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A Cooperative Space-Time Transmission Scheme Based On Symbol Combinations

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Abstract—This paper proposes a cooperative Alamouti space time transmission scheme with low relay complexity for the cooperative communication systems. In the proposed scheme, the source node combines the data symbols to construct the Alamouti-coded form at the destination node, while the conventional scheme performs the corresponding operations at the relay nodes. In simulation results, it is shown that the proposed scheme achieves the second order cooperative diversity while maintaining the same bit error rate (BER) performance as that of the conventional scheme.

Keywords—Space-time transmission, cooperative communication system, MIMO.

I. Introduction

SPATIAL diversity can be efficiently obtained by space-time coding in wireless environments [1]. The general point-to-point communication systems require multiple antennas to use the space-time coding as used in the multiple-input multiple-output (MIMO) systems. However, it may be unfeasible to design multiple antennas on small mobile devices because of the limitations of size, cost, and power [2], [3]. To apply the space-time coding to small mobile devices, cooperative communication systems have been proposed providing the spatial diversity, which is referred to as the cooperative diversity by forming the virtual MIMO systems via distributed nodes with only a single antenna [4], [5]. In the cooperative communication systems, however, symbols from distributed nodes are received at different time instants, resulting in an asynchronous environment. Thus, several schemes have been proposed to adapt the space-time coding to the cooperative communication systems in the asynchronous environments [6]-[9]; however, there is the problem that they are difficult to implement because a symbol decoding step is required at the relay nodes. Recently, in [10], a transmission scheme without symbol decoding at the relay nodes has been proposed for the cooperative communications. The scheme in [10] can obtain the well-known Alamouti coded form at the destination node by using the time-reversal and conjugation operations at the relay nodes. Thus, in [10], the second order cooperative diversity is achieved. However, an additional operation (time-reversal) is performed to the original Alamouti coding at the relay nodes.

In this paper, a novel Alamouti transmission scheme with reduced relay complexity is proposed for cooperative communication systems. The proposed scheme obtains Alamouti coded form at the destination node by combining the data symbols at the source node. The cooperative diversity is given by Alamouti coded form. It is shown that the proposed scheme reduces the complexity at the relay nodes with the second order cooperative diversity and the same bit error rate (BER) as the conventional scheme.

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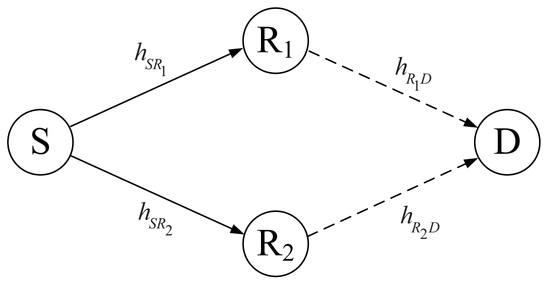

Fig. 1 A cooperative system model

II. System Model

Fig. 1 illustrates a cooperative communication system model with one source node S, one destination node D, and two relay nodes R_1 and R_2, where each node has a single antenna.

The channels between the nodes are assumed to be the flat Rayleigh channels. The channel coefficients from the source node to the mth relay node and from the mth relay node to the destination node are denoted as h_{SR_m} and h_{R_mD}, respectively, and they are modeled as independent complex Gaussian random variables with zero mean and unit variance. It is assumed that the channel coefficients are constant during two orthogonal frequency division multiplexing (OFDM) symbol duration, and a relative timing difference between the symbols arriving at the destination node from the relay nodes R_1 and R_2 is denoted by τ.

III. Conventional Scheme

In the conventional scheme [10], first, the source node generates the following two complex-valued data symbol blocks $\mathbf{X}_1$ and $\mathbf{X}_2$:

$$\mathbf{X}_i = [X_i(0), X_i(1), \cdots, X_i(N-1)]^T_, \text{ for } i = 1 \text{ and } 2, \quad (1)$$

where $X_i(k)$, $(\cdot)^T$, and N denote the complex-valued phase shift keying (PSK) or quadrature amplitude modulation (QAM) data symbol on the kth sub-carrier of $\mathbf{X}_i$, the transpose operation, and the number of the sub-carriers, respectively. Then, complex-valued baseband samples are generated as

$$x_1(n) = \mathrm{IDFT}_N(\mathbf{X}_1) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_i(k) e^{j2\pi kn/N}, \text{ for } n = 0, \cdots, N-1 \quad (2)$$

