

Min-total Relay Power Allocation Algorithm for Multi-user Cooperative Communication

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Abstract—We study the power allocation algorithms in the case of multi-source multi-relay (MSMR) amplify-and-forward wireless cooperative network in this paper. In this MRMS system, we consider that multiple users would communicate with one destination node with the help of multiple relay nodes in the same time. To guarantee the quality-of-service (QoS) for all the users and reduce the power consumption, we present min-total relay power allocation algorithm for relay nodes. Simulation results demonstrate the efficiency and fairness of our proposed strategy.

Keywords—Multi-user cooperative communication, power allocation, convex theory, second order cone programming, Rayleigh fading.

I. INTRODUCTION

Nowadays, more and more researchers and scholars are familiar with multiple-input multiple-output (MIMO) technology [1] which has been employed widely in wireless communication systems. It is well known that MIMO technology can provide space diversity and improve the system performance. But, in some cases, due to the limited size, processing power and other constraints, it is not practical for the terminals to implement multiple antennas. These limitations motivates the innovation of cooperative technology [2] based on single antenna nodes. The basic idea behind user cooperative communication is to exploit the broadcast nature of wireless transmission and create a virtual multiple antennas system. In [3], several low complexity protocols have been proposed and studied considering the main cooperative protocols, such as amplify-and-forward (AAF) and decode-and-forward (DAF).

Power allocation is a key technique for wireless system design. In cooperative communication, many power allocation strategies have been studied for different transceiver structures and protocols since the cooperative technology was proposed. The problem of power allocation for both regenerative and non-regenerative multihop systems is studied in [4]. It shows that the optimization of the power allocation enhances the system performance. In [5], the authors proposed the simple power allocation strategies for AF relaying that require only the knowledge of the mean fading coefficients of the channels, which aim to optimize the SNR gain and the outage performance to some extents. The distributed power allocation strategies for parallel relay networks with limited channel

state information at the source and the relay nodes were studied in [6]. It proposed a distributed decision mechanism for each relay to individually make its decision on whether to forward the source data or not. Two levels of channel state information, complete CSI and statistical CSI, and the optimal power allocation among the relay nodes in conventional AAF scheme was considered in [7]. In [8], the authors presented transmit power allocation for various cooperation protocols (AAF, DAF and DSTC) with mean CSI. In [9], two power allocation schemes for multi-user AAF wireless network were proposed, where the source and the destination appear in pairs.

Most of these works consider the single user scenarios and few works have considered the more practical case that the multiple users have the common destination like the base station in Cellular network. In this paper, we extend min-total based relay power allocation scheme for multi-user wireless relay systems. We take the quality-of-service (QoS) and the reduction of relay power consumption into account. This scheme aims at minimizing the total relay transmit power and guaranteeing the QoS for all the users. We show that the optimization problem can be formulated as second-order cone program (SOCP), which can be solved by using convex optimization techniques.

The rest of the paper is organized as follows. Section II describes the cooperative strategy and the model of multi-user wireless relay system. In Section III, the min-total based relay power allocation scheme has been presented. Simulation results about the system performance with the proposed power allocation scheme are presented in Section IV. Finally, the conclusions are drawn in Section V.

II. MULTI-USER COOPERATIVE SYSTEM MODEL

We consider a multi-user cooperative communication system with N_s users $S_i, i=1, 2, \dots, M$, one destination node (such as the base station) D , and N_R relays $R_j, j=1, 2, \dots, K$, as illustrated in Fig.1. N_s users have occupied orthogonal channels. And the system is assumed to be half-duplex, which means that all nodes can not transmit and receive at the same time and frequency band. We consider an AAF protocol. Each user has its own data to transmit to the destination. The transmission from each user to the destination node consists of two phases. In the first phase, each user broadcasts their information data and all the relays in listening mode. In the

