A Novel Relay Selection with Power Allocation-Based Mechanism in Interference Environment

Binh Van Nguyen, Yoondong Sung, Kiseon Kim
Department of Information and Communication
Gwangju Institute of Science and Technology (GIST)
1 Oryong-dong, Buk-Gu, Gwangju, 500-712, Republic of Korea
{binhnguyen, syd9035, kskim}@gist.ac.kr

Abstract—In this paper, the behavior of relay networks in interference environments is investigated. It has been shown that the effect of interference during Amplify-and-Forward process at relays bounds the diversity slope of the system at a well-defined static point. Moreover, the conventional relay selection criteria are also shown to be inefficient. To help our systems to improve its performance, the power allocation issue is taken into account with relay selection. However, solving a jointly optimization problem, optimizing transmitted power and maximizing the received SNR corresponding with the potential relay simultaneously, are difficult. In other words, it requires high complexity manipulation procedures. By proposing a power allocation and a relay selection separately, then combining these two methods, we form a new relay selection with power allocation-based mechanism that is less complex and has comparable performance with the optimal process.

I. INTRODUCTION

In wireless communications, the advantages of the multiple-input multiple-output (MIMO) technique is well-known. However, wireless devices may not be able to support the implementation of multiple antennas due to cost, size, and hardware limitations. In order to help single antenna equipments benefit from MIMO systems, cooperative communication was proposed. Based on the broadcast nature of wireless medium, neighbor users (devices in the source’s transmission range) can hear transmissions from the source, cooperative diversity allows these neighbor users to help the transmitter relay its signal to the receiver. Throughout literature regenerative (DnF) and non-regenerative (AnF) are the most common relaying protocols. In the DnF, the relays first decode their received signal, then re-encode and transmit it to the receiver. In AnF, the relays just amplify and forward the received signal to the destination. Hence, AnF is a more efficient protocol than DnF with respect to complexity.

Recently, the relay selection has become the center attention for many researchers. Single and multiple relay selection criteria in free-interference environment are well-studied in [1],[2]. Especially in [1], the idea of many single and multiple relay selection schemes as well as their corresponding diversities were derived. Subsequently, the effect of multi-user interference was analyzed and a switching relay selection mechanism was proposed in [3] to help legacy systems, where Best Worse Channel (BWC) relay selection is pre-designed to improve its performance with simple modifications. These approaches, however, did not take the power control issue into account. Moreover, there is a noticeable gap among proposed relay selection criteria in [3] with the optimal one, which globally chooses the best relay based on the received Signal-to-Interference plus Noise-Ratio (SINR).

In this paper, we focus on relay selection in conjunction with power allocation. We simplify the original jointly optimization problem by analyzing these two problems separately. Then, we combine them to form a new relay selection power-based allocation mechanism to help our system to increase performance in interference environments.

The structure of the paper is as follows: the system model is defined in Section II. Section III describes a power allocation mechanism that allows our systems to adapt with the change of interference level. We also propose a novel relay selection criterion in this section. Simulation results are provided in Section IV, followed by our conclusion in Section V.

II. SYSTEM MODEL

The system model, we are considering in this paper, is depicted in Fig. 1. The system is a wireless relay network with a transmitter (S), a receiver (D), and K number of relays. There is a source S’ that causes interference into the AnF process at K relays but has a negligible effect at the destination. The
respectively. Channel gains over be described by the following set of equations: If the selected relay scales it received signal with the amplified gain $G$, then forwards it to the receiver. The system model can make sure that the received signal’s power is not greater than the maximum transmitted power of the selected relay. G is defined as:

$$G = \frac{\text{Transmitted power of the selected relay}}{\text{Received signal’s power of the selected relay}}$$

Regardless of the square root calculation, the numerator of Eq. 2 is equal to $P_{k^*}$, and the denominator is equal to: $|f_{S,k^*}|^2 P_S + |f_{S',k^*}|^2 P_{S'} + N_0$, where $P_S$ and $P_{S'}$ are the transmitted power of $S$ and $S'$, respectively. We assume that each relay knows its own channel conditions, and the receiver knows all channel values through training. The signal-to-interference and noise ratio of the received signal of the destination is defined as:

$$\gamma_D = \frac{\text{Power of original source’s signal}}{\text{Power of (interference source’s signal + noise)}}$$

and can be derived as [5]:

$$\gamma_D = \frac{\left| f_{S,k^*} \right|^2 P_S}{\left| f_{INF_k^*} \right|^2 P_{S'} + 1}$$

where we have assumed that the power of the noise is equal to 1. We express (4) as two following representations for later use:

- For the power allocation related section:

$$\gamma_D = \frac{ABP_S P_{k^*}}{CP_{S'} (1 + B P_{k^*}) + AP_S + B P_{k^*} + 1}$$

where: $A = |f_{S,k^*}|^2 , B = |f_{k^*,D}|^2 C = |f_{INF_k^*}|^2$.

