ISSN 2229-5518

# Performance Analysis of Noise Uncertainty in Energy Detection Spectrum Sensing Technique using an Optimized Algorithm

Nosiri Onyebuchi Chikezie[1], Iroh Chioma Ulunma[2]

**Abstract**—The Performance of Energy Detection (ED) spectrum sensing technique depends on threshold selected for deciding the presence or absence of Primary User. In practice, noise density is uncertain and can affect the performance of ED in that sometimes presence of signals is confused for their absence (noise) and vice versa. The traditional energy detection algorithm was based on fixed threshold and has been observed to be inefficient under noise uncertainty. The technique requires optimizing the threshold to be more flexible to check the noise uncertainty effects. The paper therefore proposed an algorithm relative to a unique environment which in effect considered the dynamism relatively and dependent on the environment. The results obtained demonstrated significant improvement compared to the traditional energy detection system.

**Index Terms**— Dynamic Environment, Energy Detection, Cognitive Radio Technology, Noise uncertainty, Signal to Noise Ratio.

## 1 INTRODUCTION

ACOMMODATING the increasing number of users in wireless network and the threat for RF spectrum scarcity has given rise to cognitive Radio Technology (CRT). CRT is a new technology whose primary purpose is to maximize Radio Frequency (RF) resources and opportunistically grant ad-hoc users access to RF resources without causing harm to the original users. In this technology, the original users have the priority to occupy the given band and are known as licensed or the primary users while the ad-hoc users do not have priority to occupy the band but opportunistically do that; they are known as unlicensed or secondary users. The most essential task in ensuring the feasibility of CRT is spectrum sensing by the secondary users. It involves monitoring of the targeted band in order to ascertain the most convenient time to utilize the RF resources causing no interference to the primary users. There are several methods for carrying out this task viz; Matched filter approach which gives an optimum detection but requires the knowledge of parameters of transmitted signal. Its shortcoming is large power consumption due to various receiver algorithms that need to be executed for detection and complexity of the sensing unit [1]. Another is Cyclostationary-Based Sensing; it involves exploiting statistical features of the received signal. It can distinguish noise from primary users' signal efficiently but suffers challenges of computational complexity and longer time for observation [1]. Wave form based sensing is a usable approach also. According to [1], it utilizes synchronization in wireless system for detection, known patterns such as spread sequence and regularly transmitted pilot pattern are used. By correlating the received signal with a known copy of itself, sensing is achieved in the presence of a known pattern.


- Nosiri Onyebuchi Chikezie is a PhD holder in wireless communication Engineering. He is an academic staff, Department of Electrical and Electronic Engineering, Federal University of Technology, Owerri, Nigeria. E-mail: onyebuchi.nosiri@futo.edu.ng
- Iloh Chioma Ulunma is currently pursuing master degree program in Electrical and Electronic Engineering, Federal University of Technology, Owerri, Nigeria.E-mail: irohcu@gmail.com


This method however requires short measurement time and as a result prone to synchronization errors [2]. This paper is organized as follows: section 1 has the introduction, section 2 contains related reviewed works, section 3 presents system model and various performance characterizations. Section 4 shows the proposed algorithm while sections 5 and 6 cover results discussion and conclusion.

## 2 RELATED WORK

In the work of [3] titled "Spectrum sensing in Cognitive Radio Network" conducted a survey of techniques for spectrum sensing with a performance analysis of transmitter-based detection technique. An algorithm for minimizing sensing time under high signal to noise ratio and a fuzzy based technique for primary user detection was proposed. His results showed that the proposed algorithm has a level of reliability when compared with other transmitter detection techniques, while the fuzzy based technique provided an improved result when compared with transmitter detection technique under low SNR value but at the expense of increased computation time

The authors of [4] proposed an algorithm to improve on the performance of Energy Detection. This algorithm was based on distribution analysis using a measure of Gaussianity (kurtosis) as test statistics. The idea behind this concept was that the distribution of received signal when a channel is occupied definitely differs from that of vacant channel. According to them, noise has Guassian distribution tendency while signal which encounters multipath fading (effect) during transmission will have non Guassian distribution. This proposal poses a level of doubt because there is no how a transmitted signal would not have effects of Gaussianity distribution attributed to it.

