Spectrum Sensing and Security in Cognitive Radio

R. Manigandan
P.G. Student / M.E Computer and Communication
Ganadipathy Tulsi's Jain Engineering College
Vellore, TamilNadu, India-632102

V.Jayaprakasan
Professor / Department of ECE
Ganadipathy Tulsi's Jain Engineering College
Vellore, TamilNadu, India-632102

ABSTRACT

This paper analysis performance of energy detection technique for cognitive radio which implies spectrum sensing. Main objective is to reduce interference occur in the cognitive radio systems. Spectrum detection schemes are based on fixed threshold these are sensitive to noise; the energy detection based on dynamic threshold can improve the resistance of noise and get a good performance of detection while without increasing the complexity and improves detection performance. At the same time, security issues of cognitive radio have received more attentions recently since the inherent Properties of CR networks would pose new challenges to wireless communications.

Keywords

Cognitive Radio (CR), Primary User (PU), Secondary User (SU), Primary User Emulation (PUE), Probability of False Alarm (Pfa), Probability of Miss Detection (Pmd),MATLAB Simulink.

1. INTRODUCTION

1.1 Interference

Recently, Cognitive Radios (CR) has been proposed a possible solution to improve spectrum utilization via opportunistic spectrum sharing. Cognitive radios are considered lower priority or secondary users of spectrum allocated to a primary user. Fundamental requirement is to avoid interference to primary users in their locality. Spectrum sensing has been identified as a key enabling functionality to make certain that cognitive radios would not interfere with primary users, by constantly detecting primary user signals. For detection of a spectrum hole, the cognitive communication network relies upon the cognitive radios (CR) or secondary users. Spectrum sensing is a procedure in which a CR captures the information of a band available for transmission and then shares the frequency band without interfering the primary users.

Danijela Cabric [1] proposed Spectrum sensing has been identified as a key enabling functionality to ensure that cognitive radios would not interfere with primary users, by reliably detecting primary user signals. However, there is a lack of experimental study that shows the feasibility and practical performance limits of this approach under real noise and interference sources in wireless channels. Ajay Singh [2] improved energy detector uses an random power of the amplitude of the received samples of the Primary user's signals. The decision of each CR is orthogonally forwarded to a fusion center (FC), which takes final decision of the presence of the PU. They minimize sum of the probability of false alarm and missed detection in cooperative spectrum sensing to obtain an optimized number of CRs for detecting a spectrum hole. But the system does not reduce interference practically.

1.2 Security Threats- **Primary User Emulation (PUE) attack in spectrum sensing networks**

One of the Cognitive Radio principles is that a secondary user is allowed to use a specific band as long as it's not occupied by a primary user. However, once the secondary user detects the presence of a primary user, it must switch channels immediately to an alternative band in order not to cause interference to the primary user. If the secondary user detects another secondary user using the same band, certain mechanisms should be used to share the spectrum fairly.

Wassim-El-Hajj [4] Primary User Emulation (PUE) attack is carried out by a malicious secondary user emulating a primary user or masquerading as a primary user to obtain the resources of a given channel without having to share them with other secondary users. As a result, the attacker is able to obtain full bands of a spectrum; the motivation behind the attack is divided into two categories: Selfish PUE attack and Malicious PUE attack. In the Selfish PUE attack, the attacker's goal is to increase its share of the spectrum resources. In addition, this attack can be conducted simultaneously by two attackers to establish a dedicated link between them. In the Malicious PUE attack, the attacker's goal is to prevent legitimates.

The main idea of this paper is to develop an efficient energy detection based spectrum sensing method in order to reduce interference. At the Same time cognitive radio security is also a main concern. Proposed method for primary-user-emulation attack (PUE) as seen in this paper.

2. SPECTRUM SENSING

2.1 Transmitter Detection

Three schemes are generally used for transmitter detection: matched filter detection, energy detection, and feature detection:

i) **Matched Filter Detection:** When the information of the primary user signal is known to the CR user, the optimal detector in stationary Gaussian noise is the matched filter. However, the matched filter requires a priori knowledge of the characteristics of the primary user signal.

ii) **Energy Detection**: If the receiver cannot gather sufficient information about the primary user signal, the optimal detector is an energy detector. However, the performance of the energy detector is susceptible to uncertainty in noise power. Also, energy detectors often generate false alarms triggered by unintended signals because they cannot differentiate signal types.

iii) **Cyclo-Stationary Feature Detection**: In general modulated signals are characterized by built-in periodicity or cyclo - stationary. This feature can be detected by analyzing a spectral correlation function. However, it is computationally complex and requires significantly long observation times.

Due to the lack of interactions between primary users and CR users transmitter detection techniques rely only on weak signals from the primary transmitters. Hence, transmitter detection techniques alone cannot avoid interference to primary receivers because of the lack of primary receiver information. CR user (transmitter) can have a good line of sight to a CR receiver but may not be able to detect the primary transmitter due to shadowing. Therefore sensing information from other users is required for more accurate primary transmitter detection referred to as cooperative detection .In particular, even though a primary system may be out of any secondary system's interference range, the aggregate interference may turn out to be harmful. This uncertainty calls for more sensitive detectors as a secondary system may harmfully interfere with primary systems located beyond its interference range, and hence should be able to detect them.

