International Journal of Sciences: Basic and Applied Research (IJSBAR)

ISSN 2307-4531
(Print & Online)

http://gssrr.org/index.php?journal=JournalOfBasicAndApplied

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# Throughput Optimization and Energy Efficient Cooperative Spectrum Sensing Based on a Group of Sensors in Cognitive Networks

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**Abstract**

A technology that deals with the spectrum scarcity and underutilization is cognitive radio (CR), where by spectrum sensing is one of the most important aspects. Multiple sensors perform cooperative spectrum sensing to reduce shadowing and multipath fading in the network. Due to the limitations of energy in sensors, energy efficiency emanate as significant issue in sensor-aided CR networks. Scheduling of each group of sensor active time can definitely reduce energy consumption and boost network life time. The sensors are divided into groups depending on the geographical position, only one group of sensors is turned on at a time while maintaining the necessary detection and false alarm thresholds. Each group is activated independently and non-activated are set in a low energy sleep mode to boost the network lifetime. Also throughput optimization is achieved by increasing the bit rates of data received to the fusion center which decrease the reporting time of secondary users. Analysis and simulation are presented by considering the performance of energy detection which discovers spectrum holes or white spaces and cooperative spectrum sensing approaches by using AND, MAJORITY and OR rule.

***Keywords:*** Cooperative spectrum sensing; energy efficiency; cognitive radio (CR) networks; Throughput optimization.

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## 1. Introduction

Spectrum resources are becoming scarce with the development of various wireless devices and applications. According to the U.S. Federal Communications Commission, the distributed spectrum resources to the large extent are underutilized. This is because under the current regulatory policy, frequency bands are statically assigned to licensed/primary users (PUs), and no reutilization is allowed for unlicensed/secondary users (SUs) [2,4].Primary user means a user who has the rights to use the spectrum. Secondary user refers to the user who tries to use the frequency band allocated to primary user when the primary user is not using it [5].Cognitive radio (CR) is used to solve the challenges between limitation of spectrum and underutilization, which enables SUs to make use of channel when PUs are absent, and to quit immediately when PUs want to use its spectrum to avoid interference [4]. Energy efficiency is done by dividing the secondary users into groups and only one group is allowed to sense the spectrum while others are in sleep mode. And throughput is achieved by reducing the reporting time of secondary users to the fusion center, the rest of the paper is organized as follows. In section 2. Spectrum sensing by using energy detection method to discover the white space in PUs. In section 3. Cooperative spectrum sensing, SUs cooperate to detect the white spaces in primary users. In section 4. Energy efficiency by using cooperative spectrum sensing. In section 5. Throughput optimization. The simulation results are shown in section 6. And finally the conclusion is given in section 7.

## 2. Spectrum sensing

Spectrum sensing using Energy detection is the type of most followed method because of its simplicity in implementation and requires no prior knowledge about the primary signal [3].

In spectrum sensing there is [2]:

- Detection probability $P_d$ and
- False alarm probability $P_f$

The $P_d$, should be high to reduce interference and protect PUs and, $P_f$ must be less in order SU to reutilize efficiently the spectrum.

Assume the hypothesis model of the received signal is [3]

$$H_0: y(t) = n(t), \quad (1)$$

$H_1: y(t) = x(t) + n(t)$

Where $x(t)$ is the primary user's signal to be detected at the local receiver of a secondary user, $n(t)$ is additive white Gaussian noise; $H_0$ is a null hypothesis means there is no primary user present, then secondary users can utilize the spectrum ,and $H_1$ means the primary user's is present and using the spectrum. In this case the noise and signal are assumed to be independent and identically distributed random variable Gaussian random processes with zero mean $\delta_w^2$ and variance $\delta_x^2$ , and the received signal to noise ratio (SNR= $\gamma$) is denoted by

$\gamma = \frac{\delta_x^2}{\delta_w^2}$ [1],[6]

The detection statistics of the energy is given as the average energy of M observed samples

$$T = \frac{1}{M}\sum_{t=1}^{M}|y(t)|^2 \qquad (2)$$

The outcome on whether the spectrum is busy and occupied by primary user or not is done by comparing the detection statistics $T$ with pre-defined threshold $\lambda$ [1]

$$\lambda = \sqrt{2M(1+\gamma)^2}Q^{-1}(P_d) + M(1+\gamma) \qquad (3)$$

The performance of the detector is divided into two probabilities: the probability of detection $P_d$ and the probability of false alarm $P_f$ [3]

$$P_d = P_r(T > \lambda|H_1)$$

Probability of detection denotes the probability that a test correctly decides $H_1$

$$P_f = P_r(T > \lambda|H_0)$$

The probability of false alarm denotes the probability that the hypothesis test decides $H_1$ while it is $H_0$

