

Research Article

SNR Maximization through Relay Selection in Cognitive Radio Networks

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Abstract: In this study, we apply Artificial Bee Colony (ABC) optimization to the problem of relay selection and transmit power allocation to selected relays in non-regenerative Relay Assisted Cognitive Radio Networks (RCRN). The objective of our proposed scheme is to maximize the Signal-to-Noise Ratio (SNR) at the secondary destination while keeping the interference offered to the primary user below a certain threshold level. Simulation results verify the effectiveness of the proposed algorithm.

Keywords: Cognitive radio network, relay selection, signal-to-noise ratio, transmit power allocation

INTRODUCTION

Cognitive Radio (CR), coined by Mitola (2009), addresses spectrum scarcity problem as spectrum underutilization problem. It allows either overlay or underlay access of the spectrum to the Secondary Users (SUs) in the presence of the Primary Users (PUs). Cognitive Radio Network (CRN) is a wireless communication network in which the nodes, commonly known as CR users or the SUs, are fully programmable and can dynamically adapt their transmission parameters based on their ability to sense the operating environment. In order to guarantee the connectivity between CR nodes and the Quality of Service (QoS) requirements, relaying (Gormus *et al.*, 2006) is a powerful spatial diversity technique that makes communication possible between CR nodes even if no direct channel is available between them. A scenario of wireless MIMO system (Lay *et al.*, 2010) is created when several relays assist a source to transmit data to a destination. In practice different relaying protocols (Liu and Su, 2006) e.g., Decode and Forward (Regenerative Relaying), Amplify-and-Forward (Non-Regenerative Relaying) are being employed to improve the performance of RCRNs. Power allocation is a critical issue in RCRNs (Jia and Zang, 2009) as it helps in designing CR systems with minimal PU and SU interference. Few research contributions in this area are Liu *et al.* (2010a), Naeem *et al.* (2010) and Liu *et al.* (2010b).

In this study we investigate the problem of performance enhancement of secondary network and propose an algorithm for relay selection from a potential relay set and power allocation among the selected relays, aiming to enhance the SNR received at the secondary destination while keeping the interference offered to the PU below a certain threshold

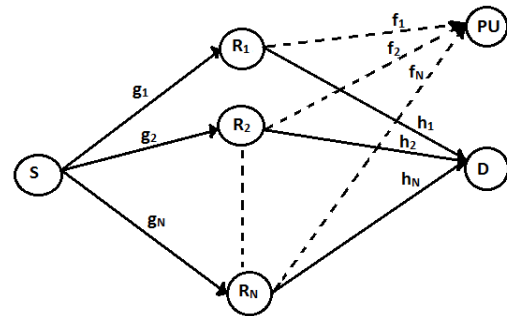


Fig. 1: The system model

level and observing the sum power constraint of the relay network. The optimization problem is solved using Artificial Bee Colony.

SYSTEM MODEL AND PROBLEM FORMULATION

We consider an underlay paradigm based RCRN, as shown in Fig. 1, with one CR source node S, one CR destination node D and N CR relay nodes to enable communication between the source and the destination nodes as no direct channel is available between them due to several reasons e.g., deep fading or larger physical distances between them. We consider the coexistence of the SUs with the PUs provided that interference introduced to the PUs by the SUs is constrained by a certain threshold.

We use Amplify-and-Forward (AF) relaying protocol where the cognitive relay just scales the received signal according to Eq. (1) and forwards it to the destination:

$$P_i = A_i^2 (P_s |g_i|^2 + N_0) \quad 1 \leq i \leq N \quad (1)$$

where,

- P_s = The transmit power of the source node
- $P_s |g_i|^2$ = The signal received at the i^{th} relay
- A_i = The amplification factor of the i^{th} relay
- N_0 = The noise variance
- P_i = The transmit power of the i^{th} relay and $P_i \geq 0$

Let g_i and h_i be the channel gains between the source and the i^{th} relay and between i^{th} relay and the destination respectively. The interference channel between i^{th} relay and the PU is f_i . The source node does not cause interference to the PU and relays are assumed to have knowledge of the interference they cause to the PU, hence their transmit power is controlled accordingly. All potential relay nodes receive the message transmitted by the source, but only the selected relays forward it to the destination. The relay selection is critical as the relay is chosen to maximize the SNR at the destination while minimizing the sum interference power I towards the PU. Let $\Psi_{initial}$ is a set of N potential relays between the source and the destination nodes and $\Psi_{selected}$ contains M relays selected to forward the message to the destination, where $M \leq N$. The end-to-end data transmission is carried out in half duplex mode and is completed in two phases. In the first phase, the source transmits data which is received by all relay nodes and the signal y_{R_i} received at the i^{th} relay R_i is given by Eq. (2):

$$y_{R_i} = x_s g_i + n_{SR_i} \quad i \in \Psi_{initial} \quad (2)$$

where,

- x_s : The signal transmitted by the source
- n_{SR_i} : The Additive White Gaussian Noise (AWGN) received from S- R_i link