2.2 Energy Detection

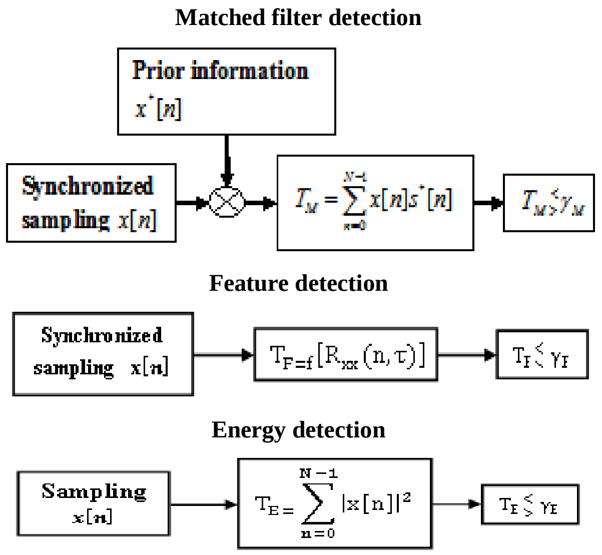
Matched filter detection
Prior information
$x^*[n]$
Synchronized sampling $x[n]$
$T_M = \sum_{n=0}^{N-1} x[n]s^*[n]$
$T_M \gtrless \gamma_M$
Feature detection
Synchronized sampling $x[n]$
$T_F = f[R_{xx}(n,\tau)]$
$T_F \gtrless \gamma_F$
Energy detection
Sampling $x[n]$
$T_E = \sum_{n=0}^{N-1} |x[n]|^2$
$T_E \gtrless \gamma_E$

Fig. 1 Spectrum Sensing Technique

While the matched filter and feature detection capabilities require prior information about primary signals, no primary signal information is required for the energy detection technique. As depicted in Figure 1, the only process required for the energy detector is that the primary signal energy is able to be measured within a specified duration. Next, the detector simply determines whether or not the measured signal energy is over the predetermined threshold level. When considering the general purpose of spectrum sensing with low complexity, the energy detection technique is decidedly the most feasible spectrum sensing scheme for detecting the white space of multiple primary spectra licensed to heterogeneous wireless communication systems. This explains why this paper focuses on spectrum sensing using energy detection.

We consider a system consisting of N number of CRs, one primary user, and a fusion center. There are two hypothesis $H0$ and $H1$ in the i-th CR for the detection of the spectrum hole.

$$H_0 : y_i(t) = v_i(t), \quad \text{if PU is absent} \quad (1)$$

$$H_1 : y_i(t) = s(t) + v_i(t), \text{ if PU is present} \quad (2)$$

Where i=1,2,……..,N, s(t)~N(0,σ_s^2),where $\sigma_s^2$is the average transmitted power of the PU ,denote a zero Gaussian signal transmitted by the PU, and v_i(t) ~ N(0,σ_n^2) is the additive white Gaussian noise (AWGN) with zero mean and σ_n^2 variance. The variance of the signal received at each secondary user under H1 will be σ_s^2+σ_n^2. It is assumed that each CR contains an improved energy detector. The i-th CR utilizes the following statistic for deciding of the presence of the PU,

$$\mathbf{W} = | y_i |^p, \mathbf{p > 0.} \quad (3)$$

It can be seen from (3) that for p = 2, W reduces to statistics corresponding to the *conventional* energy detector. In a cooperative sensing scheme, multiple CRs exist in a cognitive radio network such that each CR makes independent decision regarding the presence or absence of PU. We consider a cooperative scheme in which each secondary user sends its binary decision di (0 or 1) to the fusion center by using an improved energy detector over error free *orthogonal channels.* The fusion center combines these binary decisions to find the presence or absence of the PU as follows,

$$\mathbf{D}= \sum_{i=1}^{N} d_i \quad (4)$$

Where D is the sum of the all 1-bit decisions from the CRs. Let n, $n \le N$ corresponds to a number of cooperating CRs out of N CRs. The FC uses a majority rule for deciding the presence or absence of the PU.As per the majority decision rule if D is greater than n then hypothesis H1 holds and if D is smaller than n then hypothesis $H0$ will be true.

The hypothesis H0 and H1 can be written as

$$H_0 : D < n, \text{ if PU is absent} \quad (5)$$

$$H_1 : D > n, \text{ if PU is present} \quad (6)$$

An energy detector, which combines the measured energy during the sensing duration along the sensing nodes. Assuming each node and each sample is independent, the energy is combined with equal gain. The decision rule can be written as,

$$\mathbf{T}= \sum_{n=1}^{N}\sum_{m=1}^{M} | x_m(n) |^2 \quad \mathbf{H}_0, \mathbf{H}_1 \quad (7)$$

Where T is the test statistic for the binary hypothesis test and η is the threshold [3 & 4].

2.2.1 Energy detector

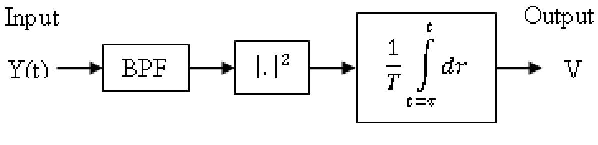

Fig. 2 Energy Detector Block Diagram

First, the input signal *y* (*t*) is filtered with a band pass filter (BPF) in order to limit the noise and to select the bandwidth of interest. The noise in the output of the filter has a band-limited, flat spectral density. Next, in the figure there is the energy detector consisting of a squaring device and a finite time integrator. The output signal V from the integrator is,

$$V = \frac{1}{T}\int_{t=T}^{t} | y(r) |^2 dr \qquad (8)$$

Finally, this output signal *V* is compared to the threshold *ç* in order to decide whether a signal is present or not. The threshold *ç* is set according to statistical properties of the output *V* when only noise is present [2].

3. PROPOSED SYSTEM

3.1 Welch's Periodogram

The idea of the Welch's Periodogram is to divide the data sequence into segments in order to reduce the large fluctuations of the Periodogram. In the Welch's method these data segments are also allowed to overlap, which is a feature that distinguishes it from some other modified Periodogram (such as Bartlett method or Blackman-Turkey method). The block diagram of the Welch's Periodogram is shown in Figure 3. First, the input data sequence is filtered and A/D-converted. After that, the data sequence is partitioned into *M* segments.

