Decode-and-Forward 협력 릴레이 통신에서의 Balanced 전송 기법

Balanced Transmit Scheme in Decode-and-Forward Cooperative Relay Communication

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요 약

무선 네트워크를 위한 협력 릴레이 통신은 공간 다이버시티를 통해 페이딩현상을 효율적으로 감소 시킬 수 있기 때문에 최근 활발히 연구되어 오고 있다. 본 논문에서 협력 릴레이 통신환경에서 decode-and-forward 기법을 적용한 balanced 전송 기법을 제안한다. 제안된 기법은 최고의 협력 다이버시티 이득을 얻기 위해 피드백 비트들을 선택한다. 제안된 기법은 기존의 기법과 비교하여 비트 오류 확률 성능을 증가시킬 수 있는 것을 모의 실험을 통해 증명하였다.

ABSTRACT

Cooperative relay communication for wireless networks has been extensively studied due to its ability to mitigate fading effectively via spatial diversity. In this paper, we propose a balanced transmit scheme in cooperative relay communication with decode-and-forward (DF) scheme. The proposed scheme selects the feedback bits to obtain the maximum cooperative diversity gain. The simulation results show that the proposed scheme improves the bit error rate (BER) performance as compare with a conventional scheme.

☞ keyword : Cooperative relay, spatial diversity, balanced transmit, decode-and-forward, bit error rate(BER)

1. Introduction

The available technology for use in mobile devices has technological limitations and practical issues when attempting to implement multiple input multiple output (MIMO) systems. These limitations are related to additional physical volume that is required to accommodate a MIMO system, as well as additional cost. To solve this problem, cooperative communication method is proposed [1], [2]. The cooperative communication is a new technique that uses the broadcast nature of radio wave in the wireless channel to make mobile devices to support and aid one another, which also offers the same advantages as those found in MIMO systems [3], [4].

Transmit diversity has been studied as an effective method to combat the fading effect. Recently, several space-time block codes (STBCs) have been proposed as transmit diversity schemes [5], [6]. The simple case of a transmit diversity scheme has been proposed by Alamouti for two transmit antennas [7]. However, a complex orthogonal design that provides full diversity and full code rate for a STBC is not possible with more than two transmitter antennas [8], [9].

In [10], when one or more feedback bits are transmitted, full rate balanced STBCs (BSTBCs), achieving full diversity for an arbitrary number of

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transmit antennas, have been proposed. Cooperative BSTBCs (CBSTBCs) are the application of BSTBCs. In order to increase the cooperative gain, a transmitted signal matrix is selected using one or more feedback bits [11].

In this paper, we propose the cooperative balanced transmit (CBT) scheme in a relay system. To maximize the cooperative balanced gain, calculated by the sum of the channel gains and the relative states between the channels, the phases of transmit signals are rotated using the feedback bits at the relay. If the number of used feedback bits is more than that of the relays, additional diversity gain is obtained by complex phase rotation at the relays.

This paper is organized as follows: Section 2 provides an overview of the CBSTBCs scheme. Section 3 illustrates the CBT scheme using feedback bits. Section 4 presents simulation results, and Section 5 provides conclusions.

2. Cooperatvie Balanced STBC

CBSTBCs have been proposed that are able to achieve full diversity for any number of the relays [11]. CBSTBCs contain two phases: broadcast and cooperation. In the broadcast phase, the source transmits signals to both the relays and the destination. Received signals are decoded at the relays. In the cooperation phase, the source and the relays transmit the signal according to selected code at the destination. When a single bit feedback is used, the source and two relays transmit the full rate STBC pair with a transmit signal matrix. The transmit signal matrix of CBSTBC can be written as

$$\mathbf{C}_{CBSTBC,R,2,f,1} = \begin{bmatrix} s_1 & \bar{s}_{2,r_1} & a\bar{s}_{2,r_2} \\ -s_2^* & \bar{s}_{1,r_1}^* & a\bar{s}_{1,r_2}^* \end{bmatrix} \tag{1}$$

