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Optimization of Cooperative Spectrum Sensing to Minimize the Total Error Rate in Cognitive Radio Networks

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Abstract: Cognitive radio is an emerging technology for the opportunistic use of under utilized spectrum. It promises to change the future technological trends forever if employed properly. Spectrum sensing is the major function of a cognitive radio network. This paper proposes a new strategy to optimize the overall performance in cooperative spectrum sensing. Optimization strategy is proposed in order to optimize the overall performance by varying the SNR. We consider optimization of cooperative spectrum sensing with energy detection to minimize the total error rate. Here we derive optimal voting rule for optimal value of cognitive radios. The effects of spectrum sensing technique type that used locally at each CR, the local SNR, and the total number of cooperated CRs on the optimal fusion rule are found. The Energy Detector(ED) spectrum sensing technique is used as local spectrum sensing techniques. Here, different error levels are founded by varying the SNR values to find the optimal number of CRs for minimizing the error levels.

Keywords: Cognitive Radio, Spectrum Sensing, Optimization, Cooperative Spectrum Sensing.

I. INTRODUCTION

The electromagnetic radio spectrum is a licensed resource. They are carefully managed by governments and authorities to provide secure and reliable wireless communication. Now a day the wireless service providers buy the license for one or more spectrum bands. And only its users known as primary user (PUs) are allowed to access these channel and use there. Examples of licensed technology are global system for mobile communications (GSM), worldwide interoperability for microwave access (WiMax) and long term evolution (LTE). On the other hand, unlicensed cognitive users with lower priority are defined as secondary users (SUs).Due to the increased number of user's demand of wireless spectrum increases and spectrum scarcity problem arises. It leads to inefficient channel utilization. To, solve this problem concept of cognitive radio emerges.

The Federal Communication Commission (FCC) defines cognitive radio as follows:
a radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters for modifying interference, facilitate interoperability, and access secondary markets. In Cognitive Radio (CR) network, a SU can access spectral resources of a PU, if the primary user is not using it. However the SU has to vacate the frequency band as soon as the PU becomes active so that negligible (or no) interference is caused to the PU. Such opportunistic access of the PU resources by the SUs is called as dynamic spectrum access. A SU can opportunistically utilize different spectrum holes corresponding to different PUs. In order to satisfy its bandwidth requirement without causing interference to the PUs as shown in Fig.1

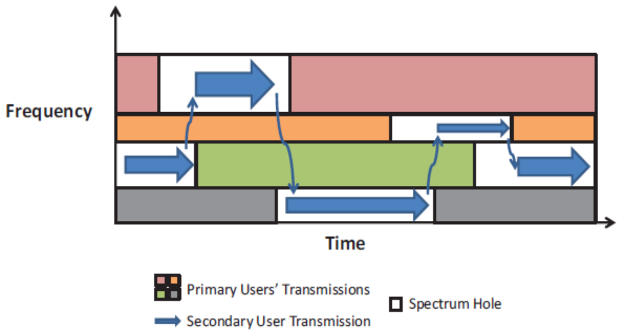

Fig1. In cognitive radios, secondary users (SUs) opportunistically use the spectrum not used by the primary users.

Spectrum sensing is a key enabler for dynamic spectrum access in cognitive radios. It is the task of obtaining awareness regarding the radio spectrum as well as identifying idle spectrum. It enables the SUs to explore and exploit the unused PU spectrum. In addition it is crucial for managing the level of interference caused to the PUs of the spectrum. Spectrum sensing can be done by an individual SU and is called as single-user sensing or local detection. Single-user sensing becomes difficult in challenging propagation environments like multipath fading, Doppler spread, and shadowing. In such a scenario a SU has to distinguish between a white space, where there is no primary signal, and a deep fade, where it is hard to detect the primary signal. Cooperative sensing (CS), where different SUs collaborate to detect the presence of a PU, provides diversity gains to tackle the fading and shadowing effects. CS also helps to increase the SNR gain and network coverage.

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Decrease the detection time, and simplify the detector design.

