Outage Minimization With Optimal Power Allocation Based On Cooperative Relaying and Partner Selection

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Abstract—Cooperative communication has characteristics of spatial diversity and virtual antenna, thus it can improve communication efficiency significantly in cellular or wireless data networks. One of the essential design issues in cooperative communication is partner selection mechanism. The problem of selecting suitable partners for a cooperative strategy is more complex when prospective partners have links of dissimilar quality to a central destination, leading to the possibility of non-reciprocal cooperation. In this paper, we consider a coded cooperative system under Rayleigh fading and path loss. We present a novel algorithm for partner selection and optimal power allocation in the Decode-and-Forward (DF) cooperative diversity that minimizes the outage probability given required total transmission power constraint. We evaluate the proposed algorithm by conducting simulations. Simulation results show that the selection strategy can increase duration of cooperation, as well as decrease the probability of unsuccessful partner selection. The results demonstrate that the outcomes of the proposed algorithm are very close to results of full search for optimal set.

Keywords—cooperative transmission, partner selection, decode-and-forward (DF), optimal power allocation, outage probability

I. INTRODUCTION

Cooperative diversity is a form of distributed spatial diversity achieved by cooperative communication among mobile users in cellular or wireless data networks [1]–[4]. The concept of cooperative diversity has been well explored in the recent years. Most existing wireless systems, such as 3G or IEEE 802.11 cellular systems, have independent nodes or users that communicate with the base station. For a low-mobility user, it is hard to exploit temporal diversity through interleaving. Meanwhile, spatial diversity through multiple antennas placed on a single device may be limited, owing to size constraints of the node. This technique of cooperative diversity has made it possible for single-antenna users in a local area to share each other’s antenna to form virtual antenna array, so that multiple independent transmission paths can be created to provide spatial diversity in the distributed way.

Furthermore, fading and interference impact on wireless channel qualities significantly. When failing to decode erroneous frames at receiving sides, those frames are dropped. Depending on application’s requirement, retransmissions may be triggered. However, retransmissions in a bad-quality channel lead to more retransmissions and thus system performance degrades seriously. Cooperative communication [5, 6] is an approach to deal with fading. The key concept of cooperative communication is the broadcast nature in wireless media. Inherently nodes can overhear signals of within-one-hop transmissions. Though the source has bad-quality channel to its destination, some neighbors may have good-quality channel conditions to the destination because of spatial diversity.

Various cooperative diversity protocols were proposed and analyzed in the recent years. In [1] and [2], Sendonaris et al. showed that cooperation between users leads not only to higher data rates, but also to little sensitivity to channel variations. Then, Lineman et al. proposed four different types of cooperation protocols, i.e. amplify-and-forward (AF), decode-and-forward (DF), selection relaying and incremental relaying [3]. The goal was to minimize the outage probability. Hunter and Nosratia [4] used rate-compatible punctured convolutional codes for the partnering users, and cyclic redundancy check (CRC) at the partner to arrive at an efficient coding scheme for cooperation. Channel capacity for cooperative systems has been studied in [5, 6].

The above-mentioned studies assume that a partner is already chosen. However, it is also important to be able to choose a partner among available users to maximize cooperation benefits for the user or the whole system. Therefore, for a given cooperative protocol, it is desirable to know exact conditions under which cooperation is useful.

In this paper, we propose a novel algorithm in order to minimize the outage probability in wireless channel. This algorithm is based on the optimal power allocation. Both of the problems of partner selection and power allocation for minimizing the outage probability with constraint of the total power are considered in this algorithm. The results of the proposed algorithm are very close to results of full search for optimal set. The outline of the paper is as follows: In Section II, the system model is introduced. Our proposed partner selection algorithm is described in Section III. Section IV analyze and discusses the performance of the system and
evaluation results. Finally, this paper concludes with Section V.

![Diagram](image)

**Figure 1. A simple model of cooperative relaying networks**

**II. SYSTEM MODEL**

As illustrated in Fig.1, the source terminal $S$ transmits information to the destination terminal $D$ with the help of the relay terminal $R$. A frame consists of two time slots with identical duration $T$. In the first time slot, source terminal $S$ broadcasts data to $R$ and $D$. In the second time slot, if non-cooperative mode is selected, $R$ remains silent and $S$ retransmits the data. Otherwise, cooperative mode is selected, and $R$ decodes and forwards the data to $D$ while $S$ keeps silent. We assume that $R$ utilizes the same code word while re-encoding. Additionally, maximum ratio combining (MRC) of the two signals is performed at $D$.

