Interference Control of Cognitive Network Based on Swarm Intelligence Algorithm

Yunbing Chi, Luyong Zhang*

School of Information and Communication Engineering, Beijing University of Posts and Telecommunication, Beijing, 100876, China

*Corresponding author’s e-mail: lyzhang@bupt.edu.cn

Abstract. This paper proposes a non-cooperative spectrum allocation algorithm based on game theory in a multi-cognitive wireless network scenario. The interference is selected as the basis for establishing the utility function. In order to avoid problems such as excessive calculation of the iterative algorithm and failure to obtain the optimal solution, etc. In this paper, an improved swarm intelligent bat algorithm is proposed. Compared with the original bat algorithm, the improved bat algorithm is richer and more accurate in speed and location update strategies, which improves the diversity of the population. The improved algorithm is applied to the spectrum allocation problem. By rationally allocating spectrum resources, the interference level of the multi-cognitive wireless network system is effectively reduced. It is applicable to dealing with the interference control problem in distributed cognitive radio networks.

1. Introduction
Spectrum allocation technology can be divided into centralized spectrum allocation and distributed spectrum allocation according to different network structures [1]. Cognitive communication has also been applied in the Internet of Vehicles [2]. In cognitive wireless networks [3], cognitive users need to periodically detect the frequency spectrum and feedback the detected structure to the central node, and the central control node allocates spectrum to the cognitive user based on the sensing results. Cognitive radio has applications in UWB communications [4]. The distributed spectrum allocation model adopts a distributed structure, and there is no central control node. The spectrum allocation is completed by each cognitive user in the cognitive wireless network. This paper studies the spectrum allocation of a multi-cognitive wireless network system composed of three distributed cognitive networks to achieve the purpose of interference control.

2. System Model
First consider a multi-cognitive wireless network system composed of three distributed cognitive networks. Each cognitive network is equivalent and there is no hierarchy.

2.1. Network Model
The actual distribution of the three cognitive networks may have multiple situations. In the actual situation, the cognitive node obtains channel state information, channel gain and other information through the channel detection mechanism [5]. Based on this information, the cognitive node judges whether the channel is occupied and the corresponding gain, and selects from it to meet the minimum data transmission rate of idle channels. Effective capacity in cognitive radio is also a focus of research [6]. At the same time, cognitive networks should avoid excessive interference with the main network.
when using channels. Figure 1 shows the possible distribution of three cognitive networks in a multi-cognitive wireless network system.

![Distribution of cognitive networks](image)

**Figure 1. Distribution of cognitive networks**

### 2.2. Cognitive Node Model

A channel is generally used by multiple users, and the channel is a competing channel [7]. In each cognitive network, the cognitive nodes are randomly distributed in a certain area. Since the three cognitive networks are equivalent, the cognitive nodes in the cognitive network are also equivalent. A cognitive node can be randomly selected for analysis.

The transmit-receive pair model is equivalent to cognitive nodes, that is, each cognitive node represents a pair of transmit-receive pairs. The cognitive nodes below represent a pair of cognitive transmit-receive pairs, unless otherwise specified. It is assumed that the cognitive nodes are randomly distributed in three cognitive networks, and the positions of the cognitive nodes are fixed or move very slowly during the spectrum allocation period.

### 2.3. Interference Control Model

In a multi-cognitive wireless network system, three distributed cognitive networks will interfere with each other [8]. For a cognitive wireless network, interference can be divided into two parts according to the source: mutual interference from internal nodes [9] of the network and interference from outside the network.

For the multi-cognitive wireless network system, the spectrum allocation problem of the cognitive system is abstracted as a game process. In this process, the cognitive node is the player in the game, and the selected channel is the strategy. Since each cognitive node always tends to choose a sub-channel with higher gain to obtain higher returns, each cognitive node is non-cooperative. This non-cooperative game model is described as:

$$G = \left[ N, \{ S_i \}, u_i \right]$$  \hspace{0.5cm} (1)

In this model, $N$ is the cognitive nodes participating in the game, $S_i$ is the spectrum strategy space selected for the cognitive nodes and $u_i$ is the utility function.

