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Research Article

Adaptive Double Threshold with Multiple Energy Detection Technique in Cognitive Radio

J. Avila and K. Thenmozhi
Department of ECE, School of EEE, SASTRA University, Thanjavur, Tamil Nadu, India

Abstract: The Cognitive Radio (CR) network is a system which lends help at the time of scarcity in spectrum. One of the process by which CR senses the spectrum is energy detection method with a fixed single threshold. When energy levels fall below the threshold, secondary user is permitted to use the spectrum of the primary user. It is shown by simulation results that having two levels of threshold i.e., double threshold improves performance by giving importance to one of the major aspects of CR, reducing the confliction of the primary and the secondary user. For enhanced performance under noise conditions, dynamic allocation or adaptive threshold is employed with the two levels of threshold. The system is made better by the use of multiple energy detectors on the reception end.

Keywords: Adaptive threshold, cognitive radio, double threshold, energy detection

INTRODUCTION

A breakthrough in the field of communication is the Wireless form of communication. The concepts of wireless communication included the allocation of the spectrum to its users. But with the heavy flow of customers, the wireless spectrum became a form of inevitable resource. This is because it is limited and should be used efficiently. Technology today raises the demand of the radio spectrum. This demand contributes to the minimized usage and constraints of bandwidth, network generation and the number of users. Studies indicate that no more free spectrum is available and the solution to this is to find the loopholes. These loopholes include holes in the spectrum which are not used although depicted as being assigned.

Cognitive Radio helps overcome the problem of insufficiency of spectrum. It is a technology uses a detection scheme called spectrum sensing which scans the bandwidth allocated for holes (unused spectrum) that can be put to use. This use is made by allotting that empty portion of the spectrum to a user to whom the spectrum does not belong i.e., secondary user. The hole present signifies the absence of the original owner of that portion, the primary user. Through this method the secondary user gains admittance into the spectrum for the purpose of communication. This admittance is made practically possible due to the detection of unoccupied part of the spectrum. The final result of this being the expansion of the utilization of the spectrum.

The first step for the CR work process is the sensing. The spectrum sensing technique here implements the energy detection method. This is one of the methods available besides cyclostationary or matched filter detection. The energy detection method is considered to be the simplest form of those existing techniques for spectrum sensing. Two factors contribute to the proper working of the CR network of which the first is that the primary user always exhibits higher priority than the secondary user. This phenomenon brings about the improved allotment among the various users. The second factor is that the primary user is never perturbed during the detection or the allocation process and also spectrum holes should be determined in an efficient manner. This detection process of the unused spectrum is the major principle behind the working of the cognitive radio (Furrtado *et al*., 2015).

Energy detection is suitable for practical and immediate applications. The mean-time for detection is comparatively lesser than the other methods of spectrum sensing. Problems arise when the Signal to Noise Ratio (SNR) is limited or in other words noise overlaps the signal. This disadvantage is compensated by enabling numerous channels for wideband detection. The long sensing time and the complexity in the computational efforts are the drawbacks of the cyclostationary technique but is reliable in spectrum detection (Dong-Chan and Yong-Hwan, 2009).

Energy detection is the method that works with the perception of the presence or absence of a signal. A comparison with the power received and a threshold level is made to decide whether spectrum is occupied or not. Any detection scheme relates to the performance of a CR by means of probability of detection P_d. This is the parameter which depicts how accurately the cognitive radio is able to distinguish a signal present and that which is absent. The end result of the CR system is the procurement of a high value of Pd because when this value is high the errors committed by the system would ultimately be low. In other word this error can be called as the probability of false alarm P_{fa}. Another parameter is the probability of missed

Corresponding Author: J. Avila, Department of ECE, School of EEE, SASTRA University, Thanjavur, Tamil Nadu, India

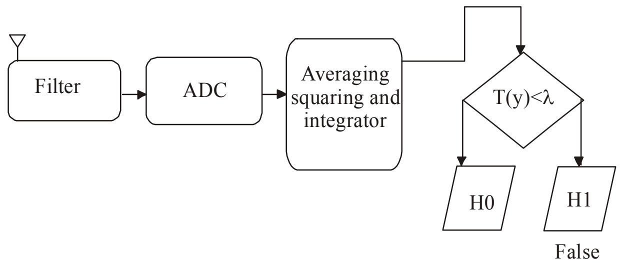

Fig. 1: Basic structure of energy detection system

detection P_m. It is derived from P_d. The two primal factors that decide the performance of CR are P_d and P_{fa}.