II. COOPERATIVE SPECTRUM SENSING

The performance of a local detector degrades in the presence of propagation effects such as shadowing and fading caused by multipath. These channel conditions may also result in the problem of hidden node. Where a secondary transceiver is outside the listening range of a primary transmitter but close enough to the primary receiver to create interference. This is known as hidden terminal problem. These issues can be overcome using cooperative sensing (CS).Where neighbouring yet geographically distributed SUs cooperate in sensing a common PU transmission. It is achieved by exchanging sensing information among them before making a final decision. Most of the CS schemes stem from the field of distributed detection.Fig.2 shows an example of CS, where N SUs sense listening channels for the PU signal activity and send the sensing information on reporting channels to the fusion center (FC) or to the common receiver, it makes the final decision. It is very unlikely that all the channels between the PU and the SUs will be in a deep fade simultaneously. Thus cooperative detection helps in mitigating the channel effects through multipath diversity. Other benefits of cooperative detection include improved detector performance, increased coverage, simplified local detector design, and increased robustness to non-idealities. Therefore, CS has generated lot of interest in the cognitive radio literature.

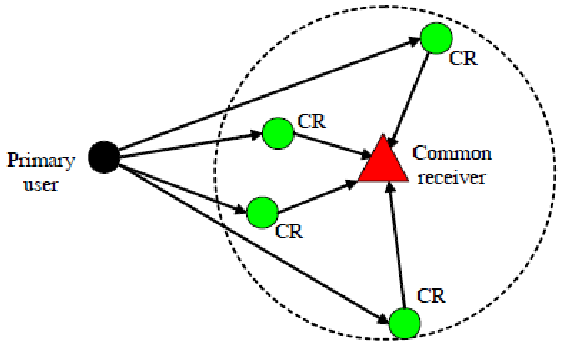

Fig 2.Spectrum sensing structure in a cognitive radio network

There are mainly two types of cooperative spectrum sensing:

1) Centralized approach: In this method, there is a central node within the network that collects all the sensing information from the neighbouring sense nodes within the network. It then process and analyse the collected information and then determines the frequencies which are used and cannot be used. The cognitive radio central node can also organize the various cognitive radio users to undertake different measurements at different times.

2) Distributed approach: In distributed approach of cognitive radio cooperative spectrum sensing there is no central or master node for all controlling operations. Instead communication exists between the different nodes and they are able to share sense information. However this approach requires for the individual radios to have a much higher level of autonomy and setting themselves up as an ad-hoc network.

Hidden terminal problem makes spectrum sensing more critical to implement. This problem is due to environmental conditions and creates the problems like multipath fading, shadowing. Due to this there may be a wrong interpretation of secondary user and loss of information occurs. So to remove this problem and to achieve efficiency in spectrum sensing, cooperative spectrum sensing is used.

Cooperative spectrum sensing will go through two successive channels: (i) Sensing channel (from the PU to CRs) and (ii) Reporting channel (from the CRs to the common receiver).

Advantages of cooperative spectrum sensing:

1) Hidden terminal problem is reduced: By using cooperative sensing system, it is possible to reduce the hidden terminal problem because a greater number of receivers will be able to build up a more accurate scenario of the transmissions in the area.

2) Increase in agility: An increase in the number of spectrum sensing nodes by cooperation enables the sensing to be more accurate and better options for channel moves to be processed. Thereby providing an increase in agility.

3) Reduced false alarms: Due to multiple nodes performing the spectrum sensing, channel signal detection is more accurate and this reduces the number of false alarms.

Disadvantage of Cooperative Spectrum Sensing:

Significant disadvantage of cooperative spectrum sensing are:-

1) Control channel: For the different elements within the cognitive radio cooperative spectrum sensing network to communicate, a control channel is required. This will take up a proportion of the overall system bandwidth.

2) System synchronization: It is normally necessary to provide synchronization between all the nodes within the cognitive radio cooperative spectrum sensing network. Accurate spectrum sensing requires a longer period of time than a rough sense to see if a strong signal has returned. By adapting the sense periods, channel throughput can be maximized. But there is a greater need to maintain synchronization under these circumstances.

