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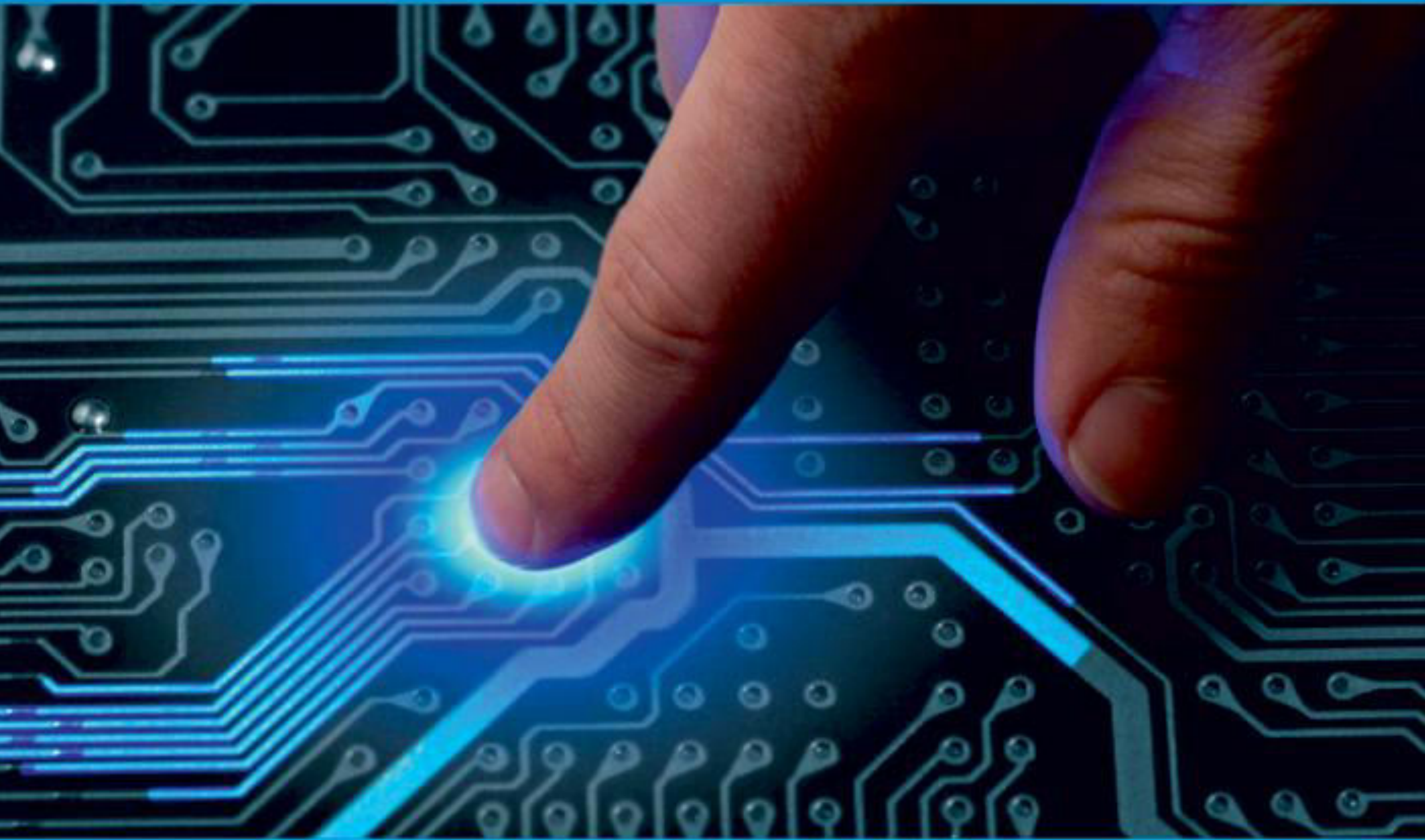

