Abstract - In cognitive radio networks the energy efficiency depends on the number of cooperative secondary users. As the number of users increases the energy consumption increases and the energy efficiency decreases. So, to improve the energy efficiency we proposed an optimization technique in this paper. The optimal number of cooperative secondary users is calculated based on AND, OR and Majority fusion rules by maximizing the energy efficiency. The simulation results shows optimal number of cooperative secondary users for AND, OR and MAJORITY fusion rules.

Index Terms - Cooperative spectrum sensing, Energy efficiency, Optimization, Hard fusion rules

I. INTRODUCTION

Recently the cognitive radio technology has been identified as a promising way to address the spectrum scarcity [1]. Firstly spectrum sensing must be performed before the cognitive radio accessing the licensed spectrum in order to avoid the interference to the primary user. The secondary user can access the channel as long as the primary user is absent and vacate the channel when the primary user comes back into the operation. However, in the wireless communication signals suffer from shadowing, multipath fading and receiver uncertainty [2], [3]. To overcome this problem cooperative spectrum sensing (CSS) has been proposed [4], [5]. In CSS, the probability of detection increases with the increase of secondary user’s [6], [7]. However, the increase of secondary users increases the energy consumption [8].

The energy efficiency is defined as the ratio of average channel throughput to the average energy consumption [9]. 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 secondary users in CSS is divided into several clusters and one cluster is activated at a certain period [10]. A partial cooperative spectrum sensing scheme was proposed in [11], 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 [12], an objection based collaborative spectrum sensing method was proposed to increase the energy efficiency by reducing the number of reporting secondary users. 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 [13] to reduce the energy consumption.

In the reduced energy sensing scheme and reduced energy reporting scheme, the energy consumption is reduced by reducing the sensing channel and by reducing the reporting channels to the fusion center. The energy consumption is reduced but which inturn reduces the average channel throughput. In [14], 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.

In this paper, energy efficiencies are calculated for hard fusion rules. We proposed optimization of secondary users in CSS by maximizing energy efficiency. For AND, OR and Majority fusion rules the optimization values are calculated and compared. The rest of the paper is organized as follows: System model is shown in the section II, energy efficiency are calculated in the section III for hard fusion rules, In section IV, the optimal number of cooperative secondary users are calculated, in section V provides the analysis and simulation results, finally in section VI conclusion is drawn.

II. SYSTEM MODEL

In this paper, we considered a system with N number of secondary users, one primary user and one fusion center which is shown in the fig 1.
The absence or presence of the PU is given by hypothesis testing as:

- H0: Primary user absent
- H1: Primary user present

The probability of detection and the probability of false alarm of the ith secondary user is given by [15] as

\[ P_{dl} = Q\left(\frac{1-H_{0,i}}{\sigma_{0,i}}\right) \]  
(1)

\[ P_{f,i} = 1 - Q\left(\frac{H_{1,i}}{\sigma_{1,i}}\right) \]  
(2)

Where Ti is the detection threshold at the ith secondary user. \( \lambda_{0,i} \) and \( \lambda_{1,i} \) are the means and \( \sigma_{0,i} \) and \( \sigma_{1,i} \) are the variances under the hypothesis H0, H1 respectively at ith secondary user [15]. Let as assume the detection threshold, mean and variances are same for each and every secondary user [16].

At the fusion center, the final probability of detection and the probability of false alarm are given by [17]

For AND fusion rule:

\[ Q_{d,AND} = \prod_{i=1}^{N} (P_{dl}) = (P_{dl})^N \]  
(3)

\[ Q_{f,AND} = \prod_{i=1}^{N} (P_{f,i}) = (P_{f,i})^N \]  
(4)

For OR fusion rule:

\[ Q_{d,OR} = 1 - \prod_{i=1}^{N} (1 - P_{dl}) = 1 - (1 - P_{dl})^N \]  
(5)

For Majority Rule:

\[ Q_{d,MAJ} = \sum_{i=\frac{N}{2}}^{N} \binom{N}{i} (P_{dl})^i (1 - P_{dl})^{N-i} \]  
(7)

\[ Q_{f,MAJ} = \sum_{i=\frac{N}{2}}^{N} \binom{N}{i} (P_{f,i})^i (1 - P_{f,i})^{N-i} \]  
(8)

III. ENERGY EFFICIENCY

Energy efficiency is defined as the ratio of average channel throughput to the average energy consumption. The average channel throughput, average energy consumption and energy efficiency are given by [12] respectively.

\[ T_x = P(H_1)Q_{d,OR}T_p + P(H_0)(1 - Q_{d,OR})(T_p + T_f) \]  
(9)

\[ E_x = N(E_1 + E_2) + P(H_1)E_p + [1 - P(H_0)]Q_{d,OR}P(H_1)Q_{d,OR}T_p \]  
(10)

\[ EE_x = \frac{T_x}{E_x} \]  
(11)

Where x represents AND, OR, Majority fusion rules, P(H0) and P(H1) are the occupied and unoccupied channel probabilities, \( T_p \), \( T_f \), denotes throughput of the primary system when secondary user is present and absent, \( E_1 \) and \( E_2 \) as the amount of energy consumed for local spectrum sensing and for reporting sensing results to the FC by the secondary user, \( E_p \) and \( E_f \) as the amount of energy consumed for transmitting data over the channel by primary and secondary users respectively.

