



A Review on: Spectrum Sensing Techniques

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Abstract- Spectrum sensing is an important and sensitive task in cognitive radio since interfering with other users is illegal. One of the main requirements of spectrum sensing is to detect the presence of the primary users as fast as possible. Cognitive radio arises to be a tempting solution to spectral crowding problem by introducing the opportunistic usage of frequency bands that are not occupied by licensed users. Cognitive radio with software-defined radio has been proposed as the means to promote the efficient use of the spectrum by exploiting the existing spectrum holes. The main objective of this paper is to study various spectrum sensing techniques used in cognitive radio to allow access to the secondary user in the case when band of frequency licensed to the main user is free and being wasted at that time.

Keywords- Spectrum Sensing, Energy Detection, Spectrum Holes.

I. INTRODUCTION

The race for occupying the increasing demand of bandwidth within a limited range of spectrum has given rise to a new technology known as **Cognitive Radio**. Spectrum sensing is an important and sensitive task in cognitive radio since interfering with other users is illegal.[2] Cognitive radio arises to be a tempting solution to spectral crowding problem by introducing the opportunistic usage of frequency bands that are not occupied by licensed users. In cognitive radio systems, unlicensed users need to have cognitive radio capabilities, such as sensing the spectrum reliably to check if it is being used by a licensed user.[1]

II. SPECTRUM HOLES

A spectrum hole is a band of frequencies assigned to a primary user at a particular time and specific location, the band is not being used by that user. The underutilization of the electromagnetic spectrum leads us to think in terms of spectrum holes Spectrum utilization can be improved significantly by making it possible for a secondary user (who is not being serviced) to access a spectrum hole unoccupied by the primary user at the right location and the time in question. Cognitive radio with software-defined radio, has been proposed as the means to promote the efficient use of the spectrum by exploiting the existing spectrum holes.[3]

Spectrum holes are not stable and they migrate with frequency and time as shown in the Fig1. The spectrum sensing algorithm is supposed to be fast enough to rapidly detect the moving holes in the spectrum in real time. Spectrum sensing is computational expensive and requires special hardware to implement. Moreover in the case of Low SNR scenario the noise power affects the operation of the spectrum sensing algorithm thereby affecting the hole detection process. The spectrum sensing algorithm used should be sensitive enough to distinguish between the signal power and the noise power. If the void spaces in the spectrum can be detected and utilized, then the problem of spectrum limitation can be solved to some extent. [2]

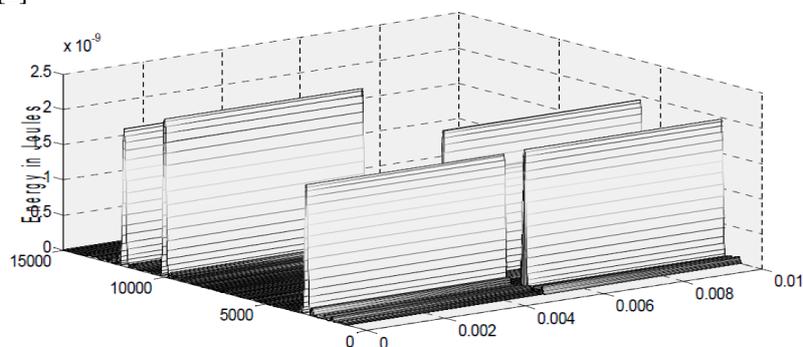


Fig 1 Migration of holes in the spectrum

III. COGNITIVE RADIO NETWORK

A cognitive radio network consists of secondary radio users that can perform spectrum sensing and then operate at the appropriate piece of unused spectrum. In the aspect of spectrum sensing, the radio measures certain characteristics of the radio waveform, and then decides if a primary system is actively using that spectrum. The energy detection method is

chosen. The block diagram of a energy detector is shown in Fig 2. The input band pass filter removes the out of band signals by selecting the center frequency f_c , and the bandwidth of interest W . We assume the secondary users have this information in order to perform spectrum sensing. After the signal is digitized by an analog to digital converter and a simple square and average device is used to estimate the received signal energy. Without loss of generality, we assume the input signal to the energy detector is real. The estimated energy, u , is then compared with a threshold, λ , to decide if a signal is present (H_1) or not (H_0).

