

Research Article

Outage Probability of Dual-Hop Relay System with Interference and Feedback Delay in Satellite M2M Networks

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The machine-to-machine (M2M) communication enables information exchange between machine devices, which can be carried out without or with minimal human interaction. In this paper, we analyse the outage probability of satellite M2M communication system using amplify-and-forward (AF) and decode-and-forward (DF) relaying schemes. Both the channel feedback delay and multiple interferers at the relay and destination are taken into consideration. The channels of the two hops are modeled as Rayleigh and Rician, respectively. The closed-form outage probability expressions for both AF fixed-gain and DF relaying system are obtained, and the validness of our analytical results are verified by the Monte Carlo simulations. It is shown that the channel delay affects the outage probability performance more significantly compared with the interferences. It is also worthy to note that the DF relaying system provides better performance than AF fixed-gain relaying system, especially when the feedback delay is short. Moreover, it can be found that the performance gaps of the two relaying schemes become trivial as the feedback delay increases.

1. Introduction

Wireless communication systems can benefit from dual-hop relaying, which is well known as an efficient way to extend coverage area, improve throughputs, obtain spatial diversity, and overcome channel impairments such as fading, shadowing, and path loss [1–4]. Dual-hop relaying can be employed in many different communication scenarios. In the wireless M2M networks, information has to be exchanged between machine devices. Because the machine devices are small and power-limited, so it is hard to guarantee the outage probability performance requirements of the destination devices due to the propagation loss between the source devices and the destination device. Recently, many increasing researches showed interest in the relay devices to deal with this problem [5, 6]. In dual-hop wireless M2M relay networks, signals are transmitted by relay node while they might be attenuated beyond detection by propagation loss if directly targeting the destination nodes, due to the low-power machine devices. Also, with the help of multiple antennas in source and destination, the spatial diversity of MIMO relay

can help to mitigate the effect of channel fading. Among various relaying schemes, amplify-and-forward (AF) and decode-and-forward (DF) are two commonly used relaying protocols. If the relay only amplifies the received signal at the relay and forwards it to the destination, it is called amplify-and-forward (AF) relaying system. Whereas, if the relay decodes the received signal, reencodes it, and forwards it to the destination, it is called decode-and-forward (DF) relaying system.

The performance analysis of dual-hop AF and DF relaying systems has been extensively investigated. Some have analyzed the performance of single-antenna AF or DF relaying networks in [7–9]. The significant benefits of deploying multiple antennas in relaying network were demonstrated in [10]. For beamforming being an important multiantenna technique, the dual-hop relaying systems employing beamforming were studied in [11–14]. Among various beamforming techniques, the combination of maximal ratio transmission (MRT) and maximal ratio combining (MRC) is widely used in two-hop multiple input and multiple output

(MIMO) relaying networks due to the efficiency and simplicity [11, 13, 14]. In [11, 13], the author studied the end-to-end outage probability and error performance of dual-hop AF and DF relaying system over Rayleigh and Nakagami-m fading channels, respectively, and the outage probability of beamforming with antenna correlation in a two-hop AF MIMO relay network was analyzed in [14]. When multiple antennas are deployed at the source, relay, and destination, the outage probability of MIMO AF relay networks with optimal beamforming was derived in [12].

However, most of literatures assumed perfect channel state information (CSI). In practical scenarios, CSI is feedback from the receiver to the transmitter, where the transmitting delay leads to a mismatch between the available CSI and the actual CSI. The effect of feedback delay on AF relaying network was studied in [15]. It was shown that feedback delay highly degrades the performance of the system since no diversity advantage can be obtained. Along with the feedback delay, the system performance is also highly degraded by the interference [16–18]. In [17, 18], the author investigated the outage probability of AF and opportunistic DF relaying system with interference over Nakagami-m fading channels, respectively. As far as we know, few works have considered the joint effect of feedback delay and interference [19, 20]. In [19], for AF dual-hop relaying system, the author studied the joint effect of feedback delay and interference over Rayleigh fading channels, but it only considered the scenario where each node is equipped with a single antenna. In [20], the authors studied the multiantenna AF relaying networks with feedback delay and interference, but it assumed that the interference only exists at the relay. Furthermore, the above works assumed the dual hops obey the same fading statistics. Nowadays, the support of M2M communication services for the vehicular market using satellite network represents a good opportunity. These services can make use of the backward satellite link capacity for the transmission of telemetry data, requiring only a small fraction of capacity in the forward direction. In the scenario of backward satellite link (from satellite mobile terminal to earth station) of the satellite system, assume satellite mobile terminal and earth station both have multiantennas, the satellite services as relay, then the channel of the satellite mobile terminal to the satellite is often modeled as Rayleigh due to large scattering, while the channel between the satellite and the earth station could be Rician fading because of the composite effect of line of sight component and scattering. To handle this scenario, our paper not only considers the effect of feedback delay but also the interferers at the relay and destination. Furthermore, we also consider the mixed Rayleigh-Rician channel. To the best of the authors' knowledge, no results with the above assumptions have been reported in public.

In this paper, we investigate the joint effect of channel feedback delay and interference for AF fixed-gain and DF dual-hop relaying systems over mixed Rayleigh-Rician channels. We firstly derive the end-to-end equivalent signal-to-interference and noise ratio (SINR), then the expressions for the outage probability of the two systems are given in closed form. Numerical results verify the validness of our theoretical analysis. Simulation results also show the outage probability

gaps of AF fixed-gain and DF dual-hop relaying systems with different parameters.

This paper is organized as follows. In Section 2, we describe the system model with feedback delay and interferers at both the relay and destination. In Section 3, we obtain the closed-form expression for the outage probability of the two relaying schemes with channel feedback delay and interferences. In Section 4, the validity of the performance analysis is verified by Monte Carlo simulations. Finally, conclusions are drawn in Section 5.

2. System Model

We consider a dual-hop half-duplex relay system in wireless M2M networks as shown in Figure 1, where a source machine device equipped with N_s antennas communicates with a destination machine device equipped with N_d antennas through a single-antenna relay.

The source employs MRT and the destination employs MRC. Due to the feedback delay, the weight vectors for the MRT are computed based on the delayed CSI. We assume a mixed channel that the source-to-relay link as Rayleigh fading and the relay-to-destination link as Rician fading. We also assume that the relay and destination operate in an interference-limited environment; therefore, the received signal at relay and destination are impaired by N_1 and N_2 cochannel interferences, respectively. In the first phase, the source transmits the signal to the relay, and then the relay receives the signal and the N_1 interfering signals. At the relay, the received signal is given by

$$y_r(t) = \sqrt{P_s} \mathbf{w}_s^H(t) \mathbf{h}_{rs}(t) s_1(t) + \sum_{i=1}^{N_1} \sqrt{P_{ri}} h_{ri}(t) s_{ri}(t) + n_r(t), \quad (1)$$

where N_1 is the number of interferers at R . $s_1(t)$, $s_{ri}(t)$, and $n_r(t)$ are the transmitted signal, the i th interferer, and zero mean additive white Gaussian noise (AWGN) at relay, satisfying $E\{|s_1(t)|^2\} = 1$, $E\{|s_{ri}(t)|^2\} = 1$ and $E\{|n_r(t)|^2\} = \sigma_r^2$, respectively. P_s and P_{ri} are the transmitted power of source and the i th interferer at relay, respectively. $\mathbf{h}_{rs}(t) = [h_{rs}^1(t), \dots, h_{rs}^{N_s}(t)]^T$ is the Gaussian channel vector from source to relay satisfying $E\{\mathbf{h}_{rs}(t) \mathbf{h}_{rs}^H(t)\} = \mathbf{I}_{N_s}$. $h_{ri}(t)$ ($i = 1, \dots, N_1$) is the i th Gaussian channel coefficient between the i th interferer and R with $E\{|h_{ri}(t)|^2\} = 1$. $\mathbf{w}_s(t)$ is the beamforming weight vector at the source, satisfying $\|\mathbf{w}_s(t)\|_F^2 = 1$; the weight vector is computed based on the outdated CSI, which is given by

$$\mathbf{w}_s(t) = \frac{\mathbf{h}_{rs}(t - T_d)}{\|\mathbf{h}_{rs}(t - T_d)\|_F}, \quad (2)$$

where $\mathbf{h}_{rs}(t - T_d)$ is the delayed channel vector by a time delay T_d of the perfect source-relay channel $\mathbf{h}_{rs}(t)$. The relationship between $\mathbf{h}_{rs}(t - T_d)$ and $\mathbf{h}_{rs}(t)$ is given by the following widely adopted time-varying channel model [21]:

$$\mathbf{h}_{rs}(t) = \rho_d \mathbf{h}_{rs}(t - T_d) + \sqrt{1 - |\rho_d|^2} \mathbf{e}(t), \quad (3)$$

