

Adaptive relay selection in cooperative communication based on space time block code

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Abstract

Wireless cooperative communication technology share resources with each other, can get space diversity gain and improve the system transmission performance, so that in recent years it has received the extensive attention of many scholars in the field of wireless communications. In view of the flat fading channel, adaptive relay node selection and transmission strategy based on space time block code under decode forward mode is put forward and closed expressions of average outage probability and bit error rate are given under the Rayleigh channel. This strategy applies the opportunistic relay scheme in collaborative space-time coding system, which can get diversity gain and coding gain. The experiment results show that the proposed relay transmission scheme has better performance than fixed relay node transmission strategy.

Keywords: adaptive relay selection, cooperative communication, space time block code, outage probability

1 Introduction

Compared with single antenna system, MIMO system can greatly increase the channel capacity, which increases system transmission rate or improves the reliability of transmission [1, 2]. In transmit diversity technique based on space-time coding, the multi-antenna technology, channel coding and modulation technology are combined together to obtain diversity gain and coding gain at the same time [3], which effectively improve the channel capacity of MIMO system. Cooperative system composed of many single antenna nodes is a kind of virtual MIMO system. For virtual MIMO systems, space-time coding is dispersed in each single antenna node to simulate the multi-antenna transmitter, so that the distributed space-time coding (DSTC) collaboration system is formed. Orthogonal space-time block code (OSTBC) is a kind of coding design theory which introduces into orthogonal matrix. Due to the relatively simple decoding algorithm and good performance, it has been taken as WCDMA standard of 3GPP officially. At present most of the research on collaborative DSTC system is based on the OSTBC.

Laneman firstly put forward the concept of DSTC collaboration system [3] and proved that the proposed DSTC collaboration system can achieve full diversity gain from the viewpoint of information theory, but a specific implementation plan was not given. Performance of distributed space-time coding systems with one and two non-regenerative relays was analyzed by Anghel [4]. Distributed space-time cooperative system with regenerative relays was also given by Anghel [5]. Performance of distributed space time block codes was analyzed by Dohler M [6]. Distributed space time coding for regenerative relay networks was proposed by Scutari G [7]. Performance limits and space time signal design under fading relay channels was given by Nabar [8]. Distributed space time block coding with imperfect channel estimation was proposed by Cheng [9]. Cooperative space

time block coding with amplify-and-forward strategy was proposed by He J [10], which gave exact bit error probability and adaptive forward schemes. Randomized space time block coding with limited feedback was proposed by He X [11]. An energy-efficient adaptive cooperative node selection scheme in WSN was proposed by Zhang Y [12]. The joint relay selection with power allocation for outage-optimization in OFDM-based cooperative relaying was given by Wang [13]. Selective relaying in OFDM multihop cooperative networks was proposed by Dai L [14]. Partner assignment algorithm for cooperative diversity in mobile communication systems was proposed by Jung Y S [15]. Energy efficient cooperative communication based on power control and selective single-relay in wireless sensor networks was proposed by Zhou Z [16]. BER performance analysis and optimum power allocation for a cooperative diversity system based on quadrature signalling was proposed by Li J [17]. Distributed relay selection and power control for multiuser cooperative communication networks using buyer/seller game was proposed by Wang B [18]. Game theory for cooperative and relay communications in mobile Ad-Hoc networks was proposed by Lu Y [19]. An experimental framework for the evaluation of cooperative diversity was proposed by G. Bradford [20]. Single and multiple relay selection schemes and their achievable diversity orders were proposed by J. Yindi, which performs much better than the corresponding single relay selection methods and is very close to the SNR-optimal multiple relay selection scheme [21]. In the next section, principle of space time block code is investigated. In Section 3, cooperative communication based on space-time block code is investigated. In section 4, simulation and analysis of adaptive relay selection based on space time block code is given. Finally, some conclusions are given in section 5.

