Evaluation of Different Energy Based Spectrum Sensing Approaches in Cognitive Radio System: Practical Perspective

Muntaser S. Falih[1], Hikmat N. Abdullah[2]

[1]Department of Information and Communication Engineering, Al-Nahrain University, Baghdad, Iraq

Abstract: ***Cognitive Radio (CR) is a modern trend of wireless communication with goal to achieve higher frequency utilization and overcome the problem of spectrum vacancy. Spectrum sensing is the basic step in CR, which enables it to distinguish spectrum states (idle or busy). In this paper a review and evaluation of different Energy Detection (ED) based spectrum sensing approaches are presented. Conventional Energy Detector (CED) and Double Threshold Energy Detector (DTED) have been introduced in this evaluation. The evaluation mechanism represents Receiver Operation Characteristic (ROC) of each approach, as well as the logical design of each approach. Finally, a proposed modification has been done on DTED method to enhance its performance. We named it MDTED. The simulation results showed that MDETD method has improved performance compared to DTED method at low SNR values less than -3 dB.***

Keywords: spectrum sensing, Energy detection, Double threshold energy detection

1. Introduction

The massive development in wireless communication technology, the grown scarcity in wireless resources and the fixed spectrum allocation policy makes congestion problem in wireless resources. By Federal Communication Commission (FCC) measurement, real utilization present of most band is between 5% and 85% which complicates efficiency finding the spectrum [2]. To solve the problem of congestion in spectrum resources, cognitive Radio (CR) was firstly proposed by Mitola and Maguire [1]. CR is a smart wireless communication system aware its environment and solves the problem of spectrum resources limitation by allowing Secondary Users (SU) to use the authorized band without interfering with Primary Users (PU). Spectrum sensing is one of the major challenges in CR development. With respect to receiver detection, three basic methods designed for spectrum sensing; Matched Filter Detection (MFD), Energy Detection (ED) and Cyclostationary Features Detection (CFD). CDF method gives high accuracy of detection but complex in implementation and requires more operation time. MFD method is a good and fast sensing method but needs a prior knowledge about signal type. ED method with specification of simple implementation and working without prior knowledge for signal type, becomes more popular than others [2].

The principle of ED is calculating the energy level of received unknown signal for certain time, then comparing average computed energy with a predefined threshold value to decide its absence or presence. Receiver Operation Characteristics (ROC) represent the performance measures of sensing algorithms. ROC parameters are Probability of Detection (P_D) and Probability of False Alarm (P_{FA}). P_D represents the correct detection probability of PU signal is present, while P_{FA} is the probability of PU signal detection when it is absent [3]. .

2. Primary Signal Detection

This term is equivalent to spectrum sensing to find the opportunity in spectrum (white spectrum). In primary signal detection binary, hypothesis is used define the presence on not of PU signals [4]. The hypothesis can be defined as follows:

H_0 : represents ideal channel
H_1 :: represents busy channel

In the ideal scenario the received signal component is noise only (no PU signal), while in the busy scenario the received signal contains PU signal in addition to environment noise. The following term shows the received signals for both scenarios.

$$H_0 : \ Y(k) = w(k) \qquad (1)$$
$$H_1 : Y(k) = s(k) + w(k) \qquad (2)$$

where w (k) is the channel noise, k is the number of received samples and s(k) is the PU original signal. This paper focusses on two types of ED methods: conventional Energy Detection (CED) and Double Threshold Energy Detection (DTED).

3. Conventional Energy Detection (CED)

CED is also called traditional single threshold energy detection. In this approach, the collected signal energy at SU node is compared with a predefined threshold value. Threshold value selection criteria defines the required system performance. Constant Probability of False Alarm (CPFA) and Constant Probability of Detection (CPD) are two ways used to evaluate the performance of PU sensing in CR. In CPFA, the required PFA is set, and then threshold value with variable P_D is found. In contrast, CPD selects PD and finds the threshold that gives this performance with variable P_{FA}. The following equation shows threshold value computing in CPFA case [6].

$$Th = (Q^{-1}(P_{FA}) + \sqrt{N_s}) + 2\sqrt{N_s}(N_s)^2 \qquad (1)$$

where Th is the threshold value, Q^{-1} is the inverse Q-function, P_{FA} is the probability of false alarm, and N_S is the number of samples. Figure ("1") shows the structure of single threshold energy detection spectrum sensing. CED algorithm is implemented via MATLAB. The simulation results will be shown in later section. Figure ("2") shows the CED algorithm flowchart that used for implementation assuming constant P_{FA} scenario.

