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Cooperative Transmission Scheme to Increase Gain by Using STBC

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***Abstract*— Multiple-Input Multiple-Output (MIMO) systems are composed of source and destination nodes with multiple antennas. But, when nodes cannot support multiple antennas due to size or other constraints, especially for mobiles, the MIMO cannot be used to provide diversity. Cooperative communication enables single antenna to realize a virtual multiple antenna transmitter by sharing their antennas. Therefore, it offers transmit diversity. To achieve high-performance by using Space-Time Block Codes (STBC), we apply pre-coding scheme to the transmit symbols. Even though pre-coding scheme has several shortcomings, it is possible to employ STBC with one transmit antenna, thereby it can achieve high gain, without loss of transmission rate. Simulation results reveal that it is possible to obtain higher error performance at the low SNR by using proposed scheme.**

***Index Terms*— Pre-coding, STBC, Amplify-and-Forward, transmit diversity, CSI.**

I. INTRODUCTION

The wireless channel suffers from fading. The fading can cause a significant fluctuation in signal strength [1]. Hence, repetitive transmission of signal can effectively mitigate the effect of fading by generating diversity. Especially spatial diversity is generated by transmitting signals from different location, so allowing receiving independently faded versions of the transmitted signal at the receiver. Spatial or multiple-antenna diversity techniques are particularly attractive as they can be easily combined with other forms of diversity, for example time and frequency diversity. They also offer dramatic performance gains when other forms of diversity are unavailable [2]. From this point of view, Multiple-Input Multiple-Output (MIMO) systems provide a number of advantages. Although MIMO systems have spatial diversity, they cannot be used to provide diversity when transmitter or receiver cannot support multiple antennas due to size, cost or hardware limitations.

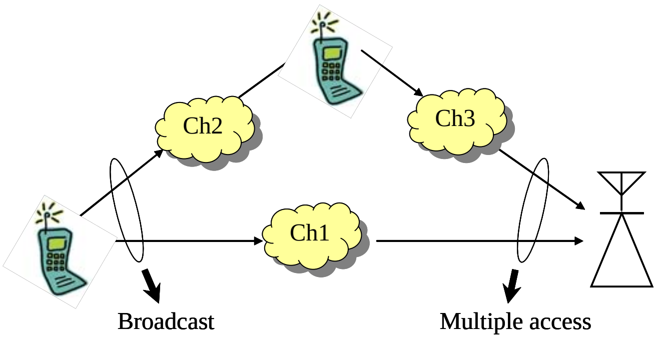

Fig. 1 Illustration of cooperative communication.

As shown in Fig. 1, a cooperative communication system is composed of source, relay, and destination nodes. Source information is broadcasted to relay and destination nodes. Information signals that were transmitted from source and relay are multiple-accessed to destination, and then they are combined. So, cooperative communication enables single antenna mobiles to generate a virtual multiple antenna transmitter by exploiting relay. Thus, it can achieve transmit or spatial diversity. It is also very useful when channel environment of direct path is inferior. Each node shares their antennas and other resources, and source acts as relay as well as information source.

To apply (2,2) Alamouti's STBC [3], a mobile is needed two transmit antennas basically. But, this paper applies pre-coding scheme [4] to the transmit symbols to employ STBC with single antenna and to achieve high gain, without loss of transmission rate. It had better a mobile has several antennas [5], but it is impossible in actuality. Pre-coding scheme is usually utilized in down-link since transmitter must know one's own transmit channel state information (CSI) and there is slight power consumption. Also, the performance is fallen if the CSI received from receiver is not perfect. However, it can achieve more improvement from the viewpoint of the performance by obtaining high gain, as well as benefit from the viewpoint of the transmission rate by transmitting symbols after pre-coding processing. Moreover, we employ amplify-and-forward for full diversity.

An outline of the remainder of the paper is as follows. Section 2 provides our system model. In Section 3, the scheme, transmitting sequences applied Alamouti's STBC for single antenna, is described. Section 4 compares the BER performance of proposed scheme with other methods and Section 5 offers conclusions.