To consider a low-mobility environment, we assume that during the transmission procedure, or for each time slot, each user observes only one fading level towards the destination. Due to the spatial separation between users, these fades are independent. Hence, the user-to-destination channel is quasi-static, and the cooperative transmission results in a block-fading environment. The interuser channel is also assumed to be quasi-static and independent of user-to-destination links. For details of the coded cooperative scheme and channel model, we refer the reader to [7].

Amplitude squares of the channel coefficients, denoted by $a = |h_{sr}|^2$, $b = |h_{rd}|^2$, $c = |h_{rd}|^2$ as in Fig.1, are exponentially distributed random variables with means $\lambda_s, \lambda_r, \lambda_c$, respectively. The means capture the effect of path loss across the corresponding link. To consider the effect of the relay location on the performance of the network, we follow the model in Fig.2. In our analysis, we normalize the distance between the source and the destination, on the straight line connecting them. For a fixed path loss exponent, the effect of this normalization is scaling the average power. We denote the source-relay distance as $d$ and the relay-destination distance as $1-d$, where $0<d<1$. Then the overall network channel state, $s=(a,b,c)$ becomes a 3-tuple of independent exponential random variables with means $\lambda_a=1$, $\lambda_b=\frac{1}{d^\alpha}$, $\lambda_c=\frac{1}{(1-d)^\alpha}$, respectively, where $\alpha$ is the path loss exponent. For the numerical analysis we assume $\alpha = 4$, although path loss exponent depends on terrain and other environmental factors, this value approximately models metropolitan areas. We assume that the channel state $S$ is known at the source, the relay and the destination, while the phase information for $h_{sr}, h_{rd}, h_{rd}$, is only available at the corresponding receivers. Furthermore, we assume that there is along-term average total transmit power limitation, $P_{avg}$.

Our cooperation protocol is based on the decode-and-forward (DF) protocol of [3]. In [3], the transmission rate as

$$R_{DF} = \frac{1}{2} \min \{\log(1 + 2aP_s), \log(1 + 2aP_r + 2cP_h)\},$$

(1)

Direct transmission (DT) is preferable in some channel states as we have a total power constraint for the source and the relay, in DT mode, the transmission rate $R_{DT}$ can be expressed as

$$R_{DT} = \frac{1}{2} \log(1 + 2hP_s),$$

(2)

For DF and DT two models, to realize the maximum of the transmission rate, we can define $R_{max}$ as

$$R_{max} = \max\{R_{DF}, R_{DT}\},$$

(3)

where $P_s$ is transmitted power, $P_r$ is received power, and $P$ is total power of the system.

For fixed repetition DF strategy, the maximum average mutual information can be readily shown as [3]

$$I_{DF} = \frac{1}{2} \min \{\log(1 + SNR|h_s|^2),$$

$$\log(1 + SNR|h_d|^2 + SNR|h_d|^2)\},$$

(4)

and the outage probability of fixed DF strategy is

$$P_{DF} = P[I_{DF} < R]$$

$$= P[|h_s|^2 < g] + P[|h_s|^2 \geq g]P[I|h_s|^2 + |h_d|^2 < g],$$

(5)

where $g=[2^{2R}-1]/SNR$ is the constant that only depends on SNR and $R$; $|h_s|^2$ is exponentially distribution with the probability density function of $f(|h_s|^2) = \frac{1}{\sigma_s^2} \exp(-\frac{|h_s|^2}{\sigma_s^2})$, and
parameter $\sigma^i$ indicates the average channel gain from node $i$ to node $j$. Without loss of generality, we can regard path loss as this average channel gain, and therefore $\sigma^i$ is only determined by the geographical information of node $i$ and $j$.

The probability distribution of the channel gain between $S$ and $R$ is

$$P(i|h, \gamma \geq g) = \frac{1}{\sigma^i} \exp\left(-\frac{h}{\sigma^i}\right)dh = 1 - \exp\left(-\frac{g}{\sigma^i}\right),$$

and the outage probability of fixed DF strategy is

$$P_{out} = 1 + \frac{\exp\left(-\frac{g}{\sigma^i}\right)}{\sigma^i} \left[\exp\left(-\frac{g}{\sigma^i}\right) - \sigma^i\exp\left(-\frac{g}{\sigma^i}\right)\right].$$

### III. A Novel Partner Selection Method

In this section we assume that the rates and powers of all users are specified and invariant to the channel realizations. Our objective is to determine the optimal power allocation at each receiver as well as the relaying strategy in order to minimize the outage probabilities. Furthermore, no channel dependent feedback is possible between the destination and any user, but a limited amount of such feedback is possible between the destination and each relay.