The scenario of [5] proposed an approach to estimate the threshold as a function of first and second order statistic of recorded signals. Their method does not require estimation of

ISSN 2229-5518

noise variance and signal to noise ratio but aims at minimizing the effects of impairments introduced by wireless channel and non-stationary noise on threshold performance. The simulation result showed that the adaptive threshold has low false alarm and missed detection rates that satisfied detection requirements of multi-channel cognitive radio when proper standard deviation coefficient is selected.

Among all these techniques, the most commonly used approach is Energy Detection because of its implementation simplicity, higher speed and its non prior knowledge requirement of the primary signal for detection as other techniques would require. It only depends on the power of its received signal to decide the presence or absence of the primary.

## 3 SYSTEM MODEL

The energy detection spectrum sensing technique is applied by the SUs; each of the received signals is first pre-filtered by Band-Pass Filter (BPF). The output of BPF is sent to analogue to digital converter to ensure compatibility of the system and improved signal to noise performance. The output of the analogue to digital converter was passed through a squaring device in order to convert the signal into pulse waves which are compatible with the integrator that summed its inputs and integrated them over time T. It then gives an output (ẏ). The output of the integrator is the energy of the filtered received signal which serves as the decision test statistics ẏ that is compared with a pre-defined threshold value λ. Transmissions by SUs are immediately started depending on the value of ẏ. Figure 1 presents the block diagram of Energy Detection Technique

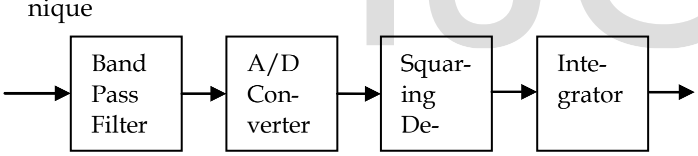


Fig.1. Block diagram of Energy Detection

Two hypotheses $H_0$ and $H_1$ are possible from the output and are used as the test statistics. $H_0$: represents the presence of only noise and absence of signal while $H_1$: represents the presence of both noise and signal. Hence three important conditions arise.

Probability of Detection ($P_d$): This is the probability of detecting a PU signal on the considered frequency. It depicts that $H_1$ is true while $H_0$ is false.

Probability of Missed Detection ($P_m$): This is the probability of deciding a PU to be absent when really it is present. Therefore, $H_1$ is true while $H_0$ is false.

Probability of False alarm ($P_{fa}$): This is the probability of deciding a PU to be present when really it is not. Therefore, it depicts that $H_0$ is true while $H_1$ is false.

The received signal by the secondary user is represented thus, [1].

$$y(t) = \begin{cases} w(t); & Ho \\ x(t) + w(t); & H1 \end{cases} \qquad (1)$$

Where (t) = Sample index.

x(t) =Signal from the PU or channel input.

w (t) = Additive White Gaussian Noise (AWGN) with zero mean and known variance = $WN_0$.

The Signal to Noise Ratio (SNR) is given as [1]

$$\gamma = \sigma_s^2 / \sigma_n^2 \qquad (2)$$

Where $\sigma^2_s$ =variance of the signal and $\sigma^2_n$ $\sigma_s^2$=variance of the noise.

Algorithm and flowchart for implementation of the Energy Detection Technique are shown below and in figure 2 respectively.

*RF environment scanning.
*Estimate the signal strength detected.
*Analyze the output detected.
*Compare output with the threshold.
*Action by SUs.
*End.

