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Multi-Relay Selection Algorithm for Optimizing Symbol Error Rate and Network Lifetime

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***Abstract*—In order to jointly optimize the performance of symbol error rate (SER) and network lifetime (NL) in cooperative communications, an efficient multi-relay selection algorithm (JOMRS) based on statistics channel gain (SCG) and node residual energy (NRE) is put forward. Firstly, this algorithm obtains the pre-selection set of relay nodes from the candidate relay nodes based on SCG. Secondly, it rearranges the relay nodes in the pre-selection set in ascending order according to the values of the weighting function constructed by SCG and NRE to get the optimization set. Finally, for minimizing the average symbol error rate of signal relay, it selects the suitable number of relay nodes *L*. Thus the selected multiple relays are the first *L* relays in the optimization set. Simulation results show JOMRS algorithm can achieve better SER performance as well as NL performance than BSRS algorithm, and obtain longer NL than BMRS algorithm.**

Keywords—cooperative communications; symbol error rate; network lifetime; multi-relay selection; statistics channel gain; node residue energy

I. INTRODUCTION

In recent times, cooperative communications, as one of the key technology to overcome fading characteristics of wireless channel, has received extensive attention in academia and industry. The basic idea of cooperative communications is to form a virtual multiple-input multiple-output system by sharing users' antennas in a multi-user environment, in order to improve the performance of the communication systems, such as lowering symbol error rate (SER), prolonging network lifetime (NL) and expanding the coverage of the communication systems [1]. Cooperative communications mainly focuses on relay node selection, power allocation and cross-layer optimization, etc. Among them, relay node selection is the key to improve the performance of cooperative communications.

Relay node selection refers to how to select suitable relay nodes from many candidate relays to achieve reliable communication and reduce the complexity of implementation. [2] proposes a single relay selection algorithm based on an optimization function with two parameters of signal-to-noise ratio (SNR) and node energy efficiency to reduce SER and prolong NL, but there's a lack of flexibility in the optimization function that cannot adjust the weight of the two parameters. Moreover, the processing ability of single relay is limited. In order to effectively improve the system performance by cooperative communications, multi-relay selection algorithm is discussed in [3-5]. In [3] a multi-relay selection algorithm based on the order of end-to-end SNR is proposed, which can obtain lower SER than that of single relay selection algorithm. Reference [4], according to the features of first order partial derivative of destination SNR, defines the cooperative efficiency and designs an iterative relay selection scheme. The scheme in [4] deletes the lowest efficiency node one by one to optimize the relay selection and increase the system throughput. While [3-4] only consider one parameter and optimize single objective. When the number of relay nodes is large, the efficiency of selection scheme in [4] is low. [5] proposes a multi-relay selection strategy to maximize SNR and minimize power consumption based on quantum particle swarm. However, all relay node selection schemes proposed in [2-5] need instantaneous channel state information among nodes, which increases the system overhead. Therefore, this paper proposes an effective multi-relay selection algorithm (JOMRS) based on statistical channel gain (SCG) and the node residual energy (NRE) to jointly optimize the performance of SER and NL.

The implementation steps of JOMRS algorithm are as follows. Obtain the pre-selection set based on SCG from the candidate relay nodes; then construct the weighting function according to SCG and NRE, on the basis of weighting function values rearrange relay nodes in pre-selection set to get the optimization set; finally, select the reasonable number of relay nodes L to minimize the average SER of single relay, under the optimization targets presented in this paper, the selected multiple relays are the first L relay nodes in the optimization set. Simulation results show that JOMRS algorithm can both reduce SER and prolong NL.

The rest of this paper is organized as follows. Heading. 2 describes the system model and cooperative process. In Heading. 3, JOMRS algorithm is derived to optimize the performance of SER and NL. Heading. 4 shows the simulation diagrams and discussions. Heading. 5 contains the conclusions.

