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Improving Dual-Hop Amplify-and-Forward Cooperative Mobile Network Based on Path selection and STBC with Pre-Coding Scheme

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Abstract— **This paper presents a path selection algorithm in conjunction with (2,2) Alamouti's space-time block code with pre-coding scheme (STBC-PC) to improve the network performance of a dual-hop amplify-and-forward cooperative mobile network. STBC-PC is applied to this study in order to employ STBC with single antenna which is incorporated in any wireless portable devices, e.g., mobile stations and to achieve high gain. The path selection algorithm is designed to be used at the mobile station where is assumed to have the knowledge of all channel gains, hence it can be designed to maximize the channel capacity and to provide better network performance. The simulation results have been shown that the cooperative transmission with STBC-PC can achieve BER of 10^{-4} at the level of SNR about 17 dB which is lower level than the cooperative transmission without STBC-PC. Moreover, the proposed method can provide BER of 10^{-2} at SNR of 3 dB which is lower level the STBC-PC–based cooperative transmission without path selection.**

Key Words: Cooperative communication; amplify-and-forward; mobile network; path selection; STBC

I. INTRODUCTION

Relay nodes-based cooperative communication has emerged as a promising solution to increase spectral and power efficiency as well as network coverage, and also to reduce outage probability for the next generation wireless networks. A cooperative Communication System consists of source, relay, and destination nodes which have been accepted as a virtual Multiple-Input Multiple-Output (MIMO) system because it can provide transmit diversity instead of implementing multiple antennas at wireless nodes in wireless communication. Although MIMO systems provide many advantages and achieve spatial diversity, they cannot be served to provide diversity when the wireless portable devices, especially for mobile stations, cannot support multiple antennas due to size and power limitations. The cooperative transmission protocols used in the relay node are either amplify-and-forward (AF) and decode-and-forward (DF). AF is often used when the relay nodes have only limited computing time or power available. Since the cooperative transmission is applied to a mobile network in this paper, thus AF protocol was chosen to consider. Moreover, the pre-coding scheme is also applied to the transmitted (2,2) Alamouti's STBC (space-time block code) symbols in this paper as proposed by Ho-Jung An *et. al.* [1] so as to employ STBC with single antenna and to achieve high gain.

In [1], the single relay and the AF protocol was considered and the simulation results have been shown that the STBC with pre-coding scheme (STBC-PC) can always achieve the low BER (bit error rate) at the low SNR (Signal to Noise Ratio). Particularly, even if the reduction of performance were proposed by using the statistical characteristics of channel, it can acquire performance advantage as ever and the proposed method is more useful when the channel impairment of a direct link exists. In mobile network, the mobile station cannot connect to the base station because that source is out of reach from the destination and the direct link cannot exist. Thus the dual-hop relaying cooperation is a feasible method to assist the mobile network.

E. Kudoh *et. al.* [2] has still proposed a lot of power and frequency efficient methods to acquire higher data rate transmission with low transmit power in wireless multihop virtual cellular network (VCN). Cooperative relaying enables one or more relay nodes to process the transmitted symbols from a source and retransmit the signals to the desired destination. The transmitted signals are then combined together in the destination by using a suitable combining technique. Therefore, path selection methods have still been proposed by a lot of researchers in order to grasp the better network performance.

Zinan Lin *et. al.* [3] proposed a simple relay search algorithms by utilizing only the knowledge of average received SNRs at the destination node.

A. Bletsas *et. al.* [4] presented an opportunistic relaying scheme which used high SNR among multiple cooperating terminals, but this scheme considered only one relay.

