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Cooperative Spectrum Sensing Parameter Optimization Algorithm in Cognitive Radio System

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Abstract: ***In this paper, an optimization for cooperative spectrum sensing (Cognitive Radio (CR) network) is proposed, to maximize the efficiency of spectrum sensing in the interference limited primary system. The proposed model defines, the jointly optimized sensing parameters in cooperative spectrum sensing i.e., transmission duration, sensing duration and number of CR users. Simulation results show the enhanced efficiency of spectrum sensing, while satisfying the limitations of interferences.***

Index Terms: ***Cognitive Radio (CR), Cooperative Spectrum Sensing (CSS).***

I. INTRODUCTION

In recent years, cognitive radio (CR) has received more and more attention because of its ability to obtain sufficient spectrum efficiency through spectrum sharing and dynamic access. It is considered to be an important way for next-generation wireless communication systems to solve the problem of spectrum scarcity. As an intelligent wireless communication system, cognitive radio first needs to perceive the surrounding radio environment. Therefore, spectrum perception is an important prerequisite for cognitive radio communication. Spectrum sensing must be able to quickly and accurately detect the presence of the primary user signal, so that the secondary user dynamically occupies the licensed frequency band with low utilization, and at the same time avoids harmful interference to the primary user. Once the main user appears, the secondary user should be able to detect it immediately, and quickly exit the frequency band it occupied [1-2]. Commonly used spectrum sensing methods include matched filter detection, energy detection, and cyclo-stationary feature detection. Energy detection is simple to implement and performs well in the case of high signal-to-noise ratio. Under actual conditions, the secondary performance is seriously degraded due to factors such as channel fading and shadowing. Cooperative spectrum sensing is a method that can effectively improve the secondary user performance, and has become a research hotspot.

The main goal of spectrum sensing is to maximize the spectrum sensing efficiency of cognitive radio systems while meeting the constraints of interference. In the periodic spectrum sensing process, the spectrum sensing and data transmission of the sensing user cannot be performed simultaneously. Therefore, it is necessary to comprehensively consider the allocation of the sensing time and the transmission time. The longer the sensing time, the higher the accuracy, and the less interference it can cause to the primary user. However, when the sensing time becomes longer, the transmission time of the secondary user will be reduced, resulting in a decrease in the sensing efficiency of the secondary user. Therefore, sensing time and transmission time are two key parameters affecting spectrum sensing efficiency and interference problems. The choice of this parameter will have an important impact on the performance of cognitive radio networks. At the same time, in cooperative spectrum sensing, the number of users participating in cooperative network also affects spectrum sensing efficiency.

At present, there has been a lot of research on the parameter optimization problem of cooperative spectrum sensing. Literature [3-4] optimizes the number of sensing users participating in cooperation to minimize the probability of error or maximize the probability of detection. In [5], a set of parameters including the perceived time and the number of recognized users participating in the cooperation are optimized under the condition, satisfying the system detection performance, so that the cognitive user's throughput is maximized. Literature [6] studied the problem of maximizing the perceived efficiency in the case of limited interference, taking into account the influence of two key parameters of sensing time and transmission time. In this paper, by jointly optimizing the sensed parameters including the sensing time, the transmission time and the number of sensed users participating in the collaboration, the spectrum sensing efficiency is maximized under the condition of limited interference.

II. SYSTEM MODEL

A. Problem Definition

Define a CR network: M secondary users, 1 base station and 1 primary user. Each sensing user makes a judgment of whether the main user signal exists by periodic spectrum sensing, and sends the judgment result to the base station, and the base station makes a final decision according to the received information. The typical frame structure of periodic spectrum sensing (see Figure 1) includes the sensing time (T_s) and the transmission time (T) [5].

To solve the problem, the following questions are first introduced:

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Step 1: Sensing efficiency refers to the ratio of the resources used to transmit data to the entire frame resource after spectrum sensing. The definition is as follows:

$$\eta = 1 - \frac{mT_s}{M.T + mT_s} \quad (1)$$

where M is the number of perceived users in the CR network; m is the number of sensed users participating in the collaboration.

