Non-Cooperative Blind Spectrum Sensing for Primary Users in Cognitive Radio Networks with DS-CDMA

T. Bahraini[1], and M. Eslami[2]
1,2- Department of Electrical and Electronics Engineering, Shiraz University of Technology, Shiraz, Iran
{t.bahraini, m.eslami}@sutech.ac.ir

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ABSTRACT:
Real-time spectrum sensing with precise accuracy is the most important step to establish cognitive radio networks (CRNs). Detecting the presence of primary users (PUs) that use DS-CDMA (Direct sequence code division multiple access) technique is a challenge for the secondary users (SUs) in CRNs. DS-CDMA transmissions with very low signal to noise ratio (SNR) results in a signal hidden below the noise level, therefore, the existing classic detection methods are not effective enough to sense the signals. In this paper, a method is proposed to resolve this challenge. The proposed method based on fluctuation of correlation estimators searches on a specific frequency band and detects primary user's signals. Simulation results show that the sensing performance of the method is better than other conventional schemes for dealing with DS-CDMA users.

KEYWORDS: Cognitive radio networks, DS-CDMA, Blind spectrum sensing, non-cooperative spectrum sensing.

1. INTRODUCTION

Frequency spectrum as the scarcest resource for next generation wireless communications systems has attracted the attention of many researchers. In allocating frequency spectrum in traditional system it has been observed that some frequency bands are heavily used in some positions but other bands are lightly utilized elsewhere. Thus spectrum opportunities are generated, which can be used by intelligent and adaptive cognitive radio (CR) transceivers. Cognitive radio is a new concept of designing systems which aim to enhance the utilization of spectrum opportunities [1]. The definition of cognitive radio adopted by Federal Communications Commission (FCC) is: "A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation." [2].

One of the most important features of the CR systems is the ability to sense spectrum and parameters related to the radio's operating environment. So secondary users (SUs) sense frequency bands and use spectrum holes when primary users (Pus) are not active. Cognitive users exploit spectrum in such a way that they do not cause interference to licensed PUs [3]-[4]. In a cognitive radio for using the licensed spectrum by SUs, PUs have no obligation to change their operating parameters and SUs can independently detect spectral opportunities without any assistance from PUs. This task can in two ways, narrow band spectrum sensing and wideband spectrum sensing [5], be investigated. Many narrow band spectrum sensing algorithms have been studied in the literature but generally all available methods are divided in three categories: match filtering (MF)-based methods [6], energy detection (ED)-based methods [7], and cyclostationary futures detectors (CSD) [8], [9]. Other important methods are; likelihood ratio test (LRT) [10], and periodogram-based methods [11].

Each of the methods need special requirements and information, such as; MF-based methods require knowledge of the channel responses from PU, LRT-based methods have great performance, but they need the distribution of sources of signals and noise and CSD needs to know the cyclic frequencies of the PUs. The three methods depend on perfect knowledge of the channel response, the user information, and other characteristics, but ED-based methods unlike the others do not require any information. ED method for detecting correlated signals is not optimal but for independent and identically distributed (i.i.d.) signals is optimal [12].

The DS-CDMA signals have been widely used in civil and military communication. These signals are well-known for their low probability of interception,