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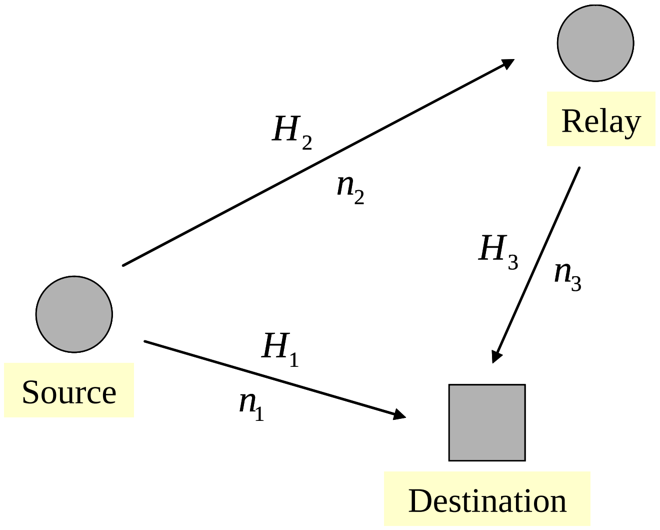

Fig. 2 Cooperative communication model in multipath and slow fading channels.

II. SYSTEM MODEL

As mentioned in Section 1, transmission of symbols applied (2,2) Alamouti's STBC requires two antennas to transmit two symbols at the same time. By using relay, it generates the effect of two transmit antennas, but transmission rate is fallen because source transmits one symbol each time with single antenna. So, we transmit sequences that combine with two symbols.

We consider the scenario as shown in Fig. 2, where each source, relay, and destination nodes have single antenna. For the proposed scheme, we assume that cooperative system channels, H_1, H_2, and H_3, undergo multipath and slow fading, and sequences are transmitted at narrow-band. Also, source must know CSI between source and relay, and between source and destination. However, source node occupies more wireless resources to have instantaneous CSI of source-relay and source-destination. Time delay and error are also generated during estimated CSI transmission, as well as bit error rate (BER) is lower by channel estimation error. Therefore we consider the statistical characteristics of channel instead of instantaneous CSI.

Source node broadcasts sequences that are multiplied Alamouti's STBC form by reciprocal of channels and are combined, by using Orthogonal Frequency Division Multiplexing (OFDM) form. Alamouti's STBC utilized in this paper are

$$\begin{pmatrix} c_1 & c_2 \\ -c_2^* & c_1^* \end{pmatrix} \tag{1}$$

and the transmit sequences processed pre-coding are as follows,

$$\begin{aligned} s_1 &= H_1^+ \cdot c_1 + H_2^+ \cdot c_2 \\ s_2 &= H_1^+ \cdot -c_2^* + H_2^+ \cdot c_1^* \end{aligned} \tag{2}$$

where H_i^+ denotes the reciprocal of H_i and $(\cdot)^*$ is the complex conjugate.

Because decode-and-forward does not achieve full diversity [2], we employ amplify-and-forward to provide full diversity. Relay in this method receives noisy version of the sequences transmitted by source, and then amplifies and retransmits this noisy version. Destination combines the received sequences from source and relay, and makes decision. Even though noisy version is amplified by relay, it can make better decision because destination receives two independently faded versions of the sequences [1].

III. EXPANSION OF COOPERATIVE TRANSMISSION

A. Proposed Scheme

For the first sequence transmission, the received sequences are as follows,

$$\begin{aligned} r_{S,D}[m] &= H_1 \cdot s_1 + n_1 \\ &= H_1 \cdot (H_1^+ \cdot c_1 + H_2^+ \cdot c_2) + n_1 \\ &= c_1 + H_1 \cdot H_2^+ \cdot c_2 + n_1 \end{aligned} \tag{3}$$

$$\begin{aligned} r_{S,R}[m] &= H_2 \cdot s_1 + n_2 \\ &= H_2 \cdot (H_1^+ \cdot c_1 + H_2^+ \cdot c_2) + n_2 \\ &= H_2 \cdot H_1^+ \cdot c_1 + c_2 + n_2 \end{aligned} \tag{4}$$