The time varying nature of wireless channels and that of primary user's actions makes the SNR of the secondary user's receiver varies with time. This may result in false detections of primary user i.e., the system may show that spectrum is being used when it is actually unused. Resulting reactions would include interference with the primary user and it should be avoided for the proper functioning of the communication system. One way to remove this issue is the establishment of two levels of threshold. The regions between the two thresholds depicting a region of uncertainty as to whether noise or signal is present. This can mitigate collision.

To take it one step further, dynamic assignment of threshold values instead of the fixed threshold is employed. Here the two levels of energy threshold are dynamically adjusted according to the SNR. Furthermore, the redundant system or the best choice principle contributes additional features to adaptive threshold which enhances detection performance. This is the mechanism by which better results of detection can be obtained. It is the use of a number of energy detectors rather at the CR reception end than the solely used main energy detector (Kale Sandikar *et al*., 2013).

The basic figure of energy detection method is as shown in the Fig. 1. The incoming signal along with noise is received and unwanted terms are filtered out. Then the power spectral density of the signal is found out. The plain energy detection involves the use of a simple model of binary hypothesis.

Absence of transmitted signal:

$$y(t) = n(t) : H_0 \tag{1}$$

Presence of transmitted signal:

$$y(t) = n(t) + s(t) : H_1 \tag{2}$$

where, s (t) is the transmitted signal, y (t) is the received signal and n (t) is the noise component. Absence of the transmitted signal (H_0) would mean the spectrum is vacant i.e., primary user is not in use and the other condition (H_1) would mean that the spectrum is occupied with primary user so that the secondary user cannot utilize the spectrum. To obtain the conclusion the energy of the signal is compared with the threshold λ. The working of this detection scheme is based on the threshold factor in addition to the basic parameters of detection and false detection.

System model: The following are the steps to calculate adaptive threshold. Let the noise and the transmitted signal be considered as random process which has a mean of zero. These are also random iid process (Nair *et al*., 2010). If:

$$\mu_n = \sigma_n^{\,2} \tag{3}$$

and,

$$\mu_s = \sigma_s^{\,2} \tag{4}$$

where, μ_n, σ_n is the variance of noise and μ_s, σ_s is the variance of the signal. Then the test statistic is given by:

$$T(y) = (1/M) * \sum_{m=1}^{M} |y[m]|^2 \tag{5}$$

Here y (m) is the received signal.

The Signal to Noise Ratio (SNR) is:

$$\gamma = \mu_s / \mu_n \tag{6}$$

The probability of false alarm:

$$P_{fa} = P(T(y) > \lambda / H_0) \tag{7}$$

The probability of detection is given as:

$$P_d = P(T(y) > \lambda / H_1) \tag{8}$$

Under the hypothesis of signal being absent and only noise present (H_0), the mean σ_0 and the variance

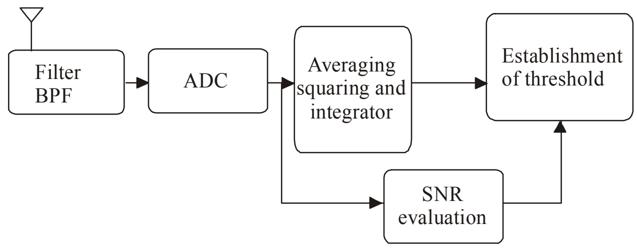

Fig. 2: Modified structure for adaptive energy detection

μ_0 of the received signal would be that of the mean and variance of the noise alone:

$$\mu_0 = \mu_n \tag{9}$$

When the number of samples (M) is quite high, the test statistic $T(y)$ is a normal distribution function. And hence the mean is given by:

$$\sigma_0 = \mu_0 / \sqrt{M} \tag{10}$$

The alternative hypothesis which involves signal being present in addition to noise (H_1), the mean and the variance of the received signal are σ_1 and μ_1 respectively. The expressions for these parameters are related to the SNR and the mean and variance of noise as follows:

$$\sigma_1^{\ 2} = (\gamma + 1) * \mu_0 \tag{11}$$

$$\sigma_1 = (\sqrt{1 + 2\gamma}) * \sigma_0 \tag{12}$$

Equation (7) and (8) provide the conditions under which the probability of detection and false alarm exists:

$$P_d = Q((\lambda - \mu_1) / \sigma_1) \tag{13}$$

$$P_{fa} = Q((\lambda - \mu_0) / \sigma_0) \tag{14}$$

Equation (13) and (14) are used for calculation of the values and are the expressions for the probabilities of detection and false alarm.

