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Multichannel Cooperative Sensing in Cognitive Radio: A literature Review

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Abstract: In recent years wireless communication industry has grown enormously. Every individual is behind in getting a share of spectrum. Day by day wireless electronic gadgets are demanding more spectrum for their applications and so the scarcity roused. To address such type of situation where a spectrum can be offered spatially and temporally cognitive radio comes up as an effective solution. This can be accomplished without disturbing the operation of primary users. However in practical situations performance is degraded by multipath fading and shadowing. To overcome with these issues cooperative sensing is used. For a practical scenario of cognitive radio where secondary users deals with multiple channel instead of single channel the study of dealing with a multiple channel becomes necessary and hence this survey has been done. The open research challenges related to multichannel cooperative sensing are also discussed in this paper.

Keywords: Cognitive Radio, Spectrum sensing, Multichannel Cognitive Radio, Cooperative sensing

I. INTRODUCTION

Cognitive Radio (CR) is a form of wireless transceiver which can sense the channel whether it is used or not. This strategy will use the spectrum effectively without causing interference to the other users. Spectral efficiency is enhanced by finding out vacant slots in channel. Secondary users use these slots without causing interference to the primary users. However in practice detection performance is affected by multipath fading, shadowing and receiver uncertainty issues. To overcome these issues cooperative spectrum sensing has come up as a promising solution [1]. In cooperative spectrum sensing, each secondary node senses the spectrum individually and shares the raw results to all the neighbouring nodes. Eventually each secondary node has multiple sensing raw results to analyse and the sensing accuracy can be improved by spatial diversity.

Cooperative sensing proves to be efficient compared to non cooperation sensing methods but in practical, cognitive radio network have multiple channels. Sensing is broadly classified into single channel sensing and Multichannel sensing. Existing literature mainly focus on different sensing techniques used for multichannel sensing. To achieve better sensing performance with multiple channels still needs to be explored more.

The remainder of this paper is organized as follows. In Section 2, the spectrum sensing techniques are briefly introduced. Section 3 describes the cooperative sensing techniques. Multi channel spectrum sensing and its performance analysis is discussed in section 4 and finally, conclusions are in 5.

II. SPECTRUM SENSING

In order to improve spectrum efficiency dynamic spectrum access technique is vital. Dynamic spectrum access techniques allow the cognitive radio to operate in the best available channel. More specifically the cognitive radio technology enables the user to determine the free portion of the spectrum [1, 2]. Spectrum Sensing is the most important function of a cognitive radio, if the result of sensing is not correct there is severe performance degradation for primary user as well as for secondary user[3]

The goal of the spectrum sensing is to decide between the two hypotheses [2], namely

$$r(t) = n(t), H0 \quad (1)$$

$$r(t) = h * s(t) + n(t), H1 \quad (2)$$

Where r(t) is the signal received by the CR user, s(t) is the transmitted signal of the primary user, n(t) is the AWGN band, h is the amplitude gain of the channel, H0 is a null hypothesis, which states that there is no licensed user signal [1].Generally, the spectrum sensing techniques can be classified into 1) Transmitter Detection, 2) Cooperative Detection and 3) Interference detection. Non Cooperative detection method i.e Transmitter detection further is classified as

a) Energy Detection
b) Matched Filter Detection
c) Cyclostationary Feature Detection

a) Energy Detection

Energy detection is the best possible technique for detection of any signal and can also be applied to cognitive radios. In energy detector, the received signal is determined by analysing its signal strength. The presence of signal is detected by measuring the given signal for a period of time and then compared with threshold. As shown in Figure 1, the received signal is filtered, converted in to digital form then squared and integrated over the observation period. The energy output is

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compared with threshold to decide the presence or absence of primary user

$$H0, \quad \text{if} \sum_{n=1}^{N} |y[n]|^2 \leq \lambda \qquad (3)$$

$$H1, \quad \text{otherwise} \qquad (4)$$

Where, λ is the threshold which depends on the receiver noise.

