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Full Length Article

Optimization of cooperative secondary users in cognitive radio networks

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A B S T R A C T

In this paper, we identified the optimal number of secondary users in a cooperative spectrum sensing by maximizing the energy efficiency. We obtain the mathematical expressions and simulation results for the optimal number of secondary users using OR and AND fusion rules. We conducted the simulation for both OR and AND rules in two categories, One by keeping signal to noise ratio constant and second by keeping the detection threshold constant. Based on the analysis we showed that the performance obtained for OR rule is better than the AND rule. We hope that our results will be useful for improving the energy efficiency in identifying the un-utilized spectrum.

1. Introduction

The increase in wireless technology inevitably brings in an increased need of spectrum resources. Federal communication commission (FCC) has declared that the licensed spectrum is under utilized by the primary users (PU) [1]. Cognitive radio is a technology that enables the secondary users(SU) to sense and detect the presence or absence of the PU, when the PU is absent then the free spectrum can be utilized by the secondary user [2]. The PU detection using single secondary user is not reliable due to multipath fading and shadowing [3]. Because of this issue secondary user may access the licensed band and cause interference to the primary user. To overcome this issue cooperative spectrum sensing (CSS) has been proposed [4] to enhance the detection accuracy.

The main idea of CSS is to improve the sensing performance by allowing the cooperation between the SUs [5–8]. In CSS, all the SU local decisions are combined at one common receiver known as fusion center (FC). It controls the three step process of CSS. First, the FC will select a channel or a frequency band of the PU for sensing and instruct all the SUs to sense and make a local decision. Second, all the SUs should report their sensing results via the control channel. Then the FC combines the received local decisions, decides the presence or absence of the PU according to fusion rules [9]. The increased number of SUs, increases the energy consumption required for spectrum sensing and reporting sensing results to the fusion center importing energy efficiency of CSS.

The energy efficiency is defined as the ratio of average channel throughput to the average energy consumption [10]. The energy efficiency can be improved either by improving the average channel throughput or by reducing the energy consumption. To reduce the energy consumption for local spectrum sensing, the total number of SUs in CSS is divided into several clusters and one cluster is activated at a certain period [11]. A partial CSS scheme was proposed in [12], to reduce the energy consumption by reducing the sensing users. Here each SU will calculate the expected energy consumption for spectrum sensing before the participation in CSS, if it is greater than the threshold then the SU will not participate, otherwise the SU will participate. In [13], an objection based collaborative spectrum sensing method was proposed to increase the energy efficiency by reducing the number of reporting secondary SUs. In this method all the SUs will sense the channel, but only one SU will report the sensing result to the FC and broadcast the same message to other SUs. Two energy efficient schemes were proposed in [14] to reduce the energy consumption. In the reduced energy sensing scheme, the channel which is identified as busy is not going to sensed for the next rounds. Therefore the energy consumption required for sensing is reduced by reducing number of SUs. In the reduced energy reporting scheme, the energy consumption is reduced by reducing the reporting SUs. Therefore, the energy consumption is reduced by using two energy efficient schemes however it reduces the average channel throughput. In [15], the distributed spectrum sensing algorithm was proposed to reduce the average energy consumption for spectrum sensing by considering the optimal sleeping rate and censoring thresholds.

Further, to improve the energy efficiency, an energy efficient and time saving CSS scheme was proposed in [16]. Only one time

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spectrum sensing is used if signal to noise ratio (SNR) is high or if there is no PU. This reduces the sensing time and energy consumption. An other energy optimization scheme was proposed with sensing and transmission duration as variables in [17]. In this method the energy efficiency is maximized by reducing the interference to PU. Throughput at different frequencies is optimized and probability of detection, probability of false alarm and the system performance are optimized [18,19]. The authors in [20] optimized the simulation time. By optimizing the simulation time they increased the spectral efficiency and bandwidth utilization. In [21], the authors divided the total available SUs into two sets one with highest priority and second one with lowest priority. They calculated important parameters like average delay, arrival rate and they improved the system performance. In cooperative spectrum sensing, we need to optimize the SUs to reduce the energy consumption and to improve the energy efficiency. The optimization of detection threshold to maximize the energy efficiency under different fading channels was proposed in [22]. In this paper, the authors proposed m out of N voting rule at the fusion center to calculate the optimized number of secondary users by maximizing the energy efficiency. However, they fail to calculate the analytical expression for optimal number of cooperative SUs. This gives us an opportunity to consider AND and OR fusion rules to calculate the optimal number of cooperative SUs.

This optimization technique is useful to improve the sensing performance and to reduce energy consumption with limited number of SUs, thereby maximizes the energy efficiency. In this paper, we focus on the optimal number of cooperative SUs by maximizing the energy efficiency. We also present the analytical expressions for optimal number of secondary users using AND, OR fusion rules. The rest of the paper is organized as follows. System model is introduced in Section II. Mathematical expressions for optimal number of secondary users for AND, OR fusion rules are presented in Section III and Conclusions are drawn in Section IV.