3) Suitable geographical spread of cooperating nodes: In order to gain the optimum sensing from the cooperating nodes within the cognitive network, it is necessary to obtain the best geographical spread. In this way the hidden node syndrome can be minimized, and the most accurate spectrum sensing can be gained.

III. SYSTEM MODEL

1) Spectrum sensing

We consider a cognitive network with K number of CR's. One primary user and one fusion center (i.e., common receiver).The spectrum sensing is done by each CR independently. The decision taken by CR is sent to the fusion center and the fusion center will decide whether the

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primary user is present or not. To determine this we are considering two hypothesis: The received signal will be

$$x_i(t) = \begin{cases} w_i(t) \\ h_i(t)s(t) + w_i(t) \end{cases}$$

When the signal is received at the ith CR in timeslot t, $s_i(t)$ is the PU signal. $h_i(t)$ is the complex channel gain of the sensing channel between the PU and i^{th} CR. $w_i(t)$ is the Additive White Gaussian Noise(AWGN).We assume that the sensing time is lesser than the coherence time of the channel. The coherence time is the time duration over which the channel impulse response remains constant. So $h_i(t)$ will be time invariant ($h_i(t) = h_i$).i.e, time independent. Also we assume that during sensing time, PU does not change its state. We use energy detection technique as PU signal is unknown. For each i^{th} CR by energy detection we found average probability of detection, false alarm, missed detection over AWGN channel with following equations:

$$p_{f,\lambda} = \frac{\Gamma\left(u, \frac{\lambda_i}{2}\right)}{\Gamma(u)}$$

$$p_{d,i} = Q_u\left(\sqrt{2\gamma_i}, \sqrt{\lambda_i}\right)$$

$$p_{m,i} = 1 - p_{d,i}$$

Where λ_i is the energy detection threshold and γ_i is the instantaneous signal to noise ratio(SNR) at the i^{th} CR.Also u is the time-bandwidth product of the energy detector. $\Gamma(a)$ is the gamma function and $\Gamma(a,x)$ is the incomplete gamma function.

$$\Gamma(a,x) = \int_x^\infty t^{a-1} e^{-t} dt$$

The generalised Mrcum Q-function is given by;

$$Q_u(a,x) = \frac{1}{a^{u-1}} \int_x^\infty t^u e^{\frac{t^2+a^2}{2}} I_{u-1}(at)\, dt$$

Where $I_{u-1}(\ )$ is the first kind and order u-1 modified Bessel function.

The cooperative spectrum sensing, where number of CR's takes binary decision based on local observation and forwards a bit decision D_i to the common receiver. These decisions are summed at common receiver and it will decide whether the PU is absent or in operation.

$$Y = \sum_{i=1}^{K} D_i \begin{cases} \geq n, H_1 \\ < n, H_0 \end{cases}$$

Here, n is the threshold representing "n-out-of-K" rule. If the number of CR is one, i.e. n=1 then it corresponds to OR rule and if n = K then it corresponds to AND rule. In the radio frequency environment around CR's, we consider the distance between any two cognitive radios is smaller than the distance between one CR and PU. Therefore the signal received at each CR follows identical path loss. For AWGN channel, $\gamma_1 = \gamma_2 = ...\gamma = \gamma_K$ and for Rayleigh fading channel $\gamma_1, \gamma_2.........\gamma_K$ as we assume that it is independent and identically distributed (i.i.d) with instantaneous SNR's. Also, these SNR's are i.i.d. exponentially distributed random variables with the same mean. We consider another assumption that threshold of each CR is same and it is $\lambda_1 = \lambda_2 = \lambda_3 = ...\lambda$.As threshold is constant for all CR, $P_{d,i}$ will be independent of i , therefore $p_{f,i} = p_f$.For AWGN channel $P_{d,i}$ is independent of i and we denote as P_d.In Rayleigh fading channel, P_d is $P_{d,i}$ averaged over the different values of $\gamma_{i[1-3]}$.