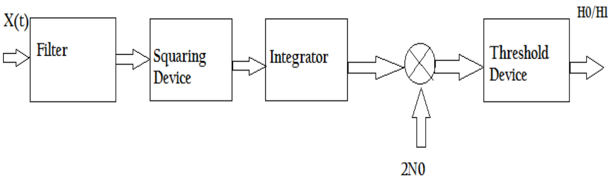

Figure 1 Energy Detector

Energy detection can be implemented without any a priori information of the primary user signal this technique has some problems associated with it.

1) It can only detect the signal of the primary user if the detected energy is greater than the threshold. It depends upon choice of the threshold level, since it is highly susceptible to the changing background noise and interference.
2) A second difficulty is that the detection of energy method cannot distinguish the primary user from other secondary users sharing the same channel. This is a crucial test when multiple primary users exist in cognitive radio networks.

The problem occurs at low signal–to–noise ratio (SNR), the energy detector requires more detection time compared to the match filter detector.

b) Matched Filter Detection

When the transmitted signal is known, the optimum spectrum detection technique is the matched filter detector [4]. Matched filter detection uses a priori knowledge of the received signal, such as frequency, bandwidth, modulation type, pulse shaping, etc. [5]. Figure 2 shows the block diagram of the matched filter. The pilot signal provides a priori knowledge of the primary signal. To detect the primary user signal, the pilot is correlated with the received signal and then compared to a threshold to determine the presence of the primary user signal (a binary decision) l, as shown in the equation below.

$$H0, \text{if} \sum_{n=1}^{N} y[n]x[n]^* \leq \lambda \qquad (5)$$

$$H1, \quad \text{otherwise} \qquad (6)$$

Where, λ is the threshold.

To achieve a certain probability of missed detection or false alarm positives, matched filtering requires a shorter detection time compared with cyclostationary detection and energy detection.

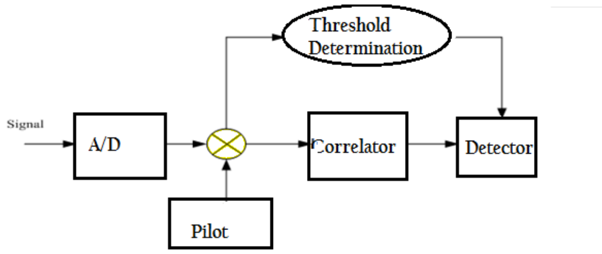

Figure 2 Matched filter Detector

The main disadvantage in the matched filter approach is the

1. Requirement of a priori knowledge.
2. The need for synchronization between transmitter and receiver.
3. The correlation adds significantly to the implementation complexity.

c) Cyclostationary Detection

The cyclostationary feature of the modulated primary user signals is exploited in the cyclostationary detection technique [6]. Cyclostationary features are caused by periodicity of the modulated signal, such as sine wave carriers, pulse trains, hopping sequences, cyclic prefixes, or repeated spreading. Modulated signals are cyclostationary with spectral correlation, due to the in-built periodicity.

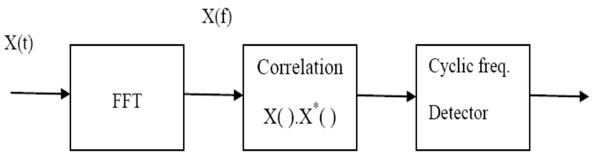

Figure 3 Cyclostationary Detector

Figure 3 shows implementation of the cyclostationary sensing technique. The figure shows that the spectral mechanisms of the input signal are calculated through the fast Fourier Transform (FFT) as:

$$R_x^\alpha(\tau) = \lim \lim_{T\to\infty} \frac{1}{T}\int_{-T/2}^{T/2} x\left(t+\frac{\tau}{2}\right)x\left(t-\frac{\tau}{2}\right)e^{-j2\pi\alpha t}dt \qquad (7)$$

Then the spectral correlation function (SCF) is estimated by spectral correlation performed on these spectral components.