Averaging is done over the M segments. The FFT is performed for the segment and after that, the samples of the segment are squared. Averaging is done over all of the segments. Finally, the output values in the band of interest are compared to the threshold and the decision whether the signal is present or not is done.

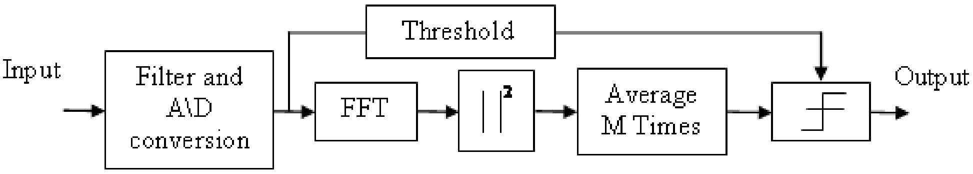

Fig. 3 Energy Detector Using Welch's Periodogram

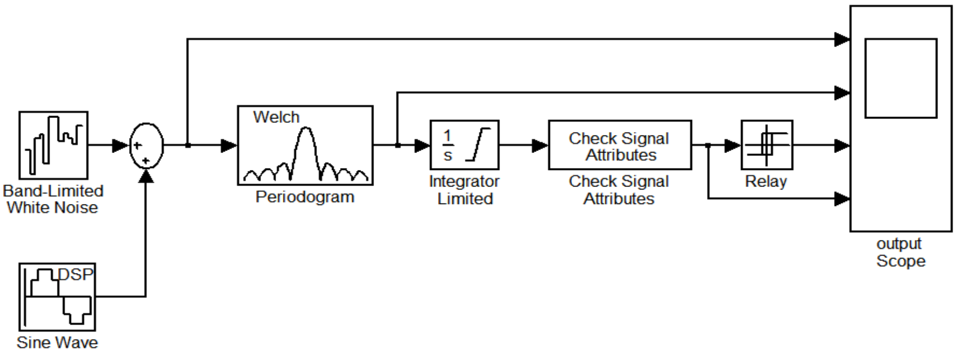

Fig. 4 Welch Periodogram Simulink Model

In order to get a near maximum reduction of the variance with the fixed length of the input sequence. If the FFT size is increased, the frequency resolution improves, which helps narrowband signal detection. The bias of the estimate of the Welch's Periodogram, as well as of the original Periodogram, can be reduced by increasing the length of the input sequence. Meanwhile, comparing to original Periodogram, the use of Welch's Periodogram reduces the variance of the estimate.

3.2 Advantages of Energy Detection

a) The implementation simplicity of the energy detector makes it favorable candidate for spectrum sensing task. However, the performance of the energy detector is highly susceptible to noise level uncertainty.

b) Noise level uncertainty refers to a situation where the noise variance is only approximately known. The noise uncertainty cause's problems especially in the case of a simple energy detector because it is difficult to set the threshold properly without the knowledge of the accurate noise level.

3.3 Proposed PUE attack model with maximum likelihood criterion

There are M malicious users in the network and are randomly and uniformly distributed in the circular region. There are two primary transmitters $Pt1$ & $Pt2$, separated by a fixed distance and their transmission are independent. The distance between secondary user and $Pt1$ is $Dp1$, the distance between secondary user and $Pt2$ is $Dp2$. No malicious user is present between within the exclusive region for the secondary user. All the users in the network know about the location of primary transmitters. The RF signals from primary and malicious transmitters undergo path loss and log normal shadowing. The position of the good secondary user changes, it moves away from primary transmiiter1 towards primary transmitter 2.

3.3.1 Proposed system model

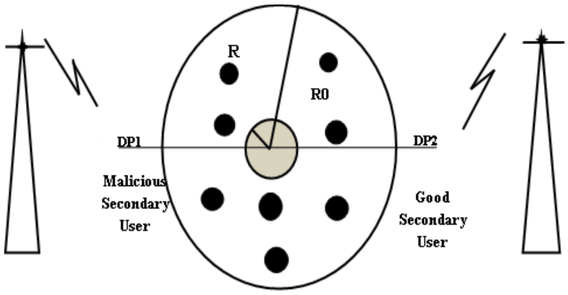

Fig. 5 Proposed System Model

There are M malicious users in the system which transmits at power 'Pm'. The primary transmitter $Pt1$ is at distance '$Dp1$' and the primary transmitter $Pt2$ is at distance '$Dp2$' from all the users and transmits at power 'Pt '. The positions of secondary and malicious users are uniformly distributed in circular region of radius R and are statistically independent of each other. Position of primary transmitter is known to all the users and is fixed at $(rp,)$. The RF signals from primary transmitter and malicious users undergo path loss and log normal shadowing. The path loss exponent for transmission from primary transmitter is 2 and that from malicious user is 4. For any secondary user fixed at co-ordinates(r,) no malicious users are present within a circle of radius Ro which is called the exclusive radius from secondary user. There is no co-operation between the secondary users. The received power at the secondary user from the primary transmitter1 is given by,

$$p_r^{(p1)} = p_{t1} d_{p1}^{-2} G_{p1}^{-2} \qquad (9)$$

The received power at the secondary user from the primary transmitter1 is given by,

$$p_r^{(p2)} = p_{t2} d_{p2}^{-2} G_{p2}^{-2} \qquad (10)$$

The total power at the receivers is then given by, $p_r^{(p)}$=$p_r^{(p1)}$+$p_r^{(p2)}$ due to their independence. The total received power at the secondary user from all the malicious users is given by,

$$p_r^{(m)} = \sum_{j=1}^{M} p_m D_j^{-4} G_j^{2} \qquad (11)$$

PDF of $p_r^{(p)}$ follows a log normal distribution and can be written as,

$$p_r^{(p)}(\gamma) = \frac{1}{\gamma A\sigma_{x\sqrt{2\pi}}} \exp\{-\frac{(10\log_{10}\gamma - \mu_x)^2}{2\sigma_x^{2}}\}$$

