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Performance Comparison of Centralized Cooperative Spectrum Sensing Based on Voting Rules in Cognitive Radio

Samrat Chandrakant Shinde[1], Ajitsinh N Jadhav[2]

[1]ME(E & TC) student , D.Y.Patil collage of Engg. & Tech. Kolhapur,Maharashtra,India
[2]HOD, Dept. of Electronics Engineering, D.Y.Patil collage of Engg. & Tech. Kolhapur,Maharashtra,India

Abstract—*In this paper we focus on optimizing the spectrum sensing capability of cognitive radio network. Cognitive users are allowed to share the licensed spectrum allotted to the primary user, when kept unutilized by it. Here energy detection technique is used for spectrum sensing of the radio environment. To overcome the individual sensing difficulties, the cooperative centralized spectrum sensing is introduced where multiple cognitive radios actively participate to enhance the sensing capability of cognitive radio environment. To optimize further the centralized cooperative sensing the decision fusion rules such as AND rule, OR rule & Majority rule are implemented under various different conditions.*
Keywords—spectrum sensing, cognitive radio, Energy detection, cooperative sensing, fusion rule.

I. INTRODUCTION

The available radio spectrum is limited and it is getting crowded day by day as there is increase in the number of wireless devices and applications. The issue of spectrum under-utilization in wireless communication can be solved in a better way using Cognitive Radio (CR). It is a system capable of monitoring different radiofrequency bands and determines if there are unused portions. The Cognitive radio network then adapts to operate in the vacant bands [1]. The spectrum sensing mechanisms implemented by CRs should reliably detect the presence and absence of primary signals in real time. If the primary user is not using the available bandwidth then it should be allotted to secondary cognitive users, to increase the efficiency of network. Once cognitive radios detect the presence of a primary user in their operating band, they must vacate the band immediately, and must not hamper the primary users functioning. Hence, accurate spectrum sensing is an essential feature of CR systems.

The spectrum sensing can be carriedout by different techniques like energy detector, cyclostationary feature detection, matched filter detection.As energy detector does not require any prior knowledge of channel under any consideration and is very easy to implement at every cognitive sensing point.Hence energy detection technique has been considered over the AWGN channel [2].The individual sensing capability of any cognitive radio node may deviate from the expected outcome due to the effects of noise and shadowing.

Thus secondary cognitive radio failing to detect the presence of primary user may interrupt the transmission of primary licensed user and disturb the whole network. To overcome this problem a technique is used, where all the sensed data of each individual CR is collected at one centralized place and fused together. The output will give more precise information about the availability of vacant bands, and this information is shared throughout the network.

Depending upon the nature in which the data of each cognitive radio is fused at the central fusion center, cooperative and non-cooperative spectrum sensing techniques are considered. In non-cooperative spectrum sensing all the cognitive radios in the respective radio environment are sensing the channels but not communicating with each other and thus there is advantage of cooperative spectrum sensing where all the cognitive radios in the vicinity exchange their sensed decision, so that the total outcome is more precise than non-cooperative spectrum sensing.

II. SPECTRUM SENSING

The sensing of signals through the radio environment which are intended for primary user is very challenging job. In this approach the energy of radio frequency channel or the received signal strength is measured to determine whether channel is busy or idle.

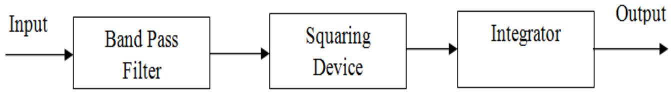

Fig.1: Energy Detector

$$X(t) = \begin{cases} n(t) & H_0 \quad \text{Primary user is absent} \\ h\,s(t) + n(t) & H_1 \quad \text{Primary user is present} \end{cases}$$

Where $x(t)$ is signal received by CR, $s(t)$ is signal transmitted for primary user, $n(t)$ is AWGN introduced and

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h is amplitude gain. In Energy detection the sensed signal is passed through band pass filter of bandwidth W and then squared to remove noise and integrated for time T interval, which gives a statistic value (Λ) this value is compared with predefined threshold value (λ). The probability of detection for energy detector (P_d) = Prob($\Lambda>\lambda|H_1$) and Probability of false alarm (P_f) = Prob($\Lambda>\lambda|H_0$) can be calculated as follows .