2 Principle of space time block code

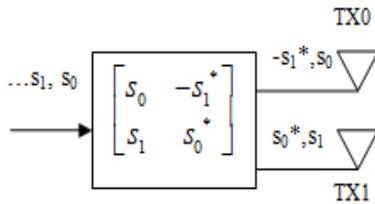


FIGURE 1 Space-time block code system block diagram

Space-time block code system block diagram is shown in figure 1. In this system, there are two transmitting antennas. Supposing that antenna 0 transmits symbol s_0 and antenna 1 transmits symbol s_1 . In the next symbol cycle, antenna 0 transmits symbol $-s_1^*$ and antenna 1 transmits symbol s_0^* . The coding matrix is $S = \begin{bmatrix} s_0 & -s_1^* \\ s_1 & s_0^* \end{bmatrix}$.

$$S = \begin{bmatrix} s_0 & -s_1^* \\ s_1 & s_0^* \end{bmatrix}$$

* represents conjugate. s_0 and s_1 represent transmitting sequence of antenna 0 and antenna 1 respectively.

$$s^1 \cdot s^2 = s_0 s_1^* - s_1^* s_0 = 0$$

$$S \cdot S^H = \begin{bmatrix} |s_0|^2 + |s_1|^2 & 0 \\ 0 & |s_0|^2 + |s_1|^2 \end{bmatrix} = (|s_0|^2 + |s_1|^2) \mathbf{I}_2$$

The transmitting sequences at two antennas are orthogonal. The signal detection of space time block code is as follows. Supposing there is N number of receiving antennas. $h_{j,i} (j=0,1,\dots,N, i=0,1)$ represents channel fading coefficients from transmitting antenna 0 and antenna 1 to receiving antenna. The channel fading coefficients are constant in two consecutive transmitting cycles. Receiving signal of the j -th antenna at time t and time $t+T$ is described as r_0^j and r_1^j respectively.

$$r_0^j = h_{j,0} s_0 + h_{j,1} s_1 + n_0^j$$

$$r_1^j = -h_{j,0} s_1^* + h_{j,1} s_0^* + n_1^j$$

n_0^j and n_1^j are independent complex variables with 0 as its mean value and δ^2 as variance. If the receiver can recover channel fading coefficients $h_{j,0}$ and $h_{j,1}$, the two determination results are \tilde{s}_0 and \tilde{s}_1 .

$$\tilde{s}_0 = \sum_{j=0}^{N-1} h_{j,0}^* r_0^j + h_{j,1} (r_1^j)^* = \sum_{i=0}^1 \sum_{j=0}^{N-1} |h_{j,i}|^2 s_0 + \sum_{j=0}^{N-1} h_{j,0}^* n_0^j + h_{j,1} (n_1^j)^*$$

$$\tilde{s}_1 = \sum_{j=0}^{N-1} h_{j,1}^* r_0^j - h_{j,1} (r_1^j)^* = \sum_{i=0}^1 \sum_{j=0}^{N-1} |h_{j,i}|^2 s_1 + \sum_{j=0}^{N-1} h_{j,1}^* n_0^j - h_{j,0} (n_1^j)^*$$

The maximum likelihood decoder should select the signal (\hat{s}_0, \hat{s}_1) , which makes the following distance minimum.

$$\sum_{t=1}^l \sum_{j=1}^m |r_t^j - \sum_{i=1}^n h_{ji} s_i^j|^2$$

The rule of maximum likelihood decoding of s_0 and s_1

can be expressed as

$$\hat{s}_0 = \arg \text{MIN}_{\hat{s}_0 \in S} [(\sum_{j=0}^{N-1} (|h_{j,0}|^2 + |h_{j,1}|^2 - 1)) |\hat{s}_0|^2 + d^2(\tilde{s}_0, \hat{s}_0)]$$

$$\hat{s}_1 = \arg \text{MIN}_{\hat{s}_1 \in S} [(\sum_{j=0}^{N-1} (|h_{j,0}|^2 + |h_{j,1}|^2 - 1)) |\hat{s}_1|^2 + d^2(\tilde{s}_1, \hat{s}_1)]$$

3 Cooperative communication based on space-time block code

The system is made up of one source node S , one destination node D and M number of relay node. All the relay nodes are in the same cluster. The distance between all relay nodes and source node are the same. The distance between all relay nodes and destination node are also the same. The maximum transmitting power of each node is P and each node cannot transmit and receive information at the same time. The channel between any two nodes is flat Rayleigh fading channel and the channel state is constant in one frame time and it varies in different frames. H_{si} represents channel gain from source node S to relay node R_i and H_{id} represents channel gain from R_i to destination node D , $i=1,2,\dots,M$. H_{si} and H_{id} are independent variables, the mean value of which are $d_{SR}^{-\alpha}$ and $d_{RD}^{-\alpha}$ respectively. d_{SR} represents the distance between source node and relay node and d_{RD} represents the distance between relay node and destination node. α represents path loss coefficient.

