Asian Journal of Scientific Research

ISSN 1992-1454

Asian Journal of Scientific Research 8 (3): 333-341, 2015
ISSN 1992-1454 / DOI: 10.3923/ajsr.2015.333.341

Enrichment of Adaptive Threshold in Cognitive Radio

J. Avila and K. Thenmozhi
Department of ECE, School of EEE, SASTRA University, 613401, Tamil Nadu, India

Corresponding Author: J. Avila, Department of ECE, School of EEE, SASTRA, University, 613401, Tamil Nadu, India

ABSTRACT

Cognitive radio is the technology that helps overcome the problem of scarcity in a spectrum. It has its application in empowering a secondary user to gain entry into the spectrum. This admittance is because of detection of unoccupied part of the spectrum. It can boost up the spectrum utilization. The sensing technique utilizes the energy detection method, one of the many available. Being the simplest form, it checks the spectrum for empty slots by comparing the energy present with a predefined threshold. The result of this is not satisfactory under noisy conditions. To enrich the detection; the fixed threshold should be made differential i.e., adaptive or other kind of threshold should be employed. 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.

Key words: Cognitive radio, energy detection, adaptive threshold

INTRODUCTION

Wireless communication was one of a kind which brought about a revolution in the field of communication and with its advent came the surge of customers in wireless network services. The wireless spectrum has become a form of inevitable resource because of its limited availability. The reason for this is the escalation in demand of the radio spectrum. It brings constraints on the bandwidth, network generation and number of users. In reality the spectrum is not systematically allocated. It is regardless of the schemes which depict how the spectrum is assigned to the user. These schemes indicate that the spectrum has run out of capacity to accommodate any further user for communication purposes.

The solution that jumps this hurdle in the less available spectrum is Cognitive Radio (CR). It is this technology that makes use of detecting scheme called a spectrum sensing characteristic. The major utilization lies in the fact that it grants access to a secondary user to occupy a part of the spectrum which is vacant at the moment. But the primary user still has more privilege than the secondary users. This phenomenon brings about the better allotment of the spectrum among the various users. This process of detection of unused spectrum contributes to the major principle of the cognitive radio. For the sensing process the primary system should remain undisturbed during allocation and usage of the spectrum by the secondary user and also spectrum holes (unused spectrum) should be identified efficiently. These contribute to the chief interests of the spectrum sensing (Furtado *et al*., 2015).

For such a sensing process, there are a variety of detection procedures. Some of which are the transmitter detection processes such as matched filter detection, energy detection and the cyclostationary-feature detection. Energy detection is suitable for pragmatic applications. The mean-time for detection is comparatively lesser than the other methods. Problems persist when the signal to noise ratio is scanty. But it makes up for the loss 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 it imparts dependable spectrum detection (Oh and Lee, 2009).

Energy detection method perceives the presence or absence of a signal by the power received and this is compared with a threshold to decide whether spectrum is occupied or not.

Be it for any one of the detection scheme the performance of a CR depends upon probability of detection Pd. This is described as the parameter, which depicts how accurately the cognitive radio is able to distinguish a signal present, 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 Pfa. Another parameter is the probability of missed detection Pm. It is derived from Pd. The two primal factors that decide the performance of CR are Pd and Pfa.

As a reason of the time varying attribute of wireless channels and primary user actions, 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. False alarm would mean the vice versa condition. Resulting reactions would include interference with the primary user and it should be avoided for the proper functioning of the communication system. The solution to the problem at hand would be to dynamically assign threshold values instead of the fixed energy detector that is being used for spectrum sensing. Here the energy threshold is dynamically adjusted according to the SNR (Farag and Ehab, 2014).

In addition to the existing methods of allotting a threshold for comparison, the redundant system or the best choice principle contributes additional features to adaptive threshold, which enhances detection performance. The mechanism by, which this can be obtained is the use of a number of energy detectors rather than the solely used main energy detector (Sandikar *et al*., 2013).