and

$$x_2(n) = \mathrm{DFT}_N(\mathbf{X}_2) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_i(k) e^{-j2\pi kn/N}, \text{ for } n = 0, \cdots, N-1, \quad (3)$$

where $\mathrm{IDFT}_N(\cdot)$ and $\mathrm{DFT}_N(\cdot)$ denote the N-point inverse discrete Fourier transform (IDFT) and N-point DFT, respectively. Then, the ith OFDM symbol at the source node $\mathbf{s}_i$ is obtained by inserting the cyclic prefex (CP) as

$$\begin{aligned}\mathbf{s}_i &= [s_i(0), s_i(1), \cdots, s_i(L_s-1)]^T \\ &= [x_i(N-N_G), x_i(N-N_G+1), \cdots, x_i(N-1), \\ &\quad x_i(0), \cdots, x_i(N-1)]^T, \end{aligned} \quad (4)$$

where $L_s \triangleq N + N_G$ with N_G the length of CP. It is assumed that N_G is longer than the relative timing difference τ at the destination node. Next, the source node transmits two consecutive OFDM symbols to the relay nodes, and then, the nth sample of the ith received symbol $\mathbf{r}_{i,m}$ of the mth relay node can be written as

$$r_{i,m}(n) = \sqrt{P_1}\; s_i(n) h_{SR_m} + w_{i,m}(n), \quad (5)$$

where P_1 and $w_{i,m}(n)$ are the transmission power at the source node and the additive white Gaussian noise (AWGN) with zero mean and unit variance, respectively.

Table I shows the signal processing of relay nodes for two consecutive OFDM symbol duration (time slot 1 and 2), where P_2 and $(\cdot)^*$ denote the transmission power at the relay nodes and conjugation operation, respectively, and $\zeta(\cdot)$ represents the time-reversal operation defined as

$$\zeta\{r_{i,m}(n)\} = \begin{cases} r_{i,m}(0), & \text{for } n = 0 \\ r_{i,m}(L_s - n), & \text{for } n = 1, \cdots, L_s - 1. \end{cases} \quad (6)$$

As shown in the Table I, in the conventional scheme, the relay nodes perform two additional time-reversal operations. However, the sample re-arranging process of the time-reversal operation may increase the complexity of relay nodes as the length of OFDM symbols increases. This disadvantage may cause the problem in implementing cooperative communication systems which use small mobile devices as the relay nodes.

TABLE I
PROCESSING AT THE RELAY NODES OF THE CONVENTIONAL SCHEME

	Relay node 1	Relay node 2
Time slot 1	$\sqrt{\frac{P_2}{P_1+1}} r_{1,1}(n)$	$-\sqrt{\frac{P_2}{P_1+1}} r^*_{2,2}(n)$
Time slot 2	$\sqrt{\frac{P_2}{P_1+1}} \zeta\{r_{2,1}(n)\}$	$\sqrt{\frac{P_2}{P_1+1}} \zeta\{r_{1,2}(n)\}^*$

IV. Proposed Scheme

Combining the complex-valued data symbol blocks $\mathbf{X}_1$ and $\mathbf{X}_2$, the source node first generates the following two symbol blocks $\mathbf{C}_1$ and $\mathbf{C}_2$:

$$\mathbf{C}_i = [C_i(0), C_i(1), \cdots, C_i(N-1)]^T_, \quad \text{for } i = 1 \text{ and } 2 \quad (7)$$

with

$$C_i(k) = \begin{cases} \frac{1}{\sqrt{2}}\{X_1(k) + jX_2(k)\}, & \text{when } i = 1 \\ -\frac{1}{\sqrt{2}}\{X_2^*(k) + jX_1^*(k)\}, & \text{when } i = 2. \end{cases} \quad (8)$$

