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Throughput Maximization for Full-Duplex Cognitive Radio Networks using Artificial Bee Colony (ABC) Optimization Technique

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ABSTRACT: Throughput maximization for a secondary user (SU) in a full-duplex cognitive radio network (FD-CRN) using Artificial Bee Colony (ABC) optimization technique is presented in this paper. In the FD-CRN, the secondary users (SUs) having self-interference suppression (SIS) capability and two separate antennas for simultaneous sensing and transmission is considered. For a FD-CRN with cooperative spectrum sensing (CSS), the throughput maximization problem is formulated by optimizing the detection threshold including constraints on the probability of misdetection by the fusion center (FC).

KEYWORDS: Throughput maximization, Secondary user, CSS , detection threshold.

I. INTRODUCTION

According to the statistics of the Federal Communications Commission (FCC), temporal and geographical variations in the utilization of the assigned spectrum range from 15% to 85%. Cognitive Radio (CR) is a new communication technology that allows unlicensed (secondary) users to utilize the vacant bands which are allocated to licensed (primary) users. However, this opportunistic access should be in a manner that does not interrupt any primary process in the band. Therefore, the secondary users (SUs) must be aware of the activity of the primary user (PU) in the target band. They should spot the spectrum holes and the idle state of the primary users in order to exploit the free bands and also promptly vacate the band as soon as the primary user becomes active. Cognitive radio encompasses this awareness by dynamically interacting with the environment and altering the operating parameters with the mission of exploiting the unused spectrum without interfering with the primary users [10]. Spectrum sensing is done by the secondary users to find the vacant spectrum before their transmissions.

A cognitive radio is defined as a radio that can change its transmitter parameters based on the interaction with the environment in which it operates. A cognitive radio (CR) has the ability (cognitive capability) to sense and gather information (such as the transmission frequency, bandwidth, power, modulation, etc) from the surrounding environment as well as has the ability to swiftly adapt the operational parameters, for optimal performance, according to the information sensed. In cognitive radio networks (CRNs), the secondary users need to sense the licensed spectrum to accurately detect spectrum holes prior to transmission [18]. To improve detection performance, cooperative spectrum sensing (CSS) is done whereby SUs can share their local sensing information to make a combined decision at the fusion center [6]. Cooperatively made final decisions on the state of the primary user which is more accurate than individually made decisions, called non-cooperative spectrum sensing (non-CSS).

Recently, Full-Duplex cognitive radio networks have been considered as a new paradigm for increasing spectral efficiency by exploring full-duplex techniques [9]. In this paradigm, an SU with an FD capability can perform concurrent spectrum sensing and data transmission on the same frequency channel. Regarding the FD-CRN scenario in which SUs having SIS capability have two separate antennas for simultaneously sensing and transmitting [12, 14]. In traditional cognitive radio networks, SUs typically access the spectrum of PUs by a two-stage "listen-before-talk" (LBT) protocol, i.e., SUs sense the spectrum holes in the first stage before transmit in the second stage[5, 15]. A novel "listen-and-talk" (LAT) protocol with the help of the FD technique allows SUs to simultaneously sense and access the vacant spectrum. Besides, though the LAT protocol suffers from self-interference, it allows longer transmission time, while the performance of the traditional LBT protocol is limited by channel spatial correction and relatively shorter transmission period [11].

In CRNs a challenging problem is that the SUs need to scan and identify the spectrum state to verify whether the spectrum is used by the PUs or not. In particular, when the SU is transmitting, it is usually hard for the SUs to identify the presence of the PUs immediately, thus causing unexpected interference and delay to PUs. This is because the SUs work in the wireless half duplex fashion, and thus cannot transmit and receive signals simultaneously [13]. The full duplex transmission mode can also have a wide range of networking applications, such as mobile multicast networks.

