

An improved relay selection of cooperative MIMO based on channel priority matching algorithm

Trung Tan Nguyen¹

¹ Faculty of Radio-Electronic Engineering, Le Quy Don Technical University, Viet Nam.
trungtan68@gmail.com

Abstract. In recent years, cooperative communication as well as relay selection problem have been known as a new research area that may provide many interesting applications in practical networking system. In this paper we consider a cooperative multiple input multiple output (Co-MIMO) system in which multiple antenna of mobile terminals are used. We examine the content of centralized cooperative relay selection and propose a new relay selection method based on channel priority matching algorithm. In the specific algorithm, we presented thresholds for Worst-Link-First Matching (WLF). Theoretical and simulated results indicated that our proposed algorithm can achieve higher performance and lower computational complexity.

Keywords: Cooperative MIMO, Worst-Link-First Matching, relay selection.

1 Introduction

Cooperative communication is a new research area that may have many interests due to spatial diversity gain, system throughput increase and multi-antenna terminals are not a requirement [1-3]. In cooperative communications network, transmission between source and destination was helped by a relay. There are more than one candidate relays, which makes the question how to select relay to maximize the system performance. Beside that, MIMO technique has known as a effective solution in performance improvement and reducing fading influence on radio communications systems. The combining of cooperative communication and MIMO is a trend.

There are many previous works focused on cooperative relay selection. In reference [4], Zinan Lin considered the concept of the user cooperative area, only when users in this area were chosen to be relay, this method required distance information between different nodes.

Reference [5] proposed user grouping method that is to match the nodes in an area into pairs to cooperative implement. Relay selection is actually how to match the pairs. Random matching is the simplest method that randomly selects two unmatched users and then matches them together until there are fewer than two unmatched users remaining. Although its computational complexity is because of randomness in matching, this method provides very limited energy gain. Partner selection based on bipartite graphs was mentioned in [5] which is an optimal algorithm that can achieve the largest gain but rarely used in practical system due to the complexity.

With a non-bipartite weighted-matching model, the energy gain optimization problem can be solved using Maximum Weighted (MW) matching algorithm that is equivalent to maximizing . In this algorithm, each mobile user in a cell is presented as a point, S is set of edges between points, the w_{ij} has a weight which equals to the energy gain by cooperation between users i and j . The maximum weighted-matching algorithm may be the optimal solution for the non-bipartite weight-matching model due to the highest energy gain achievement but still deal with complex computation . To repair this, the Greedy matching algorithm is proposed in [6] this algorithm can be an approximate optimum with lower computational complexity than bipartite weight-matching algorithm . With mobile users and interrupted traffic, the matching algorithm must be constantly implemented in real time. Thus, it is necessary to further decrease the complex computation without influence too much on energy gain. So it comes to Worst-Link-First Matching (WLF) algorithm [7] with computational complexity reducing to .

As the user with the worse channel quality (far from BS) consumes more energy than the one with a better channel quality (near BS), cooperation generally provide more energy gain to the far user than the near one. Therefore, in radio cell networks, those users have worse channel quality and higher energy consumption should be given a higher priority. In the traditional WLF algorithm, distance energy loss is used to select partner, which can guarantee lower computational complexity than the previous, but it is important to know location information for all users. On the other hand, the traditional WLF has not considered how difference when the system consists of users equipment are equipped multiple antenna.

This paper examined Decode-and-Forward (DF) scheme and centralized relay selection problem, proposed a new cooperative relay selection method based on WLF algorithm extended to MIMO systems. In the specific algorithm, we presented thresholds for WLF. Threshold 1 was established to prevent channel gain very low or no gain after cooperation. Threshold 2 guaranteed maximum system performance. Relay selection based on channel matrix used in this paper. Thus, it is not important for BS to know location information of users. Analysis and simulation results show that the proposed algorithm can yield higher performance and lower computational complexity.

The rest of paper is organized as follows. System model is described in Section 2. Section 3 presented channel priority matching algorithm between users. Section 4 shows simulation analysis in algorithm performance of the priority matching between users. Finally, a conclusion is provided in section 5.