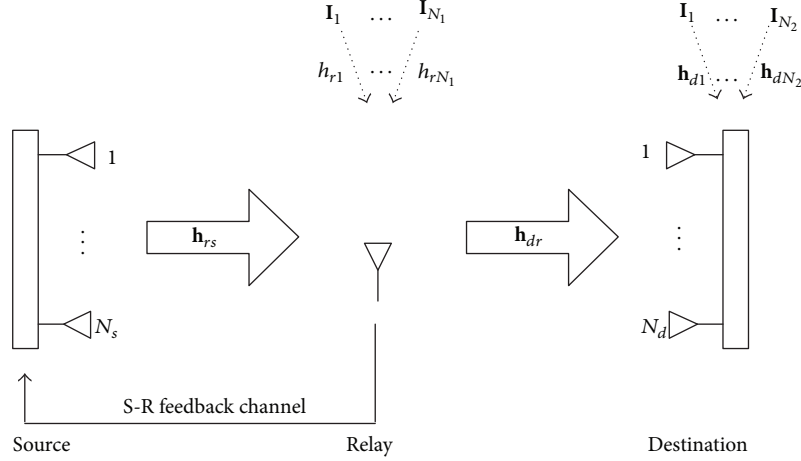


FIGURE 1: System model.

where $\rho_d = J_0(2\pi f_d T_d)$ is the normalized correlation coefficient between $h_{rs}^i(t)$ and $h_{rs}^i(t - T_d)$. $J_0(\cdot)$ is the zeroth-order Bessel function of the first kind [22], f_d is the Doppler shift, and $\mathbf{e}(t)$ is the zero mean Gaussian error vector with $E\{\mathbf{e}(t)\mathbf{e}^H(t)\} = \mathbf{I}_{N_s}$.

For a dual-hop AF relaying system, in the second phase, the received scalar signal $y_r(t)$ at the relay is multiplied by a gain G and forwarded to the destination, and the destination receives the amplified signal from the relay and the N_2 interfering signals. Then, the destination transformed the received vector signal to a scalar with a weight vector $\mathbf{w}_d(t)$, satisfying $\|\mathbf{w}_d(t)\|_F^2 = 1$, and the received signal is given by

$$y_d(t) = \mathbf{w}_d^H(t) \left(Gy_r(t) \mathbf{h}_{dr}(t) + \sum_{j=1}^{N_2} \sqrt{P_{dj}} h_{dj}(t) s_{dj}(t) + \mathbf{n}_d(t) \right), \quad (4)$$

where $\mathbf{h}_{dr}(t) = (h_{dr}^1(t), \dots, h_{dr}^{N_d}(t))^T$ is the Gaussian channel vector from relay to destination. $\mathbf{h}_{dj}(t)$ ($j = 1, \dots, N_2$) is the j th Gaussian channel vector between the j th interferer and destination with $E\{\mathbf{h}_{dj}(t)\mathbf{h}_{dj}^H(t)\} = \mathbf{I}_{N_d}$. P_{dj} is the transmitted power of the j th interferer. $s_{dj}(t)$ and $\mathbf{n}_d(t)$ are the j th interferer and zero mean additive white Gaussian noise (AWGN) at destination, satisfying $E\{|s_{dj}(t)|^2\} = 1$ and $E\{\mathbf{n}_d(t)\mathbf{n}_d^H(t)\} = \sigma_d^2 \mathbf{I}_{N_d}$, respectively. According to the principles of MRC, the weight vector $\mathbf{w}_d(t)$ is chosen to be

$$\mathbf{w}_d(t) = \frac{\mathbf{h}_{dr}(t)}{\|\mathbf{h}_{dr}(t)\|_F}. \quad (5)$$

For the fixed-gain relay system, G is given by

$$G = \sqrt{\frac{P_r}{P_s E\{|\mathbf{w}_s^H(t)\mathbf{h}_{rs}(t)|^2\} + \sum_{i=1}^{N_1} P_{ri} + \sigma_r^2}}, \quad (6)$$

where P_r is the transmit power of relay. After some manipulations, the instantaneous end-to-end SINR at destination can be expressed by

$$\begin{aligned} \gamma^{\text{AF}} = & G^2 P_s |\mathbf{w}_d^H(t)\mathbf{h}_{dr}(t)|^2 |\mathbf{w}_s^H(t)\mathbf{h}_{rs}(t)|^2 \\ & \times \left(G^2 |\mathbf{w}_d^H(t)\mathbf{h}_{dr}(t)|^2 \sum_{i=1}^{N_1} P_{ri} |h_{ri}(t)|^2 \right. \\ & + \sum_{j=1}^{N_2} P_{dj} |\mathbf{w}_d^H(t)\mathbf{h}_{dj}(t)|^2 \\ & \left. + G^2 |\mathbf{w}_d^H(t)\mathbf{h}_{dr}(t)|^2 \sigma_r^2 + \sigma_d^2 \right)^{-1}. \end{aligned} \quad (7)$$

Substituting (6) into (7) and with the assumption that relay and destination are interference-limited (i.e., $n_r(t)$ and $\mathbf{n}_d(t)$ can be neglected, the SINR is equivalent to signal-to-interference ratio (SIR)), γ^{AF} can be further written as

$$\gamma^{\text{AF}} = \frac{\gamma_1 \gamma_2}{\gamma_2 \gamma_R + C \gamma_D}, \quad (8)$$

where $\gamma_1 = \overline{\gamma_1} |\mathbf{w}_s^H(t)\mathbf{h}_{rs}(t)|^2$, $\gamma_2 = \overline{\gamma_2} |\mathbf{w}_d^H(t)\mathbf{h}_{dr}(t)|^2$, $\gamma_R = \sum_{i=1}^{N_1} (P_{ri}/\sigma_r^2) |h_{ri}(t)|^2$, $\gamma_D = \sum_{j=1}^{N_2} (P_{dj}/\sigma_d^2) |\mathbf{w}_d^H(t)\mathbf{h}_{dj}(t)|^2$, and $C = (P_s/\sigma_r^2) E\{|\mathbf{w}_s^H(t)\mathbf{h}_{rs}(t)|^2\} + \sum_{i=1}^{N_1} (P_{ri}/\sigma_r^2) + 1$ with $\overline{\gamma_1} = P_s/\sigma_r^2$, $\overline{\gamma_2} = P_r/\sigma_d^2$.