II. ARTIFICIAL BEE COLONY

In the ABC algorithm, there are three types of bees: employed bees, onlooker bees, and scout bees. The employed bees search food around the food source in their memory; meanwhile they share the information of these food sources to the onlooker bees. The onlooker bees tend to select good food sources from those found by the employed bees. The food source that has higher quality (fitness) will have a large chance to be selected by the onlooker bees than the one of lower quality. The scout bees are translated from a few employed bees, which abandon their food sources and search new ones. In the ABC algorithm, the first half of the swarm consists of employed bees, and the second half constitutes the onlooker bees. It is assumed that there is only one artificial employed bee for each food source. In other words, the number of employed bees in the colony is equal to the number of food sources around the hive. Employed bees go to their food source and come back to hive and dance on this area. The employed bee whose food source has been abandoned becomes a scout and starts to search for finding a new food source. Onlookers watch the dances of employed bees and choose food sources depending on dances.

Optimization problems exist widely in many fields such as engineering technology, management science, computer science, scientific research and so on. At present, the common optimization algorithm for solving the optimization problems can be divided into classical optimization algorithm, local search algorithm and greedy algorithm, intelligent optimization algorithm, hybrid optimization algorithm and so on. Swarm intelligence optimization is an important branch of intelligence optimization. Swarm intelligence optimization is inspired from the collective behavior of social insects and is realized by the communication and cooperation between individuals. Compare with classical optimization algorithm, intelligent optimization algorithm has a lot of advantages, such as easily operating, fast convergence, good global searching ability, strong robustness and so on. Artificial bee colony (ABC) algorithm is a swarm intelligence optimization algorithm based on the particular intelligent behavior of honeybee swarms. The advantages of ABC algorithm are simple calculation, less control parameters, fast convergence and strong robustness.

ABC is a swarm intelligence algorithm proposed by Karaboga in 2005, which is inspired by the behavior of honey bees. Since the development of ABC, it has been applied to solve different kinds of problems. Artificial bee colony (ABC) algorithm is a recently proposed optimization technique which simulates the intelligent foraging behavior of honey bees. A set of honey bees is called swarm which can successfully accomplish tasks through social cooperation.

a. ABC ALGORITHM

1. Initialize: each bee in the colony is assigned a position randomly, x_i is given by

   $x_i = l_i + rand(0,1) * (u_i - l_i)$ eq. (1)

   Where xi → food source of i_{th} bee

   u_i → upper bound of x_i

   l_i → lower bound of x_i

2. Evaluate the solutions
3. Cycle =1
4. Produce new solutions v_i for the employed bees by

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$v_i = x_i + \Phi_i (x_i - x_k)$ eq. (2)

Where $v_i$àthe new position of employed bee

$x_i$àposition of i_{th} employed bee in memory

$\Phi_i$àrandomly number within [-1, 1]

$x_k$àrandomly chosen position of kth employed bee

K àrandom index number in the colony, it has to differ from i

and evaluate these solutions

5. Calculate the probability values P_i for the solution x_i by

   $Pi=fit (x_i)/\sum_{k=1}^{SN} fit (x_k)$ eq. (3)

   Where, iài$_{th}$ employed bee

   Pià i_{th} employed bee's selection probability

   SNàtotal number of bees in colony

   fit (x_i) àith bee's fitness value

6. Produce new solutions v_i for the onlooker bees from the solutions x_i selected depending on P_i and evaluate them.
7. If an abandoned solution exists, replace it with a new randomly produced solution x_i by a scout bee.
8. Memorize the best food source found so far.
9. Cycle=cycle+1
10. If cycle arrives at the maximum iteration, ABC algorithm stops; otherwise go to step4.

III. THROUGHPUT MAXIMIZATION

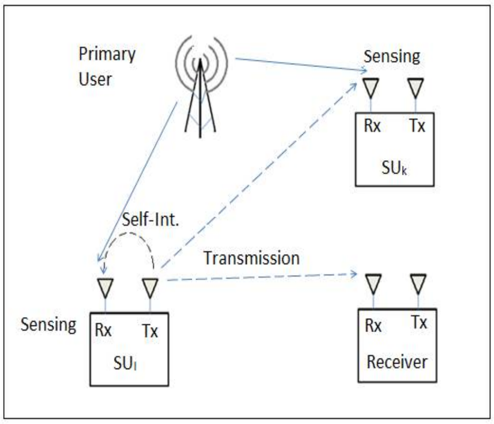

Fig. 1 System model

Asystem model with QPSK signal and AWGN noise has been considered. The secondary system could utilize the spectrum only when the primary users are inactive. The system model consists of primary users and secondary users. The secondary users make use of the licensed spectrum when the primary user is absent. The system under consideration is cooperative spectrum sensing in which the users cooperatively detect the presence of primary user. The main advantage of using cooperative spectrum sensing is hidden node problem is significantly reduced, increases the agility, false alarm can be reduced and signal detection is more accurate. Energy detection is easy to implement but the

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performance of energy detector is susceptible to uncertainty in noise power and also it cannot differentiate signal types but can only determine the presence of the signal. The cyclostationary energy detector can perform better than the energy detector in discriminating against noise due to its robustness to the uncertainty in noise power.