Step 2: The ratio of interference time is the ratio of the interference time to the duration of data transmission. It is defined as follows:

$$\varepsilon = \frac{T_I}{T} \quad (2)$$

where T_I represents the duration of the interference, i.e., the time when the primary frequency band is busy, and the user is sensed to communicate.

The goal of spectrum sensing is to find a set of optimal sensing parameters that maximize the sensed efficiency when the interference is limited, i.e.,:

$$Find: m^*, T_s^*, T^*$$

$$max: \eta(m^*, T_s^*, T^*) = 1 - \frac{mT_s}{MT + mT_s} \quad (3)$$

$$s.t.\ \ \varepsilon \leq \Gamma, 1 \leq m \leq M$$

where, m^*, T_s^*, T^* respectively, represent the optimal number of sensed users participating in the cooperation, the optimal sensed time and the optimal transmission time; Γ represents the maximum interference limit, that the system can tolerate.

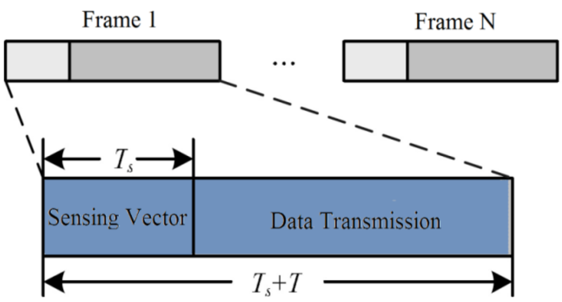

Figure 1: Spectrum Sensing Frame Structure

B. Energy Detection based on Statistical Characteristics of licensed frequency band occupancy status

The occupancy statistics of the licensed band can be seen as a periodic change in the transition between busy and idle states. The busy and idle states respectively indicate that the band is occupied and unoccupied by authorized users, and the busy and idle durations are subject to exponential distribution. The probability density functions are:

$$f_B(t) = \alpha e^{-\alpha t} \quad (4)$$

$$f_I(t) = \beta e^{-\beta t} \quad (5)$$

where α and β represent the probability of transitioning from the busy state to the idle state and the probability of transitioning from the idle state to the busy state, respectively. These two values can be estimated from the spectrum sensing of the licensed frequency band, so they are assumed to be known to the cognitive user. Then for a certain frequency band, the probability of being in a busy state and an idle state are: $P_B = \frac{\beta}{\alpha+\beta}$ and $P_I = \frac{\alpha}{\alpha+\beta}$.

Suppose H_0 indicates that the primary user signal not present, H_1 indicates that the primary user signal exists, and the signal received by the i^{th} sensed user is:

$$x_i(k) = \begin{cases} n_i(k) & H_0 \\ s(k) + n_i(k) & H_1 \end{cases}, \quad i = 1,2,\dots,M \quad (6)$$

where $s(k)$ represents the primary user transmitting signal; $n_i(k)$ represents the additive Gaussian noise with mean 0 and variance is δ_n^2; $s(k)$ and $n_i(k)$ are independent of each other. When the number of sampling points N is large enough, according to the central limit theorem, Y_i approximates a Gaussian distribution:

$$Y_i = \begin{cases} N(N\delta^2, 2N\delta^4) & H_0 \\ N(N(1+\gamma_i)\delta^2, 2N(1+2\gamma_i^2)\delta^4) & H_1 \end{cases} \quad (7)$$

At the same time, according to the literature [4], taking into account the statistical characteristics of the licensed band, for a given licensed frequency band, assuming $N = 2T_sW$, W for the bandwidth, then the first sensed user's false alarm probability and detection probability are:

$$P_{F,i} = \frac{\alpha}{\alpha+\beta} Q\left(\frac{\lambda_i - 2T_sW\delta^2}{2\delta\sqrt{T_sW}}\right) \quad (8)$$

$$P_{D,i} = \frac{\beta}{\alpha+\beta} Q\left(\frac{\lambda_i - 2T_sW(1+\gamma_i)\delta^2}{2\delta^2\sqrt{T_sW(1+2\gamma_i^2)}}\right) \quad (9)$$

where γ_i is the i^{th} perceived user receiving signal to noise ratio: $Q(t) = \frac{1}{2\pi}\int_t^{+\infty} e^{\frac{-u^2}{2}} du$