Each relay amplifies the received signal and sum interference power I due to the potential relay set $\Psi_{initial}$ is computed, where I is given in Eq. (3):

$$I = \sum_i I_i = \sum_i P_i |f_i|^2 \quad i \in \Psi_{initial} \quad (3)$$

If $I > I_{max}$, the maximum allowable interference to the PU due to potential relays, then the relays offering relatively high interference w.r.t. others in a potential relay set prevent themselves from forwarding the message to the destination and transmit power of remaining set of selected relays $\Psi_{selected}$ is increased accordingly while satisfying I_{max} . Forwarding the received message to the destination by set of M selected relays $\Psi_{selected}$ is carried out in the second phase, so, the signal y_{D_i} received at the destination D due to i^{th} selected relay is given by Eq. (4):

$$y_{D_i} = x_{R_i} h_i + n_{R_i D} \quad i \in \Psi_{selected} \quad (4)$$

where,

- $x_{R_i} = A_i y_{R_i}$: The amplified signal transmitted from i^{th} selected relay to the destination
- $n_{R_i D}$: The Additive White Gaussian noise received from R_i -D link

Based on the above discussion and combining the signals received at the destination D from M selected relays, SNR at the destination D is obtained by combining Eq. (1), (2) and (4). Thus the objective of our optimization problem is to maximize SNR (Naeem *et al.*, 2010) received at the destination node D given in Eq. (5), subject to constraints C1 and C2 given in Eq. (6) and (7):

$$SNR = \sum_i \frac{P_s |g_i|^2 P_i |h_i|^2}{P_s |g_i|^2 + P_i |h_i|^2 + 1} \quad i \in \Psi_{selected} \quad (5)$$

$$C1 : P_{sum} = \sum_i P_i \leq P_{max} \quad i \in \Psi_{selected} \quad (6)$$

$$C2 : \sum_i P_i |f_i|^2 \leq I_{max} \quad i \in \Psi_{selected} \quad (7)$$

where,

- P_{max} : The maximum power that can be transmitted by M selected relays
- I_{max} : The maximum tolerable interference for the PU

The constraints C1 and C2 are sum relay power constraint and sum interference power constraint respectively.

The proposed algorithm: Let $\Psi_{initial} = \{1, 2, \dots, N\}$ be the initial set of relays. The proposed relay selection and power allocation algorithm is a two-phase algorithm. In the first phase, sum interference power I due to $\Psi_{initial}$ towards the PU is computed and $\Psi_{selected}$ is updated by excluding those relays offering relatively high interference until I_{max} is satisfied. In the second phase, transmit power of M selected relays is increased to improve SNR at secondary destination still satisfying I_{max} . For proposed algorithm, we have used Artificial Bee Colony (ABC), a relatively new global optimization algorithm proposed by Dervis Karaboga (Sumpavakup and Chusanapiputt, 2010). ABC has recently attracted much attention in research because it works for even non-convex problem. Artificial Bees collaborate with each other to solve complex unconstrained and constrained problems. ABC emulates honey bees intelligent behavior of searching for quality food source with highest nectar (i.e., the best solution) and sharing that information with their fellows in the hive. Thus, the goal of the whole Bee Colony is to maximize the amount of nectar (in our case SNR in Eq. (5)). ABC is a 2-phase algorithm-*Initialization*