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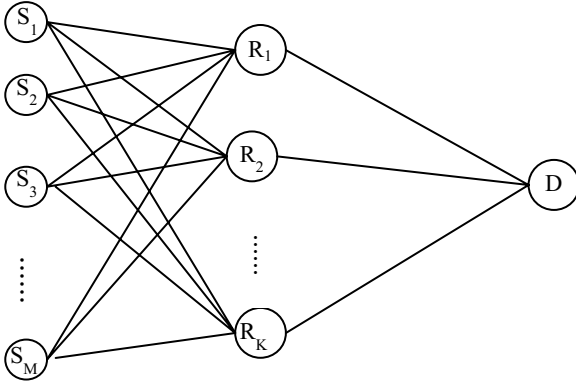


Figure 1. Simplified system multi-user cooperative model

second phase, the relays amplify the received signals and synchronously transmit them to the destination node.

In the first phase, the received signals of relay R_j from user i is

$$y_j^i = h_j^i \sqrt{P_S^i} x^i + n_j^i, \quad (1)$$

where h_j^i is channel gain between the user i and relay j , P_S^i denotes the power transmitted by user i , (S_i), x^i is transmitted signal by user i , and n_j^i is zero-mean and variance σ_1^2 white Gaussian noise adds to the signal at relay R_j . The received signal at relay R_j for each user is first normalized by $\left(\sqrt{|h_j^i|^2 P_S^i + \sigma_1^2}\right)^{-1} e^{j\theta_i}$, and the normalized signal from user i at the relay j is represented by

$$\bar{y}_j^i = \frac{1}{\sqrt{|h_j^i|^2 P_S^i + \sigma_1^2}} \left(h_j^i \sqrt{P_S^i} x^i + n_j^i \right) e^{j\theta_i}, \quad (2)$$

where the angle θ_i is used to adjust the phase of the signal. Then the normalized signal is transmitted to destination D from the relay R_j . The received signal transmitted from the user i at the destination is,

$$y_D^i = \sum_{j=1}^{N_R} g_j^i \sqrt{P_{R_j}^i} \bar{y}_j^i + n_D^i, \quad (3)$$

where g_j^i is the channel gain for user i between relay j and the destination node, $P_{R_j}^i$ is the power transmitted by the relay R_j for assisting the i th user and n_D^i is the zero-mean and variance σ_2^2 white Gaussian noise added to the signal at the destination. And it is obvious that an optimal choice of θ_i is $\theta_i = -(\arg h_j^i + \arg g_j^i)$ [1]. Thus substituting equation (2) into (3), we can get the received signal as,

$$\begin{aligned} y_D^i &= \sum_{j=1}^{N_R} |g_j^i| \frac{\sqrt{P_{R_j}^i}}{\sqrt{|h_j^i|^2 P_S^i + \sigma_1^2}} |h_j^i| \sqrt{P_S^i} x^i + \sum_{j=1}^{N_R} |g_j^i| \frac{\sqrt{P_{R_j}^i}}{\sqrt{|h_j^i|^2 P_S^i + \sigma_1^2}} v_j^i + n_D^i \\ &= \sum_{j=1}^{N_R} f_j^i l_j^i \sqrt{P_{R_j}^i} x^i + \sum_{j=1}^{N_R} f_j^i \sqrt{P_{R_j}^i} v_j^i + n_D^i \end{aligned} \quad (4)$$

where $f_j^i = \frac{|g_j^i|}{\sqrt{|h_j^i|^2 P_S^i + \sigma_1^2}}$, $l_j^i = |h_j^i| \sqrt{P_S^i}$, $v_j^i = n_j^i e^{-\arg h_j^i}$. Then

the signal received at the destination from user i can now be modelled as,

$$y_D^i = H^i F^i B^i x^i + N^i F^i B^i + n_D^i, \quad (5)$$

with row vector $H^i = [l_1^i \ l_2^i \ \dots \ l_{N_R}^i]$, diagonal matrix

$F^i = \text{diag}\{f_1^i \ f_2^i \ \dots \ f_{N_R}^i\}$, column vector

$B^i = [\sqrt{P_{R_1}^i} \ \sqrt{P_{R_2}^i} \ \dots \ \sqrt{P_{N_R}^i}]^T$ and row vector

