Optimization of Spectrum Sensing in Cognitive Radio Network using Cooperative Relay Channel

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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, Total Error Rate

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.

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.
There are mainly two types of cooperative spectrum sensing:

A. 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 analyzes 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.

B. 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:
- Sensing channel (from the PU to CRs) and
- Reporting channel (from the CRs to the common receiver).

1. Advantages of Cooperative Spectrum Sensing:

(i). 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.

(ii). 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. There by providing an increase in agility.

(iii). 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.

2. Disadvantage of Cooperative Spectrum Sensing
Significant disadvantage of cooperative spectrum sensing are:-

(i). 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.

(ii). 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.

(iii). 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. Cooperative Spectrum Sensing (CSS)
In cooperative spectrum sensing, binary hypothesis decision from each CR i.e. one bit decision (1 standing for the presence of licensed user, 0 stands for absence of licensed user) is forwarded to fusion centre. At the fusion centre, all 1-bit decisions are combined according to any one of the logic rule (AND Logic, OR Logic, and M-OUT-N Logic), a global decision will be taken; this final decision can be in favour of $H_1$ or $H_0$.

$$Y = \sum_{j=1}^{N} D_j \begin{cases} \geq m, & H_1 \\ < m, & H_0 \end{cases}$$

Where $H_1$ and $H_0$ are decisions taken by fusion Centre that the primary user is transmitted or not transmitted respectively. Threshold $m$ is an integer representing m-out of-N logic. From above the inference it can be seen that the AND logic corresponds to m=N and OR logic corresponds to m=1.

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Fig. 2: Spectrum Sensing Structure in a Cognitive Radio Network

Fig. 3: Block Diagram for System Model of Cooperative Spectrum Sensing (CSS) Technique with K SUs (Sensors), one FC and one PU. Final Decision is made at the FC.
IV. Proposed Methodology

A. System Model

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 primary user is present or not. To determine this we are considering two hypotheses: 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 i\textsuperscript{th} CR in timeslot t, s(t) is the PU signal. h(t) is the complex channel coefficient between the PU and i\textsuperscript{th} CR. w(t) is the AWGN. We assume that the sensing time is less than the coherence time of the channel. The coherence time is the time duration over which the channel impulse response remains constant. So h(t) will be time invariant (h(t) = h) 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\textsuperscript{th} CR by energy detection we found average probability of detection, false alarm, missed detection over AWGN channel with following equations:

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

\[ P_{d,i} = Q_u(\sqrt{2\gamma_i}, \sqrt{\gamma_i}) \]  

\[ P_{m,i} = 1 - P_{d,i} \]

Where \( \gamma \) is the energy detection threshold and Y is the instantaneous Signal to Noise Ratio (SNR) at the i\textsuperscript{th} CR. Also u is the time-bandwidth product of the energy detector. \( \Gamma(a, x) \) is the gamma function and \( \Gamma(a, x) \) is the incomplete gamma function.

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

In transmitter detection we have to find the primary transmitters that are transmitting at any given time. We consider a system of one Cognitive Radio (CR), one Primary User (PU) when a signal from PU is transmitted; the received signal by the CR for the detection of PU can be modelled under two hypotheses (H\(_0\) & H\(_1\)), is given as follows

\[ H_0 : y(t) = n(t) \quad \text{PU is absent} \]  

\[ H_1 : y(t) = h*s(t) + n(t) \quad \text{PU is present} \]

Where y(t) is the received signal by secondary users. s(t) is the transmitted signal of the primary user, h is the channel coefficient and n(t) is AWGN with zero mean and \( \sigma_n \) variance. The output is considered as the test statistic to test the two hypotheses H\(_0\) & H\(_1\). H\(_0\) corresponds to the presence of both signal and noise. We can define three possible cases for the detected signal:

1. H\(_1\) turns out to be TRUE in case of presence of primary user i.e. P (H\(_1\)/H\(_1\)) is known as Probability of Detection (P\(_d\)).
2. H\(_0\) turns out to be TRUE in case of presence of primary user i.e. P (H\(_0\)/H\(_0\)) is known as Probability of Missed-Detection (P\(_m\)).
3. H\(_1\) turns out to be TRUE in case of absence of primary user i.e. P (H\(_1\)/H\(_0\)) is known as Probability of False Alarm (P\(_f\)).
and the best position found by the entire swarm, named as global best (gbest).

\[ V_g(t+1) = V_g(t) + c_1 r_1 (p_{best}(t) - x_g(t)) + c_2 r_2 (g_{best}(t) - x_g(t)) \]

\[ x_g(t+1) = x_g(t) + V_g(t+1) \]

Where \( v_{ij}(t) \) denotes the velocity of \( i^{th} \) particle in \( j^{th} \) dimension at \( t^{th} \) iteration, \( c_1 \) and \( c_2 \) are referred as acceleration constants, \( r_1 \) and \( r_2 \) are uniformly distributed random values ranging in \([0, 1]\). \( y_{ij}(t) \) is referred as pbest, which is the best position found by the \( i^{th} \) particle in \( j^{th} \) dimension so far by the \( t^{th} \) iteration whereas \( y^* j(t) \) is referred as gbest, which is the best position found by the entire swarm in \( j^{th} \) dimension so far at the \( t^{th} \) iteration. \( x_{ij}(t) \) denotes the position of \( i^{th} \) particle in \( j^{th} \) dimension at \( t^{th} \) iteration. Another parameter, so-called maximum velocity, \( V_{max} \) is imposed to limit the velocity of each particle to ensure exploration within the search space. A pseudocode of PSO is shown in fig. 3 for a given minimization problem.

**V. Simulation Result**

This section describes the MATLAB-based simulation platform that provides interactive access to check the performance and comparative analysis for energy detection method theoretically as well as practically by varying various Parameters.

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. 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 \( n=5 \).

**Fig. 5: Total Error Rate of Cooperative Spectrum Sensing in AWGN Channel With 10dB SNR. Optimal Voting rule for \( n=1, 2, ..., 10 \) and \( K=10 \).**

**Fig. 6: Total Error Rate of Cooperative Spectrum Sensing in Rayleigh 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 analyzed 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 analyzed 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.

References