$Q(u)$ is the complementary distribution function. It is part of the standard Gaussian expressed as, (Xiang *et al*., 2012):

$$Q(u) = (1/2\pi) \int_u^\infty e^{-x^2/2} dx \tag{15}$$

These equations contribute in the formation of the basic energy detection scheme in the cognitive radio. The proposed methodology suitably alters the fixed threshold to provide variable values according to the SNR. Altering the threshold would stress knowledge on the channel conditions and the SNR value. The basic structure is modified for adaptability of the threshold as seen in Fig. 2 (Nastace *et al*., 2014).

The fixed threshold does not have a feedback structure which provides information regarding the SNR.

To determine the switchover of threshold, the value of the fundamental parameters for good performance is to be known. The restriction of the change is brought about by a check parameter which changes the threshold after acquiring the SNR value (Jong-Whan *et al*., 2008) and the check parameter is named as β.

If β is the check parameter with a range extending from 0 to 1, i.e., (0, 1); the threshold equation can be suitably written as:

$$\lambda = (\lambda_d - \lambda_{fa}) * \beta + \lambda_{fa,} 0 \le \beta \le 1 \tag{16}$$

The value of the check parameter can be even in non-integral form. For basic performance it can be understood that with β = 0, the threshold is that of the probability of false alarm λ_{fa} and in accordance with the conditions when the SNR is low, then check parameter can be set i.e., β = 1. That would change the threshold to that of the probability of detection λ_d. For proper functioning of the system under any SNR conditions it would be appropriate to let the parameter stay at 0, so that the threshold of false alarm would be default and has to be changed only under low SNR conditions or in other words, where detection process is to be made better.

PROPOSED METHODOLOGY

The double threshold as mentioned has two levels, lower threshold and upper threshold (Fig. 3). These two levels contribute to a region of uncertainty between them. It is uncertain because the energy level calculated is considered indecisive as to whether it is that of the noise, signal or both combined.

The advantage of including the uncertainty region helps in the reduction of the confliction of the primary and secondary. But this is done with the cost of rise in the unavailability of the spectrum for the secondary

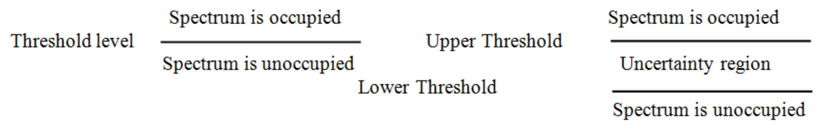

Fig. 3: Difference between single and double threshold

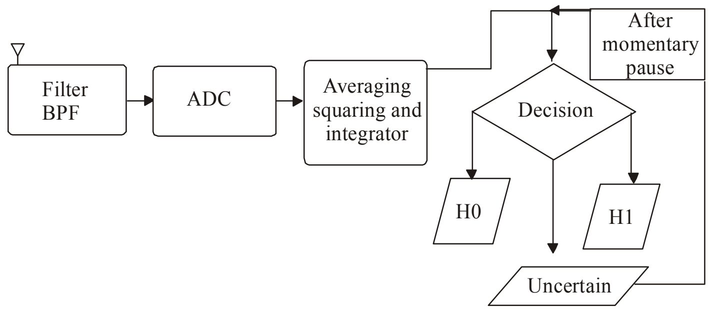

Fig. 4: Block representation of energy detection with double threshold scheme

user. If this condition persists, the CR checks the spectrum after a momentary pause as programmed (Fig. 4).