Local probability of detection and false alarm are given by

$$P_d = Q\left(\frac{\lambda - M\delta_x^2(\gamma+1)}{\delta_x^2\sqrt{2M(1+2\gamma^2)}}\right)$$

$$P_f = Q\left(\frac{\lambda - M\delta_w^2}{\delta_w^2\sqrt{2M}}\right) \qquad (4)$$

Where Q is the q-function

## 3. Cooperative spectrum sensing

Cooperative spectrum sensing is though-out as a solution for the low detection reliability, removing shadowing and multipath of a single radio detection. Each cognitive user makes a local decision about the primary user attendance and sends the results to a Fusion Center (FC) by using a time-division-multiple-access approach [1].

Decision fusion (hard combining which includes AND, MAJORITY and OR rules) is used to reduce the bandwidth spent where by ‘1’ or ‘0’ is sent to the FC to inform that the primary user is available or not available. The final decision is then made at the FC according to the received data [6].

The sensors are divided into groups and only one group is switched on and all other groups are put in a low-energy sleep mode. The group of sensors which are switched on are responsible for performing spectrum sensing and make sure that the network reaches the necessary detection and false alarm thresholds.

In cooperative spectrum sensing there are [2]:

- Cooperative detection probability $Q_d$ and
- Cooperative false alarm probability $Q_f$

To protect the PUs $Q_d$ must be greater than a predefined threshold, similarly $Q_f$ must be less than a threshold, then spectrum reutilization spaces can be ensured and occupied by SUs.

The global probability of detection and false alarm at fusion center is given by [6]

$$Q_d = Prob\{H_1|H_1\} = \sum_{l=k}^{N} \binom{N}{l} P_d^l (1 - P_d)^{N-l}$$

$$Q_f = Prob\{H_1|H_0\} = \sum_{l=k}^{N} \binom{N}{l} P_f^l (1 - P_d)^{N-l} \quad (5)$$

From (5) $Q_d$ and $Q_f$ can be observed that when the value of k is taken as 1, then k out of N (total number of users) becomes OR rule. In this rule at least one secondary user must report “1” to the fusion center. When k is taken as N, the k out of N becomes AND rules, where by all Secondary users must report “1” to the fusion center [2]. Also the MAJORITY rule can be obtained from the k out of N under the condition that k $\geq N/2$ this shows that in majority rule at least half of the secondary users must report “1” to the fusion center.

**4. Energy efficiency**

Sensor nodes in wireless sensor network are energy limited, and energy efficiency is very important in designing spectrum sensing. As the number of cooperating cognitive radios increases the detection performance also increases, but increase the network energy consumption. Therefore, as soon as the constraints are satisfied, increasing the number of cognitive users is a waste of energy which is very critical for cognitive sensor networks [1]. An efficient network should be designed so that to lower the energy consumption and still maintain the qualification on the interference and false alarm, as it is discussed in III; secondary users are divided into groups in order to achieve this condition. The first node (SU) in a group will sense energy and pass to another node in a same group this process continues until the last node. The nodes which detect the energy is more than their required threshold they start sending data. And those which detect that the energy is less they go to sleep state to save energy.

Energy efficient optimization problem as in [1] is to reduce the total number of cooperating cognitive users to get the appropriate probability of detection and false alarm for a fixed k as

$$\min_{N} N$$

$$Q_d \geq \alpha \text{ and } Q_f \leq \beta \quad (6)$$

The optimal value of N is obtained for a minimum value of N in a reasonable set of (6). Where α is the probability of detection constraints (0.93, 0.97) and

β is the probability of false alarm constraints varies ($0.01 \leq \beta \leq 0.1$)

Two things are focused [7]

- The total energy consumption needed for a single successful detection at the fusion center
- The fairness of energy consumption among sensor nodes

Fairness of energy consumption is important in increasing network life time. It is defined as ratio of maximum and minimum energy consumed by nodes in a single time slot

$$\mu \triangleq E_{max}/E_{min} \quad (7)$$

Whereby; $\mu$ is the fairness degree.

