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Performance Merit and Analysis of Dynamic-Double-Threshold Energy Detection Algorithm in Cognitive Radio System

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Abstract:*Nowadays, there's a deficiency of the spectrum as a result of advancement in wireless networks and services like Wi-Fi, Bluetooth, ZigBee and Wi-max, etc. A survey performed by the spectrum policy task force (SPTF) among the Federal communication Commission (FCC), states that really commissioned spectrum is inefficiently used as some bands stay vacant for long term period in some explicit nation-states, some frequency bands area unit partly occupied and therefore the alternative components of the spectrum bands area unit densely used. Attributable to the massive demand of spectrum, psychological feature of Cognitive Radio (CR) technology gains abundant attention because it will sense the unused spectrum bands and optimize spectrum utilization and enhance the standard of service for the general system. Many spectrum sensing techniques includes the Energy Detection (ED), Matched Filter detection (MFD) and Cyclostationary feature Detection (CFD) techniques.In observe, noise power might vary with time that is understood as Noise Uncertainty. This paper is extensively supported the study of Energy Detection technique for spectrum sensing. Dynamic-Double-Threshold technique on the framework of Energy Detection technique has been planned and analyzed through simulation studies mistreatment MATLAB2015a.*
Keywords:*Cognitive radio, dynamic-double-threshold, energy detection, spectrum hole, noise uncertainty.*

I. Introduction

In today's scenario, for wireless communication a fixed spectrum is being assigned to the specific license holders for a certain duration, in which usage of spectrum is concentrated on limited portions while a large portion of spectrum remains unutilized [1]. So, for increasing the efficiency of spectrum utilization a Dynamic spectrum Access network approach [DSNPA's] is taken into consideration in the form of technology known as cognitive radio [CR].

According to Federal Communications commission (FCC): " Cognitive radio: A radio or system that senses its operational electromagnetic environment and can dynamically and autonomously adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability, access secondary markets" [2]. Hence cognitive radio is one of the platform through which the spectrum can be utilized more efficiently and enormously. The process of determining the presence or absence of primary user in assigned spectrum band is known as spectrum sensing. This is the main part of CR, through which we can detect the spectrum holes more frequently.

In this paper, the basic spectrum sensing technique i.e. energy detection techniques is being analyzed in accordance with the dynamic double threshold energy detection scheme to increase the performance of the given process by varying the SNR value through which distinguishing process between signal and noise becomes most efficient[3].

Cognitive radio is a novel technology which improves the spectrum utilization by allowing secondary users to borrow unused radio spectrum from primary licensed users or to share the spectrum with the primary users. As an intelligent wireless communication system, cognitive radio is aware of the radio frequency environment, selects the communication parameters (such as carrier frequency, modulation type, bandwidth and transmission power) to optimize the spectrum usage and adapts its transmission and reception accordingly. By sensing and adapting to the environment, a cognitive radio is able to fill in the spectrum holes and serve its users without causing harmful interference to the licensed user. To do so, the cognitive radio must continuously sense the spectrum it is using in order to detect the re-appearance of the primary user [5]. Once the primary user is detected, the cognitive radio should withdraw from the spectrum instantly so as to minimize the interference. This is very difficult task as the various primary users will be employing different modulation schemes, data rates and transmission powers in the presence of variable propagation environments and interference generated by other secondary users [4].