Table 1: Pseudo code

Initialization
Input:
 $P_s, N_0, g_i, h_i, f_i, \Psi_{initial} = N, \Psi_{selected} = M, M = N$
for $m = 1, 2, \dots, SN$ //Initialize SN food sources
 $P_i^m = (A_i^m)^2 (P_s |g_i|^2 + N_0); \quad \forall i \in \Psi_{initial}$
 with constraint: $P_{sum}^m = \sum_i P_i^m \leq P_{max}$
while $(\sum_i P_i^m |f_i|^2 > I_{max})$ // Constraint C2
 $P_i^m = 0$ for $\max(I_i^m = P_i^m |f_i|^2)$
 $\Psi_{selected} = M - 1$
endwhile
 $P_{sum_new}^m = \sum_i P_i^m$ for $i \in \Psi_{selected}$
 $P_i^m = P_i^m + \Delta^m$; for $\forall i \in \Psi_{selected}$, //satisfying C1
 where, $\Delta^m = (P_{sum}^m - P_{sum_new}^m) / M$;
 $(SNR)^m = \sum_i \frac{P_s |g_i|^2 P_i^m |h_i|^2}{P_s |g_i|^2 + P_i^m |h_i|^2 + 1}; \quad \forall i \in \Psi_{selected}$
 $SNR = [(SNR)^1, (SNR)^2, \dots, (SNR)^{SN}]$;
end for
Optimization through artificial bee colony
for¹ LC = 1 : iterations
 Step 1: Employed Bees (EBs)
 for² $m = 1, 2, \dots, SN$
 Generate random integer $\delta \neq m$
 $[P_{new}]_i^m = P_i^m + \alpha_i^m * (P_i^m - P_i^\delta); \quad \forall i \ \& \ 1 \leq \alpha_i^m \leq 1$
 Satisfy constraints C1 and C2
 $(SNR)_{new}^m = \sum_i \frac{P_s |g_i|^2 [P_{new}]_i^m |h_i|^2}{P_s |g_i|^2 + [P_{new}]_i^m |h_i|^2 + 1}$;
 replace $(SNR)^m$ if $(SNR)_{new}^m > (SNR)^m$
 end for²
 Step 2: Onlooker Bees (OBs)
 $p^m = \frac{(SNR)^m}{\sum_{m=1}^{SN} (SNR)^m}; 1 \leq m \leq SN$
 for³ $n = 1, 2, \dots, SN$
 //Apply computations of for² loop on the food source selected via roulette wheel
 end for³
 Step 3: Scout bees
 if (rem (LC, 2) = 0)
 for⁴ $m = 1, 2, \dots, SN$
 If $(SNR)^m < SNR_threshold$, generate new food source
 end for⁴
 end if
end for¹

Phase in which SN number of potential solutions (food sources) are randomly generated and constraints are defined and *Best Solution Search Phase* in which the algorithm recursively operates until the best solution is obtained or the maximum number of iterations are expired. Artificial Bees in ABC are divided into two groups:

- Employed Bees
- Unemployed Bees

Employed bees: Search for the neighborhood solutions in the vicinity of the initialized solutions and update their memory by the best solution that improves the fitness function and satisfies the constraints. The updating process is done by Greedy Approach in ABC. The number of EBs is the same as the number of potential solutions.

Unemployed bees: Consist of Onlooker Bees OLBs and Scout Bees SBs. OLBs rely on the information shared by EBs about the discovered solutions and exploit only those solutions chosen according to the probability of their fitness function relative to the sum of all by Roulette wheel Mechanism. SBs seek for the new solutions randomly in the whole search space to replace the abandoned ones. An abandoned solution is the one that fails to improve the fitness function after several attempts w.r.t. the threshold level. UBs become EBs whenever they find a solution (food source) to act upon. The pseudo code for the proposed algorithm is given in Table 1.

SIMULATION RESULTS AND DISCUSSION

We demonstrate the performance of our proposed scheme in comparison with a traditional cooperative diversity technique in which transmission of all CR relay nodes in a potential relay set is subject to interference power constraints towards PU while forwarding the received message to the destination and the relays offering high interference towards the PU are not switched off, rather transmit power of all potential relays is suppressed to satisfy sum interference power I_{max} towards the PU. We refer it as No Relay Selection NRS Algorithm in our study. Number of PUs is set to 1. P_s and P_{max} are set to be 10W. Noise variance is assumed to be 1. The channel gains g_i, h_i and f_i have independent complex Gaussian distribution. For all simulations, N and M are number of potential relays and selected relays respectively. Figure 2 compares both algorithms at two different sum interference power threshold levels given by $I_{max} = (90 \text{ mW}, 80 \text{ mW})$ and N is set to 8. The results shown for the proposed algorithm are obtained with $M = (3, 2)$ respectively whereas NRS algorithm employs all available relays. We observe that SNR increases with an increase in the sum interference power threshold I_{max} for both algorithms because increase in the value of I_{max} gives more freedom to the relays to transmit with high power. Another observation is that the proposed algorithm results in improved SNR at the destination as compared to NRS algorithm. This improvement is due to the controlled increment in the transmit power of the M

