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Optimization of Intelligent Spectrum Sensing Techniques for Cognitive Radio Networks

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***Abstract*— Spectrum sensing is a key function of cognitive radio to prevent the harmful interference with licensed users and identify the available spectrum for improving the spectrum's utilization. However, detection performance in practice is often compromised with multipath fading, shadowing and receiver uncertainty issues. To mitigate the impact of these issues, cooperative spectrum sensing has been introduced to be an effective method to improve the detection performance by exploiting spatial diversity. Cooperative sensing is the most sophisticated approach in spectrum sensing depends on base of sharing information to eliminate error in spectrum sensing mechanism. While cooperative gain such as improved detection performance and relaxed sensitivity requirement can be obtained, cooperative sensing can incur cooperation overhead. The overhead refers to any extra sensing time, delay, energy, and operations devoted to cooperative sensing and any performance degradation caused by cooperative sensing. In this paper, the state of-the-art survey of cooperative sensing is provided to address the issues of cooperation method, cooperative gain, and cooperation overhead. Specifically, the cooperation method is analyzed by the fundamental components called the elements of cooperative sensing, including cooperation models, sensing techniques, hypothesis testing, data fusion, control channel and user selection, and knowledge base. The open research challenges related to each issue in cooperative sensing are also discussed. In this review paper, we have discussed the Cooperative sensing approach, different optimization techniques for spectrum searching and sharing features in cognitive radio.**

***Index Terms*— Cognitive radio, Energy Detection, Matched Filter**

I. INTRODUCTION

Cognitive radio (CR) is a new way technology to compensate the spectrum shortage problem for wireless environment. The demand of radio spectrum increases proportionally with the increase in number of users, and thus it causes a significant increase in utilization of spectrum. The major hurdle in the current spectrum scarcity is the fixed spectrum assignment. This spectrum shortage problem has a deep impact on research directions in the field of wireless communication. It enables much higher efficiency of spectrum by dynamic spectrum access. It allows unlicensed users to utilize the free portions of licensed spectrum while ensuring that it causes no interference to primary users' transmission. Cognitive radio cycle shows figure 1,

The wireless technology rides on the spectrum that is being allocated by the Federal Communications Commission (FCC) to the service providers with the help of government bodies.

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The service providers then provide the wireless services to the end users. The allocated spectrum to the service providers is only for the licensed user, and in some cases the spectrum is not utilized to the fullest of its extent. The wireless technology is being adapted by people very fast and there is an increase in the number of its users day by day, this is leading to scarcity of spectrum [1]. Spectrum sharing or reusing the available spectrum band is the only option left. Spectrum sharing initially was without any cost, but due to new regulatory policies "secondary markets" are available in certain countries where service providers benefits finically from sharing the spectrum on static or dynamic basis [2].

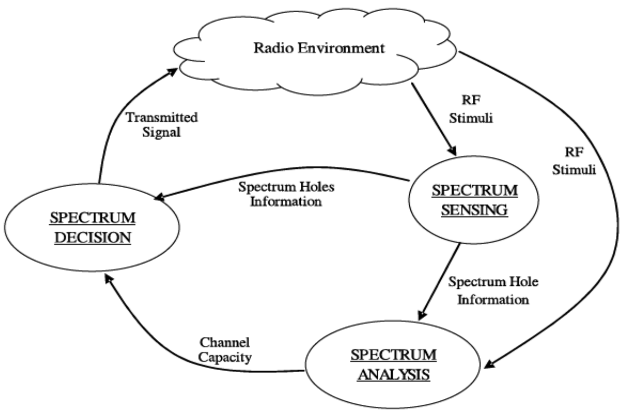

Figure 1: The Cognitive Cycle [2]