Therefore, the main goal of this paper is to analyze and improve the network performance of a dual-hop AF cooperative mobile network with multiple relay nodes which are based on a proposed path selection algorithm and STBC-PC. The propagation channels undergo the complex additive

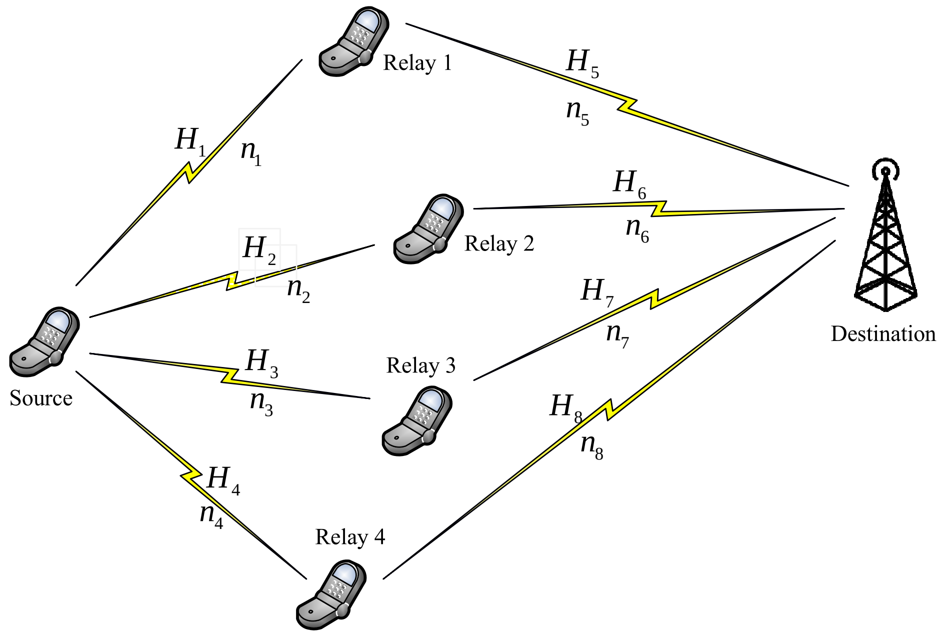

Figure 1. Cooperative mobile network model

white Gaussian noise (AWGN) and Rayleigh fading. Furthermore, the proposed path selection algorithm is implemented at the mobile station and the estimated channels are assumed to be perfect, hence it can be designed to maximize the channel capacity directly and to provide better network performance.

II. COOPERATIVE MOBILE NETWORK MODEL

Since the mobile network is considered in this paper, hence the most of wireless devices are the mobile stations and they are connected to a base station which is assumed to be located at the center of a cell. We consider a system model as depicted in Fig. 1, where each source, relay, and destination nodes have only single antenna. A source is assumed to be out of reach from the destination. The channels considered in this system model are assumed to undergo AWGN, multipath, and slow fading. Source and relay nodes must know channel state information (CSI) between source and relay as well as between relay and destination, respectively. Moreover, we have still considered the statistical characteristics of channel in this paper instead of the instantaneous CSI as explained in [1].

Refer to [1], DF protocols cannot provide the full diversity, but AF protocols can achieve full diversity. Moreover, multiple relays may receive, amplify, and retransmit the signals which are mixed by any noisy versions. The destination can combine the bit sequences from multiple relays and employ maximum likelihood (ML) decision completely, because we assume that the faded versions of each transmitted sequences in any relaying paths are independent absolutely.

III. STBC WITH PRE-CODING SCHEME [1]

In general, a mobile node must have two transmit antennas in order to apply (2,2) Alamouti's STBC. But Ho-Jung An *et. al.* [1] applied pre-coding scheme with the STBC symbols to employ STBC with single antenna. Moreover, [1] was verified that the pre-coding processing is feasibly to be used at the source node as an up-link communication instead of a down-link communication and the statistical characteristics of channel can be used instead of the instantaneous CSI completely.

Bit sequences from a source node in the form of Alamouti's STBC as shown in eq. (1) are firstly multiplied by the reciprocal of channels and then are combined by using orthogonal frequency division multiplexing (OFDM) form.