II. Spectrum Sensing Technique

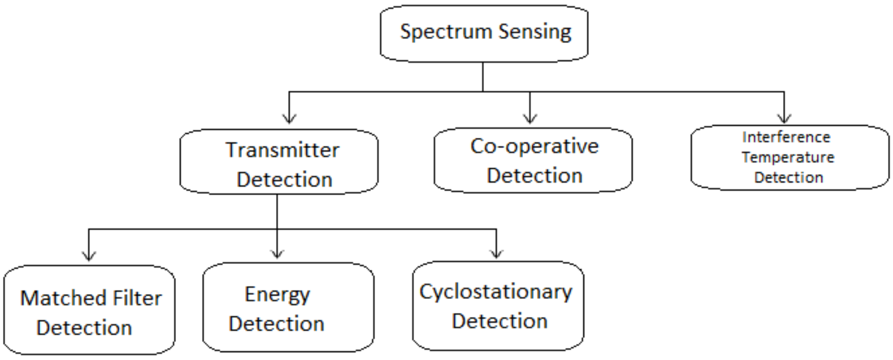

Fig. 1 Spectrum Sensing Techniques

Figure 3-1 gives the meticulous categorization of spectrum sensing techniques. They are extensively categorized in three types, transmitter detection, cooperative detection and interference based detection. In transmitter detection techniques, the received signal assessment is the key concept, and the transmitter detection techniques are also known as non-cooperative detection techniques. The transmitter detection technique is again categorized into Matched Filter Detection (MFD) Energy Detection (ED), and Cyclostationary Feature Detection (CFD) Techniques [6]. Following subsections gives the detailed explanation about these three techniques.

(a) Matched Filter Detection (MFD)

One of the eminent detection techniques in the area of signal processing for retrieving the known information from a signal at receiver end is MFD. The MFD is work on the principle of coherent detection. The MF is a linear filter and it is devised in such a way that it enlarges the Signal-to-Noise Ratio (SNR) of the PU signal at the cognitive user terminal under AWGN channel.

MFD technique can be used only when the prerequisite information like modulation type, pilot carrier, pulse shape and spreading codes, etc. are known in prior to the cognitive user. In order to access all the prior information regarding the PU signal, synchronization is must between the cognitive user terminal and the primary user transmitter. Whenever the secondary user has prior information regarding PU signal, the MFD can be applied. The block diagram of MFD is given in the fig.2 below:

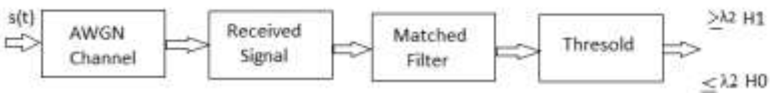

Fig.2 block diagram of matched filter detection technique

The output of the matched filter is compared with the pre-set threshold value in order to determine the spectrum occupancy, i.e. presence or absence of PU.
Since the secondary user is permitted to explore all the information of PU signal, it creates the security threat on licensed spectrum users. Also synchronization between the PU and cognitive user terminal is must, accordingly the synchronization fading cause's performance deterioration badly.
In addition, every single PU has its own properties therefore, different types of matched filters required for primary user's signal detection, which raises the CR system intricacy largely.
Matched filter operates is comparable to the correction of received unknown signal within the impulse response of matched filter, which is priory known PU signal, i.e. reference signal, or its time shifted form. Mathematically, the matched filter can be represented as follows:

$$D(x) = \frac{1}{N}\sum_{n=0}^{N-1} x(n) \times s(n) \qquad (1)$$

Where, $s(n)$= prior known signal,
$D(x)$ = test statistics.

Thus from (3) we can deduce that extra hardware are needed for synchronization, and also the information of PU signal is necessary in prior to construction of conjugate signal results in large power consumption and implementation complexity [9].

(b) Energy Detection (ED)

When the sufficient information regarding the primary user signal is not available at the cognitive user terminal, the MFD technique cannot be used. Nevertheless, if the identification of the presence of primary user's signal perverted from AWGN is required, then ED technique is worthwhile [7]. The underlying concept at the bottom of ED is evaluation of the power the PU signal received at the cognitive user terminal. The basic block diagram of ED is depicted in fig.3 below.

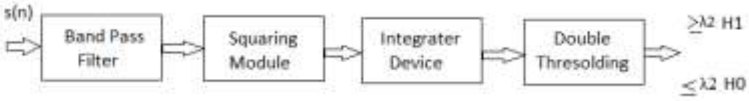

Fig.3 block diagram of energy detection technique

In order to estimate the energy of PU signal the filtered signal from the BPF is squared and integrated so as to calculate energy and then the final output of integrator is compared with a pre-set threshold value for spectrum occupancy details [8].