(12)

PDF of $p_r^{(m)}$ follows a log normal distribution and can be written as,

$$p_r^{(m)}(x) = \frac{1}{xA\sigma_{x\sqrt{2\pi}}} \exp\{-\frac{(10\log_{10} x - \mu_x)^2}{2\sigma_x^{2}}\}$$

(13)

4. SIMULATION AND ANALYSIS

4.1 Performance Analysis

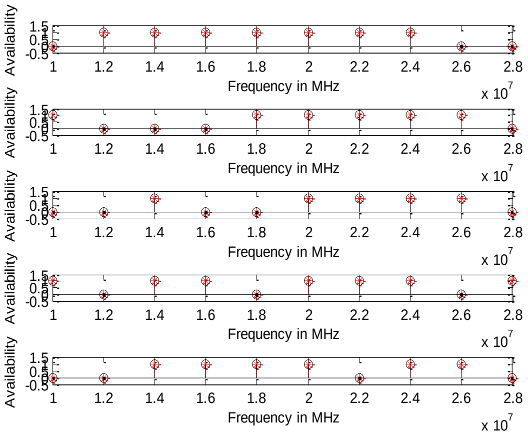

Fig. 6 Availability Vs Frequency in MHz

10 users in certain region, 200 number of frames used FFT=256 length Frames of N sample. Red dot shows availability of spectrum for respective frequency.

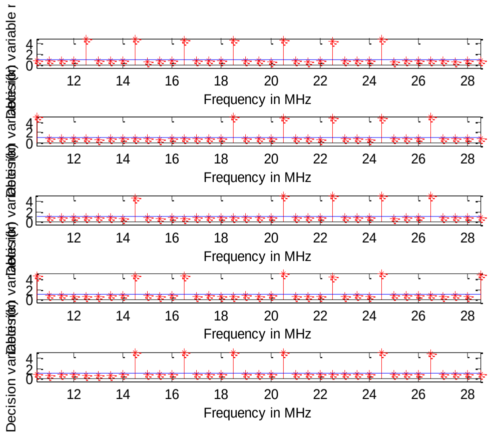

Fig. 7 Decision Variable Vs Frequency in MHz

Decision variable decision is made based on output of detector. It follows the rule of DECISION RULE:

Y (T)>=α, decide "1" is sent.

Y (T) <α, decide "0" is sent.

4.2 Energy Detection based Spectrum Sensing

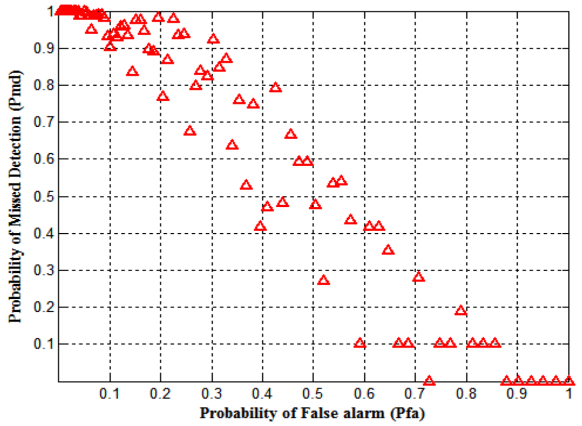

Fig. 8 Pmd Vs Pfa, CR users=7

Time bandwidth factor U=10, cognitive radio users CR=7, path loss a=2, from matlab simulation due to small number of user's, probability of misdetection reduced and probability of false alarm increases.

Figure 9 where the probability of misdetection increases, harmful interference with the primary user will increase so we should keep it as low as possible to give us good performance. If a threshold device is used to make a decision as to the presence or absence of a signal in a background of noise. The probability that the **threshold value VT** is exceeded when no signal is present is the false alarm probability.

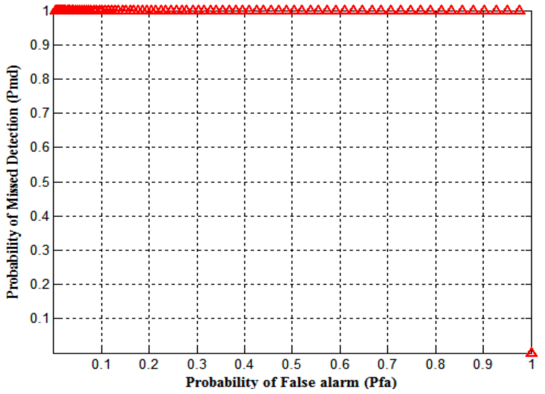

Fig. 9 Pmd Vs Pfa, CR users=20

4.3 Energy Detection Over channel

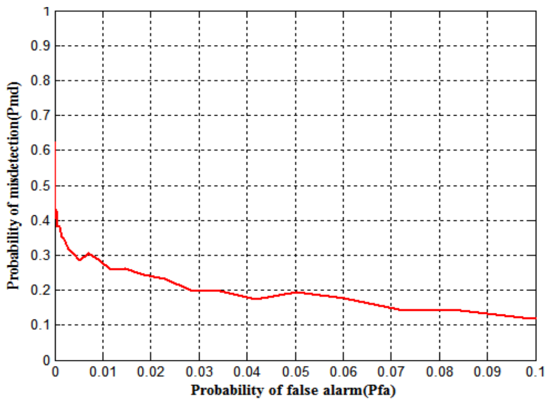

Fig. 10 Pmd Vs Pfa.

Figure 10 shows performance of energy detection here probability of misdetection and probability of false alarm decreases by given signal to noise ratio SNR is 5 and sample N is 10.