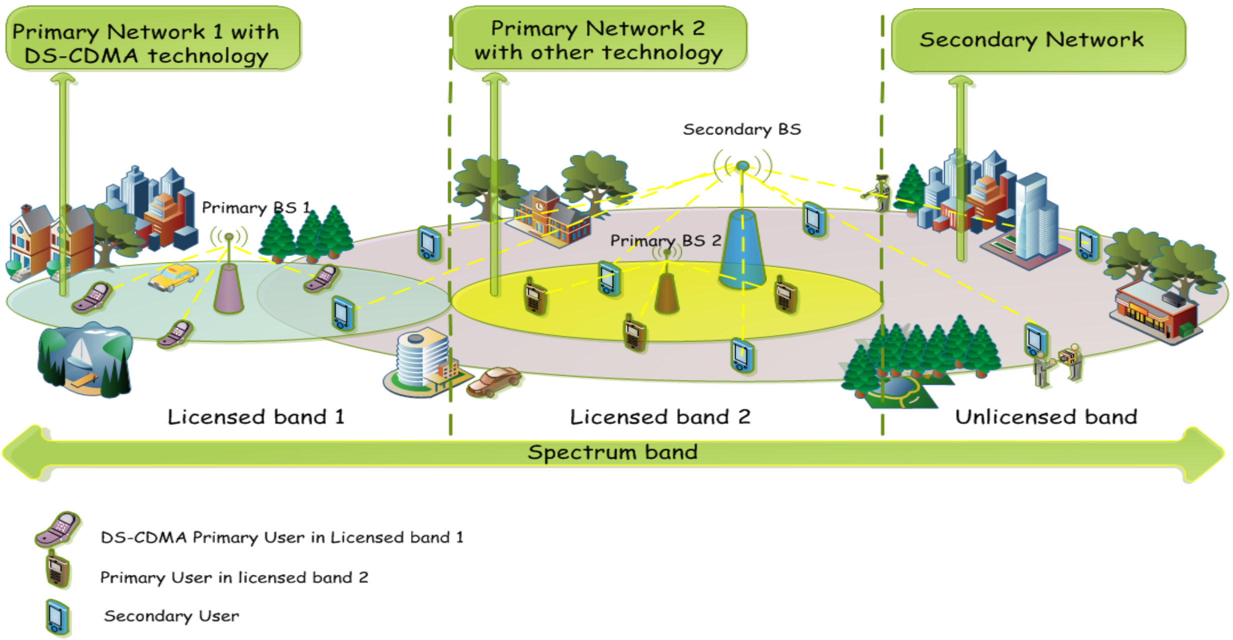


Fig. 1. Cognitive Radio Network with DS-CDMA primary Users.

because DS-CDMA signals are generated by multiplying data sequence in spreading code so power level of DS-CDMA spreading signals are below the noise level. In other words, DS-CDMA signals are transmitted at very low signal to noise ratios (SNR) in communication systems and their statistics behavior are similar to noise.

In the context of spectrum sensing in CRN with primary users that use DS-CDMA technique, the prior information of the DS-CDMA signal is unknown to the secondary users; parameters such as length of the pseudo noise sequence, symbol frequency, chip duration, etc. [13]. So detection of the DS-CDMA signals becomes very difficult and the existing classical detection methods are not effective enough to sense the presence of the signals. In this paper, we propose a blind spectrum sensing method for DS-CDMA signals in cognitive radio networks that do not need any information about the resource signals. The proposed method is based on fluctuation of correlation estimators [14].

The rest of this paper is organized as follow. The system model and problem formulation, are presented in Section 2. The proposed scheme is presented in Section 3. Simulation results, performance evaluation and comparisons are presented in section 4, and finally, our conclusions are drawn in section 5.

2. SYSTEM MODEL AND PROBLEM FORMULATION

Let us consider the general case of DS-CDMA system in a cognitive radio network with other primary and secondary users as shown in Fig. 1. In a DS-CDMA transmission, the baseband information symbols are multiplied by a pseudo random sequence, which spreads the signal bandwidth. The pseudo random sequence or spreading code, the symbol and carrier frequencies and other required parameters are known by the desired receiver, so that receiver multiplies the received signal with the pseudo random sequence in order to access the information symbols. Nevertheless in CRN, when secondary users want to use existing non-occupied channels, they first must search over frequency channels and sense white spaces ("which are free, no one sends information on this band, but it is occupied by natural and artificial forms of noise." [15].), but for the secondary users that do not have any prior information, even detect the presence of a DS-CDMA signal, it is difficult, because it is usually under the noise level.

2.1. Signal model

Suppose the received signal with BPSK modulation is expressed as:

$$y(t) = s(t) + n(t) = Ad(t)c(t)\cos(\omega_c t + \varphi_0) + n(t) \qquad (1)$$

Where $y(t)$ is the received signal, $s(t)=Ad(t)c(t)\cos(\omega_c t+\varphi_0)$ is transmit signal of PU, A denotes the signal amplitude, ω_c is the carrier frequency, φ_0 is the initial phase on the interval $(0, 2\pi)$ with a uniform distribution and $n(t)$ is additive white Gaussian noise (AWGN) with power spectral density *N0/2 w//Hz.* Also $d(t)$ denotes information data that is generated in primary user's transmitter and is defined as:

$$d(t)=\sum_{n=0}^{\infty} a_n\, g(t\text{-}nT_d) \qquad (2)$$

where $a_n \in \{-1,+1\}$ denotes the binary data sequence, T_d is the symbol period. *c(t)* is the pseudo random noise (PN) code that is defined as:

$$c(t)=\sum_{n=0}^{\infty} c_n\, g(t\text{-}nT_c) \quad (3)$$

where $c_n \in \{-1,+1\}$ is the spread spectrum sequence, and T_c is the chip period. With the spreading gain of *N* (or length of PN code), then $T_d=NT_c$. It is assumed that *s(t)* and *n(t)* statistically independent with strong autocorrelation and weak cross-correlation, therefore, the data symbols are centered and uncorrelated.