$$\begin{aligned} r_{R,D}[m+N] &= H_3 \cdot \beta \cdot r_{S,R}[n] + n_3 \\ &= H_3 \cdot \beta \cdot (H_2 \cdot H_1^+ \cdot c_1 + c_2 + n_2) + n_3 \\ &= \beta \cdot H_3 \cdot H_2 \cdot H_1^+ \cdot c_1 + \beta \cdot H_3 \cdot c_2 + n_3' \end{aligned} \tag{5}$$

where $r_{S,D}$, $r_{S,R}$, and $r_{R,D}$ denote the received sequences from source to destination, from source to relay, and from relay to destination, respectively. Also, N is the duration of one OFDM symbol, and $m = 0, 1, \cdots, N-1$. The channel impulse response is assumed to be constant for the transmission duration of one OFDM frame. And, n_1, n_2, and n_3 are complex Additive White Gaussian Noise (AWGN) containing the effect of interference and n_3' is amplified noise. β is the amplifier gain.

For the second sequence transmission, the received sequences are as follows:

$$\begin{aligned} r_{S,D}[m+2N] &= H_1 \cdot s_2 + n_1 \\ &= H_1 \cdot (H_1^{+} \cdot -c_2^{*} + H_2^{+} \cdot c_1^{*}) + n_1 \\ &= -c_2^{*} + H_1 \cdot H_2^{+} \cdot c_1^{*} + n_1 \end{aligned} \tag{6}$$

$$\begin{aligned} r_{S,R}[m+2N] &= H_2 \cdot s_2 + n_2 \\ &= H_2 \cdot (H_1^{+} \cdot -c_2^{*} + H_2^{+} \cdot c_1^{*}) + n_2 \\ &= H_2 \cdot H_1^{+} \cdot -c_2^{*} + c_1^{*} + n_2 \end{aligned} \tag{7}$$

$$\begin{aligned} r_{R,D}[m+3N] &= H_3 \cdot \beta \cdot r_{S,R}[m+2N] + n_3 \\ &= H_3 \cdot \beta \cdot (H_2 \cdot H_1^{+} \cdot -c_2^{*} + c_1^{*} + n_2) + n_3 \\ &= \beta \cdot H_3 \cdot H_2 \cdot H_1^{+} \cdot -c_2^{*} + \beta \cdot H_3 \cdot c_1^{*} + n_3' \end{aligned} \tag{8}$$

Source does not transmit sequences to destination during a transmission period of relay, because source information is multiple-accessed to destination node. In order to simplify the equations, we will use the following notations:

$$\begin{aligned} G &= H_1 \cdot H_2^{+} \\ K &= H_2 \cdot H_1^{+} \\ W &= H_3 \cdot H_2 \cdot H_1^{+} = H_3 \cdot K \end{aligned} \tag{9}$$

Then, the received sequences from direct link and relay link are separable to two symbols, c_1 and c_2, by combining. For the direct-link,

$$\begin{aligned} \tilde{c}_1 &= r_{S,D}[m] + G \cdot r_{S,D}^{*}[m+2N] \\ &= c_1 + G \cdot c_2 + n_1 + G \cdot (-c_2 + G^{*} \cdot c_1 + n_1^{*}) \\ &= (1 + G \cdot G^{*}) \cdot c_1 + N_1 \end{aligned} \tag{10}$$

$$\begin{aligned} \tilde{c}_2 &= G^{*} \cdot r_{S,D}[m] - r_{S,D}^{*}[m+2N] \\ &= G^{*} \cdot (c_1 + G \cdot c_2 + n_1) - (-c_2 + G^{*} \cdot c_1 + n_1^{*}) \\ &= (1 + G^{*} \cdot G) \cdot c_2 + N_1' \end{aligned} \tag{11}$$