The technique is most commonly used because of low computational cost and implementation complexities. ED technique is also known as Blind Detector as it only estimates energy disregarding the type and properties of the signal. Rather than this fact, the ED also suffers from some drawbacks:

- Sensing time is higher
- Cannot discriminate between the PU signal and the cognitive user signal
- Performance degraded in case of noise uncertainty

The calculation of energy can be done by following equation:

$$E = \sum_{n=0}^{N-1} |x(n)|^2 \qquad (2)$$

This is also the metric used for comparison. When PU is absent, the input signal will be x(n)=w (n), H0. The test statistic for ED technique is given as [13]:

$$D(x) = \frac{1}{N}\sum_{n=0}^{N-1}[x(n)]^2 \qquad (3)$$

Here, $D(x)$ is the test statistic, N is the number of sample taken under the observation period. For a single threshold value λ, presence or absence of licensed user can be declared as

$$\begin{cases} D(x) > \lambda & H1: Licenced\ Terminal\ is\ Present \\ D(x) < \lambda & H0: Licenced\ Terminal\ is\ Absent \end{cases}$$

(c) Cyclostationary Feature Detection (CFD)

It has been advised in the literature that the CFD technique is better than the ED and MFD techniques. As it already explained previously that the MFD is coherent type detector and needed information in prerequisite format, and though the ED technique is non-coherent but is unable to differentiate between the PU and the cognitive user signals, and its performance depends upon the noise variance.

Signal showing periodicity is known as cyclostationary signals [10]. Periodicity in the signal comes due to modulation, coding or the pilot data used for synchronization, hopping sequence, spreading code etc. These are having inbuilt periodicity. Whereas the noise is a wide sense, stationary signal with no such properties stated above. Thus extraction of noise from the received signal is feasible using any spectral correlation function. A cyclostationary feature is purposely encapsulated along with the physical property of the signals; these features can be efficiently generated and identified with the use of moderate intricacy receiver and transmitter. The block diagram for cyclostationary feature detection is shown in the fig.4 below.

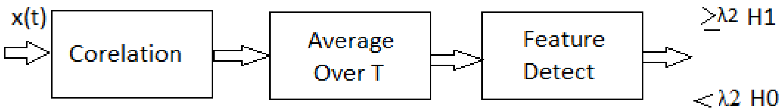

Fig.4 block diagram of cyclostationary feature detection technique

Cognitive user recognizes the arbitrary signal with a distinct modulation type, even though if it exists with a hypothetical noise by employing periodic information like auto correlation and mean of the PU signal, and the autocorrelation and mean can be evaluated via Spectral Correlation Function (SCFs).

The CFD technique has intelligence to distinguish the primary user's signal and noise; therefore, it outperforms the Energy Detection and Matched Filter Detection techniques discussed above. But larger observation time and more computational complexity are the two drawbacks.

III. System Modelling

(a) Energy Detection

In our system model, we consider that there is a cognitive terminal that needs to detect the primary terminal signal using energy detector. In this scheme, only the transmitted power of the primary system is known, therefore, this power will be detected firstly, and then compared with a predefined threshold to determine whether the spectrum band is available or not. When the energy of the received signal is greater than the detection threshold λ, the detector will indicate that the primary user is present, which will depicted by exist hypothesis H_1, otherwise, the primary user is absent, which will be represented by null hypothesis H_0.

The performance of spectrum sensing is measured by two parameters: the detection probability P_d which indicates that the primary user exists, where this parameter should be as big as possible to protect the primary users from the interference, and false alarm probability P_f which indicates that the primary user is present while in reality it is not. This probability should be as small as possible to increase the spectrum utilization.

In the rest of the paper, we will go through a mathematical analysis to determine the detection parameters. The decision of energy detector is the test of the following hypothesis:

$$x(n) = \begin{cases} w(n)H_0 & \rightarrow Signal\ Absent \\ s(n) + w(n) \quad H_1 & \rightarrow Signal\ Present \end{cases} \tag{4}$$

Where n = 0,1,2,3... N, which represents the number of samples (detection period). $x(n)$is the received signal at the secondary user, $s(n)$ is the primary user signal, and is assumed to be independent and identically distributed random process of zero mean and variance of σ_s^2. $w(n)$denotes the noise signal and is also assumed to be independent and identically distributed random process of zero mean Additive White Gaussian Noise (AWGN) with varianceσ_n^2.