2.2. The conventional autocorrelation method

The spectrum behavior of PN sequence is similar to the noise, so when primary users use DS-CDMA transmission, they have high security and low probability of intercept. PN sequence is not really random and its characteristics such as the syclo-stationary features and periodic autocorrelation can be used to detect the DS-CDMA signal. The conventional autocorrelation function of received signal *y(t)* can be computed as:

$$\begin{aligned} &R_y(\tau)=E\{r(t)r(t+\tau)\} \\ &= E\{A^2 d(t)c(t)d(t+\tau)c(t+\tau)\cos(\omega_c t+\varphi_0) \\ &\cos(\omega_c(t+\tau)+\varphi_0)\} + E\{n(t)n(t+\tau)\} \\ &+ E\{Ad(t)c(t)\cos(\omega_c t+\varphi_0)n(t+\tau)\} \\ &+ E\{Ad(t+\tau)c(t+\tau)\cos(\omega_c(t+\tau)+\varphi_0)n(t)\} \end{aligned} \quad (4)$$

The noise and signal are independent, so (4) can be simplified as:

$$R_y(\tau) = \frac{A^2}{2} R_d(\tau) R_c(\tau)\cos(\omega_c t+\varphi_0) + R_n(\tau) \quad (5)$$

where in (5) $R_c(\tau) = E\{c(t)c(t+\tau)\}$ is the autocorrelation function of the spread code, $R_d(\tau) = E\{d(t)d(t+\tau)\}$ is the autocorrelation function of the baseband data signal and $R_n(\tau) = E\{n(t)n(t+\tau)\}$ is the autocorrelation function of the noise, that its values is 0 if $\tau \neq 0$. Where SNR is not very low, one can use (5) to estimate presence of DS-CDMA signals. The autocorrelation peaks are obvious but when the SNR is low, the autocorrelation function peaks curves are submerged in the noise level and difficult to distinguish [13].

Autocorrelation function in low SNRs is not effective, because it is very sensitive to SNR. So in this article another method is proposed for sensing DS-CDMA primary users' signal in CRN. This method works well in very low SNRs (such as -20 dB).

3. PROPOSED SCHEME

Based on the system model it is determined whether there is an opportunity in frequency domain for secondary users. Proposed method is a non-cooperative scheme that each SU independently senses the spectrum bands. An AWGN channel between the primary transmitter and the secondary user's receiver is assumed. The observed baseband signal in cognitive radio receiver is *y(t)*. SU is to decide between two hypothesis testing problems:

$$\begin{aligned} &H_0 : y(t) = n(t) \\ &H_1 : y(t) = s(t) + n(t) \end{aligned} \quad (6)$$

The performance of spectrum sensing method used in SU can be characteristic by the probability of detection P_d or probability of false alarm P_f. With robust selected method SUs can achieve true decision between hypothesis and based on this result decide whether to send signals on the channel considered or not.

In the proposed method, the baseband samples of received signals are divided in to *W* sets of windows each with duration of *T*, as shown in Fig. 2. Value of *T* is arbitrary, although it is better not to be too small. An estimation of the autocorrelation function over each window has been calculated instead of computing (5), according to:

$$\hat{R}_y^{(w)}(\tau) = \frac{1}{T}\int_0^T y(t)y^*(t-\tau)dt \cdot \quad (7)$$

Second order moment of the estimated *W* autocorrelation functions is as follows:

$$\rho(\tau) = \frac{1}{W}\sum_{w=1}^{W} |\, \hat{R}_y^{(w)}(\tau)\,|^2 \quad (8)$$

where *w* is an index for each window. First, equation (7) is computed for each window and then $\rho(\tau)$ is obtained over all *W* windows. The fluctuations of the autocorrelation $\rho(\tau)$ are illustrated in Fig. 3. As shown in the figure, $\rho(\tau)$ has a series of periodic peaks, caused by cycle-stationary future of DS-CDMA signals.