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Evaluation of Energy Efficiency of Spectrum Sensing Algorithm for Cognitive Radio Networks

Niveditha Biswas[1], A. Ramya Geethika[2], S. Arshad[3], G.Prudhvi[4], C. Sai Keerthi[5], P. Sai Praveen[6]

Assistance Professor, Department of Electronics and Communication Engineering Siddharth Institute of Engineering and Technology, Chittoor, India[1]

Department of Electronics and Communication Engineering, Siddharth Institute of Engineering and Technology, Chittoor , India[2,3,4,5,6]

ABSTRACT: Cognitive Radio (CR) is a radio communications and networking technology that has attracted considerable interest from both academia and industrial sectors in recent times. As is well known, spectrum sensing forms the very backbone on which the operation of CR technology draws upon. Spectrum sensing can be defined as the task of collecting information regarding spectral resource utilization and presence of primary users (PU) in a given area; which can then be used to accommodate secondary users (SU) on a non interfering basis. Spectrum Sensing is one of the most power hungry tasks in a Cognitive Radio system. Due to the energy constraints of battery powered mobile terminals, energy efficiency emerges as a significant challenge in CR networks. However, there is a direct tradeoff between bandwidth efficiency and power efficiency according to Shannon's Channel Capacity Theorem. This paper describes an energy efficient two stage spectrum sensing algorithm that is based on joint energy detection and cyclostationary feature detection. The paper also evaluates the energy efficiency of the spectrum sensing algorithm for CR and it is shown through simulations that the scheme attempts to simultaneously achieve good power efficiency as well as bandwidth efficiency. It is also noted that the application of Compressed Sensing leads to further improvement in the energy efficiency of our algorithm.

KEYWORDS: Noted that the application of Compressed Sensing leads to further improvement in the energy efficiency of our algorithm.

I. INTRODUCTION

The demand for higher data rates is on the rise with the emergence of multimedia services that must be supported by modern wireless systems. However, a large portion of allocated spectrum remains under-utilized [1]. This scenario naturally gives rise to dynamic spectrum access techniques, a prominent one being Cognitive Radio (CR). In CR, the secondary users, i.e. those without spectrum licenses, are allowed temporary access to the unused licensed spectrum [1]. This allows more efficient utilization of spectral resources in an opportunistic manner and on a non-interfering basis with the primary users. The cornerstone of Cognitive Radio technology is the ability to sense the dynamic characteristics of the radio channel, availability of spectrum and transmit power, user requirements, available network infrastructure, and so on [2]. A primary user has higher priority or legal access to a particular segment of the spectrum whereas, a secondary user has lower priority and gains spectrum access without interfering with the PU. Hence it is the secondary user who should have cognitive capabilities like reliable spectrum sensing and dynamic adaptation of radio parameters to exploit the spectrum holes [2]. The secondary user should take care not to cause harmful interference to the primary users' transmission. The detection problem of spectral occupancy by SU is a binary hypothesis testing problem. H0 corresponds to the case where only additive noise is present and PU is absent, whereas H1 corresponds to the case when the PU signal is present. The challenge of spectrum sensing lies in accurately distinguishing between these two hypotheses. Several spectrum sensing techniques have been reported in the literature. These include: energy detection [3], matched filtering [4], waveform based sensing, cyclostationary feature detection [5], etc. The matched filter detector is an optimal technique that maximizes the signal to noise ratio (SNR), but it requires a priori knowledge of the PU signal like modulation type/order, etc. [4]. The energy detection is very popular because of its low computational complexity along with the fact that it does not require knowledge of the PU signal. However, the drawback of this technique is degradation of sensing performance due to noise uncertainty [6]. Cyclostationary feature detection, by virtue of its robustness to noise, can detect PU signals in very low SNR conditions [5]. However, the high