MATERIALS AND METHODS

Framework of energy detection: 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

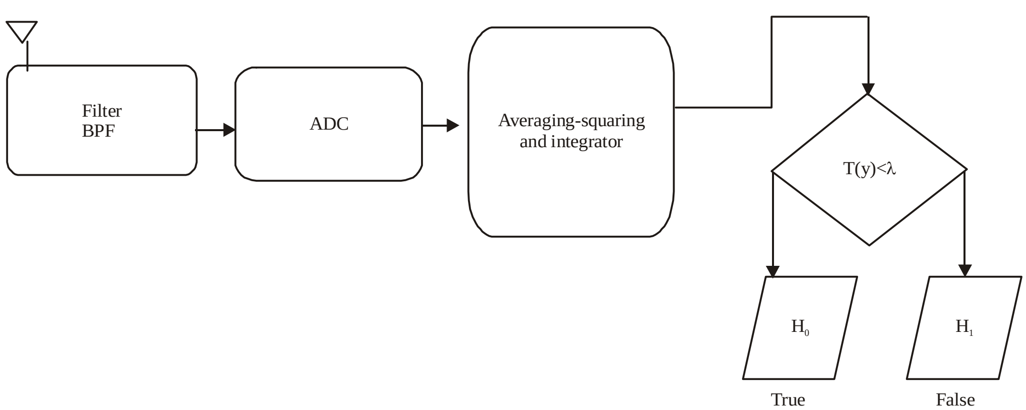

Fig. 1: Basic structure of energy detection system

the power spectral density of the signal is found out. The plain energy detection involves the use of a simple model of binary hypothesis:

$$y\ (t) = n(t){:}\ H_0\ \text{(Absence of transmitted signal)} \quad (1)$$

$$y\ (t) = n(t)+s(t){:}\ H_1\ \text{(Presence of transmitted signal)} \quad (2)$$

where, s(t) is the transmitted signal, y(t) is the receive 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.

Multiple adaptive energy detection: Let the noise and the transmitted signal be considered as a random process which has a mean of zero. These are also random iid process (Nair *et al*., 2010):

$$\text{If } \mu_n = \sigma_n^{\ 2} \text{ and } \mu_s = \sigma_s^{\ 2} \quad (3)$$

where, is μn, 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:

$$T(y) = (1/M) * \sum_{m=1}^{M} \left| y[m] \right|^2 \quad (4)$$

Here y(m) is the received signal.

The signal to noise ratio (SNR) is:

$$\gamma = \mu_s / \mu_n \quad (5)$$

The probability of false alarm:

$$P_{fa} = P(T(y) > \lambda / H_0) \quad (6)$$

The probability of detection is given as:

$$P_d = P(T(y) > \lambda / H_1) \quad (7)$$

Under the hypothesis of signal being absent and only noise present (H_0), the mean σ_0 and the variance μ_0 of the received signal would be that of the mean and variance of the noise alone:

$$\mu_0 = \mu_n \quad (8)$$

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:

$$\sigma_0 = \mu_0 / \sqrt{M} \quad (9)$$

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:

$$\sigma_1^2 = (\gamma + 1) * \mu_0 \quad (10)$$

$$\sigma_1 = (\sqrt{1+2\gamma}) * \sigma_0 \quad (11)$$

Equations 6 and 7 provide the conditions under which the probabilities of detection and false alarm exists:

$$P_d = Q((\lambda - \mu_1) / \sigma_1) \quad (12)$$

$$P_{fa} = Q((\lambda - \mu_0) / \sigma_0) \quad (13)$$

Equations 12 and 13 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 Ling *et al*. (2012):

$$Q(u) = (1/2\pi) \int_u^\infty e^{-x^2/2} dx \quad (14)$$

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 a knowledge on the channel conditions and the SNR value. The basic structure is modified for adaptability of the threshold as seen in Fig. 2 (Nastase *et al*., 2014). The fixed threshold does not have a feedback structure which provides information regarding the SNR.

