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Performance Analysis of Noise Variance Based Adaptive Spectrum Sensing In Different Fading Channels

S.Varalakshmi[1] and S.Shanmugavel[2]
[1]Research scholar, ECE Department, Anna University, Chennai.
[2]Professor, ECE Department, Anna University, Chennai.
Email: ssvlakshmi@yahoo.co.in, sethusvel@gmail.com

Abstract

In cognitive radio networks, spectrum sensing is one of the major issues to utilize the idle spectrum of the primary user channels opportunistically among the secondary users. There is a tradeoff between sensing time and quality of spectrum sensing. Therefore to improve the spectrum sensing performance of energy detector in the low SNR region and reduce the sensing error, adaptive threshold with noise variance estimation based sensing is proposed. In this adaptive sensing, to reduce spectral leakage, Discrete Fourier transform Filter Bank (DFB) is used. In this adaptive sensing, noise variance is estimated adaptively with the variation of noise in the primary user signal. This adaptive threshold reduces the Spectrum sensing error much more and improves the probability of detection in the low SNR region. The performance of this adaptive sensing technique is verified using MATLAB for different fading channels such as Rayleigh, Rician and Nakagami.

Index Terms: Adaptive spectrum sensing, adaptive threshold with noise variance estimation, Discrete Fourier transform filter bank, Fading channels.

Introduction

In wireless communication networks, due to the tremendous increase in communication services, spectrum scarcity has become a critical issue. To overcome this problem, the emerging cognitive Radio Network technology introduces Dynamic Spectrum Access (DSA) which enables the secondary users or unlicensed users to dynamically access the idle spectrum of primary users (PU) or licensed users without causing any harmful interference to the PUs [2], [3], [4]. In order to utilize the idle spectrum of the PUs, spectrum sensing has to be performed. Spectrum sensing is the process of identifying the idle spectrum of the primary users, or the process of measuring the spectral content or measuring the radio frequency energy over the spectrum, or obtaining the spectrum usage characteristics across multiple dimensions such as time, space, frequency and code.

The most commonly available spectrum sensing techniques are Energy detector, Cyclostationary detector, Matched filter detector, HMM (Hidden Markov Model) based sequence detector etc [2], [3], [4]. Different spectrum sensing techniques and their merits and demerits have been discussed in [3],[5] and [6].

In spectrum sensing there is always a tradeoff between sensing time and the accuracy of sensing. The sensing accuracy can be improved by increasing the number of samples and the sensing time. The increase in the number of samples, increases the sensing accuracy but it can be increased up to the SNR wall. Below a certain threshold even though the number of samples is increased, the detector fails to be robust [12]. This phenomenon is called as SNR wall.

When the sensing time is increased, this in turn will affect the throughput of the system. Because in one frame duration, the more is the sensing time, the lesser is the data transmission time. Therefore there is a necessity to reduce the sensing time to achieve high throughput with less sensing error. Sensing error is the sum of the probabilities of false alarm and missed detection. Energy detector is a simple and fast detector which measures the SNR value of the primary user channel and based on that it decides the occupancy of the channel. As sensing is based on the SNR value, the sensing error is high at low SNR region due to noise and it is difficult for the energy detector to discriminate the received signal and noise [13].This increases the probability of false alarm and sensing error. When the sensing error is more the sensing performance degrades. This affects the probability of detection and throughput of the secondary users.

To overcome these problems, this adaptive noise variance based sensing technique estimates the noise variance with Auto Regressive (AR) parametric estimation method. The threshold of the energy detector is varied in accordance with the variation of the noise. If the threshold value is assumed to some value it deviates from its original value when the noise level changes in the signal. This reduces the sensing error and improves the sensing performance such as probability of detection much better in the low SNR region. The performance of this adaptive sensing technique has been verified for different fading channels (Rayleigh, Rician & Nakagami) for different cases such as adaptive threshold and fixed threshold based sensing with some fixed value of noise variance.

The rest of the paper is organized as follows: Section II discusses about the related work and section III elaborates about the adaptive spectrum sensing technique. Section IV illustrates about the adaptive threshold and section V discusses the estimation of noise variance. Section VI explains the different fading channels. Section VI describes about the performance evaluation of the adaptive spectrum sensing technique and section VII discusses about the conclusion and future work.