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

The transmitted symbol sequences are processed by pre-coding scheme as shown in eq. (2) - (5).

$$s_1 = H_1^+ c_1 + H_2^+ c_2 \tag{2}$$

$$s_2 = -H_1^+ c_2^* + H_2^+ c_1^* \tag{3}$$

$$s_3 = H_3^+ c_1 + H_4^+ c_2 \tag{4}$$

$$s_4 = -H_3^+ c_2^* + H_4^+ c_1^* \tag{5}$$

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

Before the equations of each signal are shown, the symbols are used in this paper and must be addressed firstly as follows: r_{S,R_i} and $r_{R_i,D}$ denote the received bit sequences from source to i[th] relay and i[th] relay to destination, respectively. N is the duration of one OFDM symbol, and m = 0,1, …, $N-1$. $n_1 - n_8$ are the complex AWGNs including the effect of interference signals. n_5' and n_6' are amplified noise. β_{R_i} is a amplifier gain of each i[th] relay.

The received bit sequences in the first phase of transmission are shown below in eq. (6) - (13). A group of eq. (6) - (9) is the representative of signals which are transmitted from source and received by relay 1 and 2, and a group of eq. (10) – (13) is the representative of signals which are transmitted from source and received by relay 3 and 4.

$$r_{S,R_1}[m] = H_1 s_1 + n_1 \tag{6}$$

$$r_{S,R_2}[m] = H_2 s_1 + n_2 \tag{7}$$

$$r_{R_1,D}[m+N] = H_5 \beta_{R_1} r_{S,R_1}[m] + n_5 \tag{8}$$

$$r_{R_2,D}[m+N] = H_6 \beta_{R_2} r_{S,R_2}[m] + n_6 \tag{9}$$

$$r_{S,R_3}[m] = H_3 s_3 + n_3 \tag{10}$$

$$r_{S,R_4}[m] = H_4 s_3 + n_4 \tag{11}$$

$$r_{R_3,D}[m+N] = H_7 \beta_{R_3} r_{S,R_3}[m] + n_7 \tag{12}$$

$$r_{R_4,D}[m+3N] = H_8 \beta_{R_4} r_{S,R_4}[m+2N] + n_8 \tag{13}$$

The received bit sequences in the second phase of transmission are shown below in eq. (14) - (21). A group of eq. (14) - (17) is the representative of signals which are transmitted from source and received by relay 1 and 2, and a group of eq. (18) – (21) is the representative of signals which are trans-mitted from source and received by relay 3 and 4.

$$r_{S,R_1}[m+2N] = H_1 s_2 + n_1 \tag{14}$$

$$r_{S,R_2}[m+2N] = H_2 s_2 + n_2 \tag{15}$$

$$r_{R_1,D}[m+3N] = H_5 \beta_{R_1} r_{S,R_1}[m+2N] + n_5 \tag{16}$$

$$r_{R_2,D}[m+3N] = H_6 \beta_{R_2} r_{S,R_2}[m+2N] + n_6 \tag{17}$$

$$r_{S,R_3}[m+2N] = H_3 s_4 + n_3 \tag{18}$$

$$r_{S,R_4}[m+2N] = H_4 s_4 + n_4 \tag{19}$$

$$r_{R_3,D}[m+3N] = H_7 \beta_{R_3} r_{S,R_3}[m+2N] + n_7 \tag{20}$$

$$r_{R_4,D}[m+3N] = H_8 \beta_{R_4} r_{S,R_4}[m+2N] + n_8 \tag{21}$$

Below equations, eq. (22) – (25), are the examples which are shown in this paper only, after eq. (6) – (7) are replaced with s_1 from eq. (2), eq. (8) and eq. (9) are replaced with eq. (6) and eq. (7), respectively. Eq. (10) – (21) can be done in the same way.