IV. OPTIMAL NUMBER OF COOPERATIVE SECONDARY USERS

The optimal number of cooperative secondary is calculated by maximizing the energy efficiency. The optimal number of secondary users for AND, OR and Majority rule are given by
For AND fusion rule:
\[
N = \log \left( \frac{(1 - P_d) \frac{\mathcal{O}_1}{\mathcal{O}_2} + \frac{\mathcal{O}_2 P(H_a) E_p}{\mathcal{O}_2 P(H_a) E_p}}{\log \left( \frac{1}{1 - P_d} \right)} \right) \tag{12}
\]
Where \( \rho \) is
\[
\rho < \frac{\mathcal{O}_1 (1 - P_d) - (1 - P_d) \mathcal{O}_2}{2[\mathcal{O}_1 P(H_a) E_p (1 - P_d) + \mathcal{O}_2 P(H_a) E_p (1 - P_d)]} \tag{13}
\]
For OR fusion rule:
\[
N = \log \left( \frac{(1 - P_d) \frac{\mathcal{O}_2}{\mathcal{O}_1} + \frac{\mathcal{O}_2 P(H_a) E_p}{\mathcal{O}_2 P(H_a) E_p}}{\log \left( \frac{1}{1 - P_d} \right)} \right) \tag{14}
\]
Where \( \rho \) is
\[
\rho < \frac{\mathcal{O}_2 P_d - (P_d) \mathcal{O}_2}{2[\mathcal{O}_1 P(H_a) E_p (1 - P_d) + \mathcal{O}_2 P(H_a) E_p (1 - P_d)]} \tag{15}
\]
For Majority fusion rule:
\[
N = \log \left( \frac{\frac{\mathcal{O}_2}{\mathcal{O}_1} - \frac{\mathcal{O}_2 P(H_a) E_p}{\mathcal{O}_2 P(H_a) E_p}}{\log \left( \frac{1}{1 - P_d} \right)} + \beta \log \left( \frac{1 - P_d}{1 - P_d} \right) \right) \tag{16}
\]
\[
\rho < \frac{\mathcal{O}_2 (1 - P_d)^N - \mathcal{O}_1 (1 - P_d)^N}{\mathcal{O}_2 P(H_a) E_p (1 - P_d)^N + \mathcal{O}_2 P(H_a) E_p (1 - P_d)^N} \tag{17}
\]

V. SIMULATION RESULTS

In the simulations, the energy detection is used as the local spectrum sensing and \( u = 10 \) is the time-bandwidth product of the energy detector. It is assumed that the transmit power of the PU transmitter is larger than that of the SU transmitter, and \( T_p > T_s \).

We set \( T_p = 20 \) and \( T_s = 10 \), we assume that \( T_p \) and \( T_s \). The probability that the channel is idle is \( P(H_0) = 0.5 \). Due to the existence of false alarm, the time for PU to transmit data is longer than the time for SU to transmit data, it is reasonable to set \( E_p = 40 \) and \( E_s = 10 \). The sensing power is assumed to be smaller than the transmit power for each SU, and the sensing time is chosen smaller than the data transmission time [18]. Thus, \( E_1 \) is much lower than \( E_s \), and we set \( E_1 = 0.1 \) unless otherwise stated. The energy consumed by each SU to send sensing result to the FC is usually lower than \( E_1 \), and \( E_2 \) is assumed to be 0.05.

The energy efficiency versus detection threshold for \( N = 1 \) to 5 using AND fusion rule for SNR to 10dB is shown on the Fig 2. So, for a given detection threshold there exists an optimal number of cooperative secondary users that maximizes the energy efficiency. Hence the value of \( N \) plays an important role in describing the performance of energy efficiency. As the detection threshold increases the optimal number of cooperative secondary users decreases we can also observe this from Fig 3.

Fig 4 plots the energy efficiency versus detection threshold for \( N = 1 \) to 5 using OR fusion rule for SNR to 10 dB. So, for a given detection threshold there exists an optimal number of cooperative secondary users that maximizes the energy efficiency. Hence the value of \( N \) plays an important role in describing the performance of energy efficiency. It is observed that, as the detection threshold increases the optimal number of cooperative secondary users also increases which is shown in the Fig 5.
Fig 6 plots the energy efficiency versus detection threshold for N = 1 to 5 using Majority fusion rule for SNR to 10 dB. So, for a given detection threshold there exists an optimal number of cooperative secondary users that maximizes the energy efficiency. Hence the value of N plays an important role in describing the performance of energy efficiency. It is observed that, as the detection threshold increases the optimal number of cooperative secondary users decreases which is shown in the Fig 6. From the Fig 3,5,7 it is observed that, as the detection threshold increases the energy efficiency decreases which is shown in the Fig 6. From the Fig 4: Energy efficiency versus detection threshold, for N=1,2,3,4,5 using OR fusion rule.

Fig 5 shows the optimal number of cooperative secondary users versus detection threshold using OR fusion rule.

CONCLUSION

In this paper, we consider a cooperative spectrum sensing with N secondary users. The optimal number of cooperative secondary users is calculated based on AND, OR and Majority fusion rules by maximizing the energy efficiency. The mathematical expression are derived for optimal number of cooperative secondary users using AND, OR and Majority fusion rules. The performance of energy efficiency in the cooperative spectrum sensing with energy detector has been studied. It has been shown that the performance of OR fusion rule is better than the AND fusion rule and also the majority rule acts as AND rule for the lowest detection threshold values and it acts as OR rule for higher detection threshold values.

REFERENCES

Optimization of Cooperative Secondary Users using Hard Fusion Rules


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