While only noise is present or SNR is very low as is the case for which results are presented, there is no systematic relationship between volatility plotted. Due to these results, SU decides on one of the two hypotheses as the current situation, to identify whether the frequency band is busy is or not.

This detector works even at very low SNRs. The signal to noise ratio in dB at the detector output is [14]:

$$SNR_{out} = 20\log\left(\frac{m_\rho^s}{\sigma_\rho^n}\right) \quad (9)$$

$$m_\rho^s = E\left\{\left|\hat{R}_{ss}(T_d)\right|^2\right\} = E\left\{\left|\frac{1}{T}\int_0^T s(t)s^*(t-T_d)dt\right|^2\right\} \quad (10)$$
$$= \frac{T_d}{T}\sigma_s^4$$

and;

$$\sigma_\rho^n = \sqrt{\mathrm{var}\left\{\hat{E}\left\{\left|\hat{R}_{nn}(\tau)\right|^2\right\}\right\}} = \sqrt{\frac{1}{W^2}\sum_{w=0}^{W-1}\mathrm{var}\left\{\left|\hat{R}_{nn}^w(\tau)\right|^2\right\}} \quad (11)$$

where m_ρ^s is the mean value of the peaks created by DS-CDMA signal, σ_ρ^n is the standard deviation of the estimator fluctuation due to received signal without information or noise only, and σ_s^2 is the variance of the signal $s(t)$. For the flat frequency response filter in receiver with [-ω,+ω] bandwidth, equation (9) is equal to:

$$SNR_{out} = 4SNR_{in} + 20\log(2\omega T_d) + 10\log(W) - 10\log(2) \quad (12)$$

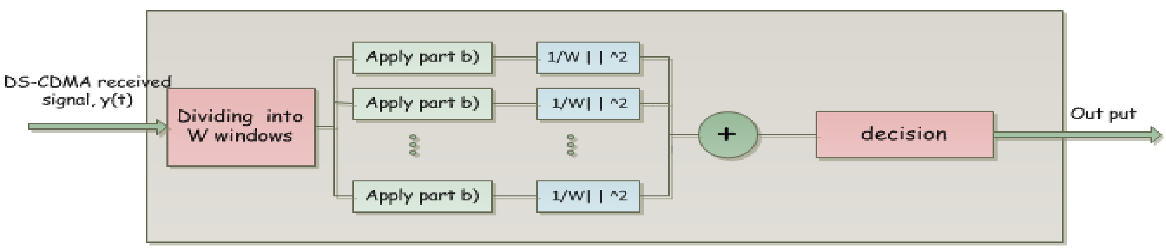
this means that by increasing the number of windows W the detector performance can be increased without limits and it depends on the available computation power and time allocated for detection.

4. SIMULATION RESULTS

In this section, we present simulation results to illustrate the effectiveness of the proposed method. The performance of the proposed scheme is verified by simulation. A Monte Carlo simulation is conducted. The parameters of simulation are summarized in Table 1. Given pseudo random sequence has length N; values of 32, 64 and 512 have been considered. It is assumed that SNR is in the range of -20 dB to 20 dB and the DSSS signal with common BPSK modulation. Number of total windows W used to the result are 2000 and in some results 1000.

We use the algorithm to estimate of PU presence and select one of the two hypotheses H_0 or H_1 from equation (6) in output of detector as final result. The results in Fig. 3 show the output of proposed method in SNR = -5 dB, and for these simulation parameters: length of PN code N = 64, W = 2000, T = 640, also Channel is AWGN and BPSK modulation is used. As you can see in this figure the curve has a series of alternating and regular peaks in deviations noise level. If the detector output fluctuations have these regular peaks we can say that the DS-CDMA primary user is present in radio environment and select H_1.

The distance between two consecutive peaks is equal to the multiples of the symbol frequency T_s, that is $T_s = NT_c$, and for result in Fig. 3, T_c = 1, so T_s = 64, that is equal to PN code length. In other words this proposed method estimate PN code length in addition to the detection DS-CDMA signals.



