

Joint Power Allocation and Relay Selection Algorithm for Multiple-Antenna Terminals in Cooperative MIMO Systems

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Abstract

The relay selection and power allocation of cooperative MIMO with multiple-antenna terminals are investigated. Based on the classic worst-link-first algorithm, we propose a joint power allocation and relay selection algorithm, which takes maximizing the system energy gain as the optimization purpose. We consider quasi-static, flat fading channels, select relays, and allocate power according to the instantaneous channel state information. Theoretical analysis and computer simulations show that the proposed algorithm can achieve higher average network energy gain than the traditional worst-link-first algorithm, and its computational complexity is much lower.

Keywords: cooperative diversity; multiple-antenna; decode-and-forward; power allocation; relay selection

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1. Introduction

Cooperative diversity is a new spatial diversity technique that was originally proposed by Sendonaris [1]. Its main idea is that different users share their antennas by exploiting the broadcast nature of radio waves. By forming a virtual multiple-input multiple-output (MIMO) system, single-antenna terminals in cooperative communication networks are able to obtain spatial diversity gain as well. Since the correlation between antennas of different mobile terminals is usually much lower than the correlation between different antennas of the same mobile terminal, a cooperative diversity system may obtain higher diversity gain than a traditional MIMO system. Cooperative diversity technology can be applied in many fields of wireless communications. For instance, in cellular networks, cooperation between users can effectively improve the communication quality of cell-edge users and greatly reduce the energy consumption of the whole system. The use of multiple-antenna terminals is an inevitable trend in wireless communications. Under the circumstances that multiple-antenna terminals are used, cooperation is still very necessary. The cooperative MIMO system with multiple-antenna terminals will bring greater multiplexing gain and diversity gain for wireless transmission.

Research shows that the power allocation scheme and the relay selection method have a great impact on the performance of a cooperative diversity system. Therefore, selecting appropriate relays and adopting appropriate power allocation strategies are very important. At present, there have been some studies on joint power allocation and relay selection in cooperative systems, and they focus on different cooperation schemes [2-5]. Relay selection methods can be divided into two major categories: centralized selection methods and distributed selection methods. Centralized selection methods are applicable for centralized networks, such as cellular networks. Typical centralized relay selection methods include the maximum weighted (MW) matching algorithm [6], Greedy matching algorithm [7], worst-link-first (WLF) matching algorithm [8], and so on. Distributed selection methods are applicable for distributed networks, such as wireless ad-hoc networks and wireless sensor networks. The most representative algorithm of distributed selection methods is the opportunistic relay selection algorithm, which was proposed by Bletsas [9]. The optimization objectives of power allocation methods include maximizing channel capacity, minimizing system outage probability or bit error rate (BER), and minimizing energy consumption of transmission.

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In this paper, the relay selection and power allocation in a cooperative MIMO system with multiple-antenna terminals are studied. In Section 2, the transmission model is introduced. In Section 3, we analyze the BER performance of the system. In Section 4, the energy gain of the system is analyzed, and then two cooperation thresholds and an approximation of the optimal power allocation coefficient are given. A joint power allocation and relay selection algorithm is presented in Section 5. The proposed algorithm is based on the classic WLF matching algorithm, and it takes maximizing the system energy gain as the optimization purpose. By setting cooperation thresholds and using the approximation of optimal power allocation coefficient, the computational complexity is greatly reduced. In Section 6, the numerical results are presented and analyzed. Finally, conclusions are drawn in Section 7.

2. Transmission Model

Cooperative communication systems with multiple-antenna terminals are more complex than cooperative communication systems with single-antenna terminals. Therefore, we adopt the three-node cooperation scheme and thus reduce the complexity of cooperation. Figure 1 shows the transmission model. The cooperative communication system is composed of one source node, one relay node, and one destination node. In order to simplify the analysis, we assume that each node is configured with two antennas. \mathbf{H}_{SD} , \mathbf{H}_{SR} , and \mathbf{H}_{RD} represent the channel matrixes of the source-destination (S-D) link, source-relay (S-R) link, and relay-destination (R-D) link, respectively.

$$\mathbf{H}_{SD} = \begin{bmatrix} h_{SD1,1} & h_{SD1,2} \\ h_{SD2,1} & h_{SD2,2} \end{bmatrix} \quad (1)$$

$$\mathbf{H}_{SR} = \begin{bmatrix} h_{SR1,1} & h_{SR1,2} \\ h_{SR2,1} & h_{SR2,2} \end{bmatrix} \quad (2)$$

$$\mathbf{H}_{RD} = \begin{bmatrix} h_{RD1,1} & h_{RD1,2} \\ h_{RD2,1} & h_{RD2,2} \end{bmatrix} \quad (3)$$

Where $h_{SDi,j}$, $h_{SRi,j}$, and $h_{RDi,j}$ ($i = 1, 2; j = 1, 2$) denote the channel between the i^{th} transmitting antenna and the j^{th} receiving antenna of the S-D link, S-R link, and R-D link, respectively.