Similarly, for the relay-link,

$$\begin{aligned} \tilde{c}_1 &= W^{*} \cdot r_{R,D}[m+N] + H_3 \cdot r_{R,D}^{*}[m+3N] \\ &= W^{*} \cdot (W \cdot c_1 + H_3 \cdot c_2 + n_3') + \\ &\quad H_3 \cdot (W^{*} \cdot -c_2 + H_3^{*} \cdot c_1 + (n_3')^{*}) \\ &= (W^{*} \cdot W + H_3 \cdot H_3^{*}) \cdot c_1 + N_3 \end{aligned} \tag{12}$$

$$\begin{aligned} \tilde{c}_2 &= H_3^{*} \cdot r_{R,D}[m+N] - W \cdot r_{R,D}^{*}[m+3N] \\ &= H_3^{*} \cdot (W \cdot c_1 + H_3 \cdot c_2 + n_3') - \\ &\quad W \cdot (W^{*} \cdot -c_2 + H_3^{*} \cdot c_1 + (n_3')^{*}) \\ &= (H_3^{*} \cdot H_3 + W \cdot W^{*}) \cdot c_2 + N_3' \end{aligned} \tag{13}$$

where N_1, N_1', N_3, and N_3' are combined noises and we neglect the amplifier gain β in order to simplify the equations. Note that multiplication used in equations is the Hadamard product because we use OFDM form, thus the order of multiplication is no matter.

B. STBC

We transmit similar to the proposed scheme sequences which combine with two symbols, but without pre-coding. Therefore the transmit sequences are as follows:

$$\begin{aligned} s_1 &= c_1 + c_2 \\ s_2 &= -c_2^{*} + c_1^{*} \end{aligned} \tag{14}$$

By transmitting combined sequences, it can obtain the same gain in comparison with the one that can obtain by transmitting one symbol each time.

C. Amplify-and-Forward

As above mentioned, relay receives noisy version of the sequences transmitted by source, and then amplifies and retransmits this noisy version. This scheme can be viewed as repetition coding from two separate transmitters, except that the relay transmitter amplifies its own receiver noise [2].

IV. SIMULATION RESULTS

Simulation results compare proposed scheme with STBC form, amplify-and-forward and direct transmission. In direct transmission, source transmits symbols c_1 and c_2 to destination without relay. So transmission rate is increased as twice in comparison with transmitting symbols employed STBC.

From the system model in Section 2, we can derive two different scenarios that the direct-link between source and destination is obstructed by shadowing effects and is unshadowed. But, transmit symbol power of source is the same as 1 for both scenarios. In the simulation, 8-path Rayleigh fading channel and QPSK modulation are used. And, we employed Maximum Likelihood (ML) decision. Also, we assume that estimated channels are perfect. To see difference of performance clearly, proposed scheme and STBC form are employed both amplifying and non-amplifying.

A. Scenario : Unshadowed Direct Llink

In this line-of-sight (LoS) scenario, the noise power of direct link, N_0, is identical to relay link, N_0. Fig. 3 shows the BER performance of this scenario. As shown in Fig. 3, proposed

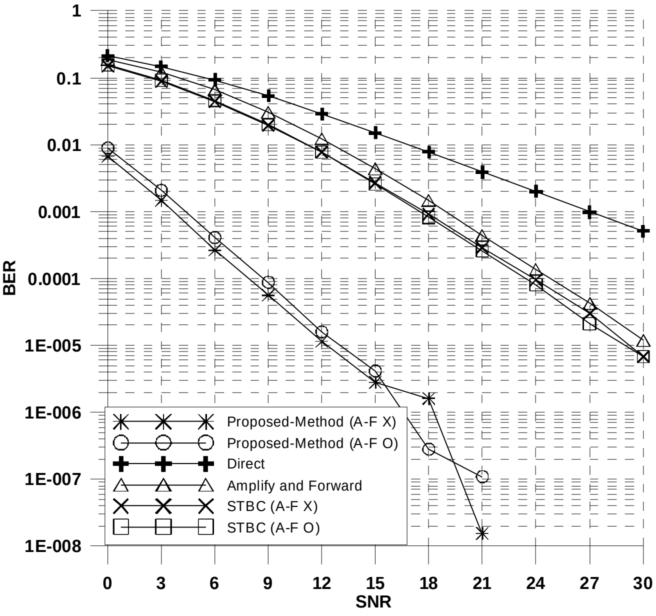

Fig. 3 BER performance comparison in case direct link is unshadowed.