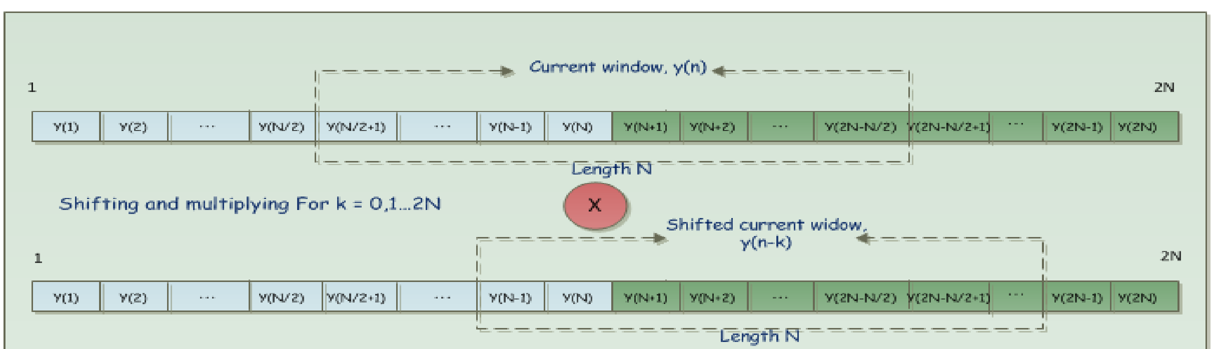


Fig. 2. The principle scheme of the proposed method, a) Detection block diagram in SU receiver. b) Computing equation (6).

Table 1. Parameters of simulations

Parameter	value
channel	AWGN
modulation	BPSK
Code type	PN
Receiver filter	RC
N	16,32,64,512
W	2000,1000
T_c	1 ms
T	640

Figure 4 compares output of proposed detector for two values of SNR = -15 and -5 dB, it show that when SNR is lower, the performance is reduced and peaks will be drowned in deviations noise level so was not detectable, with increasing SNR the method gives better results and fluctuation of curve have more regular peaks. Under the same SNR, performance improves with increasing N and W, although with increasing the more throughputs and more time is needed (as shown in Fig. 5, in SNR= -5 dB for N=16 and N=64 estimated of autocorrelation function is plotted and the curve for N=16 has more irregular deviations).

Figure 6 and 7 show the impact of changes W, in detector output. According (12), by increasing the number of windows W the detector performance can be increased without limits. These figures are plotted for W = 100 and 1000. In these for W = 1000 noise power level is lower and irregular fluctuation is less than the other. Continuing the work, we used Raised Cosine (RC) pulse shaping with Roll-off factor 0.5 with 0.5 MHz bandwidth in inputs of SU receiver.

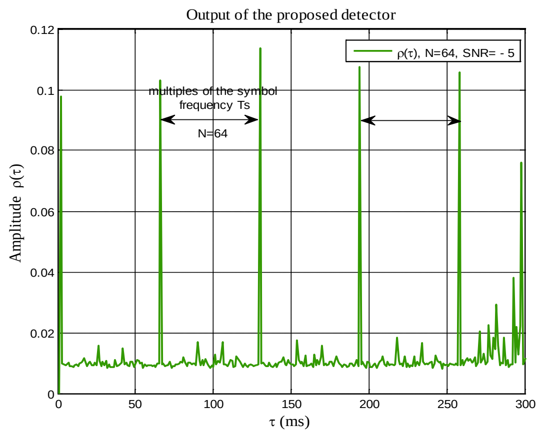


Fig. 3. Output of proposed method for PN code with N = 64, W = 2000, T = 640 in SNR = -5 dB.

For the proposed method performance review, we obtain probability of detection (P_d) curve (ROC) to be comparable with performance of other methods as can be understood from Fig. 8 (negative values of SNR is more important because the DS-CDMA signal is sent below the noise level.). The proposed method performance is plotted for P_f = 10^{-3}, 10^{-2}, 10^{-1}, N = 64, W = 2000, T = 640 and for DS-CDMA PUs.

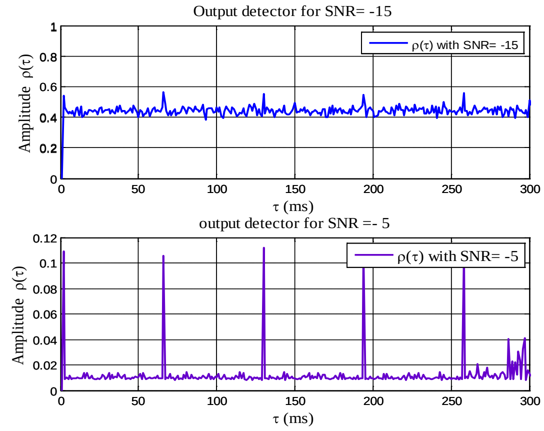


Fig. 4. Output of Proposed method for different SNR = -15 dB and -5 dB with N = 64, W = 1000, T = 640.