The decode-forward protocol based on space time block code is shown in figure 2. It is supposed the system adopts TDMA cooperation mode and one

Complete cooperation transmission is made up of two stages. In the first stage, the source node transmits information symbol x_1 and x_2 in two consecutive symbol cycles. At the same time, all the relay nodes listen to the channel.

S	x_1	x_2		
R_j			$-x_2^*$	x_1
R_j			x_1^*	x_2

FIGURE 2 Decode-forward protocol based on space time block code

In the second stage, relay node R_i sends $-x_2^*$ and x_1 to the destination node in two consecutive symbol cycles. R_j sends x_1^* and x_2 to the destination node in two consecutive symbol cycles. The transmitted symbol has unit energy and BPSK modulation is used. In the first stage, the receiving SNR of relay node R_i is set as: $\gamma_{si} = \frac{H_{si} P}{N_0}$.

In the second stage, the destination node receives the signal by ML detection and receive SNR of destination node is expressed as: $\gamma_d = \frac{P(H_{id} + H_{jd})}{N_0}$.

The SNR of destination node determines the performance of the system. In the decode-forward transmission with CRC, any relay node can not decode received information correctly every time. If there is no node to decode the

received information, the current transmission fails. If there is only one relay node to decode the received information, the relay node sends the received information to destination node again. If there are two or more than two relay nodes correctly decoding the received information, the two relay nodes are selected, which has the biggest SNR from relay node to the destination node.

The target value of system capacity is R . When channel capacity between sending and receiving nodes is more than R , no interruption occurs, meaning that the receiving node can correctly decode the received information, otherwise the interrupt occurs. For the Rayleigh fading channel, probability distribution function of receiving SNR of the source node to the arbitrary relay node and arbitrary relay node to the destination node, respectively obey the negative exponential distribution with mean value $\bar{r}_{SR} = \frac{P}{d_{SR}^\alpha N_0}$ and negative exponential distribution with mean value $\bar{r}_{RD} = \frac{P}{d_{RD}^\alpha N_0}$.

For the arbitrary relay node R_i , outage probability is defined as

$$P_{RO} = \Pr \left\{ \frac{1}{2} \log_2(1 + \gamma_{si}) < R \right\} = 1 - \exp \left(-\frac{2^{2R} - 1}{\gamma_{SR}} \right).$$

Probability of L number of relay nodes correctly decoding received information is:

$$P_{RO}^L = \binom{M}{L} (1 - P_{RO})^L (P_{RO})^{M-L}, \quad (0 \leq L \leq M).$$

$$P_{DO}^{L \geq 2} = L(L-1) \cdot \left(\frac{1}{2} - \frac{1}{2} \exp \left(-\frac{2^{2R} - 1}{\gamma_{RD}} \right) - \frac{2^{2R} - 1}{2\gamma_{RD}} \exp \left(-\frac{2^{2R} - 1}{\gamma_{RD}} \right) + \sum_{k=1}^{L-2} \binom{L-2}{k} (-1)^k \left(\frac{1}{k+2} + \frac{2}{k(k+2)} \exp \left(-\frac{(k+2)(2^{2R} - 1)}{2\gamma_{RD}} \right) - \frac{1}{k} \exp \left(-\frac{2^{2R} - 1}{\gamma_{RD}} \right) \right) \right)$$

The average outage probability of adaptive relay node selection is:

$$P_{out} = P_{RO}^0 + \sum_{L=1}^M P_{RO}^L P_{DO}^L, \quad P_{out} < P_{RO}^0 + \sum_{L=1}^M P_{RO}^L P_{SO}^L.$$

In the decode-forward protocol using cyclic redundancy check, each relay node can determine whether received information is right. For BPSK signal, bit error rate of a arbitrary relay node R_i is:

$$P_{Re} = \frac{1}{\pi} \int_0^{\pi/2} \exp \left(-\frac{\gamma_{si}}{\sin^2 \theta} \right) d\theta.$$

