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Performance analysis of DF relaying multi-hop systems over log-normal fading channels

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ABSTRACT

In this paper, we studied the end-to-end average bit error rate (BER) performance of decode-and-forward (DF) relaying multi-hop chain systems (MCSs) over log-normal fading channels. After specifying the distribution of the signal-to-noise rate for each hop, the analytical expression of the end-to-end average BER has been derived. The derived end-to-end average BER model can be used in the case that all the single-hops in the chain have different statistical behaviors, i.e., all links suffer various types of fadings, not limited to one type of fading. The comparisons between Monte Carlo simulation results and analytical results under various conditions verify the accuracy of the proposed model.

1. Introduction

Multi-hop relaying has been regarded as a promising technique for expanding network coverage and realizing space diversity [1,2]. In multi-hop relaying chain systems, a source communicates with its corresponding destination via a multi-hop chain link, which consists of several intermediate relays. Multi-hop chain link is a most common and basis communication topology in practical scenarios, especially in cell communication systems, e.g., IEEE 802.16j [3] and LTE-Advanced [4], where the base station communicates with the terminals on the edge of the cell or in the coverage hole via one/several relay stations.

The performance of amplify-and-forward (AF) cooperative systems have been widely studied over log-normal fading channels by researchers [5–10]. Among these works, the authors of [7] developed a comprehensive framework for performance analysis of multi-branch multi-hop wireless relay systems over log-normal fading channels based on the Gauss quadrature rule of the moment generation function for the log-normal distribution. In [8], end-to-end outage probability evaluations of multihop non-generative and regenerative relaying systems over log-normal shadowed channels have been presented. In decode-and-forward (DF) relaying multi-hop chain systems (MCSs), the relays decode the received signal and then forward the decoded information to the receiver of next hop.

In the past, the performance of DF two-way relaying systems has been well studied [11–15]. In [11], the authors derived the analytical expressions for the end-to-end SNR and outage probability of cooperative diversity in correlated log-normal channels. The authors of [12] derived the analytical expressions to study the cooperative diversity performance using selection relaying over correlated log-normal channels for both selection combining and maximal ratio combining techniques at the receiver.

Recently, DF relaying multi-hop systems have gained the focus from researchers [16,17]. For DF relaying MCSs, the authors of [16] proposed the closed analytical expressions for the end-to-end average bit error rate (BER) over Rayleigh and Nakagami-*m* fading channels and with various modulation schemes. However, the main conclusion of [16] (namely, Eq. (3) in [16]) limits to the case that all the single-hops in the chain have the same statistical behavior, i.e., all the links are i.i.d with equal average received SNR. In [17], the upper bounds on the average BER in closed-form for the case of Nakagami-*m* fading on all hops over a DF relaying multi-hop chain link have been derived.

These existing works clearly indicate that few contribution has been made for DF relaying systems or non-relaying systems on log-normal fading scenarios [11,12,18–20], especially there is no work on analyzing the average end-to-end BER of MCS. As another important channel model, log-normal fading channel model is recognized as a better model for indoor radio propagation environments to address the mixed effect of short-term fading and long-term fading indoor channels and shadowing effect in outdoor scenarios [21,22]. However, the literature is relatively spare in performance analysis of DF multi-hop relaying systems over log-normal fading channels.

Motivated by the observation, in this paper, the end-to-end average BER performance of DF relaying MCS over log-normal fading channels was studied. The analytical expressions for the end-to-end average BER of DF relaying MCS have been proposed

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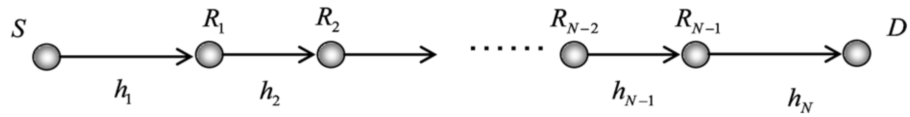

Fig. 1. Diagram of a DF relaying MCS.

by using the prosperities of log-normal distributions and mathematical induction method. Moreover, The derived closed-form expression for average BER can be applied to the cases that all the single-hops in the chain have different statistical behaviors, i.e., all the links suffer various types of fading and/or various modulations adopted at each single-hop.

The rest of this paper is organized as follows: Section 2 introduces the considered system model. In Section 3, the end-to-end average BER has been analyzed for DF relaying MCS over log-normal fading channels and the analytical expression has been derived for the end-to-end average BER. Section 4 presents simulation and numerical results to confirm our proposed model. Finally, Section 5 concludes this paper.

2. System model

Consider a DF relaying MCS with N ($N \geq 2$) hops as shown in Fig. 1. We denote R_n ($1 \leq n \leq N-1$) as the nth relay, and h_m ($1 \leq m \leq N$) as the channel gain for the mth hop. In this work, we assume that the channel gains h_m ($1 \leq m \leq N$) are independent and identically log-normal distributed, namely, $h_m \sim \log - N(\mu_m, \sigma_m^2)$, the probability density function (pdf) of which can be represented as

$$f(h_m; \mu_m, \sigma_m) = \frac{1}{h_m\sqrt{2\pi\sigma_m^2}} \exp\left(-\frac{(\ln h_m - \mu_m)^2}{2\sigma_m^2}\right), \quad (1)$$

where μ_m and σ_m are the mean and variance for h_m's natural logarithm, respectively.