II. SYSTEM MODEL

As shown in Fig. 1, this paper considers a multi-relay amplify-and-forward (AF) cooperative model consisting of a source node (S), N candidate relay nodes ($R_i, i = 1,2,..., N$),

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and a destination node (D), which are all equipped with a single-antenna. Each node is in half-duplex mode and its transmission power is P. This paper adopts the centralized relay selection strategy. D can obtain the information (including SCG and NRE, etc.) of other relay nodes and use them to select relays. In Fig .1, the channels between arbitrary two relay nodes are assumed to be independent and identical distributed quasi-static Rayleigh fading. $h_{jk}(jk \in \{sd, si, id\})$ is the channel fading coefficient from node j to node k. $h_{jk} \sim CN(0, \sigma_{jk}^2)$, $|h_{jk}|^2 \sim e(1/\sigma_{jk}^2)$. $n_{jk} \sim CN(0, N_0)$ is additive white Gaussian noise.

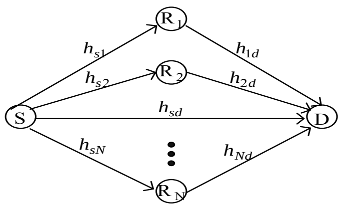

Fig. 1. multi-relay cooperative model

If D selects L relay nodes from N candidate relay nodes to assist S communication, the cooperative process is described as below. In the first time slot, S transmits a broadcast signal x. The received signals at D and $R_i(i = 1,2,..., L)$ can be respectively written as

$$y_{sd} = \sqrt{P} h_{sd} x + n_{sd} \tag{1}$$

$$y_{si} = \sqrt{P} h_{si} x + n_{si} \tag{2}$$

In the second to the first L time slot, $y_{si}(i = 1,2,..., L)$ is amplified and re-transmitted to D by $R_i(i = 1,2,..., L)$ in turn, which is AF. Then the signal $y_{id}(i = 1,2,..., L)$ received by D can be expressed as

$$y_{id} = \sqrt{P} h_{id} \beta y_{si} + n_{id} \tag{3}$$

where $\beta = \sqrt{\frac{1}{P|h_{si}|^2 + N_0}}$ is an amplification factor [6]. Finally, with the processing of Maximal Ration Combiner, D obtains y_d^{AF}

$$y_d^{AF} = a_s y_{sd} + \sum_{i=1}^{L} a_i y_{id} \tag{4}$$

where a_s and a_i are weighting coefficients. This paper defines the transmission signal-to-noise ratio as $\gamma_0 = P / N_0$. The SNR of y_d^{AF} is given as [7]

$$\gamma_d^{AF} = \gamma_{sd} + \sum_{i=1}^{L} f(\gamma_{si}, \gamma_{id}) \tag{5}$$

where $\gamma_{jk} = \gamma_0 |h_{jk}|^2 (jk \in \{sd, si, id\})$ represents the SNR of the corresponding channel, $f(x, y) = \frac{xy}{1 + x + y}$.

Because SER considers the rate, SNR, modulation modes of the physical layer which uses and combining methods of the terminal signals, etc., thus which is closer to the actual network [8]. Therefore, this paper takes SER as one of the performance analyses of relay node selection algorithm. When this paper adopts MPSK modulation, the SER of y_d^{AF} can be written as

$$P_{SER} = \frac{1}{\pi} \int_0^{(M-1)\pi / M} \exp(-\frac{b\gamma_d^{AF}}{\sin^2 \theta}) d\theta \tag{6}$$

where $b = \sin^2 \frac{\pi}{M}$. This paper uses BPSK modulation, in high SNR, (6) can be approximated as [9]

$$P_{SER} \approx g(L) \frac{1}{\gamma_0^{L+1}} \frac{1}{\sigma_{sd}^2} \prod_{i=1}^{L} \phi_i \tag{7}$$

where $g(L) = \frac{1}{\pi} \int_0^{\pi/2} \sin^{2L+2} \theta d\theta$, $\phi_i = \frac{1}{\sigma_{si}^2} + \frac{1}{\sigma_{id}^2}$ is expressed as SCG of R_i. The selection algorithm of L and R_i is described in Heading. 3.

