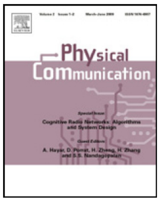
ARTICLE IN PRESS

Physical Communication ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at ScienceDirect

Physical Communication

journal homepage: www.elsevier.com/locate/phycom



Full length article

Joint optimal fair cooperative spectrum sensing and transmission in cognitive radio

Xin Liu[a,*], Min Jia[b,*]

[a] School of Information and Communication Engineering, Dalian University of Technology, Dalian 116024, China
[b] Communication Research Center, Harbin Institute of Technology, Harbin 150080, China

ARTICLE INFO

Article history:
Received 7 June 2017
Received in revised form 14 August 2017
Accepted 19 August 2017
Available online xxxx

Keywords:
Cognitive radio
Cooperative spectrum sensing
Fairness
Throughput

ABSTRACT

Since the sensing power consumption of cooperative spectrum sensing (CSS) will decrease the throughput of secondary users (SU) in cognitive radio (CR), a joint optimal model of fair CSS and transmission is proposed in this paper, which can compensate the sensing overhead of cooperative SUs. The model uses the periodic listen-before-transmission method, where each SU is assigned a portion of channel bandwidth, when the primary user (PU) is estimated to be free by the coordinator. Then, a joint optimization problem of local sensing time, number of cooperative SUs, transmission bandwidth and power is formulated, which can compensate the sensing overhead of cooperative SUs appropriately through choosing suitable compensating parameter. The proposed optimization problem can be solved by the Polyblock algorithm. Simulation results show that compared with the traditional model, the total system throughput of the fairness cooperation model decreases slightly, but the total throughput of the cooperative SUs improves obviously.

1. Introduction

Recently, cognitive Radio (CR) is proposed to alleviate spectrum resource shortage. CR adopts the opportunistic spectrum access by admitting secondary user (SU) to utilize the unlicensed spectrum or the licensed spectrum without primary user (PU), in order to improve the spectrum efficiency [1,2]. Therefore, SU has to sense the status of PU continually to avoid interfering PU. Energy detection has been widely used as an effective spectrum sensing method in CR network, because it does not need any prior information of the PU and also owns high reliability [3]. However, the “hidden terminal problem” caused by multipath fading and shadow effect may decrease the sensing performance greatly. Cooperative spectrum sensing (CSS) is proposed to overcome this problem by combining the independent sensing information of different SUs locating in different sensing areas. The cooperative diversity gain can be achieved through making a final decision in a fusion center [4].

The sensing parameters (e.g., sensing duration and the number of cooperative users, etc.) and the transmission parameters (e.g., transmission bandwidth and power, etc.) will affect the transmission performance of CR system [5,6]. The system performance can be improved obviously by jointly optimizing these system parameters. Liang proposed an optimization problem that seeks a tradeoff between the sensing duration and the SU throughput in the listening-before-transmission model. The optimization problem maximizes the SU throughput by optimizing the sensing duration, but the spectrum allocation was lack of consideration, which can improve the throughput effectively [7]. Liu studied the joint optimization algorithm of sensing parameters and transmission power under the single-user condition by using alternating directing optimization (ADO) [8], but this algorithm had a low computational efficiency and failed to consider the multiuser condition. Fan gave the joint optimization of CSS duration, transmission bandwidth and power [9], however, this optimization ignored the affection of the user overhead and power overhead on the CR system.

This paper proposes a joint optimization of multiuser fairness and transmission to improve sensing and transmission efficiency, while compensating the transmission loss caused by CSS. Polyblock algorithm is used to achieve the joint optimal allocation of sensing duration, the number of cooperative users, transmission bandwidth and transmission power. Though the total system throughput of the proposed fairness model decreases slightly, the total throughput of all cooperative SUs improves and the sensing overhead is also compensated properly.

2. System model

2.1. Energy detection

The energy detection is widely used in CR because SU cannot obtain any prior information of PU signal. As shown in Fig. 1, in

---

* Corresponding authors.
E-mail addresses: liuxinstar1984@dlut.edu.cn (X. Liu), jiamin@hit.edu.cn (M. Jia).

http://dx.doi.org/10.1016/j.phycom.2017.08.015
1874-4907/

Please cite this article in press as: X. Liu, M. Jia, Joint optimal fair cooperative spectrum sensing and transmission in cognitive radio, Physical Communication (2017), http://dx.doi.org/10.1016/j.phycom.2017.08.015.

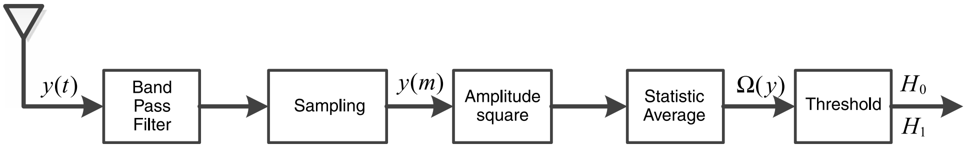


Fig. 1. Energy detection model.

energy detection, the received signal will first be processed by a band-pass filter to obtain the pure PU signal, the energy statistic is then computed by squaring the amplitude of the PU signal samples, and the achieved energy statistic is finally compared with a preset threshold to make a decision on the presence of PU. SUs will only access the spectrum if the energy statistic exceeds the threshold, which means the spectrum is idle [10].