For the second phase of the dual-hop DF relaying system, the relay decodes the source data $s_1(t)$, reencodes, and transmits it to the destination, and the destination receives the reencoded signal $s_2(t)$ with $E\{|s_2(t)|^2\} = 1$ and N_2 interfering signals. Then, the destination utilizes a weight

vector $\mathbf{w}_d(t)$ to transform the vector signal to a scalar signal, satisfying $\|\mathbf{w}_d(t)\|_F^2 = 1$, and the received signal is given by

$$y_d^{\text{DF}}(t) = \mathbf{w}_d^H(t) \left(\mathbf{h}_{dr}(t) s_2(t) + \sum_{j=1}^{N_2} \sqrt{P_{dj}} \mathbf{h}_{dj}(t) s_{dj}(t) + \mathbf{n}_d(t) \right). \quad (9)$$

From (1) and (9), the instantaneous equivalent SIR at relay and the destination can be expressed as

$$\gamma_1^{\text{DF}} = \frac{P_s |\mathbf{w}_s^H(t) \mathbf{h}_{rs}(t)|^2}{\sum_{i=1}^{N_1} P_{ri} |h_{ri}(t)|^2} \triangleq \frac{\gamma_1}{\gamma_R}, \quad (10)$$

$$\gamma_2^{\text{DF}} = \frac{P_r |\mathbf{w}_d^H(t) \mathbf{h}_{dr}(t)|^2}{\sum_{j=1}^{N_2} P_{dj} |\mathbf{w}_d^H(t) \mathbf{h}_{dj}(t)|^2} \triangleq \frac{\gamma_2}{\gamma_D}, \quad (11)$$

where γ_1 , γ_2 , γ_R and γ_D are defined as above.

3. Outage Probability

Outage probability is an important system performance metric in wireless communication. It is defined as the end-to-end instantaneous equivalent SIR falling below a given threshold γ_{th} .

3.1. Amplify-and-Forward Relaying System. For AF relaying system, it can be expressed by

$$P_{\text{out}}^{\text{AF}}(\gamma_{\text{th}}) = P(\gamma^{\text{AF}} < \gamma_{\text{th}}) = P\left(\frac{\gamma_1 \gamma_2}{\gamma_2 \gamma_R + C \gamma_D} < \gamma_{\text{th}}\right). \quad (12)$$

In order to calculate (12), we firstly evaluate the cumulative distribution function (CDF) of γ_1 , the probability distribution function (PDF) of γ_2 , γ_R , and γ_D , and also the value of C , respectively. According to [21], the CDF of γ_1 can be given by

$$F_{\gamma_1}(\gamma) = 1 - \sum_{m=0}^{N_s-1} \sum_{n=0}^{N_s-m-1} \binom{N_s-1}{m} (|\rho_d|^2)^{N_s-m-1} \times (1 - |\rho_d|^2)^m \frac{\gamma^n e^{-\gamma/\bar{\gamma}_1}}{n! \bar{\gamma}_1}. \quad (13)$$

The PDF of γ_1 can also be obtained in [21] by

$$f_{\gamma_1}(\gamma) = \frac{1}{\bar{\gamma}_1^{N_s}} \sum_{m=0}^{N_s-1} \binom{N_s-1}{m} (|\rho_d|^2)^{N_s-m-1} \times (\bar{\gamma}_1 (1 - |\rho_d|^2))^m \gamma^{N_s-m-1} e^{-\gamma/\bar{\gamma}_1} \times ((N_s - m - 1)!)^{-1}. \quad (14)$$

With the help of [22, Eq. (2-1-118)], The PDF of γ_2 is given by

$$f_{\gamma_2}(\gamma) = \frac{1}{2\sigma^2 \gamma_2} \left(\frac{\gamma}{\gamma_2 S^2} \right)^{(n-2)/4} \times e^{-(S^2 + (\gamma/\gamma_2))/2\sigma^2} I_{n/2-1} \left(\sqrt{\frac{\gamma}{\gamma_2}} \frac{S}{\sigma^2} \right), \quad (15)$$

where $I_a(x)$ is the a th-order modified Bessel function of the first kind [23, Eq. (8.431.1)], which can be expressed by

$$I_a(x) = \sum_{k=0}^{\infty} \frac{(x/2)^{a+2k}}{k! \Gamma(a+k+1)} \quad (x \geq 0). \quad (16)$$

Substituting (16) and $n = 2N_d$ into (15), The PDF of γ_2 can be further given by

$$f_{\gamma_2}(\gamma) = \sum_{k=0}^{\infty} \frac{\gamma^{N_d+k-1} S^{2k} e^{-(S^2 + (\gamma/\gamma_2))/2\sigma^2}}{\gamma_2^{N_d+k} (2\sigma^2)^{N_d+2k} k! \Gamma(N_d+k)}, \quad (17)$$

where we consider γ_2 as the sum of squares of $2N_d$ statistic independence Gaussian random variables which have the same variance $\sigma^2 = \bar{\gamma}_2^2$ and the mean values $\bar{\gamma}_2 m_i$ ($i = 1, 2, \dots, 2N_d$); here, we define $S^2 = \bar{\gamma}_2^2 \sum_{i=1}^{2N_d} m_i^2$ as the sum of squares of $\bar{\gamma}_2 m_i$ and Rice factor $K = S^2/2\sigma^2$, accordingly.

As with Theorem 2 in [24], the PDF of γ_R is given by

$$f_{\gamma_R}(\gamma) = \sum_{i=1}^{\rho(A)} \sum_{j=1}^{\tau_i(A)} \chi_{ij}(A) \frac{P_{r[i]}^j}{(j-1)!} \gamma^{j-1} \exp\left(-\frac{\gamma}{P_{r[i]}}\right), \quad (18)$$

where $A = \text{diag}(P_{r1}/\sigma_r^2, P_{r2}/\sigma_r^2, \dots, P_{rN_1}/\sigma_r^2)$, $\rho(A)$ is the number of distinct diagonal elements of A , $P_{r[1]} > P_{r[2]} > \dots > P_{r[\rho(A)]}$ are the distinct diagonal elements in decreasing order, $\tau_i(A)$ is the multiplicity of $P_{r[i]}$, and $\chi_{ij}(A)$ is the (i, j) th characteristic coefficient of A [24]. Similarly, the PDF of γ_D is given by

$$f_{\gamma_D}(\gamma) = \sum_{u=1}^{\rho(B)} \sum_{v=1}^{\tau_u(B)} \chi_{uv}(B) \frac{P_{d[u]}^v}{(v-1)!} \gamma^{v-1} \exp\left(-\frac{\gamma}{P_{d[u]}}\right), \quad (19)$$

where $B = \text{diag}(P_{d1}/\sigma_d^2, P_{d2}/\sigma_d^2, \dots, P_{dN_2}/\sigma_d^2)$, $\rho(B)$, $P_{d[u]}$, and $\chi_{uv}(B)$ are defined as (18) similarly.

With the help of (14), C can be calculated as

$$\begin{aligned} C &= \frac{P_s}{\sigma_r^2} E \left\{ |\mathbf{w}_s^H(t) \mathbf{h}_{rs}(t)|^2 \right\} + \sum_{i=1}^{N_1} \frac{P_{ri}}{\sigma_r^2} + 1 \\ &= \frac{P_s}{\sigma_r^2 \bar{\gamma}_1} E \{ \gamma_1 \} + \sum_{i=1}^{N_1} \frac{P_{ri}}{\sigma_r^2} + 1 \\ &= \frac{P_s}{\sigma_r^2 \bar{\gamma}_1^{N_s+1}} \\ &\quad \times \int_0^{\infty} \sum_{m=0}^{N_s-1} \frac{\binom{N_s-1}{m} (|\rho_d|^2)^{N_s-m-1} (\bar{\gamma}_1 (1 - |\rho_d|^2))^m}{(N_s - m - 1)!} \\ &\quad \times \gamma^{N_s-m} e^{-\gamma/\bar{\gamma}_1} d\gamma + \sum_{i=1}^{N_1} \frac{P_{ri}}{\sigma_r^2} + 1. \end{aligned} \quad (20)$$