In this paper, the decode-and-forward (DF) scheme is adopted. We consider the quasi-static flat fading channel. It is supposed that each receiver has perfect channel state information (CSI). A cooperative transmission period is comprised of two successive time blocks. In the first time block, the source broadcasts Alamouti space time block coding (STBC) [10] signals to the destination and the relay. The destination stores the received signals for subsequent processing. The relay decodes the received signals employing maximum likelihood (ML) estimation. In the second time block, the relay forwards the regenerated STBC signals to the destination. The signals received from the source in the first time block combined with the signals received from the relay in the second time block can be viewed as the equivalent of signals simultaneously received by four antennas. The destination then decodes the signals by means of the ML estimation method.

We assume binary frequency shift keying (BPSK) modulation is adopted. Modulated symbols are divided into groups, each of which consists of two consecutive symbols. The two symbols of a group are represented by x_1 and x_2 , respectively.

In the first time block, the signals transmitted from the two antennas of the source can be described as

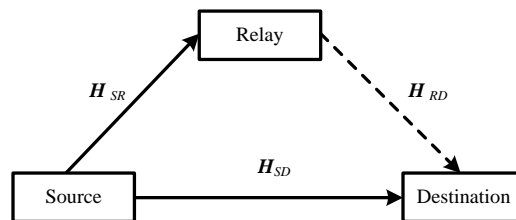


Figure 1. Transmission model

$$X_{s1} = \begin{bmatrix} x_1 & -x_2^* \end{bmatrix} \quad (4)$$

$$X_{s2} = \begin{bmatrix} x_2 & x_1^* \end{bmatrix} \quad (5)$$

During the first symbol period, x_1 and x_2 are transmitted from the first and the second antenna, respectively. During the second symbol period, $-x_2^*$ and x_1^* are transmitted from the first and the second antenna, respectively. Here, $*$ represents the complex conjugate operation.

From Equations (1), (4), and (5), we obtain the signals received by the two antennas of the destination in the first time block as

$$Y_{SD1} = \begin{bmatrix} y_{SD1}^1 & y_{SD1}^2 \end{bmatrix} = \begin{bmatrix} h_{SD1,1}x_1 + h_{SD1,2}x_2 + n_{SD1}^1 & -h_{SD1,1}x_2^* + h_{SD1,2}x_1^* + n_{SD1}^2 \end{bmatrix} \quad (6)$$

$$Y_{SD2} = \begin{bmatrix} y_{SD2}^1 & y_{SD2}^2 \end{bmatrix} = \begin{bmatrix} h_{SD2,1}x_1 + h_{SD2,2}x_2 + n_{SD2}^1 & -h_{SD2,1}x_2^* + h_{SD2,2}x_1^* + n_{SD2}^2 \end{bmatrix} \quad (7)$$

Where y_{SDj}^m and n_{SDj}^m ($j = 1, 2; m = 1, 2$) are the signal and additive white Gaussian noise (AWGN) received by the j^{th} antenna of the destination during the m^{th} symbol period of the first time block, respectively.

From Equations (2), (4), and (5), we obtain the signals received by the two antennas of the relay in the first time block as

$$Y_{SR1} = \begin{bmatrix} y_{SR1}^1 & y_{SR1}^2 \end{bmatrix} = \begin{bmatrix} h_{SR1,1}x_1 + h_{SR1,2}x_2 + n_{SR1}^1 & -h_{SR1,1}x_2^* + h_{SR1,2}x_1^* + n_{SR1}^2 \end{bmatrix} \quad (8)$$

$$Y_{SR2} = \begin{bmatrix} y_{SR2}^1 & y_{SR2}^2 \end{bmatrix} = \begin{bmatrix} h_{SR2,1}x_1 + h_{SR2,2}x_2 + n_{SR2}^1 & -h_{SR2,1}x_2^* + h_{SR2,2}x_1^* + n_{SR2}^2 \end{bmatrix} \quad (9)$$

Where y_{SRj}^m and n_{SRj}^m ($j = 1, 2; m = 1, 2$) are the signal and noise received by the j^{th} antenna of the relay during the m^{th} symbol period of the first time block, respectively.