Related Work

In general, spectrum sensing is understood as the measure of spectral content, or the radio frequency energy over the spectrum. In Cognitive radio networks, the meaning of spectrum sensing is obtaining the spectrum usage characteristics across multiple dimensions such as space, time, frequency and code. The SUs can sense the availability of the PU's spectrum by any one of the available spectrum sensing techniques such as Energy detector, Matched filter detector, Cyclostationary detector or waveform based detector etc, [2], [3]. Energy detector consumes least sensing time but the sensing error is more in the low SNR region. Therefore, there is a tradeoff between sensing time and sensing accuracy. To overcome this problem, the threshold of the energy detector is adaptively varied with the estimated noise variance.

In paper [1] the threshold of the energy detector is varied with the dynamic variation of noise variance and sensing error has been reduced. But the performance is not verified for different fading channels. The reduction of sensing error improves the probability of detection in the low SNR region. The probability of detection performance over Nakagami fading channel is analyzed in [7]. Closed form solution for the probability of detection is also obtained.The detection performance of sensing is improved with increased complexity in [8].

The adaptive sensing technique used in [14] is based on the previous channel results and channel state information (CSI).This adaptive sensing improves sensing performance with the increase of sampling frequency. But the increase of sampling frequency is restricted by hardware constraints.

In spectrum sensing there is always a tradeoff between sensing time and throughput.

System Model:

A filter bank based energy detector is considered for spectrum sensing and it is given in fig.1. This filter bank is used to reduce the spectral leakage. The received signal at any time instant n is given by,

$$X(n) = S(n) + V(n) \tag{1}$$

Where S(n) is the active radio signal in the CR system and V(n) is the AWGN with zero mean and variance σ_v^2.

The performance of the fixed threshold energy detector is good only in the high SNR region when compared to low SNR region, because it is very difficult for the energy detector to discriminate the signal and noise in the low SNR region. To improve the sensing performance of the energy detector in the low SNR region, the threshold of the energy detector is varied in accordance with the variation of noise variance. The noise variance of the detector is estimated based on the parametric method. The adaptive threshold estimation with noise variance reduces the sensing error and thus improves the sensing performance.

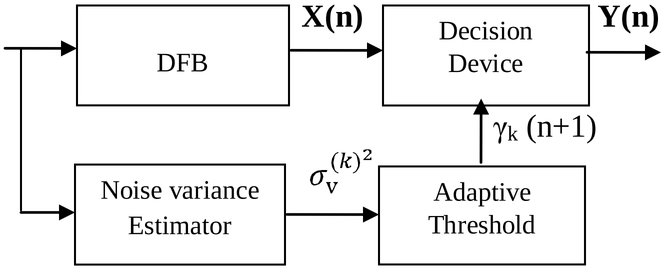

Figure 1: Block Diagram of Adaptive Noise Variance Based Sensing.

In this adaptive noise variance based sensing technique the received signal from the primary user is passed through a Discrete Fourier transform based filter bank to reduce the spectral leakage and a decision device which decides whether the primary user signal is present or absent based on the adaptive threshold. The noise variance estimator estimates the noise variance of the received signal using a parametric method and changes the threshold of the detector adaptively.

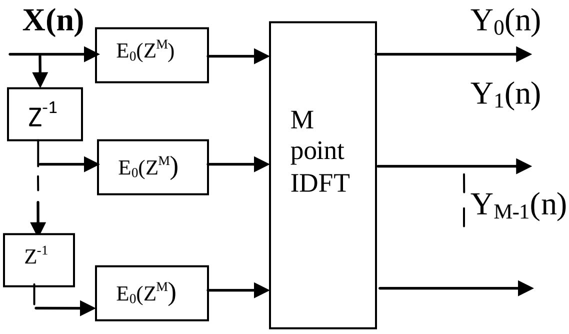

Figure 2: Block Diagram of Discrete Fourier Transform Filter Bank

The block diagram of discrete Fourier transform filter bank is given in fig.2. The signal received from the PU is passed through a DFB and the output is used for spectrum sensing. This poly phase filter bank reduces the complexity and it is zeroth order low pass filter.

