Two-Way Denoise-and-Forward MIMO Relaying for Land Mobile Satellite Communication

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Abstract: In this paper, a two-way denoise-and-forward (DNF) multiple-input-multiple-output (MIMO) relaying scheme for land mobile satellite (LMS) communication is proposed. We first describe the system model of two-way DNF MIMO relaying and the channel model used in LMS communication. Secondly, we use binary phase-shift keying (BPSK) to analyze the decoding bit error rate (BER) at the earth stations (ESs) and the satellite, and then obtain the end-to-end BER. Finally, we provide the simulation BER performance with BPSK modulation. The simulation results show that the two-way DNF MIMO relaying is suitable for LMS communication and the two-way MIMO with BPSK works well in LMS communication.

Keywords: Two-way relaying; multiple-input-multiple-output; land mobile satellite communication; shadowed-Rician fading; denoise-and-forward protocol.

1. Introduction

Land mobile satellite communication is always of great interest since it can provide various benefits like wide band transmission capability, large coverage area, and navigation assistance [1]-[3]. However, LMS communication suffers from multipath loss, shadow fading and Doppler effects, which may interrupt the communication. Also, high transmit power is demand for LMS system. Cooperative communication can provide spatial diversity to effectively resist multipath fading. And the two-way relaying can only use two time slots to complete the exchange of information, which can improve the data rate of a cooperative system compared with one-way relaying which is widely used in conventional LMS communication. MIMO technology with multiple antennas on the transceivers can promote link reliability and spectral efficiency without exact need for system bandwidth and transmit power.

There are several strategies applied for two-way relay system, such as amplified-and-forward (AF) and decode-and-forward (DF), early work of two-way AF and DF relaying can be found in [4]. A DNF protocol is proposed in [5], in which the received signal at the relay node is mapped into another symbol by applying a denoising function, and the mapped symbol can be used by each source node to decode the symbol transmitted from the other source uniquely. The DNF protocol is more efficient than DF for the relay does not need to separate message sent by source nodes. The two-way AF relaying and two-way DF relaying for satellite communication are studied in [6]-[7]. Two-way AF relaying with differential modulation for satellite communication is proposed in [8]. And [9] made a review on MIMO technologies for the satellite communications.

As summarized above, whether two-way DNF MIMO relaying is suitable for LMS communication is still an open problem. In this paper, we propose a two-way DNF MIMO relaying for LMS communication. Firstly, we describe the system model of two-way DNF MIMO relaying and the channel model used in LMS communication. Secondly, we use BPSK to analyze the decoding BER at the ESs and the satellite, and then obtain the end-to-end BER. Finally, we provide the BER performance of the two-way DNF MIMO relaying for LMS communication with BPSK modulation.

This paper is organized as follows. In Section 2, we describe the system model of two-way DNF MIMO relaying for LMS communication. In Section 3, we analyze the BER performance at the ESs and the satellite, and then obtain the end-to-end BER. In Section 4, we provide the simulation results with BSPK modulation. Finally, in Section 5, we conclude this paper.

2. System and channel model

We consider a two-way relaying with two ESs and a satellite, where the satellite is equipped with M antennas and the two ESs are equipped with N antennas, as shown in Figure 1. The two ESs communicate with each other

simultaneously over two phases. We assume that there is no direct link between the two ESs, a half-duplex system is assumed. In this scheme, ESs don't need to know full channel state information (CSI) of both channels but only know the CSI between satellite and itself and only the satellite knows the full CSI of both channels.
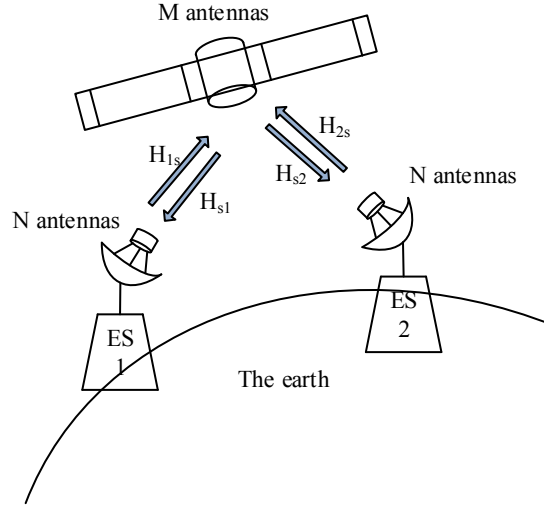