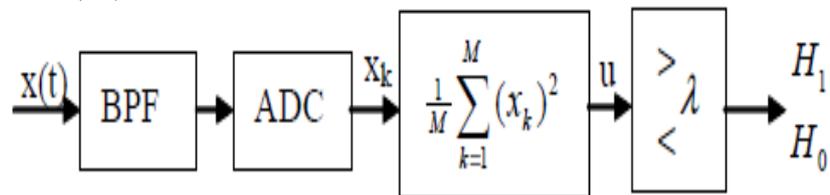


Fig 2Block Diagram of Energy Detector

The threshold can be calculated based on two principles: constant false alarm rate (CFAR) and constant detection rate (CDR). In both CFAR and CDR cases, the noise power σ^2 is needed to determine the threshold. It is assumed the exact noise variance is known and can be used to calculate the threshold. [5]

IV. COOPERATIVE SPECTRUM SENSING

One of the main requirements of spectrum sensing is to detect the presence of the primary users as fast as possible. For this reason, the CR users should continuously monitor the spectrum of the primary users and vacate it as soon as the primary user is detected. Spectrum sensing is usually performed in two successive stages: sensing and reporting. Consider the situation shown in Fig 3, in the sensing stage, every CR user (CU1, CU2, and CU3) performs spectrum sensing independently and make a decision about the observation to primary user (PU). In the reporting stage, all the local observation results are reported to a common receiver: fusion center (FC), and then a final decision will be made to indicate the absence or the presence of the primary user.

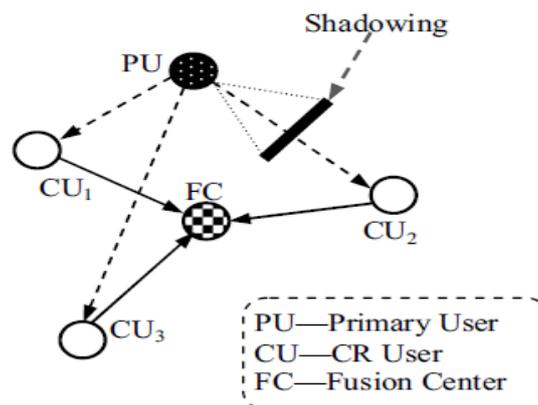


Fig 3Cooperative spectrum sensing

Each and every CR user performs its spectrum sensing individually, which can be formulated as a binary hypothesis test between the following two hypothesis:

$$X_j(t) = \begin{cases} n(t) & H_0(\text{absent}) \\ h s(t) + n(t) & H_1(\text{present}) \end{cases}$$

Where $X_j(t)$ is the signal received by the j -th CR user, $s(t)$ is the primary user's transmitted signal, $n(t)$ is the additive white Gaussian noise (AWGN) with a one sided power-spectral-density, N_0 , and h is the fading coefficient of the channel modeled as independent complex Gaussian random variables. [7]

V. COGNITIVE TASKS

For reconfigurability, a cognitive radio looks naturally to software- defined radio to perform this task. For the other tasks, the cognitive radio looks to signal-processing and machine-learning procedures for the implementation. The cognitive process begins with the passive sensing of RF stimuli and culminates with action.

- 1) Radio-scene analysis, which encompasses the following:
 - Calculation of interference temperature of the radio environment;
 - Detection of spectrum holes.
- 2) Channel identification, which encompasses the following:
 - Estimation of channel-state information (CSI);
 - Estimation of channel capacity for use by the transmitter
- 3) Transmitter-power control and the dynamic spectrum management.