In this adaptive spectrum sensing technique, the probability of detecting a PU in subband k is [1]

$$P_d^{(k)}(\gamma_k\,(n)) = \Pr[Y_k(n) > \gamma_k\,(n)|H_{1,\,k}]$$

$$= \frac{1}{2}\, erfc\left[\frac{\gamma k\,(n) - M(\sigma_v^{(k)^2} + \sigma_y^{(k)^2})}{2\sqrt{M(\sigma_v^{(k)^2} + \sigma_y^{(k)^2})2}}\right] \qquad (2)$$

The probability of false alarm for a kth subband of a PU is

$$P_{fa}^{(k)}(\gamma_k\,(n)) = \Pr[Y_k(n) > \gamma_k\,(n)|H_{0,\,k}]$$

$$= \frac{1}{2}\ erfc[\frac{\gamma k\ (n) - M\sigma_v^{(k)^2}}{2\ \sigma_v^{(k)^2}\sqrt{M}}] \quad (3)$$

The probability of missed detection of kth subband of a PU is

$$P_{fmd}^{(k)}(\gamma_k\ (n)) = 1 - P_d^{(k)}(\gamma_k\ (n)) \quad (4)$$

At any time instant n, the spectrum sensing performance depends on these probabilities and these are the functions of the variable threshold γ_k (n). $\sigma_v^{(k)^2}$ is the received signal noise variance and $\sigma_y^{(k)^2}$ is the estimated noise variance of the signal. The noise variances are varying with time.

Estimation of Adaptive Threshold

For the optimal sensing performance, both the probability of missed detection and the probability of false alarm are important along with the adaptive threshold**.** Since the sensing error is the sum of the probabilities of false alarm and missed detection. The expression for sensing error for the kth sub band is given as follows, [1]

$$E^{(k)}(\ \gamma_k\ (n)) = \delta\ P_{fa}^{(k)}(\gamma_k\ (n)) + (1 - \delta\ )P_{md}^{(k)}(\gamma_k\ (n)) \quad (5)$$

The optimal value of threshold is given for the dynamic scenarios, by using a gradient based update,

$$\gamma_k\ (n+1) = \gamma_k\ (n) - \mu_k\ \nabla E^{(k)}(n) \quad (6)$$

The expression for gradient $\nabla E^{(k)}(n)$ is given by,

$$\nabla E^{(k)}(n) = \frac{-\delta}{2\ \sigma_1^{(k)^2}\sqrt{\pi M}}\exp[-(\frac{\gamma k\ (n) - M\sigma_1^{(k)^2}}{2\ \sigma_1^{(k)^2}\sqrt{M}})^2] +$$

$$[(1-\ \delta) + \frac{(1-\ \delta)}{2\ \sigma_2^{(k)^2}\sqrt{\pi M}}]\exp[-(\frac{\gamma k\ (n) - M\sigma_2^{(k)^2}}{2\ \sigma_2^{(k)^2}\sqrt{M}})^2] \quad (7)$$

Noise Variance Estimation and Adaptive Threshold Algorithm

In AR parametric estimation based noise variance expression using auto correlation method is given as follows, [1]

$$\sigma_v^{(k)^2} = \frac{\left[\sum_{j=1}^{p} a_j^{(k)}\ \{R_X^{(k)}(j) + \sum_{i=1}^{p} a_i^{(k)}\ R_X^{(k)}(|j-i|)\}\right]}{\sum_{j=1}^{p}\ \ a_j^{(k)2}} \quad (8)$$

where $R_X^{(k)}$(j) $R_y^{(k)}$ (j) –are the autocorrelation coefficients of the noisy signal X_k(n) and uncontaminated signal y_k(n).

Adaptive threshold of spectrum sensing is calculated by making use of the estimated noise variance and the gradient based threshold adaptation.

The Adaptive threshold algorithm is given as follows,

For each sub band,

1. Calculate the average energy of the detector.
2. From the received noisy signal, compute the unbiased estimate of the autocorrelation coefficients $R_X^{(k)}$(j).
3. Evaluate the AR parameters utilizing a least squares procedure.
4. Compute the noise variance using AR model.
5. If the difference between the computed threshold in the current time instant and the lost time instant value is greater than the reference threshold, then update the threshold and the gradient values.

Then calculate the average probability of detection for different fading channels.

Spectrum Sensing In Different Fading Channels

In this proposed work, the threshold of the DFB based energy detector is varied in accordance with the variation of the noise variance. The performance of the adaptive noise variance based spectrum sensing is verified for different fading channels. The probability of detection in any fading channel is given as follows [15],

$$P_d=\int_0^{\infty} Q_u(\sqrt{2\gamma 1}, \sqrt{\lambda}) f_{\gamma 1}(\gamma_1) d\gamma_1 \tag{9}$$

If the signal amplitude follows a Rayleigh distribution, then the SNR γ_1 follows an exponential PDF given by