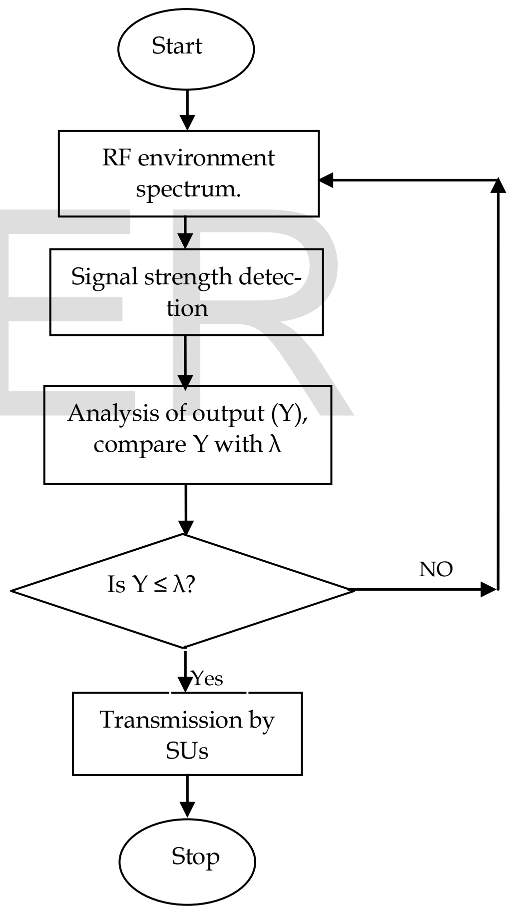


Fig. 2. Flowchart for implementation of Energy Detection

### A Performance analysis of Energy Detector

The detection performance of spectrum sensing technique is evaluated by its Probability of detection (Pd) and Probability of false alarm (Pfa). The detection algorithm of spectrum sensing techniques was based on Neyman-Pearson's lemma theorem whose objective is to maximize Pd in a fixed Pfa [6, 7]. It implies that Pd which indicates that primary users exist really should be kept as large as possible so as to avoid inter-

ISSN 2229-5518

ference to primary users while Pfa which fakes the presence of primary users should be maintained very small so as to maximize transmission opportunities. Hence maximizing Pd and minimizing Pfa are of great interest in detection technique. Another parameter used in detection performance evaluation is the Probability of missed detection (Pm) which is the inverse (opposite) of Pd; it implies that anything that can prevent the detection of primary users such as interference and shadowing should be avoided.

The optimal detection of an energy detector as given by [8]

$$D(y) = \frac{1}{N}\sum_{n=0}^{N-1} y^2(n) \gtrless_{H_0}^{H_1} \lambda \quad (3)$$

Where D(y) = Decision variable, $\lambda$ Decision threshold and N= Number of sample for detection.

Based on the test statistic, the probabilities $P_d$ and $P_{fa}$ and $\lambda$ according to [8] and ([4] are evaluated using

$$D(y) > \lambda | H_1 = Q\left(\frac{\lambda - (\sigma_s^2 - \sigma_n^2)}{\sqrt{\frac{2}{N}}(\sigma_s^2 + \sigma_n^2)}\right) \quad (4)$$

$$D(y) > \lambda | H_1 = Q\left(\frac{\lambda - (\sigma_s^2 - \sigma_n^2)}{\sqrt{\frac{2}{N}}(\sigma_s^2 + \sigma_n^2)}\right) \quad (5)$$

$$\lambda = \left(\sqrt{\frac{2}{N}}Q^{-1}(P_{fa}) + 1\right)\sigma_n^2 \quad (6)$$

$$P_{md} = 1 - P_d \quad (7)$$

Where Q(x) is the standard Gaussian complementary cumulative distribution function evaluated as [9].

$$\frac{1}{2\pi}\int_x^{\infty} e^{\left(\frac{-t^2}{2}\right)} dt \quad (8)$$

A close observation of equations (5) and (6) indicates that $P_{fa}$ and $\lambda$ are both function of noise's variance and number of samples and can be set outside the knowledge of signal's power. Hence a primary signal in the targeted band can easily be detected if its level is greater than noise's variance; this indicates the usefulness of SNR in Energy Detection technique.

