

Cooperative Beamforming Based Selection and Power Allocation for Relay Networks

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Abstract—In this paper, we consider cooperative beamforming in an amplify-and-forward (AF) cooperative network with multiple relay nodes. Specially, only “appropriate” relay nodes are selected to perform cooperative beamforming. Source node can determine the relay nodes with just mean channel gain, which will reduce the complexity of obtaining instantaneous channel state information (CSI). This scheme guarantees that the energy is allocated to those “appropriate” relay nodes, and accordingly improves the energy efficiency. Therefore, it is able to provide superior diversity over the conventional cooperative beamforming. We also prove that power allocation (PA) between source and selected relay nodes is a convex problem, which can be resolved with lower computational complexity. Simulation results demonstrate that our scheme achieves an essential improvement in terms of outage performance, as well as high energy-efficiency for energy-constrained networks.

I. INTRODUCTION

Cooperative communication, in which single-antenna users share their antennas cooperatively to create a virtual multiple-input multiple-output (MIMO) system, has attracted a lot of attention [1]–[4]. The spatial diversity resulted from such virtual MIMO system leads to much higher data rate and more reliable services over a larger coverage. So far, quite a few cooperative strategies have been proposed, among which amplify-and-forward (AF) is the most popular one due to its simplicity and intuitiveness.

In the relay-based cooperative communication system, cooperative beamforming has been widely discussed to improve the performance for multiple-relay scenario. Most of these schemes weight their input according to the channel state information (CSI) feedback [5], [6] or prior information available [7]. All of the relay nodes participate in such beamforming scheme, which is known as the “all participate” cooperative beamforming (AP-BF). However, the fading characteristics of each cooperative link (source-relay-destination link) are always different, i.e., some cooperative links are under deep fading, while others are in good condition. Consequently, not all the relay nodes have constructive impacts on the end-to-end outage performance. Motivated by this observation, we further study the cooperative beamforming in order to improve the transmission reliability. A natural solution is to perform beamforming among the “appropriate” relay nodes.

[8] and [9] have already addressed the single relay selection. However, those available approaches, in which only

single relay is selected, cannot be directly applied to cooperative beamforming. In [9], sum power over source and all relay nodes is constrained jointly. Unfortunately, it does not resolve the power allocation across source and relay nodes. Bearing these two problems (single relay selection and power allocation) in mind, we propose a simple relay selection scheme to determine potential relay nodes that participate in the beamforming. In this scheme, source node only requires the knowledge of mean channel gains, which decreases the complexity of obtaining instantaneous CSI. Moreover, the “appropriate” relay nodes can be determined prior to the source transmission and the selected relays remain activated as long as the fading conditions do not significantly change, in an average sense. This characteristic guarantees only the CSI of the selected relay nodes should be known between these relays, which will dramatically decrease the extra payload of exchanging CSI under large size of network. This special cooperative beamforming can be seen as a selection cooperative beamforming (S-BF). Furthermore, under the proposed scheme, the power allocation (PA) across source and selected relay nodes is proven to be a standard convex problem which could further improve the outage performance with low computational complexity. Not only is S-BF scheme able to make full use of the transmit power, but also effectively exploit the cooperative diversity in the “appropriate” cooperative links. Extensive simulation results demonstrate that our cooperative scheme achieves better outage performance with lower complexity.

The rest of the paper is organized as follows. In Section II, we present the system model. In Section III, we introduce our proposed selection cooperative beamforming scheme. Simulation results of the cooperative scheme are presented in Section IV. Finally, we conclude this paper in Section V.