The average Probability of detection in Rayleigh fading channel for the kth channel is given as follows, [15]

$$P_{d,ray} = \exp(-\frac{\lambda}{2})\sum_{n=0}^{u-2} \frac{1}{n!}(\frac{\lambda}{2})^n + (\frac{1+\gamma 1}{\gamma 1})^{u-1} \text{ x } \exp(-\frac{\lambda}{2(1+\gamma 1)})$$

$$\exp(-\frac{\lambda}{2}) \text{ x} \sum_{n=0}^{u-2} \frac{1}{n!}(\frac{\lambda\gamma 1}{2(1+\gamma 1)})^n \tag{10}$$

Rician Fading Channel:

The average Probability of detection in Rician fading channel for the kth channel is [15],

$$Pd,ric = Q\left(\sqrt{(\frac{2K\gamma 1}{K+1+\gamma 1})}. 4\sqrt{\frac{\lambda(K+1)}{K+1+\gamma 1}}\right) \tag{11}$$

Where K is the Rician factor.

Nagakami Fading Channel:

The average Probability of detection in Nagakami fading channel for the kth channel is [15],

$$P_{d,Nak} = \alpha\left[G_1 + \beta \sum_{n=1}^{u-1} \frac{(\frac{\lambda}{2})^n}{2n!} F_1(m; n+1; \frac{\lambda\gamma 1}{2(m+\gamma 1)})\right] \tag{12}$$

Where, m is the Nakagami parameter and $F_1(.;.;.)$ is the confluent hypergeometric function [15]

$$\alpha= \frac{1}{\Gamma(m)2^{m-1}}(\frac{m}{\gamma 1})m$$

$$\beta = \Gamma(m)\left(\frac{2\gamma 1}{m+\gamma 1}\right)^{m} \exp\left(-\frac{\lambda}{2}\right)$$

$$G_1 = \frac{2^{m-1}}{(m/\gamma 1)^m}\frac{(m-1)!\,\gamma 1}{(m+\gamma 1)} \exp\left(-\frac{m\lambda}{2(m+\gamma 1)}\right) \left[\left(1+\frac{m}{\gamma 1}\right)\left(\frac{m}{m+\gamma 1}\right)^{m-1} \times \right.$$

$$\left. L_{m-1}\left(-\frac{\lambda}{2}\frac{\gamma 1}{m+\gamma 1}\right) + \sum_{n=0}^{m-2}\left(\frac{m}{m+\gamma 1}\right)^{n} L_n\left(-\frac{\lambda}{2}\frac{\gamma 1}{m+\gamma 1}\right)\right]$$

Performance Evaluation and Numerical Results

The spectrum sensing performance of the adaptive threshold with noise variance based energy detector is verified for different fading channels using MATLAB simulation.. To improve the performance of the energy detector in the low SNR region, the threshold of the energy detector is varied in accordance with the variation of noise variance, so that the noise variance of the detector is estimated based on the Yule walker method. Using this noise variance, sensing error is calculated and accordingly the threshold of the energy detector is varied. This adaptive threshold has reduced the sensing error in the low SNR region much more.

The simulation parameters used in this adaptive sensing are given as follows,

M poly phase branch filters =32, probability constraints α = 0.1, β = 0.2, p = 2, q = 78, u = 5, algorithm tolerance ε = 0.001,weight parameter δ ranges from 0.1 to 0.9.

In the first simulation sensing error has been calculated for different threshold values such as -3dB and 3dB.

The results in figure 3.a, 3.b, 4.a and 4.b show that the sensing error increases with threshold for up to 0.3threshold and it decreases with the increase of threshold for thresholds higher than 0.3threshold. It shows that the sensing error is dominated by false alarm and missed detection probabilities in the higher and lower threshold regions respectively.

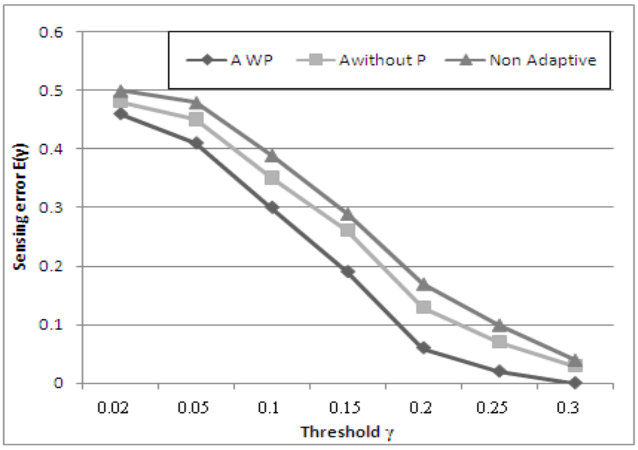

Figure 3a: Threshold Vs Sensing error (SNR = -3dB)