Probability of detection can further be written incorporating SNR factor [8, 4] as

$$P_d = Q\left(\frac{Q^{-1}(P_{fa})\left(\sqrt{\frac{2}{N}}\, Snr\right)}{1 + snr}\right) \quad (9)$$

**B. Performance Characteristics of Energy Detection Technique under AWGN Channel**

The performance characteristics of the Energy Detection Spectrum sensing technique under Additive White Gaussian Noise (AWGN) channel was carried out to evaluate its effectiveness. To achieve this, Receiver Operating Characteristics (ROC) plots for signal detection was used. ROC is the reliable tool that could be used in signal detection theory to quantify the tradeoff that exists between true positive rate and false negative rate; in this report, it is a plot probability of detection (Pd) versus Probability false-alarm (Pf) and/or a plot of probability of detection (Pd) versus probability of missed-detection (Pm). Monte-Carlo technique was used for the simulation in Matlab software platform. Figures 3, and 4 present various performance characteristics of Energy Detection under AWGN channel.

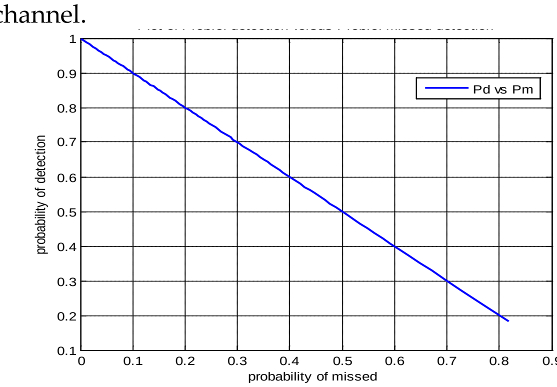


Fig. 3. Probability of missed detection against Probability of detection

## 4 PROPOSED ALGORITHM

The traditional energy detection algorithm was based on fixed threshold and has been observed to be no longer efficient under noise uncertainty; hence setting threshold should be made flexible and more encompassing in order to check the effects of noise uncertainties in an environment

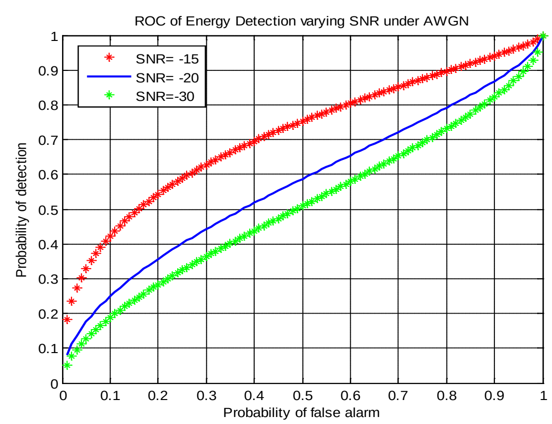


Fig. 4: Probability of false alarm versus probability of detection

**The Implementation Algorithm procedure using Threshold Based on Worst Case Scenarios are as follows:**

*Take measurements at noise only environment to get the possible maximum noise ever, known as worst case noise uncertainty.

*Measure or estimate the weakest value of signal strength known as worst case signal.

ISSN 2229-5518

*Using the values of these two steps, estimate the signal to noise ($SNR_{wc}$) ratio known as weakest or worst case ($SNR_{wc}$).

*Repeat steps 1to 3 to get the average value of the weakest SNR (This repetition includes possible tolerance needed in the measurements.

*Set the threshold ($\lambda_{wc}$) based on the value of the weakest value of the SNR measured.

*Compare the output of the detector ỳ with ($\lambda_{wc}$) if ỳ is greater than or equal to ($\lambda_{wc}$) then decide the presence of primary users ie ỳ > =($\lambda_{wc}$)|$H_1$ implying :Recan. But if ỳ is less than ($\lambda_{wc}$), then decide that primary users are absent ie ỳ < = ($\lambda_{wc}$)|$H_0$ implying Transmit.