2 System model

This paper uses system model shown in Figure 1 in which the destination (BS of radio cell or an access point in a WLAN) can supports N mobile users.

Any user can cooperate with another user. In our model, each user is equipped with multiple antenna. The numbers of antenna and relay node are optional. For simply purpose, assume all equipment uses 2 antennas, 2-hop transmission via a selected relay. s is the transmitted signal from the source nodes, $s = [s_1, s_2]^T$ in which s_n is

the symbol transmitted from the n antenna of the source node and $n = 1, 2, \dots$ is the antenna index. The communication between the source and destination is done in 2 phases. Phase 1 is the direct link between two nodes and phase 2 is the relaying link, a selected intermediate node decoded received signal and forwarded it to destination. In this model, we only take interested in link between source and intermediate relay node. The channel matrix between the source and any intermediate node $j, j = 1, 2, \dots, K$ is defined as

$$\mathbf{H}^{sr_j} = \begin{bmatrix} h_{11}^{sr_j} & h_{12}^{sr_j} \\ h_{21}^{sr_j} & h_{22}^{sr_j} \end{bmatrix} \quad (1)$$

y_j are the received signal at the relay node j .

$$y_j = \mathbf{H}^{sr_j} s + z_{r_j} \quad (2)$$

where z_{r_j} is the noise vector affecting the receiver of the relay j .

Because cooperation is not always useful, a pair of users can choose not to cooperate if it does not provide energy gain. In that case, they communicate with BS via a conventional non-cooperative scheme.

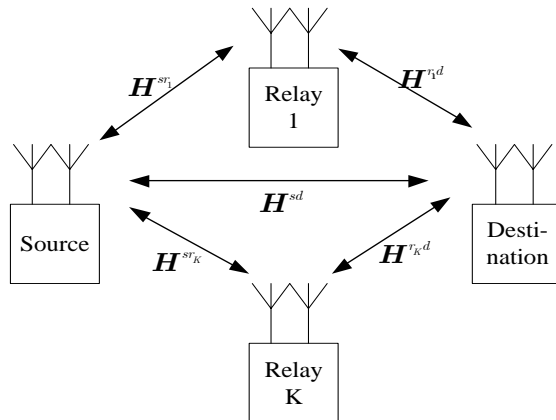


Fig.1: System Model

3 Channel priority matching algorithm between users

Traditional WLF algorithm is shown in Figure 2.

The user with the worst channel quality (furthest from BS) consumes more energy for transmission than the near one. Therefore, these users need a higher priority level because of poor channel quality and energy-consuming quantity. This requires

location information for all users. The algorithm selects the user with the best channel quality matches the user with the worst channel quality matches, and then removes those two users, selects the best one and the worst user in the remaining to match each other until the number of users have not matched is less than 2 as shown in Figure 2.

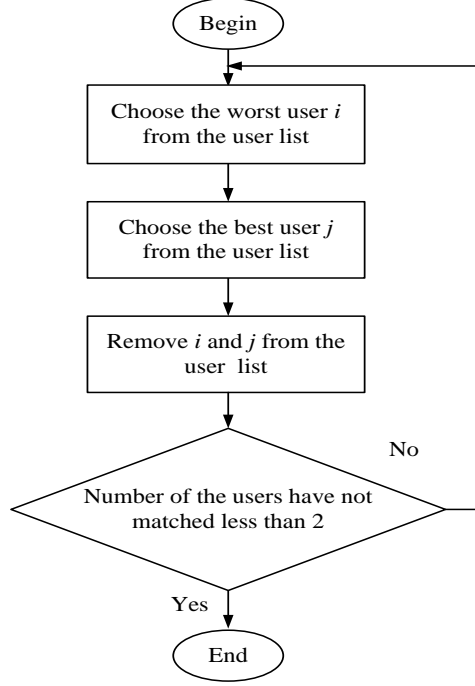


Fig. 2: Classic WLF algorithm process

A new method in Figure 3 uses channel matrix H to appreciate the channel condition and relay selection instead of the distance energy loss. So it is not important for the base station to control location of all users. Matrix H is included in CSI as basic information provided in MIMO systems use space-time block code. In this algorithm, relay j self-calculated attitude square of channel between relay j , source and destination, respectively. The minimum value is selected. The intermediate relay nodes compare all of these minimum values and choose the maximum one. Selection algorithm can be described by the following equation

$$h_j = \min \left\{ |h_{sj}|^2, |h_{jd}|^2 \right\} \quad (3)$$

The relay j that has h_j maximum is the best selected relay node.

