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Highly Effective Algorithm of the Threshold Detection in the Cognitive Radio

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Abstract

Opportunistic spectrum access (OSA) is a key technique enabling the secondary users (SUs) in a cognitive radio (CR) network to transmit over the "spectrum holes" unoccupied by the primary users (PUs). In contrast to OSA, with spectrum sharing (SS) is allowed to transmit regardless of the PU's on/off status, provided that the resulting interference to PU is kept below a predefined threshold. In this paper, we focus on the threshold detection algorithm study for spectrum sharing, which aims to get the SIR of the PUs as quickly and precisely as possible. We propose a dichotomy algorithm with lower complexity and more quickly in contrast to the traditional full search algorithm. Numerous simulation results are provided to validate the proposed algorithm.

Keyword: *opportunistic spectrum access, cognitive radio, spectrum sharing, threshold detection, dichotomy algorithm*

1. Introduction

By enabling the secondary users (SUs) to access to the occupied channel of the primary users (PUs) in a cognitive radio (CR) [1-2], spectrum sharing (SS) [3] is regarded as one promising solution to resolving the spectrum scarcity versus spectrum underutilization paradox in wireless communications [4-6]. In [7], the authors proposed a hidden power-feedback loop for the CR. If PU is reactive and reacts upon receiving SU's interference, SU will reactive a power-boosted PU signals that is easier to detect. In [8], it investigates the energy efficiency maximization problem of cognitive radio systems and proposes to study energy efficiency of cognitive relay transmission scheme based on cooperative spectrum sensing. Paper [9] proposes an improved cognitive radio spectrum sensing algorithm, which aims to improve the SU's detection performance and reduces the interference of the SUs to the PUs. But it doesn't solve the spectrum sharing between PUs and SUs.To design optimal SS strategies, two goals are addressed at the same time: the maximum signal to interference radio (SIR) of the PUs should be detected quickly and precisely. Therefore we need to find a kind of threshold detection algorithm, which can detect the SIR quickly and precisely.

The rest of the paper is organized as follows: Section II presents the system model for PUs and SUs in a CR network. Section III describes the threshold detection algorithm and simulates the proposed algorithm. Section IV analyses the simulation results and compares the proposed algorithm with the traditional full search algorithm. Finally, Section V concludes the paper.

2. System Model

We consider a CR network consisting of two SUs and two PUs. Figure 1 shows that the PUs have different spectrum access strategies, which means the PUs can switch to another communication frequency when the current communication frequency is influenced. In this paper, we assume that the two PUs are in communication with each other at F_0 in the beginning. The block diagram is as shown in Figure 2.

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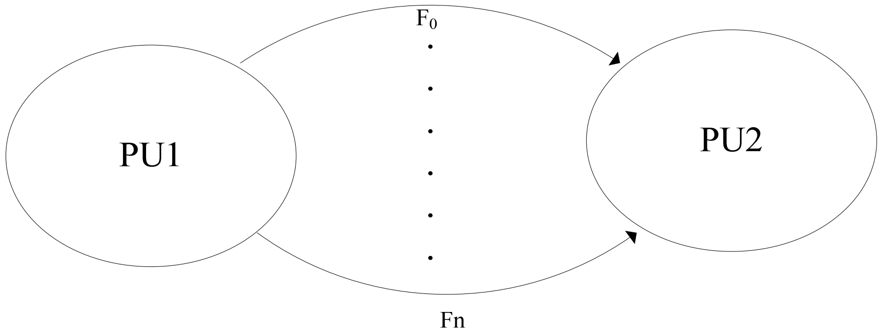