- For the relay selection related section:

$$\gamma_D = \frac{\gamma_S k^* \gamma_D}{\gamma_{INF_k^*} (1 + \gamma_{k^*},D) + \gamma_{S,k^*} + \gamma_{k^*},D + 1}$$

where:

$$\gamma_{S,k^*} = |f_{S,k^*}|^2 P_{k^*} / N_0, \gamma_{k^*,D} = |f_{k^*,D}|^2 P_{k^*} / N_0$$

are the signal-to-noise ratios over a single hop.

### III. POWER ALLOCATION AND MIN-MIN RELAY SELECTION

It is conceivable that better system performance could be achieved if the transmitter and the potential relay adjust their power in accordance with the interference intensity. However, under these circumstances, the relay selection process is quite different from the conventional one. It can be considered a jointly optimization problem in terms of power allocation and relay selection. The optimal solution can be expressed as a two step process. We first allocate the optimal transmitted powers (if they exist) for the source and the relays. Then, we choose the best relay based on the received SNR of each potential relay. These processes however, require a lot of manipulations (or high complexity). In the following subsections, we relax the problem to one which has two separated subproblems. In the first subproblem, we assume that the source and the relay have the same transmitted power, we consider the relay selection without power allocation. We use some approximations to derive a simple computation (in terms of calculating received SNR $\gamma_D$ given in (6)) criterion for selecting a relay. In the second subproblem, we propose a power allocation that allocates the transmitted power for the source and the selected relay based on the interference intensity.

#### A. Min-Min Relay Selection

From (6) we can obtain:

$$\gamma_D = \frac{\gamma_{S,k^*} \gamma_{k^*,D} + 1}{\gamma_{S,k^*} \gamma_{k^*,D} + \gamma_{INF_k^*} (1 + \gamma_{k^*,D})} \approx \frac{\gamma_{INF_k^*} (1 + \gamma_{k^*,D})}{\gamma_{S,k^*}}$$

- Firstly, a tight upper bound for modified harmonic mean function of $\gamma_{S,k^*}$ and $\gamma_{k^*,D}$ was formulated as in [4]:

$$\frac{\gamma_{S,k^*} \gamma_{k^*,D}}{\gamma_{S,k^*} + \gamma_{k^*,D} + 1} \leq \min (\gamma_{S,k^*}, \gamma_{k^*,D})$$

- Secondly, in high SNRs region we can approximate the second term on the right-hand side of (9) as:

$$\frac{\gamma_{INF_k^*} (1 + \gamma_{k^*,D})}{\gamma_{S,k^*}}$$

where
Therefore, we obtain the upper bound for $\gamma_D$ as:

$$
\gamma_D \leq \frac{1}{\min(\gamma_{S,k^*}, \gamma_{k^*,D})} + \frac{\gamma_{INR_k}}{\gamma_{S,k^*}}
$$

(11)

In low SNRs region, we can assume that the second term on the denominator of (11) is dominated by the first term. Hence, the upper bound can be simplified as $\min(\gamma_{S,k^*}, \gamma_{k^*,D})$. It is shown in [3] that using this simplified upper bound to select a relay (BWC relay selection) can give comparable system’s bit error rate (BER) performance with that of the optimal one. Therefore, we expect that the upper bound, given in (11), is sufficient to describe the behavior of our system in the whole range of SNR.

**Proposal:** In the relay selection process, the receiver selects a relay that has the maximum value of $\gamma_D$. It is equivalent to find one relay that has the minimum value of $\{\min(\gamma_{S,k^*}, \gamma_{k^*,D})\}$. We call this criterion Min-Min relay selection.

