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# Throughput Maximization by Optimizing Secondary Users in a Cooperative Cognitive Radio Network using Hard Fusion Rules

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***Abstract: Cognitive radio network is a promising technology for enabling secondary users to utilize the licensed spectrum of the primary user without causing interference. The data trans- mitted by the secondary users through primary channel without affecting the primary user is known as channel throughput. In cooperative spectrum sensing(CSS) as the number of secondary users increases the channel throughput increases which in turn reduces the spectrum efficiency due to more spectrum wastage. Therefore in this paper, channel throughput is maximized by optimizing secondary users proposed and throughput for variable secondary users for OR and AND fusion rules is investigated. The optimal secondary users is estimated mathematically and simulation results shows the variation of throughput for variable number of secondary users.***

***Keywords : Cognitive Radio Network, Cooperative Spectrum Sensing, Throughput.***

## I. INTRODUCTION

Now a days demand for spectrum usage has been increased with compendious internet use. But the accessible spectrum is very restricted as it is already given to licensed users known as primary users (PU) as per the regulations. But the TV band was largely unused by PU [1]. This gave rise to an idea of Cognitive Radios (CR) where Secondary Users (SU) can use the primary user channel when it is vacant [2]. Therefore to utilize the primary user's channel the secondary user has to identify that it is vacant or not, through spectrum sensing. Spectrum decision makes the SU to utilize the best channel for its requirements. If the sensed channel is not free then SU can shift to another channel for sensing known as spectrum mobility [3].

While doing spectrum sensing the SU should follow two main objectives, first one is, it should not cause any disturbance to primary user's transmission and whenever PU is identified the SU should vacate it immediately. Spectrum sensing can be analyzed by two parameters.

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One is Probability of false alarm (Pf), which denotes the probability of secondary users declaring the presence of primary user when it is actually free and second is the Probability of miss detection (Pm), which denotes the probability of secondary users declaring the absence of primary user when PU is actually present. The spectrum sensing done by single secondary user will undergo many practical problems like the receiver uncertainty, multipath fading and shadowing [4]. These problems can be overcome by using a technique known as Cooperative Spectrum Sensing [5].

The name Cooperative Spectrum Sensing, itself suggests that the presence of PU is observed in cooperation between SUs. In CSS a common receiver called Fusion center collects sensing data from all secondary users to decide the presence or absence of PU based on fusion rules [6]. This technique improves the probability of detection, throughput, energy efficiency and it reduces the probability of false alarm. But, the major disadvantage is that as the secondary users increases the energy consumption also increases which in turn reduces the overall system performance. The performance can be improved either by increasing the channel throughput or by reducing the energy consumption.

To improve average channel throughput the authors in [7] predicting the channel by using BP neural network as an example. In this paper the focus is on an optimal cooperative secondary users used by maximizing the throughput of a secondary network using majority fusion rule. Cognitive radio networks utilized the carrier sense multiple access technique to maximize the throughput [8]. In [9], throughput of a CR network was considered in turms of sensing time. A majority fusion rule is taken to analyze the performance of CR network by maximizing throughput for optimal number of CR users. The feature of CRs, like spectrum diversity and non-continuous OFDM are taken into account, [10] proposed a measurement assisted SNR based cross-layer throughput optimization solution.

In [11], the authors proposed a spectrum monitoring algorithm to identify the re-appearance of the PU during the secondary user transmission. But this method improves the overall system performance and reduces the channel throughput using spectrum sharing technique. In [12], throughput of a channel be improved by considering optimal number of secondary users with majority fusion rule. In literature to maximize the throughput different techniques are used by different users like optimization of SUs using majority fusion rule, SNR based cross layer optimization and carrier sense multiple access technique. This paper main objective is to identify the optimal number of cooperative secondary users to maximize throughput of the secondary network.

## II. SYSTEM MODEL

A cognitive radio network by considering cooperative spectrum sensing is as shown in fig 1. This network consists of one primary user, one fusion center and R secondary users.