$$S_x^\alpha(f)\int_{-\infty}^{+\infty} R_x^\alpha(\tau)e^{-j2\pi f\tau}d\tau \qquad (8)$$

It is shown specifically that

$$S_x^\alpha(f) = \lim_{T\to\infty}\lim_{Z\to\infty}\frac{1}{TZ}\int_{-Z/2}^{Z/2} X_T\left(t,f+\frac{\alpha}{2}\tau\right)X_T\left(t,f-\frac{\alpha}{2}\tau\right)dt \;.. \quad (9)$$

where

$$X_T(t,f) = \int_{t-T/2}^{t+T/2} X(u)e^{-j2\pi fu}du \qquad (10)$$

This spectral correlation function $S_x^\alpha(f)$ is also called cyclic, which is a function of two dimensions (frequency and cyclic frequency (α)). The spectrum is analyzed by searching for the unique cyclic frequency matching the peak in the SCF and deciding whether the signal of primary users are detected.

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III. COOPERATIVE DETECTION METHODS

The detection performance can be primarily determined on the basis of two metrics:

Probability of false alarm, which denotes the probability of a CR user declaring that a PU is present when the spectrum is actually free

Probability of detection, which denotes the probability of a CR user declaring that a PU is present when the spectrum is indeed occupied by the PU.

Since a miss in the detection will cause the interference with the PU and a false alarm will reduce the spectral efficiency, it is usually required for optimal detection performance that the probability of detection is maximized subject to the constraint of the probability of false alarm.

Many factors in practice such as multipath fading, shadowing, and the receiver uncertainty problem may significantly compromise the detection performance in spectrum sensing [7].

Cooperative Sensing System

In Cooperative Sensing the shadowing and receiver uncertainty problem is overcome. Overall detection is improved by combining the results from all cognitive users[7].[8-10] is an attractive and effective approach to combat multipath fading and shadowing and mitigate the receiver uncertainty problem.

The Cooperative Sensing is classified into [7]

a) Centralized sensing,
b) Distributed Sensing,
c) Relay Assisted Sensing.

a) Centralized Cooperative Sensing

In centralized cooperative sensing a Fusion Centre (FC) controls the process of cooperative sensing. All secondary users send their sensing results to FC via control channel, and then FC combines the received signals and finds out the presence of primary user and sends back the decision to secondary users cooperating.

b) Distributed Cooperative Sensing

Distributed cooperative sensing does not depends on Fusion Centre for making the cooperative decision. In this all CR's communicate each other sends their sensing data to each other and decides whether primary user is present or not by using a local criteria. If the criteria are not matched secondary users keeps sending their results to each other until the decision is finalized. This method takes several iterations to reach to a decision [7].

c) Relay Assisted Cooperative Sensing

In this both sensing channel and report channel are not perfect, can complement and cooperate with each other to improve the performance of cooperative sensing .There are two forms of cooperation in spectrum sensing: Hard combination and soft combination. These two cooperation forms are also known as decision fusion and data fusion, respectively [7].

❖ Hard Combination:

In this every node senses the channel and finds out whether the primary signal is present or not and sends this result to a decision maker where a final decision is made. The decision maker uses three rules a. Logical-OR Rule b. Logical-AND Rule and c. Majority Rule

❖ Soft Combination:

In the soft combination scheme, nodes directly send their sensing information to the decision maker without making any decisions [8]. The decision maker makes decision based in the information [8]. Soft combination provides better performance than hard combination, but it requires a wider bandwidth for the control channel [16]. It also requires more overhead than the hard combination scheme.

IV. MULTICHANNEL SPECTRUM SENSING

In practical scenario cognitive radio senses more than one channel. And so the sensing schemes are divided into two categories, i.e., wideband sensing and narrowband sensing. Sensing is considered wideband when multiple channels are sensed simultaneously. On the other hand, when only one channel is sensed at a time, the sensing process is called narrowband[11].There are various multichannel sensing schemes in the current literature [11-21].