where $a = \pm 1$ and $\bar{s}_{j,r_k}$ is the jth estimated signal from the kth relay. The signals s_1 and s_2 are transmitted from the source at the first and second time slots, respectively [11]. If the channels between the source and relay are good enough, the relay receives the most of the signals with no errors. When the contribution of $2a\,\mathrm{Re}\{h_{r_1,d}h_{r_2,d}^*\}$ is positive, the gain is greater than the sum of all channel gains by the feedback bit. The additional parameter $2a\,\mathrm{Re}\{h_{r_1,d}h_{r_2,d}^*\}$ comes from the balanced coding gain. If feedback bits are available, new full rate BSTBC pairs can be added to increase coding gain. The destination selects the transmit signal matrix that provides the maximum of the channel gains. The destination of six alternative codes requires three feedback bits. The additional gain supplied from the three feedback bits is a coding gain over the one or two feedback bits cases [11]. As the number of relays is increased, the required number of feedback bits is also increased in order to support full diversity gain. If three relays are present in communication system, seven different matrices are able to be obtained. When two feedback bits are used with three relays, only one matrix is used. The destination selects the transmit signal matrix to provide the maximum coding gain. The contribution of the coding gain will always be positive and the gain will be greater than the sum of all of the channel gains [12].

3. Cooperative Balanced Transmit Scheme

In the CBT scheme, the source transmits same signal whose phase is rotated by feedback bits, in order to achieve cooperative balanced gain. Similar to the CBSTBCs, the proposed scheme contains two phases: broadcast and cooperation. The channels are classified as source-relay and relay-destination. The CBT scheme transmits the signal in one symbol time slot even though the CBSTBCs scheme needs two time slot to transmit the signal matrix. Therefore, the proposed scheme has advantage for time delay aspect, but the CBT scheme needs over two feedback bits to have better bit error rate (BER)than CBSTBC scheme, since there are terms which cannot be controlled by the feedback bit, when one feedback bit is used.

In this section, we show the transmitted signal vectors of the proposed CBT scheme and calculate the cooperative diversity matrix, when two and three relays are used.

3.1 Source and Two Relays

The source transmits the signal s to both the relays and the destination. The transmitted signals are decoded at the relays and the destination receives the decoded signals from relays.

When one feedback bit is used, the phase of the transmitted signals from each relay are rotated by a. The transmit signals can be expressed as

$$\mathbf{C}_{DF,R,2,f,1} = \begin{bmatrix} s & a\bar{s}_{r_1} & a\bar{s}_{r_2} \end{bmatrix} \tag{2}$$

where $a = \pm 1$ and $\bar{s}_{r_k}$ is the estimated signal by the kth relay. In the first time slot, the received signal at the destination can be expressed as

$$r_{d,1,f,1} = h_{s,d}s + n_d. \tag{3}$$

where $h_{s,d}$ is the channel coefficients from the source to the destination and n_d is the complex Gaussian noise.

In second time slot, the received signals at the destination can be written as

$$r_{d,2,f,1} = \frac{1}{\sqrt{3}}\left[h_{s,d}s + ah_{r_1,d}\bar{s}_{r_1} + ah_{r_2,d}\bar{s}_{r_2}\right] + n. \tag{4}$$

where $h_{r_k,d}$ is the channel coefficients from the kth relays to the destination. It is assumed that the relays decode the signals correctly.

The estimated signal at the destination can be expressed as

$$\hat{s}_{d,f,1} = \left(h^*_{s,d} + a^*h^*_{r_1,d} + a^*h^*_{r_2,d}\right)r_{d,2,f,1} + h^*_{s,d}r_{d,1,f,1}\cdot \tag{5}$$

Substituting $r_{d,1,f,1}$ and $r_{d,2,f,1}$ from (3) and (4), respectively, in (5), the estimated signals can be rewritten as

$$\hat{s}_{d,f,1} = \frac{1}{\sqrt{3}}\left[\left(1+\sqrt{3}\right)\left|h_{s,d}\right|^2 + \left|h_{r_1,d}\right|^2 + \left|h_{r_2,d}\right|^2 + 2\Delta h_{DF,R,2}\right]s + \hat{n}_{DF,R,2} \tag{6}$$

where $\Delta h_{DF,R,2} = \mathrm{Re}\{a^*h_{s,d}h^*_{r_1,d}\} + \mathrm{Re}\{a^*h_{s,d}h^*_{r_2,d}\} + \mathrm{Re}\{h_{r_1,d}h^*_{r_2,d}\}$ and $\hat{n}_{DF,R,2} = h^*_{s,d}n_d + \left(h^*_{s,d} + a^*h^*_{r_1,d} + a^*h^*_{r_2,d}\right)n$. The $\Delta h_{DF,R,2}$ is denoted the relative states between the channels. $2\mathrm{Re}\{a^*h_{sd}h^*_{r_1d}\}$ and $2\mathrm{Re}\{a^*h_{sd}h^*_{r_2d}\}$ will be positive based on the feedback bit. However, $2\mathrm{Re}\{h_{r1d}h^*_{r2d}\}$ is unable to be controlled by the feedback bit because the product of a and a^* is 1. The cooperative diversity matrix by the feedback bit is calculated as

