Outage Performance Analysis of Alamouti STBC in Backward Link for Wireless Cooperative Networks

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***Abstract*—In this paper, we propose a cooperative diversity scheme to improve the end-to-end outage performance via Alamouti space-time block coding with two transmit antennas at a source node in a backward link and a best-relay selection scheme in a forward link. We derive an exact closed-form expression of the outage probability for the proposed scheme over a Rayleigh fading channel and analyze end-to-end outage probabilities.**

Keywords-cooperative communication; decode-and-forward; selective relaying; space-time block coding; outage probability.

I. INTRODUCTION

Cooperative diversity has received considerable attention in recent years to increase the reliability of wireless networks. This technique uses one or more relay nodes to forward signals transmitted from the source node to the destination node [1]. Various schemes have been proposed to achieve cooperative diversity, such as amplify-and-forward (AF) and/or decode-and-forward (DF) schemes [2]-[8]. In this paper, we focus on the DF relaying, in which each relay node fully decodes, re-encodes, and then retransmits the source signals.

Approximations of the outage probabilities for a single-relay case were provided in [2] for a high signal-to-noise ratio (SNR) and in [3] for a low SNR. For a multiple-relay case, approximate and exact expressions of the outage probabilities based on distributed space-time coding cooperative schemes [2] were presented in [4], [5] and [6]. A best-relay selection scheme (BRSS), which has a simple cooperative diversity scheme in a multiple-relay scenario, was proposed in [7], where the diversity-multiplexing tradeoff of the BRSS was identical to that of the more complex distributed space-time coding cooperative schemes presented in [2]. For the BRSS, exact expression of the outage probability was provided in [8].

In this paper, we propose a cooperative diversity scheme to improve the end-to-end outage performance via Alamouti space-time block coding (STBC) with two transmit antennas at a source node in the backward link and the BRSS in a forward link from the relay nodes to the destination node. We derive an exact closed-form expression of the outage probability for the proposed scheme over a Rayleigh fading channel and analyze the end-to-end outage probability compared to the BRSS.

The paper is organized as follows: In Section II, we present the outage probability for the proposed scheme. Numerical results are presented in Section III, and the final section gives the conclusions.

II. OUTAGE PROBABILITY

We consider a half-duplex dual-hop communication scenario, where direct path is assumed to be blocked or to have poor connection due to an intermediate wall. In this case, the communication between a source node S and a destination node D is only possible via M relay nodes. We also assume that the channel is a Rayleigh fading channel with coherence time long enough for the system to complete transmitting a block of data.

The BRSS transmission between the source node S and destination node D is established during two time slots. In the first time slot, the source node S transmits the data to the M relay nodes. After the M relay nodes decode the data from the source node S, the selected relay node k among all the M relay nodes forwards the re-encoded data to the destination node D in the second time slot.

The mutual information of the BRSS between the source node S and the relay node k, I_{BRSS}^{Sk}, is given by [8]

$$I_{BRSS}^{Sk} = \frac{1}{2}\log_2\left(1+\frac{|h_{Sk}|^2 P}{N_0 W}\right) \tag{1}$$

where $P \triangleq E\{|s|^2\}$ is the average power of a transmit signal s, h_{Sk} is the complex channel gain between the source node S and the relay node k, N_0 is the noise power spectral density, and W is the transmission bandwidth. Similarly, the mutual information of the BRSS between the relay node k and the destination node D, I_{BRSS}^{kD}, is given by [8]

$$I_{BRSS}^{kD} = \frac{1}{2}\log_2\left(1+\frac{|h_{kD}|^2 P}{N_0 W}\right) \tag{2}$$

where h_{kD} is the complex channel gain between the relay node k and the destination node D. In (1) and (2), $|h_{Sk}|^2 P / N_0 W$ is the instantaneous SNR between the source node S and the relay node k and $|h_{kD}|^2 P / N_0 W$ is the instantaneous SNR between the relay node k and the destination node D. Note that, the factors of 1/2 in (1) and (2) account for the fact that the transmissions occur over two time slots. Then, the maximum instantaneous end-to-end mutual information of the BRSS is [8]

$$I_{BRSS} = \max_{k \in K} \min\left(I_{BRSS}^{Sk}, I_{BRSS}^{kD}\right) \quad (3)$$

where K = {1,…, k,…, M}. The relay node that leads to the maximum in (3) is designated as the selected relay node k.