Energy detection is a non-coherent detection method that is used to detect the licensed User signal. It is a simple method in which prior knowledge of primary or licensed user signal is not required; it is one of popular and easiest sensing technique of non-cooperative sensing in cognitive radio networks. If the noise power is known, then energy detection is a good choice. In energy detection method, we measure the energy of the received signal and compare it with a predefined threshold to determine the presence or absence of primary user's signal. Moreover, energy detector is mainly used in ultra wideband communication to borrow an idle channel from licensed user. Probability of detection (P_d), Probability of false alarm (P_f) and Probability of missed detection (Pm = 1 - Pd) are the key measurement metrics that analyze the performance of an energy detector. As a result, energy detection is not only simple in implementation but also robust in various operating environments.

Basic hypothesis model for transmitter detection is given by,

$$x(t) = \begin{cases} n(t), H_0 \\ hs(t), H_1 \end{cases} \quad \text{eq. (4)}$$

Where h is the amplitude gain of the channel, n(t) is the AWGN, x(t) is the transmitted signal and s(t) is the transmitted signal. H_0 is null hypothesis, which states that there is no licensed user signal in a certain spectrum band and H_1 indicates that there exist some licensed user signal.

If the energy detection can be applied in a non-fading environment, the probability of detection P_d is given by,

$$P_d = P\{Y>\lambda/H_1\} = Q(\sqrt{2\gamma}, \sqrt{\lambda}) \quad \text{eq. (5)}$$

The probability of false alarm P_f is given by,

$$P_f = P\{Y>\lambda/H_0\} = (\Gamma(m, \lambda/2) / \Gamma(m)) \quad \text{eq. (6)}$$

Where γ is the received SNR, Y is the received signal, λ is the threshold, $\Gamma(m)$ & $\Gamma(m, \lambda/2)$ are complete and incomplete gamma functions and $Q(\sqrt{2\gamma}, \sqrt{\lambda})$ is the generalized Marcum Q-function

From the above functions, while a low P_d would result in missing the presence of the primary user with high probability which in turn increases the interference to the primary user, a high P_f would result in low spectrum utilization since false alarms increase the number of missed opportunities.

IV. SIMULATION RESULTS

In the CSS scenario, we used the constraint on probability of misdetection of P_m= 0.01 and assumed that SU1 had the SIS factor of χ = 0.1. We assumed that the interference from SU_1 to SU_k (k = 2, …, K) is uniform and in the range (0, 0.15). We considered the numbers of SUs, K = 1, 3, 5, and 10.

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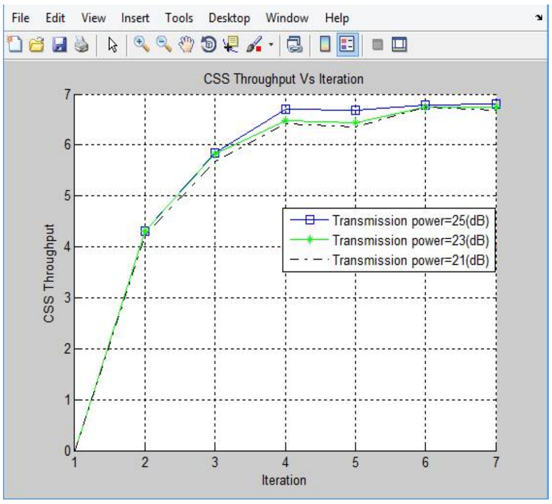