C. *Cooperative Spectrum Sensing*

It is assumed that there are m users participating in the spectrum sensing in the above cognitive radio network, i.e., $1 \leq m \leq M$. Using the logical "OR" criterion, the detection probability and false alarm probability of the cooperative spectrum sensing are:

$$Q_F = 1 - \prod_{i=1}^{m}(1 - P_{F,i}) \quad (10)$$

$$Q_D = 1 - \prod_{i=1}^{m}(1 - P_{D,i}) \quad (11)$$

without loss of generality, it is assumed that all sensed users have the same sensing performance, so here $P_{F,i}$ and $P_{D,i}$ can be represented as P_F and P_D. The false alarm probability and detection probability of a single sensed user are:

$$P_F = 1 - \sqrt{(1 - Q_F)^m} \quad (12)$$

$$P_D = 1 - \sqrt{(1 - Q_D)^m} \quad (13)$$

III. OPTIMIZATION OF COOPERATIVE SENSING PARAMETERS

A. *Interference analysis model of licensed bands*

Interference duration in the entire frame is first analyzed. In fact, the probability of licensed band state changes two or more times during each data transfer process is small and can be ignored. Therefore, the user communication can cause interference to the primary user in the following two cases:

1. During the data transmission process, the licensed frequency band is in a busy state and the sensing result is judged as an idle state;

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2. The sensing result is idle, and the licensed frequency band is changed from the idle state to the busy state during the data transmission.

Assuming that $T_{I,1}$ and $T_{I,0}$ represent the average interference time in these 2 cases, respectively, the total statistical average interference time is

$$T_I = T_{I,1}(1 - Q_D) + T_{I,0}(1 - Q_F) \quad (14)$$

when error in sensing occurs, the user sensed to be harmful to the primary user during data transmission. If the licensed band status changes from the time of data transmission to the idle state after the time τ, and the time of occurrence of the interference is τ, then $T_{I,1}$ is

$$T_{I,1} = \int_T^{\infty} f_B(\tau).Td\tau + \int_0^T f_B(\tau).\tau d\tau \quad (15)$$

If the licensed band changes from data transfer to a busy state after the time τ, the interference occurs at $t - \tau$, then $T_{I,0}$ is:

$$T_{I,0} = \int_0^T f_B(\tau).(T - \tau)d\tau \quad (16)$$

In the periodic frame structure sensed, considering the strict interference limitation to the primary user, the average time for the licensed band to be in the busy and idle state is much larger than the data transmission time, that is, $T = \frac{1}{\alpha}$, according to the Taylor series, the formula (14) ~ (16) is substituted into equation (2), which gives:

$$\varepsilon = 1 - Q_D + \frac{\alpha T}{2}(Q_D - Q_F) \quad (17)$$

B. *Optimization of cooperative sensing parameters*

Assume that the false alarm probability $\bar{Q}_F$ and the detection probability $\bar{Q}_D$ that a given system should satisfy.

1. *Sensing time T_s*

Combining equations (8) and (11) respectively to determine the detection thresholds and make them equal, the sensing time is:

$$T_S = \frac{1}{w\gamma^2}\left[Q^{-1}\left(\frac{1-\sqrt{(1-\bar{Q}_F)^2}}{F_I}\right) - \sqrt{1+2\gamma^2}Q^{-1}\left(\frac{1-\sqrt{(1-\bar{Q}_D)^2}}{F_B}\right)\right]$$

(18)

2. The transmission time T is obtained by equations (3) and (17), and the transmission time must satisfy:

$$T \le \frac{2}{\alpha}\frac{r - \bar{Q}_D}{\bar{Q}_D - \bar{Q}_F} \quad (19)$$

Using equation (3), T is derived by partially differentiating equation (3) with respect to T i.e., $\frac{\partial \eta}{\partial T} > 0$ can be seen. Therefore, the maximum value of T is taken.