The expressions for the two levels of threshold are given as follows (Horgan and Murphy, 2010):

$$\lambda_{lower} = [(\sqrt{2/M} * G(P_{fa}, M)) + 1] * P_l \quad (17)$$

$$\lambda_{upper} = [(\sqrt{2/M} * G(P_{fa}, M)) + 1] * P_h \quad (18)$$

Where G is the Gamma inverse cumulative distributive function and P_l, P_k are constants. The gamma inverse function of x is given by:

$$x = F^{-1}(p / a, b) \quad (19)$$

$$p = F\ (x / a, b) \quad (20)$$

$$p = \frac{1}{b^a \Gamma(a)} \int_0^x t^{a-1} e^{-t/b} dt \quad (21)$$

Γ () is the gamma function.

The expression for the probability of detection is given as:

$$P_d = Q((-\lambda_{upper} - (\mu_s + \mu_n)) / \sqrt{2/M} * (\mu_s + \mu_n))), u_b) \quad (22)$$

where, q is the Marcum Q function and u_b is the time bandwidth component. It is a constant value:

$$P_m = 1 - P_d \quad (23)$$

The expression for the probability of false alarm is given as:

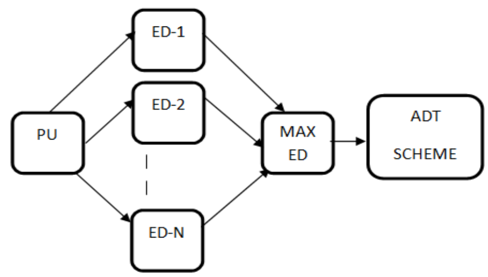

Fig. 5: Multiple energy detection with adaptive double threshold scheme

$$P_{fa} = \Gamma(u_{b,} \frac{\lambda}{2\sigma^2}) \Big/ \Gamma(u_b) \quad (24)$$

To succeed in detection process, the disadvantages in the existing methods should be accounted for. The fixed double threshold being made differential i.e., adaptive levels of threshold is implemented. In this work with simulation results it has been proved that detection is better with adaptive threshold and further enhanced by the incorporation of multiple energy detectors (Gorcin *et al*., 2010).

The improved model for reliability is shown in Fig. 5. The system provides a solution which can prove to be very favorable because of the N number of energy detectors or antennas (Bagwari and Tomar, 2014). The transmitted signal from the primary user is received under various situations and these multiple energy detectors reduce bit error and choose the least faded signal (Fang *et al*., 2013). As observed there is only one antenna for the primary user. The Max ED which is either the combiner or the selector which chooses the signal with the maximum energy or SNR. The combiner or selector can be made to work depending upon the samples if desired.

Table 1: Performance characteristics of multiple energy detection using double threshold scheme

S. No.		Channel 1	Channel 2	Channel 3	Max. energy	Selected SNR
1	SNR (dB)	-10	-5	-12		
	Energy	1.7852	2.9312	0.6092	2.9132	-5
2	SNR (dB)	-2	-7	2		
	Energy	0.3495	0.1466	1.0532	1.0532	2
3	SNR (dB)	5	4	6		
	Energy	0.1111	0.0846	0.1384	0.1384	6
4	SNR (dB)	12	8	15		
	Energy	0.0698	0.0613	0.0772	0.0772	15
5	SNR (dB)	17	14	20		
	Energy	0.0488	0.0513	0.0572	0.0572	20

S. No.	β	Lower threshold-non adaptive $\lambda_{lowe-non-ad}$	Upper threshold-non adaptive $\lambda_{upper-non-ad}$	Lower threshold adaptive λ_{lower}	Upper threshold adaptive λ_{upper}	Channel availability
1	1	0.8764	1.7568	4.1624	4.1805	Yes
2	0.25	0.8764	1.7568	0.3336	0.9092	No
3	0	0.8764	1.7568	0.0664	0.2657	Uncertain
4	0	0.8764	1.7568	0.0084	0.0334	No
5	0	0.8764	1.7568	0.0026	0.0106	No

Max.: Maximum

Under the combiner the expressions are as follows:

$$MAX\_ED_{op} = \sum_{i=0}^{N} E_i \quad (25)$$

where the term E_j represents the energy in each channel out of which either the whole sum or the maximum is obtained.

Once the output of the MAX ED is obtained, the SNR of that particular channel is measured and depending on the result, the check parameter is varied between 0 and 1. After this is done, the detection scheme in the adaptive form commences. This system is bound to give better results.