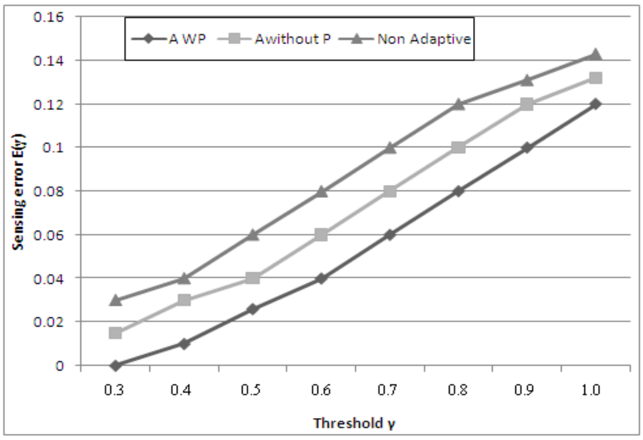

Figure 3b: Threshold Vs Sensing error (SNR = -3dB)

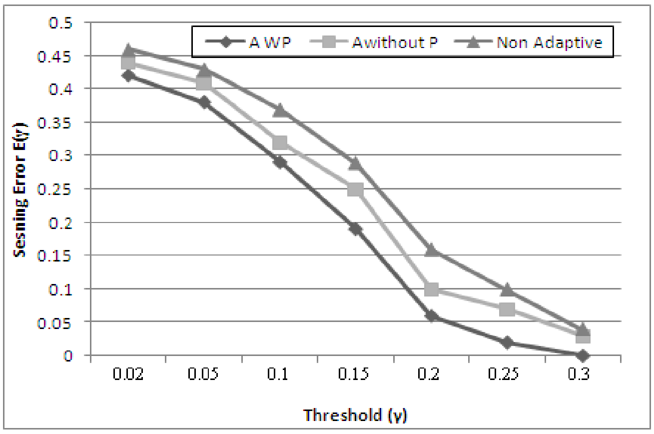

Figure 4a: Threshold Versus Sensing error (SNR = 3dB)

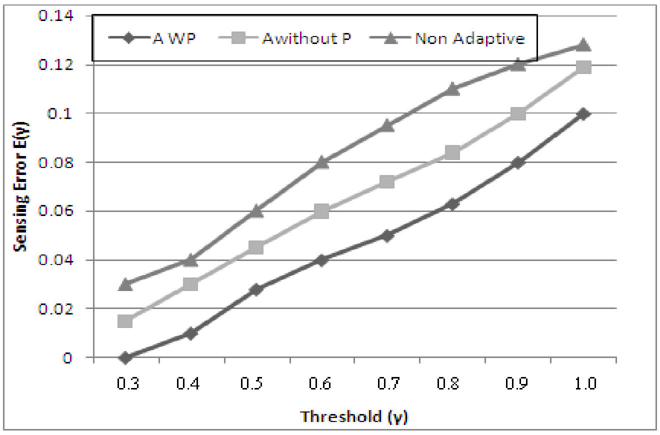

Figure 4b: Threshold Versus Sensing error (SNR = 3dB)

The adaptive threshold reduces the sensing error and improves the sensing performance. The performance of this adaptive threshold based energy detector has been verified for the following three different cases, for different fading channel conditions such as Rayleigh, Rician and Nakagami.

1. Adaptive threshold with parametric estimation
2. Adaptive threshold without parametric estimation.
3. Fixed threshold without parametric estimation.

Adaptive threshold with parametric estimation:
This is the proposed technique in which the threshold is varied in accordance with the noise variance. Noise variance is calculated with parametric estimation method.

Adaptive threshold without parametric estimation:
In this sensing method the threshold of the energy detector is varied with the SNR value.

Fixed threshold without parametric estimation:
In this cased the threshold of the energy detector is fixed. The variation of noise variance from the original value is much more in the low SNR region compared to high SNR region. Therefore the amount of sensing error is high and the probability of detection is less for this case when compared with the other two cases.

The average probability of detection performance comparison for different fading channels is shown in figure.5, 6, 7 and 8. The probability of detection performance has been improved in the low SNR region because of the reduction of sensing error. The improvement of probability of detection is better for AWGN channel compared to other channels.

