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Article

Optimized Cooperative Spectrum Sensing Scheme: A Comparative Study

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ABSTRACT

An encouraging technology that grabs the clash between spectrum scarcity and underutilization is Cognitive Radio (CR), spectrum sensing is the main task of cognitive radio. Cooperative spectrum sensing overcomes the adverse effect of shadowing and multipath. In this paper, the optimization of cooperative spectrum sensing has been proposed in order to optimize the overall performance by variation of SNR. In this optimization process, three parameters; spectrum sensing technique used locally, SNR and the number of users have been considered. Decision made by all the users is sent to the fusion center which estimate the final presence or absence of primary user.

Keywords: Cognitive Radio(CRs), Spectrum Sensing, Secondary users (SUs), Primary Users (PUs), Cooperative Spectrum Sensing Optimization, Fusion Centre (FC), Cognitive Radio Base Station(CR-BS)

Introduction

Radio spectrum is the backbone of the wireless communication due to its role of providing the transmission medium. But in this era a lot of spectrum has been occupied as a result there is scarcity of radio spectrum. Cognitive radio has provided the solution of this problem. All the licenses users do not occupy the spectrum all the time. According to the U.S. Federal Communications Commission, the allocated spectrum resources are severely underutilized in massive temporal, spatial, and spectral dimensions.[1] This is mainly because under existing governing policies, frequency bands are statically assigned to licensed/ primary users (PUs), and no reutilization is permitted for unlicensed/ secondary users (SUs). In general, spectrum sensing solutions can be categorized as cooperative and non-cooperative.[2] More specifically, cooperative solutions depend on multiple SUs to exchange spectrum occupancy information through individual local measurements. The existing studies specify that association among SUs improves the efficiency of spectrum utilization, and allows reduction of the constraints at individual SUs. Spectrum sensing is a key function of cognitive radio to inhibit the harmful interference with licensed users and identify the available spectrum for improving the spectrum's consumption. However, detection performance in practice is often compromised with multipath fading, shadowing and receiver uncertainty issues.[3] To moderate the impact of these issues, cooperative spectrum sensing has been shown to be an operative method to improve the detection performance by developing spatial diversity.

The essential task of each CR user in CR networks, in the most basic sense, is to detect the licensed usersalso known as primary users (PUs), if they are present and identify the available spectrum if they arethe better the PUs are protected; the lower the P_f, the more efficiently the channel can be reutilized by SUs. To increase the detection probability, a collection of signal detection techniques are proposed in [7] and [8].

Spectrum Sensing

In this scenario, we have considered a cognitive radio network compose of K CR_S (Secondary users) and a common receiver .In this network each cognitive radio sense the spectrum independently and decision made locally is sent to the common receiver which fuses all the decision statistics to infer the absence or presence of the PU. The binary hypothesis is represented as

H_0 : primary user is absent;

H_1 : primary user is present

This hypothesis consider the spectrum sensing in the i^{th} CR. The sensing model is to decide between the following two hypothesis[6],

$$X_i(t) = \begin{cases} W_i(t), & H_0, \\ H_i(t)S(t) + W_i(t), & H_1, \end{cases} \quad (1)$$

Where received signal is represented by $X_i(t)$ at i time slot $S(t)$ is the PU signal, $W_i(t)$ is represented as the additive white Gaussian noise (AWGN), and H_i (t) is the channel gain of the path between CR and the primary user. We assume that the sensing time is absent. This is usually achieved by sensing the RF environment, a procedure called spectrum sensing.[4] The objectives of spectrum sensing are twofold: first, CR users should not cause destructive interference to PUs by either switching to an available band or restraining its interference with PUs at an acceptable level and, second, CR users should efficiently identify and exploit the spectrum holes for necessary throughput and quality-of-service (QoS).