The relay then performs ML decoding. According to Equations (8) and (9), the estimates of x_1 and x_2 at the relay can be expressed as

$$\hat{x}_{R1} = \arg \min d^2(\tilde{x}_{R1}, \hat{x}_{R1}), \hat{x}_{R1} \in \mathbf{S} \quad (10)$$

$$\hat{x}_{R2} = \arg \min d^2(\tilde{x}_{R2}, \hat{x}_{R2}), \hat{x}_{R2} \in \mathbf{S} \quad (11)$$

Where $d(x, y)$ denotes the Euclidean distance between x and y , and \mathbf{S} is the set of transmission signals. In Equations (10) and (11), the combined signals \tilde{x}_{R1} and \tilde{x}_{R2} are given by

$$\tilde{x}_{R1} = \sum_{j=1}^2 [h_{SRj,1}^* y_{SRj}^1 + h_{SRj,2} y_{SRj}^{2*}] \quad (12)$$

$$\tilde{x}_{R2} = \sum_{j=1}^2 [h_{SRj,2}^* y_{SRj}^1 - h_{SRj,1} y_{SRj}^{2*}] \quad (13)$$

In the second time block, the signals transmitted from the two antennas of the relay are

$$X_{R1} = \begin{bmatrix} \hat{x}_{R1} & -\hat{x}_{R2}^* \end{bmatrix} \quad (14)$$

$$X_{R2} = \begin{bmatrix} \hat{x}_{R2} & \hat{x}_{R1}^* \end{bmatrix} \quad (15)$$

From Equations (3), (14), and (15), we obtain the signals received by the two antennas of the destination in the second time block as

$$Y_{RD1} = \begin{bmatrix} y_{RD1}^1 & y_{RD1}^2 \end{bmatrix} = \begin{bmatrix} h_{RD1,1}\hat{x}_{R1} + h_{RD1,2}\hat{x}_{R2} + n_{RD1}^1 & -h_{RD1,1}\hat{x}_{R2}^* + h_{RD1,2}\hat{x}_{R1}^* + n_{RD1}^2 \end{bmatrix} \quad (16)$$

$$Y_{RD2} = \begin{bmatrix} y_{RD2}^1 & y_{RD2}^2 \end{bmatrix} = \begin{bmatrix} h_{RD2,1}\hat{x}_{R1} + h_{RD2,2}\hat{x}_{R2} + n_{RD2}^1 & -h_{RD2,1}\hat{x}_{R2}^* + h_{RD2,2}\hat{x}_{R1}^* + n_{RD2}^2 \end{bmatrix} \quad (17)$$

Where y_{RDj}^m and n_{RDj}^m ($j = 1, 2; m = 1, 2$) are the signal and noise received by the j^{th} antenna of the destination during the m^{th} symbol period of the second time block, respectively.

The destination processes the signals received from the source in the first time block and the signals received from the relay in the second time block as the equivalent of signals simultaneously received by four antennas, and then it performs ML decoding. According to Equations (6), (7), (16), and (17), the final estimates of x_1 and x_2 at the destination can be expressed as

$$\hat{x}_1 = \arg \min d^2(\tilde{x}_1, \hat{x}_1), \hat{x}_1 \in \mathbf{S} \quad (18)$$

$$\hat{x}_2 = \arg \min d^2(\tilde{x}_2, \hat{x}_2), \hat{x}_2 \in \mathbf{S} \quad (19)$$

In Equations (18) and (19), the combined signals \tilde{x}_1 and \tilde{x}_2 are given by

$$\tilde{x}_1 = \sum_{j=1}^2 [h_{SDj,1}^* y_{SDj}^1 + h_{SDj,2}^* y_{SDj}^{2*}] + \sum_{j=1}^2 [h_{RDj,1}^* y_{RDj}^1 + h_{RDj,2}^* y_{RDj}^{2*}] \quad (20)$$

$$\tilde{x}_2 = \sum_{j=1}^2 [h_{SDj,2}^* y_{SDj}^1 - h_{SDj,1}^* y_{SDj}^{2*}] + \sum_{j=1}^2 [h_{RDj,2}^* y_{RDj}^1 - h_{RDj,1}^* y_{RDj}^{2*}] \quad (21)$$

From Equations (12), (13), (20), and (21), it can be seen that the above combination could achieve the same effect as maximal ratio combining (MRC).

