Double-Threshold Energy Detection Technique for Cooperative Spectrum Sensing in Cognitive Radio System

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Abstract- Now a day wireless communication is growing day by day but in limited spectrum bands. Cognitive radio deployment can successfully deal with the Necessitate and Scarceness of wireless spectrum. Spectrum sensing is a basic and crucial task for cognitive radio networks. Spectrum Detection of the existence of a licensed user in the radio spectrum is an important task for successful implementation of cognitive radio systems in present scenario of spectrum paucity. There are various spectrum sensing techniques which are already proposed as Energy detection, Matched filter detection and Cyclostationory feature detection etc. In this Paper, The problem of noise uncertainty is taken in to consideration for the existing energy detection technique, and a solution to the problem is proposed in form of Dynamic-Double-Threshold Energy Detection Scheme. This new approach solves the complication of fluctuating noise variance in the wireless channel, as well as improves the detection performance even, under low signal to noise ratio.

Key Words: Wireless Communication, Cognitive radio, Spectrum sensing, Energy detection (ED), Cyclostationory feature detection (CFD), Matched filter detection (MFD), Dynamic Double Threshold (DDT), Noise uncertainty and Threshold.

1. INTRODUCTION:

Wireless communication is growing day by day but in restricted spectrum bands. Services of wireless communication are as mobile, conductor telephone, GPS, television system etc. Concept of cognitive radio will with success agitate the necessitate and scarceness of wireless [1][2]. According to Mitola [5] cognitive radio is a well educated radio that is meant to sight offered spectrum and alter transmission parameters enabling a lot of communication. Every cognitive radio user must have following ability –Spectrum sensing, Spectrum decision, Spectrum sharing, Spectrum mobility. In these, Spectrum sensing is basic and most vital task for cognitive radio. Cognitive radio is in a position to detect the unused spectrum band of authorized user. With the assistance of cognitive radio, cognitive radio user will use the unused spectrum band of authorized user however without interfering the authorized user. In cognitive radio, there are numerous forms of spectrum sensing techniques that are already projected in last decades. They are as Energy detection methodology(ED), Matched filter detection methodology (MFD), Cyclostationory feature detection methodology (CFD). In these all, energy detection methodology is usually used because of its low complexity.There are several techniques that are projected on the premise of invariant noise power whereas there are several factors (like thermal noise, outflow of signal) of noise. So we cannot say noise is absolutely Gaussian or stationary. Practically, noise variance of received signal can't be fixed. Dynamic double threshold technique is projected in [16]. This technique corrects the matter of noise uncertainty. Double threshold scheme measure thought about this technique that is variable in nature. The results of this method are high detection probability whereas false alarm at lower mounted rate as in the case of mounted noise condition. Different a part of this paper is arranged as follows-in section (ii) general model of detection technique is explained in section (iii) double threshold is proposed. In section (iv) noise uncertainty and dynamic threshold is explained. In section (v) proposed approach is simulated and verified. And in the last, section (vi) conclusion are drawn.

2. DETECTION MODEL:

Spectrum sensing [7] permits to unauthorized user to find out regarding the radio surrounds by using one or multiple sensors. The supply of the spectrum is detected by the spectrum sensing techniques [13].

These technique are developed as

$$Y(n) = W(n) \quad : \quad H0$$
$$Y(n) = hX(n) + W(n) \quad : \quad H1$$

Where n=1, 2, 3………N and N =number of sample. Y (n) is that the received signal by cognitive user. X (n) and W (n) is the transmitted signal by the primary user where W (n) is AWGN. H0 indicates spectrum is vacant and H1 indicates spectrum is occupied and h is complex channel gain. We calculate SNR as $Y = \frac{s}{\sigma_n{}^2}$. Where s is that the average signal power and $\sigma_n{}^2$ is that the average noise variance. To measure the spectrum sensing following cases are often drawn:

- Probability of detection (P_d): Channel is occupied and declared as occupied.
- Probability of false alarm (P_{fa}): channel is vacant and declared as occupied.
- Probability of miss detection (P_{md}): channel is occupied and declared as vacant.