The common receiver calculates false alarm probability and missed detection probability with the help of average probability of each CR. The false alarm probability is given by,

$$Q_f = \sum_{l=n}^{k} \binom{k}{l} p_f^l (1-p_f)^{k-l} = \Pr ob\{H_1 / H_0\}$$

Also, the missed detection probability is given by;

$$Q_m = 1 - \sum_{l=n}^{k} \binom{k}{l} p_d^l (1-p_d)^{k-l} = \Pr ob\{H_0 / H_1\}$$

B) Optimization of cooperative spectrum sensing

In this section, we analyse optimal voting rule, optimization of number of CR and detection threshold with cooperative spectrum sensing.

1) Optimal Voting Rule

Let, K is fixed then what will be optimal value of n so that we get minimum error rate $(Q_f + Q_m)$, this is the optimal voting rule and optimal value of n is called as n_{opt} . We have plotted graph for n=1 to n=10. For each n, for different threshold values, we calculated error rate. For small threshold value, we get more error rate and optimal rule AND rule (i.e. n =10). For large threshold value, optimal rule is OR rule. But when n = 5, we get more error rate for medium threshold values.

Statement 1: To find n_{opt} value for minimum error rate we proposed solution as follows; where and [.] denotes the ceiling function

$$n_{opt} = \min\left(K, \left\lceil \frac{K}{1+\alpha} \right\rceil\right)$$

$$\alpha = \frac{\ln \frac{P_f}{1-P_m}}{\ln \frac{P_m}{1-P_f}}$$

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2) Optimal Energy detection Threshold

Here we consider that K, n and SNR are known then what will be optimum threshold λ* such that total error rate minimum. We have plotted in figure 1 total error rate curve with different threshold values. For only one threshold value, figure has the low error rate for given n. i.e. there will be one and only value of λ for which $\left(Q_f + Q_m\right)$ is minimum

$$\lambda^* = \arg\left\{\min\left(Q_f + Q_m\right)\right\}$$

For optimal energy threshold:

$$\frac{\partial Q_f}{\partial \lambda} + \frac{\partial Q_m}{\partial \lambda} = 0$$

$$\frac{\partial Q_f}{\partial \lambda} = \sum_{l=m}^{K}\binom{K}{l} l.P_d^{l-1}.\frac{\partial P_d}{\partial \lambda}\left(1-P_f\right)^{K-l} - \sum_{l=m}^{K}\binom{K}{l} P_f^l\left(K-l\right) - \frac{\partial P_f}{\partial \lambda}\left(1-P_f\right)^{K-l-1}$$

$$\frac{\partial Q_m}{\partial \lambda} = -\sum_{l=n}^{K}\binom{K}{l} l.P_d^{l-1}.\frac{\partial P_d}{\partial \lambda}\left(1-P_d\right)^{K-l} + \sum_{l=n}^{K}\binom{K}{l} P_d^l\left(K-l\right)\frac{\partial P_d}{\partial \lambda}\left(1-P_d\right)^{K-l-1}$$

3. Optimal Number of Cognitive Radios

In cooperative spectrum sensing, large number of CR's used, but it increases the time slot and becomes impractical. As only one CR should send its local decision at a time to the fusion centre so it may take whole sensing time intolerably long. This problem can be solved by permitting CR's to send the decision concurrently but this is difficult for common receiver to separate each decision. There is another way to send decisions using orthogonal frequency bands, but large bandwidth requirement is the problem. So we proposed efficient sensing algorithm, in which we define some error bound and calculated optimal number of CR's. Also each CR sends decision in one time slot. By this method we get required error rate with use of few CR's only.