The generated symbol blocks satisfy the following property:

$$\begin{cases} \mathbf{C}_1^* = j\mathbf{C}_2 \\ \mathbf{C}_2^* = j\mathbf{C}_1, \end{cases} \quad (9)$$

which enables the destination node to construct the Alamouti coded form. Then, complex-valued baseband samples corresponding to $\mathbf{C}_i$ are generated as

$$c_i(n) = \mathrm{IDFT}_N\{\mathbf{C}_i\} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} C_i(k) e^{j2\pi kn/N}, \text{ for } n = 0, \cdots, N-1, \quad (10)$$

and then, the ith OFDM transmission symbol $\mathbf{u}_i$ is obtained as

$$\begin{aligned}\mathbf{u}_i &= [u_i(0), u_i(1), \cdots, u_i(L_s-1)]^T \\ &= [c_i(N-N_G), c_i(N-N_G+1), \cdots, c_i(N-1), \\ &\quad c_i(0), \cdots, c_i(N-1)]^T \end{aligned} \quad (11)$$

by inserting the CP. Next, the source node transmits two consecutive OFDM symbols to the relay nodes, and the nth sample of the ith received symbol $\mathbf{v}_{i,m}$ of the mth relay node can be written as

$$v_{i,m}(n) = \sqrt{P_1}\; u_i(n) h_{SR_m} + w_{i,m}(n). \quad (12)$$

Then, each relay node transmits the symbols obtained by the signal processing as in Table II to the destination node.

Now, we describe the demodulation step at the destination node. The nth samples of the first and second received symbols at the destination node can be expressed as

$$\begin{aligned} y_1(n) =& \sqrt{\frac{P_2}{P_1+1}} \big[v_{1,1}(n) h_{R_1D} + v_{2,2}(n-\tau) h_{R_2D}\big] \\ &+ z_1(n) \end{aligned} \quad (13)$$

and

$$\begin{aligned} y_2(n) =& \sqrt{\frac{P_2}{P_1+1}} \big[-jv_{1,1}(n) h_{R_1D} + jv_{2,2}(n-\tau) h_{R_2D}\big] \\ &+ z_2(n), \end{aligned} \quad (14)$$

respectively. After the CP removal and N-point DFT operation, the output can be expressed as

$$\begin{aligned} Y_1(k) =& \sqrt{\frac{P_2}{P_1+1}} \big[\sqrt{P_1} C_1(k) h_{SR_1} h_{R_1D} \\ &+ \sqrt{P_1} C_2(k) h_{SR_2} h_{R_2D} e^{-j2\pi k\tau/N} \\ &+ W_{1,1}(k) h_{R_1D} + W_{2,2}(k) h_{R_2D} e^{-j2\pi k\tau/N}\big] \\ &+ Z_1(k) \end{aligned} \quad (15)$$

TABLE II
PROCESSING AT THE RELAY NODES OF THE PROPOSED SCHEME

	Relay node 1	Relay node 2
Time slot 1	$\sqrt{\frac{P_2}{P_1+1}}v_{1,1}(n)$	$\sqrt{\frac{P_2}{P_1+1}}v_{2,2}(n)$
Time slot 2	$-j\sqrt{\frac{P_2}{P_1+1}}v_{1,1}(n)$	$j\sqrt{\frac{P_2}{P_1+1}}v_{2,2}(n)$

for the first received symbol and

$$\begin{aligned}Y_2(k) =& \sqrt{\frac{P_2}{P_1+1}}\big[-\sqrt{P_1}jC_1(k)h_{SR_1}h_{R_1D} \\ &+ \sqrt{P_1}jC_2(k)h_{SR_2}h_{R_2D}e^{-j2\pi k\tau/N} \\ &+ W_{1,1}(k)h_{R_1D} + W_{2,2}(k)h_{R_2D}e^{-j2\pi k\tau/N}\big] \\ &+ Z_2(k) \end{aligned} \quad (16)$$

for the second received symbol, where $W_{i,m}(k)$ and $Z_i(k)$ denote the DFT outputs of $w_{i,m}(n)$ and $z_i(n)$, respectively. Using the property in (9), we can rewrite (15) and (16) in the following matrix form:

$$\begin{bmatrix} Y_1(k) \\ Y_2^*(k) \end{bmatrix} = \sqrt{\frac{P_2}{P_1+1}}\mathbf{H}\begin{bmatrix} \sqrt{P_1}C_1(k) \\ \sqrt{P_1}C_2(k) \end{bmatrix} + \begin{bmatrix} N_1(k) \\ N_2(k) \end{bmatrix}, \quad (17)$$

where N_1 and N_2 denote noise components of $Y_1(k)$ and $Y_2(k)$, respectively. $\mathbf{H}$ is the channel matrix defined as