With the help of [23, Eq. (3.351.3)],

$$\int_0^\infty x^n e^{-\mu x} dx = n! \mu^{-n-1} \quad (\text{Re } \mu > 0). \quad (21)$$

C can be further obtained as

$$C = \frac{1}{\gamma_1} \sum_{i=1}^{N_s-1} \binom{N_s-1}{i} (|\rho_d|^2)^{N_s-i-1} (1-|\rho_d|^2)^i (N_s-i) + \sum_{i=1}^{N_1} \frac{P_{ri}}{\sigma_r^2} + 1. \quad (22)$$

With the help of (13), (17), (18), and (19) and also the binomial theorem, (12) can be further formulated as

$$\begin{aligned} P_{\text{out}}^{\text{AF}}(\gamma_{\text{th}}) &= P(\gamma^{\text{AF}} < \gamma_{\text{th}}) \\ &= P\left(\gamma_1 < \frac{(\gamma_2 \gamma_R + C \gamma_D) \gamma_{\text{th}}}{\gamma_2}\right) \\ &= \iiint_0^\infty F_{\gamma_1}\left(\frac{(\gamma_2 \gamma_R + C \gamma_D) \gamma_{\text{th}}}{\gamma_2}\right) \\ &\quad \times f_{\gamma_R}(\gamma_R) f_{\gamma_2}(\gamma_2) f_{\gamma_D}(\gamma_D) d\gamma_R d\gamma_2 d\gamma_D \\ &= 1 - \int_0^\infty \sum_{m=0}^{N_s-1} \sum_{n=0}^{N_s-m-1} \sum_{p=0}^n \binom{N_s-1}{m} (|\rho_d|^2)^{N_s-m-1} \\ &\quad \times (1-|\rho_d|^2)^m \\ &\quad \times \left(\frac{\gamma_{\text{th}}^n \gamma_R^p e^{-\gamma_{\text{th}} \gamma_R / \gamma_1}}{n! \gamma_1^n} \right) \\ &\quad \times f_{\gamma_R}(\gamma_R) d\gamma_R \\ &\quad \times \iint_0^\infty \left(\frac{C \gamma_D}{\gamma_2} \right)^{n-p} e^{-\gamma_{\text{th}} C \gamma_D / \gamma_1 \gamma_2} f_{\gamma_2}(\gamma_2) f_{\gamma_D}(\gamma_D) d\gamma_2 d\gamma_D \\ &= 1 - I_1 \times I_2, \end{aligned} \quad (23)$$

where

$$\begin{aligned} I_1 &= \int_0^\infty \sum_{m=0}^{N_s-1} \sum_{n=0}^{N_s-m-1} \sum_{p=0}^n \binom{N_s-1}{m} (|\rho_d|^2)^{N_s-m-1} \\ &\quad \times (1-|\rho_d|^2)^m \\ &\quad \times \frac{\gamma_{\text{th}}^n \gamma_R^p e^{-\gamma_{\text{th}} \gamma_R / \gamma_1}}{n! \gamma_1^n} f_{\gamma_R}(\gamma_R) d\gamma_R, \end{aligned} \quad (24)$$

$$I_2 = \iint_0^\infty \left(\frac{C \gamma_D}{\gamma_2} \right)^{n-p} \times e^{-\gamma_{\text{th}} C \gamma_D / \gamma_1 \gamma_2} f_{\gamma_2}(\gamma_2) f_{\gamma_D}(\gamma_D) d\gamma_2 d\gamma_D.$$

Substituting (18) into I_1 , I_1 can be derived as

$$\begin{aligned} I_1 &= \int_0^\infty \sum_{m=0}^{N_s-1} \sum_{n=0}^{N_s-m-1} \sum_{p=0}^n \sum_{i=1}^{\rho(A)} \sum_{j=1}^{\tau_i(A)} \left(\chi_{ij}(A) \binom{N_s-1}{m} \right. \\ &\quad \times \binom{n}{p} (|\rho_d|^2)^{N_s-m-1} \\ &\quad \times (1-|\rho_d|^2)^m \gamma_{\text{th}}^n \\ &\quad \times \left(n! \gamma_1^n (j-1)! P_{r[i]}^j \right)^{-1} \Big) \\ &\quad \times \gamma_R^{p+j-1} e^{-(\gamma_{\text{th}}/\gamma_1+1/P_{r[i]})\gamma_R} d\gamma_R. \end{aligned} \quad (25)$$

With the help of [23, Eq. (3.351.3)], I_1 can be further obtained as

$$\begin{aligned} I_1 &= \sum_{m=0}^{N_s-1} \sum_{n=0}^{N_s-m-1} \sum_{p=0}^n \sum_{i=1}^{\rho(A)} \sum_{j=1}^{\tau_i(A)} \chi_{ij}(A) \binom{N_s-1}{m} \\ &\quad \times \binom{n}{p} (|\rho_d|^2)^{N_s-m-1} \\ &\quad \times (1-|\rho_d|^2)^m \gamma_{\text{th}}^n (p+j-1)! \\ &\quad \times \left(n! \gamma_1^n (j-1)! P_{r[i]}^j \right. \\ &\quad \times \left. \left(\frac{\gamma_{\text{th}}}{\gamma_1} + \frac{1}{P_{r[i]}} \right)^{p+j} \right)^{-1}. \end{aligned} \quad (26)$$

Substituting (17) into I_2 , I_2 can be derived as

$$\begin{aligned} I_2 &= \iint_0^\infty \sum_{k=0}^\infty \left(S^{2k} (c \gamma_D)^{n-p} e^{-S^2/2\sigma^2} \right. \\ &\quad \times \left((2\sigma^2)^{Nd+2k} \frac{1}{\gamma_2^{Nd+k}} \right. \\ &\quad \times \left. k! \Gamma(N_d+k) \right)^{-1} \Big) \\ &\quad \times \gamma_2^{Nd+k+p-n-1} \\ &\quad \times e^{-(\gamma_{\text{th}} C \gamma_D / \gamma_1 \gamma_2 + \gamma_2 / 2\sigma^2 \gamma_2)} f_{\gamma_D}(\gamma_D) d\gamma_2 d\gamma_D. \end{aligned} \quad (27)$$

With the help of [23, Eq. (3.471.9)],

$$\int_0^\infty x^{\nu-1} e^{-(\beta/x)-\gamma x} dx = 2 \left(\frac{\beta}{\gamma} \right)^{\nu/2} K_\nu \left(2\sqrt{\beta\gamma} \right) \quad (\text{Re } \beta > 0, \text{Re } \gamma > 0). \quad (28)$$

I_2 can be further obtained as

$$I_2 = \int_0^\infty \sum_{k=0}^\infty \left(2^{(p-N_d-3k-n+2)/2} S^{2k} (c\gamma_D)^{(N_d+k+n-p)/2} \right. \\ \times e^{-S^2/2\sigma^2} \sigma^{p-n+2-N_d-3k} \gamma_{th}^{(N_d+k+p-n)/2} \\ \times \left(\overline{\gamma_2}^{(N_d+k+n-p)/2} \overline{\gamma_1}^{-(N_d+k+p-n)/2} k! \Gamma(N_d+k) \right)^{-1} \\ \times K_{N_d+k+p-n} \left(2 \sqrt{\frac{\gamma_{th} C \gamma_D}{2\gamma_1 \gamma_2 \sigma^2}} \right) f_{\gamma_D}(\gamma_D) d\gamma_D, \quad (29)$$

where $K_n(x)$ is the n th-order modified Bessel function of the second kind [23, Eq. (8.432.1)]. Substituting (19) into (28) and after some algebraic manipulations, I_2 can be given by

$$I_2 = \int_0^\infty \sum_{u=1}^\infty \sum_{v=1}^\infty \sum_{k=0}^\infty \left(\chi_{uv}(B) 2^{(p-N_d-3k-n+2)/2} S^{2k} \right. \\ \times (c\gamma_D)^{(N_d+k+n-p)/2} e^{-S^2/2\sigma^2} \\ \times \sigma^{p-n+2-N_d-3k} \gamma_{th}^{(N_d+k+p-n)/2} \\ \times \gamma_D^{v-1} e^{-\gamma_D/P_{d[u]}} \\ \times \left(P_{d[u]}^v \overline{\gamma_2}^{(N_d+k+n-p)/2} \right. \\ \times \overline{\gamma_1}^{-(N_d+k+p-n)/2} \\ \times (v-1)! k! \Gamma(N_d+k) \left. \right)^{-1} \\ \times K_{N_d+k+p-n} \left(2 \sqrt{\frac{\gamma_{th} C \gamma_D}{2\gamma_1 \gamma_2 \sigma^2}} \right) d\gamma_D. \quad (30)$$