For convenience, considering the transmission of fixed frame length, and each frame contains K number of symbols. In the first phase of the information transmission, a relay node only correctly decodes K number of symbols sent by

Because $\lim_{x \rightarrow 0} (1 - \exp(-x)) = x$, when SNR of relay node is large enough, P_{RO}^L is expressed as:

$$P_{RO}^L \approx \binom{M}{L} \left(\frac{2^{2R} - 1}{\gamma_{SR}} \right)^{M-L}.$$

$$P_{DO}^{L=1} = 1 - \exp \left(-\frac{2^{2R} - 1}{\gamma_{RD}} \right).$$

When $L \geq 2$, R_i and R_j with the largest γ_{iD} and γ_{jD} are selected. The joint probability distribution function is

$$P_D^{L \geq 2}(\gamma_{iD}, \gamma_{jD}) = L(L-1)(P_D(\gamma_{jD}))^{L-2} P_D(\gamma_{jD}) P_D(\gamma_{iD}) = L(L-1) \sum_{k=0}^{L-2} \binom{L-2}{k} (-1)^k \left(\frac{1}{r_{RD}} \exp \left(-\frac{(k+1)\gamma_{jD}}{r_{RD}} \right) \frac{1}{r_{RD}} \exp \left(-\frac{\gamma_{iD}}{r_{RD}} \right) \right),$$

$\gamma_{jD} < \gamma_{iD} \cdot P_D$ represents probability distribution function and P_D represents CDF. The outage probability of destination node is

$$P_{DO}^{L \geq 2} = \Pr \left\{ \frac{1}{2} \log_2(1 + \gamma_{iD} + \gamma_{jD}) < R \right\} = \Pr \{ \gamma_{iD} + \gamma_{jD} < 2^{2R} - 1 \}$$

$\Pr \{ \gamma_{iD} + \gamma_{jD} < 2^{2R} - 1 \} < \Pr \{ \gamma_{iD} < 2^{2R} - 1 \} = P_{so}^L$, average outage probability of space time block code transmission adopted by two optimal relay is less than average outage probability of single optimal relay transmission. P_{so}^L represents outage probability of optimal single relay node transmission in L number of correctly-decoded relays.

source nodes, the frame is received correctly.

Then average error frame rate of relay node is:

$$P_{Fe} = 1 - \int_0^\infty (1 - P_{Re})^K p_{SR}(\gamma_{si}) d\gamma_{si}.$$

$p_{SR}(\gamma_{si})$ represents the probability of distribution function for γ_{si} . When a frame received by relay node is decoded correctly, the relay node becomes active node, then probability of $L(0 \leq L \leq M)$ number of relay nodes becoming

the active nodes is: $P_{ac}^L = \binom{M}{L} P_{Fe}^{M-L} (1 - P_{Fe})^L$.

When $L = 1$, there is only one relay node correctly decoding received packets and for BPSK modulation signal under Rayleigh fading channel, the average BER is given for destination node.

$$P_{De}^{L=1} = \frac{1}{2} \left(1 - \sqrt{\frac{\bar{\gamma}_{RD}}{\bar{\gamma}_{RD} + 1}} \right)$$

When $L \geq 2$, the selected cooperation relay nodes are R_i and R_j , bit error rate of destination node is:

$$P_{De}^{L \geq 2} = \frac{1}{\pi} \int_0^\infty \int_0^{\pi/2} \int_0^{\pi/2} \exp\left(-\frac{\gamma_{iD} + \gamma_{jD}}{\sin^2 \theta}\right) p(\gamma_{iD}, \gamma_{jD}) d\gamma_{iD} d\gamma_{jD} d\theta$$

$$P_{De}^{L \geq 2} = \frac{L(L-1)}{\pi} \left[\frac{1}{4(\bar{\gamma}_{RD} + 1)^2} B\left(\frac{5}{2}, \frac{1}{2}\right) F\left(\frac{1}{2}, 2:3, \frac{1}{\bar{\gamma}_{RD} + 1}\right) + \sum_{k=1}^{L-2} \binom{L-2}{k} \frac{(-1)^k \pi}{2k} \left(1 - \sqrt{\frac{\bar{\gamma}_{RD}}{1 + \bar{\gamma}_{RD}}} \right) - \sum_{k=1}^{L-2} \left(\frac{1}{k+2} - \frac{2\sqrt{\bar{\gamma}_{RD}}}{(k+2)\sqrt{4\bar{\gamma}_{RD} + 2k + 4}} \right) \right]$$

