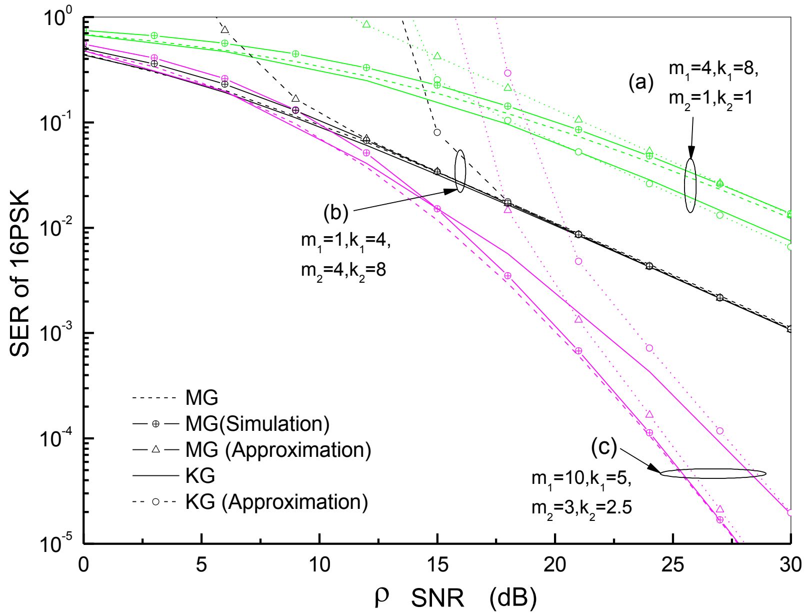

FIGURE3 Average SER of 16PSK for the dual-hop link versus unfaded SNR (ρ) over non-i.i.d fading channels

In Figure 3, their approximation results are also given by using (23) and (24). These results are similar as the ones in Figure 1 and Figure 2. From these figures, it can be seen that they show agreements between the composite NL distribution and the MG distribution if the value of N is enough large, however, only some results match well between the MG distribution and the KG distribution, for example, the case that the value of *k* is more than the value of *m*, and/or the case of low SNR region.

6 Conclusion

In this paper, the end-to-end performance of a dual-hop AF relaying system is investigated over non-i.i.d NL fading channels by using MG distribution and KG distribution, respectively. We derived some novel closed-form expressions for the PDF and MGF of the end-to-end SNR, and evaluated some performance criterion. Numerical and simulation results are shown to verify the accuracy of the analytical results. These results show that it is more precise to approximate the NL distribution by using the MG distribution than using the KG distribution in the performance analysis of cooperative relaying systems. These works in this paper can be helpful to analyse the performance of cooperative relaying systems with co-channel interference over composite NL fading channels in the future.

References

[1] Laneman J N, Tse D N C, Wornell G W 2004 *IEEE Transactions Information Theory* **50** 3062-80
[2] Hasna M O, Alouini M S 2003 *IEEE Trans. Wireless Commun*. **2** 1126-31
[3] Karagiannidis G K, Tsiftsis T A, Mallik R K 2006 *IEEE Trans. Commun*. **54** 18–22
[4] Ikki S, Ahmed M H 2007 *IEEE Commun. Letter* **11** 334-6
[5] Lianhai W, Jiaru L, Kai N, Zhiqiang H 2009 Performance of dual-hop transmissions with fixed gain relays over generalized-k fading channels *Proceedings of the ICC, Germany* 1-5
[6] Efthymoglou G P, Bissias N, Aalo V A 2010 On the error rate analysis of dual-hop amplify-and-forward relaying in Generalized-K fading channels *Journal of Electrical and Computer Engineering*, 1-5 doi:10.1155/2010/584594
[7] Bissias N, Efthymoglou G P, Aalo V A 2012 *International Journal of Electronics and Communications* **66**(1) 39-44
[8] Peppas K P, Datsikas C K, Nistazakis H E, Tombras G S 2010 *Journal of the Franklin Institute* **347**(9) 1643-53
[9] Datsikas C K, Peppas K P, Lazarakis F I, Tombras G S 2010 *International Journal of Electronics and Communications* **64**(11) 1094-9
[10] Jianfei C, Lie-Liang Y, Zhangdui Z H 2010 Performance analysis of multihop wireless links over Generalized-K fading channels *IEEE Vehicular Technology Conference (Fall)* Beijing 1-5
[11] Atapattu S, Tellambura C, Jiang H, 2010 Representation of composite fading and shadowing distributions by using mixtures of gamma distributions *Proc. IEEE Wireless Commun.* 1-5
[12] Atapattu S, Tellambura C, Jiang H 2011 *IEEE Trans. Wireless Commun*. **10** 4193-203
[13] Bithas P S, Sagias N C, Mathiopoulos P T, Karagiannidis G K, Rontogiannis A A 2006 *IEEE Commun. Letter* **10** 353-5
[14] Gradshteyn I S, Ryzhik I M 2000 *Table of Integrals, Series and Products* New York: Academic
[15] Abramowitz M, Stegun I A 1965 *Handbook of Mathematical Functions: With Formulas, Graphs and Mathematical Tables* Dover Publications
[16] Abdi A, Kaveh M 1998 *Electron Letter* **34** 851-2
[17] Simon M K, Alouini M S 2005 *Digital Communication over Fading Channels* New York: Wiley
[18] *The Wolfram functions site* http://functions.wolfram.com

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