When the cognitive node performs normal communication, it will be interfered by other cognitive nodes [10]. After considering both the interference experienced by a cognitive node on a channel and the interference caused by a cognitive node to other cognitive nodes, the interference level of a cognitive node in the cognitive system can be expressed by the following formula:

$$U_i(s_i, s_{-i}) = - \sum_{j=1, j\neq i}^{N} p_j h_{ij} a_{ij} F(s_j, s_i) - \sum_{j=1, j\neq i}^{N} p_j h_{ji} a_{ji} F(s_i, s_j)$$  \hspace{0.5cm} (2)

In Equation 2, $p_j$ represents the transmit power of cognitive node $j$ received by cognitive node $i$, $h_{ij}$ represents the channel gain, $a_{ij}$ is the network identifier of the cognitive node, and represents whether cognitive node $i$ and cognitive node $j$ belong to the same recognition. Knowledge network, because only intra-network interference is considered here, when cognitive node $i$ and cognitive node
j belong to the same cognitive network, $a_{ij} = 1$, otherwise $a_{ij} = 0$, $F(s_i, s_j)$ is the interference function, which represents cognitive node $i$ and cognitive node $j$ uses the same channel, which is specifically expressed as:

$$ F(s_i, s_j) = \begin{cases} 1 & s_i = s_j \\ 0 & s_i \neq s_j \end{cases} $$

Refer to the analysis above to derive the interference control utility function of the multi-cognitive network system. The goal is also to minimize the level of system interference. The interference utility function of cognitive nodes $i$ after inter-network interference is added as:

$$ U_i(s_i, s_{-i}) = -\sum_{j=1, j \neq i}^{N} p_j h_{ij} a_{ij} F(s_j, s_i) - \sum_{j=1, j \neq i}^{N} p_j h_{ij} b_{ij} F(s_j, s_i) $$$$ - \sum_{j=1, j \neq i}^{N} p_j h_{ij} b_{ij} F(s_i, s_j) $$

In Equation 4, $p_j$ represents the transmission power of cognitive node $j$ received by cognitive node $i$, $h_{ij}$ represents the channel gain, $a_{ij}$ is the intra-network identification of the cognitive node, and $b_{ij}$ is the inter-network identification of the cognitive node, which are defined as:

$$ a_{ij} = \begin{cases} 1 & \text{Cognitive node } i \text{ and cognitive node } j \text{ belong to the same network} \\ 0 & \text{others} \end{cases} $$

$$ b_{ij} = \begin{cases} 1 & \text{Cognitive node } i \text{ and cognitive node } j \text{ belong to the different network} \\ 0 & \text{others} \end{cases} $$

After determining the interference of the multi-cognitive network system, it is necessary to consider that the interference control for the primary user should be satisfied when the spectrum is allocated, and the interference to the primary user mainly comes from the cognitive node and white noise interference. Considering the interference experienced by the receiving end of the main user $m$ is:

$$ I_m = \sum_{i=1}^{N} p_i h_{im} F(s_i, s_m) + \sigma^2 $$

In Equation (7), $p_i$ is the transmit power of cognitive node $i$, $h_{im}$ is the gain of the same channel used by cognitive node $i$ and main user $m$, and $\sigma^2$ is the Gaussian white noise power received by the receiver of main user $m$. Here, the constraint condition is that the interference received by main user $m$ cannot exceed the interference threshold $\gamma_{th}$, that is,

$$ \sum_{i=1}^{N} p_i h_{im} F(s_i, s_m) + \sigma^2 \leq \gamma_{th} $$

Where $\gamma_{th} = k \times T_{th}$, $k$ are Boltzmann constants and $T_{th}$ is a preset interference temperature threshold.

3. Game Theory Based Spectrum Allocation Model
This utility function is similar to the potential function in the potential game. Therefore, consider establishing a spectrum allocation model based on the potential game.

The basis of a latent game is a latent function. According to the latent game theory and the utility function derived above, the latent function can be obtained:
\[ P_i(s_i, s_{-i}) = \frac{1}{2} \sum_{j=1}^{n} U_j(s_i, s_{-i}) = \frac{1}{2} \sum_{j=1}^{n} \sum_{j \neq i} p_j h_j a_j F(s_j, s_i) - \sum_{j=1}^{n} p_j h_j a_j F(s_j, s_i) - \sum_{j=1}^{n} p_j h_j b_j F(s_j, s_i) \]

Equation (9) is the latent function of this game model. It can be seen that the latent function can ensure that the changes in the returns of the cognitive nodes are the same as the changes in the returns of the cognitive network. It can be seen that this game model is a strictly latent game (that is, the latent function (9) is a strictly latent function), that is, there is a unique Nash equilibrium solution.

4. Spectrum Allocation Model
Bat Algorithm (BA) is a swarm intelligence optimization algorithm proposed by Yang in 2010 [11]. This algorithm obtains the optimal solution by simulating the natural process of bats searching for prey.