Let, SNR and threshold values are known then we calculated least number CR's in cooperative spectrum sensing to achieve target error bound. i.e. $(Q_f + Q_m) \leq \in$, where $\in$ is the target error bound. As we have stated for earlier optimal voting rule.

$$n_{K^*}^{opt} = \min\left(K^*, \left[\frac{K^*}{1+\alpha}\right]\right)$$

Here $K^*\left(1 \leq K^* \leq K\right)$ is the least number of CR's to satisfy target error bound $(Q_f + Q_m) \leq \in$ and α is calculated from P_f , P_m and and known SNR and l values. We define the function,

$$F\left(k, n_k^{opt}\right) = Q_f + Q_m - \in$$

Where k is the number of cooperative CR's in cooperative spectrum sensing and n_k^{opt} is calculated. The probability Q_f and Q_m are functions of k and n_k^{opt} . Therefore we get;

$$F\left[k^*, n_{k^*}^{opt}\right] \leq 0$$

$$F\left(k^* - 1, n_{k^*-1}^{opt}\right) > 0$$

Using above equations we can get $k^* = [k_0]$, where k_0 is the first zero crossing point of the function $F(k, n_k^{opt})$ in terms of k. Therefore, fast sensing algorithm can be implemented by considering only k^* CR's instead of K. This reduces the time slot for common receiver from K to k^* maintaining the target error bound.

IV. SYSTEM MODELLING WITH ENERGY DETECTION OF SIGNAL

Here, the energy of signal is calculated and probability of false alarm and detection is calculated. For AWGN channel, first we define different threshold values and calculate the energy of received signal. If energy of received signal is $x_1\left(t\right) = s\left(t\right) + w\left(t\right)$ then the energy of $x_1\left(t\right)$ is calculated, also if received signal is $x_2\left(t\right) = w\left(t\right)$ then energy of $x_2\left(t\right)$ is calculated. If energy of $x_1\left(t\right)$ is greater than threshold value then that would be probability of detection and if energy of $x_2\left(t\right)$ is greater than threshold value then that would be probability of false alarm.

$$E_1 = \frac{1}{N_{02}}\sum_n\left(s\left(n\right) + w\left(n\right)\right)^2 \quad \text{and}$$

$$E_2 = \frac{1}{N_{02}}\sum_n\left(w\left(n\right)\right)^2$$

where N_{02} is the two sided noise power spectral density and is given by;

$$N_{02} = \frac{\sum_n\left(s\left(n\right)\right)^2}{\left(2 * SNR\right)}$$

For Rayleigh Fading Channel, the SNR values are exponentially distributed. We consider SNR values as exponential random number with same mean. To determine Rayleigh fading channel gain we have used.

$$h = \sqrt{\frac{\left(2 * SNR\right)}{\sum_n\left(s\left(n\right)\right)^2}}$$

Then we find the two sided noise power by;

$$N_{02} = \frac{\left\{h^2 * \sum_n\left(s\left(n\right)\right)^2\right\}}{\left(2 * SNR\right)}$$

Then using this value of N_{02} and equation (11) we calculated the energy of the received signal and find

probability of false alarm and detection using threshold values.
The energy becomes in Rayleigh Fading Channel;

$$E_1 = \frac{1}{N_{02}} \sum_n \left(h * s(n) + w(n)\right)^2$$

V. RESULTS AND DISCUSSION

In the figure, we found error rate for different threshold values and number of CR's by keeping SNR=10 db. In figure, the error rate is low for n =5 and it is high n =10 and n =1.i.e. with use of 5 CR's out of 10 we can achieve low error rate.

This figure explains the optimal rule. This figure explains the optimal rule. The error rate is nothing but $\left(Q_f + Q_m\right)$.
That is probability of missed detection and false alarm probability is high if very few or high number CR's are used. So the number of CR's used should be half of total CR's, i.e. for n=5 the probability of missed detection and false alarm probability is low, so cooperative spectrum sensing allocation is done in correct way.
Also, by modelling the system, we compare results get from modelling and formulae for n =5. The both results are same. For modelling, we use equations explained in section 4.