The outage probability of the BRSS can be written as [8]

$$P_{out}^{BRSS} = \prod_{k=1}^{M}\left[1 - \exp\left(-\left(\lambda_{Sk} + \lambda_{kD}\right)\left(2^{2R} - 1\right)\frac{N_0 W}{P}\right)\right] \quad (4)$$

where R is the fixed threshold rate, λ_{Sk} and λ_{kD} denote the channel conditions of the backward and forward links, respectively, which are the reciprocals of the expected values for the exponential random variables $x_{Sk} = |h_{Sk}|^2$ and $x_{kD} = |h_{kD}|^2$. Since channel gain h can be modeled as a complex Gaussian random variable, it is straightforwardly to show that the probability density function (PDF) of $x = |h|^2$ becomes the exponential PDF $f_X(x) = \lambda \exp(-\lambda x)$, $x \geq 0$, with parameter λ.

In order to improve the end-to-end outage performance, we propose a cooperative diversity scheme via Alamouti STBC with two transmit antennas at the source node S in the backward link and the BRSS in the forward link. The proposed scheme can obtain an additional transmit diversity gain in the backward link from two transmit antennas at the source node S. The proposed communication between the source node S and the destination node D is performed during four time slots without loss of rate.

In the first two time slots, the source node S transmits the two space-time block coded symbols to the M relay nodes. After the M relay nodes decode the two space-time block coded symbols from the source node S, the selected relay node k among all the M relay nodes forwards the two re-encoded symbols to the destination node D in the remaining two time slots. Then, the maximum instantaneous end-to-end mutual information of the proposed scheme is

$$I_{Prop.} = \max_{k \in K} \min\left(I_{Prop.}^{Sk}, I_{Prop.}^{kD}\right) \quad (5)$$

where $I_{Prop.}^{Sk}$ is the mutual information between the source node S and the relay node k, $I_{Prop.}^{kD}$ is the mutual information between the relay node k and the destination node D. The mutual information between the source node S and the relay node k is given by

$$I_{Prop.}^{Sk} = \frac{1}{2}\log_2\left(1 + \sum_{i=0}^{1}\frac{|h_{Sk,i}|^2 P}{2N_0 W}\right) \quad (6)$$

where $h_{Sk,i}$ is the complex channel gain between the source node S and the relay node k obtained by using the i-th transmit antenna in the source node S. Note that, the factor of $(P/2)$ in (6) accounts for the fact that the total transmission power is the same as that of the BRSS. The mutual information between the relay node k and the destination node D is the same as (2) and is given by

$$I_{Prop.}^{kD} = \frac{1}{2}\log_2\left(1 + \frac{|h_{kD}|^2 P}{N_0 W}\right). \quad (7)$$

The outage probability of the proposed scheme to maximize the minimum mutual information between the backward and forward links can be expressed as

$$\begin{aligned} P_{out}^{PROPOSED} &= P\left\{\max_{k \in K} \min\left(I_{Prop.}^{Sk}, I_{Prop.}^{kD}\right) < R\right\} \\ &= \prod_{k=1}^{M} P\left\{\min\left(I_{Prop.}^{Sk}, I_{Prop.}^{kD}\right) < R\right\} \quad (8) \\ &= \prod_{k=1}^{M}\left[1 - \left\{1 - P\left(I_{Prop.}^{Sk} < R\right)\right\}\left\{1 - P\left(I_{Prop.}^{kD} < R\right)\right\}\right] \end{aligned}$$

where $P\left(I_{Prop.}^{kD} < R\right)$ is the outage probability between the relay node k and the destination node D and $P\left(I_{Prop.}^{Sk} < R\right)$ is the outage probability between the source node S and the relay node k. We can obtain the outage probabilities, respectively, by

$$P\left(I_{Prop.}^{kD} < R\right) = 1 - \exp\left(-\lambda_{kD}\left(2^{2R} - 1\right)\frac{N_0 W}{P}\right) \quad (9)$$

and

$$P\left(I_{Prop.}^{Sk} < R\right) = P\left(\sum_{i=0}^{1} x_{Sk,i} < \left((2^{2R} - 1)\frac{2N_0 W}{P}\right)\right) \quad (10)$$