If there is no deterministic knowledge about the signal *X*(*n*), i.e., we only know the average power of the signal. In this case the optimal detector is energy detector or radiometer [10], the test statistic is given by

$$D(x) = \frac{1}{N}\sum_{n=0}^{N-1} x(n)^2 \begin{cases} > \lambda & H_1 \\ < \lambda & H_0 \end{cases} \tag{5}$$

where*D*(*x*) is the decision variable and λ is the decision threshold, *N* is the number of samples. If the noise variance is known and without noise uncertainty, based on *central limittheorem* (CLT), it has: [12-13]

$$\begin{cases} D(x|H_0) \sim \mathrm{N}(\sigma_n^2, 2\sigma_n^4/N) \\ D(x|H_1) \sim \mathrm{N}(P + \sigma_n^2, 2(P + \sigma_n^2)^2/N \end{cases}$$

where$P = \frac{1}{N}\sum_{n=0}^{N-1} |x(n)|^2$is the average signal power, σ2*n* is the noise variance. Then, we can obtain the probabilityof detection, false alarm probability, and missing probability,respectively [12-13].

$$P_d = P_r(D(x) > \lambda|H_1) = Q\left(\frac{\lambda - (P+\sigma_n^2)}{\sqrt{2/N}(P+\sigma_n^2)}\right) \tag{6}$$

$$P_{fa} = P_r(D(x) > \lambda|H_0) = Q\left(\frac{\lambda - \sigma_n^2}{\sqrt{2/N}\sigma_n^2}\right) \tag{7}$$

$$P_{md} = 1 - P_d = 1 - Q\left(\frac{\lambda - (P+\sigma_n^2)}{\sqrt{2/N}(P+\sigma_n^2)}\right) \tag{8}$$

where Q(·) denotes standard Gaussian complementary cumulative distribution function (*CDF*). P_d, P_{fa} and P_{md} represent detection probability, false alarm probability and missing probability respectively. To find out relation between SNR, P_d and P_{fa} calculating value of λ from equation 7:

$$\lambda = Q^{-1}(P_{fa}) \times \sqrt{2/N}\sigma_n^2 + \sigma_n^2 \tag{9}$$

Now putting value of λ from eq(9) to eq(6)

$$P_d = Q\left(\frac{Q^{-1}(P_{fa}) \times \sqrt{2/N}\sigma_n^2 + \sigma_n^2 - (P+\sigma_n^2)}{\sqrt{2/N}(P+\sigma_n^2)}\right) \tag{10}$$

Solving eq(10)

$$Q^{-1}(P_d) \times \sqrt{2/N}(P + \sigma_n^2) = Q^{-1}(P_{fa}) \times \sqrt{2/N}\sigma_n^2 - P$$

$$Q^{-1}(P_{fa}) \times \sqrt{2/N}\sigma_n^2 - Q^{-1}(P_d) \times \sqrt{2/N}(P + \sigma_n^2) = P$$

$$\sqrt{2/N}[Q^{-1}(P_{fa}) \times \sigma_n^2 - Q^{-1}(P_d) \times (P + \sigma_n^2)] = P$$

$$\frac{2}{N}\ [Q^{-1}(P_{fa}) \times \sigma_n^2 - Q^{-1}(P_d) \times (P + \sigma_n^2)]^2 = P^2$$

$$\frac{2}{N}\ [Q^{-1}(P_{fa}) - Q^{-1}(P_d) \times (\frac{P}{\sigma_n^2} + 1)]^2 = \frac{P^2}{(\sigma_n^2)^2} \tag{11}$$

Now SNR can be defined as ratio of signal power to noise power, hence

$$SNR = \frac{P}{\sigma_n^2}$$

Putting value of SNR in eq(11)

$$\frac{2}{N}\ [Q^{-1}(P_{fa}) - Q^{-1}(P_d) \times (SNR + 1)]^2 = SNR^2 \quad (12)$$

Now from eq(12) value of SNR can be obtained.