RESULTS AND DISCUSSION

Ejaz *et al*. (2012) adopted adaptive technique based on SNR to calculate mean detection time. An algorithm depending on noise level with multiple steps involve setting of a fixed threshold was proposed by Dong-Chan and Yong-Hwan (2009). Jinbo *et al*. (2009) proposed two level threshold or double threshold to reduce collision between primary and secondary user. Chabbra *et al*. (2014) used a dynamic threshold level which is established as a result of the relation between the SNR of the transmitted signals and the number of samples of the same. Yixian *et al*. (2010) utilizes algorithm to find the optimal value of threshold from a set of fixed threshold values. Multiple transmissions or relays of the primary user are employed in Atapattu *et al*. (2011) and the scheme proposed involves single transmission with multiple receptions. Adaptiveness in window size is the concept in the energy detection method proposed by Xu and Alam (2009). Bagwari and Tomar (2014) suggest the use of multiple energy detection with varying detection scheme.

Figure 6 shows the complementary Receiver Operating Characteristics (ROC) curve. It shows the comparison between fixed and double threshold. From

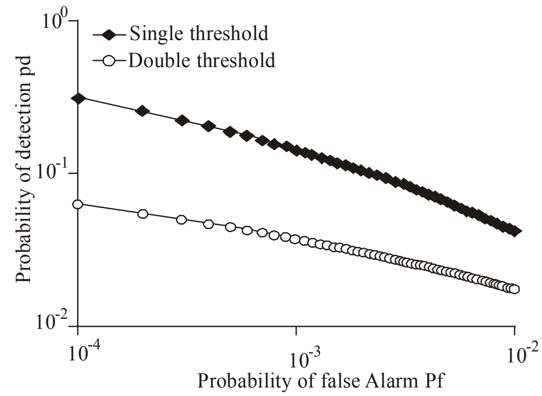

Fig. 6: Comparison between the threshold

the graph it is clear that double threshold is better than single threshold.

In Table 1 three energy detectors are utilized. Five trails are carried out for each energy detector. The SNR value is set as given in given in (Table 1). Based on the SNR value the energy is calculated by the individual detector and are given to the control unit. The control unit checks the energy value received from all the three energy detectors and selects the highest of the three. In the first trail it is 2.9312, in the second case it is 1.0532, in the third case it is 0.1384, in the fourth case it is 0.0772 and in the last case it is 0.0572. The SNR of the channel with the highest energy value is used to decide the value of the check parameter β. The beta value is set between 0 and 1. Applying the values in Eq. (25) and (26) gives the adaptive double threshold. This maximum energy is now compared with the adaptive threshold and the presence or absence of the primary user is concluded.

Example: In the first trail the max energy value obtained is 2.9312. So the corresponding SNR value is -5 Db. The adaptive double threshold values are 4.1624 and 4.1805. When compared with the threshold it falls below the lower threshold. Hence it is concluded that the primary user is absent and secondary user can access free spectrum.

For adaptive double threshold:

$$\lambda_d = 4.16, \lambda_{fa} = 3.32$$

$$\lambda_{lower} = (1.25 * 3.32) = 4.1624$$

Using Eq. (25) and (26):

$$\lambda_{upper} = (1 * (4.16 - 3.32) + 3.32) = 4.1624$$

For non-adaptive threshold:

$$\lambda_{lower-non-ad} = 0.8764$$

Using Eq. (17) and (18):

$$\lambda_{upper-non-ad} = 1.7568$$

CONCLUSION

As gathered from the performance characteristics, the double threshold provides better results than fixed threshold and similarly adaptive double performs better than the adaptive single threshold. To improve reliability and in some cases redundancy, the multiple energy detectors offer better results under various channel conditions. Each channel considered to be affected by a type of noise. The tabulation is performed with concept of AWGN being introduced in each channel but with different SNR values. The end result displays the reduction or increase in the threshold in accordance with the noise conditions. The detection probability is higher in the case of using adaptive threshold. The multiple-detection scheme is used where priority to the message i.e., transmitted signal is required. The adaptive scheme is used in the final stage comparison of the system so that the complex arrangement of the multiple energy detectors do not go in vain.

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