Fig. 2 Iteration index vs Throughput

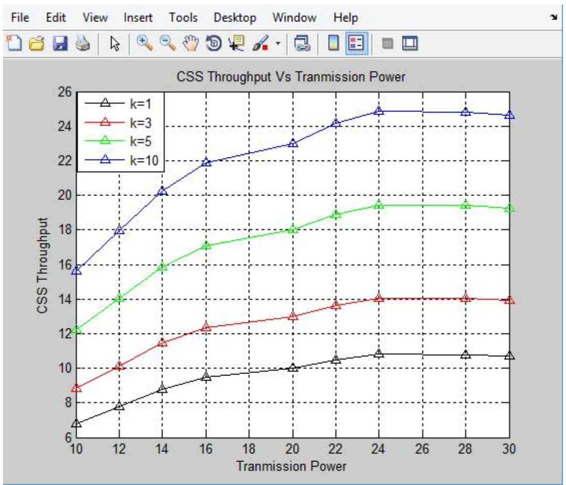

Fig. 3 Transmission power vs Throughput

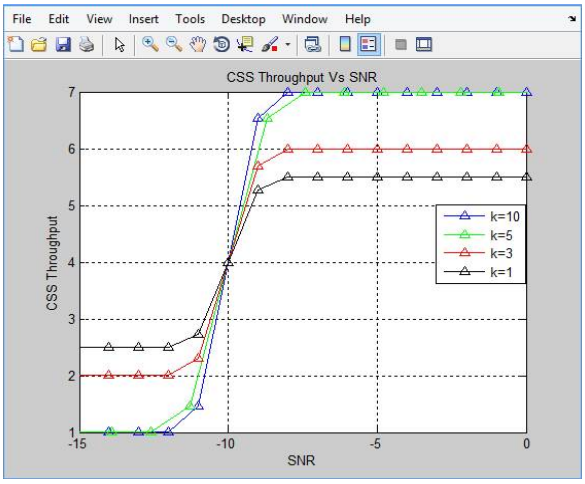

Fig. 4 SNR vs Throughput

Fig. 1 shows the output of Cooperative Spectrum Sensing (CSS) throughput of cognitive radio networks using Artificial Bee Colony (ABC) algorithm. It describes the convergence behavior of ABC algorithm for number of users K=5 with respect to relative transmission power. For transmission power 21(dB), the secondary user throughput is stabilized after sixth iteration but in particle swarm optimization algorithm (PSO), the secondary user throughput is optimized at tenth iteration. For transmission power 25(dB), secondary user throughput is stabilized at fourth iteration and in PSO throughput is stabilized at eighth iteration. From this it is clear known that ABC algorithm has faster convergence than PSO algorithm.Fig.2 shows the relative transmission power versus CSS throughput of full-duplex cognitive radio networks for different secondary users. For secondary users K = 1,3,5 and 10 the maximized throughput is obtained by varying the relative transmission power as shown in the fig. The Non-Cooperative Spectrum Sensing (non-CSS) ie., K=1 has less throughput than the cooperative spectrum sensing (CSS) in full-duplex cognitive radio networks. For secondary users k=10 the throughput is maximum with respect to relative transmission power when compared to the other users because the cooperative spectrum sensing with large number of users provide higher throughput.Fig.3 shows the maximum throughput of the secondary user in the CSS full-duplex cognitive radio

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networks for average value of the Signal-to-Noise ratio. For secondary users K = 1,3,5 and 10 the maximized throughput is obtained with respect to signal-to-noise ratio as shown in the fig. The Non-Cooperative Spectrum Sensing (non-CSS) ie., K=1 has less throughput than the cooperative spectrum sensing (CSS) full-duplex cognitive radio networks. For secondary users K=10 the throughput is maximum with respect to average SNR when compared to the other users because the cooperative spectrum sensing with large number of users provide higher throughput.

V. CONCLUSION

Detection threshold is optimized to maximize the throughput for full-duplex cognitive radio networks using artificial bee colony (ABC) algorithm. The maximized throughput obtained in PSO algorithm is 11.2 bps/Hz and in ABC algorithm is 15.7 bps/Hz. The results shows that the Artificial Bee Colony optimization technique has less computational complexity, high convergence speed and more flexible than Particle Swarm optimization technique. Thus the throughput of secondary user in full-duplex cognitive radio network is maximized by optimizing the detection threshold.

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