$$\mathbf{D}_{R,2,f,1} = \begin{bmatrix} 1 & 1 & 1 \\ -1 & -1 & 1 \end{bmatrix}\begin{bmatrix} \mathbf{H}_{S-R,2} \\ \mathbf{H}_{R-R,2} \end{bmatrix} \tag{7}$$

where $\mathbf{H}_{S-R,2} = \begin{bmatrix} 2\mathrm{Re}\{h_{s,d}h^*_{r_1,d}\} \\ 2\mathrm{Re}\{h_{s,d}h^*_{r_2,d}\} \end{bmatrix}$, $\mathbf{H}_{R-R,2} = \begin{bmatrix} 2\mathrm{Re}\{h_{r_1,d}h^*_{r_2,d}\} \end{bmatrix}$.

The cooperative balanced gain is the maximum element of the matrix.

In order to rotate the phase of transmitted signals at the relays, two feedback bits are required. In the case of two feedback bits, the transmit signals can be expressed as

$$\mathbf{C}_{DF,R,2,f,2} = \begin{bmatrix} s & a\overline{s}_{r_1} & b\overline{s}_{r_2} \end{bmatrix} \tag{8}$$

where $a = \pm 1$, $b = \pm 1$. The cooperative diversity matrix achieved by the feedback bits is calculated as

$$\mathbf{D}_{R,2,f,2} = \begin{bmatrix} \mathbf{f}_{S-R,2,f,2} & \mathbf{f}_{R-R,2,f,2} \\ -\mathbf{f}_{S-R,2,f,2} & \mathbf{f}_{R-R,2,f,2} \end{bmatrix} \begin{bmatrix} \mathbf{H}_{S-R,2} \\ \mathbf{H}_{R-R,2} \end{bmatrix} \tag{9}$$

where $\mathbf{f}_{S-R,2,f,2} = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$, $\mathbf{f}_{R-R,2,f,2} = \begin{bmatrix} 1 \\ -1 \end{bmatrix}$.

If the number of available feedback bits is more than the number of relays, additional diversity gain can be achieved by complex phase rotation. When three feedback bits are used, the phases of transmitted signals from each relay are rotated by each of the feedback bits. The transmit signals can be expressed as

$$\mathbf{C}_{DF,R,2,f,3} = \begin{bmatrix} s & ac\overline{s}_{r_1} & bc\overline{s}_{r_2} \end{bmatrix} \tag{10}$$

where $a = \pm 1$, $b = \pm 1$, and *c*=1 or *j*. The cooperative diversity matrix achieved by the feedback bits is calculated as

$$\mathbf{D}_{R,2,f,3} = \begin{bmatrix} \mathbf{f}_{S-R,2,f,2} & \mathbf{f}_{R-R,2,f,2} \\ -\mathbf{f}_{S-R,2,f,2} & \mathbf{f}_{R-R,2,f,2} \end{bmatrix} \begin{bmatrix} \mathbf{H}_{S-R,2} & \overline{\mathbf{H}}_{S-R,2} \\ \mathbf{H}_{R-R,2} & \mathbf{H}_{R-R,2} \end{bmatrix} \tag{11}$$

where $\overline{\mathbf{H}}_{S-R,2} = \begin{bmatrix} 2\operatorname{Re}\{e^{-j} h_{s,d} h^*_{r_1,d}\} \\ 2\operatorname{Re}\{e^{-j} h_{s,d} h^*_{r_2,d}\} \end{bmatrix}$. When three feedback bits are used, the values of the relative states of the channels between the source-destination and the relays-destination can be rotated by a complex phase. The values of the relative state of the channels between each of the relays and the destination, $\operatorname{Re}\{h_{r_1,d} h^*_{r_2,d}\}$, are not changed by the third feedback bit.