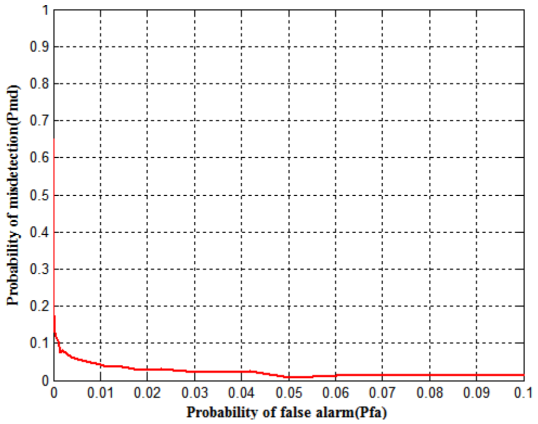

Fig. 11 Pmd Vs Pfa

Figure 11 shows performance of energy detection here probability of misdetection and probability of false alarm decreases by given signal to noise ratio SNR is 15 and sample N is 1.

Table 1 Overall Comparison of Proposed Performance with Existing

Energy Detection based Spectrum Sensing	**Probability of Miss Detection(Pmd)**	**Probability of False Alarm(Pfa)**
Existing System[5]	0.9	0.1
Proposed System	0.6	0.1

4.4 Energy Detection Model

4.4.1 Welch Periodogram

Welch's method (also called the Periodogram method) for estimating power spectra is carried out by dividing the time signal into successive blocks, forming the Periodogram for each block, and averaging. The signal is split up into overlapping segment. If D=$\frac{M}{2}$overlap=50% if D=0 overlap=0%.overlapping segment are then windowed.

Figure 13 shows of an simulation output of an figure 4, welch Periodogram helps into reduce noise as like hypothetical concept input is band limited noise after noise to welch Periodogram block noise is reduced .