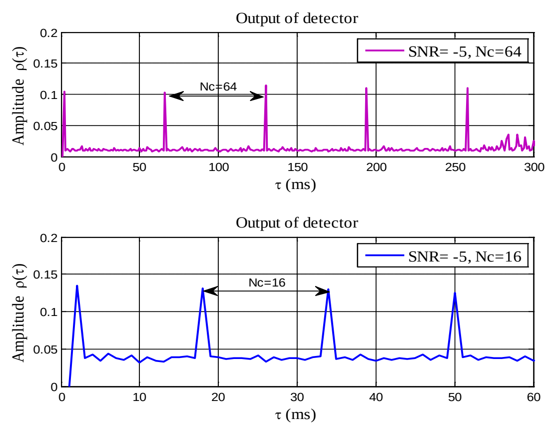


Fig. 5. Output of Proposed method for different N = 64 and 16, with SNR = -5 dB, W = 2000, T = 640.

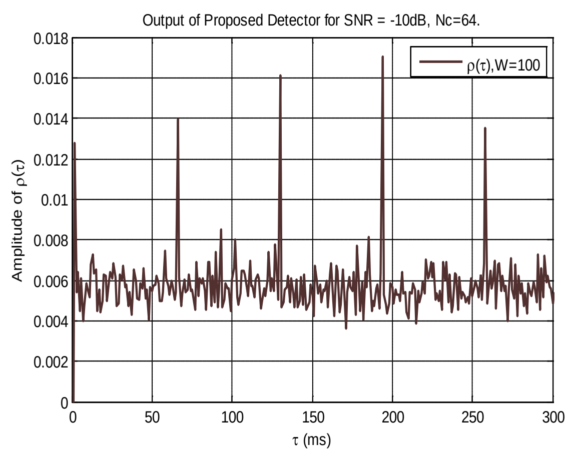


Fig. 6. Output of Proposed method for W = 100 with SNR = -10 dB, T = 640, N = 64.

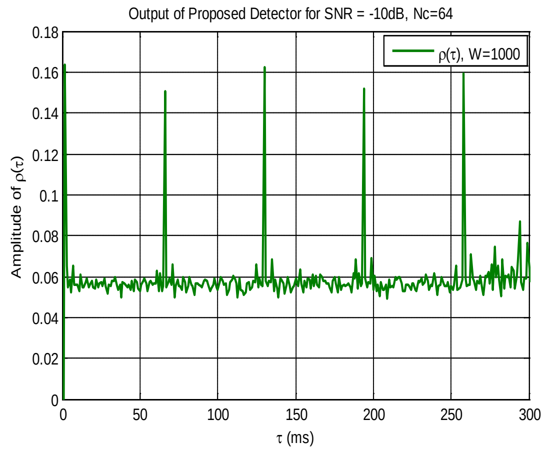


Fig. 7. Output of Proposed method for W = 1000 with SNR = -10 dB, T = 640, N = 64.

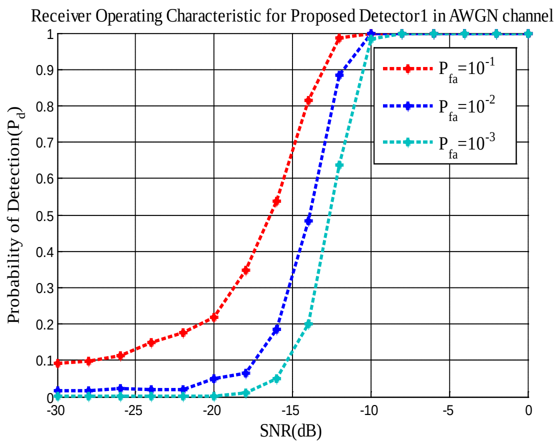


Fig. 8. Performance of proposed method (ROC curve) for different P_{fa}.

5. CONCLUSIONS

In this paper, the blind spectrum sensing for DS-CDMA transmission in cognitive radio network was developed. According to results the method can work perfectly in very low SNR compared to other existing methods such as energy detection based methods or conventional autocorrelation based methods. The presented simulation results show that the proposed algorithm is effective for detecting presence of DS-CDMA primary users. This blind method does not require any prior information, and it has relatively low complexity architecture.

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