where λ_{kD} and $\lambda_{Sk,i}$ are the parameters of the exponential random variables $x_{kD} = |h_{kD}|^2$ and $x_{Sk,i} = |h_{Sk,i}|^2$, respectively. Note that the outage probability between the source node S and the relay node k in (10) is simply the cumulative distribution function (CDF) of the sum, $x_{Sk,sum} = \sum_{i=0}^{1} x_{Sk,i}$. We assume that the channels between two transmit antennas at the source node S and each relay k in the backward link are independent and identically distributed $\left(\lambda_{Sk} = \lambda_{Sk,0} = \lambda_{Sk,1}\right)$. Under this assumption, we use the method of moment generating function (MGF) to find the CDF of $x_{Sk,sum}$. The MGF of $x_{Sk,sum}$ can be obtained as [9]

$$M_{Sk,sum}(s) = \left(\lambda_{Sk} / \left(s + \lambda_{Sk}\right)\right)^2. \quad (11)$$

Then, applying inverse Laplace transform and integration for (11), we can obtain the outage probability in the backward link as

$$P\left(I_{Prop.}^{Sk} < R\right) = 1 - \left(1 + 2\lambda_{Sk}\Psi\right)\exp\left(-2\lambda_{Sk}\Psi\right) \quad (12)$$

where $\Psi = (2^{2R} - 1)N_0 W / P$.

Finally, by using (8), (9), and (12), a closed-form expression of the end-to-end outage probability for the proposed scheme can be obtained as

$$P_{out}^{PROPOSED} = \prod_{k=1}^{M}\left[1 - \left(1 + 2\lambda_{Sk}\Psi\right)\exp\left(-\left(\lambda_{kD} + 2\lambda_{Sk}\right)\Psi\right)\right]. \quad (13)$$

III. Numerical Results

We compare the outage probabilities of the proposed scheme and the BRSS. In this paper, we assume that λ_{Sk} and λ_{kD} are uniformly distributed in [0, 1], and the target threshold rate R is 1 bit/sec/Hz.

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In Figure 1, we illustrate the outage probabilities of the proposed scheme and the BRSS, when M = 2, 4, and 10, respectively. This figure shows that the proposed scheme outperforms the BRSS on the outage probabilities. When M = 2, 4, and 10 relays are employed under the assumed channel condition, the proposed scheme outperforms the BRSS at the outage probability of 10^{-4} by 2.95 dB, 2.38 dB, 1.13 dB, respectively. This is because the proposed scheme can obtain the additional transmit diversity gain in the backward link from two transmit antennas at the source node S.

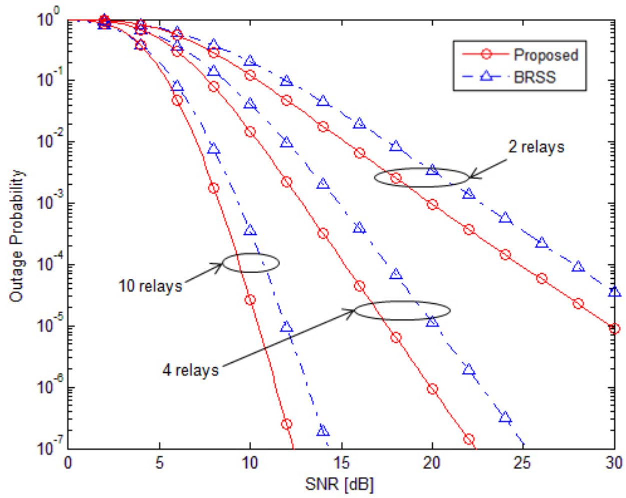

Figure 1. Outage probabilities of proposed scheme and BRSS with R = 1 bit/sec/Hz.

IV. CONCLUSIONS

In this paper, we proposed a cooperative diversity scheme with DF relaying to improve the end-to-end outage performance via Alamouti STBC with two transmit antennas at the source node. We derived an exact closed-form expression of the outage probability for the proposed scheme over a Rayleigh fading channel and analyzed the end-to-end probability compared to the BRSS. From the results, it was confirmed that end-to-end outage probability of the proposed scheme outperformed the BRSS in wireless cooperative networks.

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