$N^i = [N_1^i \ N_2^i \ \dots \ N_{N_R}^i]$. Then the signal-to-noise rate at

the destination γ^i is

$$\gamma^i = \frac{|H^i F^i B^i|^2}{\|F^i B^i\|^2 \sigma_1^2 + \sigma_2^2}. \quad (6)$$

III. MIN-TOTAL BASED RELAY POWER ALLOCATION IN MULTI-USER RELAY SYSTEM

In this section, we propose the min-total based relay power allocation scheme. The idea of scheme is to improve utilizations of relay's power, reduce relay power consumption and guarantee the transmission quality for each user. To simplify the processing at source, each user doesn't know the CSI, which is more practical in cellular network. Destination and relay nodes know CSI perfectly, which can be implemented by using training sequence or other channel estimate method.

In wireless communication network, to guarantee the transmission QoS of each user and to reduce the power consumption have the same importance. Due to case that the users do not know the CSI, we assume that the users have the same transmit power and we only consider the power allocation among the relay nodes. The power allocated to each relay is different with that the relay assigned to each user for the transmission of the user's information. We must ensure that the signal-to-noise ratio is not lower than the threshold and the total transmission power of all the relays can be minimized at the same time. So the power allocation scheme can be formulated as,

$$\begin{aligned} \min_{B^i} \sum_{i=1}^{N_S} \|B^i\|^2 \\ \text{s.t. } \gamma^{(i)} \geq \gamma_0. \\ i = 1, 2, \dots, N_S \end{aligned} \quad (7)$$

The constraint can be expressed as

$$\|F^{(i)} B^{(i)}\|^2 \sigma_1^2 + \sigma_2^2 \leq \frac{1}{\gamma_0} |H^{(i)} F^{(i)} B^{(i)}|^2. \quad (8)$$

It can be reformulated as

$$\|G^{(i)} B^{(i)} + b\|^2 \leq \frac{1}{\gamma_0} |H^{(i)} F^{(i)} B^{(i)}|^2, \quad (9)$$

where $G^{(i)} = \begin{bmatrix} f_1^{(i)}\sigma_1 & L & 0 \\ L & O & M \\ 0 & L & f_{N_R}^{(i)}\sigma_1 \\ 0 & L & 0 \end{bmatrix}$ is the $(N_R+1) \times N_R$ matrix

and $b = [0 \ L \ 0 \ \sigma_2]^T$ is the (N_R+1) column vector.

Without loss of generality, we can put in extra constraint as,

$$H^{(i)}F^{(i)}B^{(i)} \geq 0, i=1,2,L,N_s. \quad (10)$$

In the following, we make the definition of a column vector $B = [B^1 \ L \ B^{N_s}]^T$. The power allocation problem can be further modelled as,

$$\begin{aligned} \min_B \quad & \|B\|^2 \\ \text{s.t.} \quad & \|G^{(i)}B^{(i)} + b\| \leq \frac{1}{\gamma_0} H^{(i)}F^{(i)}B^{(i)} \\ & H^{(i)}F^{(i)}B^{(i)} \geq 0 \\ & i=1,2,L,N_s \end{aligned} \quad (11)$$

The power allocation problem can now be expressed as a SOCP like,

$$\begin{aligned} \min_B \quad & t \\ \text{s.t.} \quad & \|B\| \leq t \\ & \|G^{(i)}B^{(i)} + b\| \leq \frac{1}{\sqrt{\gamma_0}} H^{(i)}F^{(i)}B^{(i)} \\ & H^{(i)}F^{(i)}B^{(i)} \geq 0 \\ & i=1,2,L,N_s \end{aligned} \quad (12)$$

It can be shown that the optimization problem (12) is convex and its solution could be calculated with the application of the standard convex algorithms. The dual of this standard SOCP is

$$\begin{aligned} \min_x \quad & -\sum_{i=1}^{N_s+1} (b_i^T z_i + d_i w_i) \\ \text{s.t.} \quad & \sum_{i=1}^{N_s+1} (A_i^T z_i + C_i w_i) = f \\ & \|z_i\| \leq w_i, i=1,2,L,N_s+1 \end{aligned} \quad (13)$$

which can be solved by primal-dual potential reduction algorithm.

