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# Power control algorithm in cognitive radio system based on modified Shuffled Frog Leaping Algorithm

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ABSTRACT

Based on the non-cooperative power control game introduced by David Goodman, in this paper, we will introduce the concept of target SIR, modify the utility function, and propose a modified power control game algorithm. In this proposed power control game algorithm, it will be proved that the Nash equilibrium exists and is unique. To further improve the accuracy of the solution, the Shuffled Frog Leaping Algorithm (SFLA) will be modified and adopted by incorporating the basic ideas of Artificial Fish (AF). It can be shown that the proposed algorithm will have better global convergence and will have less possibility to be tripped in local optimum. Simulation results show that the proposed power control algorithm based on modified Shuffled Frog Leaping Algorithm (MSFLA) can not only increases the controllability on the target SIR but also reduces the user transmission power and improves system performance.


## 1. Introduction

Along with the fast development of information technology, the radio spectrum has become the indispensable and precious resources of modern society. The growth of radio business and the development of wireless communication system cause the frequency spectrum resources scarce day by day. However, research indicates that [1,2] more than 70 percent of the frequency spectrum resources which have been allocated are not fully used, which obviously is contradictory to the shortage of frequency spectrum resources.

Cognitive radio (CR) [3–5] is one kind of new intelligent radio technology. Using the frequency spectrum detection technology, CR can recognize the usage of frequency spectrum, and readjust the signal frequency and the emissive power adaptively in order to adapt to the change of wireless environment, to achieve the effective use of idle frequency spectrum and to enhance the reliability of communication system as well as the utilization ratio of frequency spectrum.

The distributed power control is adopted in the CR system to expand the operating region of communication system, while the emissive power of each cognitive user is the main source of causing interference to other users. Therefore the power control is one of the key technologies in cognitive radio system. In literature, there are several distributed power control algorithms. In [6], a non-cooperative power control game (NPG) was proposed and proved to have Nash equilibrium. In [7] the non-cooperative power control game problem based on cost function was studied, which can obtain Pareto improvement and have better performance. In [8], a fixed Signal to Interference Ratio (SIR) convergence value was used for the equilibrium algorithm, that is, it does not alter along with the change of multiple access interference and environment noise. Therefore it will reduce the capacity of the system throughput. In [9], a K–G algorithm was proposed, in which the SIR convergence value changes with the change of interference and environment noise. But it only considered the SIR upper limit threshold, so that some users' SIR convergence values could be lower than the lower limit threshold, therefore the far-near unfairness were both existent.

By considering the user objective SIR values and modifying the utility function, a new non-cooperative power control game algorithm (NPG-New) based on the non-cooperative power control game is proposed in this paper. The characteristic of game playing in this algorithm is the balance between the selfish competition of user pursuing own benefit maximization and the consideration of the other user's influence. In order to improve the search precision, a modified Shuffled Frog Leaping Algorithm (MSFLA) based on the Shuffled Frog Leaping Algorithm (SFLA) is utilized to solve the NPG-New optimization problem.

The rest of the paper is organized as follows. The new power control game algorithm based on non-cooperative game theory will be proposed and introduce in Section 2. The Shuffled Frog Leaping Algorithm (SFLA) will be presented and modified in Section 3.

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Simulation results will be presented and discussed in Section 4 followed by conclusions in Section 5.

## 2. The power control model based on non-cooperative game theory

In a wireless cognitive radio (CR) system with $N$ users, assume $M$ is the number of total bites transmitted in a date frame, $L$ is the information bites number of one date frame ($L<M$), the transmission rate is $R$ (bps), $W$ is the bandwidth, the Signal to Interference Ratio (SIR) of the receiver $i$ is $r_i$. In an AWGN channel, the effective function in the way of the non-related FSK modulation is [10,11]:

$$f(r_i)=(1-e^{-r_i/2})^M \tag{1}$$

The common SIR expression is [10,11]:

$$r_i=\frac{Gh_ip_i}{\sum_{j\neq i}h_jp_j+\delta^2} \tag{2}$$

where the spread spectrum gain is $G=W/R$, $h_i$ is the gain from user $i$ to base station, $p_i$ is the emissive power of user $i$, $\delta^2$ is the background noise power of base station. Goodman proposed a non-cooperative power control game (NPG) in wireless data network [6], and gave its utility function as:

$$u_i=\frac{LR(1-e^{-(r_i/2)})^M}{Mp_i} \tag{3}$$

In NPG algorithm, each user adjusts power just to get the maximum benefit for itself. But any user increasing its emissive power will reduce other's revenue, so the affected user will also increase its own emissive power to improve its revenue, thus enhancing the various component values of the power vector on the balanced point.

A non-cooperative power control game via pricing (NPGP) [7] is proposed by Goodman et al., which makes each user communicate with a lower emissive power. The utility function is changed to:

$$u_i=\frac{LR(1-e^{-(r_i/2)})^M}{Mp_i}-\alpha p_i \tag{4}$$

where $\alpha p_i$ is the cost function, $\alpha$ is constant called as cost factor.

Eq. (4) does not consider the demand of user's threshold. In the actual cognitive radio environment, different cognitive users have different QoS requirements, thus reflecting the difference of SIR threshold. For example, the speech user can select a larger SIR threshold, but the data user reduces the SIR threshold to increase the system throughput.