Figure 5 presents the flowchart implementation of the proposed algorithm.

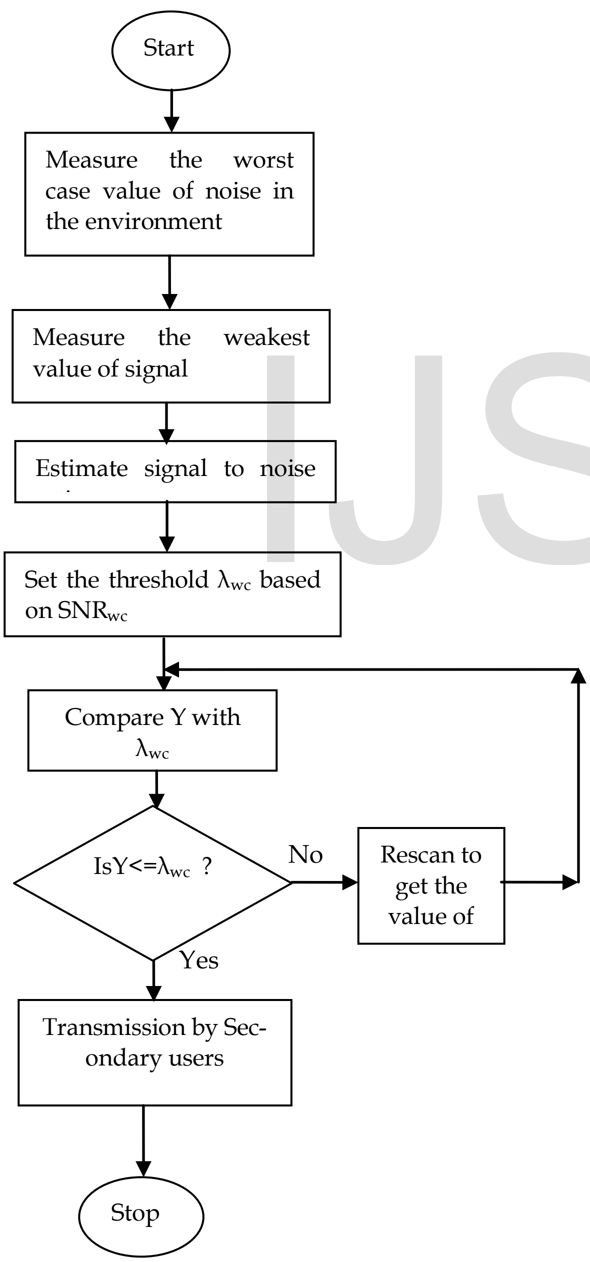


Fig. 5. The flowchart for implementation of the proposed algorithm

**Significance of the steps**

*Increment in the sensitivity and specificity of the detection technique.

*Sampling rate is increased since sampling must be repeated over time in order to ascertain the worst case scenarios.

*The probability of detection will be increased since number of sampling (N) (observation rate) would be increased.

*The probabilities of false alarm and missed detection are drastically reduced since number of observation would be increased.

*Interference and shadowing effects are greatly minimized since Pfa and Pm are minimized.

*Reduction in any occur-able sensing errors.

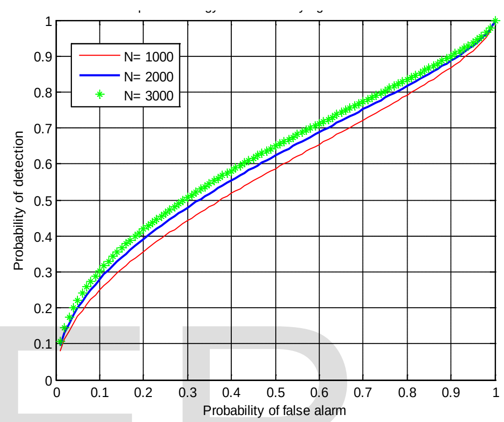


Fig. 6. The effects of the proposed algorithm on the probability of detection and false alarm



## 5 RESULTS AND DISCUSSION

Figure 3 depicts a plot of $P_m$ versus $P_d$ which has an inverse relationship; it can be observed that increase in $P_m$ decreases $P_d$. It therefore becomes necessary to mitigate factors that can obstruct the detection of PUs such as interference and noise.