2. System model

We consider a CSS in cognitive radio network with one primary user, L secondary users and one fusion center as shown in Fig. 1. Let us assume that each SU contains N multiple antennas, FC and PU contains single antenna. In CSS, each SU sense the channel and make their own local decisions based on two hypotheses [22]. They are

$$H_0 : y(n) = w(n) \tag{1}$$
$$H_1 : y(n) = s(n) + w(n) \tag{2}$$

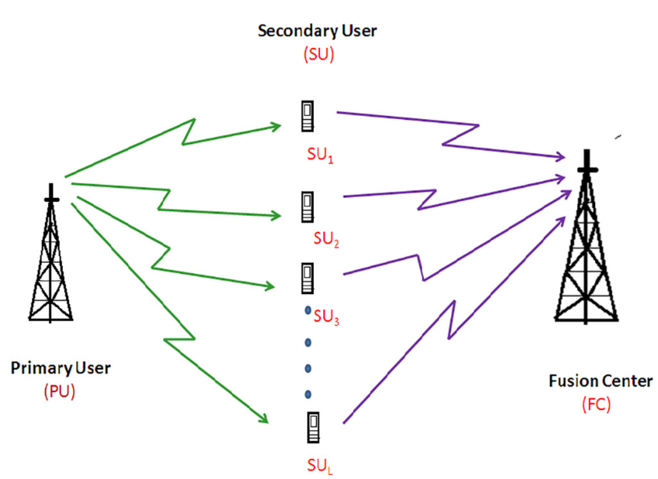

Fig. 1. System model for cooperative spectrum sensing.

where Hypotheses-H_0 represents absence of the PU and Hypotheses-H_1 represents presence of the PU, $s(n)$ is the primary user's signal, $w(n)$ is the additive white Gaussian noise signal and $y(n)$ is SU received signal.

In CSS, the probability of false alarm and probability of miss detection of the i^{th} secondary user using energy detection method over additive white Gaussian noise channel is given below in [23].

$$P_{f,i} = Q\left(\frac{T_i - \lambda_{0,i}}{\phi_{0,i}}\right) \tag{3}$$
$$P_{m,i} = 1 - Q\left(\frac{\lambda_{1,i}}{\phi_{1,i}}\right) - Q\left(\frac{T_i - \lambda_{1,i}}{\phi_{1,i}}\right) \tag{4}$$

where T_i is the detection threshold, $\lambda_{0,i}$ and $\lambda_{1,i}$ are the means and $\phi_{0,i}$ and $\phi_{1,i}$ are the variances under the hypotheses H_0, H_1 respectively at i^{th} secondary user. Authors in [24] assumed that all the secondary users use the same detection threshold T, same mean values λ_0, λ_1 and same variances ϕ_0, ϕ_1. Therefore, the probability of false alarm and the probability of miss detection are same for all the SUs. In summary

$$T_1 = T_2 = T_3 = \ldots\ldots = T$$
$$\lambda_{0,1} = \lambda_{0,2} = \lambda_{0,3} = \ldots\ldots = \lambda_0$$
$$\lambda_{1,1} = \lambda_{1,2} = \lambda_{1,3} = \ldots\ldots = \lambda_1$$
$$\phi_{0,1} = \phi_{0,2} = \phi_{0,3} = \ldots\ldots = \phi_0$$
$$\phi_{1,1} = \phi_{1,2} = \phi_{1,3} = \ldots\ldots = \phi_1$$
$$P_{f,1} = P_{f,2} = P_{f,3} = \ldots\ldots = P_f$$
$$P_{m,1} = P_{m,2} = P_{m,3} = \ldots\ldots = P_m$$

According to the author of [25], final probability of false alarm and probability of miss detection at the fusion center using OR, AND and MAJORITY fusion rules are given below as

For OR fusion rule:

$$Q_{f,OR} = 1 - (1 - P_f)^L \tag{5}$$
$$Q_{m,OR} = (P_m)^L \tag{6}$$

For AND fusion rule:

$$Q_{f,AND} = (P_f)^L \tag{7}$$
$$Q_{m,AND} = 1 - (1 - P_m)^L \tag{8}$$

For MAJORITY fusion rule:

$$Q_{f,MAJ} = \sum_{r=n}^{L} \binom{L}{r} (P_f)^r (1 - P_f)^{L-r} \tag{9}$$

$$Q_{m,MAJ} = 1 - \sum_{r=n}^{L} \binom{L}{r} (1 - P_m)^r (P_m)^{L-r} \tag{10}$$

We may like to convey that the Eqs. (5)–(10) are used to calculate final probability of false alarm, probability of miss detection, energy consumption, channel throughput and optimal number of cooperative SUs. In this paper, we are using only OR and AND fusion rules to calculate the optimal number of cooperative SUs. Because its not possible to derive the exact analytical expression for optimal number of cooperative SUs using MAJORITY fusion rule even though MAJORITY fusion rule is a special case of OR and AND fusion rules.

3. Optimal number of secondary users using OR, AND fusion rules

Let $\bar{t_p}$, t_p denotes throughput of a primary system when SU is present, absent and $\bar{t_s}$, t_s denotes throughput of a secondary system when PU is present, absent respectively. Assume the