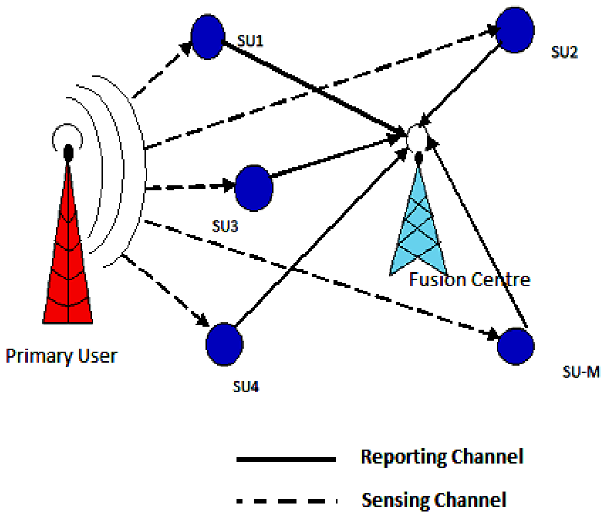


**Fig. 1. System Model of Cooperative spectrum sensing in CR network**

Each SU sense the channel and the sensed data is given by X(t) and is represented as

$$X(t) = S(t) + n(t) : H1$$
$$= n(t) : H0$$

Where $S(t)$ is a PU signal, $n(t)$ is a Gaussian noise, $H_0$ and $H_1$ are two hypothesis of SU when primary user is absent and present respectively.

From the Fig 1 it is observed that each SU sense the channel and its decision is forwarded to Fusion Centre (FC). The FC combine the decisions from different SUs based on hard fusion rules i.e. AND, OR rules. In OR rule, if at least one SU makes a choice on the existence of PU, then FC will take a decision in favor of PU to avoid interference to PU. In AND rule, all SU users should accept that the channel is free then only FC consider as PU is present.

The performance of CSS is calculated based on probability of false alarm (Pf ), probability of miss detection (Pm) and Probability of detection (Pd). The Pf , Pm, and Pd of $i^{th}$ SU are given by Marcum-Q function as

$$P_{fi} = Q\left(\frac{\rho_i - \mu_{i0}}{\sigma_{i0}}\right) \quad (1)$$

$$P_{mi} = 1 - Q\left(\frac{\mu_{i1}}{\sigma_{i1}}\right) - Q\left(\frac{\rho_i - \mu_{i1}}{\sigma_{i1}}\right) \quad (2)$$

$$P_{di} = 1 - P_{mi} \quad (3)$$

Where $\rho_i$ is detection threshold at i-th SU. $\mu_{i0}$ , $\mu_{i1}$ are the means and $\sigma_{i0}$ , $\sigma_{i1}$ are the variances of hypothesis H0 and H1 respectively .Also we assume that $P_m$ and $P_f$ has equal probability.

For R secondary users the total false alarm probability and miss detection probability at the fusion center using OR fusion rule is given by [12].

$$G_{(f,OR)} = 1 - (1 - P_f)^R \quad (4)$$

$$G_{(m,OR)} = (P_m)^R \quad (5)$$

Similarly, the overall false alarm probability and miss detection probability for R SU is given by

$$G_{(f,AND)} = (P_f)^R \quad (6)$$

$$G_{(m,AND)} = 1 - (1 - P_m)^R \quad (7)$$

For OR/AND fusion rules the probability of correct detection is given by

$$G_d = 1 - G_m \quad (8)$$

In CSS, with the increase of SUs the probability of detection increases, probability of miss detection and false alarm decreases. But at the FC, the overall system efficiency reduces due to increase in required spectrum sensing energy and reporting sensing. Hence, by reducing the required number of SUs will increase the system efficiency by optimization of secondary users using throughput has been proposed.

## III. OPTIMIZATION OF SECONDARY USERS USING THROUGHPUT

Throughput of a system is defined as the successful data delivery. In the proposed system two users i.e. primary and secondary users are transmitting their data successively without interrupting others. Secondary user will transmit its data only when primary user is not using its channels. Therefore for transmitting SU's data on the primary channel, the SU should sense it and make a final decision with the help of FC. If the PU is not present i.e. SU detects correctly then the SU can transmit its data. If SU miss detects the channel i.e. PU is present but identified as not preset then both primary user and secondary users will simultaneously send the data which may end in interference in the channel. When PU detects correctly then primary user sends the data and Secondary user waits until the channel is free or can shift to another

channel for sensing. Similarly when the fusion centers decision is probability of miss detected then primary user will be Idle and secondary user will be on hold state which results in Idle or unused channel. Therefore the average throughput based on the above condition is given by

$$T = P(H1)(1 - Gm)tp + P(H1)Gm(ts1 + tp1) + P(H0)(1 - G_f)t_s \quad (9)$$

Where,

$t_{p1}$- throughput of PU when SU is present

$t_p$ - throughput of PU when SU is absent

$t_{s1}$ - throughput of SU when PU is present

$t_s$ - throughput of SU when PU is absent

P(H0)- Probability of idle channel

P(H1)- Probability of occupied channel

P(H0)+P(H1)=1

In this paper OR, AND fusion rules are used for optimizing the secondary users. MAJORITY rule is the optimal method for estimation the optimal number of secondary users but the drawback is its difficulty in calculations and gives the outputs based on the assumptions. Hence OR, AND fusion rules selected for estimating the optimal number of secondary users.