General model of spectrum sensing is shows as:

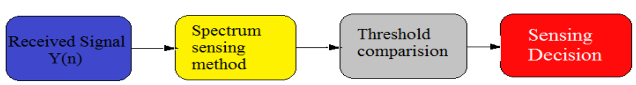

Figure1: General model of spectrum sensing

Cognitive user receives the signal as Y (n). According to detection technique we discover the test static of the received signal. Then this test static is going to be compare with pre-defined threshold that is completely different for all detection techniques. If test static is greater than threshold, spectrum is busy [H1] otherwise spectrum is busy [H0]. For all sensing techniques this model is applicable only change in spectrum sensing technique block.

2.1 Matched filter detection technique:

This detection methodology is employed when cognitive user have preceding information of primary information of primary user signal. Matched filter could be a most selected filter that is employed to maximizing the output SNR.

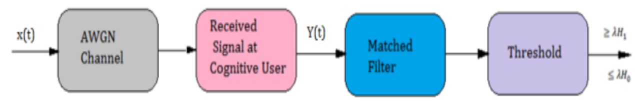

Figure 2: block diagram of matched filter detection scheme

Where H0=absence of primary user, H1=presence of primary user

From the figure, it's clear that a frequency vary is chosen from the BPF that is passed through the matched filter where test static of the received signal is calculated for MFD then it's compared with pre-defined threshold.

The test static is given for MFD:

$$Ts = \sum_N Y(n) x_p{}^*(n) \tag{2}$$

Where Y(n)=received signal by cognitive user, $x_p{}^*(n)$=synchronization code to produce synchronization between primary user and cognitive user. N is total number of sample. For the detection, probability of detection (Pd) and probability of false alarm (Pf) calculated for MFD as:

$$Pd = Q\left(\frac{\lambda - E}{\sqrt{E\sigma_n{}^2}}\right) \tag{3}$$

Where λ =pre-defined threshold for MFD,E=primary user signal Energy, $\sigma_n{}^2$=noise variance, Q is Q-function

$$Pf = Q\left(\frac{\lambda}{\sqrt{E\sigma_n{}^2}}\right) \tag{4}$$

The pre-defined threshold is calculated from the pd as:

$$\lambda = Q^{-1}(Pf)\sqrt{E\sigma_n{}^2} \tag{5}$$

But it's a disadvantage, if secondary user doesn't have preceding information about the first user MFD perform defectively. And another disadvantage is that each cognitive radio wants synchronization between cognitive user and primary user that is not possible practically. This makes less useful to MFD.

2.2 Energy detection methodology:

Energy detection methodology [8] is prime method for detection. This methodology is use for detection when primary user signal is distorted from AWGN. There is no need of preceding information about primary user.

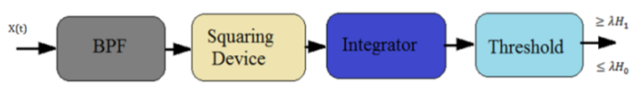

Figure 3: Block diagram of energy detection scheme

From the figure it's clear that a spread of frequency passed through the BPF squared and integrated through the respective device thus on calculates test static which is able to be compared with pre-defined threshold for ED and consequently take decision. The test static for energy detection methodology is given as:

$$\mathrm{Ts} = \frac{1}{N} \sum_{n=0}^{N} \mathrm{Y}(n)^2 \quad (6)$$

Where Ts is the test static that is compared with predefined threshold λ as: If Ts > λ, H1: authorized user is present. If Ts<=λ, H0: authorized user is absent. Energy detection provides high detection performance at high SNR. However this methodology is most in use due to its less complexness. There are some cases which are mentioned for this methodology to enhance the detection performance:

(i) Noise variance is fixed and uncertainty of noise is not considered:

$$\mathrm{Ts} \sim \left(N\sigma_n^2, \frac{\sigma_n^2}{N}\right) \qquad : H0$$

$$\mathrm{Ts} \sim \left(N\sigma_n^2(1+\Upsilon), \frac{\sigma_n^4}{N}(1+\Upsilon)^2\right) \qquad : H1$$

To find channel is vacant or busy we've got to calculate probability of detection (Pd) and probability of false alarm (Pf) and probability of miss detection (Pmd). Now, Pd, Pmd, Pfa is formulated as:

$$\mathrm{Pd} = \Pr(\mathrm{Ts} > \lambda : H1) = Q\left(\frac{\frac{\lambda}{\sigma n^2} - (1+\Upsilon)}{\sqrt{\frac{2}{N}}(1+\Upsilon)}\right) \quad (7)$$

$$\mathrm{Pf} = \Pr(\mathrm{Ts} > \lambda : H0) = Q\left(\frac{\lambda - \sigma_n^2}{\sqrt{\frac{2}{N}}\sigma_n^2}\right) \quad (8)$$

$$\mathrm{Pmd} = 1 - \mathrm{Pd} - 1 - Q\left(\frac{\frac{\lambda}{\sigma n^2} - (1+\Upsilon)}{\sqrt{\frac{2}{N}}(1+\Upsilon)}\right) \quad (9)$$

Q (.) represents the standard Gaussian complementary cumulative distribution function and λ is the predefined threshold value.