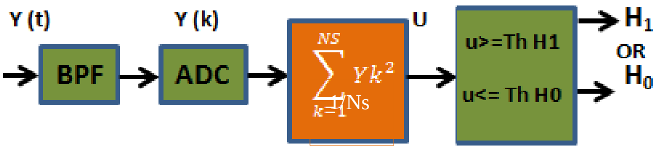

Figure 1: Single Threshold Energy Detection Spectrum Sensing

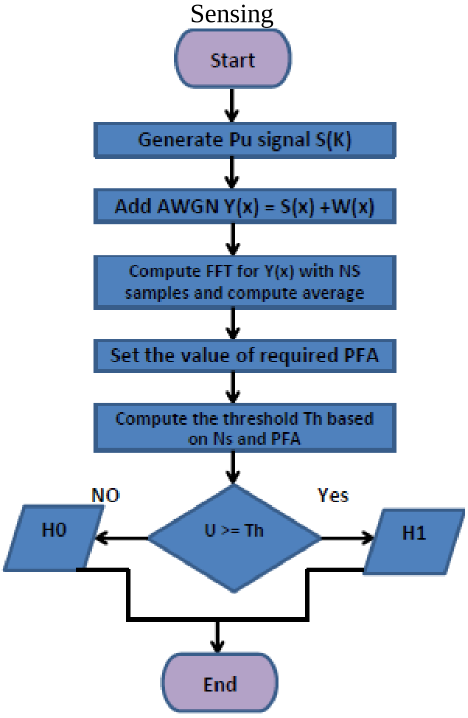

Figure 2: CED Flowchart

4. Double threshold Energy Detection (DTED)

In DTED there are two threshold values instead of single threshold. The main goal of this approach is to increase P_D by eliminating noise uncertainty. Noise uncertainty means the fast fluctuation in noise level (noise variance) between maximum and minimum values. With DTED, there is a way to control noise fluctuation; this magic is represented by the two values of threshold. Figure ("3") shows probability distribution of PU single level with respect to noise. From ("3"), the region between two thresholds valued called confusion region. Confusion region is intersection of PU and noise power. In CED with single threshold is a difficult to distinguish this region.

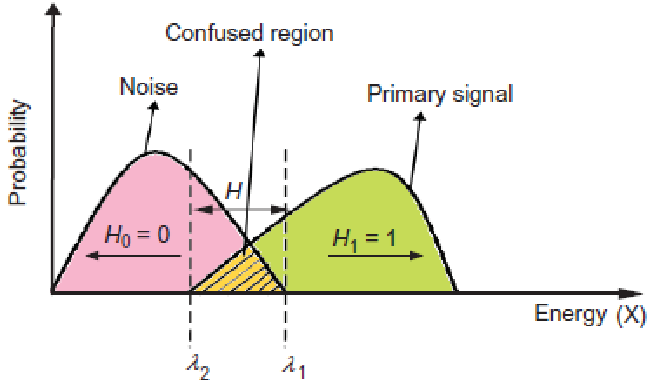

Figure 3: PU Energy Distribution in Noisy Channel [5]

Figure ("4") shows DTED system model. As it is clear in this figure, the average energy samples enter to decision process to sense the PU status (idle or busy). *Th1* and *Th2* values computed are based on maximum and minimum noise variance. If the received energy is smaller than *Th1* this is H_0 (noise only), but if received energy is greater than or equal to *Th2*, this H_1 (PU single plus noise). Otherwise the energy entered confusion region. Confusion region procedure processes the decision when the received energy is between *Th1* and *Th2*.