The delay time at j th relay node is $T_j = \frac{\lambda}{h_j}$ with λ is constant.

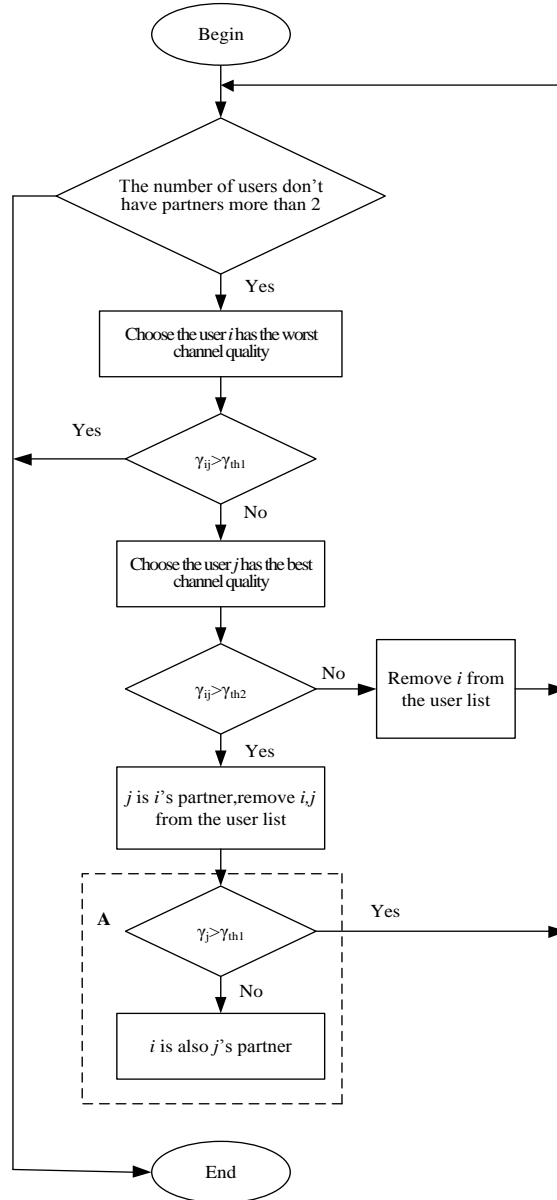


Fig.3: WLF algorithm with threshold

In the specific algorithm, we presented thresholds for WLF. Threshold 1 is to avoid the situation as channel conditions between the users and the base station are so rich that no necessary to cooperation or cooperation provides immeasurable gain. This threshold implies that relay and relay selection just are applied when extremely necessary to minimize complexity. Threshold 2 was set up to guarantee maximum average energy gain. Threshold 1 and 2 can be expressed in equation 4. In Figure 3, A proce-

sure is to avoid wasted resource when channel station is good so no essential for user j does not need to select a partner.

Assume that space-time coding used in transmitter and maximum likelihood decoding for receiver. Signal-to-noise ratio in the process of selecting should be

$$\gamma = \frac{E\|H\|_F^2}{2N_0} \quad (4)$$

is required energy to send 1bit information. N_0 is one-sided power spectral density of Gaussian white noise. H is channel matrix for the corresponding link, $\|\bullet\|_F^2$ is Frobenius square norm, that is $\|H\|_F^2 = \sum_{i=1}^{M_t} \sum_{j=1}^{M_r} |H_{j,i}|^2$, $H_{j,i}$ is the channel coefficient from the j -th transmitting antenna to the i -th receiving antenna.