The information obtained is then analysed to ascertain characteristics of the environment; i.e. to estimate the spectrum holes. Based on this evaluation, the radio determines its alternatives; selecting an option in a way that improves the evaluation carried out previously [3]. The radio then employs these observations and decisions to improve its operation. As seen from the figure, the initial phase of the cognitive cycle consists of the sensing process. Hence, it is evident that reliable spectrum sensing is the most critical function of the cognitive radio process [4]. By sensing and adapting to the environment, a cognitive radio will possess the ability to fill in the spectrum holes and serve its users without causing harmful interference to the primary user. Ultimately, a spectrum sensing scheme should give a general picture of the medium over the entire radio spectrum. This allows the cognitive radio network to analyze all parameters (time, frequency and space) in order to ascertain spectrum usage [5]. Cognitive radio (CR) is a key technology for dealing with the current underutilization of spectrum [6]. The CR network allows CR users or secondary users (SUs) to access a spectrum which is not in use by a licensed user or primary user (PU). The most essential task of a CR network is to detect the presence or absence of a PU in order for the SU to use the licensed band efficiently and to avoid interference in the PU vicinity. The process of PU detection is called spectrum sensing. Currently, spectrum sensing techniques focus on PU transmitter detection. The local sensing techniques considered to be important are energy detection, matched filter detection, and cyclostationary detection [7]. Energy detection needs less sensing time but performs poorly under low signal-to-noise ratio (SNR) conditions. One of the well-known coherent detection techniques in the field of spectrum sensing is matched filter detection. Cyclostationary detection provides reliable detection but is computationally complex. The probability of detection (Pd) and the probability of false alarm (Pf) are the metrics for the detection performance of spectrum sensing. The probability that an SU declares the presence of a PU when the spectrum is occupied by the PU is called the probability of detection, whereas the probability that an SU declares the presence of the PU when the spectrum is idle is called the probability of false alarm. The probability of miss detection (Pm) indicates the probability that an SU declares the absence of a PU when the spectrum is occupied. The probability of miss detection is simply, Pm= 1 −Pd. In view of the fact that false alarms reduce spectral efficiency and miss detection causes interference with the PU, generally it is vital for optimal detection performance so that the maximum probability of detection is achieved subject to the minimum probability of false alarm [8]. The matched filter is optimal if structure of PU waveform is known. If deployment of CR is limited to operate in few PU bands then matched filer is the best choice. However, the implementation cost and complexity will increase if more PU bands are considered because dedicated circuitry is required for each primary licensee to achieve synchronization [9]. Practically, it is not possible to devote circuitry for each PU licensee. However, matched filter can be considered for most frequent sensed channels to get optimal sensing results with minimum sensing time if PU waveform is known. This approach can be very healthy for CR applications for disaster management; smart grid, and so on to get reliable sensing results with minimum sensing time. Many improved local sensing schemes are proposed in [10 -17], including our own fuzzy logic-based and SNR-based adaptive spectrum sensing for improved local sensing. In the proposed scheme, channels with known PU waveform will be sensed by matched filter detection and rest of the channels by the detectors which do not need dedicated circuitry and prior knowledge of PU waveform.

II. COGNATIVE RADIO CONCEPTS

The cognitive radio concept was first introduced in [18], where the main focus was on the Radio Knowledge Representation Language (RKRL) [19]. A few formal definitions of Cognitive Radio exist; the two most complete are given by Haykin and Thomas in [20] respectively: Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind:

1. Highly reliable communications whenever and wherever needed;

2. Efficient utilization of the radio spectrum."

“A Cognitive Radio is a radio that can change its transmitter parameters based on interaction with the environment in which it operates."

Fig.2 shows the spectrum access technique, it is a way to overcome the spectrum management and improve the efficiency. A spectrum hole or white space is band of frequencies assigned to a primary user but at a specific time and particular geographic area, the band is not being utilized by that user. These white spaces can occur in two fashions, in time or in space. When a primary user is not transmitting at a given specific time, then there is a temporal spectrum hole, if a primary user is transmitting in a certain portion of the spectrum but it is too far away from the secondary user so that the secondary user or cognitive user can reuse the frequency, then a spatial spectrum hole exists. The main concept of the cognitive radio is to continuously monitor the radio spectrum, detect the occupancy of the spectrum and then opportunistically use spectrum holes with minimum interference with primary user. [5] - [7].