Figure 1. Two-way MIMO relaying for LMS communication

2.1 Channel model

The channels between the satellite and the ES are assumed to be shadowed-rician (SR) fading. The channel matrix between the satellite and the ES is given by [10]

$$
\begin{aligned}
H &= \bar{H} + \tilde{H} \\
&= A(t)\exp(j\alpha(t)) + Z(t)\exp(j\zeta_0)
\end{aligned} \tag{1}
$$

Here, the entries in channel matrix H are independent and identically distributed SR fading entries. $A(t)$ and $Z(t)$ denote the amplitudes of the scatter and line-of-sight (LOS) component, following Rayleigh and Nakagami distributions respectively. $\alpha(t)$ is the stationary random phase process, which satisfies the uniform distribution over $[0,2\pi)$, ζ_0 represents the determined phase of the LOS component.

$$
p_A(a) = \frac{a}{b_0}\exp(\frac{-a^2}{2b_0}), \qquad a \geq 0
$$

$$
p_Z(z) = \frac{2m^m}{\Gamma(m)\Omega^m}z^{2m-1}\exp(\frac{-mz^2}{\Omega}), \qquad z \geq 0, \tag{2}
$$

where $2b_0 = E\left[A^2\right]$ is the average power of the scatter component, $\Gamma(\square)$ is the gamma function, $m = \left(E\left[Z^2\right]\right)^2 \Big/ Var\left[Z^2\right] \geq 0$ is the Nakagami parameter, $Var[\square]$ denotes the variance, $\Omega = E\left[Z^2\right]$ is the average power of the LOS component.

2.2 System model

In the multiple access (MAC) phase, the ES1, ES2 transmit to the satellite, the received signal at the satellite can be expressed as

$$
y_s = \sqrt{P_1}H_{1s}M(x_1) + \sqrt{P_2}H_{2s}M(x_2) + w_s, \tag{3}
$$

Where P_1 and P_2 is the power of the ES1 and ES2, H_{1s} and H_{2s} denote the channel matrix from the ESs to the satellite, respectively. $M(x_1)$ and $M(x_2)$ represent the modulated signal. w_s indicates the additive white Gaussian noise (AWGN) vector which contains complex-valued Gaussian random variables (RVs) with zero mean and variance σ_s^2.

The satellite decodes the received signal from the two ESs by using the ML decision rule as follows

$$
\hat{x} = \hat{x}_1 \oplus \hat{x}_2 = \arg\min_{x_1 \oplus x_2}\left|y_r - \left(\sqrt{P_1}H_{1s}M(x_1) + \sqrt{P_2}H_{2s}M(x_2)\right)\right|^2, \tag{4}
$$

In the broadcast (BC) phase, the satellite broadcast the processed message to ES1 and ES2, the received signal at ES1, ES2 can be written as

$$y_1 = \sqrt{P_s} H_{s1} M(\hat{x}) + w_1 ,\tag{5}$$

$$y_2 = \sqrt{P_s} H_{s2} M(\hat{x}) + w_2 ,\tag{6}$$

Where P_s is the transmit power of the satellite, and we have $P_s = P_1 + P_2$, H_{s1} and H_{s2} denote the channel matrix from the satellite to the ESs, respectively. w_1, w_2 indicate the Gaussian noise with zero mean and variance σ_1^2, σ_2^2, respectively.