With the help of [23, Eq. (6.631.3)],

$$\int_0^\infty x^\mu e^{-\alpha x^2} K_\nu(\beta x) dx \\ = \frac{1}{2} \alpha^{-(1/2)\mu} \beta^{-1} \Gamma\left(\frac{1+\nu+\mu}{2}\right) \\ \times \Gamma\left(\frac{1-\nu+\mu}{2}\right) e^{\beta^2/8\alpha} W_{-(1/2)\mu, (1/2)\nu}\left(\frac{\beta^2}{4\alpha}\right) \\ (\text{Re } \mu > |\text{Re } \nu| - 1). \quad (31)$$

After further calculations, I_2 can be finally obtained as

$$I_2 = \sum_{u=1}^{\rho(B)\tau_u(B)} \sum_{v=1}^\infty \sum_{k=0}^\infty \chi_{uv}(B) \left(2S^{2k} C^{(N_d+k+n-p)/2} \right. \\ \times e^{(\gamma_{th} CP_{d[u]}/4\overline{\gamma_1}\overline{\gamma_2}\sigma^2 - S^2/2\sigma^2)} \\ \times (2\sigma^2)^{(p-n-N_d-3k)/2} \\ \times \gamma_{th}^{(N_d+k+p-n)/2} \\ \times P_{d[u]}^{(N_d+k+n-p-1)/2} \\ \times \Gamma(N_d+k+v) \\ \times \Gamma(v-p+n) \\ \times \left(\overline{\gamma_1}^{(N_d+k+p-n)/2} \right. \\ \times \overline{\gamma_2}^{(N_d+k+n-p)/2} \\ \times k! (v-1)! \\ \times \Gamma(N_d+k) \left. \right)^{-1} \\ \times W_{-(N_d+k+n-p+2v-1)/2, (N_d+k+p-n)/2} \left(\frac{\gamma_{th} CP_{d[u]}}{2\overline{\gamma_1}\overline{\gamma_2}\sigma^2} \right), \quad (32)$$

where $W_{ij}(x)$ is the Whittaker function defined in [23, Eq. (9.222.1)]. Now substituting (14) and (32) into (23), the closed-form expression for the outage probability can be obtained in

$$P_{out}^{AF}(\gamma_{th}) \\ = 1 - \left[\sum_{m=0}^{N_s-1} \sum_{n=0}^{N_s-m-1} \sum_{p=0}^n \sum_{i=1}^n \sum_{j=1}^n \binom{N_s-1}{m} \right. \\ \times \binom{n}{p} (|\rho_d|^2)^{N_s-m-1} \\ \times (1-|\rho_d|^2)^m \\ \times \left(\chi_{ij}(A) \gamma_{th}^n (p+j-1)! \right. \\ \times \left(n! \overline{\gamma_1}^n (j-1)! \right. \\ \times \left(\frac{\gamma_{th}}{\gamma_1} + \frac{1}{P_{r[i]}} \right)^{p+j} \\ \times P_{r[i]}^j \left. \right)^{-1} \left. \right]$$

$$\begin{aligned}
& \times \sum_{u=1}^{\rho(B)\tau_u(B)} \sum_{v=1}^{\infty} \sum_{k=0}^{\infty} \chi_{uv}(B) \left(2S^{2k} C^{(N_d+k+n-p)/2} \right. \\
& \quad \times e^{(\gamma_{th} CP_{d[u]}/4\gamma_1\gamma_2\sigma^2 - S^2/2\sigma^2)} \\
& \quad \times (2\sigma^2)^{(p-n-N_d-3k)/2} \\
& \quad \times \gamma_{th}^{(N_d+k+p-n)/2} \\
& \quad \times P_{d[i]}^{(N_d+k+n-p-1)/2} \\
& \quad \times \Gamma(N_d+k+v) \\
& \quad \times \Gamma(v-p+n) \\
& \quad \times (\gamma_1^{-(N_d+k+p-n)/2} \\
& \quad \times \gamma_2^{(N_d+k+n-p)/2} \\
& \quad \times k! (v-1)! \\
& \quad \times \Gamma(N_d+k))^{-1} \\
& \quad \times W_{-(N_d+k+n-p+2v-1)/2, (N_d+k+p-n)/2} \\
& \quad \times \left. \left(\frac{\gamma_{th} CP_{d[u]}}{2\gamma_1\gamma_2\sigma^2} \right) \right].
\end{aligned} \tag{33}$$

3.2. Decode-and-Forward Relaying System. For the dual-hop DF relaying system, the outage probability can be defined as the probability that the minimum of the single-hop SIRs falls below a given threshold γ_{th} . Therefore, it can be expressed by

$$\begin{aligned}
P_{out}^{DF}(\gamma_{th}) &= P(\min(\gamma_1^{DF}, \gamma_2^{DF}) < \gamma_{th}) \\
&= 1 - P(\gamma_1^{DF} > \gamma_{th}, \gamma_2^{DF} > \gamma_{th}) \\
&= 1 - (1 - F_{\gamma_1^{DF}}(\gamma_{th}))(1 - F_{\gamma_2^{DF}}(\gamma_{th})).
\end{aligned} \tag{34}$$

By using the CDF of γ_1 in (13), the outage probability of the γ_1^{DF} in (10) can be calculated as

$$\begin{aligned}
F_{\gamma_1^{DF}}(\gamma_{th}) &= P\left(\frac{\gamma_1}{\gamma_R} < \gamma_{th}\right) = P(\gamma_1 < \gamma_{th}\gamma_R) \\
&= \int_0^\infty F_{\gamma_1}(\gamma_{th}\gamma_R) f_{\gamma_R}(\gamma_R) d\gamma_R
\end{aligned}$$

$$\begin{aligned}
&= 1 - \int_0^\infty \sum_{m=0}^{N_s-1} \sum_{n=0}^{N_s-m-1} \sum_{i=1}^{\rho(A)\tau_i(A)} \sum_{j=1}^{\infty} \left(\chi_{ij}(A) \binom{N_s-1}{m} \right. \\
& \quad \times (|\rho_d|^2)^{N_s-m-1} \\
& \quad \times (1 - |\rho_d|^2)^m \gamma_{th}^n \\
& \quad \times (n! \gamma_1^n (j-1)! P_{r[i]}^j)^{-1} \\
& \quad \times \gamma_R^{n+j-1} e^{-(\gamma_{th}/\gamma_1 + 1/P_{r[i]})\gamma_R} d\gamma_R.
\end{aligned} \tag{35}$$