Assume N nodes are uniformly deployed in a square meter, and energy consumed in every transmission is proportional to the transmission distance by a fixed factor η; the average energy consumption of internode transmission is $\eta N^{-1/2}$ and that of transmission from node to the fusion center is η [7]

The total energy used for a single detection at the fusion center is given by

$$E(N) = e_{avg}.N \quad (8)$$

Where; $e_{avg}$ is the average amount of energy needed in transmission for one hop

**Non cooperative**

Every node needs to transmit the result detected to the fusion center in every slot then $e_{avg} = \eta$ and energy will be $E(N) = \eta.N$ but every node is given by $\eta N^{-1/2} + \eta$

$$E(N) = \left(\eta N^{-1/2} + \eta\right).N \quad (9)$$

Fairness degree from (7)

$E_{max} = E_{min}$

$\mu = 1$

**Cooperative sensing**

The energy consumption for the first node in every group is given by

$\eta N^{-1/2} + \eta$ and for the second node $\eta$

The average total energy consumption is given by

$E(N) = \eta P_d N + \eta N^{-1/2}(1 - P_d).N + \eta(1 - P_d).N$

$$E(N) = (1 - Q_d)\eta N^{-1/2} + \eta N \quad (10)$$

Since $E_{max} = \eta N^{-1/2} + \eta$ and $E_{min} = \eta$

Fairness degree in cooperative spectrum is

$\mu = 1 + N^{-1/2}$

***AND rule***

Based on what is shown in [1], for general k denoting $Q_f$ as the $P_f$ evaluated as

$$Q_{d,AND} = \alpha^{1/N} \quad (11)$$

Then; $E(N) = \left(1 - Q_{d,AND}\right)\eta N^{-1/2} + \eta N$

***OR rule***

$Q_{d,OR} = 1 - (1 - \alpha)^{1/N}$

$$E(N) = \left(1 - Q_{d,OR}\right)\eta N^{-1/2} + \eta N \quad (12)$$

***Majority rule***

$Q_{d,MAJORITY} = \alpha^{2/N}$

$$E(N) = \left(1 - Q_{d,MAJORITY}\right)\eta N^{-1/2} + \eta N \quad (13)$$

Assume $\eta$ is unity

Using cooperative spectrum sensing the energy consumption is reduced by the network because when using one sensor in every time slot the power consumed will be the same in every node. The fairness of energy consumption for non-cooperative spectrum sensing will be more which reduces the network lifetime.

## 5. Throughput optimization

Optimization of the reporting time has received less attention in the literature, although it is a necessary redundancy in the system. Minimizing it leads to an inflation in the throughput of the cognitive radio network [1].Each time slot consist sensing slot and transmission slot. Where in sensing slot the SU accumulate the energy and make local decision also report to the FC. Therefore the sensing time $T_s$ is fixed and target on optimizing the reporting time $NT_R$ where $T_R$ is given by $T_R = {}^{1}/_{R_b}$

$R_b$ is the transmission bit rate for the cognitive radio. The throughput of the cognitive radio network should be maximized while maintaining the required probability of detection.

The optimization problem is given by,

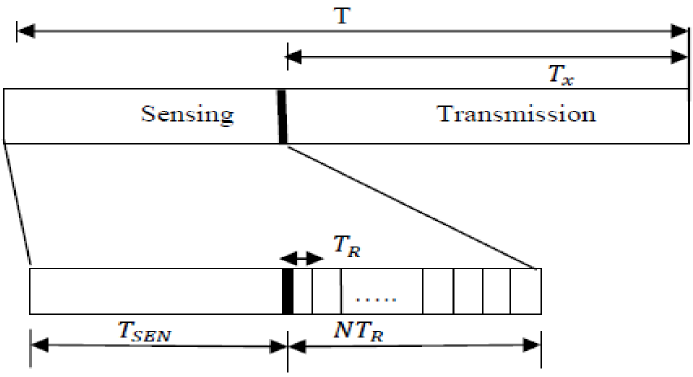


**Figure 1:** Sensing and transmission

$$Throughput = \left(\frac{T - T_{SEN} - NT_R}{T}\right)(1 - Q_f)$$

and

$$1 \le N \le \left(\frac{T - T_{SEN}}{T_R}\right) \quad (14)$$

***AND rule***

$$Throughput = \left(\frac{T - T_{SEN} - NT_R}{T}\right)(1 - Q_{f,AND}^{N})$$

$$Q_{f,AND} = Q\left(\frac{M.\gamma}{\sqrt{2M}} + Q^{-1}(Q_{d,AND})(\gamma + 1)\right) \quad (15)$$