### A. Optimizing Secondary Users Using OR Fusion Rule

The spectrum sensing can be improved if the total error is reduced. The total error can be minimized if the cooperation is made by R optimal number of SUs among R SUs.

The optimal value can be attained by differentiating equation (9) by substituting equations (4) and (5) with respect to R Secondary users and equating it to zero is

$$\frac{dT}{dR} = 0 \tag{10}$$

$$P(H0)(1-P_f)^R(t_s)\log(1-P_f) = P(H1)(P_m)^R (t_{s1}+t_{p1}-t_p)\log(P_m) \tag{11}$$

By applying logarithm on both sides to equation (11) and after simplification the Optimized value of Secondary Users using OR fusion rule is obtained as

$$R_{opt} = \frac{\log\left(\frac{P(H1)(t_p - t_{p1} - t_{s1})\log(P_m)}{P(H0)\log(1-P_f)t_s}\right)}{\log\left(\frac{1-P_f}{P_m}\right)} \tag{12}$$

### B. Optimizing Secondary Users Using AND Fusion Rule

The optimal value can be attained by differentiating equation (9) by substituting equations (6) and (7) with respect to Rd Secondary users and equating it to zero is

$$\frac{dT}{dR} = 0 \tag{13}$$

$$P(H0)(P_f)^R(t_s)\log(P_f) = P(H1)(t_p - t_{s1} - t_{p1}) (1-P_m)^R\log(1-P_m) \tag{14}$$

By applying logarithm on both sides to equation (14) and after simplification the Optimized value of Secondary Users using AND fusion rule is obtained as

$$R_{opt} = \frac{\log\left(\frac{P(H0)t_s\log(P_f)}{P(H1)(t_p - t_{p1} - t_{s1})\log(1-P_m)}\right)}{\log\left(\frac{1-P_m}{P_f}\right)} \tag{15}$$

## IV. SIMULATION RESULTS

In this section, we provide simulation results using MATLAB by observing the performance of CSS for optimal SUs using OR and AND fusion rules. Assume equal probability of presence and absence of a primary user that is P(H0)=P(H1)=0.5 and the number of secondary users as R = 5. The throughput values of primary user and secondary users under possible conditions such as tp =30bits, ts=20bits, tp1 =10bits and ts1=5bits are assumed respectively.

### A. OR Fusion Rule

The optimal secondary users in OR fusion rule are estimated using eq(12). The variation of channel throughput with detection threshold for different number of secondary users is plotted in the Fig 2. From Fig 2 it is observed that throughput increases rapidly with the increase of detection threshold up to some optimal value and then it decreases slowly. In OR rule the probability of detection is high for small values of threshold, but with the increase of secondary users the false alarm probability increases. At large detection thresholds, with the increase of secondary users the probabilities of detection increases and false alarm decreases. Therefore, for small values of detection threshold, throughput decreases with the increases of secondary users and it increases for detection thresholds.

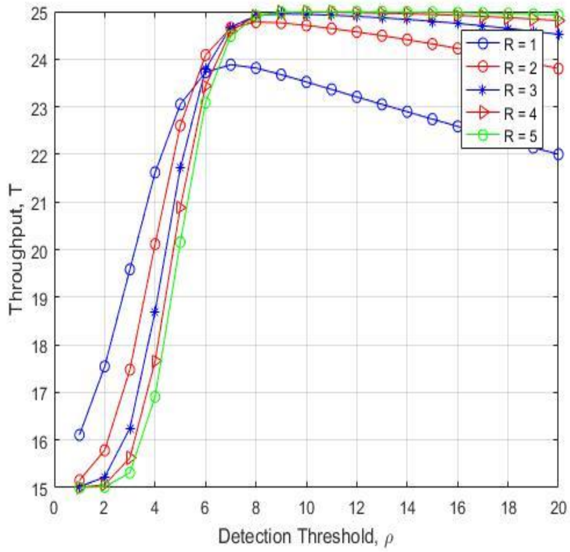


**Fig. 2.Throughput vs Detection Threshold for R=1,2,3,4,5 using OR fusion**

Fig 3 shows the optimal secondary users with detection threshold for different SNRs using OR fusion Rule. Optimal cooperative secondary users increases with the detection threshold. But as the SNR increases the optimal SUs decreases for a given detection threshold. This is due to the increases of detection probability with the increases of SNR in OR rule.