With the help of [23, Eq. (3.351.3)], the outage probability of γ_1^{DF} can be further obtained as

$$\begin{aligned}
F_{\gamma_1^{DF}}(\gamma_{th}) &= 1 - \left[\sum_{m=0}^{N_s-1} \sum_{n=0}^{N_s-m-1} \sum_{i=1}^{\rho(A)\tau_i(A)} \sum_{j=1}^{\infty} \binom{N_s-1}{m} (|\rho_d|^2)^{N_s-m-1} \right. \\
& \quad \times (1 - |\rho_d|^2)^m \\
& \quad \times \left(\chi_{ij}(A) \gamma_{th}^n \left(\frac{\gamma_{th}}{\gamma_1} + \frac{1}{P_{r[i]}} \right)^{-n-j} (n+j-1)! \right. \\
& \quad \times \left. \left. (n! \gamma_1^n (j-1)! P_{r[i]}^j)^{-1} \right) \right].
\end{aligned} \tag{36}$$

In order to calculate the CDF of γ_2^{DF} , we firstly evaluate the CDF of γ_D . Given the PDF of γ_D in (19), the CDF of γ_2^{DF} can be calculated as

$$\begin{aligned}
F_{\gamma_D}(\gamma) &= \int_0^\gamma f_{\gamma_D}(x) dx \\
&= \int_0^\gamma \sum_{u=1}^{\rho(B)\tau_u(B)} \sum_{v=1}^{\infty} \chi_{uv}(B) \frac{P_{d[u]}^{-v}}{(v-1)!} x^{v-1} \exp\left(-\frac{x}{P_{d[u]}}\right) dx.
\end{aligned} \tag{37}$$

With the help of [23, Eq. (3.351.1)],

$$\begin{aligned}
\int_0^u x^n e^{-\mu x} dx &= \frac{n!}{\mu^{n+1}} - e^{-u\mu} \sum_{k=0}^n \frac{n!}{k!} \frac{u^k}{\mu^{n-k+1}} \\
&(u > 0, \text{Re } \mu > 0, n = 0, 1, 2, \dots).
\end{aligned} \tag{38}$$

The CDF of γ_D can be given by

$$\begin{aligned}
F_{\gamma_D}(\gamma) &= \sum_{u=1}^{\rho(B)\tau_u(B)} \sum_{v=1}^{\infty} \chi_{uv}(B) - \sum_{u=1}^{\rho(B)\tau_u(B)} \sum_{v=1}^{\infty} \sum_{l=0}^{v-1} \chi_{uv}(B) \frac{\gamma^l e^{-\gamma/P_{d[u]}}}{l! P_{d[u]}^l} \\
&= 1 - \sum_{u=1}^{\rho(B)\tau_u(B)} \sum_{v=1}^{\infty} \sum_{l=0}^{v-1} \chi_{uv}(B) \frac{\gamma^l e^{-\gamma/P_{d[u]}}}{l! P_{d[u]}^l},
\end{aligned} \tag{39}$$

where the fact $\sum_{u=1}^{\rho(B)} \sum_{v=1}^{\tau_u(B)} \chi_{uv}(B) = 1$ is utilized. Using the CDF given in (39), the outage probability of γ_2^{DF} in (11) can be derived as

$$\begin{aligned}
 F_{\gamma_2^{\text{DF}}}(\gamma_{\text{th}}) &= P\left(\frac{\gamma_2}{\gamma_D} < \gamma_{\text{th}}\right) = P\left(\gamma_D > \frac{\gamma_2}{\gamma_{\text{th}}}\right) \\
 &= \int_0^\infty \left(1 - F_{\gamma_D}\left(\frac{\gamma_2}{\gamma_{\text{th}}}\right)\right) f_{\gamma_2}(\gamma_2) d\gamma_2 \\
 &= \int_0^\infty \sum_{u=1}^{\rho(B)} \sum_{v=1}^{\tau_u(B)} \sum_{l=0}^{v-1} \sum_{k=0}^\infty \left(\chi_{uv}(B) S^{2k} e^{-s^2/2\sigma^2}\right. \\
 &\quad \times \left(\gamma_{\text{th}}^l l! k! \Gamma(N_d + k) \bar{\gamma}_2^{-N_d+k}\right. \\
 &\quad \times \left.(2\sigma^2)^{N_d+2k} P_{d[u]}^l\right)^{-1} \\
 &\quad \times \gamma_2^{N_d+k+l-1} \\
 &\quad \times e^{-(1/\gamma_{\text{th}} P_{d[u]} + 1/2\sigma^2 \bar{\gamma}_2) \gamma_2} d\gamma_2.
 \end{aligned} \tag{40}$$

With the help of [23, Eq. (3.351.3)], the outage probability of γ_2^{DF} can be further obtained as

$$\begin{aligned}
 F_{\gamma_2^{\text{DF}}}(\gamma_{\text{th}}) &= \sum_{u=1}^{\rho(B)} \sum_{v=1}^{\tau_u(B)} \sum_{l=0}^{v-1} \sum_{k=0}^\infty \chi_{uv}(B) S^{2k} e^{-s^2/2\sigma^2} \\
 &\quad \times (N_d + k + l - 1)! \\
 &\quad \times \left(\frac{1}{\gamma_{\text{th}} P_{d[u]}} + \frac{1}{2\sigma^2 \bar{\gamma}_2}\right)^{-N_d-k-l} \\
 &\quad \times \left(\gamma_{\text{th}}^l l! k! \Gamma(N_d + k) \bar{\gamma}_2^{-N_d+k}\right. \\
 &\quad \times \left.(2\sigma^2)^{N_d+2k} P_{d[u]}^l\right)^{-1}.
 \end{aligned} \tag{41}$$

Substituting (36) and (41) into (34), the outage probability can be further derived as

$$\begin{aligned}
 P_{\text{out}}^{\text{DF}}(\gamma_{\text{th}}) &= 1 - \left[\sum_{m=0}^{N_s-1} \sum_{n=0}^{N_s-m-1} \sum_{i=1}^{\rho(A)} \sum_{j=1}^{\tau_i(A)} \binom{N_s-1}{m} (|\rho_d|^2)^{N_s-m-1} \right. \\
 &\quad \times (1 - |\rho_d|^2)^m \\
 &\quad \times \left. \left(\chi_{ij}(A) \gamma_{\text{th}}^n \left(\frac{\gamma_{\text{th}}}{\bar{\gamma}_1} + \frac{1}{P_{r[i]}}\right)^{-n-j}\right) \right]
 \end{aligned}$$

$$\begin{aligned}
 &\times (n + j - 1)! \\
 &\times \left(n! \bar{\gamma}_1^n (j - 1)! P_{r[i]}^j\right)^{-1} \\
 &\times \left(1 - \sum_{u=1}^{\rho(B)} \sum_{v=1}^{\tau_u(B)} \sum_{l=0}^{v-1} \sum_{k=0}^\infty \chi_{uv}(B) S^{2k} e^{-s^2/2\sigma^2}\right. \\
 &\quad \times (N_d + k + l - 1)! \\
 &\quad \times \left(\frac{1}{\gamma_{\text{th}} P_{d[u]}} + \frac{1}{2\sigma^2 \bar{\gamma}_2}\right)^{-N_d-k-l} \\
 &\quad \times \left(\gamma_{\text{th}}^l l! k! \Gamma(N_d + k) \bar{\gamma}_2^{-N_d+k}\right. \\
 &\quad \times \left.(2\sigma^2)^{N_d+2k} P_{d[u]}^l\right)^{-1} \Bigg).
 \end{aligned} \tag{42}$$

4. Numerical Results

In this section, we verify the theoretical analysis via Monte Carlo simulations. We assume that $\bar{\gamma}_1 = \bar{\gamma}_2$, the value of C is defined in (22). Here, we consider two interferers as $N_1 = N_2 = 2$. The power distribution factor of interference is defined as $m = P_{r[1]}/P_{r[2]} = P_{d[1]}/P_{d[2]} = 2$ and SIR is defined as $\text{SIR} = \bar{\gamma}_1/(P_{r[1]} + P_{r[2]}) = \bar{\gamma}_2/(P_{d[1]} + P_{d[2]})$. With the help of [24] and the references therein, for $m > 1$, it can be obtained that $\rho(A) = \rho(B) = 2$, $\tau_1(A) = \tau_2(A) = \tau_1(B) = \tau_2(B) = 1$, $\chi_{11}(A) = P_{r[1]}/(P_{r[1]} - P_{r[2]})$, $\chi_{11}(B) = P_{d[1]}/(P_{d[1]} - P_{d[2]})$, $\chi_{21}(A) = P_{r[2]}/(P_{r[2]} - P_{r[1]})$, $\chi_{21}(B) = P_{d[2]}/(P_{d[2]} - P_{d[1]})$.