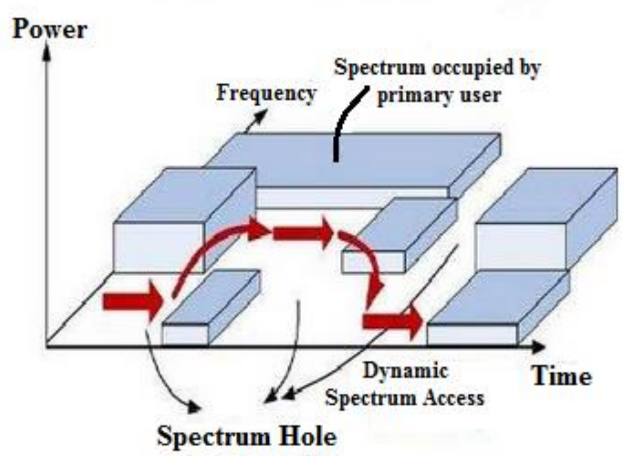

Figure 2: Spectrum Hole Concept

The main idea of cooperative sensing is to enhance the sensing performance by exploiting the spatial diversity in the observations of spatially located CR users. By cooperation, CR users can share their sensing information for making a combined decision more accurate than the individual decisions [8]. The performance improvement due to spatial diversity is called cooperative gain. The cooperative gain can be also viewed from the perspective of sensing hardware. Owing to multipath fading and shadowing, the signal-to-noise ratio (SNR) of the received primary signal can be extremely small and the detection of which becomes a difficult task. Since receiver sensitivity indicates the capability of detecting weak signals, the receiver will be imposed on a strict sensitivity requirement greatly increasing the implementation complexity and the associated hardware cost. More importantly, the detection performance cannot be improved by increasing the sensitivity, when the SNR of PU signals is below a certain level known as a SNR wall [9]. Fortunately, the sensitivity requirement and the hardware limitation issues can be considerably relieved by cooperative sensing.

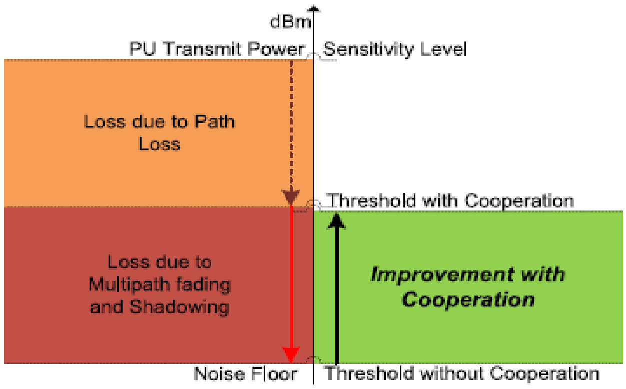

Figure 3: Improvement of sensitivity with cooperative sensing

As shown in Fig. 3, the performance degradation due to multipath fading and shadowing can be overcome by cooperative sensing such that the receiver's sensitivity can be approximately set to the same level of nominal path loss without increasing the implementation cost of CR devices. However, cooperative gain is not limited to improved detection performance and relaxed sensitivity requirement. For example, if the sensing time can be reduced due to cooperation, CR users will have more time for data transmission so as to improve their throughput.

In this case, the improved throughput is also a part of cooperative gain. Thus, a well-designed cooperation mechanism for cooperative sensing can significantly contribute to a variety of achievable cooperative gain.

In [10], Cabric et al. identified the ''three main questions regarding cooperative sensing'' as follows [10]

• How can cognitive radios cooperate?
• How much can be gained from cooperation?
• What is the overhead associated with cooperation?