Using BPSK modulation, the instantaneous bit error rate in the non-cooperative scheme can be expressed as

$$P_1 = Q(\sqrt{2\gamma_{SR}}) \quad (5)$$

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{t^2}{2}} dt \quad (6)$$

Similar in the case of cooperation

$$P_{CO} = P_1 \times \alpha + (1 - P_1) \times P_2 \quad (7)$$

P_1 for phase 1, error probability at relay can be

$$P_1 = Q(\sqrt{2\gamma_{SR}}) \quad (8)$$

P_2 for phase 2, when relay decoded received signal from source, error probability at destination is expressed as

$$P_2 = Q(\sqrt{2(\gamma_{SR} + \gamma_{RD})}) \quad (9)$$

α for the error probability at destination when relay decoded incorrectly. When relay decodes incorrectly, which means the source sends BPSK s , while relay forwards $-s$ so when $\gamma_{SD} \geq \gamma_{RD}$, it is equivalent to send s , so

$$\alpha = Q\left(\sqrt{\frac{(\gamma_{SD} - \gamma_{RD})^2}{\gamma_{SD} + \gamma_{RD}}}\right) \quad (10)$$

When $\gamma_{SD} < \gamma_{RD}$, it is equivalent to send $-s$, so

$$\alpha = 1 - Q\left(\sqrt{\frac{(\gamma_{SD} - \gamma_{RD})^2}{\gamma_{SD} + \gamma_{RD}}}\right) \quad (11)$$

System performance evaluation based on the average BER usually used for the distributed algorithm. In the centralized algorithm, user matching is performed by the base station, so applying it is no longer suitable (because BER of individual users may be high however the average BER of the system is low). Thus this paper appreciated system performance based on the average energy gain. The definition can be written as [7].

$$G = 10\lg\left(\frac{\sum_{i=1}^N E_{bi}^{no}}{\sum_{i=1}^K (E_{bi}^S + E_{bi}^R) + \sum_{i=K+1}^N E_{bi}^{no}}\right) \quad (12)$$

In the cellular uplink channel, energy loss is a significant problem. Thus, energy gain can be a measurement for the relay selection algorithm. Generally, there is a requirement for minimum bit error rate in each system, under a given acceptable BER, the average energy gain is used in terms of energy saving in cooperation compared to non-cooperation. Assume that a system can support N users, K users is matched to cooperate, the remaining $N - K$ users do not have a partner.

E_{bi}^m , ($m = R, S, no$) represents the required energy for source node (user i) to transmit 1 bit in non-cooperative scheme. E_{bi}^S, E_{bj}^S represents the required energy for source

node (user i) and relay node (user j) to transmit 1 bit in cooperative scheme. $\sum_{i=1}^N E_{bi}^{no}$ is

independent on matching algorithm, from equation 12 we can see that when

$\sum_{i=1}^K (E_{bi}^S + E_{bi}^R)$ is minimum, the system can achieve maximum average energy gain.

4 Simulation analysis performance of the priority matching between users

4.1. Simulation parameters.

The simulation conditions are summarized in Table 1. We assume that there are N mobile users, Rayleigh fading channel, the base station can know CSI between the terminals and the base station.

Setting of the Threshold 1: Figure 4 shows how the average power gain of multi-antenna system changes with threshold 1 (γ_{th1}) when the number of users are 60, 80, 100. Threshold 1 was established to prevent channel gain from being very low or no gain after cooperation. This reduces the complexity of the system and avoids unnecessary cooperation. At this time, threshold 2 (γ_{th2}) is replaced by two theoretic

cal thresholds to guarantee the transmission performance of the cooperation. Two theoretical thresholds are $\gamma_{SR} > \gamma_{SD} \times 2$ and $\gamma_{RD} > \gamma_{SD}$. First assumes that $R \rightarrow D$ link state is ideal, and three-point single-hop model, when $\gamma_{SR} > \gamma_{SD} \times 2$ cooperative gain is occurred. Further assumes that the link $S \rightarrow R$ is ideal, the source and relay transmits with unit power. Then the equivalent SNR is $\gamma_{RD} + \gamma_{SD}$, in cooperative scheme total energy is 2. In the non-cooperative scheme, the equivalent SNR is γ_{SD} and the total energy is 1. If the transmit energy increases to 2, the corresponding equivalent SNR increases to $2\gamma_{SD}$. To make sure that the cooperative gain can be achieved, $\gamma_{RD} + \gamma_{SD} > 2\gamma_{SD}$ is satisfied, that is the threshold $\gamma_{RD} > \gamma_{SD}$. From the above analysis, we can see that both of these thresholds are minimum in the theoretical analysis to start achieving energy gain.