3. BER Performance Analysis

We assume that the transmission power of the source is P_s , the transmission power of the relay is P_r , and each antenna belonging to the same node has equal transmission power. The average power of noise received by each antenna is assumed to be N . The combined signals \tilde{x}_1 and \tilde{x}_2 can also be expressed as

$$\begin{aligned} \tilde{x}_1 = & \frac{P_s}{2} \sum_{i=1}^2 \sum_{j=1}^2 |h_{SDj,i}|^2 x_1 + \frac{P_r}{2} \sum_{i=1}^2 \sum_{j=1}^2 |h_{RDj,i}|^2 \hat{x}_{R1} + \sqrt{\frac{P_s}{2}} (h_{SD1,1}^* n_{SD1}^1 + h_{SD2,1}^* n_{SD2}^1 + h_{SD1,2}^* n_{SD1}^{2*} + h_{SD2,2}^* n_{SD2}^{2*}) \\ & + \sqrt{\frac{P_r}{2}} (h_{RD1,1}^* n_{RD1}^1 + h_{RD2,1}^* n_{RD2}^1 + h_{RD1,2}^* n_{RD1}^{2*} + h_{RD2,2}^* n_{RD2}^{2*}) \end{aligned} \quad (22)$$

$$\begin{aligned} \tilde{x}_2 = & \frac{P_s}{2} \sum_{i=1}^2 \sum_{j=1}^2 |h_{SDj,i}|^2 x_2 + \frac{P_r}{2} \sum_{i=1}^2 \sum_{j=1}^2 |h_{RDj,i}|^2 \hat{x}_{R2} + \sqrt{\frac{P_s}{2}} (h_{SD1,2}^* n_{SD1}^1 + h_{SD2,2}^* n_{SD2}^1 - h_{SD1,1}^* n_{SD1}^{2*} - h_{SD2,1}^* n_{SD2}^{2*}) \\ & + \sqrt{\frac{P_r}{2}} (h_{RD1,2}^* n_{RD1}^1 + h_{RD2,2}^* n_{RD2}^1 - h_{RD1,1}^* n_{RD1}^{2*} - h_{RD2,1}^* n_{RD2}^{2*}) \end{aligned} \quad (23)$$

From Equations (22) and (23), it is easy to find that the instantaneous signal-to-noise ratios (SNRs) of the S-D link, S-R link, and R-D link are

$$\gamma_{SD} = \frac{P_S}{2N} \|\mathbf{H}_{SD}\|_F^2 = P_S \xi_{SD} \quad (24)$$

$$\gamma_{SR} = \frac{P_S}{2N} \|\mathbf{H}_{SR}\|_F^2 = P_S \xi_{SR} \quad (25)$$

$$\gamma_{RD} = \frac{P_R}{2N} \|\mathbf{H}_{RD}\|_F^2 = P_R \xi_{RD} \quad (26)$$

Where $\|\mathbf{H}\|_F$ denotes the Frobenius norm of \mathbf{H} . ξ_{SD} , ξ_{SR} , and ξ_{RD} are the instantaneous SNRs of the S-D link, S-R link, and R-D link, respectively, while $P_S = P_R = 1$.

$$\xi_{SD} = \frac{\|\mathbf{H}_{SD}\|_F^2}{2N} \quad (27)$$

$$\xi_{SR} = \frac{\|\mathbf{H}_{SR}\|_F^2}{2N} \quad (28)$$

$$\xi_{RD} = \frac{\|\mathbf{H}_{RD}\|_F^2}{2N} \quad (29)$$

For a quasi-static flat fading channel, the channel fading can be viewed as constant during a frame period. We assume BPSK modulation and consider a single frame. The final BER after decoding can be expressed as

$$p_{e_CO} = (1 - p_{e_r}) \times p_{e_d1} + p_{e_r} \times p_{e_d2} \quad (30)$$

Where p_{e_r} is the decoding error probability of the relay, p_{e_d1} is the decoding error probability of the destination while the relay decodes correctly, and p_{e_d2} is the decoding error probability of the destination while the relay decodes incorrectly.

The decoding error probability of the relay p_{e_r} can be calculated by the following expression:

$$p_{e_r} = Q(\sqrt{2\gamma_{SR}}) \quad (31)$$

Where $Q(\cdot)$ represents the Gaussian Q-function.