Spectrum sensing is essential for CR networks as it detects the state of channel for opportunistic reutilization.[5] There are two important metrics in spectrum sensing: (1) detection probability and (2) false alarm probability P_f.[6] The higher the P_d, the smaller than the coherence time of the channel. Then, the sensing channel can be viewed as time-invariant during the sensing process. Without loss of generality, we denote $H_i(t)$ as Hi For the ith cognitive radio the probability of detection and probability of false alarm in AWGN channel is represented as[4]

$$P_{f,i} = \frac{\Gamma(u, \frac{\lambda_i}{2})}{\Gamma(u)},$$

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

$$\text{And } P_{m,i} = 1 - P_{d,i}$$

In the above equation, λ_i and γ_i denote the energy detection threshold and signal to noise ratio at the CR respectively, u is the time bandwidth product of the energy detector and $\Gamma(a,x) = \int_x^{\infty} t^{a-1} e^{-t} d(t)$.

Type of Cooperative Sensing

Two types of spectrum sensing techniques have been discussed below.

Centralized Sensing

In this methodology to CR cooperative spectrum sensing, there is a central CR called Fusion Centre (FC) within the network that collects the sensing information from all the sense CRs within the network. For data cooperative, all CRs are altered to a control channel where a physical point-to-point link between each cooperating CR and the FC for sending the sensing results is called a broadcasting channel as shown in Figure (1-a). FC then analyses the information and regulates the bands that can and cannot be used.

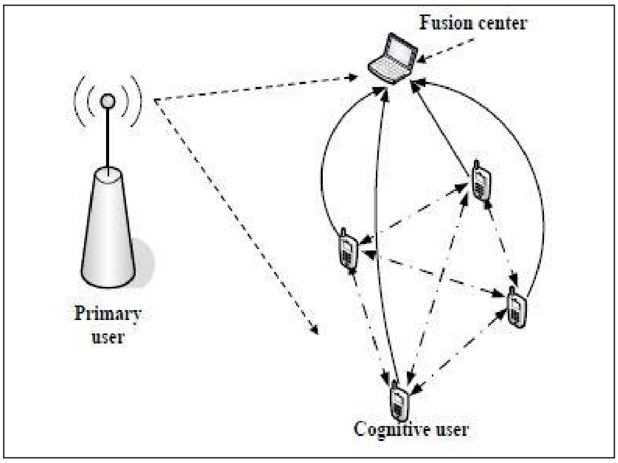


Figure 1(a).Broadcasting channel for centralized sensing

Distributed Sensing

Unlike centralized approach, distributed cooperative sensing does not rest on a FC for making the cooperative decision. Using the distributed approach for CR cooperative spectrum sensing, no CR takes control. Each CR sends its specific information of sensing to other CRs and fuses its data with the received data of sensing, and decides whether or not the PU is present by using a local condition as shown in Figure(1-b). However this approach requires for the individual CRs to have a much upper level of independence, and possibly setting themselves up as an ad-hoc network.