Each ES decodes the signal using the ML decision rule as follows

$$\hat{\hat{x}}_1 = \arg\min_{\hat{x}} \left| y_1 - \sqrt{P_s} H_{s1} M(\hat{x}) \right|^2 ,\tag{7}$$

$$\hat{\hat{x}}_2 = \arg\min_{\hat{x}} \left| y_2 - \sqrt{P_s} H_{s2} M(\hat{x}) \right|^2 ,\tag{8}$$

Each ES knows what itself transmit, therefore, the ES1 can get the message sent by ES2. Similarly, the ES2 can get the message sent by ES1.

3. Performance analysis

We use BPSK to analysis the end-to-end BER performance.

3.1 Relay decoding BER

In the multiple access (MAC) phase, the two ESs transmit message to the satellite, the satellite decoding BER is

$$P_s = \frac{1}{2} \left[P(\hat{x} = 1 \mid x_1 \oplus x_2 = 0) + P(\hat{x} = 0 \mid x_1 \oplus x_2 = 1) \right] ,\tag{9}$$

3.2 Source decoding BER

In the broadcast (BC) phase, the satellite broadcast the processed message to ES1 and ES2, the BER between the message transmitted by ES1 and decoded at ES2, called $P_{2\to1}$, can be shown as

$$\begin{aligned}
P_{2\to1} = P(\hat{\hat{x}}_1 \neq x_1) &= 1 - (1 - P_s)(1 - P_{s,1}) - P_s P_{s,1} \\
&= P_s + P_{s,1} - 2 P_s P_{s,1}
\end{aligned},\tag{10}$$

with $P_{s,1} = P(\hat{\hat{x}}_1 \neq \hat{x}_1)$.

Similarly,

$$\begin{aligned}
P_{1\to2} = P(\hat{\hat{x}}_2 \neq x_2) &= 1 - (1 - P_s)(1 - P_{s,2}) - P_s P_{s,2} \\
&= P_s + P_{s,2} - 2 P_s P_{s,2}
\end{aligned},\tag{11}$$

with $P_{s,2} = P(\hat{\hat{x}}_2 \neq \hat{x}_2)$.

Finally, the total system BER is as follows

$$\begin{aligned}
P_{total} &= \frac{1}{2} \left(P_{1\to2} + P_{2\to1} \right) \\
&= \frac{1}{2} \left[\left(P_s + P_{s,1} - 2 P_s P_{s,1} \right) + \left(P_s + P_{s,2} - 2 P_s P_{s,2} \right) \right]
\end{aligned},\tag{12}$$

4. Simulation results

In this section, we provide simulation results of two-way DNF MIMO relaying for LMS communication with BPSK modulation. In this scheme, we first compare the BER performance between the MIMO and the two-way DNF MIMO relaying scheme, and then we consider how the distance between the two ESs to the satellite influence the BER. The LMS channel parameters for different shadowing scenarios are shown in Table 1. We consider infrequent light shadowing (ILS) in our simulation. And we assume that the antennas equipped in the two ESs and the satellite are same, for example, we consider M=N=2 in this scheme. $P_1 = P_2$ is assumed and BER refers to the decoding error probability at ES1, that is $P_{2\to1}$.

Table 1. LMS channel parameters [10]

Shadowing	b	m	Ω
Infrequent light shadowing (ILS)	0.158	19.4	1.29
Average shadowing (AS)	0.126	10.1	0.835
Frequent heavy shadowing (FHS)	0.063	0.739	0.000897

