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OPTIMAL POWER ALLOCATION FOR COOPERATIVE RELAY SYSTEM

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Abstract. *In this paper an optimal power allocation with artificial fish swarm algorithm (AFSA) and particle swarm optimization (PSO) is proposed for the cooperative relay system. The instantaneous symbol error rate (SER) of the amplify-and-forward (AF) relay system is first derived. Then the power allocation problem is transformed into a global optimal problem by building an objective function with augmented Lagrangian function. The SER of system for optimal power allocation is minimized by combining the ASFA and PSO. Simulation result shows that the algorithm has a fast and precision convergence.*

Keywords: Cooperative communication, Power allocation, Relay, Artificial fish swarm, Particle swarm

1. **Introduction.** Cooperative communication has gained wide attention due to the highly inefficient utilization of limited spectrum. It can not only improve the link quality and reliability of wireless communication systems, but also increase the coverage of cells. Many cooperative schemes have been proposed in the literature [1-4]. Traditionally, three typical relay strategies, namely, the amplify-and-forward (AF), decode-and-forward (DF), and compress-and-forward (CF) strategies, have been proposed for cooperative communication system. Among the three, AF is the most commonly used strategy due to its low complexity and low power consumption as a result of straightforward retransmission without requiring decoding procedures. However, power allocation (PA) is the most important in relay system because of a given power constraint. Many previous researches have been working on the PA of the cooperative relay system. Li et al. proposed a joint PA issue in a class of MIMO relay system to optimize the PA for any given power ratio of the relay and source in [5]. In [6] PA scheme has been proposed to choose the best relay in a system with multiple relays. Maric and Roy present the optimum power allocation among the AF relays with water-filling algorithm in [7]. Joung and Sun studied the resource allocation in orthogonal frequency division multiple access (OFDMA) relay cellular networks. They used the per-subchannel power constraint which is stricter than the sum power constraint.

An optimal power allocation with AFSA and PSO is proposed for the cooperative relay system in this paper. We formulate a power allocation problem to minimize the SER for the AF relay system. To transform the power allocation problem into a global optimal problem, we then rebuilt the objective function. To get optimal power allocation, we combine the AFSA and PSO to minimize the SER of system.

The rest of the paper is organized as follows. In Section 2, we introduce the system model. In Section 3, the objective function has been formulated. The algorithm of power allocation for AF relay is given in Section 4. The simulation results are carried out in Section 5. Finally, Section 6 concludes the paper.

2. **System Model.** We consider the PA problem of a relay system that is based on the AF relaying strategy. It is assumed that the system has one source, one relay and one destination. It is also assumed that perfect channel state information is available in relay. The cooperative system model is shown in Figure 1, where S denotes the source, R denotes the relay and D denotes the destination.

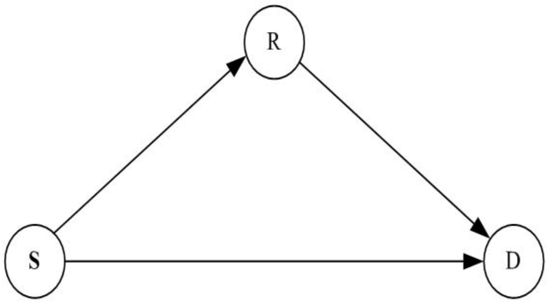

FIGURE 1. The cooperative system model

Transmission occurs over two time slots. In the first time slot, the relay nodes receive the signal transmitted by the source node. After processing the received signals, the relay nodes transmit the processed data to the destination node during the second time slot while the source node remains silent. We assume perfect synchronization at the destination node. The received signals at the relay and destination nodes can be written as

$$y_{SD} = \sqrt{P_S} h_{SD} x + n_{SD} \tag{1}$$

$$y_{SR} = \sqrt{P_S} h_{SR} x + n_{SR} \tag{2}$$

respectively, where P_S is the energy used for transmission by the source node, x is the zero mean unit energy transmitted symbol, n_{SD} and n_{SR} are the complex white Gaussian noises which follow the complex white Gaussian distribution CN $\sim (0, N_0)$, and h_{SD} and h_{SR} are the fading gains between the source and the destination, and between the source and the relay, respectively.