II. SYSTEM MODEL

We consider a half-duplex dual-hop relay wireless network in Fig. 1, where the direct path between the source (\mathcal{S}) and destination (\mathcal{D}) cannot be neglected. In the system model, \mathcal{S} communicates with \mathcal{D} with the help of K_R relay (\mathcal{R}) nodes. In order to keep low implementation complexity of the system, it is assumed that all the nodes employ a single antenna. The channels from source to relays, source to destination and relays to destination are assumed to be frequency non-selective

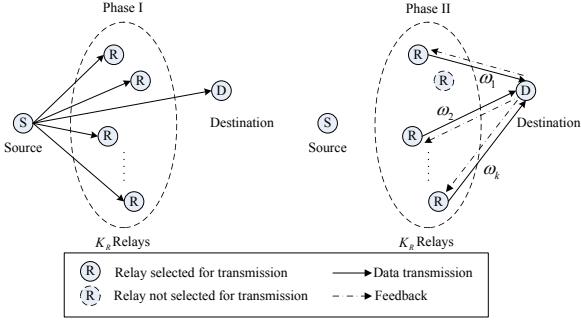


Fig. 1. System model used in this paper. Direct path between source and destination cannot be neglected.

and Rayleigh block-fading, i.e., the fading coefficients remain constant within each block and are independent between different blocks. In this paper, we further consider a sum power constraint over source and all relay nodes

$$\mathcal{P}_s + \mathcal{P}_r = \mathcal{P}_{sum}, \quad (1)$$

where \mathcal{P}_s is the transmission power of the source, \mathcal{P}_r is the aggregate relay transmission power allocated to the set $S_R = \{1, 2, \dots, K_R\}$ of K_R relay nodes. \mathcal{P}_{sum} is the end-to-end (i.e., source-relay-destination) transmission power. Notice that, the source power constraint and the aggregate relay power constraint are

$$\mathcal{P}_s = \zeta \mathcal{P}_{sum} \quad \text{and} \quad \mathcal{P}_r = (1 - \zeta) \mathcal{P}_{sum}, \quad (2)$$

where $\zeta \in (0, 1)$ and $(1 - \zeta) \in (1, 0)$ denote the fractions of the end-to-end sum power \mathcal{P}_{sum} allocated to the source transmission and overall relay transmission, respectively.

The transmission from \mathcal{S} to \mathcal{D} can be split into two phases. In the first phase, source broadcasts s with power \mathcal{P}_s to relay nodes and the destination node. Hence, the input-output relations of $\mathcal{S} \rightarrow \mathcal{R}_i$ and $\mathcal{S} \rightarrow \mathcal{D}$ links are given by

$$y_{s,i} = \sqrt{\mathcal{P}_s} h_{s,i} s + n_i, \quad (3)$$

$$y_{d,1} = \sqrt{\mathcal{P}_s} h_{s,d} s + n_{d,1}, \quad (4)$$

where s is the user data with unit energy, $h_{s,i} \sim \mathcal{CN}(0, \Omega_{s,i})$ and $h_{s,d} \sim \mathcal{CN}(0, \Omega_{s,d})$ denote the channel coefficients corresponding to the source to i th relay and source to destination links, respectively. n_i and $n_{d,1}$ represent the complex additive white Gaussian noise (AWGN) at the relay and destination nodes. We assume that the complex AWGN at each node has a power spectral density of N_0 .

In the second phase, relay node first scales the received signal uniformly. Then, it is amplified and forwarded to the destination. The equivalent signal to be transmitted at the i th relay node can be written as

$$x_i = \frac{y_{s,i}}{\sqrt{E\{|y_{s,i}|^2\}}} = \frac{\sqrt{\mathcal{P}_s} h_{s,i} s + n_i}{\sqrt{\mathcal{P}_s |h_{s,i}|^2 + N_0}}, \quad (5)$$

where $E\{\cdot\}$ denotes the statistic average. All K_R relay nodes transmit x_i , weighted by a complex beamforming weight w_i ,

simultaneously to the destination. So, the received signal at the destination is

$$y_{r,d} = \sum_{i=1}^{k_R} \frac{\sqrt{\mathcal{P}_s} \sqrt{\mathcal{P}_r} h_{s,i} h_{i,d} w_i s}{\sqrt{\mathcal{P}_s |h_{s,i}|^2 + N_0}} + \sum_{i=1}^{k_R} \frac{\sqrt{\mathcal{P}_r} h_{i,d} w_i n_i}{\sqrt{\mathcal{P}_s |h_{s,i}|^2 + N_0}} + n_{d,2}, \quad (6)$$

where $h_{i,d} \sim \mathcal{CN}(0, \Omega_{i,d})$ is the channel coefficient from the i th relay to destination, $n_{d,2}$ is the AWGN at the destination during the second phase.