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computational complexity involved is the main limiting factor in the implementation of cyclostationary feature detection. In recent years, there has been an unprecedented growth in wireless network infrastructure and network users, which has led to a drastic increase in energy consumption of wireless networks. This gives rise to an increase in demand for battery (energy) capacity, besides causing severe electromagnetic (EM) pollution to the global environment [7]. Increased energy consumption in wireless is one of the major reasons for greenhouse gas emissions. It has been reported that Information & Communications Technology (ICT) generates about 2 percent of worldwide CO2 emissions [8]. Also, consumption of power in ICT is reported to be increasing by 16 to 20 percent every year. In this scenario, 'Green Wireless Communications' is an emerging paradigm which seeks to find novel solutions to improve the energy efficiency of wireless applications. The maximization of bits-per-Joule energy efficiency (EE) is one of the major topics in the research on green wireless communication.

II.RELATED WORK

[1]. Dr. E. K. S. Au. S. Eryigit and T. Tugcu are with the Department of Computer Engineering, Bogazici University, Istanbul 34342, Turkey in this paper deals with the "Energy-Efficient Multichannel Cooperative Sensing Scheduling With Heterogeneous Channel Conditions for Cognitive Radio Networks " S.Bayhan is with Helsinki Institute for Information Technology, Aalto University, 00076 Espoo, Finland. The accuracy of spectrum sensing is paramount for both finding the spectral voids and for protecting the PU communications. Hence, a sensing period is reserved at the beginning of each frame for the spectrum sensing task. Considering the periodic nature of sensing, even a small amount of savings in each sensing period leads to considerable improvement in the long run. In this paper, we consider the problem of energyefficient (EE) spectrum sensing scheduling with satisfactory PU protection. [2]. E. Hepsaydir is with Network Technology, Hutchison 3G, U.K., Maidenhead SL6 1EH, U.K. (e-mail: erol.hepsaydir@three.co.uk). X. Ge is with the School of Electronic Information and Communications, Huazhong University of Science and Technology, Wuhan 430074, China (e mail: xhge@mail.hust.edu.cn). D. Yuan is with the School of Information Science and Engineering, Shandong University, Jinan 250100, China. In this paper, we focus on the spectral and energy efficiency for the interference-tolerant CR networks. The spectral efficiency is defined as the number of bits per second transmitted over a given bandwidth (in bps/Hz) while the energy efficiency is defined as the required energy per bit (in joules/bit) for reliable communication, normalized to the background noise level. 3. X. Li and H. Chen are with the Key Laboratory of Cognitive Radio and Information Processing, Guilin University of Electronic Technology, Guilin 541004, China spectral efficiency (SE), which evaluates how effectively limited available spectrum resources are utilized, and energy efficiency (EE), which measures how efficiently energy resources are consumed, are two key performance metrics for the next generation (5G) wireless communications. It is foreseen that by 2020 there will be more than 50 billion devices connected through cellular networks to implement the ubiquitous communications, and the data traffic is anticipated to increase by 1000 times over the next ten years. However, obtaining such a large capacity by simply scaling up the transmit power is clearly impossible. The reason is that it would lead to excess emission of greenhouse gas and electromagnetic pollution, along with an unmanageable energy demand. Hence, a sharp improvement on EE, at a similar power consumption level as present, is considered to be an effective way to achieve such goal.[4]. Reza Ghazizadeh rghazizade@birjand.ac.ir Hamid Farrokhi Hfarrokhi@birjand.ac.ir Maryam Najimimaryamnajimi1361@yahoo.com Cognitive radio (CR) has been recently proposed as a candidate solution to alleviate spectrum shortages by allowing unlicensed users (secondary users, SUs) to opportunistically access or share the frequency bands allocated to the licensed users (primary users, PUs) when they are detected to be idle. In order to avoid causing harmful interference to the PU, the CRs need to monitor the PU's activities periodically to find a suitable spectrum band for possible utilization. Thus, effective and efficient spectrum sensing is an essential component for CR systems.[5]. Yu H G, Tang W B, Li S Q. Joint optimal sensing time and power allocation for multi-channel cognitive radio networks considering sensing-channel selection. In recent years, throughput maximization is one of the main challenges in the multi-channel cognitive radio network (CRN). For this reason, researchers have proposed many schemes to maximize the multi-channel CRN's throughput through the optimization of different parameters. In the optimal sensing-order problem is studied when the SU can only sense the channels sequentially. In the joint optimization of sensing-channel selection and power allocation is formulated when the SU can sense a subset of channels simultaneously.