In the second time slot, the relay nodes transmit the processed data to the destination node with power P_R. The received signal at the destination from the relay is

$$y_{RD} = \sqrt{P_R} \beta h_{RD} x + n_{RD} \tag{3}$$

where, h_{RD} is the fading gain between the relay and the destination, n_{RD} is the complex white Gaussian noise variables, following the distribution CN $\sim (0, N_0)$, and β is the amplification factor at the relay.

$$\beta = \frac{\sqrt{P_R}}{\sqrt{P_S \left| h_{SR} \right|^2 + N_0}} \tag{4}$$

with MAC receiving mode, the destination receiver combines the information of the two slots and decodes the signal at the same time. The combined signal is

$$y = a_1 y_{SD} + a_2 y_{RD} \tag{5}$$

where,

$$a_1 = \frac{\sqrt{P_S} h_{SD}}{N_0} \tag{6}$$

$$a_2 = \frac{\sqrt{P_S}\beta h_{SR} h_{RD}}{N_0\left(\beta^2 \left|h_{RD}\right|^2 + 1\right)} \tag{7}$$

Assuming the average energy of the transmission signal is 1, the instantaneous signal to noise ratio (SNR) at the destination node is given by

$$r = r_1 + r_2 \tag{8}$$

where r_1 is the SNR aroused by the source node directly, and r_2 is from the relay link. r_1 and r_2 are given by

$$r_1 = \frac{P_S \left|h_{SD}\right|^2}{N_0} \tag{9}$$

$$r_2 = \frac{P_S \left|h_{SR}\right|^2 P_R \left|h_{RD}\right|^2}{\left(P_S \left|h_{SR}\right|^2 + P_R \left|h_{RD}\right|^2\right) N_0} \tag{10}$$

3. **Symbol Error Rate Optimization.** In an M-PSK modulation system, the instantaneous symbol error rate (SER) of the destination node could be denoted as

$$SER' = \frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} e^{-\frac{g_{psk}\cdot r}{\sin^2\theta}} d\theta \tag{11}$$

where θ is the phase of subcarrier, M is the number of the subcarrier, and $g_{psk} = \sin\left(\frac{\pi}{M}\right)^2$. From (8), (9), (10), and (11), the average SER is derived as

$$F(P) = SER = B\frac{N_0^2}{g_{psk}^2}\frac{1}{P_S\sigma_{SD}^2}\left(\frac{1}{P_S\sigma_{SR}^2} + \frac{1}{P_R\sigma_{RD}^2}\right) \tag{12}$$

where $B = \frac{3(M-1)}{8M} + \frac{\sin(2\pi/M)}{4\pi} - \frac{\sin(4\pi/M)}{32\pi}$. Our goal is to maximize system performance by optimally allocating transmission power of the relay nodes with a constrained power. We adopt the SER at the destination node as the performance metric and formulate the objective function as follows:

$$\begin{aligned} &\min SER \\ \text{s.t.}\ \ & P_S + P_R = P \\ & P_S \geq 0 \\ & P_R \geq 0 \end{aligned} \tag{13}$$

4. **Power Allocation for AF Relay.** It is a constrained global optimization problem in (13). We propose an algorithm that combines artificial fish swarm algorithm and particle swarm optimization to minimize the SER for optimal power allocation. AFSA algorithm has some attractive characteristics such as simple in principle, good robustness, and tolerance of parameter setting. However, it also showed some unsatisfactory aspects in practical applications, such as premature convergence and poor ability in global optimization. To solve the problem, we combine PSO algorithm with AFSA. The PSO algorithm has a fast convergence rate by adjusting the current position and velocity dynamically. However, PSO algorithm suffers from drawbacks like premature convergence at local optimum solution. In order to accelerate the convergence speed of AFSA algorithm, PSO algorithm is used to compare fitness function of every particle.