These three questions surrounding the issues of Cooperation Method, Cooperative Gain, and Cooperation Overhead, respectively, should be addressed in every cooperative sensing scheme. In this paper, we aim to survey the state of-the-art research in cooperative sensing centering these three issues by first analyzing the cooperation method with the fundamental components of cooperative sensing and then presenting the impacting factors of achievable cooperative gain and incurred cooperation overhead. In addition, we identify open research challenges related to each issue in cooperative sensing along with the discussion.

CR has following function which is very essential for spectrum sensing. [4]

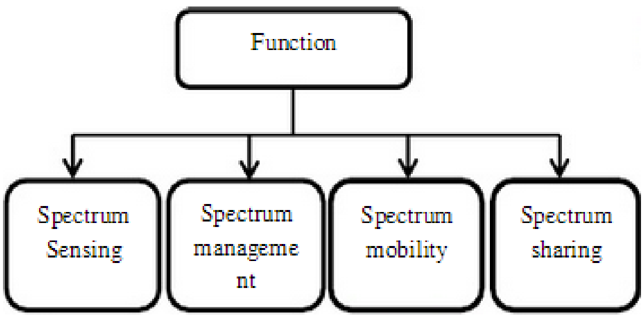

Figure 4: Cognitive Radio Function

- Spectrum sensing detects the unused spectrum/spectrum hole of licensed spectrum or user and determining if a primary user is present, detecting the spectrum hole.
- Spectrum management is a process of CR in which it captures the best suitable spectrum which is fulfills the communication requirement of user.
- Spectrum mobility is the case when a secondary user speedily allocates the channel or spectrum band to the primary user when a primary user wants to retransmit again.
- Spectrum sharing is a process in which the best suitable channel having coordination with others.

III. SPECTRUM SENSING

Spectrum sensing (SS) is the procedure that a cognitive radio user monitors the available spectrum bands, captures their information, reliably detects the spectrum holes and then shares the spectrum without harmful interference with other users. It still can be seen as a kind of receiving signal process, because spectrum sensing detects spectrum holes actually by local measurement of input signal spectrum which is referred to as local spectrum sensing. The cognitive users in the network don't have any kind of cooperation. Each CR user will independently detect the channel through continues spectrum sensing, and if a CR user detects the primary user it would vacate the channel without informing the other CR users.

The goal of spectrum sensing is to decide between the following two hypotheses:

H_0: Primary user is absent

H_1: Primary user is present in order to avoid the harmful interference to the primary system.

A typical way to detect the primary user is to look for primary transmissions by using a signal detector. Three different signal processing techniques that are used in the systems are matched filter, energy detector and feature detection. In the next subsections we discuss advantages and disadvantages about them

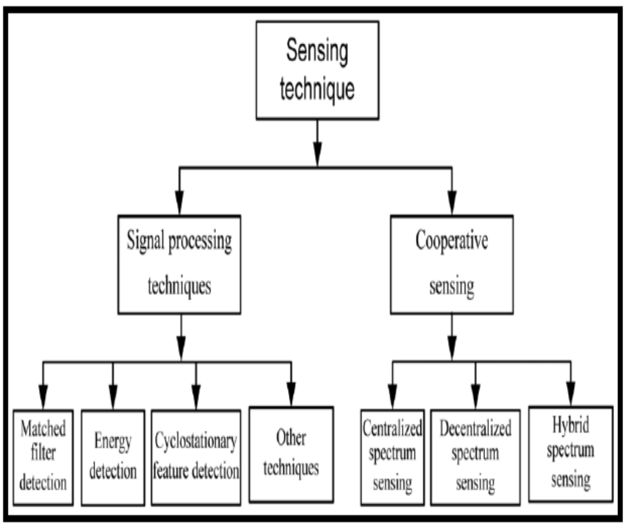

Figure 5: Classification of Spectrum Sensing Techniques

A. MATCHED FILTER

Matched filter [26] is an optimal way for any signal. It is a linear filter which maximizes the received signal-to-noise ratio in the presence of additive stochastic noise. However, a matched filter effectively requires demodulation of a primary user signal.