$$r_{S,R_1}[m] = c_1 + H_1 H_2^+ + n_1 \tag{22}$$

$$r_{S,R_2}[m] = H_1^+ H_2 c_1 + c_2 + n_2 \tag{23}$$

$$\begin{aligned} r_{R_1,D}[m+N] &= \beta_{R_1} H_5 (c_1 + H_1 H_2^+ c_2 + n_1) + n_5 \\ &= \beta_{R_1} H_5 c_1 + \beta_{R_1} H_5 H_1 H_2^+ c_2 + n_5' \end{aligned} \tag{24}$$

$$\begin{aligned} r_{R_2,D}[m+N] &= \beta_{R_2} H_6 (H_1^+ H_2 c_1 + c_2 + n_2) + n_6 \\ &= \beta_{R_2} H_6 H_1^+ H_2 c_1 + \beta_{R_2} H_6 c_2 + n_6' \end{aligned} \tag{25}$$

In order to simplify the equations, the following notations, eq. (26) – (29), will be used, after eq. (6) – (21) are replaced and arranged completely. The sampled terms can be seen from eq. (22) – (25).

$$G = H_1 H_2^+ \tag{26}$$

$$K = H_2 H_1^+ \tag{27}$$

$$W = H_3 H_4^+ \tag{28}$$

$$Y = H_4 H_3^+ \tag{29}$$

At the destination, the received bit sequences from 4 relay links are combined as shown in eq. (30) – (37). Those combined bit sequences are then passed through the maximum likelihood (ML) decision.

Eq. (30) – (31) are the representatives of the combined bit sequences from the signal reception from relay 1.

$$\tilde{c}_1 = H_5^* . r_{R_1,D}(m+N) + H_5 . G . r_{R_1,D}^*(m+3N) \tag{30}$$

$$\tilde{c}_2 = (H_5 . G)^* r_{R_1,D}(m+N) - H_5 . r_{R_1,D}^*(m+3N) \tag{31}$$

Eq. (32) – (33) are the representatives of the combined bit sequences from the signal reception from relay 2.

$$\tilde{c}_1 = (H_6 . K)^* r_{R_2,D}(m+N) + H_6 . r_{R_2,D}^*(m+3N) \tag{32}$$

$$\tilde{c}_2 = H_6^* r_{R_2,D}(m+N) - (H_6 . K) r_{R_2,D}^*(m+3N) \tag{33}$$

Eq. (34) – (35) are the representatives of the combined bit sequences from the signal reception from relay 3.

$$\tilde{c}_1 = H_7^* r_{R_3,D}(m+N) + (H_7 . W) r_{R_2,D}^*(m+3N) \tag{34}$$

$$\tilde{c}_2 = (H_7 . W)^* r_{R_3,D}(m+N) - H_7 r_{R_3,D}^*(m+3N) \tag{35}$$

Eq. (36) – (37) are the representatives of the combined bit sequences from the signal reception from relay 4.

$$\tilde{c}_1 = (H_8.Y)^* r_{R_4,D}\left(m+N\right) + H_8.r^*_{R_4,D}\left(m+3N\right) \qquad (36)$$

$$\tilde{c}_2 = H_8^* r_{R_4,D}\left(m+N\right) - (H_8.Y) r^*_{R_4,D}\left(m+3N\right) \qquad (37)$$

IV. PROPOSED PATH SELECTION SCHEME

In this section, the proposed path selection scheme is addressed. Refer to [5], an equation to find a channel capacity of each hop, s -> ith relay or ith relay -> d, can be seen in eq. (38). Moreover, the variances are assumed to be the agencies of a distance of each hop approximately. Therefore, the net channel capacity of each path between the source and the destination is derived from the sum of a channel capacity of each hop as shown in eq. (39). Among those net channel capacities, the selected path can be chose from the maximum one as defined in eq. (40). Because 4 relays are considered in this paper, so there exist 4 values of the net channel capacities.

$$C = \log_2\left(1 + \frac{P_T}{\sigma_n^2}|h|^2\right) \qquad (38)$$

$$Path(i) = C_{S\to R_i} + C_{R_i \to D} \qquad (39)$$

$$Path_{sel} = \underset{n}{\operatorname{argmax}}\left\{Path(1), Path(2), ... Path(n)\right\} \qquad (40)$$