III. PROPOSED WORK

We proposed this "Energy Efficiency of Spectrum sensing algorithm in cognitive radio networks" to analyse the spectral and energy efficiency in cognitive radio networks. In this section, we will study the spectral and energy efficiency for a CR-based cellular network

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The intention here is not to build a complete cellular network using the concept of CR, but rather to enhance the spectral efficiency of the cellular networks for a short period of time by sharing a spectrum that belongs to another licensed network. We assume that a CR network consists of a single ST, i.e., macro BS, which transmits signals to multiple SRs. The CR network shares a spectrum owned by an indoor primary network. The primary network also consists of multiple PRs, i.e., primary indoor access points (APs). The SRs and PRs are indexed by $n \in N = \{1,...,N\}$ and $k \in K = \{1,...,K\}$, respectively. The SRs and PRs are uniformly distributed in a cell of radius d and a cell of radius $D(d \leq D)$, respectively. The downlink transmissions of the CR network are considered and assumed to occur in the uplink transmission of the primary network. There are many advantages for sharing the spectrum of the uplink transmissions of an indoor network. First, since the primary network is assumed to be an indoor one, the mutual interference between the primary and secondary networks will be scaled down because of the penetration losses. Secondly, as the PRs, are all fixed in position, this offers an opportunity to easily detect them by the ST. Hence, the STs can detect the pilot channel broadcast from indoor PRs and decide how many PRs with which they are surrounded. The ST can then rely on channel reciprocity and estimate the channel coefficient of the interference channel using injected pilots in the uplink channel of the PRs. Finally, it is also possible that the interference channel status information (ICSI) is sent from all PRs along with their identities and collected by a certain central unit. In fact, using a separate wireline control channel that broadcasts the interference measured over a broadband connection is a very practical solution. Before the secondary network can utilize the spectrum, it must register itself with the central unit first to be updated regarding the ICSI. However, the PRs do not necessarily need to identify each registered ST. The ICSI can inform the STs regarding the status of the worst aggregate interference that a PR suffers. The STs can also use ICSI as an alternative way to estimate the channel status to that PR and regulate their transmit power accordantly. In this work, we assume that there is only one registered CR network with a single secondary cell.