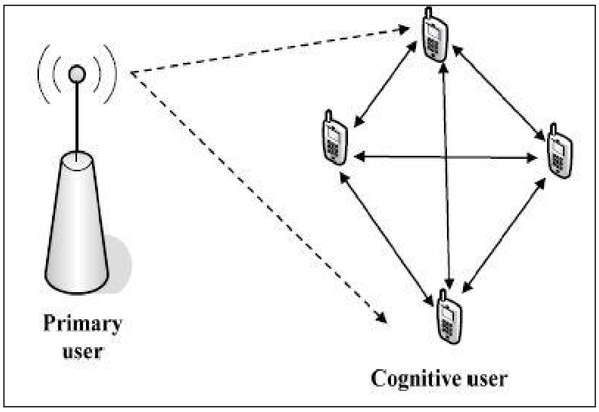


Figure 1(B).Broadcasting channel for distributed sensing

Concept of Optimization

There are two type of decision rule that are used to detect the presence of the primary user, Soft decision rule and hard decision rule. In this paper we use the hard decision rule.Every user in the cooperative system detect the presence of the primary user and derive a decision in the form of bit either 1 or 0. If user detect the presence of the primary user it detect 1 or the absence is presented in form of 0. All the users send their decision to the fusion center known as base station. All these decision are combined together to derive a final result with AND or OR rule. Different schemes and factors have been investigated to optimize the hard cooperative sensing performance by minimizing the total error probability, or exploiting the probability of detection.[4] It was achieved by optimizing the number of cooperated Cognitive radios and the threshold. The author has choosen the total probability of detection in “OR” and “AND” fusion rules to peak by fixing the total false alarm probability In.[7] To decrease the total error probability under Neyman Pearson, and Bayesian criterions different strategies have been adopted in.[12] We assume that, compared with the distance from any cognitive radio to the primary transmitter, the distance between any two cognitive radios is trivial[4], so that the received signal at each cognitive radio experiences almost same path loss. Therefore, in the case of an AWGN environment, we can assume that λ_i and $\gamma_i = \gamma_k = \gamma = \bar{\gamma}$. In the case of a Rayleigh fading environment, it is sensible to assume that we have independent and identically distributed (i.i.d.) Rayleigh fading with the instantaneous SNRs $\gamma_1, \cdots, \gamma_k$ being i.i.d. exponentially distributed random variables with the same mean. Furthermore, we assume that all cognitive radios use the same threshold λ, suggesting $\lambda_1 = \cdots = \lambda_k = \lambda$. This results in, being independent of *i*, and we denote it as P_f. In the case of an AWGN channel P_{di}, is independent of *i* (we denote this as P_d). In the case of a Rayleigh fading channel, let P_{di} be P_d, averaged over the statistics of γ_i. For both kinds of channels, we have $P_m = 1 - P_d$. Therefore, the false alarm probability of cooperative spectrum sensing is given by[8]

$$Q_f = \text{Prob}\{H_1|H_0\} = \sum_{l=n}^{K}\binom{K}{l}P_f^l(1-P_f)^{K-l} \quad (3)$$

The missed detection p pectrum sensing is given by

$$Q_m = \text{Prob}\{H_0|H_1\} = 1 - \sum_{l=n}^{K}\binom{K}{l}P_d^l(1-P_d)^{K-l} \quad (4)$$

In this paper, we add our contribution to the hard cooperative spectrum sensing optimization area, by adding an important factor that can be controlled in term to minimize the total error probability. Our work here can be applied to all mentioned optimization strategies to take them to the optimist point. All optimization published works, focused only on ED as a local spectrum sensing. In this paper, the effects of using different numbers of CRs, different SNR on the optimal fusion rule have been investigated

Proposed Optimization of Cooperative Spectrum Sensing

In this section we are considering the optimization of cooperative communication when energy detection and decision fusion with hard cooperative spectrum sensing is applied. In the hard decision fusion scheme, local decisions of the nodes are sent to the decision maker. Cooperative sensing is done by Fusion the sensing data of individual secondary users and make a final decision at the secondary BS. To minimize the transmission overhead of the sensing data, every secondary users will make their own sensing decision and transmit their one-bit decision to the secondary BS for fusion The main advantage of this method is the fact that it needs limited bandwidth.[10]

We have a number of G (or r = 1, 2. . . K) CRs in the CR network, where each CR performs spectrum sensing locally using Energy Detection. Each CR transceiver is maintained by (N-IFFT/ FFT) processers to perform both tasks of communication and sensing the environment. The primary transmitter with N subcarriers (N-IFFT/ FFT) transmits OFDM-QPSK signal with energy over each sub carrier, and Ts which is symbol duration.[1] So, each CR estimates the power within each subcarrier in the frequency domain, with = 0, 1/N, 2/N. . . N-1/N are the bins of normalized frequency. We assume that the total number of user K is fixed.[1] The optimal voting rule for cooperative spectrum sensing that minimize $Q_f + Q_m$ is describe as follows Suppose G is a function given by

$$G(n) = \sum_{l=n}^{k}\binom{k}{l})[P_f^l(1-P_f)^{k-l} - (1-P_f)^l P_m^{k-l}] \quad (5)$$