III. JOMRS ALGORITHM

A. The Derivation of JOMRS Algorithm

In order to ensure SER performance, improve the efficiency of relay node selection and save system overhead, JOMRS algorithm selects the pre-selection set $\Re_{pre}$ satisfying (8) from N candidate relay nodes.

$$\Re_{pre} = \{R_i | \phi_{i-1} < \phi_i \le \bar{\phi}\}, i = 1,2,...M, 1 \le M \le N \tag{8}$$

where $\bar{\phi} = \upsilon \frac{1}{N} \sum_{i=1}^{N} \phi_i$ is expressed as the system setting value of SCG threshold, υ is a positive adjustable coefficient to soften the decision condition. Assume $\phi_0 = 0$.

For prolonging NL, in addition to considering SCG, JOMRS algorithm should also consider NRE. We assume the energy of each $R_i(i = 1,2,..., M)$ in $\Re_{pre}$ is E_{ci}. The duration of one node to forward information is an unit time. Then the NRE after R_i involving in a cooperation is expressed as $E_{ri} = E_{ci} - P$. This paper uses ϕ_i and E_{ri} to construct the weighting function WF_i

$$WF_i = \mu\phi_i + (1-\mu)/E_{ri} \quad (9)$$

where μ satisfying $0 \le \mu \le 1$ is a weighting factor, we can adjust μ to focus on the required optimization goal. Calculate $WF_i\,(i = 1,2,...,M)$ of each R_i in $\Re_{pre}$ according to (9), and reset R_i in ascending order based on WF_i to get the optimization set $\Re_{jo}$.

Known from the Heading. 1: Compared with selecting a single relay, selecting multiple relays for cooperation can achieve better communication quality, but this advantage is at expense of more resources consumption. Thus this paper defines the average SER of single relay function P_{SER}^{av} to select reasonable number of relay nodes L for cooperation.

$$P_{SER}^{av} = \frac{P_{SER}}{1+L} \quad (10)$$

The optimization goal is

$$\min P_{SER}^{av} \quad (11)$$

The parameters in (7) are not negative, where P is a setting parameter of the system, and other parameters can be calculated by D according to the obtained information. We can get the optimal value of L from (7), (10) and (11) is

$$L = \arg\max_{L}\{q(L)\phi_L < \gamma_0\} \quad (12)$$

where $q(L) = \frac{L(2L+1)}{(L+1)(2L+2)}$.

Prove: The P_{SER}^{av} is minimized by selecting L relay nodes, that is,

$$P_{SER}^{av}(L) < P_{SER}^{av}(L-1) < \cdots < P_{SER}^{av}(1) \quad (13)$$

$$P_{SER}^{av}(L) < P_{SER}^{av}(L+1) < \cdots < P_{SER}^{av}(M) \quad (14)$$

Then (15) and (16) can be obtained from (7), (10), (13) and (14)

$$\frac{1}{\phi_l} > \frac{q(l)}{\gamma_0},\ \ l = 1,2,\cdots,L \quad (15)$$

$$\frac{1}{\phi_l} < \frac{q(l)}{\gamma_0}, l = L+1, L+2,\cdots,M \quad (16)$$

Because $q(l)$ and $\phi_l\,(\phi_l \in \Re_{pre})$ both are increasing sequences of l, (15) and (16) are equivalent to

$$\frac{1}{\phi_L} > \frac{q(L)}{\gamma_0} \quad (17)$$

$$\frac{1}{\phi_{L+1}} < \frac{q(L+1)}{\gamma_0} \quad (18)$$

We get $q(L)\phi_L < \gamma_0 < q(L+1)\phi_{L+1}$. (12) is proved. At last, JOMRS algorithm selects L former relay nodes in $\Re_{jo}$ to optimize the performance of SER and NL.

B. *The Analysis of JOMRS Algorithm*

The computational complexity of global search (GS) algorithm contains (2^N -1) times computation of SER and (2^N -1) times comparison. While the computational complexity of JOMRS algorithm includes L times and M times computation of the number of relay nodes and the weighting function respectively, and $[N + 2(M-1)^2 + L]$ times comparison. From Fig. 2 in Heading. 4, we get L, M and N satisfy $L \le M < N/2$. So the computational complexity of JOMRS algorithm is far less than that of the GS algorithm, the more greater N is, the more obvious the advantage is. Moreover, JOMRS algorithm can prolong NL, so JOMRS algorithm shows the most advantages when it is applied to the scene that has numerous candidate relay nodes and node energy is strictly limited.