Under the condition that the destination has the knowledge of all CSI and noise distributions, the received SNR at the destination for the AP-BF scheme can be expressed as

$$\gamma_d^{AP} = \gamma_{s,d} + \gamma_{r,d} = \frac{\mathcal{P}_s |h_{s,d}|^2}{N_0} + \frac{\left| \sum_{i=1}^{k_R} h_{sig}^i w_i \right|^2}{\left(1 + \sum_{i=1}^{k_R} |h_n^i|^2 |w_i|^2 \right) N_0}, \quad (7)$$

where h_{sig}^i and h_n^i represent

$$h_{sig}^i = \frac{\sqrt{\mathcal{P}_s} \sqrt{\mathcal{P}_r} h_{s,i} h_{i,d}}{\sqrt{\mathcal{P}_s |h_{s,i}|^2 + N_0}}, \quad (8)$$

$$h_n^i = \frac{\sqrt{\mathcal{P}_r} h_{i,d}}{\sqrt{\mathcal{P}_s |h_{s,i}|^2 + N_0}}. \quad (9)$$

The optimal cooperative beamforming vector can be determined by [10]

$$\mathbf{w}^* = \frac{(\mathbf{I} + \mathbf{h}_n \mathbf{h}_n^\dagger)^{-1} \mathbf{h}_{sig}}{\|(\mathbf{I} + \mathbf{h}_n \mathbf{h}_n^\dagger)^{-1} \mathbf{h}_{sig}\|_F}, \quad (10)$$

where \mathbf{w} and \mathbf{h}_{sig}^\dagger are column vectors, and their entries are w_i and h_{sig}^i , respectively. $\mathbf{h}_n = diag\{h_n^1, \dots, h_n^i, \dots, h_n^{K_R}\}$ is a diagonal matrix. $(\cdot)^\dagger$ denotes the Hermitian or conjugate transpose. $\|\cdot\|_F$ represents the Frobenius norm. The optimal cooperative beamforming vector is developed under the assumption of knowing full CSI at each relay node. Although it is hard for system implementation, optimal cooperative beamforming can serve as a reference compared with other beamforming schemes with limited feedback.

III. SELECTION BEAMFORMING FOR AF (S-BF-AF) COOPERATIVE NETWORKS

A. Relay Selection Scheme

Different source-relay-destination cooperative pairs have different fading characteristics for multiple-relay networks (i.e., some pairs have constructive impacts on end-to-end outage performance, while others have destructive ones). In this paper, a simple relay selection scheme is developed to determine which relay nodes will perform cooperative beamforming in the second phase. Initially, all the relay nodes are included in the relay subset. Then, the ones, which cannot satisfy the threshold, will be excluded step by step. Let x denote a relay node in the subset Ψ_{m+1} and cannot satisfy

the selection threshold. Consequently, the outage relationship between the Ψ_{m+1} and Ψ_m (excluding x th relay) should be

$$P_O^{m+1}/P_O^m > 1, \quad (11)$$

where P_O^m denotes the end-to-end outage probability from source to destination with m relays. Given the relay set Ψ_m , outage probability for the cooperative beamforming has been developed [10]

$$\begin{aligned} P_O^m \approx & \frac{1}{m!(m+1)} \cdot [(2^{(m+1)R} - 1)N_0]^{m+1} \\ & \cdot \frac{1}{\mathcal{P}_s \Omega_{s,d}} \cdot \prod_{i=1}^m \left(\frac{1}{\mathcal{P}_s \Omega_{s,i}} + \frac{1}{\mathcal{P}_r \Omega_{i,d}} \right), \end{aligned} \quad (12)$$

where R is the system rate. It has been proven that (12) has a better approximation with high SNR. Therefore, the left part of (11) can be rewritten as