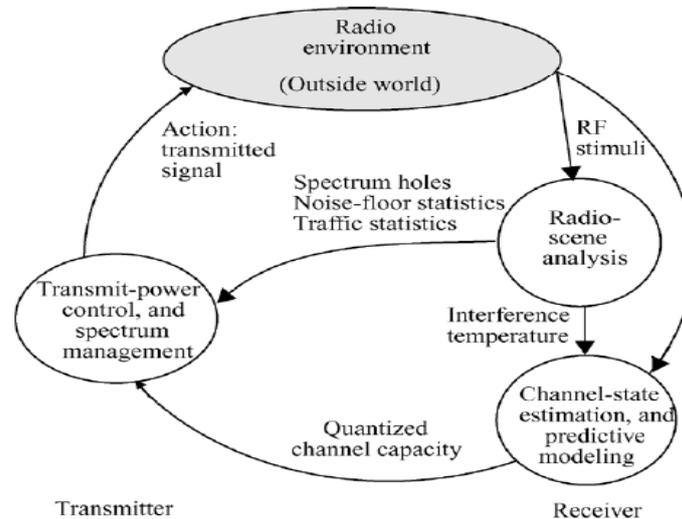


Fig 4 Basic Cognitive Cycle

Tasks 1 and 2 are carried out in the receiver, and the task 3 is carried out in the transmitter. Through interaction with the RF environment, these three tasks results in a cognitive cycle of tasks, which is pictured in its most basic form in Fig 4. From this brief discussion, it is apparent that the cognitive module in the transmitter must work in a harmonious manner with the cognitive modules in the receiver. In order to maintain this harmony between the cognitive radio's transmitter and received at all times, there is a need of a feedback channel connecting the receiver to the transmitter. Through the feedback channel, the receiver is enabled to convey information on the performance of the forward link to the transmitter. So, cognitive radio is an example of a feedback communication system.

One other comment is in order. A broadly defined cognitive radio technology accommodates a scale of differing degrees of cognitions. At the one end of the scale, the user may simply pick a spectrum hole and build its own cognitive cycle around that particular hole and at the other end of the scale, the user can use multiple implementation technologies to build its cognitive cycle around a wideband spectrum hole or set of narrowband spectrum holes to provide the best expected performance in terms of spectrum management and transmit-power control, and do that in the most highly secure manner possible. [3]

VI. RELATED WORK

The various techniques used for spectrum sensing in cognitive radio are discussed below:

A. Cooperative spectrum sensing in cognitive radio systems:

The problem of use the reliability of unlicensed users for cooperative spectrum sensing in cognitive radio systems by analyzing the Huffman encoding algorithm study by Xueqiang Zheng, Li Cui, Juan Chen, Qihui Wu and Jinlong Wang. A novel cooperative spectrum sensing algorithm in cognitive radio systems is presented. The close-form expressions for the average sending bits for each unlicensed user for cooperation and expression for the probability of the detection and the false-alarm for the novel cooperative spectrum sensing scheme are derived. Finally, show through numerical results the potential cooperative spectrum sensing performance improvement with using the reliability of unlicensed users is shown.

B. Energy detection technique for spectrum sensing in cognitive radio:

With unprecedented growth of the subscribers in modern cellular and wireless data communications, there is an acute scarcity of additional bandwidth to meet the ever increasing demand. To make the constraint of additional bandwidth an easy task, utilization of the existing system has been a topic of interest now-a-days. Cognitive Radio is therefore, a new technique in which the spectral holes in unutilized spectrum are determined to be used for instantaneous communication by secondary users. The Cognitive Radio determines the occupancy of the frequency spectrum observed over a time interval by spectrum sensing methods. Spectrum sensing forms a key front end block of Cognitive Radio systems. The design and simulation of the spectrum sensing algorithm for Cognitive Radio under low SNR scenario study by Anirudh M. Rao, B. R. Kartikeyan, and Dipayan Mazumdar.