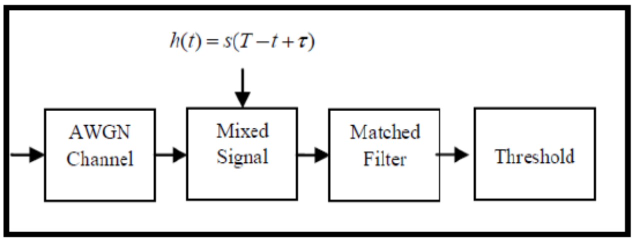

Figure 6: Block Diagram of Matched filter detection

If X[n] is completely known to the receiver then the optimal detector is:

$$T(Y) = \sum_{n=0}^{N-1} Y[n]X[n] \gtrless_{H_0}^{H_1} \gamma$$

Here γ is the detection threshold, and then the number of samples required for optimal detection is:

$$N = [Q^{-1}(P_D) - Q^{-1}(P_{FD})]^2 (SNR)^{-1} = O(SNR^{-1})$$

B. ENERGY DETECTOR

The energy detection is a non-coherent detection technique, the primary user detection and its statistics does not need any prior knowledge of the primary user signal to determine whether the channel is occupied or not. Consequently, it is considered the one of simplest techniques of spectrum sensing to detect primary user transmitter [24]. The most advantages of using energy detection, low computational cost, easy implementation, less complexity which depend only on the power of PU signal whether the signal present or absence, these advantages makes energy detection the simplest method to detect primary user signal. In contrast, in this technique the signal detection is depend on comparing power of the received signal to the threshold level, whereas threshold level rely on the noise floor which can be estimated but the signal power is difficult to estimate as it changes relying on two factories distance between primary user and cognitive radio another factor is ongoing transmission characteristics [25].

If the PU waveform is unknown, the energy detector is applied on the received signal r(t). An energy detector with bi-thresholds is used for detection in which two thresholds are λ1 andλ2. The received energy is given by,

$$E = \sum_{K=0}^{j-1} r(K)^2$$

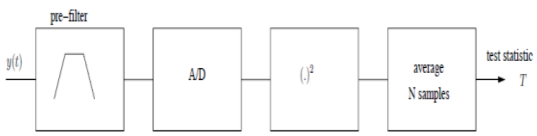

Figure 7: Block diagram of an Energy Detector. [26]

Where, j is determined from the time bandwidth product. If the received energy E is greater thanλ1, then the presence of a PU is declared. Similarly, if the received signal is less thanλ2, then the absence of a PU is declared. If the received signal energy is between λ1 and λ2, it is in the region of uncertainty (RU), and the energy detector is not reliable for PU detection, which is evaluated as

$$Decision = \begin{cases} 1 & if\ E > \lambda_1 \\ RU & if\ \lambda_2 \le E \le \lambda_1 \\ 0 & if\ E < \lambda_2 \end{cases}$$

As a consequence, the selection of an appropriate threshold level caused some drawbacks of the energy detection; threshold is might too low that is makes some noise as primary signal which causing in false alarm. On the other hand, when the threshold is too high, the missed detection will occur because of a weak primary signals will ignore. Therefore the performance of energy detection is depending on the suitable selection of the threshold in the frequency domain. Another disadvantage the accuracy of signal detection is low compared with other techniques.