$$P_d = Q_{N/2}\left(\sqrt{\frac{a\gamma}{\sigma^2}}, \sqrt{\frac{\lambda}{\sigma^2}}\right)$$

$$P_f = \frac{\Gamma\left(N/2, \frac{\lambda}{2\sigma^2}\right)}{\Gamma(N/2)} \qquad (2)$$

III. COOPERATIVE SENSING

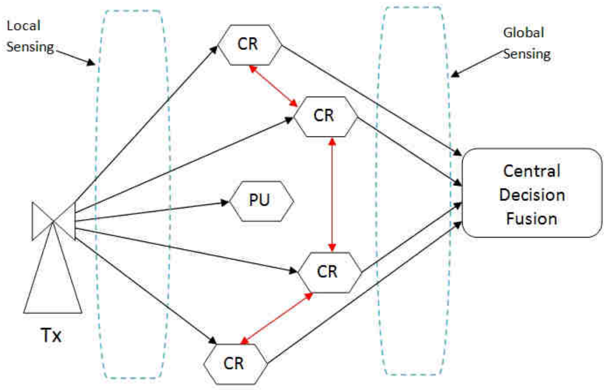

Fig.2: Cooperative spectrum sensing: Cognitive Radios (CR) senses the radio channel by local sensing, intended for Primary user (PU) .Here each CR is sharing information with each other and then sends the status of channel to central fusion block as global sensing.

To increase the sensing capability of individual cognitive radio all the cognitive radios in the network send the sensed data to the centralized fusion center as shown in Fig.2. The transmitter is transmitting for the primary licensed user the channel is continuously monitored by all the cognitive radios for the free spectrum. When free spectrum is available all the CR's in the network send the sensed data to the fusion center and decision is made regarding the availability of spectrum.

The decision generated by each CR at local sensing is one bit decision {0, 1} is transmitted to the central decision fusion center transmitted in binary form. {0} indicated that primary user is absent and {1} indicates that primary user is present. At central fusion center one bit decisions of all the CR's are clubbed together using Eq. (3). Here H_1 and Ho is the processed decision of central fusion center whether primary user is present or absent.

$$Z = \sum_{i=1}^{K} D_i \begin{cases} \geq n, & H_1 \\ < n, & H_0 \end{cases} \qquad (3)$$

In non-cooperative sensing all the CR's individually sense the radio spectrum and send the sensed data, they do not have any information of other CR's in the neighborhood. The channel is imperfect and position of each CR is different so all the CR's have different signal to noise ratio and threshold level. So there is ambiguity at the fusion center about the actual correctness of situation

In cooperative sensing all the cognitive radios monitor the spectrum and send the sensed data to the centralized fusion center for processing, the same as explained for non-cooperative spectrum sensing. The difference is that here all the CR's are in synchronous with each other as shown in Fig.2. Even though their positions are different they maintain same signal to noise ratio and threshold level, this leads to robust decision at fusion center. Considering the same threshold (λ) level at each CR, the false alarm probability (Q_f) and missed detection probability (Q_m) for cooperative sensing can be found using Eq.(4) and Eq.(5).

$$Q_f = 1 - \prod_{i=1}^{K} [(1 - P_{f,i})] \qquad (4)$$

$$Q_m = \prod_{i=1}^{K} P_{m,i} \qquad (5)$$

Where $P_{f,i}$, $P_{m,i}$ are the probability of false alarm and probability of missed detection for local spectrum sensing of $(i)^{th}$ CR respectively.

IV. FUSION RULES

The data send by all the cognitive radios in the network is collected at the central fusion center. This data needs to be processed and the fusion center has to come to conclusion regarding the availability of vacant spectrum. For this processing we are considering hard decision combining technique. In this technique one bit locally sensed data from each cognitive radio is collected and combined using k-out-of-N rule.

$$Qd = \sum_{l=k}^{N} \binom{N}{l} (P_{d,i})^l (1 - P_{d,i})^{N-l} \qquad (6)$$

A. OR Rule: This rule determines the presecnce or absensce of signal when even one of of the user notifies the fusion center. This can be implemented by putting k=1 in Eq.(6) there by the Eq.(6) in the modified form is given by Eq.(7). OR rule is best when the decision threshold is very high.

$$Qd = 1 - \left(1 - P_{d,i}\right)^{N} \qquad (7)$$

B. AND Rule: This rule determines the presence or absence of signal when all the users notify to the fusion center. This can be implemented by putting k=N in Eq. (6) thus the modified equation is given by Eq. (8). AND rule is preferred when the decision threshold is very small.