$$\begin{aligned} \frac{P_O^{m+1}}{P_O^m} = & \prod_{\substack{i \in \Psi_{m+1} \\ i \neq x}} \frac{\frac{1}{\mathcal{P}_s \Omega_{s,i}} + \frac{1}{\mathcal{P}_r \Omega_{i,d}}}{\frac{1}{\mathcal{P}_s \Omega_{s,i}} + \frac{1}{\mathcal{P}_r \Omega_{i,d}}} \cdot \left[\frac{2^{(m+2)R} - 1}{2^{(m+1)R} - 1} \right]^{m+1} \\ & \cdot \frac{N_0 [2^{(m+2)R} - 1]}{(m+1)(m+2)} \cdot \left(\frac{1}{\mathcal{P}_s \Omega_{s,x}} + \frac{1}{\mathcal{P}_r \Omega_{x,d}} \right). \end{aligned} \quad (13)$$

It is reasonable that $\prod_{\substack{i \in \Psi_{m+1} \\ i \neq x}} \left(\frac{1}{\mathcal{P}_s \Omega_{s,i}} + \frac{1}{\mathcal{P}_r \Omega_{i,d}} \right) / \left(\frac{1}{\mathcal{P}_s \Omega_{s,i}} + \frac{1}{\mathcal{P}_r \Omega_{i,d}} \right) = 1$.

Under the constraint of (11), we have

$$\left(\frac{1}{\mathcal{P}_s \Omega_{s,x}} + \frac{1}{\mathcal{P}_r \Omega_{x,d}} \right) > \frac{(m+1)(m+2)}{N_0} \cdot \frac{[2^{(m+1)R} - 1]^{m+1}}{[2^{(m+2)R} - 1]^{m+2}}, \quad (14)$$

then, by performing some algebraic manipulations in (14), we have

$$\begin{aligned} \frac{1}{\zeta \cdot \Omega_{s,x}} + \frac{1}{(1-\zeta) \cdot \Omega_{x,d}} & > \frac{\mathcal{P}_{sum} \cdot (m+1) \cdot (m+2)}{N_0} \\ & \cdot \frac{[2^{(m+1)R} - 1]^{m+1}}{[2^{(m+2)R} - 1]^{m+2}}. \end{aligned} \quad (15)$$

In the next subsection, we will discuss how to calculate the PA coefficient ζ . Prior to source transmission, source node can decide the selected relay nodes with only mean channel gains, which will decrease the complexity of obtaining the instantaneous CSI and the payload of exchanging CSI between unnecessary relay nodes. The detailed procedure of the proposed selection cooperative beamforming scheme is introduced as Table I. Although this work mainly focus on the selection for optimal beamforming with unlimited feedback, the results can be easily extended to a limited feedback scenario and further reduce the information exchange.

Obviously, only K_R searches will be needed for our proposed scheme. Hence, this scheme reduces the complexity of selection procedure dramatically. The threshold in (15) is a monotone function of sum power and relay number. With fixed sum power, the larger size of subset leads to the smaller threshold, which means more relay nodes selected is a small probability event. On the contrary, the threshold will increase with the increasing of sum power when m is fixed. This characteristic shows that smaller size subset is more suitable

TABLE I
DETAIL PROCEDURE OF THE SELECTION COOPERATIVE BEAMFORMING FOR AF COOPERATIVE NETWORKS.

Step 1:	Initially, all potential relay nodes are included in the relay subset Ψ_m and set counter to $m = K_R$.
Step 2:	Calculate the selection metrics of each relay, $\theta_i = \frac{1}{\zeta \Omega_{s,i}} + \frac{1}{(1-\zeta) \Omega_{i,d}}$, and define two quantities (a) $Th_{K_R-m+1} = \frac{\mathcal{P}_{sum} \cdot (m+1) \cdot (m+2)}{N_0} \cdot \frac{[2^{(m+1)R} - 1]^{m+1}}{[2^{(m+2)R} - 1]^{m+2}}$, (b) $\Gamma_m = \max_{i \in [1, \dots, K_R]} (\theta_i)$. If $\Gamma_m \leq Th_{K_R-m+1}$, go to step 5. Else if $\Gamma_m > Th_{K_R-m+1}$, the i th relay is excluded from Ψ_m .
Step 3:	Set size of relay nodes to $m = m - 1$. Update Γ_m and threshold Th_{K_R-m+1} .
Step 4:	If $m = 1$, go to Step 5 . Else if $m > 1$, go to Step 2 .
Step 5:	Finally, each selected relay calculates the beamforming vector with (10) and forwards the received signal of the first hop multiplied by beamforming vector simultaneously.

for the poorer channel condition, while larger size subset will lead to more cooperative diversity gain under better channel condition.