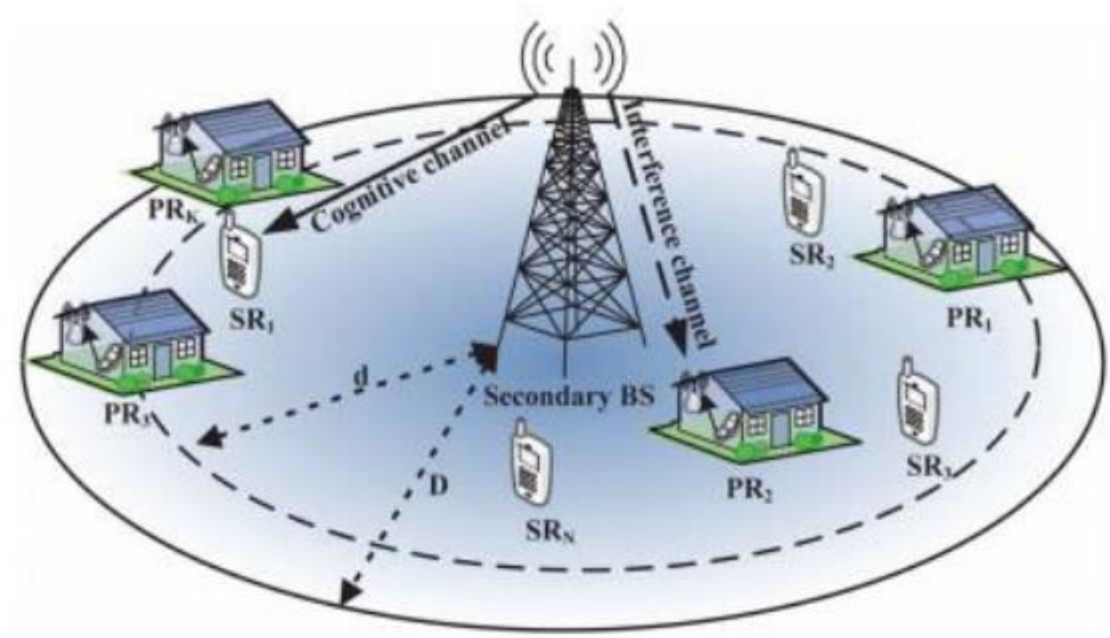

Fig:1 System model of CR-based cellular network with secondary BS, multiple PRs, and multiple SRs.

IV. METHODOLOGY

Energy detection i.e., periodogram technique is the most common way of spectrum sensing because of its low computational and implementation complexities. In addition, receivers do not need any knowledge on the primary users' signal. The signal is detected by comparing the output of the energy detector with a threshold which depends on the noise floor. Some of the challenges with energy detector based sensing include selection of the threshold for detecting primary users, inability to differentiate interference from primary users and noise, and poor performance under low signal-to-noise ratio (SNR) values. Let us assume that the received signal has the following simple form

$$y(n) = s(n) + w(n) \quad (1)$$

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where,
s(n) is the signal to be detected.
w(n) is the additive white Gaussian noise (AWGN) sample.
n is the sample index.
Note that s(n) = 0 when there is no transmission by primary user.
The decision metric for the energy detector can be written as

$$M = \sum_{n=0}^{N} |y(n)|^2 \quad (2)$$

Where,
N is the size of the observation vector.
The decision on the occupancy of a band can be obtained by comparing the decision metric M against a fixed threshold λ. This is equivalent to distinguishing between the following two hypotheses.

$$H0 : y(n) = w(n), \quad (3a)$$
$$H1 : y(n) = s(n) + w(n) \quad (3b)$$

The expressions for the probability of false alarm and probability of detection for energy detection over AWGN and Rayleigh fading channels are as below

$$P_f = \frac{\Gamma\left(N/2, \frac{\lambda}{2\sigma^2}\right)}{\Gamma(N/2)} \quad (4)$$

$$P_d = Q_{N/2}\left(\sqrt{\frac{a\gamma}{\sigma^2}}, \sqrt{\frac{\lambda}{\sigma^2}}\right) \quad (5)$$

$$\bar{P}_{d,\mathrm{Ray}} = e^{-\frac{\lambda}{2\sigma^2}} \sum_{i=0}^{N/2-2} \frac{\left(\frac{\lambda}{2\sigma^2}\right)^i}{i!} + \left(\frac{2\sigma^2 + a\bar{\gamma}}{a\bar{\gamma}}\right)^{N/2-1} \times \left[e^{-\frac{\lambda}{2\sigma^2 + a\bar{\gamma}}} - e^{-\frac{\lambda}{2\sigma^2}} \sum_{i=0}^{N/2-2} \frac{\left(\frac{\lambda a\bar{\gamma}}{2\sigma^2(2\sigma^2 + a\bar{\gamma})}\right)^i}{i!}\right]. \quad (6)$$