Using augmented Lagrangian function the objective function is rebuilt as:

$$F(P,r) = F(P) + r\left[(P_S + P_R - P)^2 + P_S^2 u(P_S) + (P_R)^2 u(P_R)\right] \tag{14}$$

where r is a positive penalty parameter, and the corresponding problem in (13) is formulated as:

$$\min F(P,r) \tag{15}$$

The algorithm AF-PSO based on the augmented Lagrangian is presented below.

Step 1. Randomly generate the size of the population N, crowed factor of artificial fish δ, visual distance of artificial fish individuals *Visual*, step: size of the movement of artificial fish, position and velocity of particle, try number, learning factors c1 and c2, the inertia weight w, mutation probability q, the maximum number of iterations.

Step 2. The population N is divided into N_1 and N_2 equally. The fitness value of every artificial fish, denoted as t, is obtained with AFSA according to the objective function $F(P, r)$ in population N_1. In population N_2, the fitness value of each particle, denoted as s, is got by PSO. The optimum is selected to the bulletin board between t and s.

Step 3. In population N_1, compute the optimal value g of each artificial fish with objective function $F(P, r)$.

Step 4. Update the position of each artificial fish and get new population N_1'.

Step 5. In population N_2, compute the P_{best} and Z_{best} of each particle according to the objective value.

Step 6. Update the population N_2 to N_2'.

Step 7. Select the optimum between g and Z_{best}, compare the optimum with the value of bulletin board, and then update the bulletin board with the optimum.

Step 8. Find five minimum objective value in population $N_1' \cup N_2'$. If the objective value is less than q, set $X_i = h + rand$, where X_i denotes the worst artificial fish/particle, h is the value on the bulletin board, $rand \in [0, 1]$ is random data which denote the objective value.

Step 9. End if reaching the maximum number of iterations, otherwise turn to Step 3.

The last value in bulletin board is the minimum SER and the position of artificial fish/particle is the optimal power.

5. **Simulation Results.** The SER derived in (12) is a gradual approximation value. To test the relationship between the SER in (12) with the real SER, we do experiments in a