From equation (3) and (4) we get the total error probability

$$Q_{error} = Q_f + Q_m = 1 + G(n) \quad (6)$$

we know that to get the maximum value of a curve can be obtained by differentiating it,

so $\frac{\partial G(n)}{\partial n} \approx G(n+1) - G(n)$

$$\binom{k}{n}[(1-P_m)^n P_m^{k-n} - P_f^n(1-P_f)^{k-n}] \quad (7)$$

The optimal value of *n* is obtained when $\frac{\partial G(n)}{\partial n} = 0$

$(1-P_m)^n P_m^{k-n} = P_f^n(1-P_f)^{k-n}$

we get $n \approx \left\lceil \frac{k}{1+\alpha} \right\rceil$

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

we can make the following remarks which apply to any detector

- Usually, P_f and P_m have the similarorder,i.e., $\alpha \approx 1$.

Thus, the optimal choice of *n* is *K*/2.

- The OR rule is optimal when $\alpha \geq K - 1$.

This means

that $P_f \leq P_m^{k-1}$

- This implies that $P_f << P_m$ for a

large value *K*. This can be achieved when the detection threshold λ is very large.

- The AND rule is optimal when $\alpha \rightarrow 0$.

This is achieved

when<<, i.e., for a very small λ.[11]

Results and Discussions

The Simulation Results have been Discussed Below

In this section we are examining the performance optimization of cooperative spectrum when local spectrum sensing is used. We have considered different frequencies will be computed at a specific frequency bin $f_{i..}$ Fig. 2 shows the total error probability (Q_{error}) versus the chosen local threshold for SNR = 10 db & g = 5 by monte-carlo simulation method using ED technique. Let us take k=10 number of CRs cooperate the spectrum sensing decision at a CR-BS, in the CR's network.

We have taken SNR = 10 db & L=10 sample (i.e OFDM BLOCKS) are used locally for sensing.[11] In the fig shows the total error probability (Q_{error}) versus the chosen local threshold for different number of n out of k CRs that controls the fusion rule in using ED technique. If we compare the different curves that signify the total error for different numbers of n in Fig. 3, we observe, there are visible difference in the performance through using n = 1 to 10 as a k=10 fusion rule. Here, n= 10 which represent "AND" fusion rule, gives great total error associated to the other curves; it is found that n= 5 gives the minimum total error (min Q_{error}) at the Equal values of SNR and threshold. Hence, n = 5 is the optimal fusion rule here (i.e., n optimal=2). The increase in SNR causes decrease in the min with variation in number of CRs. Furthermore, for fixed SNR if the number of the total co-operated CRs, k, is increased above optimal then the is (Q_{error}) increased.

Error on different no of K CRs:

In this section we are trying to find (Q_{error}) at different number of SNR. Table 1 and fig 4 shows the min at different SNR. As per the analysis we have found that as we are increasing the SNR we get improvement in the total error rate.

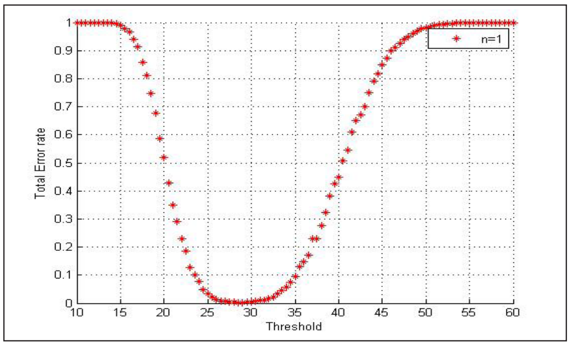


Figure 2.Total error probability (Q_{error}) for n= 5 CRs versus local threshold when ED is used locally with SNR = 10 db and L = 10 sensed samples used at each CR