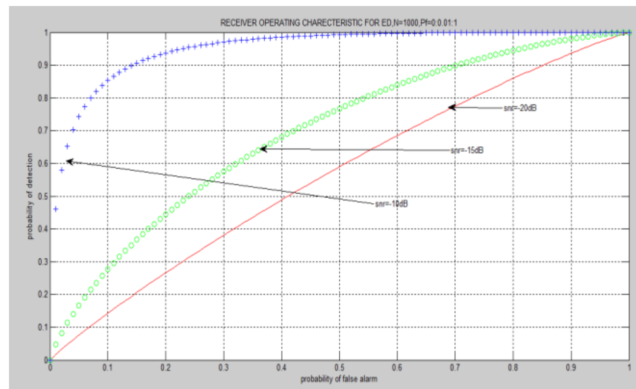

Figure 1-ROC for ED, N=1000, Pf-0:0.01:1, different SNR

Figure 1 shows the mathematical outcome for ED technique plotted between Pf vs. Pd. Pd at different values of SNR=-20dB,-15dB,-10dB. In the graph, for Pf 0 to 0.01 the value of Pd varies from 0 to 0.15 for SNR=-20dB, 05 to 0.3 for SNR=-15, 45 to 0.9 for SNR=-10. From the figure we will analyze that the probability of detection is increasing as SNR is increasing. The detection performance at low SNR is incredibly poor.

(ii) Under the consideration of noise variance and uncertainty of noise:

In this case, the uncertainty of noise affects the variance of noise which may be shown as:

$$\sigma \in \left(\frac{\sigma_n^2}{\rho}, \rho\sigma_n^2\right)$$

Where ρ is the noise uncertainty constant and has value larger than 1. Then Pd, P_{md}, Pf is formulated as:

$$\mathrm{Pd} = \min_{\sigma^2 \in \left(\frac{\sigma_n^2}{\rho}, \rho\sigma_n^2\right)} Q\left(\frac{\lambda 1 - (s+\sigma^2)}{\sqrt{\frac{2}{N}}(s+\sigma^2)}\right)$$

$$\mathrm{Pd} = Q\left(\frac{\lambda 2\frac{\rho}{\sigma n^2} - (\rho\Upsilon+1)}{\sqrt{\frac{2}{N}}(\rho\Upsilon+1)}\right) \quad (10)$$

$$Pf = max_{\sigma^2 \in \left(\frac{\sigma_n^2}{\rho}, \rho\sigma_n^2\right)} Q\left(\frac{\lambda 1-\sigma^2}{\sqrt{\frac{2}{N}}\sigma^2}\right)$$

$$P_f = Q\left(\frac{\lambda 1 - \rho\sigma_n^2}{\sqrt{\frac{2}{N}}\rho\sigma_n^2}\right) \quad (11)$$

$$P_{md} = 1 - P_d = 1 - Q\left(\frac{\lambda 2\frac{\rho}{\sigma n^2} - (\rho\Upsilon+1)}{\sqrt{\frac{2}{N}}(\rho\Upsilon+1)}\right) \quad (12)$$

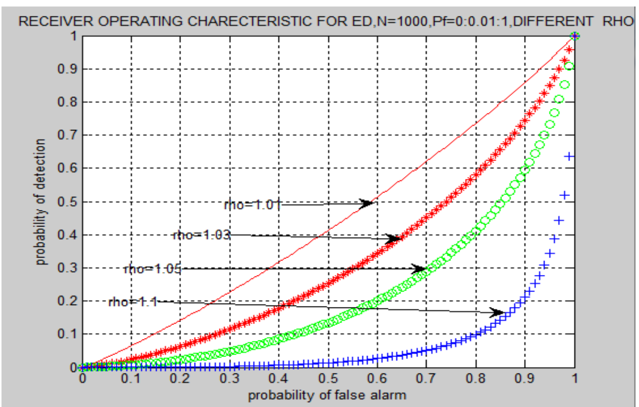

Figure2: ROC for ED under noise uncertainty consideration

Figure 2 is plotted between Pd vs. Pf at the various value of rho (σ). From the figure we are able to analyze that as σ factor is increasing, detection performance is decreasing gradually. σ factor is nearer to 1 but larger than one.