Where

N is the number of degrees of freedom of chi-square distribution.
λ is the detection threshold, σ is the signal standard deviation.
a is a noncentrality parameter.
γ is the average SNR.
Γ is the incomplete gamma function.
Q is the generalized Marcum Q function.
The cyclic spectral density (CSD) function of a received signal can be calculated as

$$S(f, \alpha) = \sum_{\tau=-\infty}^{\infty} R_y^{\alpha}(\tau) e^{-j2\pi f \tau},$$

where

$$R_y^{\alpha}(\tau) = E\left[y(n+\tau) y^*(n-\tau) e^{j2\pi\alpha n}\right] \quad (7)$$

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The detection and false alarm probabilities for second order cyclostationary detection are

$$P_{\mathrm{f,TFD}} = \exp\left[-\frac{(2N+1)\lambda^2}{2\delta^4}\right]. \quad (8)$$

$$P_{\mathrm{d,TFD}} = Q_1\left(\frac{\sqrt{2\gamma_{\mathrm{cp}}}}{\delta}, \frac{\lambda}{\delta_{\mathrm{B}}}\right), \quad (9)$$

$$\delta_{\mathrm{B}}^2 = \frac{2\delta_{\mathrm{cp}}^2\delta^2 + \delta^4}{2N+1} = \frac{(2\gamma_{\mathrm{cp}}+1)\delta^4}{2N+1}. \quad (10)$$

Where,
δ is the signal standard deviation.
λ is the detection threshold.
γcp is the average SNR.
Q is the generalized Marcum Q function.

BLOCK DIAGRAM

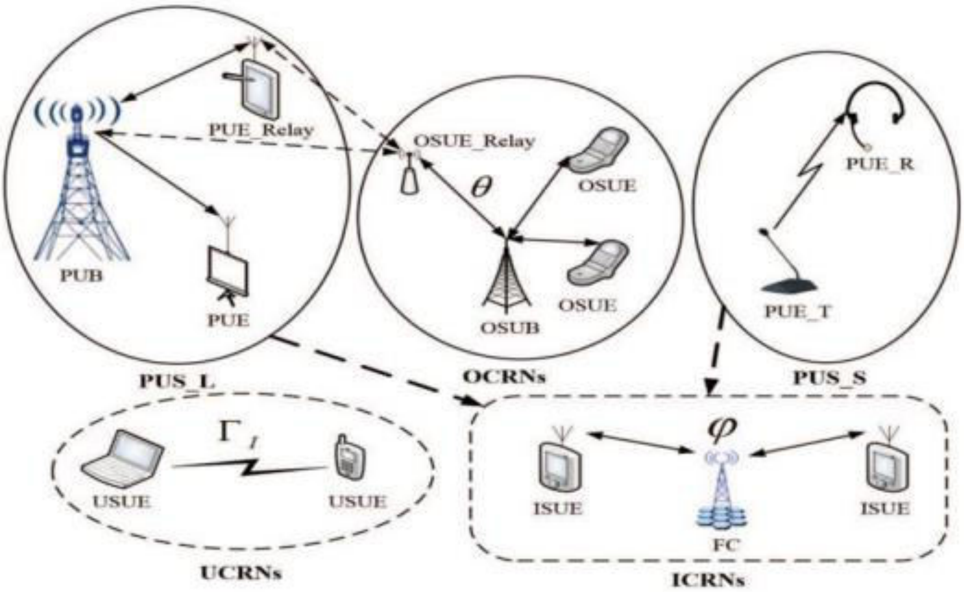

Fig:2 Block diagram of spectrum sensing cognitive radio networks

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V. SIMULATION RESULTS

First we report the performance characteristics of energy detection over an AWGN channel by simulating its complementary ROC curve.