#### A. Generic Partner Selection Method

For a given user, generic partner selection method makes the single relay, which provides “best” end-to-end path between source and BS, to be selected as the partner [8]. Here, the “best” means maximum energy gain over the fixed DF cooperative diversity [9]. As illustrated in Table 1, A sub-optimal relay selection algorithm is described as followed three rules, which can reduce the load of computing comparing methods mentioned in [9].

The algorithm needs all of channel gain information in node $S$ and $R$, but this simple comparison is a rough estimation and it cannot give any accurate modes of reaching maximum data rate based on the channel state information (CSI) of fading channel, so it is a second-best algorithm.

#### TABLE I. GENERIC PARTNER SELECTION METHOD

<table>
<thead>
<tr>
<th>Algorithm 1</th>
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<tbody>
<tr>
<td>(1) The channel quality between source and partner (received SNR at partner) should larger than the value of threshold [11];</td>
<td></td>
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<tr>
<td>(2) The user closest to the source user will be selected as the partner;</td>
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<tr>
<td>(3) Users whose channel quality (received SNR at BS) is better than the source should be selected first.</td>
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#### B. An Improved Algorithm Based On Optimal Power Allocation

As illustrated in Table 2, when the optimal model is DF mode, according to the channel state information (CSI) of fading channel, we make reasonable allocations of the average transmit power on node $S$ and $R$ and then we can further reduce the outage probability.

Therefore, for determining the optimal model, the algorithm needs only to view the current state of the channel belonging to the corresponding emission region and gives the best model accurately, and it only feeds back one parameter $M$, which can realize the optimal model under equal and optimal power distribution.

When the system is working on DF model, in a time slot, the average transmission power of node $S$ and $R$ satisfied

$$P = P_S + P_R.$$  

We assume that $P_S$, $P_R$ satisfied

$$P_R = kP_S(0 < k < \infty),$$

#### TABLE II. AN IMPROVED ALGORITHM BASED ON OPTIMAL POWER ALLOCATION

<table>
<thead>
<tr>
<th>Algorithm 2</th>
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<tbody>
<tr>
<td>(1) At node $D$ compares any instantaneous channel parameters $a$, $b$ and $c$, then selects these parameters of the optimal model belonging to the minimum emission pattern range of outage probability;</td>
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<tr>
<td>(2) Then, under current power constraints calculate the current optimal power allocation parameter $k$; and thus get the parameter $M$ $(0$ or $1)$ on the current needs of feedback;</td>
<td></td>
</tr>
<tr>
<td>(3) If the optimal model is DT mode, then feedback $M=0$ ; if it is DF mode , $M = k^*$;</td>
<td></td>
</tr>
<tr>
<td>(4) Then according to the value of $M$, node $S$ and $R$ can calculate the transmission power respectively.</td>
<td></td>
</tr>
</tbody>
</table>

When we have the maximum of the transmission rate $R_{DF}$ expressions which can be calculated as below:

when $R_1 = R_2$ , $a$, $b$, and $k$ satisfied $b = a + kc$ the transmission rate $R_{DF}$ can be further expressed as

$$R_{DF} = \left\{ \begin{array}{l} R_1,a + k c \geq b \\
R_2,a + k c < b \end{array} \right.$$  

where we substitutes the value of $R_{DF}$ from (3), (8) and $b = a + k c$ , then we have

$$R_{DF} = \frac{1}{2} \log(1 + 2b(k + 1)P_s),$$

and then we have the maximum of the transmission rate $R_{DF}$ expressions which can be calculated as below

$$R_{DF} = \left\{ \begin{array}{l} R_{DF},(c \geq a,a \leq \frac{b}{1 + k}) \\
R_{DF},(else) \end{array} \right.$$  

From (8), we define $R_{DF} = \log(1 + 2bP_s)$, $R_{DF} = \log(1 + 2aP_s + 2cP_R)$ respectively, the problem of
maximizing $R$ can be converted to the problem of optimization as below

$$\text{arg max}_{b, a, k} R_{\text{ESL}} = \log(1 + \frac{2b}{1+k} P),$$  \hspace{1cm} (13)$$