$B(\cdot, \cdot)$ Represents Beta function and $F()$ represents hyper-geometric function. The bit error rate can be expressed as: $P_{BER} = P_{ac}^0 + \sum_{L=1}^M P_{ac}^L P_{De}^L$.

4 Simulation and analysis

Monte Carlo simulation is used to verify the performance of adaptive relay node selection and transmission strategy based on space-time block code. Flat Rayleigh fading channel is used in the simulation and distance between source node and destination node is unit distance. $d_{SR} = 0.5$, $d_{RD} = 0.5$, $\alpha = 2$, $N_0 = 1$. Figure 3 shows outage probability. Fixed relay means outage probability of fixed relay transmission strategy. The green line represents outage probability of adaptive relay selection when the number of relay nodes is 4 and the red line represents outage probability when the number of relay nodes is 5. Outage probability of adaptive relay selection is represented by m6 when the number of relay nodes is 6.

It can be seen that outage probability of the proposed space time block code decreases with the increment of relay nodes. Outage probability of proposed scheme is smaller than outage probability of fixed relay transmission scheme. Figure 4 shows bit error performance. It can be seen that bit error performance of the proposed relay transmission scheme decreases with the increment of relay nodes. Bit error rate of proposed scheme is smaller than bit error rate of fixed relay transmission scheme. Relation between bit error rate and frame length is shown in figure 5 when the number of relay nodes is 5. K40 means the frame length is 40 bits, k60 means the frame length is 60 bits and k80 means the frame length is 80 bits. It can be seen that bit error rate increases with the increment of K and K does not influence

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the diversity gain of the system. When K is 20, it can save 1.5dB SNR compared with K=60. In the actual system, suitable frame length should be selected to get better bit error rate performance.

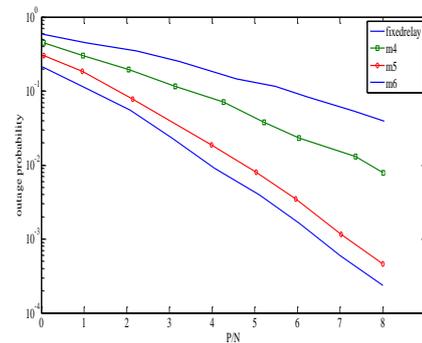


FIGURE 3 Outage probability

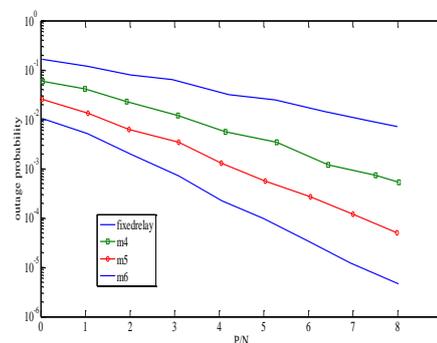


FIGURE 4 Bit error performance

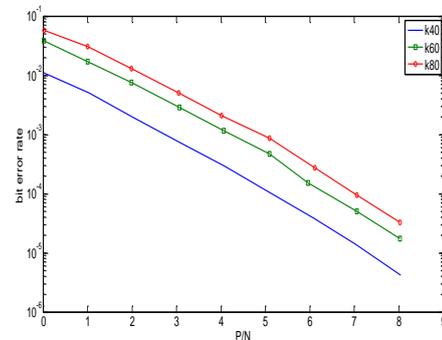


FIGURE 5 Relation between bit error rate and frame length

5 Conclusions

Under flat fading channel environment, cooperative space time block code transmission problem is investigated. In order to get high diversity gain and coding gain, adaptive relay node transmission scheme is put forward and system average outage probability and bit error rate expression is given. Only two relay nodes participate in cooperative transmission, which is conducive to the realization of the actual system.

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