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# Optimization of Power Allocation in Relay based Cooperative Communication using Amplify and Forward Protocol

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**Abstract**—This paper considers the power allocation problem in a single relay cooperative wireless system. In cooperative wireless systems, both source and relay transmits data in different phases. Here we optimize transmit power allocation (PA) for source and relay so as to minimize the average BER at destination. We use one of the global optimization techniques named Bacterial Foraging Optimization algorithm (BFOA). BFOA is an evolutionary technique based on the foraging behavior of Escherichia coli bacteria in human intestine. This algorithm has been applied to solve many real-world optimization problems arising in several application domains. Performance of power optimization using BFOA, that uses BER minimization as objective function has been analyzed and it is shown that performance of proposed scheme with BFOA optimization based power allocation outperforms equal power allocation scheme in the high value of SNR.

**Index Terms**— Amplify-and-Forward, Bacterial Foraging, Cooperative communication, Optimization , Power allocation, Relay, Signal-to-Noise ratio (SNR)

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## 1 INTRODUCTION

Generally, in wireless environment, the strength of received signal degrades due to path-loss and shadowing from various obstacles along propagation path. In order to improve the performance of a wireless communication system and to achieve diversity gain, MIMO technique has been proposed. But practical implementation of MIMO requires more antennas and it is more complex. So it is difficult to implement MIMO in real scenario especially in next generation cellular communication systems which are supposed to handle high data rate and large coverage area[1]. At the same time, the mobile terminals in cellular communication systems must be simple, cheap, and smaller in size. In order to overcome the difficulty of MIMO, one of the method called Cooperative communication has been introduced. The concept of Cooperative communication has been well studied in [1].

Cooperative communication provides diversity in a different way. In this technology, apart from having direct path, there is a relay which supports the transmission. Cooperative communication helps to increase capacity, increase coverage area, reduce path loss and reduce the effects of fading. Three different types of cooperative protocols implemented in relay namely amplify and forward (AF), decode and forward (DF) and coded cooperation and its performance has been discussed in [1]. In cooperative communication, source-destination link is enhanced in a supportive way by relays or in a cooperative way by other users. Thus relays may be fixed or mobile. Importance of user cooperation for next generation wireless systems has been studied in [2]. Many issues in cooperative communication still need to be researched. Major issues include

- Power allocation,
- Relay selection,
- Interference compensation,
- Spectrum allocation.

This paper addresses the problem of power allocation.

Power allocation is necessary for systems that are limited in size and limited in transmit power. In cooperative communication, many nodes will help to transmit the data. So it is essential to allocate the power between source and relay nodes for efficient transmission. Generally power allocation schemes are classified into two groups namely: closed-loop and open –loop[4]. This paper deals with closed-loop power allocation scheme. Closed-loop power allocation scheme requires the knowledge of instantaneous channel state information (CSI) at both source and relay i.e., power is optimized based on channel condition.

Here we consider a global optimization technique for power allocation. Global optimization techniques have been influenced by the biological processes such as evolution, food searching behavior of ants etc. Some of the global optimization techniques that are widely used in engineering are Evolutionary Programming (EPs), Genetic Algorithms (GA), Particle Swarm Optimization (PSO) and Bacterial Foraging Optimization algorithm (BFOA) [7],[8]. These techniques have been applied to solve multidimensional objective functions with many potential local maximas. The major features of these optimization techniques are that they are largely independent of initial conditions and incorporate random variations and selection of parameters. Here we used BFOA algorithm for power allocation. The Bacterial Foraging Algorithm is inspired by the group foraging behavior of bacteria such as E.coli and

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M.Xanthus. The details of BFOA algorithm is presented in section III in a detailed manner.

This paper is organized as follows. Section II describes about system model of single relay cooperative communication. In section III, we present proposed power allocation scheme based on BFOA. Simulation results have been presented in section IV. Section V concludes the paper.

## 2 SYSTEM MODEL

We consider a single relay cooperative communication system as shown in Fig. 1. It consists of three nodes source (S), relay (R) and destination (D). A typical cooperative protocol can be modeled with two phases.