Shokri-ghadikolaei et al [11] proposed sequential channel sensing problems for single and multiple secondary users (SUs) networks which are effectively modelled using finite state Markovian processes. In order to address multiple secondary users case, the model includes the modified p-persistent access (MPPA) protocol. To mitigate the problem of high level collision among the secondary users a p-persistent random access (PPRA) protocol is considered, which offers higher average throughput for secondary users by distributing their loads among all channels. Consequently, this lowers the conflict among secondary users for accessing same channels and in turn offers higher average throughput.

Seung-Jun et al proposed sequential spectrum sensing algorithm which takes into account the sensing time overhead and average data rate of CR transmitters. A policy using Lagrange multipliers to opt the best set of available channel and stop time for taking measurement is formulated, while sticking to hard "collision" constraints imposed to protect primary links. A basis expansion-based sub-optimal strategy is employed to mitigate the prohibitive computational complexity of the optimal stopping policy. Cooperative sequential sensing generalizations are also provided with either raw or quantized measurements collected at a central processing unit [12].

The work in [13] is based on cooperative spectrum sensing policy using spatially displaced multiple cognitive radios. It senses multiple frequency bands simultaneously and mitigates the effects of shadowing and fading through spatial diversity.

Secondary transmitter and receiver are easily paired so that they can communicate to find the spectral opportunities. It offers sensing multiple discontinuous bands of different bandwidths and also sets priorities to different sub bands based on the availability of the spectrum. The sensing requirement of primary signal is achieved through pseudorandom scheme and priorioritize sub bands according to their expected benefits. This feature is important in cognitive networks where there are possibly few SUs and many licensed sub bands. The proposed

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scheme assures that each sub band is sensed by every SU within one hopping code period. This rapids up the detection of possible hidden nodes, when only one or few secondary users have a free channel to the primary transmitter.

An optimization problem is proposed in [14], which maintains a predefined threshold of detection probability and increases throughput of secondary users. Two sensing modes are explored: slotted time sensing mode and continuous-time sensing mode.

With a slotted-time sensing mode, the sensing time of each secondary user consists of a number of mini slots, each of which can be used to sense one channel. The initial optimization problem is a non convex mixed integer problem which is solved by polynomial-complexity algorithm .

With a continuous-time sensing mode, the sensing time of each secondary user for a channel can be continuous value. The initial non convex problem is converted into a convex bi-level problem, which can be successfully solved by existing methods. Authors suggest problem statement to solve from a game theoretical point of view, in which each secondary user is assumed to be selfish but rational. Finding an optimal subset of channel is an open research topic open for further investigation.

This paper [15] focuses on the coordination among multiple channels in cooperative spectrum sensing. Multi-channel coordination in theoretical aspects is studied first and then a centralized and a distributed algorithm is implemented. Theoretically cooperative sensing improved significantly if the coordination among multiple channels is considered. To verify licensed channels were measured and then the simulations were conducted on collected data. The results show that the proposed algorithms can approximate optimal solution very well.

V TumuluruIn et al [16] developed an opportunistic spectrum scheduling scheme for multi-channel cognitive radio networks. In the proposed scheme, the primary user activity and channel quality vary on a slot-by slot basis. The scheduling is performed at the beginning of the frame which consists of multiple slots. The scheduling algorithm estimates the expected number of packets which can be transmitted over the frame by each secondary user for each licensed channel. A Markov chain is formulated to calculate the expected number of packets which can be transmitted over the frame for a secondary user corresponding to each licensed channel. Based on these expected packet transmissions, a central scheduler allocates the licensed channels to the secondary users. The objective of the scheduling algorithm is to allocate the licensed channels to maximize the aggregate throughput of the secondary users. Compared with the existing dynamic spectrum access schemes, the proposed scheduling scheme incurs smaller scheduling overheads and achieves higher throughput. An analytical framework for modelling the proposed algorithm using Markov chain analysis is also presented. The performance of the proposed scheduling scheme is evaluated in terms of average user throughput and blocking probability. The proposed scheme outperforms the existing DSA schemes in terms of average channel throughput, blocking probability, and scheduling overhead. Despite the advantages, the proposed scheme requires a central scheduler and the information exchange between the central scheduler and each user, which may become a disadvantage and restrict the proposed scheme to be applied to some network environments To develop a distributed scheduling scheme would be an interesting topic for the future work.