For BPSK modulation, if the relay decodes x_1 correctly, i.e., $\hat{x}_{R1} = x_1$, we have

$$\begin{aligned} \tilde{x}_1 = & \frac{P_S}{2} \sum_{i=1}^2 \sum_{j=1}^2 |h_{SDj,i}|^2 x_1 + \frac{P_R}{2} \sum_{i=1}^2 \sum_{j=1}^2 |h_{RDj,i}|^2 x_1 + \sqrt{\frac{P_S}{2}} (h_{SD1,1}^* n_{SD1}^1 + h_{SD2,1}^* n_{SD2}^1 + h_{SD1,2} n_{SD1}^{2*} + h_{SD2,2} n_{SD2}^{2*}) \\ & + \sqrt{\frac{P_R}{2}} (h_{RD1,1}^* n_{RD1}^1 + h_{RD2,1}^* n_{RD2}^1 + h_{RD1,2} n_{RD1}^{2*} + h_{RD2,2} n_{RD2}^{2*}) \end{aligned} \quad (32)$$

From Equation (32), we can see that while the relay decodes correctly, the SNR of the combined signal \tilde{x}_1 is

$$\gamma_1 = \gamma_{SD} + \gamma_{RD} \quad (33)$$

With regard to \tilde{x}_2 , we obtain a similar result.

From Equation (33), we see that under the condition that the relay decodes correctly, the decoding error probability of the destination is

$$P_{e_d1} = Q\left(\sqrt{2(\gamma_{SD} + \gamma_{RD})}\right) \quad (34)$$

For BPSK modulation, if the relay decodes x_1 incorrectly, we have

$$\begin{aligned} \tilde{x}_1 = & \frac{P_S}{2} \sum_{i=1}^2 \sum_{j=1}^2 |h_{SDj,i}|^2 x_1 - \frac{P_R}{2} \sum_{i=1}^2 \sum_{j=1}^2 |h_{RDj,i}|^2 x_1 + \sqrt{\frac{P_S}{2}} (h_{SD1,1}^* n_{SD1}^1 + h_{SD2,1}^* n_{SD2}^1 + h_{SD1,2} n_{SD1}^{2*} + h_{SD2,2} n_{SD2}^{2*}) \\ & + \sqrt{\frac{P_R}{2}} (h_{RD1,1}^* n_{RD1}^1 + h_{RD2,1}^* n_{RD2}^1 + h_{RD1,2} n_{RD1}^{2*} + h_{RD2,2} n_{RD2}^{2*}) \end{aligned} \quad (35)$$

From Equation (35), we can see that while the relay decodes x_1 incorrectly, if $\frac{P_S}{2} \sum_{i=1}^2 \sum_{j=1}^2 |h_{SDj,i}|^2 - \frac{P_R}{2} \sum_{i=1}^2 \sum_{j=1}^2 |h_{RDj,i}|^2 \geq 0$, i.e., $\gamma_{SD} \geq \gamma_{RD}$, the overall effect is x_1 . If $\frac{P_S}{2} \sum_{i=1}^2 \sum_{j=1}^2 |h_{SDj,i}|^2 - \frac{P_R}{2} \sum_{i=1}^2 \sum_{j=1}^2 |h_{RDj,i}|^2 < 0$, i.e., $\gamma_{SD} < \gamma_{RD}$, the overall effect is $-x_1$.

While the relay decodes incorrectly, the SNR of the combined signal \tilde{x}_1 is

$$\gamma_2 = \frac{\left(\frac{P_S}{2N} \sum_{i=1}^2 \sum_{j=1}^2 |h_{SDj,i}|^2 - \frac{P_R}{2N} \sum_{i=1}^2 \sum_{j=1}^2 |h_{RDj,i}|^2 \right)^2}{\frac{P_S}{2N} \sum_{i=1}^2 \sum_{j=1}^2 |h_{SDj,i}|^2 + \frac{P_R}{2N} \sum_{i=1}^2 \sum_{j=1}^2 |h_{RDj,i}|^2} = \frac{(\gamma_{SD} - \gamma_{RD})^2}{\gamma_{SD} + \gamma_{RD}} \quad (36)$$

We obtain a similar result with regard to \tilde{x}_2 .