***OR rule***

$$Throughput = \left(\frac{T - T_{SEN} - NT_R}{T}\right)(1 - Q_{f,OR})^{N}$$

$$Q_{f,OR} = Q\left(\frac{M.\gamma}{\sqrt{2M}} + Q^{-1}(Q_{d,OR})(\gamma + 1)\right) \quad (16)$$

***Majority rule***

$$Throughput = \left(\frac{T - T_{SEN} - NT_R}{T}\right)(1 - Q_{f,MAJORITY}^{N})$$

$$Q_{f,MAJORITY} = Q\left(\frac{M.\gamma}{\sqrt{2M}} + Q^{-1}(Q_{d,MAJORITY})(\gamma + 1)\right) \quad (17)$$

## 6. Simulation results

Several secondary users have been considered for simulation and each cognitive radio accumulates M=250 samples in energy detection for local decision making. Under these bit rates the simulation has been performed $R_b$=30Kbps, $R_b$=60Kbps, $R_b$=90Kbps.The signal to noise ratio is assumed to be 20dB, and -8dB

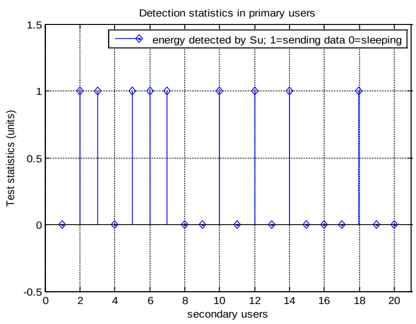


**Figure 2:** Energy detection by the secondary users (one group of 20 SU) when the primary user is absent. One means SUs are transmitting data and zero means are in sleep mode.

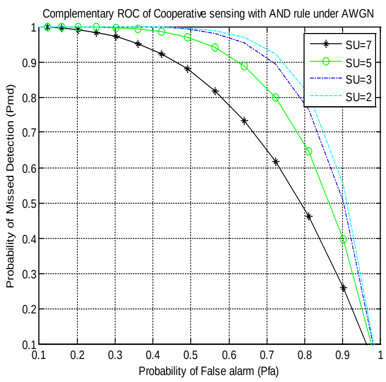


**Figure 3:** Relationship between the probability of miss detection and false alarm in AND rule under AWGN, as the number of secondary users increases the probability of false alarm decreases as well as that of miss detection.

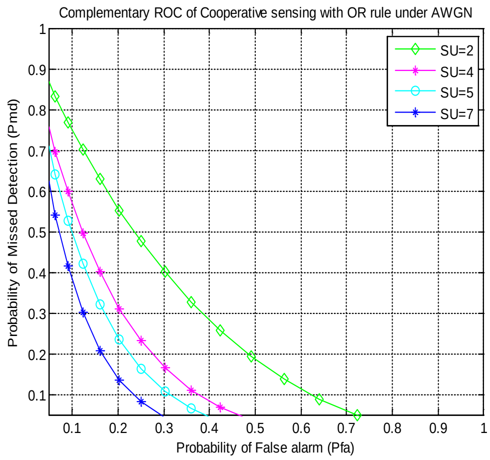


**Figure 4:** Relationship between the probability of miss detection and false alarm in OR rule under AWGN, as the number of secondary users increases the probability of false alarm decreases. This makes OR rule to perform better than AND rule and Majority rule.

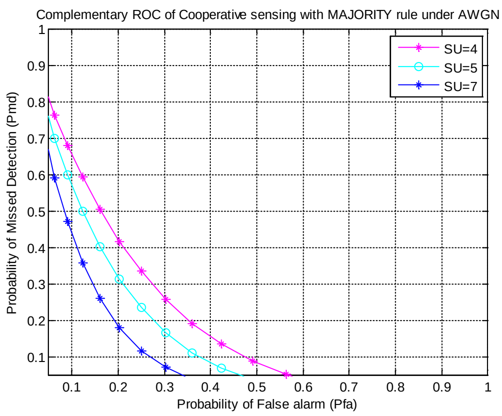


**Figure 5:** Relationship between the probability of miss detection and false alarm in MAJORITY rule under AWGN, as the number of secondary users increases the probability of false alarm decreases as well as that of miss detection.