The Energy Based Spectrum Sensing (EBSS) technique has been identified for its relatively simple implementation. In conventional PCA the ratio of the signal space power to the noise space power do not usually match the actual SNR. There is a correction factor for PCA technique which is then applied to the ratio of decomposed signal space power and the noise space power to equate it to the actual SNR. The noise power obtained through the modified PCA based technique and the chosen value of probability of false alarm determines the threshold energy for the EBSS algorithm. The method proposed in the study which is a combination of PCA and EBSS has been validated for wide range of SNRs, different probabilities of false alarm and frequencies of interest. The correction factor to the PCA and the clearly defined process for Threshold Energy computation invoking the PCA as well as the Radar principles.

C. Brain empowered wireless communications: Cognitive Radio:

Cognitive radio is viewed as a good approach for improving the utilization of a precious natural resource: the radio electromagnetic spectrum. The cognitive radio which is built on a software-defined radio, is a brilliant wireless communication system that is aware of its environment and uses the methodology of understanding- by-building to learn from the environment and adapt to statistical variations in the input stimuli study by Simon Haykin, The discussion of interference temperature as a new metric for the quantification and management of interference.

Three fundamental cognitive tasks are addressed: Radio scene analysis, Channel state estimation and predictive modeling, Transmission power control and management of dynamic spectrum.

D. Energy detection of unknown signals over fading channels:

The problem of energy detection of an unknown signal over a multipath channel study by Fadel F. Digham, Mohamed-Slim Alouini and and Marvin K. Simon. It begins with the no-diversity case, and then presents some alternative closed-form expressions for the probability of detection to those recently reported in the study. The detection capability is boosted by implementing both square-law combining and square-law selection diversity schemes.

E. Energy Detection using Estimated Noise Variance for Spectrum Sensing in Cognitive Radio Networks:

The performance of spectrum sensing based on energy detection study by Zhuan Ye, Gokhan Memik, John Grosspietsch. An estimated noise variance is used to calculate the threshold used in the spectrum sensing based on energy detection. A new analytical model to evaluate the statistical performance of the energy detection. The analytical results are verified through numerical examples and simulations. Through these examples, the effectiveness of our analytical model: it can be used to set the appropriate threshold such that more spectrum sharing can be done, especially when connected with cooperative spectrum sensing method.

F. Energy detection based spectrum sensing in cognitive radio:

The energy detection technique for spectrum sensing in cognitive radio systems study by Zhai Xuping, Pan Jianguo. The detection performance and the impact of the noise uncertainty on the detection probability are analyzed. To deal with the hidden terminal problem and the local spectrum sensing in wireless the detection of wireless signals, a distributed M-cooperative sensing scheme is proposed. The benefits of the proposed scheme in increasing the agility of cognitive radio systems. With a little tradeoffs between the detection probability and the false alarm probability, the schemes provide improvement in the spectrum sensing ability greatly in low SNR situations.

G. Asynchronous cooperative spectrum sensing in cognitive radio:

In cognitive radio networks, the cognitive radio users can be collaborated to perform spectrum sensing so as to detect the primary user more accurately study by Xiong Zhang, Zhandding Qiu and dazhong Mu. However, when the sensing nodes are affected from fading, shadowing, and time-varying nature of wireless channels, it is needed to set a long observation time for all of the nodes to make decisions and forward the results to fusion center, which results in the severe degradation of the sensing performance. An asynchronous cooperative spectrum sensing method is the one in which the cognitive radio user with high SNR finishes the detection earlier than the one with low SNR, and then the duty of fusion center is to make the final decision depending on the earliest local decision. The proposed method can exploit the user's SNR diversity so that the sensing performance can be improved. Simulation results in reduction of detection time significantly at the expense of a little sensing performance degradation compared to the conventional cooperative spectrum sensing.