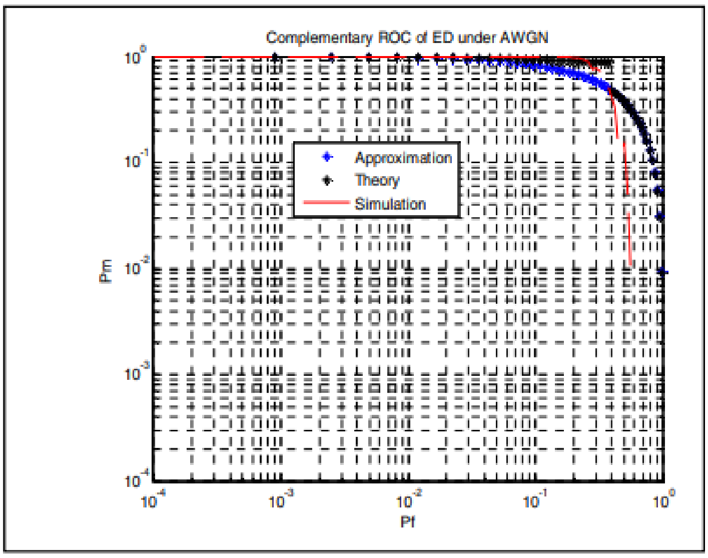

Fig:3 Complementary ROC of ED over AWGN channel

A comparison between the detection performance of energy detection over AWGN and Rayleigh fading channels is shown below. Clearly, ED performs much better over an AWGN channel than over a Rayleigh fading channel.

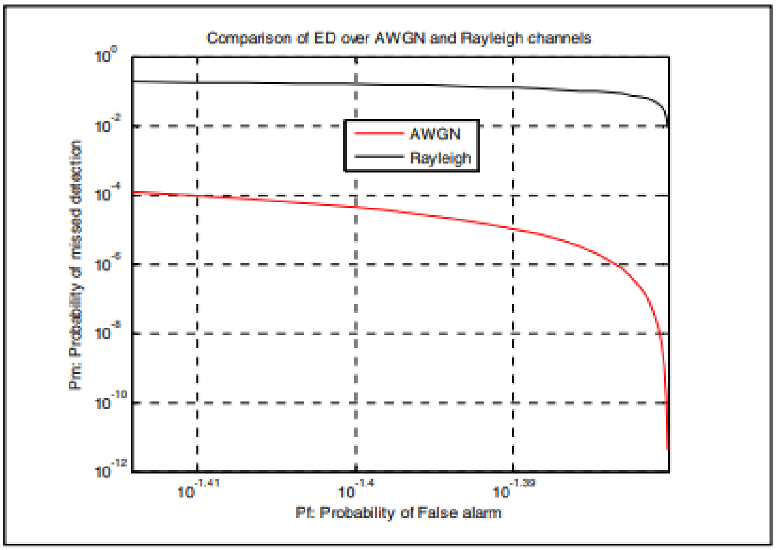

Fig:4 Comparison of ED over AWGN and Rayleigh channels

Next we present a comparison between the complementary ROC curves of our proposed algorithm and only energy detection in case of hypothesis H1. The figure clearly illustrates that the detection performance of the proposed scheme is superior to only ED because of the fine sensing stage based on CFD [20].

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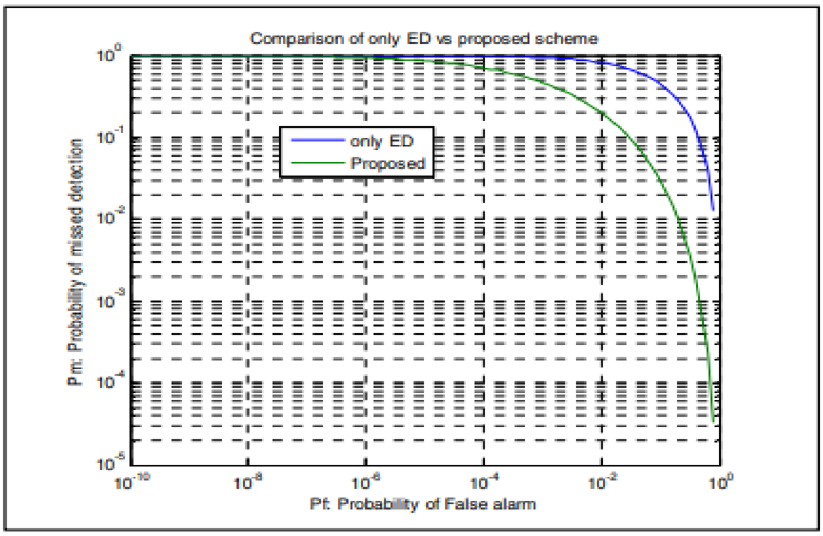