(b) Dynamic Double Threshold Energy Detection Technique

The performance of system is degraded sharply as the noise uncertainty coefficient is increasing, which results in severe interferences to the licensed terminals. In order to improve the reliability of decision double threshold scheme is implemented. $\rho^{'}$ is the dynamic threshold factor and it is closer to 1, i.e. $\rho^{'} > 1$ The limits for dynamic-double-threshold can be defined as [14] [16]:

$$\begin{cases} \lambda^{'} \epsilon [\frac{\lambda}{\rho^{'}}, \rho^{'}\lambda] \\ \sigma^2 \epsilon [\frac{\sigma_n^2}{\rho}, \rho\sigma_n^2] \end{cases}$$

While, considering dynamic-double-threshold under noise uncertainty, probability of detection can be defined as Considering both threshold values same

$$P_d = \underset{\sigma^2 \epsilon [\frac{\sigma_n^2}{\rho}, \rho\sigma_n^2]}{min}\ \underset{\lambda^{'} \epsilon [\frac{\lambda}{\rho^{'}}, \rho^{'}\lambda]}{min} \left(\frac{\lambda^{'} - (P + \sigma^2)}{\sqrt{2/N(P + \sigma^2)}} \right)$$

$$P_d = Q\left(\frac{\lambda/\rho^{'} - (P + \sigma_n^2/\rho)}{\sqrt{\frac{2}{N}}(P + \sigma_n^2/\rho)} \right) \quad (13)$$

$$P_{fa} = \underset{\sigma^2 \epsilon [\frac{\sigma_n^2}{\rho}, \rho\sigma_n^2]}{max}\ \underset{\lambda^{'} \epsilon [\frac{\lambda}{\rho^{'}}, \rho^{'}\lambda]}{max} \left(\frac{\lambda^{'} - \sigma^2}{\sqrt{2/N\sigma^2}} \right)$$

$$P_{fa} = Q\left(\frac{\lambda\rho^{'} - \sigma_n^2\rho}{\sqrt{\frac{2}{N}}\sigma_n^2\rho} \right) \quad (14)$$

$$P_m = 1 - P_d = 1 - Q\left(\frac{\lambda/\rho^{'} - (P + \sigma_n^2/\rho)}{\sqrt{\frac{2}{N}}(P + \sigma_n^2/\rho)} \right) \quad (15)$$

Now using eq(14) finding value of λ

$$\lambda = Q^{-1}(P_{fa}) \sqrt{\frac{2}{N}} \sigma_n^2 \frac{\rho}{\rho^{'}} + \sigma_n^2 \frac{\rho}{\rho^{'}}$$

Putting value of λ to eq(13), we get

$$\frac{1}{\rho^{'}} \sqrt{\frac{2}{N}} \left[Q^{-1}(P_{fa}) \frac{\sigma_n^2\rho}{\rho^{'}} - \rho^{'} Q^{-1}(P_d) \left(P + \frac{\sigma_n^2}{\rho} \right) \right] = \frac{1}{\rho^{'}} \left[\rho^{'} \left(P + \frac{\sigma_n^2}{\rho} \right) - \frac{\sigma_n^2\rho}{\rho^{'}} \right]$$

$$\sqrt{\frac{2}{N}} \left[Q^{-1}(P_{fa}) \frac{\rho}{\rho^{'}} - \rho^{'} Q^{-1}(P_d) \left(\frac{P}{\sigma_n^2} + \frac{1}{\rho} \right) \right] = \left[\rho^{'} \left(\frac{P}{\sigma_n^2} + \frac{1}{\rho} \right) - \frac{\rho}{\rho^{'}} \right]$$

$$\sqrt{\frac{2}{N}} \left[Q^{-1}(P_{fa}) \frac{\rho}{\rho^{'}} - Q^{-1}(P_d) \left(\rho^{'} SNR + \frac{\rho^{'}}{\rho} \right) \right] = \left[\left(\rho^{'} SNR + \frac{\rho^{'}}{\rho} \right) - \frac{\rho}{\rho^{'}} \right]$$

$$N = 2 \left[Q^{-1}(P_{fa}) \frac{\rho}{\rho^{'}} - Q^{-1}(P_d) \left(\rho^{'} SNR + \frac{\rho^{'}}{\rho} \right) \right]^2 \left[\left(\rho^{'} SNR + \frac{\rho^{'}}{\rho} \right) - \frac{\rho}{\rho^{'}} \right]^{-2} \quad (16)$$