In Figure 2, we compare the simulated BER results of the MIMO and the two-way DNF MIMO relaying scheme. And in Figure 3, we compare the simulated BER results of the two-way DNF MIMO relaying with different distance between ES1 to the satellite and the ES2 to the satellite. Here, d1 denotes the distance between the ES1 and the satellite, d2 is the distance between the ES2 and the satellite, and d=d1+d2 is a constant. It is obvious that the BER becomes smaller with the SNR increasing.
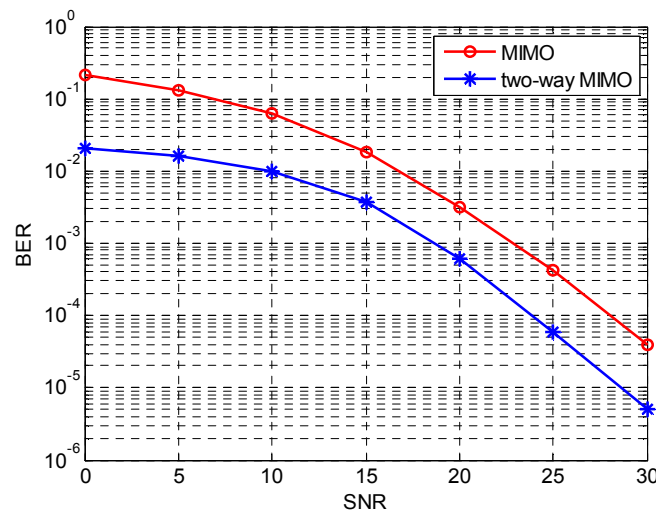

Figure 2. Simulated BER versus SNR performance between the MIMO and the two-way DNF MIMO relaying scheme, d1:d2=1:1.
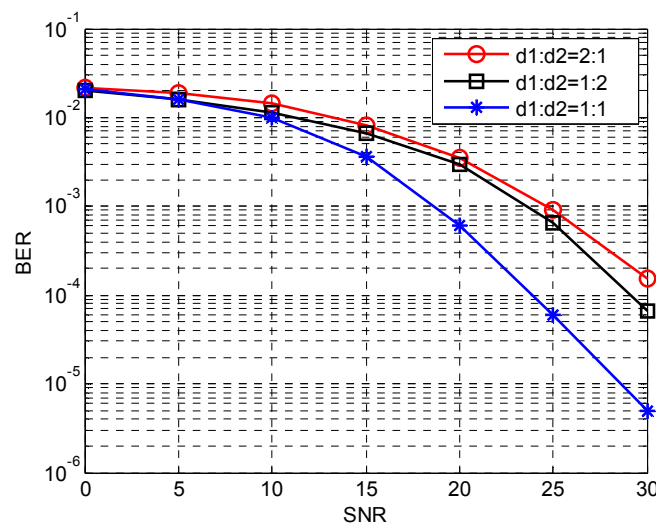

Figure 3. Simulated BER versus SNR performance of the two-way DNF MIMO relaying with different distance between ES1 to the satellite and ES2 to satellite.

From Figure 2, we observe that the BER with the two-way DNF MIMO relaying scheme is smaller than the MIMO scheme, which is because in the two-way MIMO relaying scheme, the satellite firstly decodes the received signal transmitted from the two ESs, and then broadcast the processed signal to the two ESs, thus

reducing the BER. We can draw a conclusion that the two-way DNF relaying is suitable for LMS communication.

From Figure 3, it is apparent that the BER is different with different distance between ES1 to the satellite and ES2 to satellite. We can see that the BER is smallest when d1:d2=1:1, which is due to the high channel gains of both ES to satellite channels, the BER with d1:d2=1:2 is similar to d1:d2=2:1, however, the BER with d1:d2=1:2 is slightly smaller than that with d1:d2=1:2, this is because the relaying decoding BER under the two case are same, then the end-to-end BER at the ES1 depends on the channel from the satellite to the ES1, the channel fading becomes larger with the distance increasing.

5. Conclusion

In this paper, we propose a two-way DNF MIMO relaying scheme for LMS communication. We analyze the decoding BER at the ESs and the satellite, and then obtain the end-to-end BER. And then we provide the simulation results of the BER performance of the two-way DNF MIMO relaying for LMS communication with BPSK modulation. The simulation results show that the two-way DNF MIMO relaying is suitable for LMS communication, the two-way MIMO with BPSK works well in LMS communication and we can get the smallest BER when the distance between ES1 to satellite and ES2 to satellite are same in the equal power allocation scenario.

Acknowledgements

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