Table 1: Simulation parameters

Cooperative model	2 hops, DF
Cooperative scenarios	Time division duplex, transmitting and receiving in the same frequency
Transmit diversity scheme	Alamouti Space-time block code
Modulation	BPSK
Number of antennas in each node	2
System error rate	10^{-3}
Channel	Rayleigh Flat fading channel
Power spectral density for Gaussian white noise	1

Figure 4 evidently shows that value of threshold 1 rises, the system performance improves quickly. This is because the threshold 1 was set to decline the requirement of cooperation. But if threshold 1 is greater than 5, the system gain is not obvious. This is due to the excessively high value of threshold 1, users with better self-condition channel still cooperate even when they can achieve significant performance without cooperation. However, the smaller γ_{th1} value can reduce the computational complexity of the system. So the appropriated value of γ_{th1} can be 5.

Setting of the Threshold 2: Figure 5 shows how the average power gain of the MIMO system and threshold 2 (γ_{th2}), when the numbers of users are 80, 90, 100. Obvious from the diagram, in the case of threshold 1 is fixed, average energy gain varies quickly with the threshold 2. As the value of threshold 2 increased, the system performance improves. This is because the adding of threshold 2 increases the quality of cooperation. However when this threshold continues to increase, the average energy gain of the system began to decline sharply. From Figure 5, maximum average

energy gain is obtained when threshold 2 is approximate 3, so select 3 as the value of threshold 2.

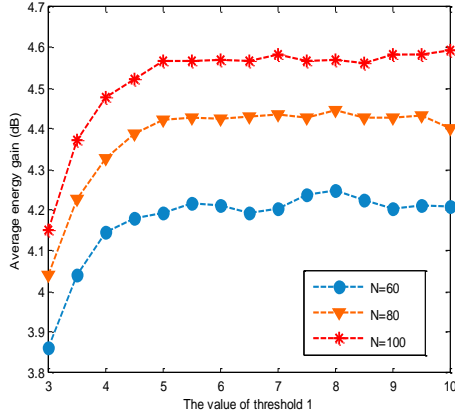


Fig. 4: The determination of threshold 1

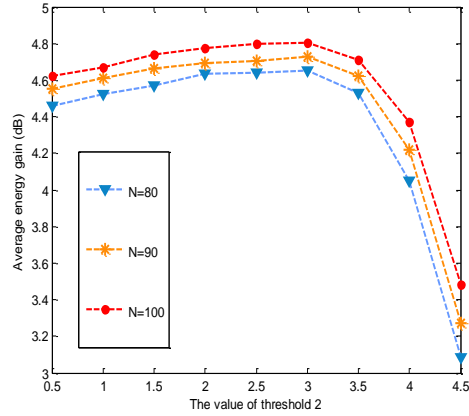


Fig. 5: The determination of threshold 2

Figure 6 is a performance comparison between 2 situations. First, the value of threshold 1 is 5, and threshold 2 is 3. Second, using 2 theoretical thresholds $\gamma_{SR} > \gamma_{SD} \times 2$ and $\gamma_{RD} > \gamma_{SD}$. As can be seen from the figure, more than 0,25dB in average energy compared with the case using the two theoretical thresholds. So we choose the threshold 2 instead of two theoretical thresholds.

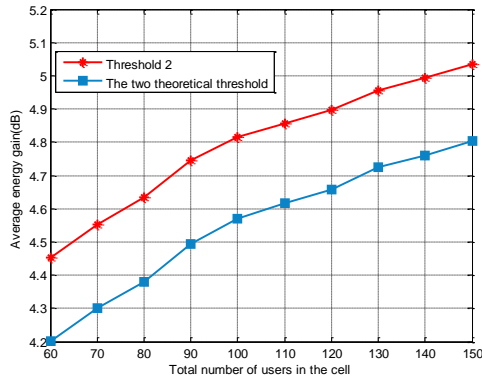


Fig.6: Performance comparison of channel priority matching algorithm between users using the threshold 2 and using 2 theoretical thresholds.