Spectrum sensing can be seen as a binary hypothesis problem. Supposing that H_0 and H_1 represent idle status and busy status of the PU, respectively, the received signal sample $y(m)$ at SU can be given as

$$y(m) = \begin{cases} n(m), & H_0 \\ s(m)\, h_m^{\mathrm{ps}} + n(m), & H_1 \end{cases} \quad m = 1, 2, \ldots, M \tag{1}$$

where $s(m)$ is the PU signal with power of p_s, $n(m)$ is the white Gaussian noise with mean of 0 and variance of σ_n^2, h_m^{ps} denotes the channel gain between the SU and the PU, and M is the number of samples. If the sensing duration and frequency are τ and f_s, respectively, M can be given by

$$M = \tau f_s. \tag{2}$$

The energy statistic $\Omega(y)$ is calculated by acquiring the mean square value of the M sample amplitudes as follows [11]

$$\Omega(y) = \frac{1}{M}\sum_{m=1}^{M} |y(m)|^2. \tag{3}$$

According to the Center Limit Theorem, $\Omega(y)$ approximately obeys the Gaussian distribution as follows

$$\Omega(y) \sim \begin{cases} \mathbb{N}\left(\sigma_n^2, \sigma_n^4/\tau f_s\right), & H_0 \\ \mathbb{N}\left((\gamma+1)\,\sigma_n^2, (2\gamma+1)\,\sigma_n^4/\tau f_s\right), & H_1. \end{cases} \tag{4}$$

Supposing that the threshold is λ, the false alarm probability P_f and the detection probability P_d can be represented as follows

$$\begin{cases} P_f = \mathrm{P_r}\left(\Omega(y) \geq \lambda | H_0\right) = \mathrm{Q}\left(\left(\dfrac{\lambda}{\sigma_n^2} - 1\right)\sqrt{\tau f_s}\right) \\ P_d = \mathrm{P_r}\left(\Omega(y) \geq \lambda | H_1\right) = \mathrm{Q}\left(\left(\dfrac{\lambda}{\sigma_n^2} - \gamma - 1\right)\sqrt{\dfrac{\tau f_s}{2\gamma+1}}\right) \end{cases} \tag{5}$$

where $\gamma = p_s \left|h_m^{\mathrm{ps}}\right|^2/\sigma_n^2$ is the signal to noise ratio (SNR) at SU and $Q(\cdot)$ is the Normal complementary integral function as follows

$$Q(x) = \frac{1}{2\pi}\int_x^{+\infty} \exp\left(-\frac{t^2}{2}\right) dt. \tag{6}$$

The sensing threshold is selected according to false alarm probability or detection probability. If the false alarm probability is ordered, the sensing threshold is selected as follows

$$\lambda = \left(\frac{Q^{-1}(P_f)}{\sqrt{\tau f_s}} + 1\right)\sigma_n^2 \tag{7}$$

while if the detection probability is settled, the sensing threshold is chosen as follows

$$\lambda = \left(Q^{-1}(P_d)\sqrt{\frac{2\gamma+1}{\tau f_s}} + \gamma + 1\right)\sigma_n^2. \tag{8}$$

2.2. Cooperative spectrum sensing

The "hidden terminal problem" caused by shadow effect and multipath fading weakens the sensing signal at SU, thus leading to the misjudgment on the PU status and lowering the whole sensing performance of CR system. CSS has been proven to gain perfect solution to the hidden terminal problem and improve the whole sensing performance of CR system, through letting the SUs in good channel conditions help the SUs in poor channel conditions for sensing PU, as shown in Fig. 2. In CSS, a fusion center is adopted to manage and control the cooperative SUs. These cooperative SUs send their sensing information about PU to the fusion center and the fusion center will reach a final decision on the status of PU by combining all the received sensing information [12]. The final decision results are broadcasted to all the SUs by the fusion center.

Supposing that k SUs participate in CSS and the local energy statistic of SU i is represented by $\Omega(y_i)$ for $i = 1, 2, \ldots, k$, the cooperative energy statistic is defined as the average value of all the local energy statistics, as follows

$$\Phi(y) = \frac{1}{k}\sum_{i=1}^{k} \Omega(y_i). \tag{9}$$

Substituting (9) into (5), false alarm probability Q_f and detection probability Q_d of cooperative spectrum sensing can be obtained by

$$\begin{cases} Q_f = \mathrm{Q}\left(\left(\dfrac{\lambda}{\sigma_n^2} - 1\right)\sqrt{k\tau f_s}\right) \\ Q_d = \mathrm{Q}\left(\left(\dfrac{\lambda}{\sigma_n^2} - \overline{\gamma} - 1\right)\sqrt{\dfrac{k\tau f_s}{2\overline{\gamma}+1}}\right) \end{cases} \tag{10}$$

where $\overline{\gamma}$ is the average sensing SNR of k sensing users.

2.3. Traditional cooperative sensing and transmission model

Since PU owns the privilege utilization of the licensed channel, the SU can access the licensed channel on the premise that it will not disturb PU, and the CR system needs to detect the status of PU in an efficient and real-time way. Recently, the periodic spectrum sensing can be seen as an effective detection method. As shown in Fig. 3, the transmission time of CR system is divided into a number of sensing periods, and the listen-before-transmission mode is used in each sensing period, which means that SU firstly senses the PU and then transmits data if PU is detected to be idle [13].

In periodic CSS, the sensing duration includes local sensing and cooperative overhead. In the local sensing phase, the SUs will detect the status of PUs independently, and then in the cooperative phase, they report the sensing information to the fusion center through a common channel [14]. In the cooperative phase, time division multiple access (TDMA) is used to allocate the reporting time of each SU, in order to save the bandwidth of common channel and avoid the interference between cooperative SUs. Fixed slots will be allocated to different SUs in TDMA. We suppose that the sensing duration is T, the local sensing duration is τ, and the cooperative overhead of k SUs is

$$T_c = k\xi \tag{11}$$

Please cite this article in press as: X. Liu, M. Jia, Joint optimal fair cooperative spectrum sensing and transmission in cognitive radio, Physical Communication (2017), http://dx.doi.org/10.1016/j.phycom.2017.08.015.