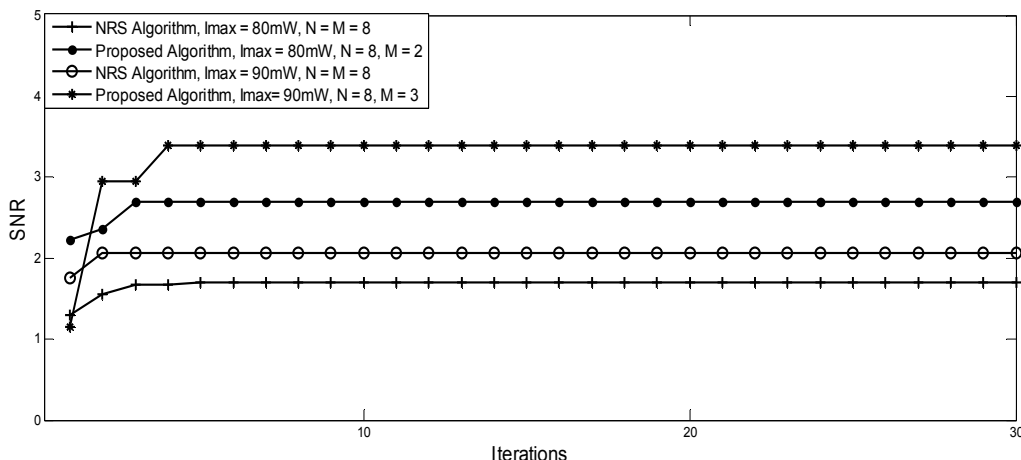


Fig. 2: Comparison of both algorithms for $P_{\max} = 10W$, $N = 8$, $I_{\max} = (90 \text{ mW}, 80 \text{ mW})$

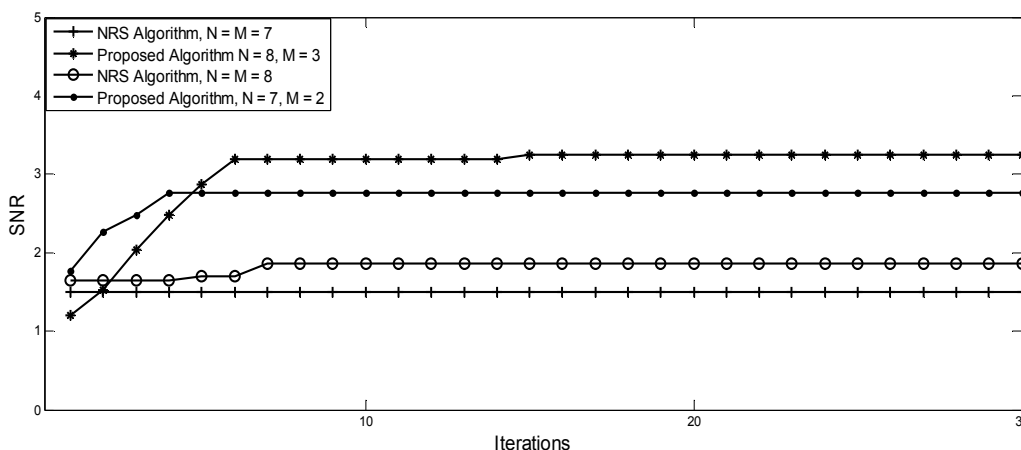


Fig. 3: Comparison of both algorithms for $I_{\max} = 85 \text{ mW}$, $P_{\max} = 10W$, $N = (8, 7)$

selected relays while satisfying I_{\max} . Figure 3 compares SNR received at the destination for both algorithms in case of different number of potential relays N . I_{\max} is set to 85 mW. We consider two cases for N and take $N = (8, 7)$. It is observed that SNR increases with an increase in the value of N because more relays add more flexibility to the system with higher SNR achieved in the case of proposed algorithm employing $M = (3, 2)$ relays as compared to NRS algorithm which utilizes $M = N$ number of relays.

CONCLUSION

We focused on underlay CRNs and propose an adjustable power allocation scheme for relay-assisted cognitive radio networks. Our relay selection based cooperative diversity scheme increases the SNR at the CR destination node keeping the total interference offered by the selected relays to the primary user below a certain threshold level and offers better results than the scheme employing all potential relays between source and destination nodes.

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