3. DYNAMIC THRESHOLD ENERGY DETECTION SCHEME:

We are able to see in above figure detection performance is degrading under noise uncertainty .uncertainty constant affecting the Pd. To resolve this drawback dynamic threshold scheme is projected [16],[18]. During this scheme, to make the threshold dynamic a constant factor is multiplied in threshold.

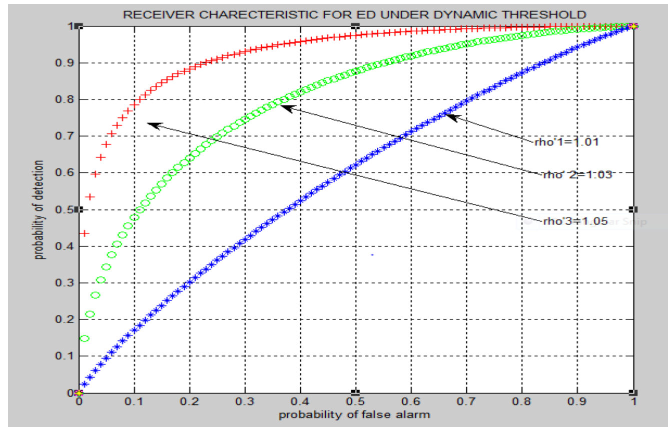

Figure 3-ROC for ED under different value of σ’

Figure 3 shows the mathematical results for ED technique plotted Pf vs. Pd at N=1000, Pd=0:0.01:1, σ=1.008, different value of σ’=1.01, σ’=1.03, σ’=1.05.From the figure as σ’ factor is increasing, detection probability is increasing.

4. DOUBLE THRESHOLD SCHEME:

Two thresholds as λ_1, λ2 are illustrated to improve the reliability of decision.[17]

We define: $\lambda_2 - \lambda_1 = \Delta\lambda$ (13)

Here, λ1=lower threshold bound and λ2=upper threshold bound. Then the test statics Ts isn't considered between λ1, λ2.if Ts is higher than than λ2, H1 (spectrum is said as occupied).and if Ts is lower than λ1, H0 (spectrum is said as vacant). Then Pd, Pmd, Pfa is changed as:

$$\mathrm{P_d} = \mathrm{Pr}\ (\mathrm{T_s} > \lambda_2 : \mathrm{H1}) = Q\left(\frac{\frac{\lambda 2}{\sigma n^2} - (\Upsilon+1)}{\sqrt{\frac{2}{N}}(\Upsilon+1)}\right) \quad (14)$$

$$\mathrm{Pfa} = \mathrm{Pr}(\mathrm{Ts} < \lambda 1 : \mathrm{H0}) = Q\left(\frac{\lambda 1 - \sigma n^2}{\sqrt{\frac{2}{N}}\sigma n^2}\right) \quad (15)$$

$$\mathrm{Pmd} = 1 - \mathrm{Pd} = 1 - Q\left(\frac{\frac{\lambda 2}{\sigma n^2} - (\Upsilon+1)}{\sqrt{\frac{2}{N}}(\Upsilon+1)}\right) \quad (16)$$

$\Delta\lambda$ Plays very important role to show detection or false alarm in this scheme. If $\Delta\lambda$ has higher value then there is the probability that test static Ts will fall between λ_1 & λ_2, sensing process will take place again. If $\Delta\lambda$ has lower value then there will be probability for false alarm or miss detection. So an appropriate value should be selected for$\Delta\lambda$.