**B. Power Allocation Mechanism**

We assume that the total transmitted power for the source and the selected relay is $E_T$. Firstly, without individual power constraints, we can consider our objective as maximizing (5) which is a function of $P_S$ and $P_{k^*}$. Using the 'Lagrange Multiplier' (LM) method, we formulate our problem as: maximizing the objective function given in (5) with respect to (w.r.t) the constraints: $g(P_S, P_{k^*}) = P_S + P_{k^*} = E_T$. We note that the transmitted powers have to be greater than 0 (because there is no direct transmission from S to D), and the solutions from LM do not tell us whether they give maximum or minimum values. Therefore, we need to substitute all possible solutions into our objective function to discover the desired one. After some manipulations, we get:

$$
\begin{align*}
P_S &= \frac{N_1}{B(1 + CP_{S^*})} \sqrt{N_1(1 + AE_T + CP_{S^*})} - A \\
= & \frac{\sqrt{N_1(1 + AE_T + CP_{S^*})} - (1 + AE_T + CP_{S^*})}{B(1 + CP_{S^*})} - A
\end{align*}
$$

(12)

where: $N_1 = (1 + BE_T)(1 + CP_{S^*})$

Secondly, if the individual power constraints: $0 < P_S \leq P_{S_{\text{max}}}$ and $0 < P_{k^*} \leq P_{k_{\text{max}}}$ are taken into account, we can formulate our problem as:

$$
\min \left( -\frac{ABP_S P_{k^*}}{CP_{S^*}(1 + BP_{k^*}) + AP_S + BP_{k^*} + 1} \right)
$$

with respected to:

$$
\begin{align*}
-P_S < 0; P_S &\leq P_{S_{\text{max}}} \\
-P_{k^*} < 0; P_{k^*} &\leq P_{k_{\text{max}}}
\end{align*}
$$

Solving above problem with the Karush-Kuhm-Tucker (KKT) condition procedures, we get:

$$
P_S = P_{S_{\text{max}}}; P_{k^*} = P_{k_{\text{max}}}
$$

(13)

as the only solution. Therefore, in this case, the optimal solution for power allocation is that each terminal should transmit with its maximum power.

**Proposal:** During the relay selection process, the receiver selects a relay following a pre-designed relay selection scheme. Then based on the interference level and the available $E_T$, the source and the selected relay adjust their transmitted powers with the power allocation rule given in (12) or (13).

**C. Relay Selection with Power-based Mechanism**

It is feasible to combine the two techniques, which are mentioned in two previous sub-sections, to form a power-based relay selection scheme: firstly, the receiver chooses a relay with the Min-Min relay selection method. Then, the transmitter and the selected relay adjust their power with the power allocation rule given in (12)-(13). Apparently, this scheme is much simpler than the best relay selection with optimal power allocation (their complexity orders are K+1 and 2K respectively).

**IV. SIMULATION RESULTS**

In this section, simulation have been carried out to validate the system performance of the proposed schemes. The simulation environment follows the system model of Section II with the set of parameters that are chosen similar to those in [3] and listed in TABLE II.

In Fig. 2, we simulate the average system’s BER versus total transmitted power to show the advantage of the proposed power control mechanism. In the case of BWC relay selection without power allocation, we assume that the source and the selected relay have the same transmitted power. In both cases (the interference levels are set to 10 dB and 20 dB), our scheme outperforms the conventional one. Generally speaking, the proposed power allocation scheme can be used for legacy systems, where conventional relay selection criteria are pre-designed, to improve system performance.

In following simulations, we use $L$ to control the interference level. A comparison of BER curves of several relay selection criteria with Min-Min relay selection method, which are considered in the context that each terminal transmit with its maximum power, show that our scheme can give almost the same performance with the best relay selection criterion (Fig. 3). Also note that in low SNRs region, Min-Min relay selection has the same performance as the BWC relay selection method. Hence, our proposed relay selection technique, which is based on the upper bound given in (11), is efficient to describe the system behavior throughout SNR’s range.

Fig. 4 shows the comparison among system performances

<table>
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<td><strong>SIMULATION PARAMETER</strong></td>
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Min-Min relay selection with power-based allocation mechanism, best relay selection with optimal power allocation, and other conventional relay selection criteria. Despite incurring simple manipulation procedures, the proposed scheme significantly improves the performance of the system. Moreover, it has comparable performance with the best relay selection in conjunction with optimal power allocation, which requires high complexity in selecting the relay node.

V. CONCLUSION

In this paper, we proposed Min-Min relay selection with a power-based allocation mechanism. Instead of allocating optimal power for each potential relay and then selecting the relay based on the received SINR, our scheme only controls the source and the selected relay transmit power, which is chosen by Min-Min relay selection criterion. The complexity order of our proposed scheme is \(K+1\) in comparison with \(2K\) of the best relay selection with optimal power allocation (where \(K\) is the number of relays in the network). Apparently, our scheme reduces the complexity of the relay selection process in the network with large number of relays. Although the proposed scheme incurs simple calculation procedures, it has comparable performance in comparison with the best relay selection combining with optimal power allocation. Finally, finding a practical technique that reduces the effect of interference at the relays’ side is considered as our future work.

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REFERENCES