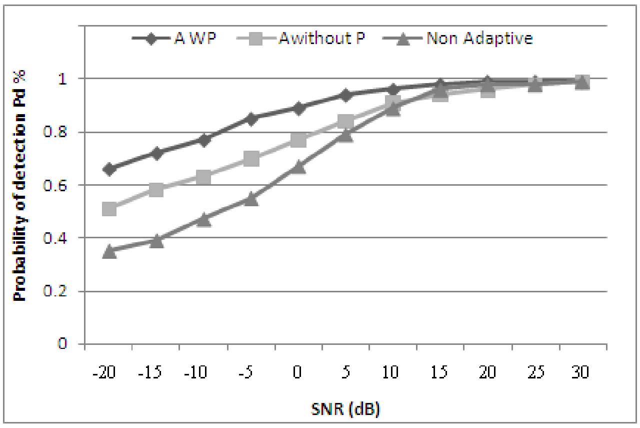

Figure 5: SNR Vs Probability of detection performance in AWGN channel

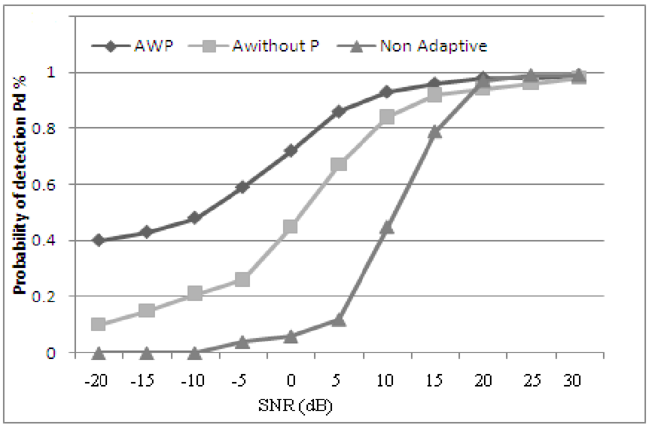

Figure 6: SNR Vs Probability of detection Performance in the Rayleigh fading channel

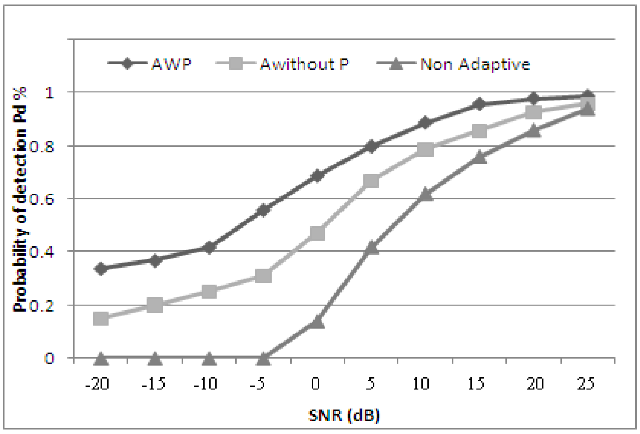

Figure 7: SNR Vs Probability of detection performance in Rician fading channel

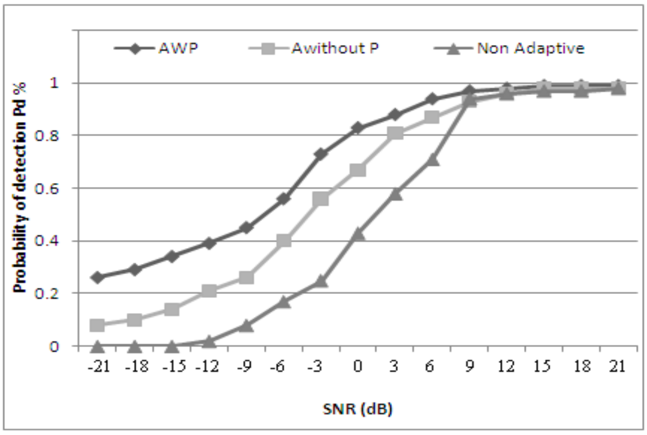

Figure 8: SNR Vs Probability of detection performance in Nakagami fading channel.

Conclusion and Future Work

The spectrum sensing performance of this adaptive threshold energy detector has improved better in the low SNR region. The performance of Nakagami fading channel outperforms any other channels discussed.

In future, the performance of this adaptive noise variance based energy detector can be verified by estimating the noise variance with other parametric estimation methods to reduce the computational complexity.

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