C. CYCLOSTATIONARY FEATURE DETECTION

Cyclostationary feature detection needs high computation complexity, the best detection point is determined through simulation analysis on different detection points, and then we intend combination detection method using multiple detection points to obtain better performance. Output validate the effectiveness of the suggested method Cyclostationary feature detection can be able to have high detection probability under low SNR, actually, it requires high computation complexity. In reality, based on channel and a given location, the licensed users' signal parameters are known and the SNR is changing gradually, so we assume that we can obtain the licensed users' signal type and SNR before making detection. Using of the licensed users' prior knowledge like properties of signal, we only makes detections in some specific frequencies and cycle frequencies, and multiple combine detection points to increase the performance further. And then given the PD required by licensed users, the probability of false alarm (PFA) under different SNRs is implemented. Through the threshold adjustment, we decrease the PFA to make better use of spectrum hole when the SNR is high and increase the PFA to avoid interference to the licensed users when the SNR is low. Also CFD method can distinguish among noise and primary user signal at very low signal-to-noise ratio (SNR) values. In addition, the detection of this method is relies on the inherent redundancy in the primary user transmissions [27]. One of the most advantage, CFD method is represented its ability to identify the modulation scheme.

Figure 8: Block diagram of cyclostationary detection [7]

The cyclostationary detector is applied for a reliable decision of sensing accuracy. Researchers suggest that cyclostationary feature detection is more suitable than the energy detector technique when the noise uncertainties are unknown [7]. Commonly, the primary modulated waveforms are coupled with patterns also characterized as cyclostationary features, like sine wave carriers, pulse trains, repeating spreading, hopping sequences, and cyclic prefixes inducing periodicity. An SU can detect a random signal with a specific modulation type in the presence of random stochastic noise by exploiting periodic statistics like the mean and auto-correlation of a PU waveform. Features like autocorrelation and mean are estimated by analyzing spectral correlation functions (SCFs). A block diagram of cyclostationary detection using the SCF is shown in Figure 4. The SCF, also called a cyclic spectrum, is a two dimensional function with a cyclic frequency α [28]. In the spectrum sensing scheme, when the received energy is between λ1 and λ2, channels are sensed by the cyclostationary detector. On the other hand, the CFD takes long time during computation which is considered slightly complex. And also it is the worst when the noise is stationary than energy detection In addition, the cost of this technique is slightly high caused by the partial knowledge which required this method to detect the primary user. The second-order cyclic analyses built-in in modulated signals is used to detect the signals. Because of high complexity of cyclostationary feature detection and so we choose to detect specific frequencies and cyclic frequencies based on the signal's feature to decrease complexity greatly. We collate the detection performance of different points to find the best detection points through simulation analysis and propose to combination detection method using multiple detection points to get better performance.

IV. Results

The sensing performance of each detection scheme is quantified by the receiver operating characteristic (ROC), such as P_f versus P_d and the mean sensing time. Monte Carlo simulation was used for the experimentation under the following system settings: there are 10 randomly distributed Gaussian channels with zero mean and variance 1, and an SU looking for spectrum holes in these channels.

Figure 9 shows the probability of detection versus the average SNR, when the probability that channels the combined energy and cyclostationary detector goes to the cyclostationary stage, changes from 0.9 to 0.1 with a step of −0.4. The probability *Pr* that the channels are sensed by the combined energy and cyclostationary detector is fixed at 0.8. A change in *P* means that the thresholds λ_1 and λ_2 of the bi-threshold energy detector change. Increasing λ_1 and decreasing λ_2 will increase the overall probability of detection at the cost of increased detection time. In this sense, Figure 5.1 can serve as a guideline for network designers to set optimal values of thresholds $\lambda_1$and λ_2 for the desired probability of detection.

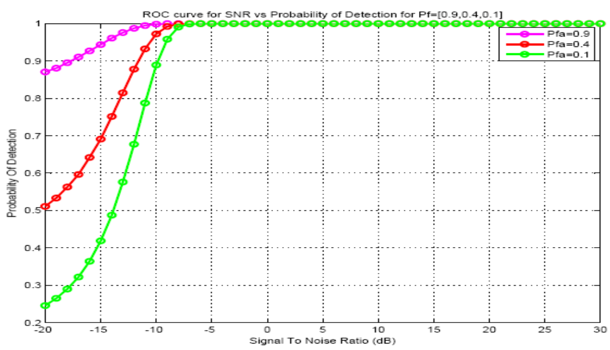

Figure 9: Probability of detection versus average SNR/dB for *Pr*=0.8.