To determine the switch over 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 (Lee *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:

$$\lambda = (\lambda_d - \lambda_{fa})^* \beta + \lambda_{fa} \quad 0 \le \beta \le 1 \quad (15)$$

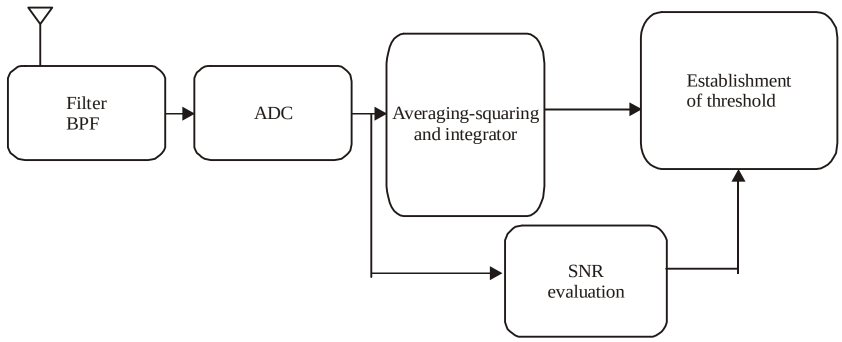

Fig. 2: Modified structure for adaptive energy detection

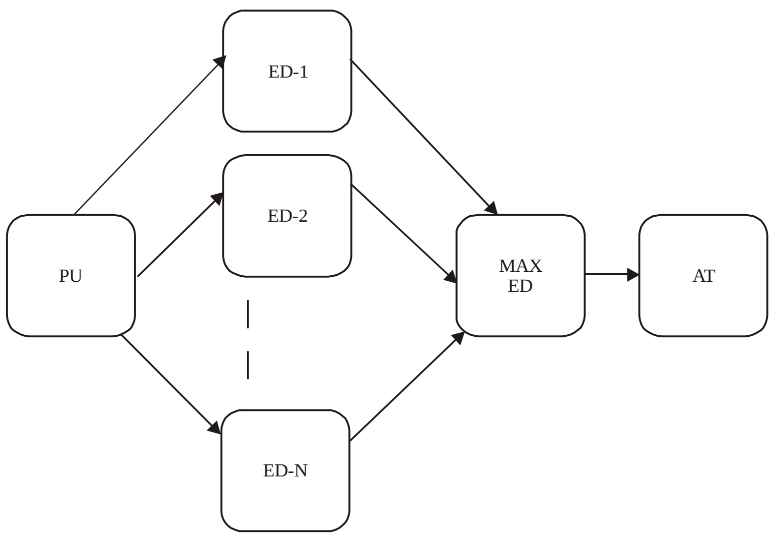

Fig. 3: Multiple energy detection scheme

The value of the check parameter can be even in non-integral form. For basic performance it can be understood that with $\beta = 0$, the threshold is that of the probability of false alarm λ_d and in accordance with the conditions when the SNR is low, then check parameter can be set i.e., $\beta = 1$. 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 (Gorcin *et al*., 2010).

The improved model for reliability is shown in Fig. 3. The system provides a solution which can prove to be very favourable, 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 chooses the least faded signal (Liu *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.

Under the combiner the expressions are as follows:

$$MAX - ED_{op} = \sum_{i=0}^{N} E_i \tag{16}$$

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. Wu *et al*. (2009). After this is done, the detection scheme in the adaptive from commences. The 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 Oh and Lee (2009). Wu *et al*. (2009) proposed 2 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. Liu *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 reception. Adaptiveness in window size is the concept in the energy detection method proposed by Xu and Alam (2009). Bagwari and Tomar (2014) suggests the use of multiple energy detection with varying detection scheme.

This work focuses on incorporating adaptiveness in the threshold and same is used in multiple energy detector method. Figure 4 shows the comparison between adaptive threshold and fixed threshold. From the output it is quite clear that there a great improvement in SNR value in the adaptive case, when compared to the non-adaptive threshold.