B. Power Allocation Scheme

For the sum-power-constraint networks, the overall transmit power of the source and selected relays is a significant requisite resource. In this section, we present a low computational PA algorithm. This method can be used to resolve the PA for the sum power constrained cooperative networks, where only part of the relay nodes is selected for cooperative beamforming. Mathematically, the PA problem can be written as

$$\begin{aligned} \zeta^* = \arg \min_{0 < \zeta < 1} & P_O^m \\ \text{subject to : } & \mathcal{P}_s = \zeta \mathcal{P}_{sum} \\ & \mathcal{P}_r = \sum_{i=1}^m \mathcal{P}_i = (1-\zeta) \mathcal{P}_{sum} \\ & \mathcal{P}_s, \mathcal{P}_i \geq 0. \end{aligned} \quad (16)$$

Considering the relay subset Ψ_m^* with m relay nodes, this optimization problem can be simplified by

$$\begin{aligned} \zeta^* = \arg \min_{0 < \zeta < 1} & \frac{1}{\zeta \mathcal{P}_{sum}^{m+1} \Omega_{s,d}} \cdot \prod_{i=1}^m \left[\frac{1}{\zeta \Omega_{s,i}} + \frac{m}{(1-\zeta) \Omega_{i,d}} \right] \\ \text{subject to : } & \mathcal{P}_s + \mathcal{P}_r = \mathcal{P}_{sum} \\ & \mathcal{P}_{sum} \geq 0. \end{aligned} \quad (17)$$

With the relation between arithmetic and geometric inequality, we have

$$\begin{aligned} f(\zeta) & = \frac{1}{\zeta \mathcal{P}_{sum}^{m+1} \Omega_{s,d}} \cdot \prod_{i=1}^m \left[\frac{1}{\zeta \Omega_{s,i}} + \frac{m}{(1-\zeta) \Omega_{i,d}} \right] \\ & \leq \frac{1}{m^m \mathcal{P}_{sum}^{m+1} \Omega_{s,d}} \cdot \left\{ \sum_{i=1}^m \left[\frac{1}{\zeta^{1+\frac{1}{m}} \Omega_{s,i}} + \frac{m}{\zeta^{\frac{1}{m}} (1-\zeta) \Omega_{i,d}} \right] \right\}^m. \end{aligned} \quad (18)$$

The following theorem establishes the fact that the right part of the inequality (18) is a standard convex problem. Furthermore, the convex solution is developed.

Theorem 1. Given function $g(\zeta) = \zeta^{-\frac{1}{m}}[\frac{A}{\zeta} + \frac{Bm}{(1-\zeta)}]$, where $0 < \zeta < 1$, $A = 1/\sum_{i=1}^m \Omega_{s,i}$ and $B = 1/\sum_{i=1}^m \Omega_{i,d}$. $g(\zeta)$ is a convex function and the optimal solution of $g(\zeta)$ is

$$\zeta^* = \frac{-b + \sqrt{b^2 - 4ac}}{2a}, \quad (19)$$

where

$$\begin{aligned} a &= (m+1)(Bm-A), \\ b &= 2A(m+1)-Bm, \\ c &= -A(m+1). \end{aligned}$$

Proof: The second-derivative of $g(\zeta)$ with respect to ζ can be given by

$$\begin{aligned} \frac{d^2g(\zeta)}{d\zeta^2} &= A(1+\frac{1}{m})(2+\frac{1}{m})\zeta^{-\frac{1}{m}-3} + B\zeta^{-\frac{1}{m}-1}(1-\zeta)^{-3} \\ &\cdot [(\frac{m+1}{m} + 2m+2)\zeta^2 + 2(\frac{m+1}{m} - 1)\zeta + \frac{m+1}{m}]. \end{aligned} \quad (20)$$