$$Qd = \left(P_{d,i}\right)^{N} \qquad (8)$$

C. MAJORITY Rule: This rule determines the presence or absence of signal when majority of the cognitive radios in the vicinity convey their decision to the central fusion center, that is more than half of the users notify to the fusion center. This can be implemented by putting k= [N/2] in Eq. (6), thus the modified equation is given by Eq. (9). MAJORITY rule is preferred when the decision threshold is not small or high enough or not known for surely.

$$Qd = \sum_{l=[N/2]}^{N} \binom{N}{l} \left(P_{d,i}\right)^{l} \left(1 - P_{d,i}\right)^{N-l} \qquad (9)$$

V. SIMULATION RESULTS

Considering the concept of centralized fusion center, we collect all the data from each cognitive radio and fuse that collected data at fusion center. The fusion is carried out by the considering the number of cognitive radios taking part in the decision process. Here we have considered the cooperative spectrum sensing where all the cognitive radios share their sensed information with each other.

A. *AND rule:*

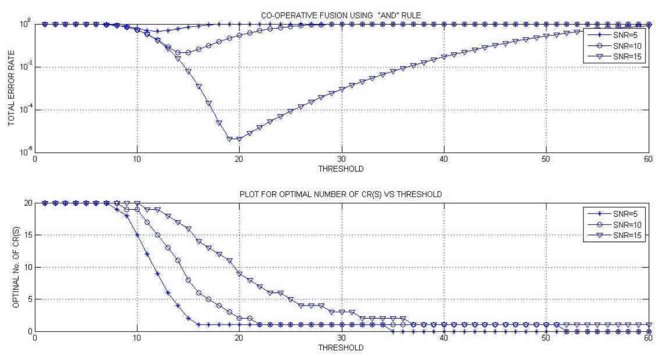

Fig.3: Plot of Threshold vs. Total Error Rate and Threshold vs. Optimal number of Cognitive radios , this helps in analyzing optimal number of radios and threshold for AND rule .

If we choose to implement AND rule at the central fusion center then we take into consideration most of the cognitive radios in the vicinity, but it is not feasible to choose all of them , because more the number of radios the more the sensing time will be required and thus may hamper the faithful execution of system. So we have to optimize the number of number of radios to be considered. As seen from the table below for different SNR values the total error rate is 0.5 and threshold value is 10 and number of cognitive radios required will be 20, which explains that AND rule can be implemented when the threshold value is low and have to take into consideration all the cognitive radios in the radio environment .

Table 1: AND rule implemented for different SNR conditions

Sr. No.	SNR Value	Total Error Rate	Threshold	Optimal number of Cognitive radio
1	5	0.4	10	20
2	10	0.5	10	20
3	15	0.5	10	20

B.*OR rule:*

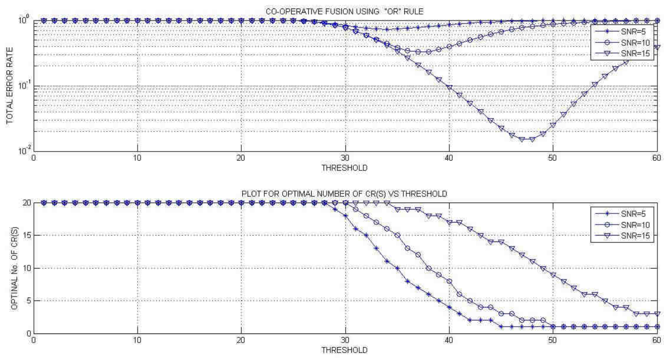

Figure 4: Plot of Threshold vs. Total Error Rate and Threshold vs. Optimal number of Cognitive radios, this helps in analyzing optimal number of radios and threshold for OR rule

If we choose to implement the OR rule at the central fusion center, we can choose very few cognitive radios so that the sensing time is also less and we could get a effective result. As seen from the table for SNR value 10 the error rate is 0.6 and cognitive radios required are also 7 but the required threshold is 40. Hence if we want to implement the OR rule at the fusion center, then we should have threshold value to be higher side, else the results may not be promising.