5. PROPOSED DYNAMIC DOUBLE THRESHOLD SCHEME:

From the above approach we can analyzed that as noise uncertainty is increasing, the detection performance is degraded. To resolve this problem dynamic threshold scheme initialized. ρ' is the dynamic threshold factor and it is closer to 1. The limits for dynamic double threshold can be defined as:

$$\left\{\lambda 1' = \frac{\lambda 1}{\rho'}, \lambda 1\rho'\right.$$

$$\left\{\lambda 2' = \frac{\lambda 2}{\rho'}, \lambda 2\rho'\right. \qquad (17)$$

Under the consideration of dynamic double threshold for noise uncertainty P_d, P_{md}, P_f can be formulated as:

$$\mathrm{Pd} = \min_{\sigma^2 \in \left(\frac{\sigma_n^2}{\rho}, \rho\sigma_n^2\right)} \min_{\lambda 2' \in \left(\frac{\lambda 2'}{\rho'}, \rho'\lambda 2\right)} Q\left(\frac{\lambda 2 - (s+\sigma^2)}{\sqrt{\frac{2}{N}}(s+\sigma^2)}\right)$$

$$\mathrm{Pd} = Q\left(\frac{\left(\frac{\lambda 2}{\rho'}\right)\frac{\rho}{\sigma n^2} - (\rho\Upsilon+1)}{\sqrt{\frac{2}{N}}(\rho\Upsilon+1)}\right) \qquad (18)$$

$$Pfa = max_{\sigma^2 \in \left(\frac{\sigma_n^2}{\rho}, \rho\sigma_n^2\right)} max_{\lambda 1' \in \left(\frac{\lambda 1}{\rho'}, \lambda 1\rho'\right)} Q\left(\frac{\lambda 1' - \sigma^2}{\sqrt{\frac{2}{N}}\sigma^2}\right)$$

$$Pfa = \mathrm{Q}\left(\frac{\frac{\lambda 1}{\rho'} - \rho\sigma_n^2}{\sqrt{\frac{2}{N}}\rho\sigma_n^2}\right) \qquad (19)$$

$$\mathrm{Pmd} = 1 - \mathrm{Pd} = 1 - Q\left(\frac{\lambda 2\frac{\rho}{\sigma n^2} - (\rho\Upsilon+1)}{\sqrt{\frac{2}{N}}(\rho\Upsilon+1)}\right) \qquad (20)$$

In the figure graph is plotted between Pd vs. Pf for different value of $\Delta\lambda$. In this simulation additive white Gaussian noise is considered with SNR=-20dB, N=1000, Noise uncertainty is not considered but dynamic threshold factor is taken as $\sigma' = 1.1$

From the figure we can see at Pf=.1, Pd has values as .65, .7,.85 ,.45 for $\Delta\lambda = .15, .12, .1, 0$ respectively. So we can analyze at except zero as $\Delta\lambda$ is increasing, the value of Pd is decreasing because as $\Delta\lambda$ will increase, it will increase null region then sensing cycle will increase. At 0.1, detection performance is good. So it is very important to choose an appropriate value of $\Delta\lambda$ for better detection.

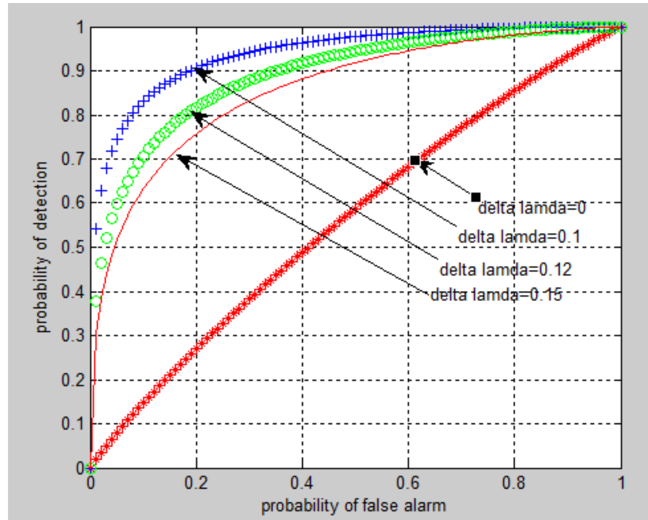

Figure 4: ROC curve of ED scheme under noise uncertainty with different $\Delta\lambda$

Simulation result:

The noise channel is taken as AWGN channel for figure 4. Signal to noise ratio (SNR) is taken as -20db. Number of sample (N) =1000 and modulation technique is used of BPSK type .Pf is considered as 1:.01:1. $\boldsymbol{\Delta\lambda}$ is considered as 0.1. The below plot is drawn between Pd vs. Pf for different cases as:

1. Without consideration of noise uncertainty
2. With consideration of noise uncertainty
3. With consideration of noise uncertainty and dynamic threshold

From the figure 5 it can be analyzed that at Pf=0.1, Pd=0.1, .05, 0.55 for without consideration of noise uncertainty, consideration of noise uncertainty and consideration of noise uncertainty with dynamic threshold respectively. So it can be seen that detection performance is improved by proposed scheme under noise uncertainty.

