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Energy Efficiency in Cognitive Radio Network using Hard Fusion Rules

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Abstract— In cognitive Radio networks, cooperation can improve the spectrum sensing performance. However, for spectrum sensing and reporting sensing results to the fusion center requires more energy. Cognitive radio plays an important role in improving energy efficiency in wireless networks. In this paper, we calculated the energy efficiencies for Hard fusion rules and compared. Simulation results show the energy efficiencies for AND, OR and MAJORITY fusion fusions. Based on the results we show that the AND and OR fusion rules are special cases of MAJORITY fusion rule.

Keywords— Cognitive radio; Cooperative spectrum sensing; Energy efficiency; Hard fusion rules.

I. INTRODUCTION

The concept of cognitive radio technology has been proposed to solve the problem of spectrum scarcity [1]. It allows the secondary users (SU) to utilize the primary users (PU) spectrum when it is free and the SU could not cause harmful interference to the PU. Therefore spectrum sensing is an important task in cognitive radio technology. The SU has to detect the presence or absence of the primary user accurately. Spectrum sensing techniques available are matched filter detection, energy detection and cyclostationary future detection [2]. Each technique has its own advantages and disadvantages. Energy detection method is used most of the time because it does not require any prior information regarding PU. Spectrum sensing is a very difficult task because of multipath fading, shadowing and receiver uncertainty. Due to fading effects, SU fail to identify the presence of PU and cause interference to the PU by accessing the licensed band [3], [4]. To overcome these problems cooperative spectrum sensing (CSS) has been proposed [5]- [7].

Cooperative spectrum sensing improves the sensing performance by allowing cooperation among the SUs. All SUs sense the licensed channel and forward their one bit local decision to the fusion center (FC). Fusion center combines all the SUs local decisions by using Hard combining rules i:e. AND, OR and MAJORITY rule and make a final decision regarding whether presence of the PU [8]. As the number of cooperative secondary users increases the detection probability increases but, energy consumption required for spectrum sensing and reporting sensing results to the FC by all the SUs increases. Our aim is to increase the energy efficiency by reducing the energy consumption.

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

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secondary SUs. In this method all the SUs will sense the channel but only one SU will report the sensing result to the fusion center 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.

In this paper, we calculated energy efficiencies for AND, OR and MAJORITY fusion rules and compared. The rest of the paper is organized as follows: System model is explained in Section II, energy efficiencies are calculated in Section III, simulation results are in Section IV and finally conclusion is drawn in Section V.

II. SYSTEM MODEL

Cooperative spectrum sensing with *R* secondary users, one primary user and one Fusion Center is shown in the Fig 1. All the SUs sense the PU channel and forward their local decisions to the FC. The FC will identify the presence or absence of the PU based on the hypotheses testing as

$$x(t)=\begin{cases} n(t)------H_0 \\ hs(t)+n(t)--H_1 \end{cases} \qquad (1)$$

Where *x(t)* is the signal received by the secondary user, *n(t)* is the additive white Gaussian noise (AWGN), *h* is the channel gain, *s(t)* is the PU transmitted signal, H_0 represents the absence of the PU and H_1 represents the presence of the PU.

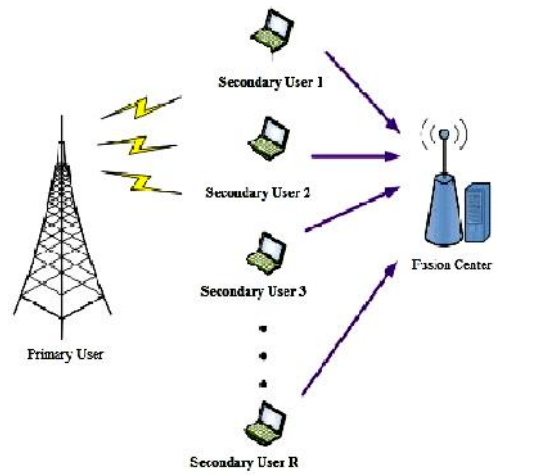

Fig 1: Cooperative spectrum sensing system model

The SUs signal energy is calculated from the received signal and compared with the detection threshold. If it is greater than the detection threshold then the SU will identify that the channel is busy with PU, otherwise the channel is free [14]. The probability of detection, probability of false alarm and probability miss detection for the ***i*** i^{th} SU are given by [15]

