Performance Analysis of Dual-Hop Satellite Relaying

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***Abstract*—Satellite communication is considered as an indispensable method in the future seamless wireless networks. In this paper, we first propose an opportunistic user scheduling scheme for a dual-hop satellite relaying with decode-and-forward (DF) protocol. Then, by supposing that the satellite links experience Shadowed-Rician (SR) fading, we derive the closed-form outage probability (OP) expression for the considered system. Finally, computer simulation results are given to demonstrate the validity of the performance analysis and verify that the OP of the dual-hop satellite relaying system can be improved through multi-user diversity. Our work is helpful for the engineers in designing a practical satellite network.**

Keywords*—*dual-hop satellite relaying, decode-and-forward (DF), outage performance, shadowed Rician (SR) fading.

I. Introduction

Recently, satellite communication has become a hot research topic due to its potential to provide services such as broadcasting, disaster relief, and navigation assistance for the users all over the world, especially in remote areas [1]-[3].Usually, the satellite relaying system exploits two protocols, namely, amplify-and-forward (AF) and decode-and-forward (DF), to assist signal transmission between the source and destination on the ground. As for AF relaying, signals are amplified at the relay and then forwarded to the destination. By considering both variable and fixed gain relaying, the authors of [4] investigated the performance of a dual-hop AF satellite relaying network and derived the closed-form expressions of outage probability (OP), ergodic capacity and average symbol error rate. The main drawback of AF protocol is that not only the desired signals but also the noises are amplified at the relay. On the other hand, when DF relaying is used, the received signals from the source are decoded, re-encoded, and then forwarded to the destination. Since only the desired signal is forwarded to the destination, DF relaying scheme is suitable for data transmission in noisy scenarios. With the development and application of on-board processing, the dual-hop satellite communication has received more and more attention recently. For example, in [5], the authors analyzed the performance of a dual-hop DF satellite relaying system over Shadowed-Rician (SR) channels. Besides, the performance of hybrid satellite-terrestrial network with terrestrial relaying was also evaluated in [6] and [7].

However, the main drawback of the previous works is that they only consider the case of signal user. In a practical satellite communication, due to the nature of wide coverage, there are often many users to be served. Under this situation, we herein propose an opportunistic user scheduling scheme and derive the analytical expression of OP for a dual-hop satellite relaying with DF protocol. To the best of the authors' knowledge, this is for the first time that such kind of expressions has been obtained.

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II. System Model

As shown in Fig 1, we consider a dual-hop satellite relaying system, which consists of N terrestrial source (S) nodes, M terrestrial destination (D) nodes and a satellite relaying (R). In this system, each node is equipped with single antenna and both of the uplink (S-R) and downlink (R-D) undergo SR fading. Due to the long distance and heavy attenuation of the propagation, the direct links between the sources and the destinations are unavailable. In addition, we assume that Time Division Multiplexing Access (TDMA) scheme is employed, thus a single user is served at each time slot.

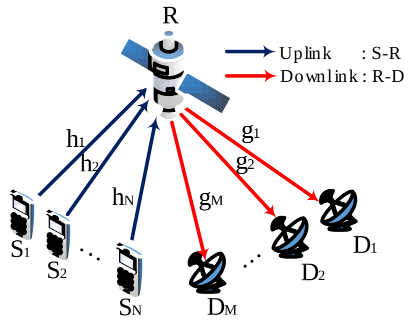

Fig. 1. System model of the dual-hop satellite relaying

The total communication occurs in two time slots. During the first time slot, the i-th S sends its signal $x_i(t)$ with $E[|x_i(t)|^2]=P_s$ to R. Then, the received signal at R can be written as

$$y_i(t)=\sqrt{P_{s,i}}h_i(t)x_i(t)+n_i(t) \tag{1}$$

where h_i denotes the channel response of the i-th S-R link and $P_{s,i}$ the transmitted power of the i-th source. Meanwhile, n_i represents the additive white Gaussian noise (AWGN) with zero mean and equal variance N_0. As a result, the instantaneous output signal-to noise ratio (SNR) at R is given by

$$\gamma_{s,i}=|h_i|^2\times\bar{\gamma}_{s,i} \tag{2}$$

where $\bar{\gamma}_{s,i} = P_{s,i} / N_0$ is the average SNR of the i-th S-R link. Without loss of generality, it is often supposed that $\bar{\gamma}_{s,i} = \bar{\gamma}_s (i = 1, 2, \ldots N)$. In this paper, the opportunistic user scheduling scheme is exploited to select the best user. Thus, the received SNR at R is given by

$$\gamma_1 = \max_{i=1,2\ldots N} \left(\bar{\gamma}_s \left| h_i \right|^2 \right) \tag{3}$$