From Equation (36), we see that while the relay decodes incorrectly, the decoding error probability of the destination is

$$P_{e_d2} = \begin{cases} Q\left(\sqrt{\frac{2(\gamma_{SD} - \gamma_{RD})^2}{\gamma_{SD} + \gamma_{RD}}}\right), & \gamma_{SD} \geq \gamma_{RD} \\ 1 - Q\left(\sqrt{\frac{2(\gamma_{SD} - \gamma_{RD})^2}{\gamma_{SD} + \gamma_{RD}}}\right), & \gamma_{SD} < \gamma_{RD} \end{cases} \quad (37)$$

4. Energy Gain Analysis

We assume that the BER is required to be less than or equal to p_e , and the transmission rate of the cooperative MIMO system is the same as that of direct transmission. The energy gain of the cooperative MIMO system can be written as

$$G = 10 \lg \left(\frac{P_d}{P_{co}} \right) \quad (38)$$

Where P_d and P_{co} are the minimum transmission power of the direct transmission and the cooperative transmission, respectively, that satisfy the BER requirement.

From Equations (24) and (27), we obtain the minimum transmission power of the direct transmission as

$$P_d = \frac{[Q^{-1}(p_e)]^2}{2\xi_{SD}} \quad (39)$$

In Equation (38), the minimum transmission power of the cooperative transmission can be expressed as

$$P_{co} = P_{co}^S + P_{co}^R \quad (40)$$

Where P_{co}^S is the transmission power of the source and P_{co}^R is the transmission power of the relay.

In this paper, we define the power allocation coefficient of the cooperative MIMO system as

$$k = P_{co}^S / P_{co} \quad (41)$$

We consider two extreme scenarios. While $\gamma_{RD} \gg \gamma_{SD}$ and $\gamma_{RD} \gg \gamma_{SR}$, according to Equations (24) to (31), (34), and (37) to (41), we get the following approximate expressions:

$$P_{co} \approx \frac{[Q^{-1}(p_e)]^2}{2k\xi_{SR}} \quad (42)$$

Combining Equations (38), (39), and (42), we get

$$G \approx 10 \lg \frac{k\xi_{SR}}{\xi_{SD}} \quad (43)$$

While $\gamma_{SR} \gg \gamma_{SD}$ and $\gamma_{SR} \gg \gamma_{RD}$, we have

$$P_{co} \approx \frac{[Q^{-1}(p_e)]^2}{2k\xi_{SD} + 2(1-k)\xi_{RD}} \quad (44)$$

Combining Equations (38), (39), and (44), we get

$$G \approx 10 \lg \left[k + (1-k) \frac{\xi_{RD}}{\xi_{SD}} \right] \quad (45)$$

It can be seen from Equations (43) and (45) that notable energy gain is possible to be obtained only when the following two conditions are satisfied simultaneously:

$$\xi_{SR} > \xi_{SD} \quad (46)$$

$$\xi_{RD} > \xi_{SD} \quad (47)$$

If one of these two conditions is not satisfied, the energy gain will be negative or very small.

Figure 2 shows the energy gain curves of the cooperative MIMO system varying with k under different channel conditions. It can be seen that when Equation (46) or Equation (47) is not satisfied, the energy gain is very small or even negative. The previous theoretical analysis is validated.

We can also see from the figure that when both Equations (46) and (47) are satisfied, the approximation of the optimal power allocation coefficient could be expressed as [11].