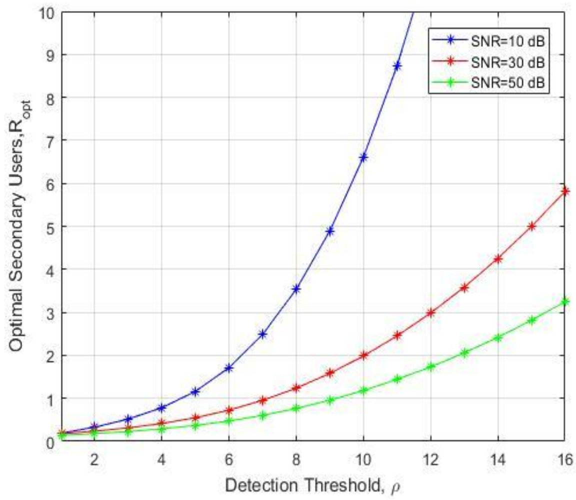


**Fig. 3. Optimal users vs Detection Threshold using OR fusion rule**

### B. AND Fusion Rule

In AND rule, with the increased detection threshold the probability of false alarm decreases and detection probability increases. Hence average channel throughput increases with the detection threshold upto some optimal value and then decreases for large values.

As the SUs increases the average channel throughput decreases for a given detection threshold which is shown in the Fig 4.

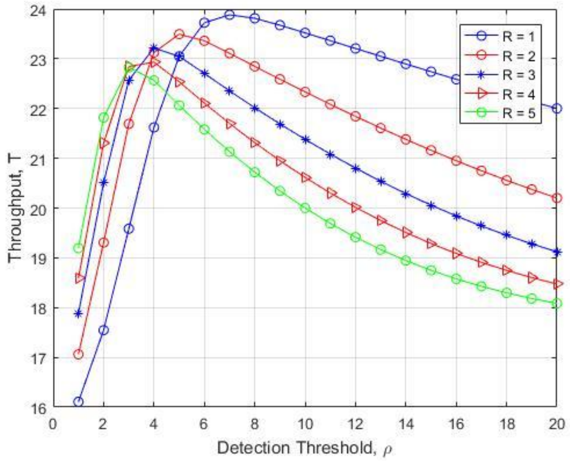


**Fig. 4.Throughput vs Detection Threshold for R=1,2,3,4,5 using AND fusion**

Fig 5 shows the optimal secondary users with detection threshold for different SNRs using AND fusion Rule. As the SNR increases the probability of detection increases in the AND rule. Therefore with the increase of detection threshold optimal SUs required is reduced.

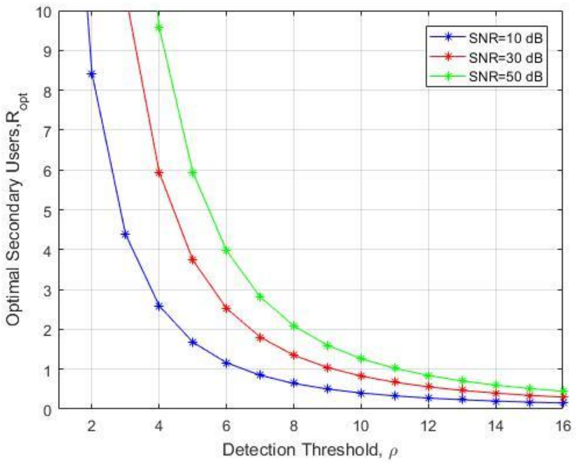


**Fig. 5. Optimal users vs Detection Threshold using AND fusion rule**

## V. CONCLUSION

In this paper, average throughput maximized by choosing the optimal cooperative secondary users. The mathematical expressions are optimal secondary users are derived for OR, AND fusion rules. From the simulation results it is observed that the average channel throughput is more for less number of secondary users in OR rule and it is more for more number secondary users in AND rule for given detection threshold. Similarly the optimal secondary users increases with the detection threshold in OR rule and decreases in AND rule for a given SNR. Therefore based on the application any one can choose OR or AND rule for maximizing the throughput and also to improve the capacity of the system.

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