During the second time slot, by using the DF protocol, R first decodes the received signal $y_i(t)$ with the maximal SNR, and then sends the corresponding decoding signal $x_i(t)$ with an average power $P_{r,j}$ to D. Then, the received signal at the j-th D can be written as

$$y_{d,j}(t) = \sqrt{P_{r,j}} g_j(t) x(t) + n_j(t) \tag{4}$$

where g_j denotes the channel response of the j-th R-D link. Meanwhile, n_j represents the AWGN with zero mean and variance N_0. As a result, the instantaneous output SNR at the j-th D is given by

$$\gamma_{d,j} = \left| g_i \right|^2 \times \bar{\gamma}_{d,j} \tag{5}$$

where $\bar{\gamma}_{d,j} = P_{r,j} / N_0$ is the transmit SNR at R for the j-th user. Without loss of generality, it is often supposed that $\bar{\gamma}_{d,j} = \bar{\gamma}_d (j = 1, 2, \ldots M)$. Again, we exploit the opportunistic user scheduling scheme to select the user with maximal output SNR is selected, giving

$$\gamma_2 = \max_{j=1,2\ldots M} \left(\bar{\gamma}_d \left| g_j \right|^2 \right) \tag{6}$$

Consequently, the end to end SNR of the DF satellite relaying system can be expressed as

$$\gamma = \min(\gamma_1, \gamma_2) \tag{7}$$

III. Performance Analysis

Outage probability is an important measure of wireless communication service quality, which is defined as the probability that the signal output SNR γ is below a certain threshold [8]-[9], namely,

$$\begin{aligned} P_{out}(x) &= \Pr[\gamma < x] = \Pr[\min(\gamma_1, \gamma_2) < x] \\ &= 1 - \Pr[\gamma_1 \geq x, \gamma_2 \geq x] \\ &= 1 - [1 - F_{\gamma 1}(x)][1 - F_{\gamma 2}(x)] \end{aligned} \tag{8}$$

where $F_{\gamma 1}(x)$ and $F_{\gamma 2}(x)$ denotes the cumulative distribution function (CDF) of γ_1 and γ_2 respectively. In what follows, we derive the closed-form expression of $F_{\gamma 1}(x)$ and $F_{\gamma 2}(x)$.

Suppose that both of S-R and R-D links are subject to SR fading, the probability density function (PDF) of $|h_i|^2$ and $|g_j|^2$ can thus be uniformly expressed as [10].

$$\begin{aligned} f_\delta(x) &= \frac{1}{2b_i} \left(\frac{2b_i m_i}{2b_i m_i + \Omega_i} \right)^{m_i} \exp\left(-\frac{x}{2b_i}\right) \\ &\times {}_1F_1\left(m_i; 1; \frac{\Omega_i x}{2b_i(2b_i m_i + \Omega_i)}\right), \delta \in \left\{ |h_i|^2, |g_j|^2 \right\} \end{aligned} \tag{9}$$

where the parameter Ω_i is the average power of line of sight (LOS) component, $2b_i$ the average power of the multipath component, m_i the Nakagami parameter ranging from 0 to ∞, and the function ${}_1F_1(a;b;z)$ the confluent hypergeometric function given by [11]

$${}_1F_1(a;b;z) = \sum_{n=0}^{\infty} \frac{(a)_n z^n}{(b)_n n!} \tag{10}$$

where $(x)_n = x(x+1)\ldots(x+n-1)$.

As for the derivation of $F_{\gamma 1}(x)$, we assume that all S-R channels are independent, which is commonly used in the existing works, then we can obtain

$$\begin{aligned} F_{\gamma 1}(x) &= \Pr[\gamma_1 \leq x] = \Pr[\max_{i=1,2\ldots N} (\gamma_{s,i}) \leq x] \\ &= \Pr[\gamma_{s,1} \leq x, \ldots, \gamma_{s,N} \leq x] \\ &= \prod_{i=1}^{N} \Pr(\gamma_{s,i} \leq x) = \prod_{i=1}^{N} F_{\gamma_{s,i}}(x) \end{aligned} \tag{11}$$

where

$$F_{\gamma_{s,i}}(x) = \int_0^x f_{\gamma_{s,i}}(\tau) d\tau \tag{12}$$

with $f_{\gamma_{s,i}}(\tau)$ being the PDF of $\gamma_{s,i}$. By employing (2) and (9), the PDF of $\gamma_{s,i}$ can be further written as

$$\begin{aligned} f_{\gamma_{s,i}}(x) &= \frac{1}{\bar{\gamma}_{s,i}} \times f_{|h_i|^2}\left(\frac{x}{\bar{\gamma}_{s,i}}\right) = \frac{1}{2b_i \bar{\gamma}_{s,i}} \left(\frac{2b_i m_i}{2b_i m_i + \Omega_i} \right)^{m_i} \exp\left(-\frac{x}{2b_i \bar{\gamma}_{s,i}}\right) \\ &\times {}_1F_1\left(m_i; 1; \frac{\Omega_i x}{2b_i \bar{\gamma}_{s,i}(2b_i m_i + \Omega_i)}\right), \quad for \quad x \geq 0 \end{aligned} \tag{13}$$