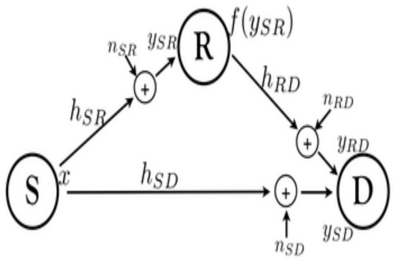

Fig. 1. A three node relay-based cooperative communication

In first phase, source transmits data to both destination and relay with power $E_t$. The received signal at the destination and relay is given by

$$y_{s,d} = \sqrt{E_t}\,h_{s,d}x + n_{s,d} \tag{1}$$

$$y_{s,r} = \sqrt{E_t}\,h_{s,r}x + n_{s,r} \tag{2}$$

where $E_t$ is the transmitted power at source, $x$ is the transmitted information symbol. $n_{s,d}$ and $n_{s,r}$ are additive white Gaussian noise. They are modeled as zero-mean complex random variables with variance $N_0$. $h_{s,d}$ and $h_{s,r}$ are the channel coefficients from the source to the destination and the relay respectively. They are modeled as zero-mean, complex Gaussian random variables with variances $\delta^2_{s,d}$ and $\delta^2_{s,r}$ respectively.

In second phase, relay can help source by forwarding or retransmitting the data to the destination based on the protocol designed in relay. This can be modeled as

$$y_{r,d} = h_{r,d}\, f(y_{s,r}) + n_{r,d} \tag{3}$$

where $f(y_{s,r})$ depends on the protocol implemented in relay, $h_{r,d}$ is the channel coefficient from relay to the destination, $n_{r.d}$ is additive noise.Here we considered amplify and forward (AF) protocol. In this protocol relay receives the signal, amplifies it and forward to the destination. This process is based on the channel condition.

### 2.1 Amplify and forward protocol

In an AF protocol, during phase 2 the relay amplifies the received signal and forwards it to the destination with transmitted power $E_r$. The received signal at the destination in phase 2 can be written as

$$y_{r,d} = \beta h_{r,d}\, y_{s,r} + n_{r,d} \tag{4}$$

where $\beta$ is an amplification factor and it depends on received SNR i.e. on channel condition.

$$\beta = \frac{\sqrt{E_r}}{\sqrt{E_t\left|h_{s,r}\right|^2 + N_0}} \tag{5}$$

Substituting (5) in (4),

$$y_{r,d} = \frac{\sqrt{E}}{\sqrt{E\left|h_{s,r}\right|^2 + N_0}}\sqrt{E}\, h_{r,d} h_{s,r} x + n'_{r,d} \tag{6}$$

where

$$n'_{r,d} = \frac{\sqrt{E}}{\sqrt{E\left|h_{s,r}\right|^2 + N_0}} h_{r,d} n_{s,r} + n_{r,d} \tag{7}$$

At the output, signal from direct path and via relay are combined using receiver diversity schemes. Here we used Maximal ratio combining (MRC) as a receiver diversity scheme. The combined signal at the destination is given by,

$$y = a_1 y_{s,d} + a_2 y_{r.d} \tag{8}$$

where $a_1$ and $a_2$ are the combining factors defined by,

$$a_1 = \frac{\sqrt{E_t}}{N_0} \qquad \text{and} \qquad a_2 = \frac{\sqrt{\dfrac{E_t E_r}{E_t + N_0}}}{\left(\dfrac{E_r}{E_t + N_0} + 1\right) N_0}$$

## 3 Proposed Power Allocation Scheme

This section describes about Bacterial Foraging optimization algorithm which is one of the global optimization technique to allocate the power used for transmission. The objective function is designed to minimize the Bit error rate(BER).