In such a system, the source (S) communicates with the destination (D) via half duplex relay R_n. The received signal at the mth hop, y_m, is given by

$$y_m = h_m x_m + z_m, \quad (2)$$

where x_m denotes the transmitted signal via the mth hop, z_m denotes the noise at the receiver of the mth hop, which can be modeled as a zero-mean, circularly symmetric, complex Gaussian random variable with variance N_{0_m}. When DF relaying scheme is employed, the signal transmitted by the relay terminal R_n ($1 \leq n \leq N-1$) is an estimation of the original transmitted signal at S, which is obtained by decoding and regenerating the received signal by the relay terminal R_n.

3. The end-to-end average BER analysis

Under DF relaying scheme, relays decode the received signal before forwarding. In this section, making use of the prosperities of log-normal distributions and multi-hop chains, the analytical expression has been derived for the end-to-end average BER for DF relaying MCS. The SNR at the receiver of mth hop can be written as

$$\gamma_m = \frac{P_{m-1}(h_m)^2}{N_{0_m}}, \quad (3)$$

where P_k ($0 \leq k \leq N-1$) denotes the transmitting power at the ($n+1$)th hop. By employing the prosperities of log-normal distribution [23], it deduces

$$\gamma_m \sim \log - N(\mu_{\gamma_m}, \sigma_{\gamma_m}^2), \quad (4)$$

where $\mu_{\gamma_m} = \ln(P_{m-1}/\sigma_{\gamma_m}^2) + 2\mu_m$ and $\sigma_{\gamma_m}^2 = 4\sigma_m^2$. As presented in [24], the BER for many modulation scheme can be given by

$$\varepsilon_m \approx aQ\left(\sqrt{b\gamma}\right), \quad (5a)$$

where γ is the SNR of the received signal and $Q(x) = 1\sqrt{2\pi}\int_x^\infty \exp(-t^2/2)\,dt$, and with

$$a = \begin{cases} \dfrac{2}{\log_2^M} & \text{for } M-\text{PSK} \\ \dfrac{4}{\log_2^M} & \text{for } M-\text{QAM} \end{cases}, \quad (5b)$$

$$b = \begin{cases} 2\log_2^M\left(\sin^2\left(\dfrac{\pi}{M}\right)\right) & \text{for } M-\text{PSK} \\ 3\log_2^M \dfrac{1}{K-1} & \text{for } M-\text{QAM} \end{cases}. \quad (5c)$$

Thus, the end-to-end average BER for mth single-hop link can be obtained by averaging the conditional BER, i.e.,

$$\begin{aligned} \varepsilon_m &= a\int_0^\infty Q\left(\sqrt{b\gamma_m}\right) f(\gamma_m)d\gamma_m \\ &= \frac{2a}{\sqrt{2\pi\sigma_{\gamma_m}^2}}\int_0^\infty \frac{Q(x)}{x}\exp\left(-\frac{(2\ln x - \ln b - \mu_{\gamma_m})^2}{2\sigma_{\gamma_m}^2}\right)dx. \end{aligned} \quad (6)$$

Gaussian Q-function can be approximated as [25]:

$$\begin{aligned} Q(x) \approx Q_k(x) = 1 - \sum_{q=0}^{k}\sum_{p=0}^{k}\frac{(-1)^{q+p}\binom{k}{p}}{q!(k-q)!}\left(\frac{k}{12}\right)^{p/2}\left(\frac{k}{2}-q\right)^{k-p} \\ \times x^p U\left[x - \sqrt{\frac{12}{k}}\left(\frac{k}{2}-q\right)\right], \end{aligned} \quad (7)$$

where k is a adjustable factor affecting approximation precision, and $U(\cdot)$ is the unit step function defined as $U(x) = 1$ if $x > 0$, $U(x) = 1/2$ if $x = 0$, and $U(x) = 0$ if $x < 0$.

Using (7) in (6), the average BER can be expressed as

$$\begin{aligned} \varepsilon_m \approx a - \sum_{q=0}^{k/2-1}\sum_{p=0}^{k} g(q,k,p)Q\left(\frac{\ln[(24/k)((k/2)-q)^2] + \mu_{\gamma_m}}{\sigma_{\gamma_m}}\right. \\ \left. - \frac{\sigma_{\gamma_m}}{2}p\right) - \sum_{q=k/2}^{k}\sum_{p=0}^{k} g(q,k,p), \end{aligned} \quad (8)$$

where

$$\begin{aligned} g(q,k,p) = a\frac{(-1)^{q+p}\binom{k}{p}}{q!(k-q)!}\left(\frac{k}{12}\right)^{p/2}\left(\frac{k}{2}-q\right)^{k-p} \\ \times \exp\left(\frac{\sigma_{\gamma_m}^2}{8}p^2 + \frac{1}{2}(\ln b + \mu_{\gamma_m})p\right). \end{aligned}$$