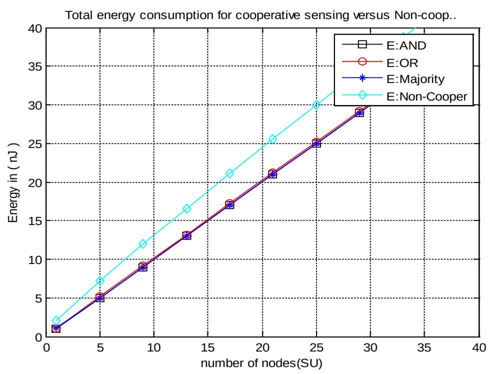


**Figure 6:** Relationship of energy consumed and number of nodes (SU) between cooperative spectrum sensing and non-cooperative sensing.

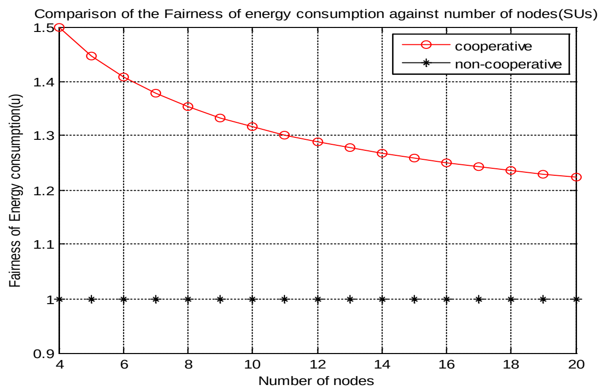


**Figure 7:** Fairness of energy consumption and number of nodes. The fairness energy consumption will get reduced as the number of secondary user increases this will increase network life time

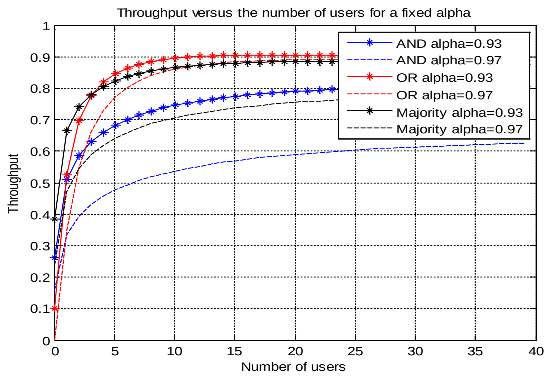


**Figure 8:** Relationship between throughput and the number of secondary users at fixed alpha (0.93, 0.97) .It shows that OR rule perform better followed by majority and then AND rule, as the number of secondary users increases also the throughput increases which utilize the empty spectrum.

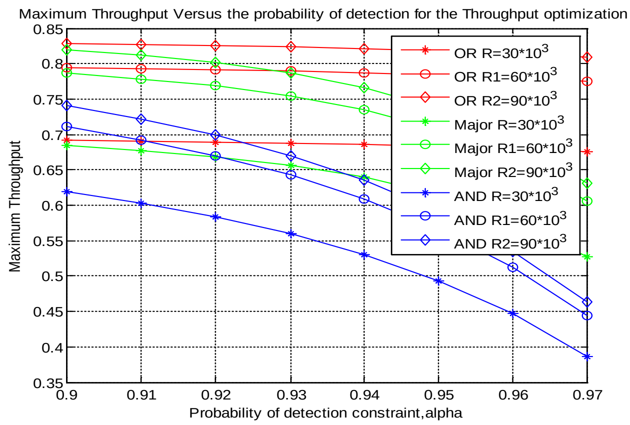


**Figure 9:** Relationship of the maximum throughput with the probability of detection constraints at different bit rates at different bit rates OR rule performs better, then Majority follows and last AND rule. The throughput will increase as the bit rates increases

## 7. Conclusion

In this paper I focus on spectrum sensing by using energy detection method because it is easy to implement and no require prior knowledge about primary signals. Also centralized cooperative spectrum sensing has been considered by using decision fusion (hard combining) which reduces the bandwidth by sending only one bit to the FC. Therefore energy efficient has been achieved by considering small groups at a time and throughput has been optimized by minimizing the sensing time and increasing the bit rates which reduces the reporting time of secondary users.

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