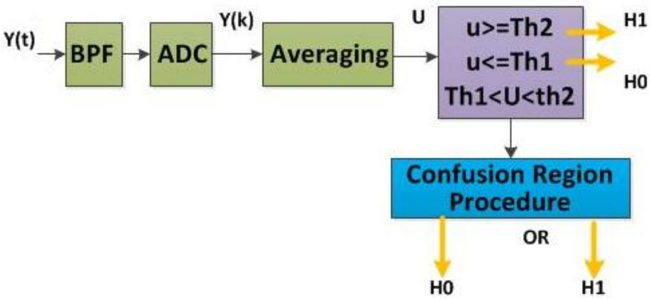

Figure 4: DTED System Model

4.1 Confusion Region Decision Procedure

This procedure is used to solve the problem of noise uncertainty when the received energy falls between *Th1* and *Th2*. Different approaches are proposed to do this procedure. In this paper quantization based method is used. In quantization based method, the confusion region is subdivided into four regions called sub-threshold (ST) using two-bits quantization as shown in Figure ("5") [5]. Each ST value is computed as follows:

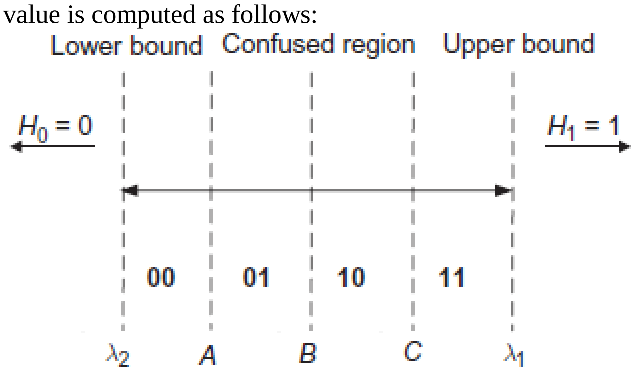

Figure 5: Confusion Region Quantization [5]

$$ST=\begin{cases} A = Th1 + D \\ B = A + D \\ C = B + D \\ Th2 = C + D \end{cases} \quad (2)$$

where D is the quantization distance and computed as follow:

$$D = (Th2 - Th1)/4 \quad (3)$$

To make decision, each ST takes Decimal Value (DV). Assume M represents the binary code of each ST, yields the following criteria [5]:

$$DV = \begin{cases} \text{If } M = 00, \text{ respective decimal value} - 0 \\ \text{If } M = 01, \text{ respective decimal value} - 1 \\ \text{If } M = 10, \text{ respective decimal value} - 2 \\ \text{If } M = 11, \text{ respective decimal value} - 3 \end{cases} \quad (4)$$

The last step for defining PU status (H_1 or H_0) is by comparing the resulting DV with predefined threshold value that computed based on CPFA as in (1). Figure ("6") shows the flowchart of DTED.

$$\begin{cases} H1 & if\ DV \geq Th \\ H0 & if\ DV \leq Th \end{cases} \quad (5)$$

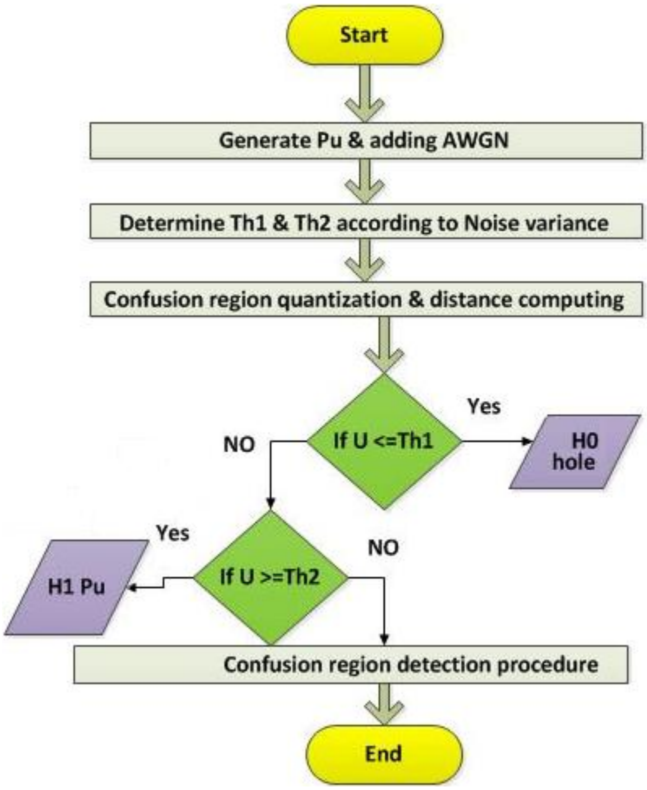

Figure 6: DTED Flowchart

5. The Proposed Method

In this paper a proposed modification on the method in [5] is presented. We call it "Modified Double Threshold Energy Detection" (MDTED). It has been achieved to enhance the detection performance of DTED method. MDTED is also based on confusion region quantization mechanism.