After some computation with the Maclaurin series of exp(-x) and the equation [11, Eq. (2.01.1)], the CDF of $\gamma_{s,i}$ can be further given by

$$\begin{aligned} F_{\gamma_{s,i}}(x) &= A_i x \, {}_1F_1(m_i; 2; B_i x) + \sum_{k=1}^{\infty} (-1)^k \\ &\frac{A_i x^{k+1}}{(k+1)!(2b_i \bar{\gamma}_{s,i})^j} \, {}_2F_2(k+1, m_i; k+2, 1; B_i x) \end{aligned} \tag{14}$$

where

$$A_i = \frac{1}{2b_i \bar{\gamma}_{s,i}} \left(\frac{2b_i m_i}{2b_i m_i + \Omega_i} \right)^{m_i} \quad , \quad B_i = \frac{\Omega_i}{2b_i \bar{\gamma}_{s,i}(2b_i m_i + \Omega_i)}$$

$${}_2F_2 = (a_1, a_2; b_1, b_2; z) = \sum_{n=0}^{\infty} \frac{(a_1)_n (a_2)_n}{(b_1)_n (b_2)_n n!} z^n$$

In a similar manner, the CDF of γ_2 can be written as

$$F_{\gamma 2}(x) = \Pr[\gamma_2 \leq x] = \prod_{j=1}^{M} \Pr(\gamma_{d,j} \leq x) = \prod_{j=1}^{M} F_{\gamma_{d,j}}(x) \tag{15}$$

where $F_{\gamma_{d,j}}(x)$ is given by (14) with i replaced by j.

Finally, by substituting (14) and (15) into (8), the OP of the dual-hop DF satellite relay network can be obtained as

$$P_{out}(x) = 1-(1-\prod_{i=1}^{N} A_i x_1 F_1(m_i;2;B_i x) + \sum_{k=1}^{\infty}(-1)^k \frac{A_i x^{k+1}}{(k+1)!(2b_i \overline{\gamma_{s,i}})^k} {}_2F_2(k+1,m_i;k+2,1;B_i x))(1-\prod_{j=1}^{M} A_j x_1 F_1(m_j;2;B_j x) + \sum_{k=1}^{\infty}(-1)^k \frac{A_j x^{k+1}}{(k+1)!(2b_j \overline{\gamma_{d,j}})^k} {}_2F_2(k+1,m_j;k+2,1;B_j x)) \tag{16}$$

IV. Numerical Results

This section gives numerical results to demonstrate the validity of the opportunistic user scheduling scheme and the theoretical analysis. The threshold is assumed to be 1. The parameters for the SR fading channel are shown in Table I. We assume that the average transmit SNR of the S-R link is equal to the R-D link, namely, $\overline{\gamma} = P_{s,i} / N_0 = P_{r,j} / N_0$. Without loss of generality, we consider that all S-R links and R-D links are identical. In addition, we set the upper limit of k in formula (14) and (16) to be 20.

TABLE I. SR channel parameters [12]

shadowing	b	m	Ω
Frequent heavy shadowing	0.063	0.739	8.97×10^{-4}
Average shadowing	0.126	10.1	0.835

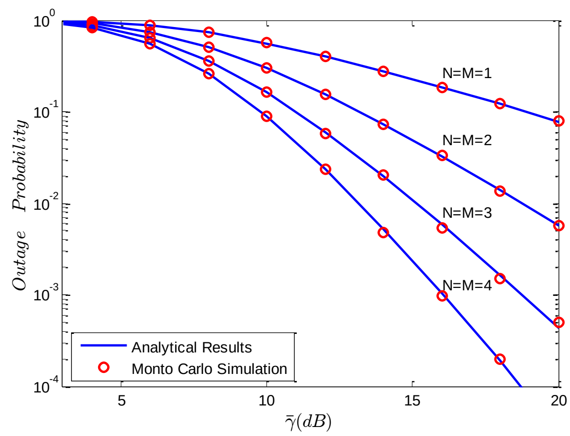

Fig. 2. OP of the dual-hop satellite relaying

Fig. 2 shows the outage probability of a satellite relaying system in which the satellite adopts the DF protocol to transmit message from source to destination by selecting the best S-R and R-D links for different number of sources and destinations $N = M = 1,2,3,4$. As we see, the analytical results match well with the Monto Carlo simulations, confining the validity of the theoretical formula. Obviously, the larger average transmit SNR provides a more reliable transmission, thus, the OP performance can be improved. In addition, it can be observed that the OP of the considered system is improved with the increase of source and destination nodes. This is because when the average transmit SNR is fixed, the more of source and destination number, the greater the possibility of better path selection, yielding the improvement of diversity gain.

V. Conclusion

In this paper, we have investigated the OP of a dual-hop communication system over a satellite relaying with multiple sources and multiple destinations. Firstly, we have proposed an opportunistic user scheduling scheme. Then, the analytical expression of OP for the system has been derived. Simulation results have confirmed the accuracy of the theoretical analysis. Furthermore, our study reveals that the performance of the satellite relaying communication system can be improved through multi-user diversity. The obtained outage expressions will provide valuable insight into the satellite relaying network.

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