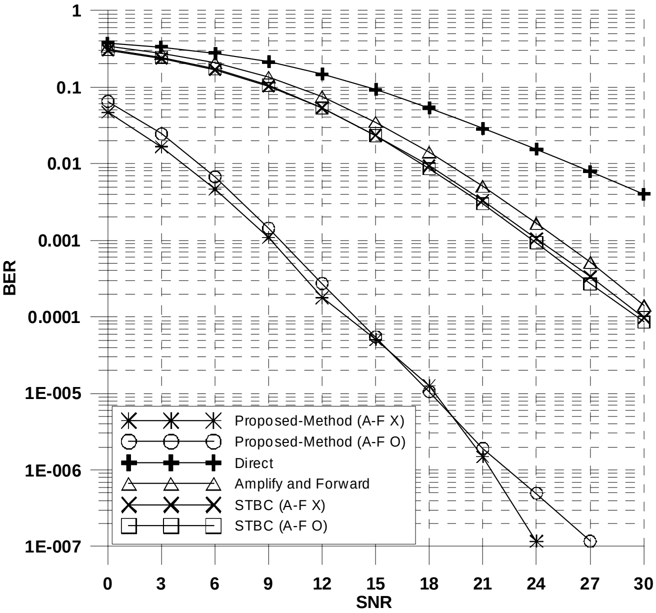

Fig. 4 BER performance comparison when path-loss of direct link is 3 dB.

method, both amplifying and non-amplifying, can bring a great performance improvement compared with STBC that is not employed pre-coding. It also shows high BER performance at the low SNR. In case of non-amplifying, BER of 10^{-4} is accomplished at 8 dB, while it is attained at 9 dB in case of amplifying.

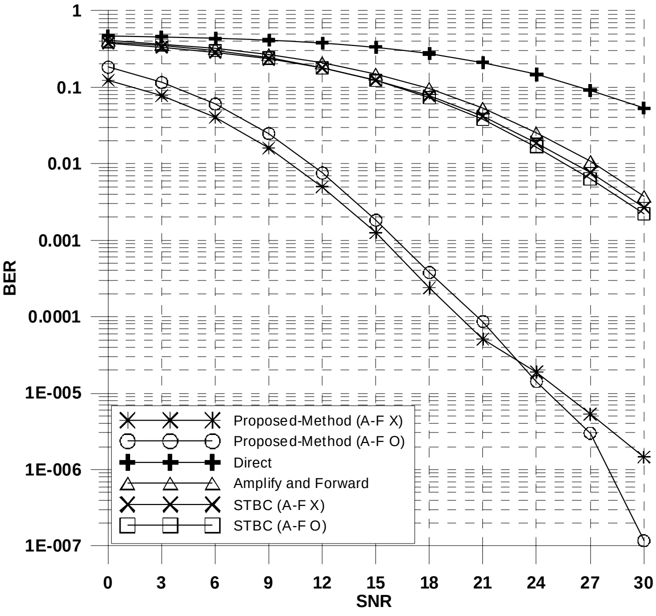

Fig. 5 BER performance comparison when path-loss of direct link is 7 dB.

B. Scenario : Shadowed Direct Link

In this scenario, we consider that direct link suffers from path-loss, thus relative noise power is larger than relay link. Fig. 4 and Fig. 5 reveal the performances when path-loss is 3 dB and 7 dB, respectively.

As we can see in the simulation results, BER performance became worth as the path-loss of direct link is increased. In case the path-loss is 7 dB, BER of 10^{-3} is attained at 16 dB, while it is accomplished at 9 dB in case the path-loss is 3 dB. Nevertheless, the proposed method, both amplifying and non-amplifying, can bring a great performance improvement compared with other schemes.

V. CONCLUSIONS

In this paper, to achieve high-performance by using (2,2) Alamouti's STBC, we presented cooperative transmission which employs pre-coding scheme. The proposed method can bring high BER performance even at the low SNR. Since we utilize the statistical characteristics of channel not completely known channel, the result of BER performance may be lower than provided simulation results in actuality. Even if we consider the reduction of performance by using the statistical characteristics of channel, it can acquire performance benefit as ever. Moreover, as shown in simulation results, proposed scheme is more useful when channel condition of direct link is bad.

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