$$P_{d,i}=Q_u(\sqrt{2¥},\sqrt{T}) \qquad (2)$$

$$P_{f,i}=\frac{\Gamma(u,T/2)}{\Gamma(u)} \qquad (3)$$

and

$$P_{m,i}=1-P_{d,i} \qquad (4)$$

Where T is the detection threshold, u is the time bandwidth product, γ is the signal to noise ratio, Γ(.) and Γ(.,.) are complete and incomplete gamma functions and Q(.,.) is the generalized Marcum Q function [16]

Individual probability detection and probability of false alarm are calculated using equations (2) and (3). Now to calculate the final decision probability at fusion center we have to combine all these SUs individual decisions using AND, OR and MAJORITY fusion rules. Probability of detection and probability of false alarm at FC according AND, OR and MAJORITY fusion rules are given by [8] respectively

For AND rule:

Probability of detection: $Q_{d,AND}=(P_{d,i})^R$ (5)

Probability of false alarm: $Q_{f,AND}=(P_{f,i})^R$ (6)

For OR rule:

Probability of detection: $Q_{d,OR}=1-(1-P_{d,i})^R$ (7)

Probability of false alarm: $Q_{f,OR}=1-(1-P_{f,i})^R$ (8)

For MAJORITY rule:

Probability of detection:

$$Q_{d,MAJ} = \sum_{l=\lfloor R/2 \rfloor}^{R} \binom{R}{l} P_{d,i}^{l} (1-P_{d,i})^{R-l} \quad (9)$$

Probability of false alarm:

$$Q_{f,MAJ} = \sum_{l=\lfloor R/2 \rfloor}^{R} \binom{R}{l} P_{f,i}^{l} (1-P_{f,i})^{R-l} \quad (10)$$

III. ENERGY EFFICIENCIENCS FOR HARD FUSION RULES

Energy efficiency is defined as ratio of average channel throughput to the average energy consumption. In CSS, the total energy consumption is the sum of energy consumption for local spectrum sensing (e_1), energy consumption for reporting results to the FC (e_2) and energy consumption for transmitting data through the channel by the PU (e_p) and SU (e_s). Throughput is nothing but successful data transmission through the PU system when SU is present ($\bar{t}_p$) and SU is absent (t_p) and through the PU system by the SU when PU is present ($\bar{t}_s$) and PU is absent (t_s) in the channel. Therefore energy consumption, throughput and energy efficiencies for AND, OR and MAJORITY fusion rules are given by [17] as

Average channel throughput:

$$(TP)_x = P_0(1-Q_{f,x})t_s + P_1(Q_{d,x})t_p + P_1(1-Q_{d,x})(\bar{t}_p + \bar{t}_s) \quad (11)$$

Average energy consumption:

$$(EC)_x = P_1 Q_{d,x}[R(e_1+e_2)+e_p] + P_1(1-Q_{d,x}) [R(e_1+e_2)+e_p+e_s] + P_0(1-Q_{f,x}) [R(e_1+e_2)+e_s] + P_0 Q_{f,x} R(e_1+e_2) \quad (12)$$

Energy efficiency:

$$(EE)_x = \frac{(TP)_x}{(EC)_x} \quad (13)$$

Where x represents AND, OR and MAJORITY fusion rules, P_0, P_1 are ideal and occupied channel probabilities ($P_0 + P_1 = 1$).

IV. SIMULATION RESULTS

Energy efficiencies for AND, OR and MAJORITY fusion rules are calculated in the previous section and Plotted with respect to the detection threshold. Typical values are $P_0 = P_1 = 0.5$, signal to noise ratio =10dB, e_1 =0.1J, e_2 =0.05J, e_1 =40Jand e_s =10J. A CSS with cooperative secondary users R=1,2,3,4 and 5 the energy efficiencies with detection threshold is shown in Fig 2.