### 3.1 Bacterial Foraging Optimization Algorithm (BFOA)

This algorithm is based on foraging behavior of a swarm of bacteria. This algorithm is based on the following four processes:

- Chemotaxis
- Swarming
- Reproduction
- Elimination and dispersal

Generally in order to maximize the energy, bacteria search for nutrients. An individual bacterium also communicates with others by sending signals. During foraging, locomotion is achieved by bacteria by means of flagella. Tumbling and swimming are the two basic operations performed by bacteria during foraging. This process of movement of bacteria by taking small steps is called Chemotaxis. Generally bacteria like to move towards a nutrient gradient and avoid noxious environment. When they get sufficient food, bacteria increase in its length. At this time, bacteria break in the middle to create an exact replica of itself in the presence of suitable temperature. This process is called reproduction. When suitable temperature is not present or when there is some sudden environmental changes, chemotactic process has been disturbed and some groups of bacteria may move to noxious environment. Those groups of bacteria should be eliminated. This process is called elimination-dispersal. This algorithm proposed by Passino[7] is described below.

BFO Algorithm

```
1) Initialize input parameters p, $N_c$, $N_b$, $N_{re}$, $N_{ed}$, $P_{ed}$, C(i)
   (i=1,2…S), $\theta^i$
2) Create a random initial swarm of bacteria
        $\theta^i$ ( j, k , 1) ∀ i, i = 1,.... $S_b$

3) Evaluate f($\theta^i$ ( j, k , 1)) ∀ i, i = 1,.... S

   for l =1 to $N_{ed}$ Do
      for k =1 to $N_{re}$ Do
        for j =1 to $N_c$, Do
          for i =1 to $N_b$ Do
               Perform the chemotaxis for
               bacteria $\theta^i$ ( j, k , 1)
          end
        end

 Perform the reproduction process by eliminating
 half of the worst bacteria and duplicating the other half
 end
 Perform the elimination −dispersal process for all bacteria
 $\theta^i$ ( j, k , 1) ∀i, i =1,.... $N_b$ with probability
0≤Ped ≤1
 end
```

The chemotactic step was modeled by Passino [7] with the generation of a random direction search given by

$$\varphi(i) = \frac{\Delta(i)}{\sqrt{\Delta(i)^T \Delta(i)}} \qquad (9)$$

where Δ(i) is a randomly generated vector within the interval [-1, 1]. This equation represents a tumble (search direction). After that, each bacteria $\theta^i(j,k,l)$ modifies its position according to the following equation

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\phi(i) \qquad (10)$$

where *C(i)* represents the step size value, based on the limits of the decision variable. The above equation represents a swim process. The swim will be repeated *Nc* times if the new position is better than the previous one Where *C(i)* represents the step size value, based on the limits of the decision variable. The above equation represents a swim process. The swim will be repeated *Nc* times if the new position is better than the previous one with a probability $0 \le P_{ed} \le 1$.

The input parameters for BFOA are the number of bacteria in the population $N_b$, dimension search space *p*, the chemotactic loop limit $N_c$, reproduction loop limit $N_{re}$, the elimination–dispersal loop limit $N_{ed}$ and the probability of elimination–dispersal $P_{ed}$.

### 3.2 BER based power allocation

BER based power allocation scheme minimizes the average BER at the destination. BER for Amplify-and-Forward protocol is derived as [4]:

$$P_e \square \frac{1}{2\tilde{E}_t\sigma_{r,d}^2\tilde{E}_t\sigma_{s,r}^2} + \frac{\ln(\tilde{E}_r\sigma_{r,d}^2)}{2\tilde{E}_t\sigma_{r,d}^2\tilde{E}_r\sigma_{r,d}^2} \qquad (11)$$

where $\tilde{E}_t = \frac{E_t}{N_o}$, $\tilde{E}_r = \frac{E_r}{N_o}$

The objective function is

$$\min \quad \frac{1}{2\tilde{E}_t\sigma_{r,d}^2\tilde{E}_t\sigma_{s,r}^2} + \frac{\ln(\tilde{E}_r\sigma_{r,d}^2)}{2\tilde{E}_t\sigma_{r,d}^2\tilde{E}_r\sigma_{r,d}^2} \qquad (12)$$

subject to $E_t + E_r = E_{total}$

$0 \le E_t \le E_{total}$

$0 \le E_r \le E_{total}$

Steps involved in Power optimization

1) Initialize power values. (Assume equal power allocation to begin the optimization).
2) Obtain channel state information (CSI) of three channels by namely Source-Destination, Source-Relay and Relay-Destination. Calculate the variance of these channels.
3) Substitute the value of variance in (12) and we obtain objective function. Perform Bacterial Foraging optimization algorithm by using this objective function.
4) Get the optimized power values and use for transmission.