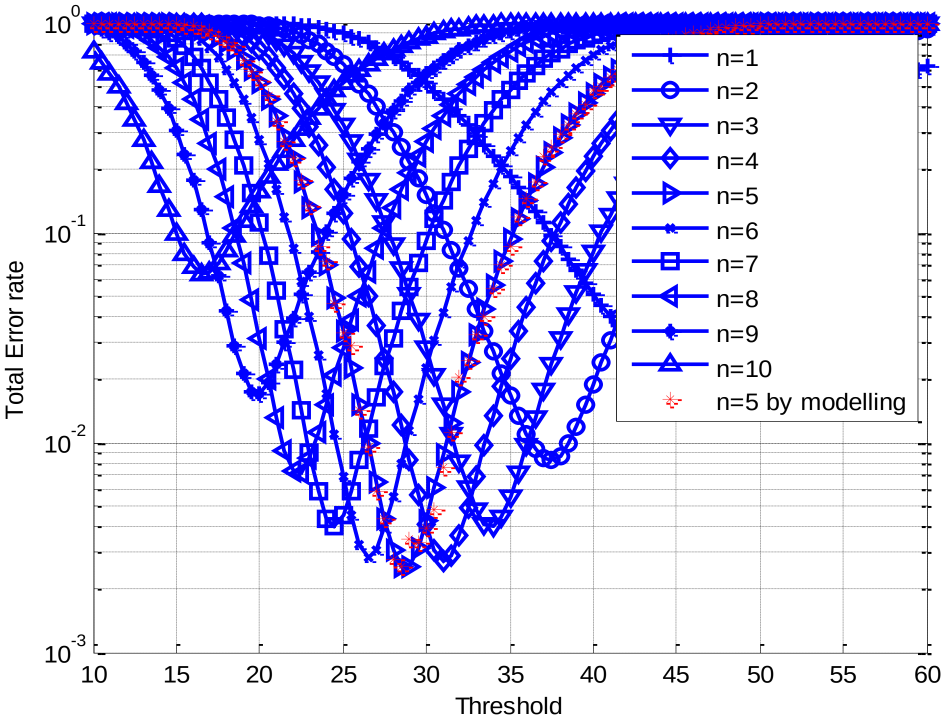

Fig. Total error rate of cooperative spectrum sensing in AWGN channel with 10dB SNR. Optimal voting rule for n=1, 2,........., 10 and K=10.

VI.CONCLUSION

We have studied the cooperative spectrum sensing with energy detection using formula and modelling the system. We analysed the system with optimum voting rule for minimum error rate and K/2 is optimal value. Also, optimization of threshold has been done with minimum values of probability of missed detection and false alarm probability. We analysed the system, for the less probability of missed detection and false alarm probability so that spectrum allotted correctly to secondary user. We proposed the fast sensing algorithm and calculated least number of CR's a given error bound. We eliminated the intolerably long sensing time with fast sensing algorithm.

REFERENCES

[1] Wei Zhang, Member, IEEE, Ranjan K. Mallik, Senior Member, IEEE, and Khaled Ben Letaief, Fellow, IEEE "Optimization of Cooperative Spectrum Sensing with Energy Detection in Cognitive Radio Networks", IEEE transactions on wireless communications, vol. 8, no. 12, December 2009.
[2] Harry Hrkowitz, Member, IEEE, "Energy Detection of Unknown Deterministic Signals" Proceeding of the IEEE, Vol. 55,Issue no.4 , 1967, Pg.No. 523 – 531.
[3] Fadel F. Digham, Member, IEEE, Mohamed-Slim Alouini, Senior Member, IEEE, and Marvin K. Simon, Fellow, IEEE," On the Energy Detection of Unknown Signals Over Fading Channels", IEEE transactions on communications, vol. 55, no. 1, January 2007.
[4] Fadel F. Digham, Mohamed-Slim Alouini, and Marvin K. Simon, "On the Energy Detection of Unknown Signal over Fading Channels", Communications, 2003, ICC '03. IEEE International Conference on, pg. no. 3575 – 3579, vol.5, 11-15 May 2003.
[5] Federal Communications Commission, "Spectrum Policy Task Force", Rep. ET docket no. 02-135, Nov. 2002.
[6] Danijela Cabric, Shridhar Mubaraq Mishra, Robert W. Brodersen, Berkeley Wireless Research Center, University of California, Berkeley, "Implementation Issues in Spectrum Sensing for Cognitive Radios",
[7] Marvin K. Simon Mohamed-Slim Alouini, "Digital Communication over Fading Channels", A Unified Approach to Performance Analysis A Wiley-Inter science Publication JOHN WILEY & SONS, INC.