Obviously, the first term of the right part of (20) is greater than zero. For the convenience of presentation, we define the quadratic function

$$y = (\frac{m+1}{m} + 2m+2)\zeta^2 + 2(\frac{m+1}{m} - 1)\zeta + \frac{m+1}{m}, \quad (21)$$

with the relation between roots and coefficients

$$\begin{aligned} \Delta &= 4(\frac{m+1}{m} - 1)^2 - 4(\frac{m+1}{m} + 2m+2)(\frac{m+1}{m}) \\ &= \frac{-8m^2 - 20m - 16}{m}, \end{aligned} \quad (22)$$

therefore, $\Delta < 0$. Because $\frac{m+1}{m} + 2m+2 > 0$, it can be concluded that $y > 0$. Consequently, we have $\frac{d^2g(\zeta)}{d\zeta^2} > 0$. With the help of [11, chap. 3.1.4], $g(\zeta)$ is a convex function. The derivative of $g(\zeta)$ with respective to ζ is given by

$$\begin{aligned} \frac{dg(\zeta)}{d\zeta} &= m\zeta^{-\frac{1}{m}}\zeta^{-2}(1-\zeta)^{-2}[(Bm-A)(m+1)\zeta^2 \\ &\quad + (2Am + 2A - Bm)\zeta - A(m+1)]. \end{aligned} \quad (23)$$

Setting (23) to zero, we get

$$\zeta_1 = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \quad \text{or} \quad \zeta_2 = \frac{-b - \sqrt{b^2 - 4ac}}{2a}. \quad (24)$$

With the prerequisite that $0 < \zeta < 1$

$$\zeta^* = \frac{-b + \sqrt{b^2 - 4ac}}{2a}, \quad (25)$$

where a, b and c are defined as Theorem 1. ■

In practical implementation, source node will calculate the PA coefficient with (25) according to the present relay subset and update the selection metrics θ_i before each selection.

IV. NUMERICAL AND SIMULATION RESULTS

In this section, simulation results are given to show the performance of the proposed cooperative scheme. In the simulation, there are only one source and one destination utilizing single antenna. There are $K_R = 20$ relays randomly located, which also maintain one antenna each. We consider a sum power constrained relay network, in which $\mathcal{P}_s + \mathcal{P}_r = \mathcal{P}_{sum}$. It is also assumed that the variance of AWGN at relay and destination nodes is $N_0 = 0dB$. We will quantify the performance differences between the proposed scheme and other schemes.

A. Comparison of Proposed Scheme with Other Schemes

In this section, we compare the proposed scheme with other cooperative schemes for the unlimited feedback scenario. We assume that all channels from source to destination are complex Gaussian distribution

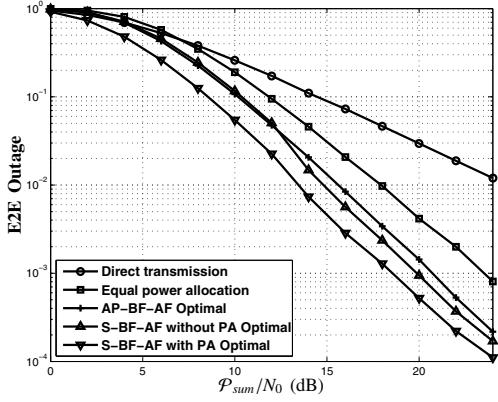
$$h_{a,b} \sim \mathcal{CN}(0, \frac{1}{(1+d)^\alpha}),$$

where “a” denotes the transmit node, “b” represents the receive node, d stands for the distance between node “a” and node “b”, α is the pathloss exponent (i.e., in this paper, $\alpha = 3$).