These equations show that the dynamic-double threshold scheme is main idea to deal with the noise uncertainty issue. Here, unlike the traditional dynamic threshold scheme [16], the dynamic factor is associated with both the upper and lower bounds of the two thresholds in (13) and (14), which causes the performance enhancement [14]. Equation (16) shows relation between SNR and probability density function.

IV. Results &Discussion

Fig. 5 shows plot of probability of detection with respect to probability of false alarm at different values of SNR. According to graph as the signal strength increases probability of detection also increases. When false alarm is 0.1 probability of detection is 0.977 at SNR = 10dB, probability of detection is 0.993 at SNR = 15dB, probability of detection is 0.997 at SNR = 20dB.

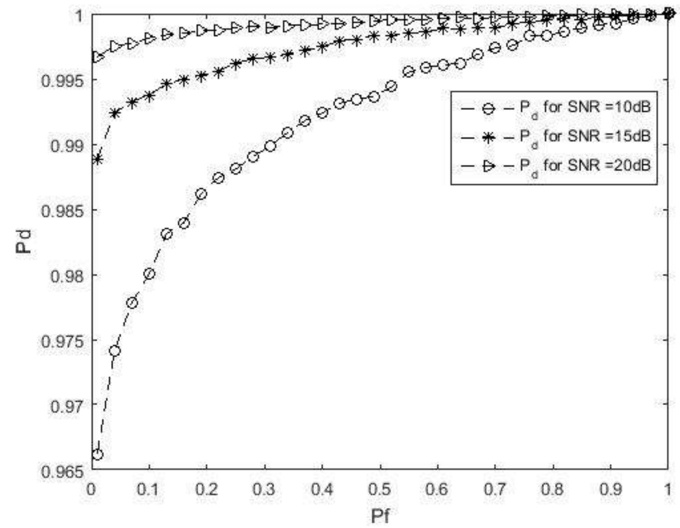

Fig. 5 Probability of detection at different SNR values

Fig. 6 shows plot of probability of detection with respect to probability of false alarm at different values of number of signal (N). According to graph as number of signal increases probability of detection also increases. And as probability of false alarm increases probability of detection increases rapidly for low values of probability of false alarm and slowly for higher value of false alarm. When false alarm is 0.1 probability of detection is 0.97 at N = 50, probability of detection is 0.975at N = 80,probability of detection is 0.977 at N = 100.

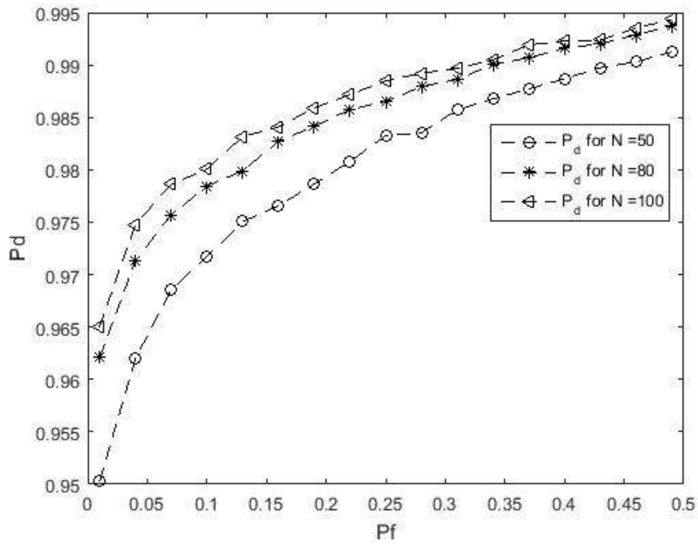

Fig. 6 Probability of detection at different number of signal (N) values

Fig. 7 shows plot of probability of detection with respect to probability of false alarm at different values of noise uncertainty. According to graph as noise uncertainty increases probability of detection also decreases. And as probability of false alarm increases probability of detection increases rapidly for low values of probability of false alarm and slowly for higher value of false alarm. Parameter are taken as values of ρ = [1.05, 1.05, 1,1.05], $\rho^{'}$ = [1.03,1.04,1,1] and SNR = [5, 10, 15,20]. When false alarm is 0.1 probability of detection is