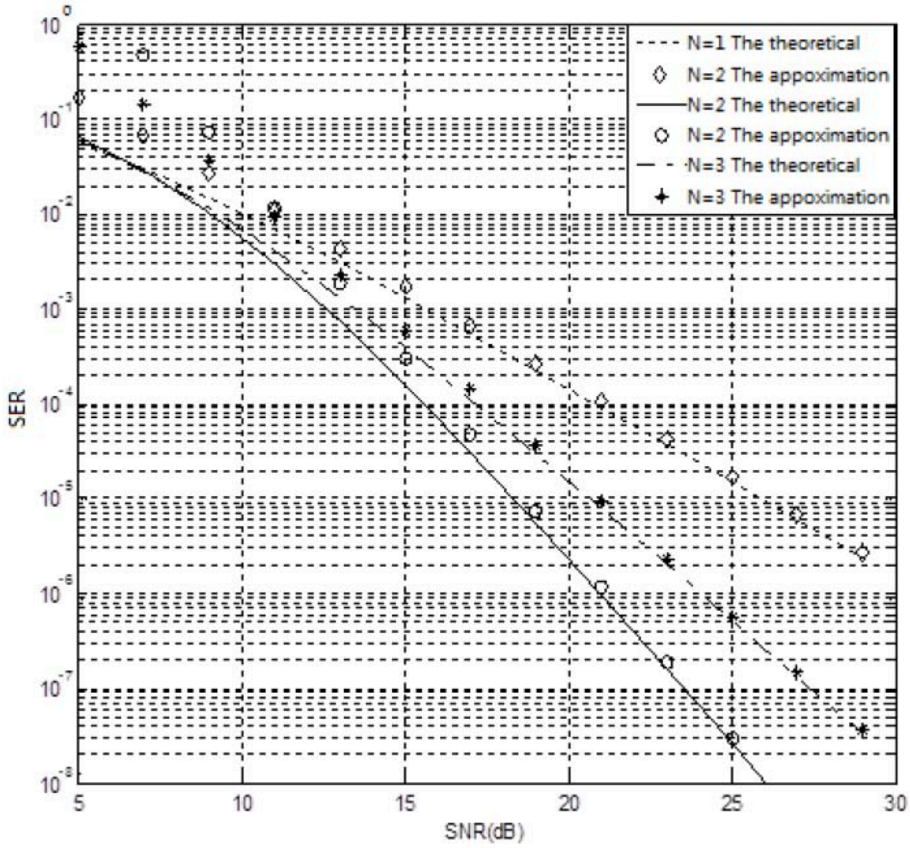

FIGURE 2. The SER of the AF system

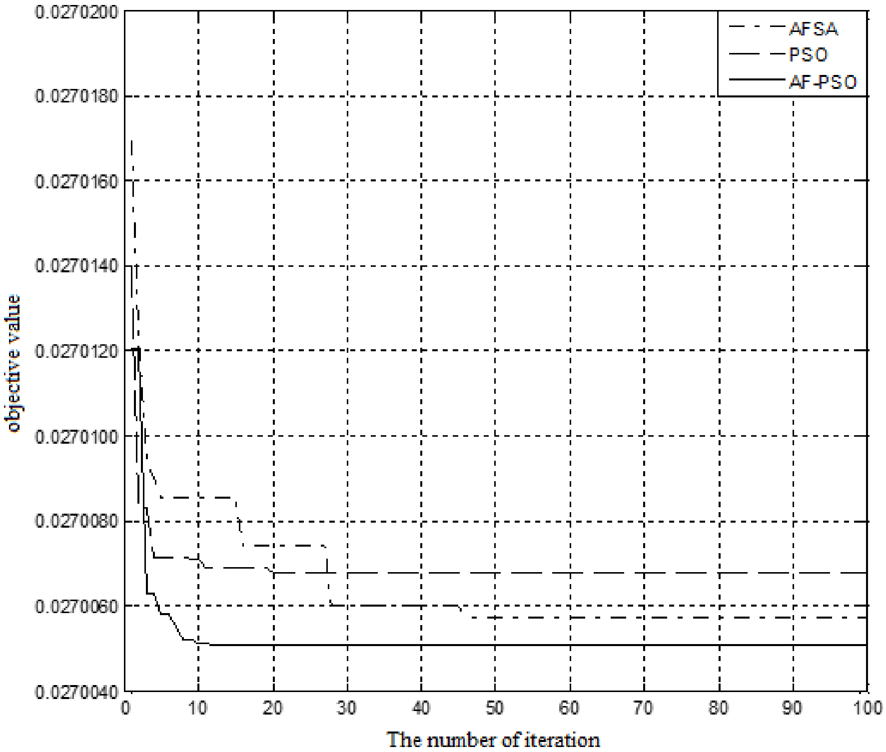

Figure 3. The curves of iteration evolution

high SNR condition. The channel gains are assumed to follow the Rayleigh distribution. Assuming N_0 is 1, the path loss factor is 3. Relay node is located between the source node and the destination node. The power allocation adopt average power allocation scheme. The number of relay node $N = 1, 2, 3$, respectively.

Figure 2 shows the SER curve of gradual approximation value and theoretical value with different relay node numbers based on AF system. As can be seen from Figure 2, for different N the gradual approximation value of SER is consistent with the theoretical value of SER. Figure 3 shows the curves of iteration evolution of the AFSA, the PSO and the AF-PSO. It should be noted that the objective value of the AF-PSO is better than the PSO and AFSA. The convergence accuracy has been improved in AF-PSO.

6. Conclusions.

In this paper, we derive the SER for the AF relay system and transform the optimal power allocation problem into a global optimization. Combining the ASFA and PSO, minimize the SER of system for optimal power allocation. Simulation results show that the AF-PSO algorithm has a fast and precision convergence. In the future work, we will focus on the power allocation for a multi relay system.

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