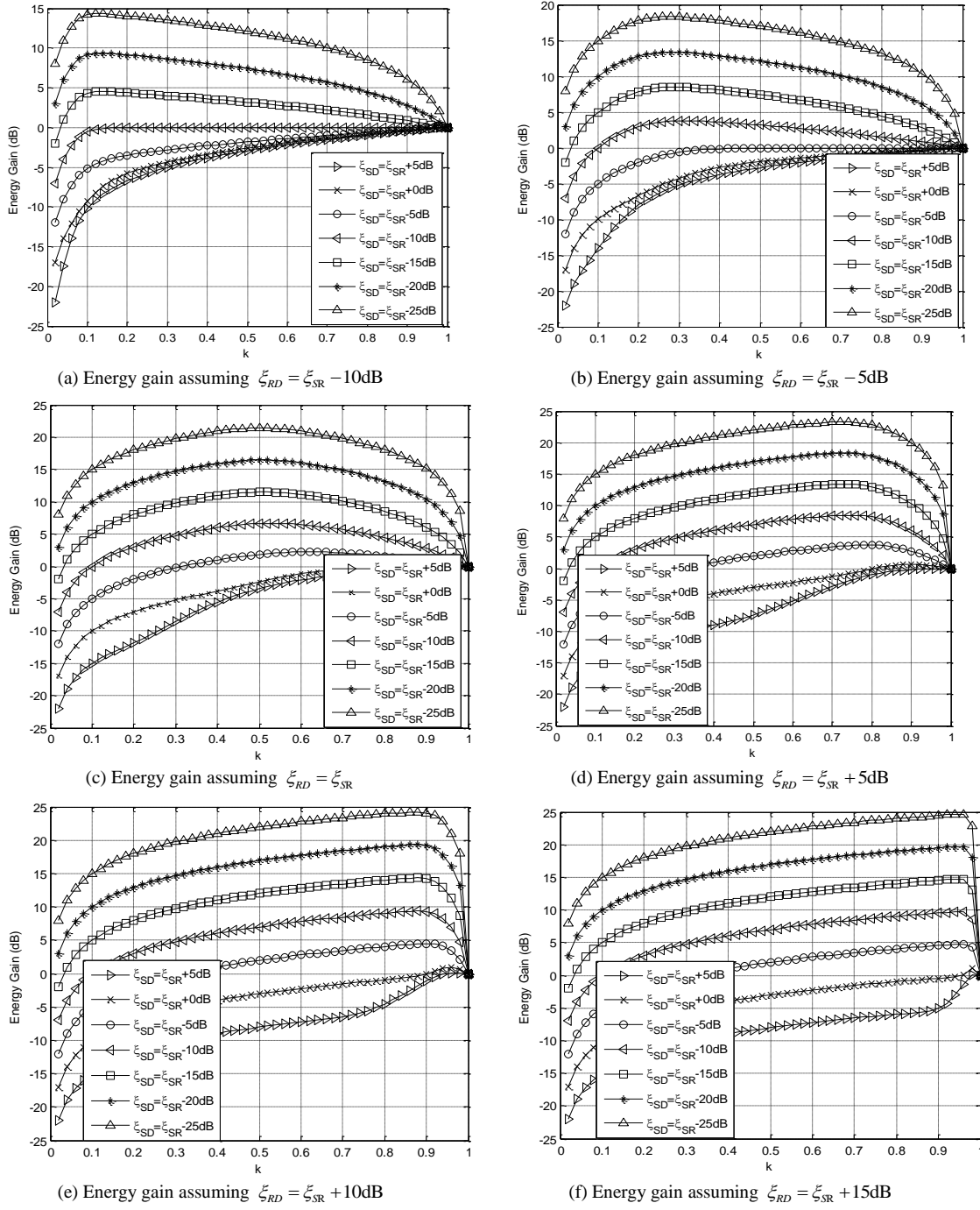


Figure 2. Energy gain

$$\tilde{k}_{opt} = \begin{cases} 0.1, & \xi_{RD}(\text{dB}) - \xi_{SR}(\text{dB}) \leq -10\text{dB} \\ 0.5 + 0.04[\xi_{RD}(\text{dB}) - \xi_{SR}(\text{dB})], & -10\text{dB} < \xi_{RD}(\text{dB}) - \xi_{SR}(\text{dB}) < 10\text{dB} \\ 0.9, & \xi_{RD}(\text{dB}) - \xi_{SR}(\text{dB}) \geq 10\text{dB} \end{cases} \quad (48)$$

It can be seen from the figure that if the power allocation coefficient k equals \tilde{k}_{opt} , the energy gain is very close to the maximal value, which means that if we substitute \tilde{k}_{opt} for the exact optimal power allocation coefficient k_{opt} , the reduction in energy gain would be slight.

5. Improved WLF Relay Selection Algorithm Combined with Power Allocation

In this paper, we consider non-reciprocal cooperation in the environment of quasi-static fading. We select relay and allocate transmission power according to instantaneous CSI. The optimization objective is to maximize the average energy gain of the network, which means minimizing the total transmission power while a certain BER requirement is satisfied.

The proposed algorithm is based on the classic WLF matching algorithm, which can achieve very high average energy gain with low computational complexity. The basic idea of the WLF matching algorithm is that the user with worse channel condition has a higher priority to choose its partner. Since the user with worse channel condition needs more energy consumption, its cooperation usually brings higher energy gain.

For each candidate relay, we need to calculate the optimal power allocation coefficient k_{opt} and then calculate the minimum transmission power that satisfies the BER requirement. Therefore, the number of candidate relays and the calculation method for k_{opt} have a great impact on the computational complexity of the algorithm. In the presented joint power allocation and relay selection algorithm, a considerable portion of relay candidates that cannot provide notable energy gain are directly excluded according to two cooperation thresholds, i.e., Equations (46) and (47). The approximation \tilde{k}_{opt} , which can be easily calculated according to Equation (48), is used to replace the exact optimal power allocation coefficient k_{opt} . Thus, the computational load would be reduced greatly.