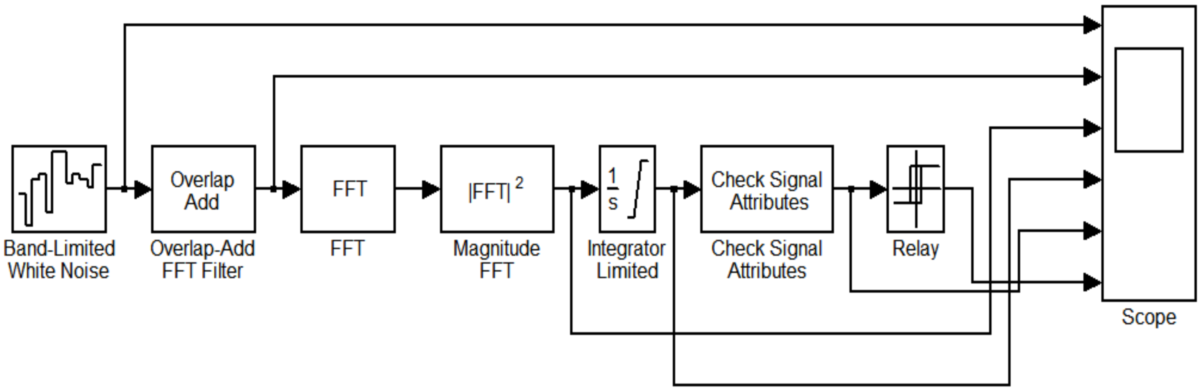

Fig. 12 Welch Periodogram based Energy Detection using Simulink Model

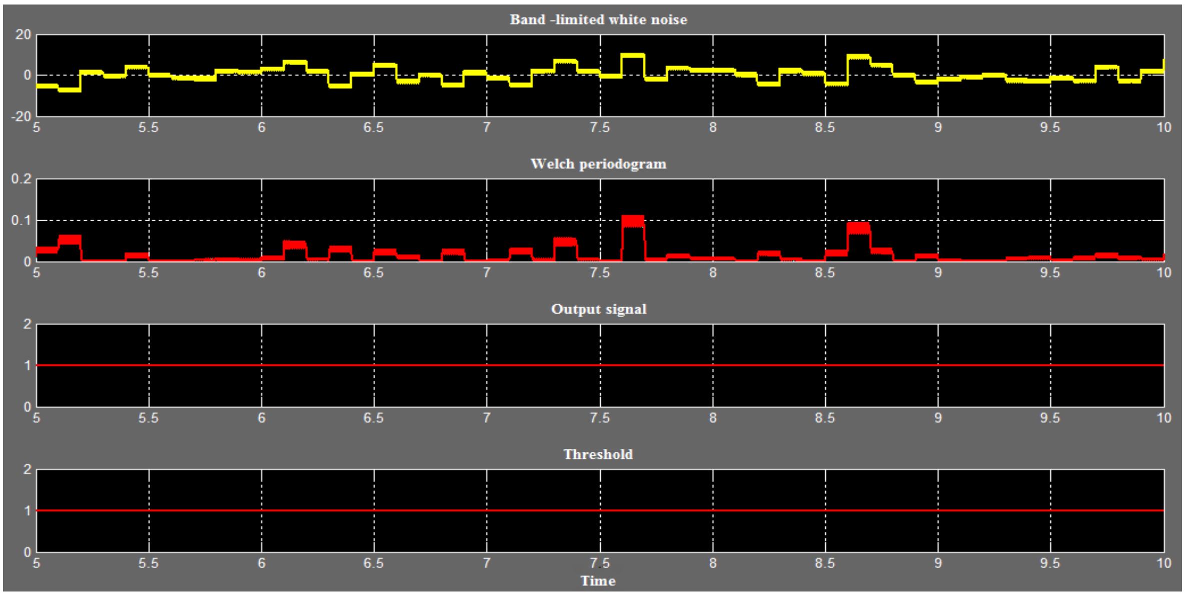

Fig .13 Output of Welch Periodogram Simulation Model

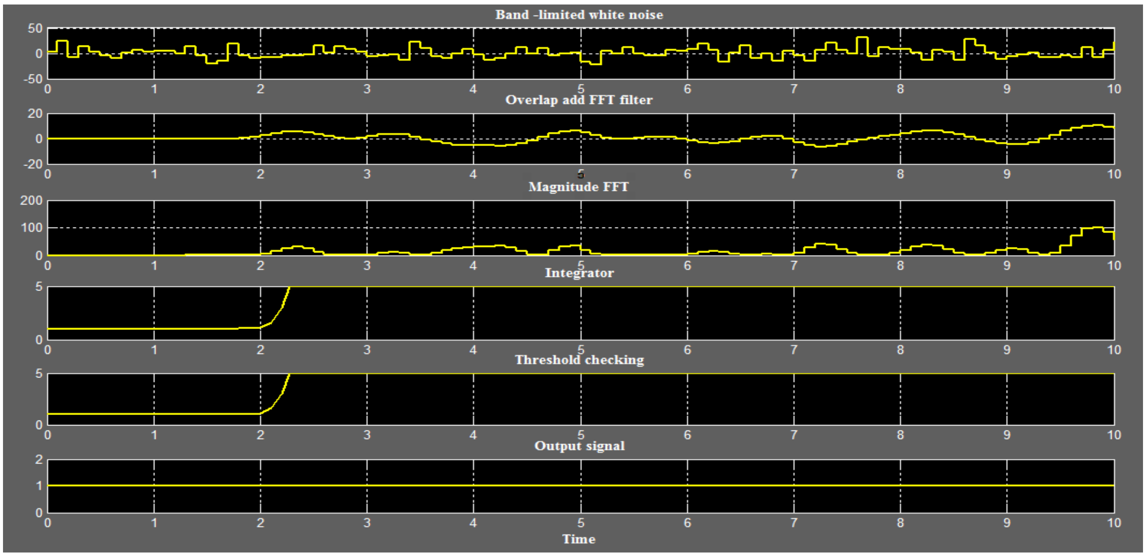

Fig. 14 Simulation output of Welch Periodogram based Spectrum Sensing

Figure 14 is an simulation output of an figure 12, Band limited noise as an input signal, is been through overlap-add FFT filter which helps in to evaluate the discrete convolution of a very long signal and output of an filtered signal is been processed with the FFT and magnitude FFT blocks after that processed signal is integrated by help of integrator block help to reset the block output to its initial value depending on how the input changes. After integrated signal is been processed to check signal attributes which use for threshold checking because block terminates the simulation with an error. When the input signal does or does not match selected attributes exactly.

4.5 Adaptive Noise Cancellation

If there is no interference (v (n) =0) optimal learning rate for NLMS =μ_{opt}=1, If interference v (n) not equal to 0 optimal learning state is $\mu_{opt}=\frac{E[|y(n)-\check{y}(n)|^2]}{E[|e(n)|^2]}$.