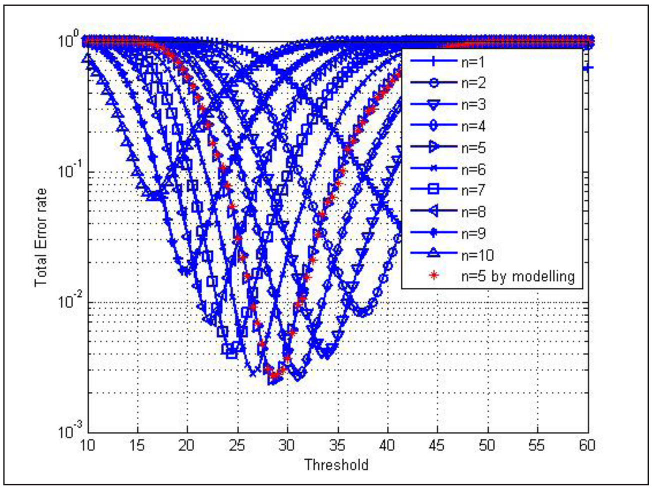
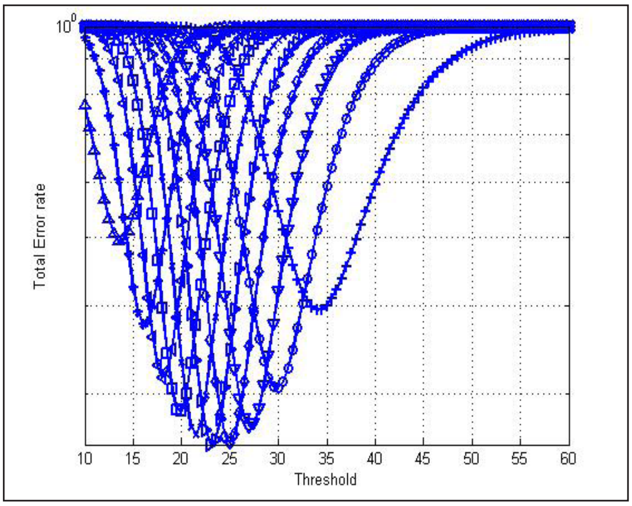
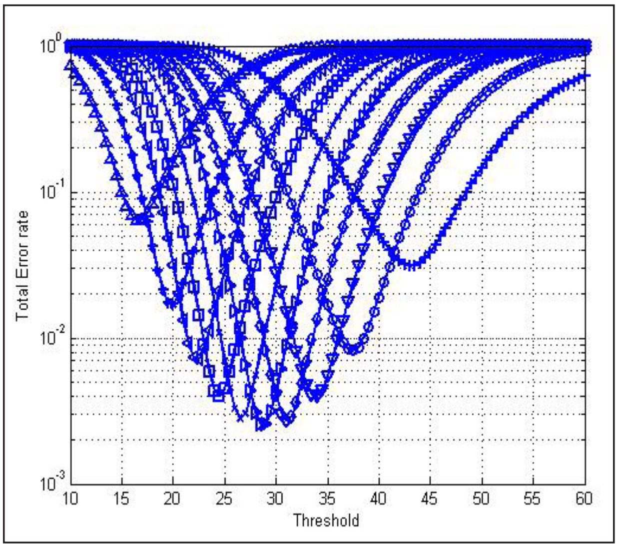


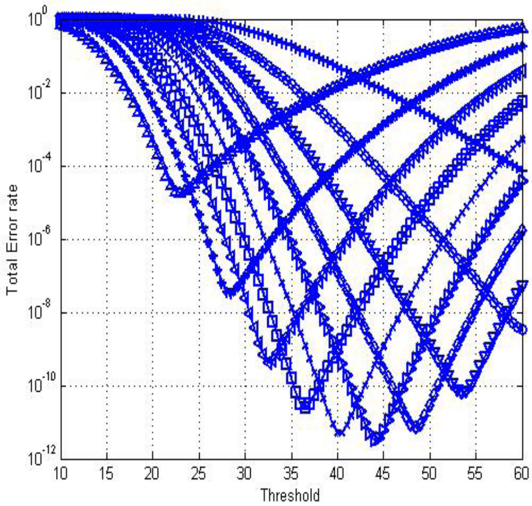
Figure 3.Total error probability (Q_{error}) for g out of k= 10 CRs versus local threshold when ED is used locally with SNR= 10 db and L = 10 sensed samples used at each CR