The improved WLF relay selection algorithm combined with power allocation can be described as follows:

- 1) The base station (BS) selects a user i with the worst channel condition from the set \mathbf{S}_{un} . Here, \mathbf{S}_{un} denotes the set of users that have not been matched with relays.
- 2) For each candidate relay in the set \mathbf{S}_r that satisfies Equations (46) and (47), the BS calculates the approximation of the optimal power allocation coefficient according to Equation (48) and then calculates the minimum transmission power of the cooperative transmission that satisfies the BER requirement. Here, \mathbf{S}_r represents the set of candidate relays.
- 3) The BS selects a user j from the set \mathbf{S}_r as the relay of user i , such that the cooperation would provide the maximum energy gain. The BS then deletes user i from the set \mathbf{S}_{un} and deletes user j from the set \mathbf{S}_r .
- 4) Repeat Steps 1 to 3 until the set \mathbf{S}_{un} is empty.

6. Numerical Results

In this section, we present numerical results for the improved WLF relay selection algorithm combined with power allocation and the traditional WLF relay selection algorithm.

We consider the uplink transmission in cellular networks. Users are uniformly distributed on a unit disk centred at the BS. We assume quasi-static flat Rayleigh fading channels. The average channel coefficients are inversely proportional to d^α , where d is the transmission distance, and α is the path loss exponent that takes the value 3 in the simulation. It is assumed that the correlation coefficient between the antennas of the same terminal (source or relay) is 0.3, and the correlation coefficient between the antennas of the BS (destination) is 0.

Figure 3 shows the average energy gains of three relay selection algorithms. It can be seen that the average energy gain of the improved WLF relay selection algorithm combined with power allocation is approximately 0.5 dB higher than that of the traditional WLF algorithm. In addition, the average energy gains of the two algorithms are much higher than that of the random selection algorithm, and they increase slightly as the number of users in a cell increases. This is because the number of candidate relays increases as the number of users increases, and thus the BS is more likely to find a better relay for each source.

Figure 4 shows the average calculation amounts of the proposed algorithm and the traditional WLF relay selection algorithm. It is supposed that the calculation amount of calculating the approximation of the optimal power allocation coefficient \tilde{k}_{opt} according to Equation (48) is negligible, and the calculation amount of calculating the required minimum

transmission power according to the instantaneous SNRs and \tilde{k}_{opt} is 1. We can see that the average calculation amount of the improved WLF algorithm combined with power allocation is much lower than that of the traditional WLF relay selection algorithm. This is because the proposed algorithm uses two cooperation thresholds to exclude a considerable part of candidate relays, and the approximations of the optimal power allocation coefficients can be easily calculated.

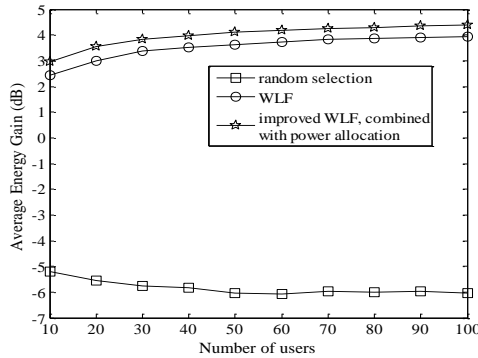


Figure 3. Average energy gain

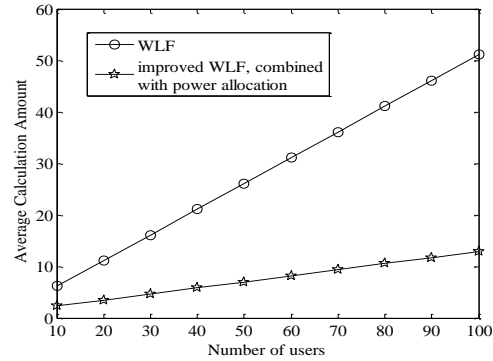


Figure 4. Average calculation amount

7. Conclusions

In this paper, an improved WLF relay selection algorithm combined with power allocation is proposed. The presented algorithm takes maximizing the average energy gain as the optimization purpose, and it selects relays and allocates transmission powers according to the instantaneous SNRs. Since the approximations of the optimal power allocation coefficients can be easily calculated and two cooperation thresholds are used to exclude a considerable part of candidate relays, the computation load is reduced greatly. The numerical results show that compared with the traditional WLF relay selection algorithm, the average energy gain of the proposed algorithm is higher and the computational complexity is much lower.

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