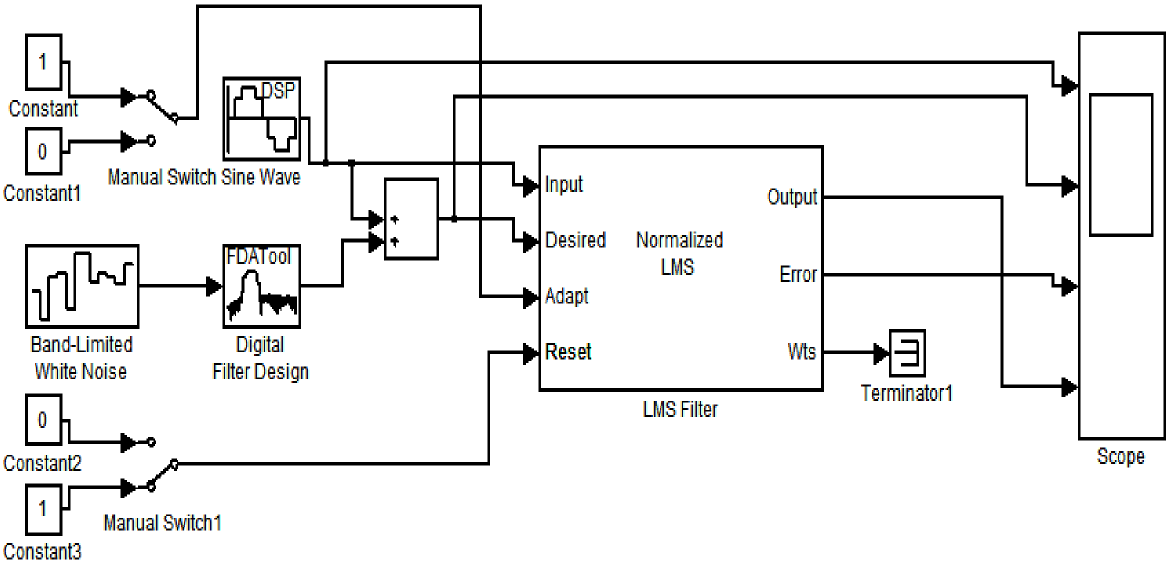

Fig. 15 Adaptive Noise Cancellation Block

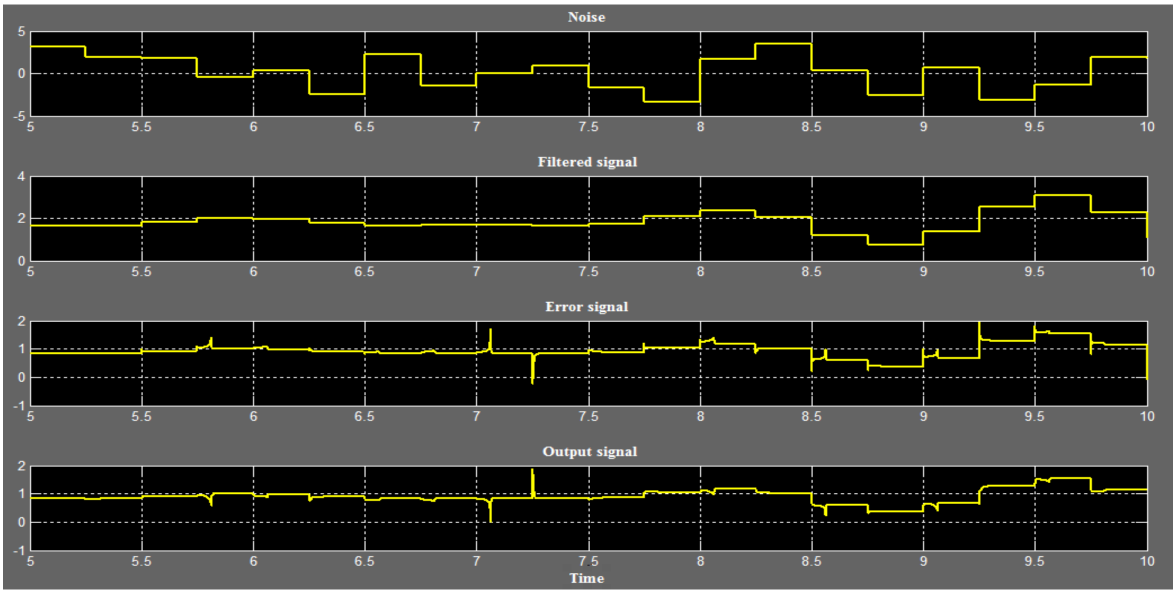

Fig. 16 Simulation Output of Adaptive Noise Cancellation Block

Figure 16 is an simulation output of an figure 15. Signal 1 is an noise, signal 2 is an filtered signal where noise+data are been summed signal 4 is an output signal which is been get through the normalized LMS.

4.6 Adaptive Noise Cancellation with Energy Detection

Figure 17 shows simulation diagrams where adaptive noise cancellation and energy detection are been propose to reduce noise during interference. Previous method are been tell apart using of normalized LMS from Adaptive Noise Cancellation Block, Welch method from figure 4 and figure 12 welch method for energy detection and LMS for reduce noise.

Figure 18 is a simulation output of an figure 17, energy detection based adaptive noise cancellation technique help into reduce noise occur during interference.