3.2 Source and Three Relays

When one feedback bit is used, the phases of transmitted signals from each relay are rotated by each feedback bits. The transmitted signals can be expressed as

$$\mathbf{C}_{DF,R,3,f,1} = \begin{bmatrix} s & a\overline{s}_{r_1} & a\overline{s}_{r_2} & a\overline{s}_{r_3} \end{bmatrix} \tag{12}$$

where $a = \pm 1$ and $\overline{s}_{r_k}$ is the signal estimated by the *k*th relay. The received signals can be written as

$$r_{d,2,f,1} = \frac{1}{2}\begin{bmatrix} h_{s,d}s + ah_{r_1,d}\overline{s}_{r_1} + ah_{r_2,d}\overline{s}_{r_2} + ah_{r_3,d}\overline{s}_{r_3} \end{bmatrix} + n_d \tag{13}$$

where the factor 1/2 realizes a constant transmission power for each signal slot. After combining of the received signals, the estimated signals can be expressed as

$$\hat{s}_{d,f,1} = \frac{1}{2}\left[3|h_{s,d}|^2 + |h_{r_1,d}|^2 + |h_{r_2,d}|^2 + |h_{r_3,d}|^2 + 2\Delta h_{DF,R,3}\right]s + \hat{n}_{DF,R,3} \tag{14}$$

where $\Delta h_{DF,R,3} = \operatorname{Re}\{a^* h_{s,d} h^*_{r_1,d}\} + \operatorname{Re}\{a^* h_{s,d} h^*_{r_2,d}\} +$ Re

$\{a^* h_{s,d} h^*_{r_3,d}\} +$ $\mathrm{Re}\{h_{r_1,d} h^*_{r_2,d}\} +$ $\mathrm{Re}\{h_{r_2,d} h^*_{r_3,d}\} +$ $\mathrm{Re}\{h_{r_3,d} h^*_{r_1,d}\}$ and $\hat{n}_{DF,R,3} = h^*_{s,d} n_d +$ $\left(h^*_{s,d} + a^* h^*_{r_1,d} + a^* h^*_{r_2,d} + a^* h^*_{r_3,d}\right) n_d$. The $\Delta h_{DF,R,3}$ denotes the relative states between the channels. The destination sends the feedback bit to each relay in order to maximize the sum of the values of the relative states of channels. The cooperative diversity matrix achieved by the feedback bit is calculated as

$$\mathbf{D}_{R,3,f,1} = \begin{bmatrix} \mathbf{f}_{S-R,3,f,1} & \mathbf{f}_{R-R,3,f,1} \\ -\mathbf{f}_{S-R,3,f,1} & \mathbf{f}_{R-R,3,f,1} \end{bmatrix} \begin{bmatrix} \mathbf{H}_{S-R,3} \\ \mathbf{H}_{R-R,3} \end{bmatrix} \tag{15}$$

where $\mathbf{H}_{S-R,3} = \begin{bmatrix} 2\,\mathrm{Re}\{h_{s,d} h^*_{r_1,d}\} \\ 2\,\mathrm{Re}\{h_{s,d} h^*_{r_2,d}\} \\ 2\,\mathrm{Re}\{h_{s,d} h^*_{r_3,d}\} \end{bmatrix}$, $\mathbf{H}_{R-R,3} = \begin{bmatrix} 2\,\mathrm{Re}\{h_{r_1,d} h^*_{r_2,d}\} \\ 2\,\mathrm{Re}\{h_{r_2,d} h^*_{r_3,d}\} \\ 2\,\mathrm{Re}\{h_{r_3,d} h^*_{r_1,d}\} \end{bmatrix}$,

$\mathbf{f}_{S-R,3,f,1} = \begin{bmatrix} 1 & 1 & 1 \end{bmatrix}$ and $\mathbf{f}_{R-R,3,f,1} = \begin{bmatrix} 1 & 1 & 1 \end{bmatrix}$. The cooperative balanced gain is the maximum element of matrix.