In figure6 shows the comparison between single threshold and dynamic double threshold for ED for different cases. As:

1. Without consideration of noise uncertainty
2. With consideration of noise uncertainty
3. With consideration of noise uncertainty and dynamic threshold

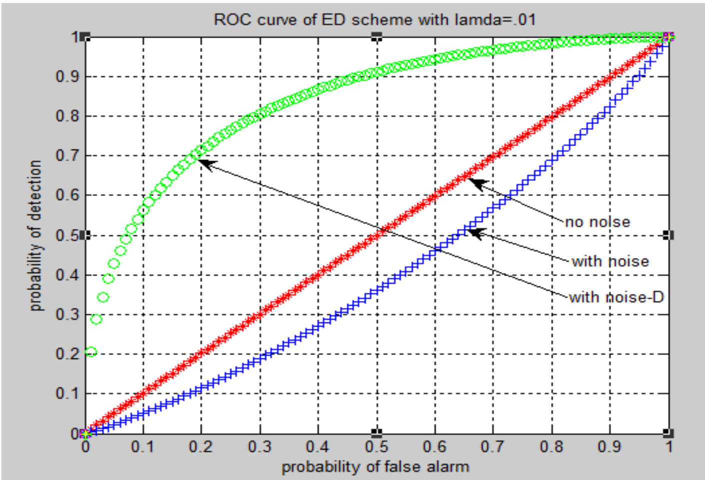

Figure5: ROC curve of ED scheme with dynamic double threshold for different cases at N=1000, SNR=-20 dB

NU* shows noise uncertainty with double threshold, NU*-D shows noise uncertainty with dynamic- double threshold, NU shows noise uncertainty under single threshold, NU-D shows noise uncertainty with dynamic single threshold.

So for Pf=0.1, Pd=0.1, 0.05, 0.57 for without NU, with NU and with NU-D under single threshold respectively. And under double threshold consideration, for Pf=.1, Pd=0.15, 0.1, 0.65 for without NU, with NU and with NU-D respectively. Therefore from the analysis it will conclude that detection performance is improved under proposed scheme.

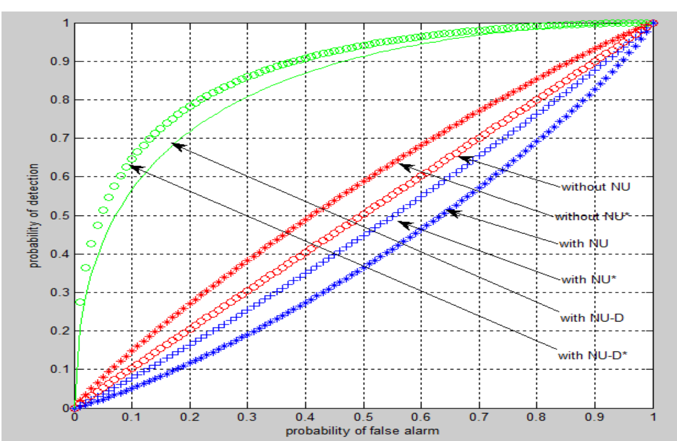

Figure: 6 Comparison between for single threshold and double threshold for detection performance of ED

6. CONCLUSION:

The energy detection technique among all other detection techniques is employed as a result of its terribly straightforward in use. However the noise variance continuously affects the wireless channel. Therefore this technique is in danger towards the noise uncertainty. To resolve this drawback a technique is projected in this paper that is thought as Double-Dynamic-threshold spectrum sensing method. This scheme improved the detection performance of ED under low SNR condition. The performance of this scheme depends on choice of $\Delta\lambda$ and dynamic threshold factor ρ'. In simulation result it will be seen that detection performance is improved at low Pf value. If appropriate value of these factors is chosen, the detection performance of ED under noise uncertainty will be improved and spectrum use will be improved.

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8. BIOGRAPHIES

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