Figure 2 shows the outage probability versus average SNR per hop for the dual-hop AF and DF relaying systems. The system parameters are set to be $N_s = N_d = 3$ and $P_{r[1]} = P_{d[1]} = 5$ dB, and the SIR threshold is selected as $\gamma_{\text{th}} = 5$ dB. Figure 3 shows the outage probability with average SIR chosen from 5 dB to 30 dB, and the average SNR is selected as $\bar{\gamma}_1 = \bar{\gamma}_2 = 10$ dB. Here, we assume Jake's fading spectrum, and the feedback delay parameters are set as $\rho_d = 1$, $\rho_d = 0.64$ and $\rho_d = 0.29$ corresponding to $f_d T_d = 0$, $f_d T_d = 0.2$, and $f_d T_d = 0.3$, respectively. It can be found that the simulation results and analytical results are perfectly matched, which demonstrates the effectiveness of our performance analysis. It can be seen that long feedback delay, that is, ρ_d , significantly degrades the outage probability performance. We can also find that the outage probability decreases as the SNR per hop or SIR per hop increases. It is also worthy to note that DF relaying system performances are better than AF relaying system when feedback delay is short, while the performance gap becomes small as the feedback delay increases.

Figures 4 and 5 show the outage probability versus Rician factor K for the two systems. We choose SIR threshold and average SNR per hop as $\gamma_{\text{th}} = 10$ dB and $\bar{\gamma}_1 = \bar{\gamma}_2 = 10$ dB, respectively. Here, we consider four different scenarios, that is, channel delay and channel interference (CD + CI), channel delay only (CD only), channel interference only (CI only), and without channel delay and channel interference (No CD,

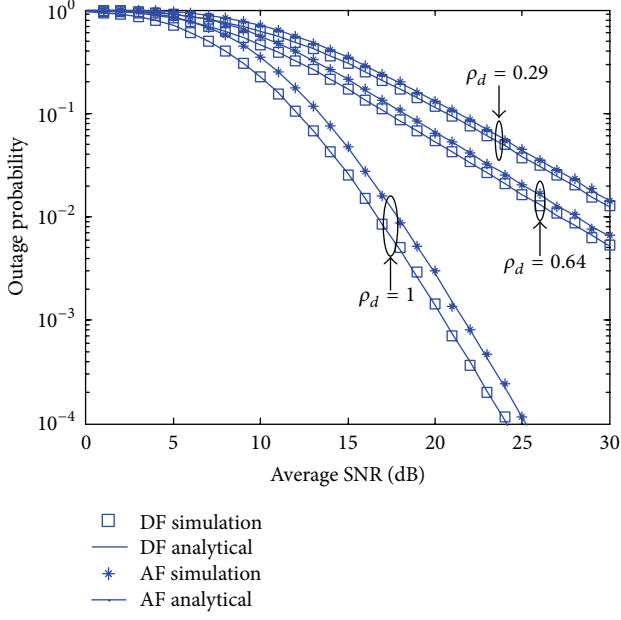


FIGURE 2: Outage probability of AF and DF relaying system for different ρ_d with $P_{r[1]} = P_{d[1]} = 5$ dB, $N_s = N_d = 3$, and $\gamma_{th} = 5$ dB.

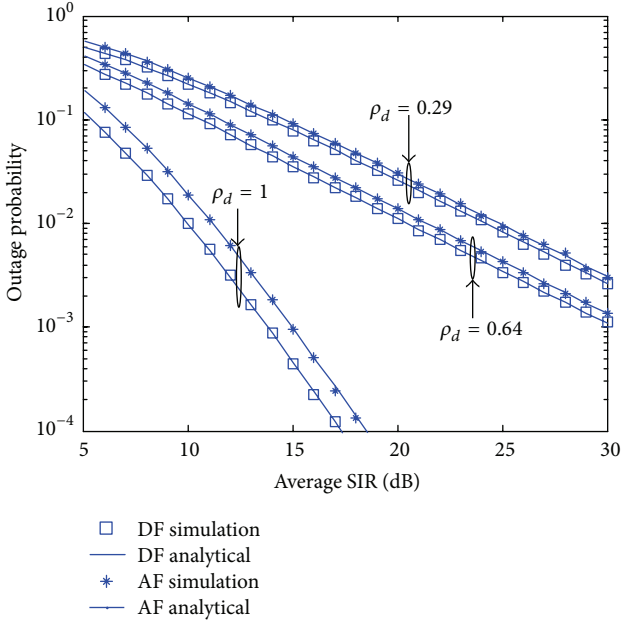


FIGURE 3: Outage probability of AF and DF versus different SIR with $N_s = N_d = 3$, $\gamma_1 = \gamma_2 = 10$ dB, and $\gamma_{th} = 5$ dB.

No CI). For the scenarios with CD, we choose $\rho_d = 0.29$ and $P_{r[1]} = P_{d[1]} = 2$ dB. As can clearly be seen from Figures 4 and 5, the outage probability decreases as the K increases for both AF and DF relaying systems, but the improvement is slow and unobvious, which means that the outage probability is not decided by the second hop. It is shown that the simulation results and the analytical results are in perfect agreement. It also can be noticed that the best performance can be obtained

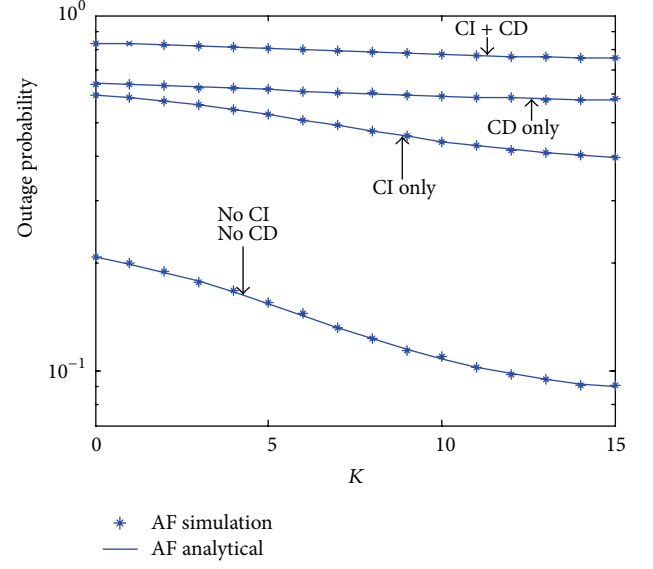


FIGURE 4: Outage probability of AF versus different K with $\gamma_{th} = 10$ dB, $N_s = N_d = 3$.