$$\mathbf{H} = \begin{bmatrix} h_{SR_1}h_{R_1D} & h_{SR_2}h_{R_2D}e^{-j2\pi k\tau/N} \\ h_{SR_2}^*h_{R_2D}^*e^{j2\pi k\tau/N} & -h_{SR_1}^*h_{R_1D}^*, \end{bmatrix}, \quad (18)$$

which is in an Alamouti coded form (i.e., 2×2 orthogonal matrix). Thus, we can obtain the estimates $\widehat{C}_1(k)$ and $\widehat{C}_2(k)$ for $C_1(k)$ and $C_2(k)$ as

$$\begin{bmatrix} \widehat{C}_1(k) \\ \widehat{C}_2(k) \end{bmatrix} = \mathbf{H}^H\begin{bmatrix} Y_1(k) \\ Y_2^*(k) \end{bmatrix}, \quad (19)$$

where $(\cdot)^H$ denotes the Hermitian transpose operation. Finally, we can obtain the estimates $\widehat{X}_1(k)$ and $\widehat{X}_2(k)$ for $X_1(k)$ and $X_2(k)$ as

$$\widehat{X}_1(k) = \frac{1}{\sqrt{2}}\big[\mathrm{Re}(\widehat{C}_1(k)) - \mathrm{Im}(\widehat{C}_2^*(k))\big] \quad (20)$$

and

$$\widehat{X}_2(k) = \frac{1}{\sqrt{2}}\big[\mathrm{Im}(\widehat{C}_1(k)) - \mathrm{Re}(\widehat{C}_2^*(k))\big], \quad (21)$$

respectively, where $\mathrm{Re}\{\cdot\}$ and $\mathrm{Im}\{\cdot\}$ denote the real and imaginary parts, respectively.

V. SIMULATION RESULTS

In this section, the proposed scheme is compared with the conventional scheme in terms of the BER performance. For simulations, we assume the following parameters as in [10]: $N = 64$, $N_G = 16$, and $P_1 = 2P_2$, and we consider the binary PSK data modulation. It is also assumed that the relative timing difference τ between the symbols arriving at the destination node from the relay nodes is distributed uniformly over $[0, 16]$ samples. Fig. 2 shows the BER performance of the proposed and conventional schemes where that of the traditional Alamouti scheme is shown for reference. From Fig. 2, it is clearly observed that, both of the proposed and conventional schemes demonstrate the same BER performance, and moreover, the slope of the BER curves are the same as that of the Alamouti scheme for 2×1 multiple-input single-output (MISO) systems when the value of P_1 is large, which means that both proposed and conventional schemes achieve the second order cooperative diversity. We also can see that the BER performance of the proposed and conventional schemes are degraded compared with that of the Alamouti scheme. This is due to the fact that the signal is contaminated by noise at both channels between source and relay nodes and relay and destination nodes in the cooperative communication systems, meanwhile, in the MISO systems, the noised is added at the channels between the transmitter and receiver only.

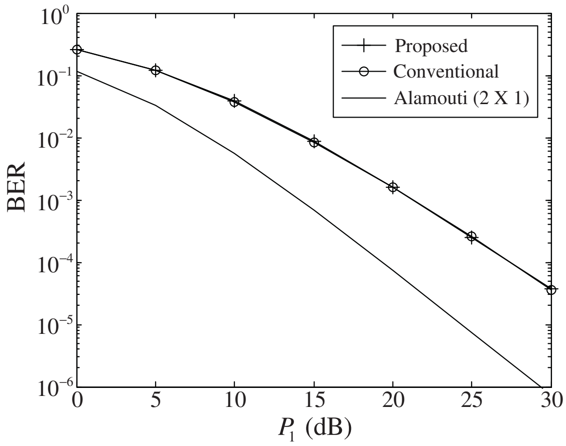

Fig. 2 BER performance of the proposed and conventional schemes as a function of P_1.

VI. CONCLUSION

In this paper, it has been proposed a novel Alamouti space-time transmission scheme with reduced relay complexity for cooperative communication systems. The conventional scheme requires time-reversal operation at the relay nodes for the Alamouti coded form. Unlike the conventional scheme, the proposed scheme obtains the Alamouti coded form at the destination node using a simple combination of data symbols at the source node. From the simulation results, it is confirmed that the proposed scheme has the same cooperative diversity order and BER performance as the conventional scheme.

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