V. SIMULATION RESULTS

In the simulation, BPSK modulation is used and the propagation channels of mobile network undergo the complex additive white Gaussian noise (AWGN) and Rayleigh fading. Furthermore, the estimated channels are assumed to be perfect and the statistical characteristics' channel can be used instead of the instantaneous CSI completely. The STBC-PC scheme and the proposed path selection algorithm are assumed to be processed at the mobile stations in order to make this proposed method possible through up-link communications, and ML decision is also assumed to be processed at the base station.

Firstly, the mobile network model is composed of 1 source, 2 relays, and 1 destination in order to compare the network performance of cooperative transmissions between without STBC-PC and with STBC-PC. Also, the distances (variances) of all hops are equal to 1. The simulation result has been shown that the cooperative transmission with STBC-PC can bring low bit error rate (BER) even at the low SNR and outperforms the cooperative transmission without STBC-PC absolutely.

Refer to Fig. 2 in the next page, BER of 10^{-2} at the level of SNR about 6 dB can be achieved by using the cooperative transmission with STBC-PC, while it must be attained at SNR about 16 dB by using the cooperative transmission without STBC-PC. Moreover, BER of 10^{-4} at the level of SNR about 17 dB can be accomplished sufficiently by using the cooperative transmission with STBC-PC, while it must be attained at SNR of more than 25 dB by using the cooperative transmission without STBC-PC.

Secondly, the mobile network model is composed of 1 source, 4 relays, and 1 destination in order to compare the network performance of STBC-PC–based cooperative transmissions between without path selection and with proposed path selection. Also, the distances (variances) of all hops are not equal which are 0.5, 1, 5, 10, 15, 20, 25, and 30. The simulation result has been shown that the STBC-PC–based cooperative transmission with proposed path selection outperforms the STBC-PC–based cooperative transmission without path selection completely. The proposed scheme can bring low bit error rate (BER) at the lower level of SNR about 4 – 5 dB.

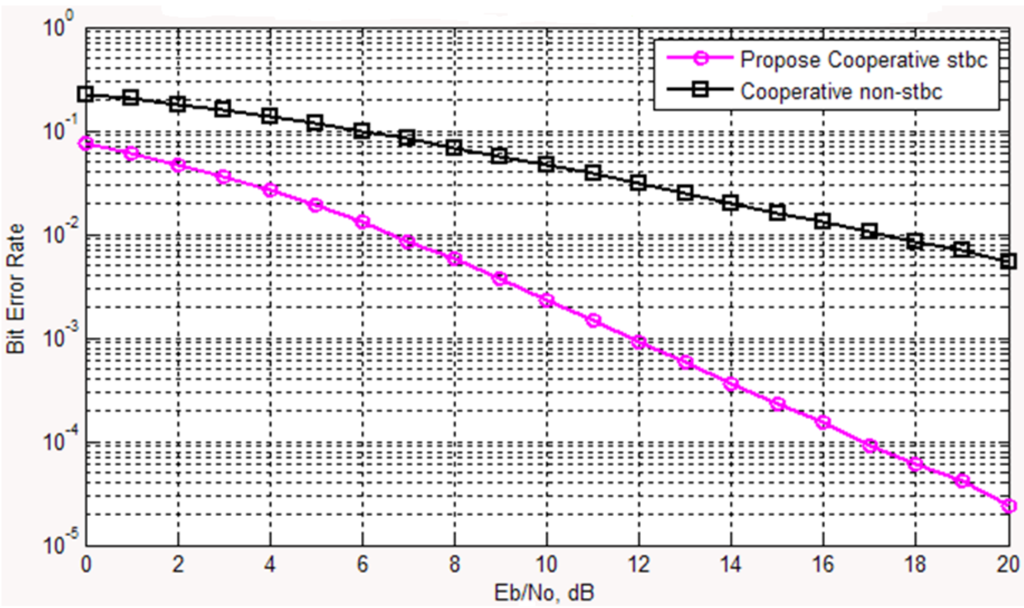

Figure 2. BER comparison of cooperative transmissions between with STBC-PC and without STBC-PC