Cost function must be a non-negative convex function which has a positive minimum. In this paper, considering the relationship of the user's threshold demand and the power, we adopt the following utility function.

$$u_i=\frac{LR(1-e^{-(r_i/2)})^M}{Mp_i}-\alpha e^{p_i}-\beta(r^{\mathrm{tar}}-r_i)^2 \tag{5}$$

In Eq. (5), $\alpha$ and $\beta$ are proportional coefficients, which are real constants, $r^{\mathrm{tar}}$ is the target SIR. The utility function has the effect to alter each user purely pursuing selfish self-interest maximization goal, to reduce the user transmission power, also to consider the user's QoS requirement, and to increase the controllability on the target SIR. The NPG-New proposed in this paper maximizes each utility function in Eq. (5) by adjusting the emissive power $p_i$ of each user.

The key issue of the power control game algorithm is to determine whether the algorithm can find balanced emissive powers for all cognitive users and no single cognitive user can benefit by changing its own emissive power. According to game theory, it is Nash equilibrium. For the power control game algorithm to have Nash equilibrium, it needs to meet the following two conditions [19]:

(I) Its strategy space is a compact set;
(II) The utility function meets $(\partial^2u_i/\partial p_i\partial p_j)\geq 0\,\forall j\neq i\in N$.

The emissive power $p_i$ of each cognitive user is greater than zero and has the power upper limit, which apparently satisfy the first condition.

$$\frac{\partial u_i}{\partial p_i}=\frac{LR}{Mp_i{}^2}\left(r_i\frac{\partial f(r_i)}{\partial r_i}-f(r_i)\right)-\alpha e^{p_i}-\beta\left(2r_i\frac{\partial r_i}{\partial p_i}-2r^{\mathrm{tar}}\frac{\partial r_i}{\partial p_i}\right)$$

$$\frac{\partial^2u_i}{\partial p_i\partial p_j}=\frac{LR}{Mp_i{}^2}\left(\frac{\partial r_i}{\partial p_j}\frac{\partial f(r_i)}{\partial r_i}+r_i\frac{\partial r_i}{\partial p_j}\frac{\partial^2 f(r_i)}{\partial r_i{}^2}-\frac{\partial r_i}{\partial p_j}\frac{\partial f(r_i)}{\partial r_i}\right)$$
$$-2\beta\left(\frac{\partial r_i}{\partial p_j}\frac{\partial r_i}{\partial p_i}+r_i\frac{\partial^2 r_i}{\partial p_i\partial p_j}-r^{\mathrm{tar}}\frac{\partial^2 r_i}{\partial p_i\partial p_j}\right)=\frac{LRr_i}{Mp_i{}^2}\frac{\partial r_i}{\partial p_j}\frac{\partial^2 f(r_i)}{\partial r_i{}^2}$$
$$-2\beta(1+r_i-r^{\mathrm{tar}})\frac{\partial^2 r_i}{\partial p_i\partial p_j}$$

because $(\partial r_i/\partial p_j)=-\left(Gh_ih_jp_i/\left(\sum_{j\neq i}h_jp_j+\delta^2\right)^2\right)<0$, so we need $(\partial^2 f(r_i)/\partial r_i^2)\leq 0$

$$\frac{\partial f(r_i)}{\partial r_i}=\frac{M}{2}e^{-(r_i/2)}(1-e^{-(r_i/2)})^{M-1}$$

$$\frac{\partial^2 f(r_i)}{\partial r_i{}^2}=\frac{M(M-1)}{4}e^{-r_i}(1-e^{-(r_i/2)})^{M-2}$$
$$-\frac{M}{4}e^{-(r_i/2)}(1-e^{-(r_i/2)})^{M-1}=\frac{M}{4}e^{-(r_i/2)}(1-e^{-(r_i/2)})^{M-2}$$
$$[(M-1)e^{-(r_i/2)}-(1-e^{-(r_i/2)})]$$

$$\frac{\partial^2 f(r_i)}{\partial r_i{}^2}\leq 0,\quad \text{so}\quad (M-1)e^{-(r_i/2)}-(1-e^{-(r_i/2)})\geq 0$$

that is when $r_i\geq 2\ln M$, $(\partial^2 f(r_i)/\partial r_i^2)\leq 0$.

Assume that the influence of noise on $N$ users' total power received is negligible, $\sum_{j\neq i}h_jp_j+\delta^2\approx(N-1)h_ip_i$. Usually $r^{\mathrm{tar}}=G/N$, so

$$\frac{\partial^2 r_i}{\partial p_i\partial p_j}=-\frac{Gh_ih_j}{\left(\sum_{j\neq i}h_jp_j+\delta^2\right)^2}<0$$

$$1+r_i-r^{\mathrm{tar}}=\frac{(1-r^{\mathrm{tar}})\left(\sum_{j\neq i}h_jp_j+\delta^2\right)+Gh_ip_i}{\sum_{j\neq i}h_jp_j+\delta^2}$$
$$=\frac{h_ip_i(G-(r^{\mathrm{tar}}-1)(N-1))}{\sum_{j\neq i}h_jp_j+\delta^2}=\frac{h_ip_i(G/N+N-1)}{\sum_{j\neq i}h_jp_j+\delta^2}>0$$

From the above, it can be claimed that as long as the emissive power of each cognitive user meets the inequality:

$$r_i\geq 2\,\ln M \tag{6}$$

the NPG-New algorithm proposed in this paper has a unique Nash equilibrium solution.

## 3. Modified Shuffled Frog Leaping Algorithm (MSFLA)

In [7], the optimal emissive power was obtained by letting the first derivative of utility function to be zero, but it was very complex and its computation cost was huge. In [12], series of emissive power values, which cause the utility function be the maximum, were first calculated, then the minimum of the series of emissive power values was considered as the user's emissive power. But