In [17], the adaptive threshold method is proposed as an alternative approach to estimate the threshold as a function of first and second order statistics of recorded signals. The proposed method does not require estimation of noise variance or signal to noise ratio and aims to minimize the effects of impairments introduced by wireless channel and non-stationary noise. The simulation results indicate that adaptive threshold has low false alarm and missed detection rates that can satisfy the detection requirements of multi-channel cognitive radios for either narrow or wideband spectrum sensing, when the standard deviation coefficient is selected properly. Critical parameters of the adaptive threshold are introduced and the detection performance is investigated. Assumption of uniform SNR through the detection band is the main limitation within the proposed study, which is also the subject of further research in the area of adaptive threshold estimation.

In [18] this paper, we study energy-efficient cooperative multi-channel spectrum sensing in CRNs. A cooperative spectrum sensing and accessing (CSSA) scheme for all the secondary users (SUs)is proposed. The SUs cooperatively sense the licensed channels of the primary users (PUs) in the sensing slot. If a channel is determined to be idle, the SUs which have sensed that channel will have a chance to transmit packets in the data transmission slot. After this multi-channel spectrum sensing problem as a coalition formation game is formulated, where a coalition corresponds to the SUs that have chosen to sense and access a particular channel. The utility function of each coalition takes into account both the sensing accuracy and energy efficiency. Distributed algorithms to find the optimal partition that maximizes the aggregate utility of all the coalitions in the system is proposed. Simulation results show that the proposed algorithms result in the self organization of the SUs that achieves a higher aggregate utility after each iteration.

Energy efficient distributed multi channel MAC protocol for CR network is proposed in [19]. In this model all nodes get equal access to the medium.802.11 timing structure is used for performance improvement. This MMAC protocol is based on the single rendezvous (SRV) scheme. The terminals are allowed to enter a sleep state when no communication is taking place, this way MAC protocol achieves energy-efficient communication. Further, the sensing algorithm depends on two phases: 1) a low power inaccurate scan and 2) a high-power accurate scan.

The CR's keep measuring the frequencies used by Primary networks. When every CR cannot detect primary user the other CR's who has the information can share with the nearby CR i.e. distributed sensing with OR technique is used. This technique has shown to contribute 5% of energy cost in scanning a node and this cost is compensated by

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reducing 40% of energy consumption. The limitation for this method is extra hardware and deployment cost which is needed for extra scan nodes.

In [20], the cooperative sensing schemes for narrow band and wideband are presented. Based on analytical model the optimal single licensed channel with Fusion scheme with OR rule is employed, which determines optimal sensing parameters is implemented first. Then the multichannel sensing modeled based on sensing parameters is presented which shows improvement in sensing efficiency. They have used interference analysis for periodic spectrum analysis. The objective is to maximize the sensing efficiency and to reduce the harmful interference to primary users.

Joen et al in [21] proposed a Collaborative Channel sensing policy .They have considered CR based adhoc network using multiple channel .The hidden Primary User problem related to multichannel CR network where primary signal is only detectable to some secondary users. The proposed MAC scheme improves throughput and packet delay. In collaborative sensing the CR senses the spectrum as and when it gets opportunity and adjusts its properties based on collaborative decision. The same nodes are used by primary user as well as secondary users without interfering in to primary users data, this improves system throughput. The reserved data channel transmits multiple packets so the proposed method reduces traffic on control channel. Thus the proposed scheme improves throughput and lowers the overheads associated with proposed scheme.

V. CONCLUSION

A survey on multichannel spectrum sensing techniques and evaluation methods are presented though it is not extensive it may not have been covered widely but it gives depth of the previous work in related field. In future as per the study we can work in the succession of the existing methods for multichannel spectrum sensing so that we can have efficient spectrum sensing and better detection probability.

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