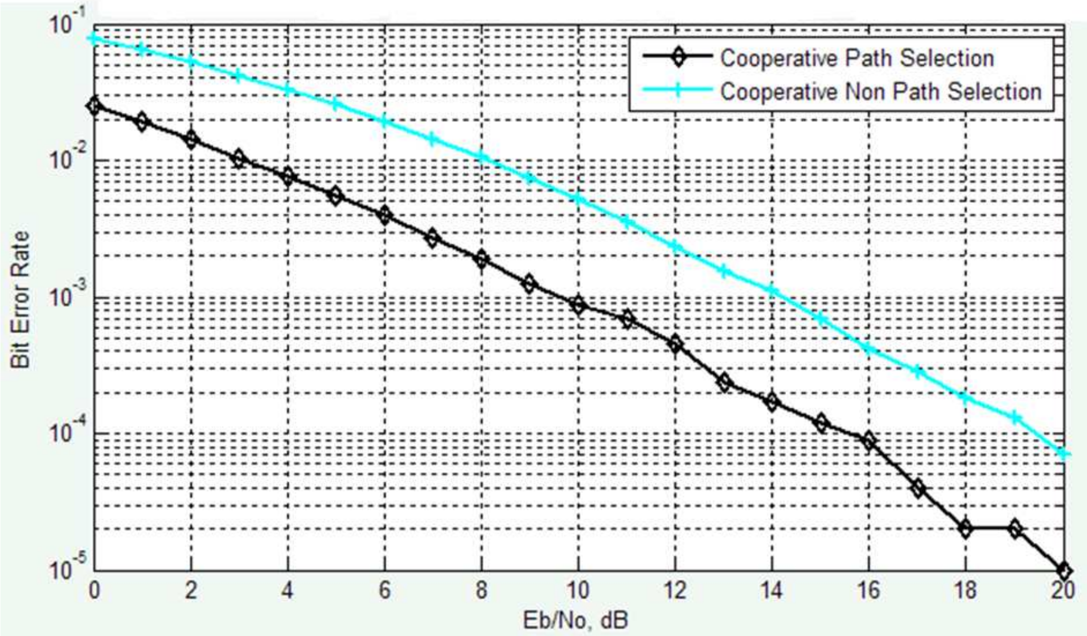

Figure 3. BER comparison of cooperative transmissions between with path selection and without path selection

Refer to Fig. 3, BER of 10^{-2} at SNR of 3 dB can be accomplished by using the proposed method, while it must be attained at SNR of 8 dB by using the STBC-PC–based cooperative transmission without path selection. Also, BER of 10^{-4} at SNR about 15 dB can be accomplished by using the proposed method, while it must be attained at SNR of 19 dB by using the STBC-PC–based cooperative transmission without path selection.

VI. CONCLUSION

A path selection algorithm in conjunction with (2,2) Alamouti's space-time block code with pre-coding scheme (STBC-PC) are proposed in this paper in order to improve the network performance of a dual-hop amplify-and-forward cooperative mobile network. The STBC-PC scheme and the proposed path selection algorithm are assumed to be processed at the mobile stations through up-link communications and ML decision is also assumed to be processed at the base station. The simulation results have been shown that BER of 10^{-4} at the level of SNR about 17 dB can be accomplished sufficiently by using the cooperative transmission with STBC-PC, while it must be attained at SNR of more than 25 dB by using the cooperative transmission without STBC-PC. Moreover, the STBC-PC–based cooperative transmission with proposed path selection outperforms the STBC-PC–based cooperative transmission without path selection completely. The proposed scheme can bring low bit error rate (BER) at the lower level of SNR about 4 – 5 dB.

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