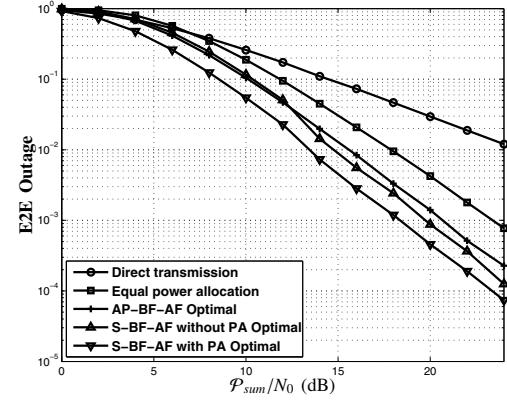
Fig. 4 shows the average outage performance for the cooperative beamforming with unlimited feedback, in which 6 relays and 8 relays are deployed, respectively. Cooperative beamforming schemes (i.e., AP-BF-AF, S-BF-AF) outperform the equal power allocation between all the relay nodes. In the lower SNR region, the performance improvement of S-BF-AF is finite for both 6 relays and 8 relays scenarios. Under this condition, only one relay can be selected to cooperate with source-destination pair, which dramatically decreases the amount of information exchange across all relay nodes without performance degradation. However, about $1 \sim 2dB$ improvement is achieved compared with AP-BF-AF for high SNR region. When the PA method is utilized, S-BF-AF achieves about $2 \sim 3dB$ performance improvement regardless of the reign of transmission power. Although (15) is derived based on the high SNR assumption, simulation results prove that S-BF-AF efficiently improves the outage performance. From this figure, we can also see that Figure 4 (b) achieves more performance improvement than Figure 4 (a). This finding shows that the proposed scheme is more meaningful for the larger size cooperative network subject to the sum power constraint.

B. Improvement of SNR Gain over Equal Power Allocation

Fig. 5 compares the improvement of SNR gain over the equal power allocation between the S-BF-AF and AP-BF-AF schemes. The “axis Z” represents the ratio of SNR gain obtained by S-BF-AF and AP-BF-AF to equal power allocation, respectively. SNR gain is compared when the number of relay nodes and \mathcal{P}_{sum} change simultaneously. This figure demonstrates that the SNR gain is the monotone increasing function of the number of relay nodes and \mathcal{P}_{sum} . Significantly,



(a) $K_R = 6$ relay nodes are randomly located.



(b) $K_R = 8$ relay nodes are randomly located.

Fig. 2. End-to-End outage probability is compared as the function of P_{sum}/N_0 for AF cooperative network with unlimited feedback, $R = 1$.

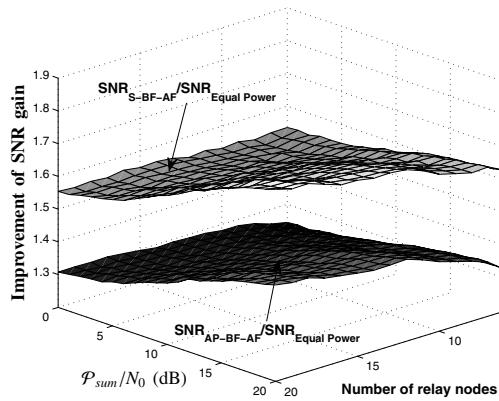


Fig. 3. Improvement of SNR gain as a function of number of relay nodes and P_{sum}/N_0 . The gain of S-BF-AF and AP-BF-AF over equal power allocation is demonstrated, respectively.

the proposed scheme achieves a better SNR gain over the AP-BF-AF scheme. This fact shows that our scheme outperforms “all participate” cooperative beamforming in terms of energy efficiency.

V. CONCLUSIONS

In this paper, we presented a cooperative beamforming scheme for a dual-hop multiple-relay cooperative network under the sum power constraint. Different from the “all participate” cooperative beamforming, a relay selection algorithm is utilized to select the “appropriate” relay nodes to perform beamforming. This scheme can make full use of the channel resource. Besides, a simple power allocation method across source and selected relay subset is developed to further improve the energy efficiency with low computational complexity. Monte-Carlo simulations show that our proposed cooperative scheme has a better outage performance. We conclude that this selection cooperative beamforming conducted by only those “appropriate” relay nodes could further improve

the energy efficiency without increasing the complexity of the system implementation.

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