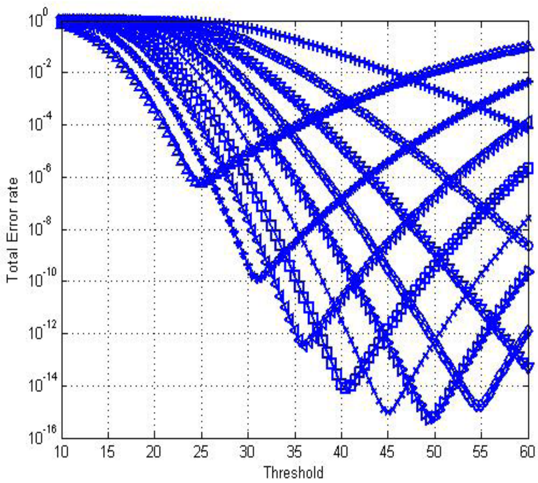
SNR=5db



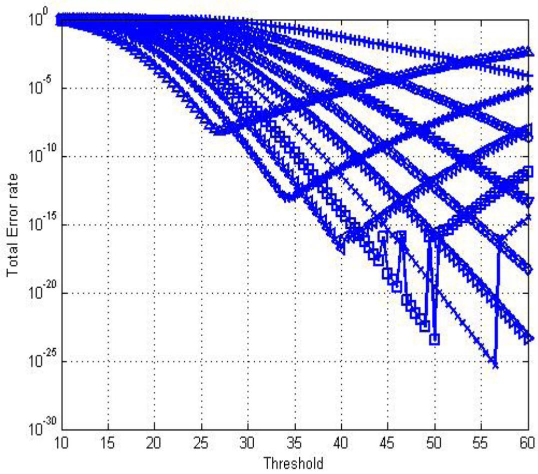
SNR=10db



SNR=15db



SNR=16db



SNR=17db

Fig. 4 Total error probability (Q_{error}) for n out of K= 10 CRs versus local threshold when ED is used locally with SNR= 5, 10, 15, 16, 17 db and L = 10 sensed samples used at each CR.

Table1.min error rate at different value of snr

SNR in db	Min error rate
5	1
10	0.9995
15	0.556
16	.0968
17	0.0041

From the above fig 4, we can look that if we are increasing the SNR,the performance is increasing.

Table.2 shows the optimal fusion rule and min when SNR is varied and the ED is used locally, with same number of the sensed samples (i.e. L = 10). The improvement in the performance by increasing the total number of user K for different SNR at CRs at fixed L, is noticeable. For example, min = 0.2511 when SNR=5 db and CRs = 4 or 5, and min=0.00251 when SNR is increased to 10 db and CRS = 5. The increase in SNR causes decrease in the min with variation in number of CRs.

Table 2.Optimal number of n CRs for different SNR and its error level

SNR in db	Error level	Number of cognitive user
5	$10^{-0.6}$	4 or 5
10	$10^{-2.6}$	5
13	$10^{-6.4}$	5 or 6
17	$10^{-2.6}$	6
18	$10^{-3.4}$	8
20	$10^{-4.5}$	9

Conclusion

In the present work, the performance of cooperative spectrum sensing with energy detection in cognitive radio networks has been computed. The research work elaborates that the optimal decision voting rule to minimize the total error probability is basically tbe half-voting rule. The optimal design threshold has been obtained by a numerical method. In addition, an efficient optimization factor and the number of cognitive radio user, K have been introduced. The simulation results show that there are different SNRs for each CR module. The total error rate for different n (1 to 10) has been derived depending upon SNRs. For SNR value 5, 10, 17, 18, 20, we get optimal as 4, 5, 5, 6, 6.

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