When two feedback bits are used, they cannot be transmitted to each relay separately. The third relay uses the feedback bit that is the product of *a* and *b*. The phases of transmitted signals from each relay are rotated by the feedback bits. The transmitted signals can be expressed as

$$\mathbf{C}_{DF,R,3,f,2} = \begin{bmatrix} s & a\bar{s}_{r_1} & b\bar{s}_{r_2} & ab\bar{s}_{r_3} \end{bmatrix} \tag{16}$$

where $a = \pm 1$, $b = \pm 1$. The matrix of cooperative diversity according to the feedback bits is calculated as

$$\mathbf{D}_{R,3,f,2} = \begin{bmatrix} \mathbf{f}_{S-R,3,f,2} & \mathbf{f}_{R-R,3,f,2} \end{bmatrix} \begin{bmatrix} \mathbf{H}_{S-R,3} \\ \mathbf{H}_{R-R,3} \end{bmatrix} \tag{17}$$

where $\mathbf{f}_{S-R,3,f,2} = \begin{bmatrix} 1 & 1 & 1 \\ -1 & -1 & 1 \\ -1 & 1 & -1 \\ 1 & -1 & -1 \end{bmatrix}$, $\mathbf{f}_{R-R,3,f,2} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & -1 & -1 \\ -1 & -1 & 1 \\ -1 & 1 & -1 \end{bmatrix}$.

When two feedback bits are used, four cases are achieved by employing the feedback bits.

If three feedback bits are available, the phases of transmitted signals from each relay are rotated by the feedback bits that is consist of eight cases. The transmitted signals can be expressed as

$$\mathbf{C}_{DF,R,3,f,3} = \begin{bmatrix} s & a\bar{s}_{r_1} & b\bar{s}_{r_2} & c\bar{s}_{r_3} \end{bmatrix} \tag{18}$$

where $a = \pm 1$, $b = \pm 1$, $c = \pm 1$. The cooperative diversity matrix achieved by the feedback bits is calculated as

$$\mathbf{D}_{R,3,f,3} = \begin{bmatrix} \mathbf{f}_{S-R,3,f,2} & \mathbf{f}_{R-R,3,f,2} \\ -\mathbf{f}_{S-R,3,f,2} & \mathbf{f}_{R-R,3,f,2} \end{bmatrix} \begin{bmatrix} \mathbf{H}_{S-R,3} \\ \mathbf{H}_{R-R,3} \end{bmatrix}. \tag{19}$$

The sums of the relative states of the channels between the source-destination and the relays-destination can be changed by the rotating phase from each relay.

If the number of available feedback bits is more than the number of relay, additional diversity gain is obtainable. When four feedback bits are used, the phases of transmitted signals from each relay are complex rotated by the fourth feedback bit. The transmitted signals can be expressed as

$$\mathbf{C}_{DF,R,3,f,4} = \begin{bmatrix} s & ad\bar{s}_{r_1} & bd\bar{s}_{r_2} & cd\bar{s}_{r_3} \end{bmatrix} \tag{20}$$

where $a = \pm 1$, $b = \pm 1$, $c = \pm 1$, and d=1 or j. The cooperative diversity matrix achieved by the feedback bits is calculated as

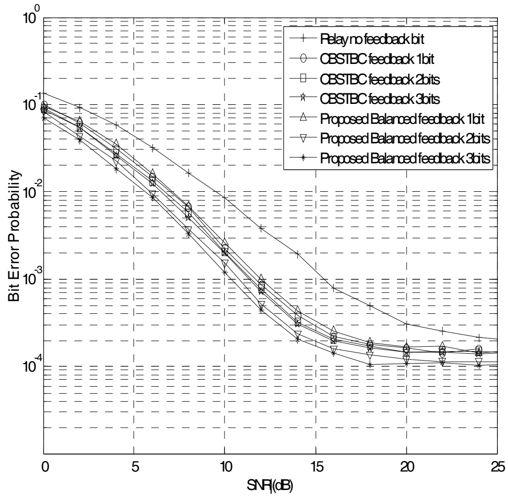
$$\mathbf{D}_{R,3,f,4} = \begin{bmatrix} \mathbf{f}_{S-R,3,f,2} & \mathbf{f}_{R-R,3,f,2} \\ -\mathbf{f}_{S-R,3,f,2} & \mathbf{f}_{R-R,3,f,2} \end{bmatrix} \begin{bmatrix} \mathbf{H}_{S-R,3} & \overline{\mathbf{H}}_{S-R,3} \\ \mathbf{H}_{R-R,3} & \mathbf{H}_{R-R,3} \end{bmatrix} \tag{21}$$

where $$\overline{\mathbf{H}}_{S-R,3} = \begin{bmatrix} 2\mathrm{Re}\{e^{-j}h_{s,d}h^*_{r_1,d}\} \\ 2\mathrm{Re}\{e^{-j}h_{s,d}h^*_{r_2,d}\} \\ 2\mathrm{Re}\{e^{-j}h_{s,d}h^*_{r_3,d}\} \end{bmatrix}.$$

4. Simulation Results

In this section, the bit error performances of the CBT scheme are compared to CBSTBCs for two and three relays. The simulations are performed by Matlab simulator. Quadrature phase shift keying (QPSK) modulation is used, and relays cannot transmit and receive the signal simultaneously. The relays use the decode and forward cooperative protocol, and the source and destination do not know whether the relays decode the signal correctly. It is assumed that the signal-to-noise ratio (SNR) of the source-relay channel is 30dB, and that of source-destination and relay-destination channel are 0dB to 25dB.