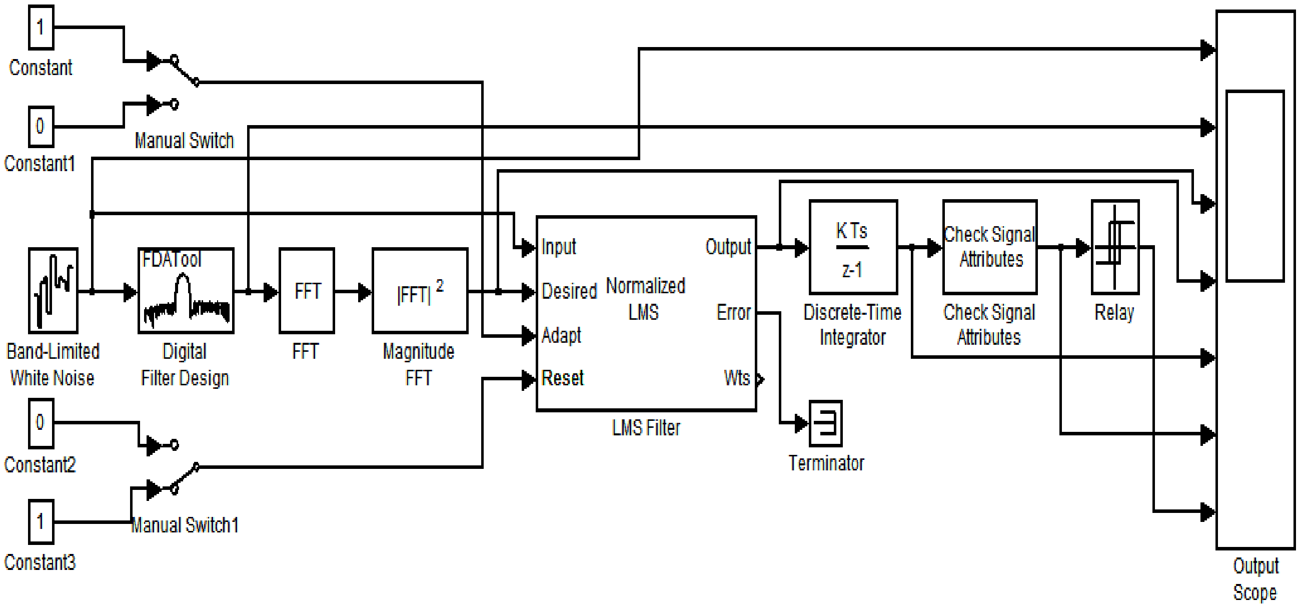

Fig. 17 Energy Detection with Adaptive Noise Cancellation Block

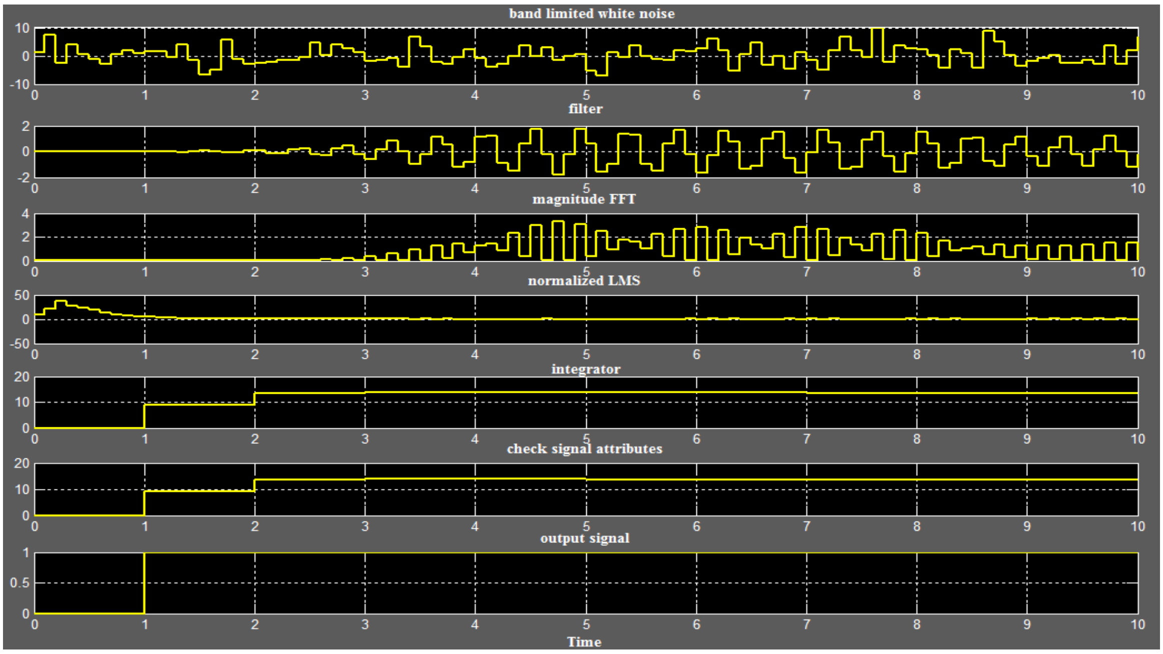

Fig. 18 Simulation Output of an Energy Detection Block with Adaptive Noise Cancellation

4.7 PUE Attack Model Simulation

The radius of outer region is R=700m, Radius of primary exclusive region $R0$=30m, primary transmitter power Pt=100Kw, Malicious transmitter power is Pm=4w, σm=5.5dB, σp= 8dB. Probability of miss detection and false alarm are calculated for 500 numbers of simulations. The threshold value chosen for above simulation is set to 2 i.e. λ=2.

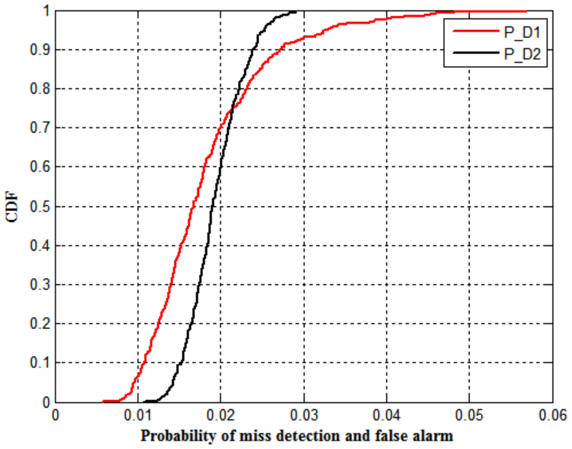

Fig. 19 Probability of Misdetection and False Alarm

The number of malicious users in this case is M=10, The radius of outer region R=200m, Radius of primary exclusive region $R0$ =30m, primary transmitter power $Pt1$ = 100, primary transmitter power $Pt2$ = 50Kw, Malicious transmitter power Pm=4w, $\sigma m1$ = 8dB, $\sigma m2$ = 10dB. It is observed that the probability of false alarm does not change too much over the distance 50Km to 100Km. But the probability of miss detection decrease with the distance.

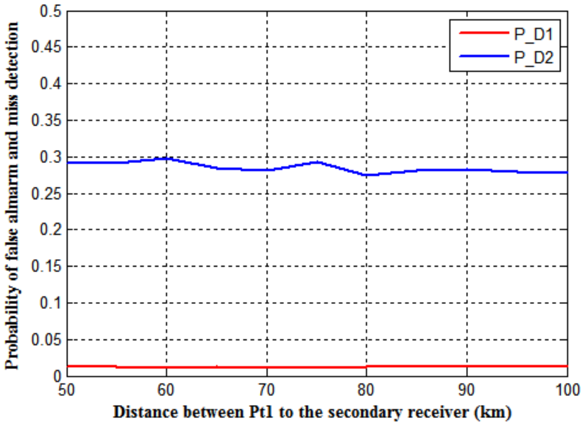

Fig. 20 Average Probability for Misdetection and False Alarm

5. CONCLUSION

This project help in to sense the spectrum whether free or not by help of energy based spectrum sensing technique and also help in to reduce aggregate interference by help of an adaptive noise cancellation technique . And also seen performances for primary user emulation attacks, and the proposed a novel system model with different configurations of the primary users and conduct research on maximum likelihood criterion. This model helps in to find out the characteristic of Primary User Emulation attack. In future Sequential Energy Detection (SED) scheme help to reduce the average required sample number and sensing time for spectrum sensing.

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7. AUTHORS’ PROFILE

R.Manigandan received his Bachelor’s Degree in Electronics and Communication Engineering from Anna University, Chennai, India in the year 2010. Presently he is pursuing Master Degree in Computer and Communication Engineering in Anna University, Chennai, India. His areas of interest are Wireless communication and Signal Processing.

V.Jayaprakasan received his Bachelor’s Degree in Electronics and Communication Engineering from Bharadhidasan University, Tiruchirappalli, India in the year 1999 and Master’s Degree in Communication Systems from Anna University, Chennai, India in the year 2006. He has started his teaching profession in the year 2006 in Ganadipathy Tulsi’s Jain Engineering College, Vellore. Earlier he has 11 years industrial experience in an electronics based industry. At present he is a Professor in Electronics and Communication Department. He has published 1 research papers in International Journals and 2 research papers in International Conferences. His areas of interest are Wireless communication, Networking and Signal Processing. He is a life member of ISTE.