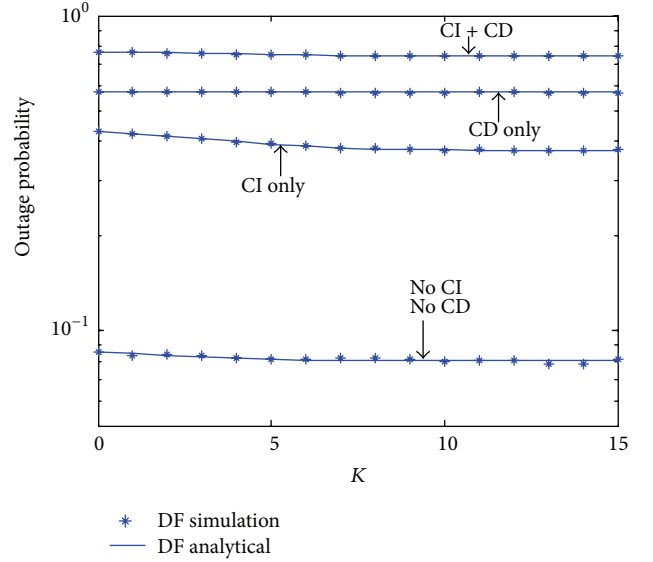


FIGURE 5: Outage probability of DF versus different K with $\gamma_{th} = 10$ dB, $N_s = N_d = 3$.

without channel delay and interference. Moreover, we can find that channel delay has larger influence on the outage probability compared with the interference.

Figures 6 and 7 show the performance of outage probability for different antenna configurations. The system parameters are set as $\gamma_{th} = 5$ dB, $f_d T_d = 0.2$, and $P_{r[1]} = P_{d[1]} = 5$ dB. It can be seen clearly that the analytical results exactly agree with the simulation results. We can find that the outage probability is improved as the number of antenna increases for both AF and DF relaying system. It is also worthy to note that the number of transmit antennas at source significantly influences the outage probability performance, which means

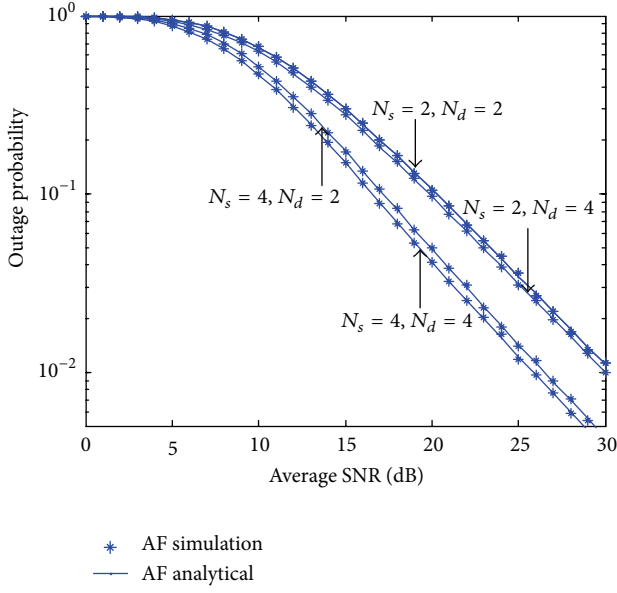


FIGURE 6: Outage probability of AF versus different N_s and N_d with $\gamma_{th} = 5$ dB, $f_d T_d = 0.2$.

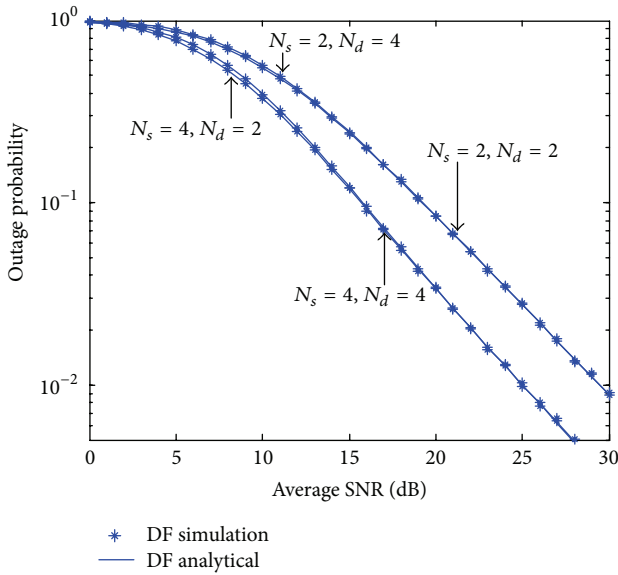


FIGURE 7: Outage probability of DF versus different N_s and N_d with $\gamma_{th} = 5$ dB, $f_d T_d = 0.2$.

that the channel delay in the first hop is the main cause that affects the outage probability performance.

Figures 8 and 9 show the outage probability versus average SNR (dB) per hop for the two systems. Here, we also consider four different scenarios, that is, CD + CI, CD only, CI only, and No CD, No CI. It is shown that the simulation results and the analytical results are in perfect agreement. Similar to Figures 4 and 5, same conclusion can be reached that, without channel delay and interference, the best performance can be obtained, while channel delay degrades the outage

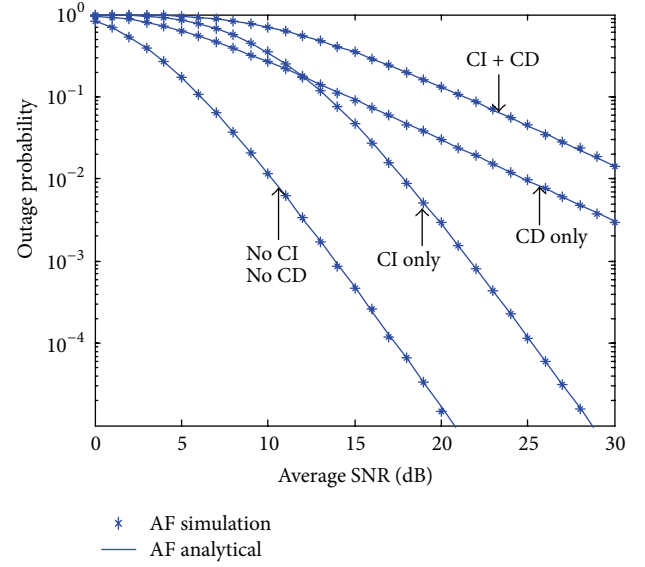


FIGURE 8: Outage probability of AF versus different scenarios with $\gamma_{th} = 5$ dB, $N_s = N_d = 3$.

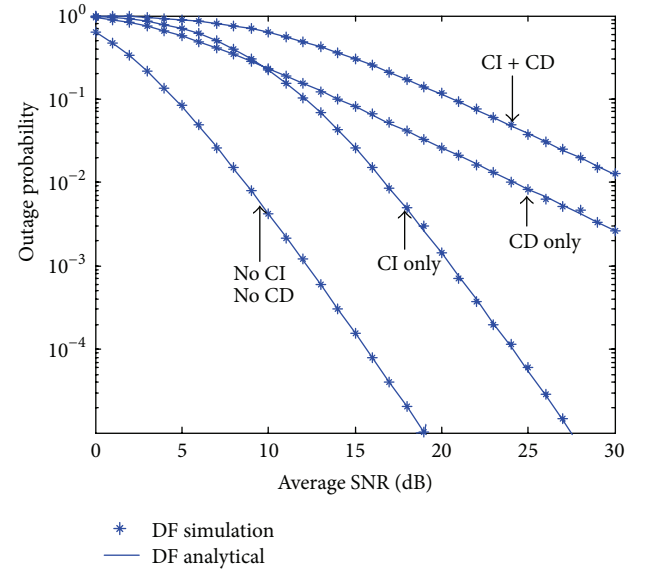


FIGURE 9: Outage probability of DF versus different scenarios with $\gamma_{th} = 5$ dB, $N_s = N_d = 3$.

probability performance more significantly compared with the interference.

5. Conclusions

In this paper, we investigated the effects of channel feedback delay and cochannel interference on the performance of outage probability in dual-hop relaying system. We considered a mixed Rayleigh and Rician fading channel model and obtained closed-form outage probability expressions for both AF fixed-gain and DF relaying system. The validity of our analytical results was verified by Monte Carlo simulations.

Our analysis is useful to the system design engineer for performance evaluation of satellite M2M networks.

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