The constraint condition is $a \leq \frac{b}{1+k}, a + kc \leq b$, when $k = k_{\text{min}}$, the $R_{\text{ESL}}$ reaches its maximum which is

$$\frac{b-a}{c} \leq k \leq \frac{b-a}{c} - 1,$$  \hspace{1cm} (14)

The optimal solution of (13) can be expressed as

$$k^* = k_{\text{min}} = \frac{(b-a)/c}{c},$$  \hspace{1cm} (15)

The problem of maximizing $R_2$ can be converted to the problem of optimization as

$$\text{arg max}_{0, k} R_{\text{ESL}} = \log(1 + \frac{2aP}{1+k} + \frac{2ckP}{1+k}),$$  \hspace{1cm} (16)$$

The constraint condition is $c \geq a, a + kc \leq b$. The extreme value problem is converted to the optimization function $f(k)$ as

$$\text{arg max}_{0, k} f(k) = \frac{a + ck}{1+k},$$  \hspace{1cm} (17)$$

To calculate the derivative or differential of (17), we have

$$f(k)' = \frac{c-a}{(1+k)^2} \geq 0,$$  \hspace{1cm} (18)$$

When $k = k_{\text{max}}$, the $R_{\text{ESL}}$ reaches its maximum

$$0 \leq k \leq \frac{b-a}{c},$$  \hspace{1cm} (19)$$

The optimal solution of (16) can be expressed as

$$k^* = k_{\text{max}} = \frac{(b-a)/c}{c},$$  \hspace{1cm} (20)$$

Therefore, under optimal power allocation conditions, we can realize the minimum emission pattern range of outage probability when system only feeds back one parameter $M$.  

IV. SIMULATION RESULT AND ANALYSES  

In this section, we present the simulation results to show the accuracy of the proposed power allocation and partner selection algorithm. We have implemented a full search program using the technique of numerical optimization of [11] and the program is based on the optimal allocation of power with total power constraint proposed in [12]. We compare our results with the results of this full search approach.  

A. Simulation Settings  

As a sample simulation set up, 20 candidate nodes for cooperation are chosen in transmission from the source $S$ to the destination $D$. Path loss and quasi-static Rayleigh fading are considered, thus the channel gain between node $i$ and $j$ can be written as $H_{ij} = K_0 h_i d_i^{-\alpha}$, where $K_0$ and $\alpha$ are the path loss coefficient and exponent respectively, set up $K_0=1$ and $\alpha = 2$, we set $W=1Hz$, $N_w = 5 \times 10^6 Watt$ and $M = 10$ bits frame.  

B. Simulation Result  

Figure 3 shows the comparison between the performances of different algorithm outage probabilities when the system total average transmission power is $P=10dB$, the system transmission rate is $R=1$, and the distance parameter $d$ varies between 0.05 and 0.95. According to the results, the proposed algorithm is much better than DF mode as in [10]. The reason is that the proposed algorithm can calculate out and give the best mode precisely under any enhanced information channels while not just simply estimate value. The performance of the proposed algorithm could have great improvement when being operated under optimal power distribution, which is obviously better than DF mode. Therefore, it is an important way to improve the system performance.  

Figure 4 gives the performance curve of outage probabilities and the system total average transmission power $P$ when $d=0.5$ and the system transmission rate $R=1$. It is clear to observe from the graph that the Algorithm DF can get 5dB performance enhancement when using the algorithm of optimal power distribution which is given in this paper. Meanwhile, the algorithm presented in this paper greatly reduces the complexity of calculation and feedback, and get the result which is closest result to theoretical minimum outage probabilities as well.  

V. CONCLUSIONS  

In this paper, we propose a novel algorithm in order to minimize the outage probability in wireless channel. This algorithm is based on the optimal power allocation. Both of the problems of partner selection and power allocation for minimizing the outage probability with constraint of the total power consumption are considered in the proposed algorithm. The results of the proposed algorithm are very close to results of full search for optimal set. The simplicity of the proposed algorithm makes it suitable for implementation. Simulation results show that the proposed selection relaying scheme can efficiently minimize the outage probability.
Figure 3. Outage probabilities of different strategies. Simulated for: $P=10\,\text{dB}$, $R=1\,\text{bits/Hz}$.

Figure 4. Outage probabilities of different strategies. Simulated for: $d=0.5$, $P=10\,\text{dB}$, $R=1\,\text{bits/Hz}$.

REFERENCES