IV. SIMULATION RESULTS

In this section, we present simulation results of the two relay power allocation schemes over relay fading channel. In the multi-user relay system, we assume that the channel state information is perfectly known at the destination and relay nodes and users do not know SCI. This is easier to implement in cellular network. Take fixed nodes as relays which help those users whose channel state is very bad to base station.

Figure 2 and Figure 3 shows the total relay transmit power and SNR of the worst user for two relay power allocation respectively, min total relay power based power allocation and equal power allocation. In equal power allocation scheme each

relay has same transmit power and distributes equally among all relayed users and each user's SNR should not below the threshold. For the two scheme, we give the simulation results with SNR defined as $SNR = P_s/N_0$ (here we assume that $\sigma_1^2 = \sigma_2^2 = N_0$). We assume four users and three relays in the wireless relay network and the total relay power has a constraint. All users are assumed to have equal minimum SNR threshold $\gamma_0 = 10$ dB. And the total relay power can not exceed the constraint which we set 40.0dB to reduce power consume for practical consideration. As seen in Figure 2, we observe that the min total relay power allocation scheme has about 10dB gains at Total relay power=25.0dB compared with equal power allocation scheme. And it can reduce about 15.0dB power consumption at SNR=18.0dB compared with equal power allocation scheme. And in Fig.3 we can see that the two power allocation schemes can satisfy the SNR threshold in high SNR and the worst user's SNR of min total relay power allocation scheme is higher than that of equal power allocation scheme in low SNR. Then we draw the conclusion that the min total relay power allocation can provide better QoS and have lower total power consumption than equal power allocation scheme.

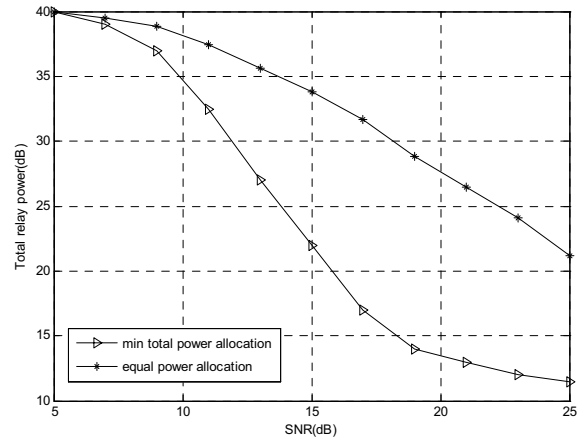


Figure 2. Performance of the total relay power vs SNR

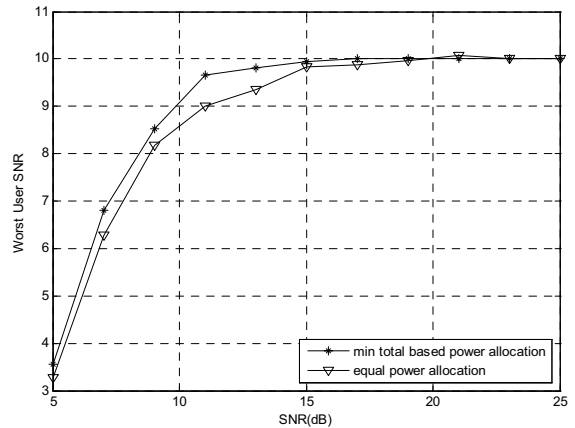


Figure 3. Worst user SNR case

V. CONCLUSIONS

In this paper, we have proposed min-total based relay power allocation schemes for wireless multi-user relay system. We have reformulated the optimization problems as a convex problem. Numerical results demonstrate the efficiency of the proposed relay power allocation scheme which can guarantee the QoS of each user evidently and reduce the relay power consumption.

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