4.2. Analysis of algorithm performance.

Table 2 indicates that in the channel priority matching algorithm between users using multiple antenna, the number of users has not found a partner is independent on the total number of users. The data are average of 1000 simulation calculation. When the total number of users increases, the number of users has not found partner un-

changed. So probability that users are not able to find partners is low when distributed density of users is high (The number of users is large). We vary the number of users for both high density and low density case. Figure 3, 4, 5, 6 all show that the larger number of users, the higher average energy gain of the system can be achieved. It implies the that channel priority matching algorithm can get better performance in a high density system such as in the shopping malls, schools, apartments, stadiums.

Table 2: Number of users can not find partners when total number of users is changed

Total number of users in the cell	60	70	80	90	100	110	120	130	140	150
Users not find partner	5	5	5	5	5	5	6	6	6	6

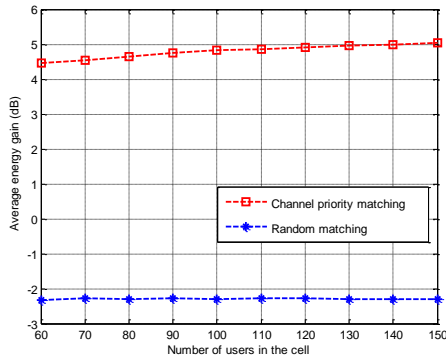


Fig.7: Performance comparison of channel priority matching and random selection algorithms

Figure 7 is a performance comparison between the priority matching algorithms and random selection algorithms applied to the MIMO system in terms of energy consumption. Random selection algorithm is simple but low energy gain. The energy gain is nearly unchanged when the number of users changes. With the channel priority matching algorithm, the larger number of users, the higher distributed density, the more considerable energy gain. This also describes how much important of the selection algorithms is in the cooperative MIMO system.

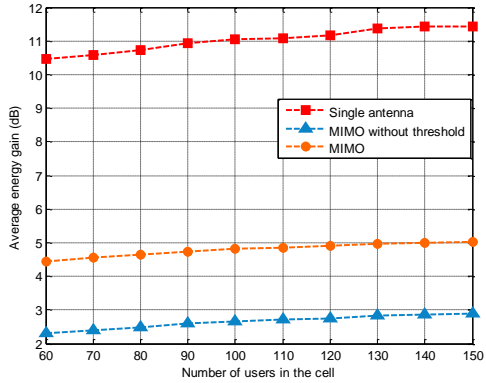


Fig.8: Performance comparison of performance comparison at different situations

Figure 8 shows how the average energy gain of the WLF algorithm for the multi-antenna system is influenced by the number of users in case using threshold and without threshold. And it is also the relation between the average energy gain and number of users in MIMO system compared with the single antenna system.

We can obviously see from Figure 8 that the selection algorithm with threshold provides higher average energy gain. Average power gain of the MIMO system has been lower than the single antenna system. Channel priority matching algorithm for

MIMO system has brought average energy gain, but it is less than the single-antenna systems. Because each MIMO terminal is equipped multiple antennas (it is assumed that 2 antennas in this paper), so even if without cooperation, it still yields the diversity gain, under a same certain BER, required energy for MIMO terminal users to transmit 1 bit is less than that for single-antenna system users without cooperation, while the gain from the cooperation is limited, so the average energy gain for the MIMO system with relay selection is not as much as the single antenna system. In simulation process, under the same number of simulation, the performance of the MIMO system is more stable, while performance of the single antenna system is volatile. Only when the number of simulation increases to a magnitude, the performance of the single-antenna system become stable.

5 Conclusion

In this paper, a channel priority selection algorithm between users for multiple antenna system was proposed. Analysis and theoretical results for average energy gain were put into simulation. The simulation results match the theoretical ones and proves that the channel priority algorithm between users provided a better gain of average energy and better performance in a high distributed density network, and it is more suitable for shopping malls, schools, apartments, and this kind of high-density user system. Threshold setting and selecting a channel priority matching algorithms between users have great impact on the performance of multi-antenna system. Reasonable setting of the threshold gains 2dB more in average energy.

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