IV. Simulation Analysis

We assume: All nodes are located in the two-dimensional plane. The distance between S and D is 100m, N candidate relays distribute uniformly in the square area, whose two opposite sides have S and D as the middle point respectively. $P = 1, \upsilon = 1, \mu = 0.5$. Each node energy randomly distributes in (0J,10J).

Fig. 2 shows the different number of candidate relay nodes N corresponds to the number of relay nodes M in the pre-selection set under JOMRS algorithm. It can be learned that by obtaining the pre-selection set JOMRS algorithm can remove most of the relays with poor quality that don't need to participate in the calculation of the weighting function or its sorting, which greatly reduces the amount of calculation and raises the selection efficiency.

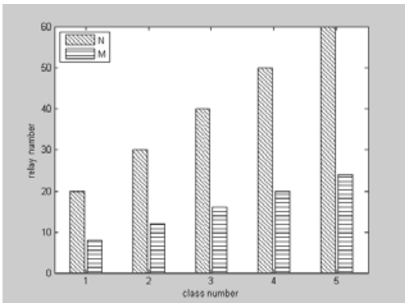

Fig. 2. N corresponds to M

Fig. 3 simulates the SER performance in different γ_0 under JOMRS algorithm, best single relay selection (BSRS) algorithm and best multi-relay selection (BMRS) algorithm when $N=20$. The last two algorithms among them adopt GS strategy to minimize SER. JOMRS algorithm is more effective than BSRS algorithm to lower SER. While the SER of JOMRS algorithm is higher than that of BMRS algorithm. The reason is that, combining SCG and NRE, JOMRS algorithm selects the sub-optimal set of relay nodes to minimize SER.

The definition of network lifetime is the network's survival time until the number of dead nodes reaches the preset threshold (Nt). Fig. 4 shows when $N=20$ the comparison of NL in different Nt under different algorithms. BSRS algorithm and BMRS algorithm don't consider NRE. It causes that node energy consumption is not balanced and nodes die easily, so the NL of them is always shorter than that of JOMRS algorithm. Moreover, compared with BSRS algorithm, BMRS algorithm has the larger average number of selected relays, which increases energy consumption, thus whose NL is the shortest.

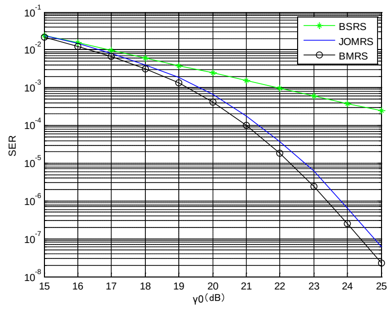

Fig. 3. The comparison of SER in different γ_0 under three algorithms

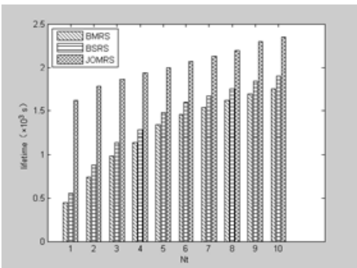

Fig. 4. The comparison of NL in different Nt under three algorithms

V. Conclusion

JOMRS algorithm proposed in this paper, first of all, obtains the pre-selection set of relay nodes from the candidate relay nodes according to SCG to improve the selection efficiency. In order to optimize the performance of SER and NL, then it uses the values of the weighting function calculated by SCG and NRE to rearrange the relay nodes in the pre-selection set in ascending order to get the optimization set. Finally, it finds the number of relay nodes L, which can minimize the average SER of single relay and reduce the average number of selected relay nodes. Accordingly, the selected multiple relays are the former L relays in the optimization set. JOMRS algorithm can effectively prolong NL and reduce SER. The simulation results verify the effectiveness of JOMRS algorithm.

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