The results of the proposed method is shown in Table 1. Here three energy detectors are utilized. Five trails are carried out for each energy detector. The SNR value is set. Based on the

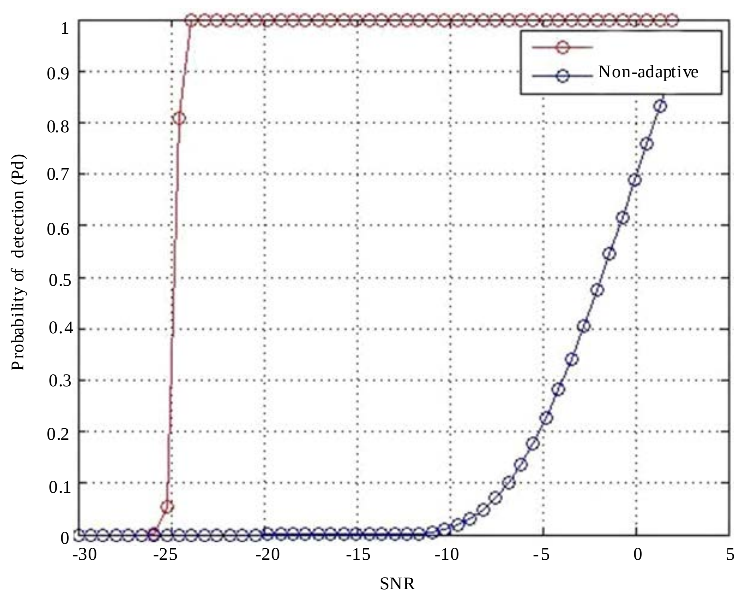

Fig. 4: Performance comparison between adaptive and non-adaptive threshold

Table 1: Multiple energy detection scheme using adaptive threshold and comparison with that of non-adaptive threshold

Parameters	Energy detector 1	2	3	Max. energy	Selected SNR	β	Adaptive threshold λ_{ad}	Non-adaptive threshold $\lambda_{non\text{-}ad}$	Channel availability
SNR (dB)	-3	-5	-2						
Energy	1.6872	1.5995	3.701	3.701	2	0.5	2.13	1.67	No
SNR (dB)	10	-6	5						
Energy	10.8138	0.5134	2.6168	10.8138	10	1	11.0007	10.5760	Yes
SNR (dB)	9	5	2						
Energy	9.2930	0.8197	0.5653	9.2930	9	1	8.9438	8.4008	No
SNR (dB)	4	-10	-15						
Energy	0.4776	0.3086	0.3437	0.4776	4	0.25	0.6661	0.4220	Yes
SNR (dB)	17	23	28						
Energy	0.2528	0.2554	0.2684	0.2684	28	0	0.0017	0.0017	Yes

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 3.701, in the second case it is 10.8138, in the third case it is 9.2930, in the fourth case it is 0.4476 and in the last case it is 0.2684. 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 equation 16 gives the adaptive 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 3.701. So the corresponding SNR value is -2 Db. The adaptive threshold value is 2.23. When compared with the threshold it is lower value. Hence, it is concluded that the primary user is available and there is no free spectrum.

Calculation of Adaptive threshold.

Since the SNR is low, beta is set high (0.5):

$$\lambda_d = 2.59,\ \lambda_{fa} = 1.67 \text{ (Using Eq. 12 and 13)}$$

$$\lambda_{ad} = (2.59\text{-}1.67)^*\ 0.5\text{+}1.67 = 2.13$$

For Non-Adaptive threshold or fixed threshold.

β = 0 (default) because SNR value is not known in this case:

$$\lambda_{non\text{-}ad} = \lambda_{fa} = 2.13$$

CONCLUSION

As gathered from the performance characteristics, the adaptive threshold provides better results at low SNR conditions. 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 results 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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