Figure 4 shows a plot of Pfa versus $P_d$ with SNR -15dB, -20dB and -30dB. It can be observed that when SNR = -15dB, an increase in $P_{fa}$ increased $P_d$ with an output that outperforms the scenarios of SNR = -20dB and -30dB. This implies that probability of detecting a primary user signal will be enhanced if loss in (dB) in SNR is minimized to barest minimum. Also figure 6 illustrated the effects of the proposed algorithm on the traditional Energy Detection Technique. Increase in sampling rate is a major suggestion for adoption of this proposed algorithm. The figure shows a plot of probability of Pfa versus Pd, varying number of sampling for 1000, 2000 and 3000 and maintaining a fixed SNR of -20dB. From the figure, it was observed that as the number of sampling increases, the detection probability increases. For an instance, in the scenario of N=1000, Pfa=0.25 while Pd= 0.4, also when N=3000, Pfa=0.25 and Pd=0.45. This shows an increase in detection probability which implies that sampling at higher rate improves detection ability of Energy Detection technique, hence the suggestion of this proposed algorithm serves as an approach towards improving the performance of ED under the influence of noise

ISSN 2229-5518
uncertainty.

## 6 CONCLUSION

The detection characteristics of Energy Detection Technique under the influence of noise uncertainty in a changing environment were studied using ROC. It was observed that a fluctuation in value of SNR affects the traditional ED which is dependent on fixed threshold for primary signal's detection. Relative to this deduction, a new algorithm based on worst case SNR scenario was proposed in order to check the effects of these noise uncertainties in detection ability of ED. The simulation results indicate that the proposed algorithm improved detection sensitivity and shows robustness against noise uncertainty.

## REFERENCES


[1] H. Arslan "Cognitive Radio Software Defined and Adaptive Wireless Systems". Springer, University of South Florida Tampa FL USA, 2007.

[2] H. Tang "Some layer issues of wide band Cognitive System", *Proceedings of IEEE int. Symposium on New Frontiers in Dynamic Access Networks*. Baltimore Maryland pp. 151-159, 2005.

[3] W. Ejaz, "Spectrum Sensing in Cognitive Radio Network", a thesis submitted to the Faculty of Computer Engineering Department, College of Electrical and Mechanical Engineering, National University of Science and Technology, Pakistan.

[4] Agus, Sugihartono and Nana "A Cognitive Radio Spectrum Sensing Algorithm to Improve Energy Detection at Low SNR" Vol.12, No.3, , pp. 717~724, September 2014.

[5] G. Ali, A. Khalid and C. Hassan. "An adaptive threshold method for spectrum sensing in multi-channel Cognitive Radio Networks", 17th International Conference on Telecommunication. Pp. 425-429, 2010.

[6] H. Urkowitz, "Energy Detection of Unknown Deterministic signals", Proceeding of IEEE. vol. 55, no.4, pp. 523-231, doi:10.1109/PROC.1967.5573,1967.

[7] S. Kay " Fundamentals of Statistical Signal processing : Detection Theory", 1st Edition, Prentice Hall, Upper Saddle River. 1998.

[8] Y. Guicai, L. Chengzhi. and X. Maintain "A novel Energy Detection Scheme based on dynamic threshold in Cognitive Radio Systems" pp. 2245-2252, 2012.

[9] Gradshteyn and I. M. Ryzhik, "Table of Integrals, Series, and Prod ucts," 7th Edition, Academic, San Diego, 2007.