C. *Program steps*

The proposed scenario uses a one-dimensional search, and the detailed steps are as follows:

Step 1: Initialization $\alpha, \beta, \bar{Q}_D, \bar{Q}_F, \Gamma, \eta_{max} = 0$, calculation $P_I, P_B, T = \frac{2}{\alpha}\frac{r-1+\bar{Q}_D}{\bar{Q}_D - \bar{Q}_F}$;

Step 2: For m from 1~M, calculate T_s, η, if $\eta > \eta_{max}$, then $m^* = m, T_s^* = T_s, T^* = T$.

IV. SIMULATION RESULTS

The simulation conditions are as follows: $M = 50$, $\bar{Q}_F$ and $\bar{Q}_D$ are 0.01% and 99.99%, respectively, signal-to-noise ratio γ−3 dB, bandwidth $W = 10000\ Hz$. Figure 2 shows the relationship between the sensed efficiency of cooperative spectrum sensing and the number of sensed users participating in cooperation in different licensed band occupancy states.

It can be seen that when the statistical characteristics of the licensed frequency band are certain, as the number of participating users increases, the sensed efficiency η increases first and then decreases, there is a maximum value, and there is a set of optimal cooperative sensing parameters (see Figure 2 for labelling). Maximize the spectrum sensing efficiency of cognitive radio networks. When comparing the statistical characteristics of different licensed frequency bands, the frequency band with high availability needs to allocate more resources for sensing, so its sensing efficiency is lower than the frequency sensing efficiency with lower availability.

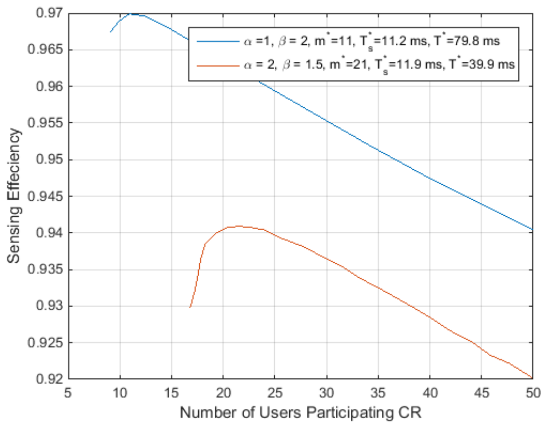

Figure 2 Comparison of cooperative spectrum sensing efficiency under different licensed frequency band occupancy probabilities

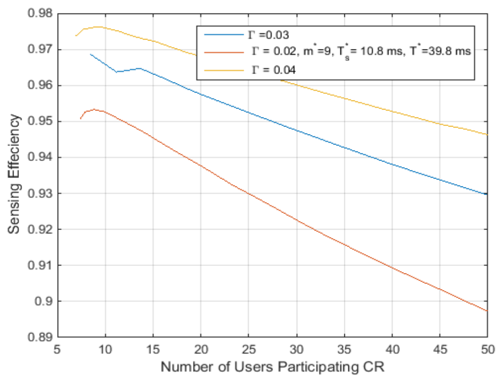

Figure 3 Comparison of cooperative spectrum sensing efficiency under different interference constraints

Figure 3 shows the relationship between sensed efficiency and the number of sensed users participating in cooperation under different interference constraints. It can be seen that when the interference limit that the system can tolerate is certain, there is a set of optimal cooperative sensing parameters (labelled in Figure 3) for the convex function of the number m of users participating in the collaboration when the same efficiency η is perceived.

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The spectrum sensing efficiency of the radio network is maximized. For interference limits that can be tolerated by different systems, the greater the interference limit, the longer the transmission time and the higher the perceived efficiency.

It is proved by the above simulation analysis that there is a set of optimal cooperative sensing parameters to maximize the spectrum sensing efficiency of the cognitive radio network.

V. CONCLUSIONS

In this paper an optimized algorithm for spectrum sensing for CR system is proposed. By jointly optimizing the perceptual parameters including sensing time, transmission time and the number of sensing users participating in collaboration, the spectrum sensing is analyzed under the condition of limited interference. The problem of maximizing efficiency is verified by simulation. The current work is mainly for the case of a single primary user channel, and the next step will be to study the situation of multiple primary user channels.

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