Calculate and update according to the speed \( v_i \), position \( x_i \) and frequency \( f_i \) of the current bat individual, the specific formula is as follows [12]:

\[ v_i^{t+1} = v_i^t + (x_i^t - x^*) \cdot f_i \]

\[ x_i^{t+1} = x_i^t + v_i^{t+1} \]

\[ f_i = f_{\text{max}} + \left( f_{\text{max}} - f_{\text{min}} \right) \cdot \beta \]

This section improves the bat algorithm based on previous research. After updating the bat population, first calculate the fitness value of the bat individuals, and analyze the fitness value \( F_k \) corresponding to all bat individuals of the \( k \) generation:

\[ F_k = [f_{k1}, f_{k2}, \ldots, f_{ki}, \ldots, f_{kN}] \]

After adding the weight, the speed update formula becomes:

\[ v_i^{t+1} = w \cdot v_i^t + (x_i^t - x^*) \cdot f_i \]

\[ w = r_{ki}^t = k \frac{r_{ki}}{r_{ki}^{\text{max}}} \]

(15)

\[ r_{ki} = \frac{f_{ki}}{f_k} \]

(16)

In formula (15), \( r_{ki}^{\text{max}} \) is the maximum value of the fitness value \( r_{ki} \), and \( k \) is a constant. Since \( r_{ki}^t \) should not be too large, \( k \) is 2 here. It can be seen that the range of adaptive weight \( w \) is (0,2], which avoids the situation that the bat individual is too fast.

5. Simulation Results
In this section, the original BA algorithm and the WBA algorithm proposed in this paper are combined in the spectrum allocation problem in a multi-cognitive wireless network system, and analyzed and compared to verify the effectiveness of the proposed algorithm. Assume that there are three cognitive wireless networks in a multi-cognitive wireless network system, and the network radius is 200. The number of cognitive nodes is 30, the transmission power is randomly initialized in 30-50mw, the number of available spectrum is 10, the background noise power \( \sigma^2 = 5 \times 10^{-15} W \). The original BA algorithm and the improved WBA algorithm parameters: population size \( NP = 20 \), loudness \( A = 0.6 \), frequency \( r = 0.7 \). The maximum number of iterations of the two algorithms is \( T = 500 \). In order to
reduce the contingency of the algorithms, all optimization results are the average of each algorithm running 30 times under the same conditions.

Figure 2 represents the changes in the total revenue of the cognitive system using the original BA algorithm for spectrum allocation and the WBA algorithm for spectrum allocation when the three network overlap rates in the cognitive system are 0%, 50%, and 100%, respectively. In order to effectively measure the interference level of the cognitive system, the total system revenue is defined here, which numerically represents the sum of the signal-to-interference ratio of all cognitive nodes, that is:

$$\text{Sum of system benefits} = \sum_{j=1}^{N} \gamma_j$$  \hspace{1cm} (17)

![Figure 2](image1)

Figure 2. The relationship between the total revenue of cognitive systems and the number of iterations in different network environments.

From left to right in Figure 2, the changes in the interference level of the cognitive system when the original BA algorithm is used for spectrum allocation and the WBA algorithm is used for spectrum allocation when the network overlap rates are 0, 50%, and 100% respectively. It can be seen from the relationship diagram between the interference level and the number of iterations that the improved WBA algorithm has a significantly faster convergence speed than the original BA algorithm. When the overlap rate rises, the performance gap between the two algorithms for interference control becomes more and more obvious, and the number of iterations corresponding to the convergence also increases.

Figure 3 shows the simulation results of the average SINR and the number of channels of the cognitive system in different network environments when the number of cognitive nodes is fixed at 30. It can be seen from the figure that after the number of channels increases, the probability of mutual interference between cognitive nodes decreases, the average signal-to-interference ratio SINR obtained by the user increases, and the average SINR obtained by the WBA algorithm is higher than the BA algorithm.

![Figure 3](image2)

Figure 3. Relationship between the average SINR and the number of channels in different network environments.

6. Conclusion
This paper mainly describes and analyzes the spectrum allocation problem in interference control of multi-cognitive wireless network systems. Aiming at the spectrum allocation problem, an improved WBA algorithm is proposed. By comparing with the original BA algorithm, the improved WBA algorithm effectively improves the global search capability and convergence speed. The interference
level of the system improves the total revenue of the multi-cognitive network system, and proves the effectiveness of the algorithm in controlling network interference and improving network performance.

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