Here, the confusion region is divided into six sub-regions from A_1 to A_6 instead of four-sub region in the previous method as shown in Figure ("7"). Each sub-region has width of W computed by (6). The new Sub-Thresholds ST_N are computed using (7). In our method the digital assignment of each sub-region is omitted to save redundant computations and DV_N are immediately assigned to float values from 0 to 2.5 with an increase by 0.5 for each sub-region. DV_N for each sub-region represented in (8). The final decision in MDTED is based on the value of ST_N is taken according to (5). Changing the number of sub-intervals from four to six would produce more provide more precise recognition to spectrum status and hence prevents wrong decisions due channel imperfections.

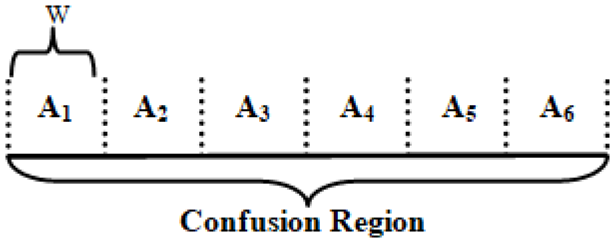

Figure 7: MDTED Confusion Region Division

$$W = (Th2 - Th1)/6 \quad (6)$$

$$ST_N=\begin{cases} A1 = Th1 + W \\ A2 = A1 + W \\ A3 = A2 + W \\ A4 = A3 + W \\ A5 = A4 + W \\ A6 = Th2 \end{cases} \quad (7)$$

$$DV_N=\begin{cases} 0\ for\ A1 \\ 0.5\ for\ A2 \\ 1\ for\ A3 \\ 1.5\ for\ A4 \\ 2\ for\ A5 \\ 2.5\ for\ A6 \end{cases} \quad (8)$$

6. Simulation Results

The three spectrum sensing methods CED, DTED and MDTED are simulated via MATLAB by generating a PU signal model. The transmission scenario assumes AWGN and non-cooperative sensing. CPFA is assumed to compute the performance in terms of sever SNR values versus P_D. Table (1) shows the simulation parameters used in our simulations

Table 1: Simulation Parameters

PU signal Type	QPSK
Channel Type	AWGN
P_{FA}	10^{-3}
Number of Samples	1000
SNR Range	-13 to -3 dB

Figure ("8") shows the performance of CED and DTED methods. From ("8"), it is clear that DTED gives better performance than CED especially at low SNR values. The detection probability is improved by about 50% at -13 dB SNR using DTED and this improvement is decreased as SNR increased. The reason for this improvement is related to the resistance of DTED method against noise uncertainty at low SNR values. At SNR equals -9 dB and higher, the performance of CED and DTED becomes almost the same.

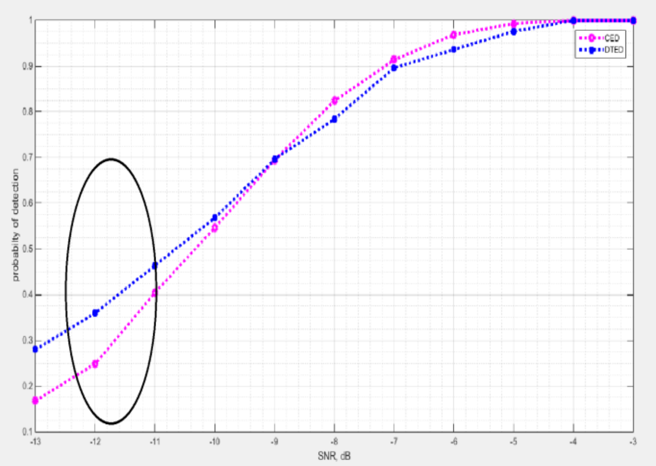

Figure 8: Performance CED and DTED Methods

The performance of DTED and MDTED methods is revealed in Figure (“9”). From (“9”), it can be seen that the detection probability is improved by 200% at SNR equals -13 dB using MDTED. Furthermore, the detection probability reaches 1 as early as at SNR=-9 dB with 5 dB gain compared to CED. The MDTED enhancement is related to further subdivisions of confusion region that makes decision more accurate for PU signal than that done by DTED method.