Figure.1. Multiple spectrum access strategies model for the PUs

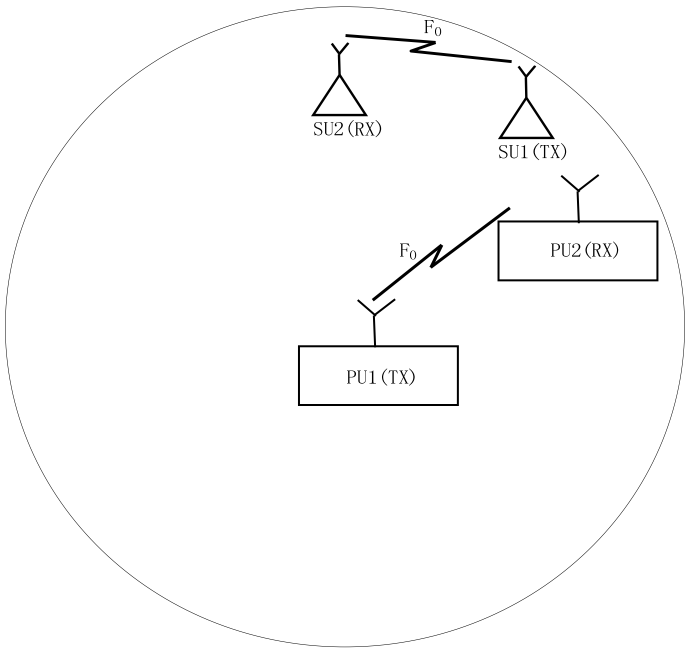

Figure.2. Spectrum sharing model for PUs and SUs

As shown in Figure 2, the two SUs are within the power coverage of the PU1. If the two SUs also want to communicate at F_0, there are two competing goals should be addressed at the same time: the quality of communication for SUs should be guaranteed as far as possible, whereas the interference from SUs can not affect the normal communication between the PU1 and PU2. In other words, we need to control the transmit power of the SUs and keep it below a predefined threshold of the PU2. Therefore we should get the maximum SIR of the PU2. In this paper, we put forward a method that SU1 sends a tentative interference power to PU2, then we can determine whether the PU2' communication is interfered through the feedback channel. If the PU2' communication is influenced, we should reduce the transmit power of the SU1 with a unit of $\triangle P$ as soon as possible. Otherwise, we should increase the transmit power with a unit of $\triangle P$ as soon as possible. $\triangle P$ is variable. After several iterations, we can eventually get the PU2's anti-interference threshold-SIR.

3. Algorithm Design

The thought of the algorithm design comes from the detection algorithm of the relatively cognitive signal, which sends the interference power to the objective cognitive system at a working frequency F_0. Each time the value of interference power is different. After several iterations, we can get the critical power of interference when PUs are forced to switch the working frequency.

The traditional full search algorithm (FSA) [10] is described as follows: First, it need to determine a fixed power step size $\triangle$P. Then SU randomly sends a tentative interference power P_0 towards the PU2. If the PU2 switches the frequency, the power P_0 is larger than the anti-interference threshold of PU2 and the interference power that will be sent next time should subtracts $\triangle$P. Otherwise we should add a $\triangle$P. After several iterations, the SIR of PU2 will be acquired. Its accuracy of convergence is related to $\triangle$P, which means the less $\triangle$P is, the higher the accuracy of convergence is. However the higher accuracy of convergence is at the cost of higher complexity, which cannot meet the goal of fast and efficient detection. In this paper we propose a algorithm based on dichotomy [11], which is a fast search algorithm. The based-on dichotomy algorithm is better than FSA in the terms of the speed of the accuracy of the convergence. In this paper we put forward a threshold detection algorithm based on dichotomy, which are described as following:

Firstly, like the FSA, we should set a minimum power resolution $\triangle$(dBm) and 2^N optional interference power $p_i=i*\triangle$, i=1,2,3,……,2^N . Secondly, defining events $E_{1-0}(p)$ and$E_{1-1}(p)$. The $E_{1-0}(p)$ means the PU cannot stand the interference, stop communicating or switch to another frequency when interference power switch to p. Similarly, $E_{1-1}(p)$ represents that when interference power switch to p, it means the interference power is below the interference threshold of PU. Therefore, to acquire the critical interference power, the interference power should meet the following conditions: (1)$E_{1-0}(p_h)$; (2)$E_{1-1}(p_l)$; (3)$p_h - p_l=\triangle$.