## 4 Simulation Results and Discussions

In this paper, optimized values of power using BER-based objective function has been computed. The performance of this proposed scheme has been simulated using Monte-Carlo method in MATLAB. Parameters used for simulation are summarized in Table 1. and the parameters used for BFOA algorithm are summarized in Table 2. In Fig.2, BER performance of optimized power allocation scheme has been compared with equal power allocation scheme.

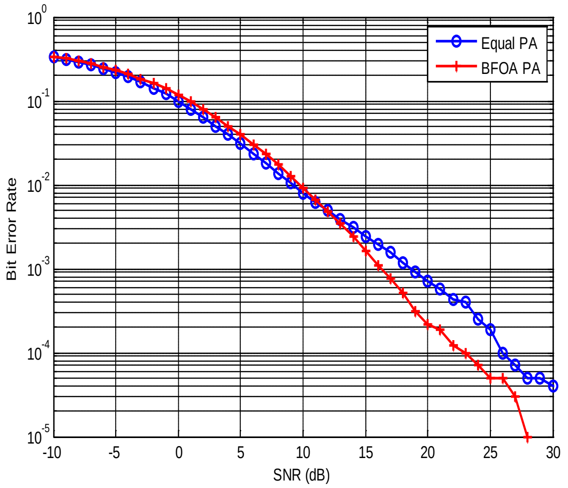

Fig. 2. Comparison of BER performance of proposed power allocation scheme with equal power allocation scheme.

Table 1
Simulation parameters

| Parameters | Values |
|---|---|
| Length of data | $10^6$ |
| Number of iterations | 100 |
| Type of modulation | BPSK |
| Range of transmitted SNR | 0dB to 30dB |
| Channel type | Rayleigh fading |
| Combiner scheme used | Maximal ratio combining |
| Number of iteration in BFA | 10 |

Table 2
Parameters used in BFO algorithm

| Parameters | Values |
|---|---|
| Dimension of search space (p) | 2 |
| Number of bacteria ($N_b$) | 100 |
| Number of chemotactic steps ($N_c$) | 100 |
| Number of swarming steps ($N_s$) | 4 |
| Number of reproduction steps ($N_{re}$) | 4 |
| Number of elimination dispersal steps ($N_{ed}$) | 2 |
| Probability of elimination dispersal ($P_{ed}$) | 0.25 |
| Step size *C(i) (i=1,2…S)* | 0.001 |

We observe that the proposed power allocation performs better than equal power allocation scheme. In equal power allocation scheme, power is allocated independent of CSI. Our proposed scheme is based on instantaneous channel state information i.e., our proposed scheme adapts the power allocation scheme according to the varying channel condition. It is observed that BER value of $10^{-4}$ is achieved at 22dB in our proposed scheme. Proposed scheme yields about 2-3 dB SNR gains compared to equal power allocation scheme. This SNR gain increases as the received SNR increases.

## 5 Conclusion

In this paper, we proposed BER-based power allocation scheme for cooperative wireless systems using BFO algorithm. BER-based power allocation scheme using closed-loop technique minimizes the average BER at the destination. The proposed scheme consists of four steps: initializing power values, obtaining channel state information (CSI), computing objective function and performing BFO algorithm. Simulation results conclude that the proposed scheme is better than equal power allocation scheme. BFOA based proposed scheme yields about 2-3 dB SBR gain compared to equal power allocation scheme. This proposed power allocation scheme can be further extended to other cooperative protocols like Decode-and-Forward (DF) protocol, Compress-and-Forward (CF) protocol. Also this scheme can be performed for a relay system with more than one hop. Also this scheme can be further investigated by estimating channel. Estimation of channel is done by sending known pilot symbols.

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