H. Cooperative Spectrum Sensing in Cognitive Radio Networks Over Non-Identical Nakagami-m Channels:

The analysis of relaybased cognitive radio (CR) networks and presents a detect-amplifyand- forward (DAF) relaying strategy for cooperative spectrum sensing over non-identical Nakagami- m fading channels study by Sattar Hussain and Xavier N. Fernando. An advanced statistical approach is introduced to derive new exact closed-form expressions for average false alarm probability and average detection probability. The inconsistency of several assumptions that are typically used for performance analysis of CR networks and reveals that channel fading on the relaying links yields similar performance degradations as it yields on the sensing channel. The literature study also shows that it is not necessary to incorporate all CRs in the cooperative process and that a small number of reliable radios are enough to achieve practical detection level. When compared with the amplify-and-forward strategy, the heavily faded relays in the DAF strategy improve the detection accuracy and reduce the bandwidth requirement of the relay links. The analysis presented could lead to intuitive system design guidelines for CR networks impaired with non-identical faded channels.

I. Energy Detection Based Spectrum Sensing for Cognitive Radios in Noise of Uncertain Power:

Energy detection based spectrum sensing has been weak PU signal, which might experience deep fade before its proposed and studied widely for the arrival at SU of the primary user PU, from the background noise. Thus, a detection in the literature study by Bin Shen, Longyang Huang, Chengshi Zhao, Zheng Zhao and Kyungsup Kwak. With the help of multiple secondary users (SU) in the cognitive radio network, many cooperative sensing schemes are investigated to enhance the performance of energy detection. However, the impacts of noise power fluctuating effects on the detection performance in multipath fading and user cooperative sensing scenarios are seldom evaluated in relevant literature. A modified version of the classic energy detection model is presented, where the noise power uncertainty (U) is introduced

into threshold setting. With an approximate derivation, accurate predictions of SNR wall constraints imposed by U in Rayleigh fading environments have been provided. In addition, a simple hard decision fusion rule when used, then the collaborative gain in spectrum sensing performance is also quantified with respect to U. The analysis and numerical results confirm that collaboration can significantly improve the spectrum sensing performance in a noise power fluctuating environment.

VII. SUMMARY OF SPECTRUM SENSING TECHNIQUES

METHOD	BASED ON	FEATURES
Cooperative Spectrum sensing	Huffman Encoding Algorithm	High probabilities of detection even in the case that the prior Knowledge of licensed user is unknown is achieved. The close-form expressions for the average sending bits for each unlicensed user for cooperation and expression for the probability of the detection and the false-alarm for the novel cooperative spectrum sensing scheme are derived. The detection performance gain using quantization is obtained by exploiting the reliability of the unlicensed users' local test statistics.
Energy Detection Technique	EBSS and PCA Technique	PCA based detection technique allows computation of noise power and threshold. The ratio of the signal power to noise power in the conventional PCA usually does not match the actual SNR. The signal power estimated by PCA is not equal to the transmitted power. A first order correction term has been applied to the results of the conventional PCA technique to equate the ratio of signal power to noise power (as computed by PCA) with the SNR of the actual signal.
Relay based cooperative spectrum sensing	Over Nakagami-m channels	The employed general fading model yields more realistic results compared to AWGN and i.i.d. Rayleigh channel. The DAF strategy outperforms the AF strategy in all suggested scenarios.
Energy detection using estimated noise variance	Using estimated noise variance	The expected probability of false alarm or detection for spectrum sensing using energy detection method is evaluated. A method to determine the threshold that can achieve the desired probability of detection or false alarm using estimated noise variance is derived.
Energy detection based spectrum sensing	M-cooperative sensing scheme	The benefits of the proposed scheme in increasing the agility of cognitive radio systems.
Asynchronous cooperative spectrum sensing	Using asynchronous cooperative spectrum sensing method	Improving the sensitivity of the spectrum sensing in cognitive radio networks. Both local decision and final fusion scheme are derived.

VIII. CONCLUSION

The sensitivity of spectrum sensing in cognitive radio networks can be improved by using asynchronous cooperative spectrum sensing method. The expected probability of false alarm or detection for spectrum sensing using energy detection method is evaluated. PCA based detection technique allows computation of noise power and spectrum. The benefits of M-cooperative sensing scheme are in increasing the agility of cognitive radio systems. The Nakagami m-channels yields more realistic results then the AWGN channels.

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