In Figure 10, the probability of miss detection versus average SNR is presented for the probability of false alarm as 0.1 and 0.01, respectively. The results are conducted for *Pr* = 0.8 which means that most of the channels are sensed by the combined energy and cyclostationary detector. *P* is taken to be 0.5, which means that half of the channels detected by the combined energy and cyclostationary detector need to go through the cyclostationary detector. The result shows that the probability of miss detection is decreased with the increase of average SNR. For a specific value of average SNR, high P_f results in a low probability of miss detection because of the decreased threshold.

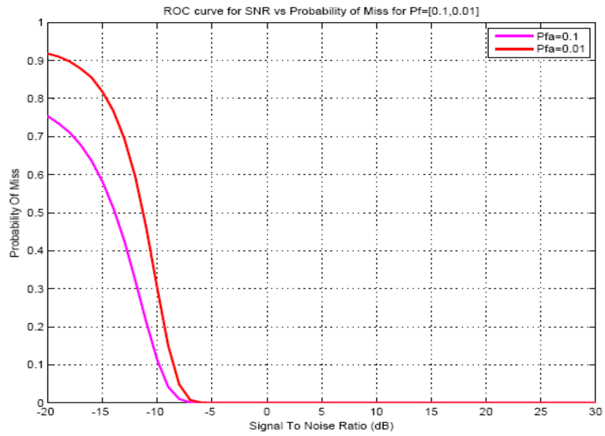

Figure 10: Probability of miss detection versus average SNR/dB for *Pf* =0.1 and *Pf* =0.01 (*Pr*=0.8, *P*=0.5).

Figure 11 shows the ROCs of the spectrum sensing scheme, the matched filter detection, the energy detection, and the cyclostationary detection.

In this scenario, it is assumed that the average SNR is $-10dB$. Both *Pr* and *P* are taken to be 0.5. The result shows that the proposed scheme performs as well as cyclostationary detection for *Pf* greater than 10^{-1}.

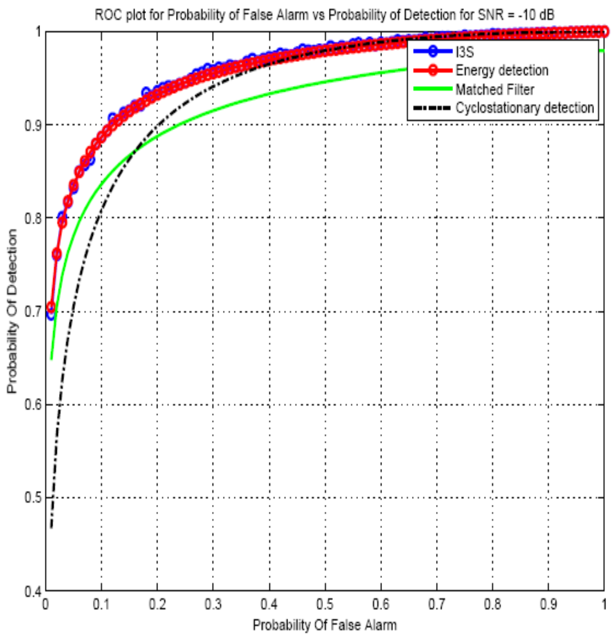

Figure 11: The ROC curves of the spectrum sensing scheme, matched filter detection, energy detection, and cyclostationary detection

V. CONCLUSION

The wireless spectrum is limited and getting scarce, thus to have maximum utilization we use cognitive radio where we share the available resources in adaptive manner. For spectrum sensing energy detector is used, as easy to implement and does not require synchronization information to monitor.

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