To achieve the above goal, firstly, we use exponential algorithm to roughly search for the threshold. Secondly, when approaching the threshold, we adjust the power by dichotomy algorithm to test the PU. After N times' iterations, the critical power of interference can be found. The algorithm is as following:

a) Initializing parameters: k=1, $p_I^1 = 2^{N-1}*\Delta$, p_T^1=f(p_I^1,r_0).

b) k++, if the event of $E_{1-0}(p_I^{k-1})$ happens, $p_I^k = p_I^{k-1} - 2^{N-K} * \Delta$, else the event of $E_{1-1}(p_I^{k-1})$ must happen, $p_I^k = p_I^{k-1} + 2^{N-k} * \Delta$. Depending on the interference power, we can get $p_I^k = f(p_I^k, r_0)$.

c) If k<N, go back to □, else end and get the critical power of interference, which is divided into three conditions:

(ⅰ)If $p_I^k = 2^N * \Delta$ and both of $E_{1-1}\left(p_I^{k-1}\right) \text{and}\, E_{1-1}(p_I^k)$ happen, it is beyond the range of estimation $\bar{p}$threshold>$2^N * \Delta$, it means the method does not work.

(ⅱ) If $p_I^k = \Delta$ and $E_{1-0}(p_I^{k-1})$, $\bar{p}$threshold=Δ/2+p_0.

(ⅲ) $\bar{p}$threshold=($p_I^k + p_I^{k-1}$) /2+p_0.

4. The Analysis of Simulation Results

We use the convergence of the steady-state value to judge the accuracy of the estimation of the critical power of interference. We use the number of iterations to measure the convergence speed of the algorithm. Figure 3 shows that different $\triangle$P have different convergence results in the FSA. When the $\triangle$P is large enough, the FSA can also achieve the same speed of the convergence as the dichotomy algorithm. However, the accuracy of the convergence will declines as the $\triangle$P increases. In Figure 4 we can see when using exponential algorithm to roughly search for the anti-interference threshold of PU, the choice of the base number is very important. If the base number is too large, the number of PU's switching working frequency will increase, which may affect the PU's communication. However, if the base number is too little, the number of the iterations to approach the anti-interference threshold of the PU will also increase. Therefore, a proper base number is very important. Figure 5 shows that different simulation on condition that the SIR of the PU is 4dB and the SNR is 20dB, 10dB and 0dB. Depending on the results of the simulation, we can see when the SNR is 20dB as shown in Figure 5(a), the number of the iterations of the FSA is 30 when the dichotomy algorithm's is 15. When the SNR declines to 10dB and 0dB as shown in Figure 5(b), (c), the number of the iterations of FSA keeps the same as the result of when the SNR is 20dB. But the convergence of the steady-state value has a minor fluctuations. However the dichotomy algorithm almost remains the same as the result of when the SNR is 20dB. When the SNR continues to decline to -20dB as shown in Fig.5.(d), the convergence speed of FSA is rather slow, which almost cannot converge. But at the same time the convergence speed and the accuracy of convergence of the dichotomy algorithm are almost still unchangeable. Therefore, the dichotomy algorithm is a fast and highly effective algorithm, which is very fit for the threshold detection of the PU.

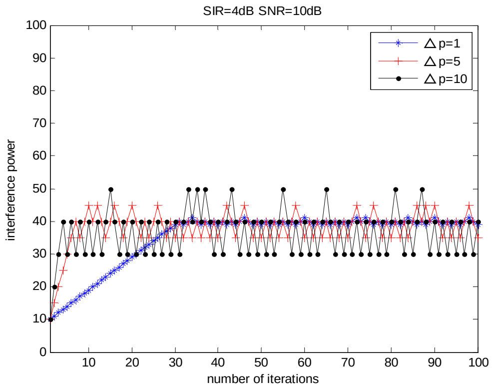

Figure 3. The Results of Simulation of Different △p for FSA

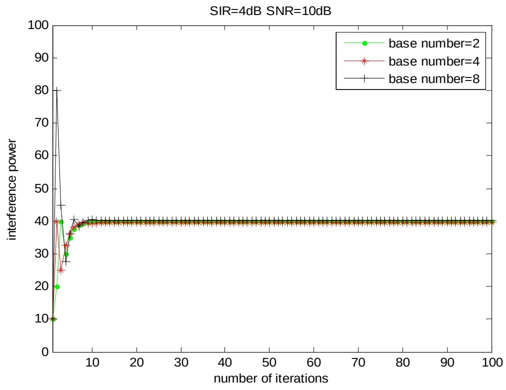

Figure 4. The Results of Simulation of different Base number for Dichotomy Algorithm