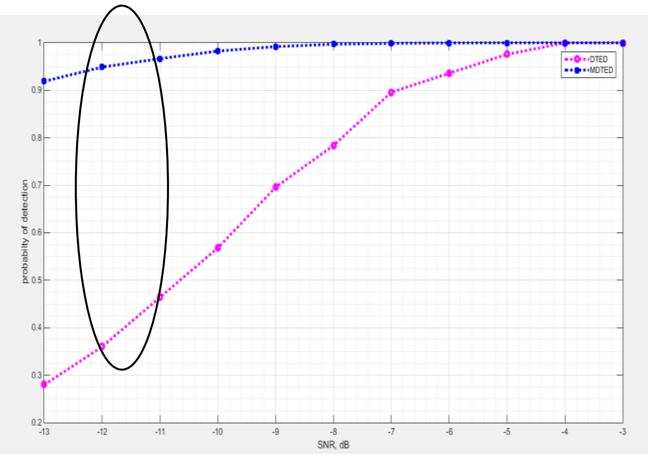

Figure 9: Performance DTED and MDTED Methods

7. Conclusion

DTED method is suitable of spectrum sensing at low SNR environment when noise uncertainty is high. The resistance to noise uncertainty came from recognizing the confusion region. Quantizing the confusion region enables to separates the noise and signal components. Precise quantization can give high accuracy of decisions. MDTED gives improved performance compared to DTED method and this improvement is increased as SNR decreased. From successive tests, it found out that dividing the confusion region into six provide the optimum compromise between detection performance and computation cost.

References

[1] Mitola, J., Maguire Jr., G.Q. (2009), Cognitive radio: making software radios more personal. IEEE Pers. Commun. 6(4), pp.13–18.

[2] Zhou X., Jing X., Huang H., Li J. (2018) An Enhanced Double Threshold Energy Detection in Cognitive Radio. Signal and Information Processing, Networking and Computers Conference ICSINC, vol. 473. Springer, Singapore.

[3] López-Benítez, M., Casadevall, F. (2010): Performance of spectrum sensing for cognitive radio based on field measurements of various radio technologies. In: IEEE Wireless Conference pp. 969–977.

[4] Alexander M., M, Nekovee and Y. Thomas Hou. (2010). Cognitive Radio Communications and Networks Principles and Practice, Elsevier.

[5] Ashish Bagwari & Geetam Singh Tomar. (2013) Adaptive double-threshold based energy detector for spectrum sensing in cognitive radio networks, International Journal of Electronics Letters, 1:1, 24-32, DOI: 10.1080/21681724.2013.773849

[6] Hikmat N. Abdullah and Hadeel S. Sami. (2017), Improvement of Energy Consumption in Spectrum Sensing Cognitive Radio Networks using an Efficient Two Stage Sensing Method," ACTA Polytechnica Journal, Vol.57, No.4, pp. 235-244.

Author Profile

Muntaser S. Falih was born in Al- Imara, Iraq in 1990. He obtained his B.Sc. in Information and Communication Engineering in 2013 at University of Baghdad, Iraq, M.Sc. in Networking Engineering in 2016 at Al- Nahrain University, Iraq and now he is Ph.D. student in Information and Communication Engineering department at Al-Nahrain University, Iraq. He is working on the project of developing sensing algorithms for cognitive radio. He is interested in subject of wireless communications, security and cognitive radio networks.

Hikmat. N. Abdullah was born in Baghdad, Iraq in 1974. He obtained his B.Sc. in Electrical Engineering in 1995, M.Sc. in Communication Engineering in 1998 at Al-Mustansiryah University, Iraq and Ph.D. in Communication Engineering in 2004 at University of Technology, Iraq. From 1998 to 2005 he worked as associate professor in the Electrical Engineering Department, at Al-Mustansiryah University, Iraq. Since the beginning of 2015 he works as full professor in college of Information Engineering at Al-Nahrain University, Iraq. From 2011–2013 he got a research award at university of applied sciences, Germany. He is a senior member of IEEE association since 2014. He is interested in subject of wireless communications, chaotic communications and cognitive radio networks.