Table 2: OR rule implemented for different SNR conditions

Sr. No.	SNR Value	Total Error Rate	Threshold	Optimal number of Cognitive radio
1	5	0.9	40	4
2	10	0.6	40	7
3	15	0.1	40	15

C .*MAJORITY rule:*

If we choose to implement the majority rule at the central fusion center then we can choose some required number of cognitive radios which are not less and not all. We can consider majority of the cognitive radios and not all to make the decision regarding the presence of primary user. By looking at the table we can conclude that for SNR value 5 and total error rate 0.4 we have threshold value of 25 and required optimal number of cognitive radios is just 5. Also by increasing the SNR values the total error rate decreases for same threshold value.

Table 3: MAJORITY rule implemented for different SNR conditions.

Sr. No.	SNR Value	Total Error Rate	Threshold	Optimal number of Cognitive radio
1	5	0.4	25	5
2	10	0.1	25	8
3	15	0.01	25	12

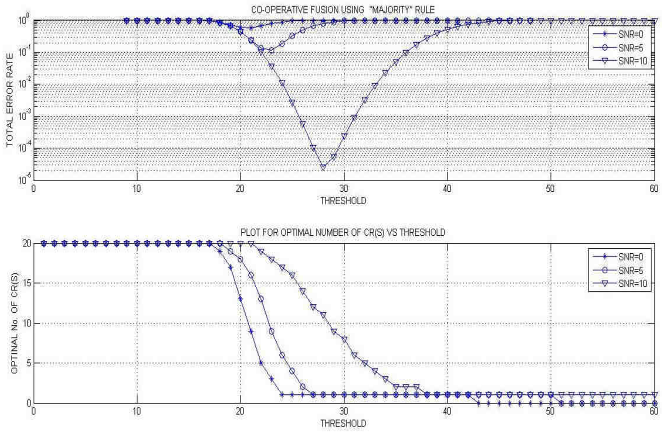

Fig.5: Plot of Threshold vs. Total Error Rate and Threshold vs. Optimal number of Cognitive radios, this helps in analyzing optimal number of radios and threshold for MAJORITY rule.

D. *Comparison between AND, OR, MAJORITY*

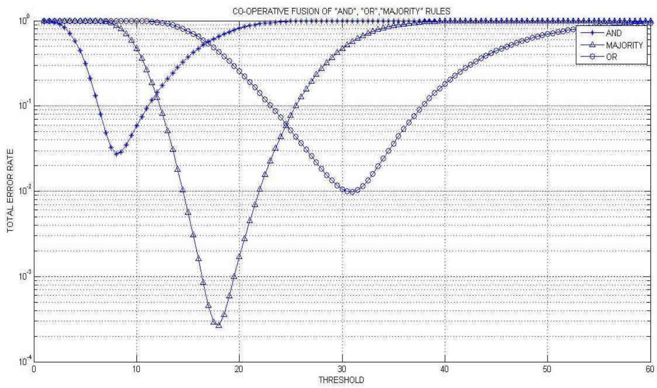

Fig. 6: Plot of Threshold vs. Total Error Rate, here all the Fusion rules are compared with SNR=10, and number of cognitive radios N=10.

After individual implementation of above rules we have to optimize which fusion rule is best so that that one can be considered best out of studied ones. So looking at the Fig.6 we could clearly make out that Majority rule ahs lowest total error rate out off the three rules. So to achieve the total error rate less than 0.01 we have to choose the Majority fusion rule at the central fusion center. Also the threshold value required for achieving that error rate is less that is 18. Comparing the results with the Fig.5, we came to a conclusion that the optimum number of cognitive radios for this would be 5 and thus makes the MAJORITY rule to be optimum rule among above all.

Further to optimize the Majority rule, we have to chosen the SNR value to be 10 and required error rate to less < 0.01 and also the number of cognitive radios to be lass so that sensing time required is less. Thus optimum value of threshold is 16 and number of cognitive radios is 5 which is the optimized depending upon fixed SNR values

VI. CONCLUSION

In wireless communication spectrum is very valuable resource. Cognitive radio is one of the efforts to utilize the available spectrum more efficiently through opportunistic spectrum usage. One of the important elements of cognitive radio is sensing the available spectrum opportunities. The new interpretation of spectrum space creates new opportunities and challenges for spectrum sensing. To overcome individual sensing issues like fading, shadowing and hidden node cooperative spectrum sensing is considered suitable. Further in cooperative sensing the various fusion rules like AND, OR, MAJORITY are implemented and optimized for different SNR conditions. Comparing the three, MAJORITY fusion rule is the best suitable for less threshold and less total error rate under the same conditions.

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