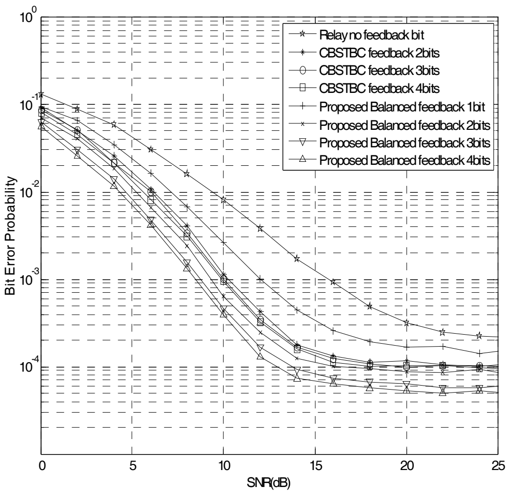
Fig. 1 shows the BER performance of the proposed CBT and CBSTBCs scheme with feedback bits for two relays. When one feedback bit is used, the BER performance of the CBT scheme is slightly lower than the CBSTBC scheme (0.3dB with BER=10^{-3}), since the $2\mathrm{Re}\{h_{r1d}h^*_{r2d}\}$ cannot be controlled by feedback bit, which prevent getting maximum balanced coding gain. However, when two feedback bits are used, the proposed scheme has about 0.7dB performance gain than the CBSTBC scheme with BER=10^{-3}, since there are no terms, which cannot be controlled by two feedback bits. Finally, the performance gap between the proposed scheme and the CBSTBC scheme is approximately 1dB at BER=10^{-3}, while three feedback bits are used. When the SNR of the source-destination and relay-destination is 18dB, both the proposed scheme and CBSTBCs scheme indicate an error floor above which mean no additional performance gain.



(Fig. 1) BER with the source and two relays

Fig. 2 shows the simulation results of the CBT and the CBSTBC scheme with feedback bits for three relays. When one bit feedback is used, the CBT scheme has 1.7dB lower BER performance than the CBT with two bit feedback, since the $2^{\mathrm{Re}\{h_{r_1,d}h^*_{r_2,d}\}}$, $2^{\mathrm{Re}\{h_{r_2,d}h^*_{r_3,d}\}}$, and $2^{\mathrm{Re}\{h_{r_3,d}h^*_{r_1,d}\}}$ terms cannot be controlled by one feedback bit, which prevent getting maximum balanced coding gain. Because the CBSTBC scheme needs over two feedback bits, while three relays are used, we cannot compare both the CBT and CBSTBC with one feedback bit. When two and three feedback bits are used, the proposed CBT scheme has about 0.83dB and 1.17 dB performance gains respectively than the CBSTBC scheme with BER=10^{-3}. Finally, the CBT scheme has approximately 1.5dB BER performance gain than the CBSTBC scheme, while four feedback bits are used and the BER is 10^{-3}.

Furthermore, from fig.1 and fig. 2, we can see that



(Fig. 2) BER with the source and three relays

the BER performances of the CBT scheme with one feedback bit are almost same, when two and three relays are used. Even though, we can have more cooperative gain while thenumber of relays is increased, the number of terms, which cannot be controlled by one feedback, is also increased. This make the balanced gain of the proposed CBT scheme reduced. Therefore, the reduced balanced gains offset the increased cooperative gains.

5. Conclusion

In this paper, a CBT scheme is proposed for cooperative relay communication using the feedback bits. The destination selects the feedback bits in order to obtain the maximum value of cooperative balanced gain, which is dependent on the sum of the channel gains. The cooperative balanced gains are computed by the channel coefficients and feedback bits. As a result, the simulation shows that the proposed scheme performs better than the CBSTBC. If the number of feedback bits is sufficient, additional cooperative balanced gain can be obtained through complex phase rotation of the relative states between the channels.

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