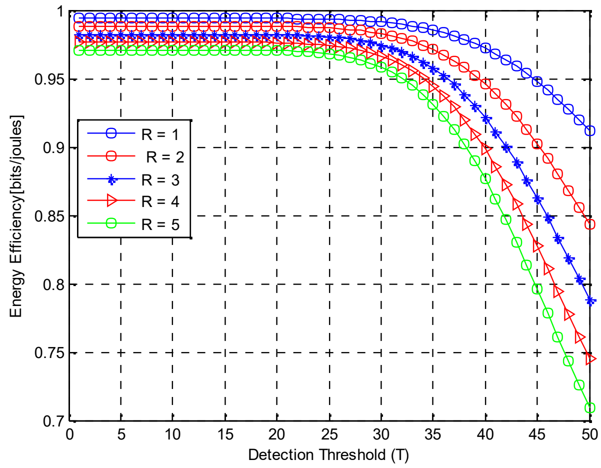

Fig 2: Energy efficiency for AND fusion rule with R=1,2,3,4,5

From the Fig 2 it is observed that the energy efficiency is constant up to a detection threshold of 30 and then decreases. As the detection threshold increases the probability detection decreases in the AND rule, it in turn decreases the throughput. Therefore the energy efficiency decreases in the AND rule as the detection threshold increases. But, in the OR rule as the detection threshold increases the false alarm probability increases and detection probability decreases this reduces the channel throughput. Therefore energy efficiency decreases for small values of detection threshold in the OR fusion rule. This is also shown in the Fig 3. As the SUs increases the energy efficiency increases in the OR rule but in the AND rule it decreases. In the OR rule, the interference increases to the PU as the SUs increases but in the AND rule interference decreases and the usage of the channel decreases as the SUs increases.

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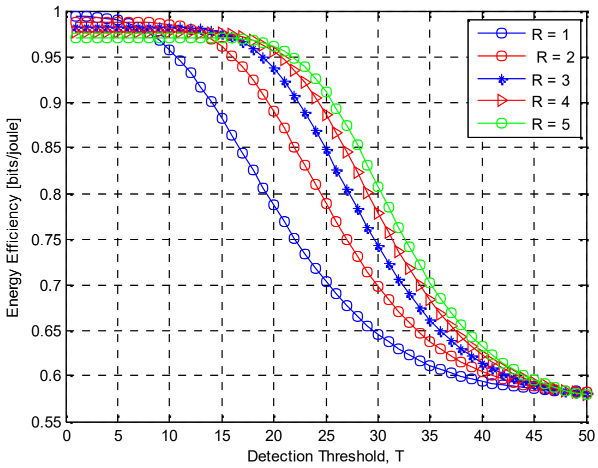

Fig 3: Energy efficiency for OR fusion rule with R=1,2,3,4,5

In the MAJORITY rule, the energy efficiency is constant up to some optimum value of detection threshold and then increases. This is shown in the Fig 4. From AND, OR and MAJORITY rules, it is observed that the AND rule is opposite to the MAJORITY rule.

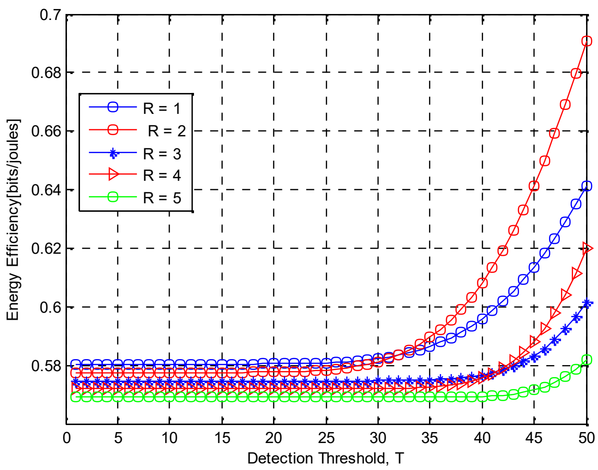

Fig 4: Energy efficiency for MAJORITY fusion rule with R=1,2,3,4,5

V. CONCLUSION

In cognitive radio network, Cooperative spectrum sensing is used to improve the spectrum sensing performance. Cooperative increases the energy consumption that decreases the energy effciency. Energy efficeincies are calculated for AND, OR and MAJORITY fusion rules. It has been shown that for small values of detecction threshold OR rule follows the AND rule and alsit is observed that AND, OR rules are the special case of MAJORITY rule.

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