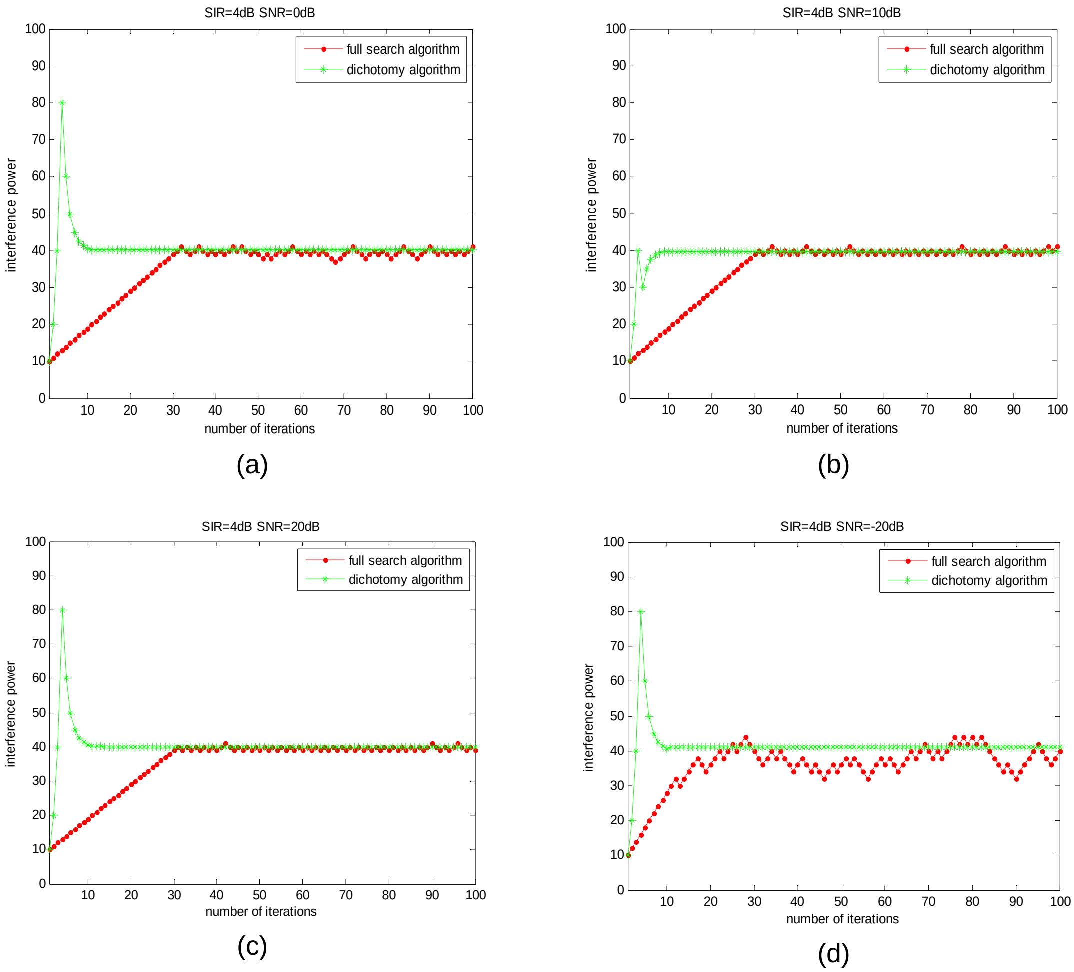

Figure 5. The Results of for Different SNR

5. Conclusion

The FSA sacrifices its convergence speed to get the accuracy of convergence, which cannot be adaptive to the terminal equipments with cognitive function. It does not have the quick reaction capability. In contrast, the dichotomy algorithm is very fast and effective, which is widely used in math search. In this paper we make full use of the advantage of the dichotomy algorithm to detect the SIR of the PU. We also compare the two algorithms by computer simulation. From the results, we can see the dichotomy algorithm is better than the FSA.

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