Fig:5 Comparison of complementary ROC of proposed scheme and only ED

Finally we present the energy efficiency comparison between only cyclostationary feature detection, our proposed scheme and the improved scheme presented in the previous section. Clearly, CFD is the most wasteful of energy, while our proposed scheme and the improved scheme gain 2 dB and 6 dB respectively compared to CFD at a false alarm probability of 0.0001.

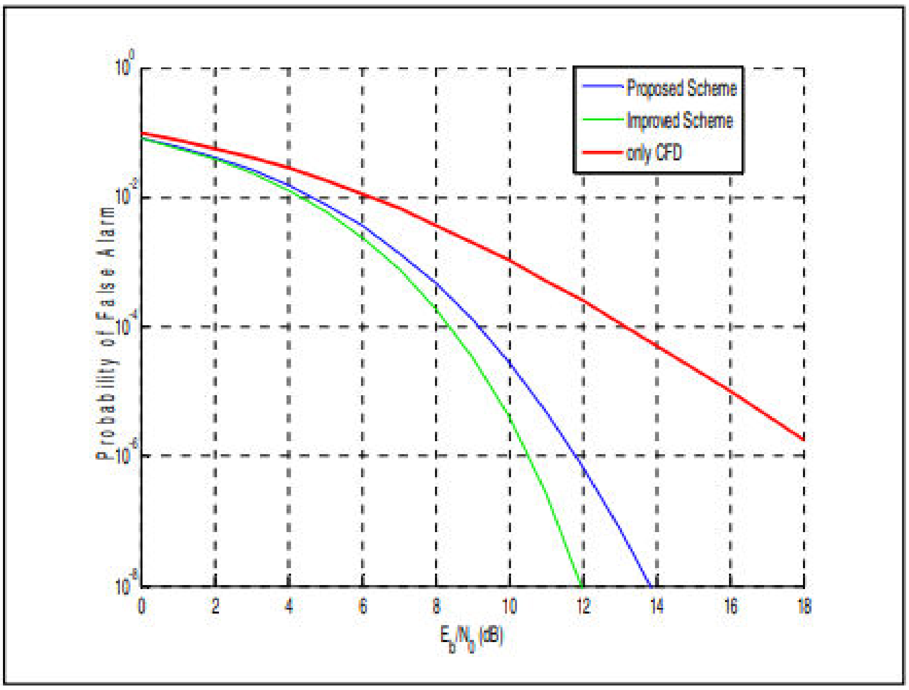

Fig:6 Comparison of energy efficiency of only CFD, proposed scheme and improved scheme

Note that in the above figure, probability of false alarm was plotted against required SNR at a constant value of detection probability of 0.9.

VI. CONCLUSION

The Energy efficient spectrum sensing algorithm for cognitive radio networks that was based on a two stage joint energy detection as well as cyclostationary feature detection. The technique outlined can be used as a means to obtain

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spectral efficiency while not degrading the energy efficiency, the latter being extremely important for battery powered terminals. The simulation results presented outline the effectiveness of the technique to simultaneously obtain good detection performance as well as energy efficiency. Further improvement in the energy efficiency of our algorithm was noted by the application of Compressed Sensing (CS) techniques to the second stage of the two stage spectrum sensing scheme. This CS based spectrum sensing will be the subject of our next detailed investigation. Also, a theoretical study of the detection and false alarm probabilities for the two stage scheme can be incorporated in further works.

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