0.9 for first pair ofρ, ρ', probability of detection is 0.968for first pair ofρ, ρ',probability of detection is 0.985for first pair ofρ, ρ', probability of detection is 0.988 for first pair of ρ, ρ',.

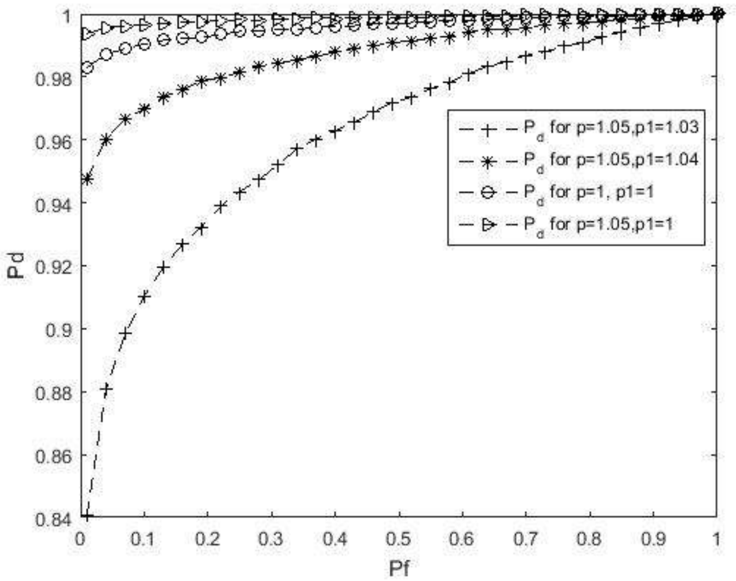

Fig. 7 Probability of detection at different values noise uncertainty

V. Conclusion

The most exceptional technology in use within the fashionable wireless trade is psychological feature radio so. All the rising technology is exploitation Cr for its entire system or as a supporting system. Consequently, all the systems got to wear down the primitive demand of spectrum sensing in Cr. There are varied techniques that are enforced to envision the spectrum occupancy details of the underutilized authorised spectrum bands. The thesis explores the three basic spectrum sensing techniques with their pros and cons, and their performance are analysed beneath noise unsure atmosphere. To beat the result of unsure noise power, the dynamic threshold implementation has been done on the transmitter detection techniques.

The fastened frequency allocation strategy is the main drawback of spectrum utilization, which ends up at spectrum shortage. The conception of psychological feature radio links sort out this issue up to some extent. The spectrum sensing techniques has been mentioned and it's discovered that the dynamic double threshold feature detection technique outperformed technique. From simulation results it's clear that the performance improves with a lot of range of samples throughout bound detection amount even at low SNR worth.

The detection performance is often improved with implementation of the dynamic threshold conception. The simulation results shows that the, performance is degraded with increasing noise uncertainty; for noise uncertainty issue one, 1.01, 1.02, 1.03, 1.05. The dynamic threshold constant is enforced and it offers the performance improvement from zero.08 to 0.58 beneath noise uncertainty thought and noise uncertainty and dynamic threshold implementation. From the numerical analysis, it's all clear that the detection performance and also the range of samples turning into terribly massive that isn't possible in sensible state of affairs considering noise uncertainty and also the introduction of dynamic threshold leads to reduced N worth, that is doable.

The energy detection technique has been used amongst the essential transmitter detection techniques as a result of its less complexness and implementation price. This methodology is extremely abundant prone towards the noise uncertainty drawback as a result of varied channel condition and conjointly systems noise. This treatise projected dynamic-double-threshold energy detection theme so as to minimize the result of varied noise uncertainty and it performs higher even beneath low S/N (SNR) condition.

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