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Enhanced Cognitive Radio Energy Detection Technique based on estimation of Noise Uncertainty

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Abstract— **Cognitive radio is a modern technique for the effective utilization of electromagnetic spectrum. In CR, there are many functions out of which spectrum sensing is one of the important function. Spectrum sensing is the method of detecting unused spectrum without causing interference to the primary users. Out of number of spectrum sensing techniques proposed by authors, energy detection is widely used due to its simplicity, low computational cost and its ease of use. The conventional energy detection technique which was based on concept of fixed threshold was un-optimized due to its dependency on noise uncertainty. The new energy detection technique proposed is dynamic energy detection algorithm in which we use two threshold values instead of single threshold value. The two threshold values are estimated by the average energy received in a specific period of observation from the legal user. By estimating noise uncertainty factor threshold values are evaluated. The thresholds evaluated are needed to enlarge the probability of detection (P_d) and reduce the probability of false alarm (P_{fa}). In this paper, comprehensive review of both conventional energy detection technique and proposed energy detection technique is reviewed. Along with this tradeoff between detection probability and false alarm probability is analyzed.**

Index Terms—**Cognitive Radio, Probability of detection, Probability of False Alarm, Spectrum Sensing.**

I. Introduction

Today wireless communications depends upon allocation of fixed spectrum, due to which the spectrum is assigned to any of the users fixedly at any time. The result of which is that spectrum is un-utilized efficiently and effectively.
Cognitive Radio is founded to be the best solution which can work for the conflicts between spectrum underutilization and growing demand for spectrum.

The aim of CR is to utilize the spectrum efficiently by making secondary illegal users to access the spectrum in an opportunistic manner and without causing any lossful interference to the primary legal users.

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The major challenge for cognitive radio was that secondary user need to sense the spectrum that is not utilized by the primary user and to leave the spectrum as primary user arrives so as to avoid the harmful to interference to the authorized legal users. This function is known as Spectrum Sensing. There are various methods of Spectrum Sensing which includes: Energy detection, matched-filter detection, Eigen-value based detection and cyclostationary detection. These available methods provide trade-off between sensing time, complexity, capabilities of detection but practical ability depends upon the quantity of information available for the primary user. Generally, CR is not expected to provide us with the information of primary user that is using the radio spectrum. Therefore, when secondary user is unable to gather information about primary user, Energy Detection is the best method can be used for Spectrum Sensing. The main disadvantage of Energy detection method is its dependency upon noise power, little change in power of noise can result in large decline in the performance of Energy detector due to SNR thresholds. Most of the studies in Energy detection method involve constant noise power, but it is completely impractical to keep the noise power constant, hence noise uncertainty is completely unavoidable.
Various authors theoretically found out that to remove the problem of noise uncertainty, two threshold levels needed to be defined. The two threshold levels are estimated depending upon the noise uncertainty factor values. Out of the two thresholds, the smaller one is used to enlarge the value of probability of detection (P_d) and the larger one is used to minimize the value of probability of False alarm (P_{fa}). Hence, the main aim is to use two threshold levels to calculate the value of P_d and P_{fa}.
But any practical methodology is not given by any of the authors for how to estimate the values of two thresholds so as to enlarge the value of P_d and reduce the value of P_{fa}.
Depending upon the work of various authors, in the following paper, a practical dynamic threshold value energy detection technique for CR is researched. This proposed dynamic threshold detection method is dependent upon checking the absence or presence of primary user. The prediction of primary user can be done by calculating the average of energies received from primary user during particular period. This experiment performed to the some extent can help us to predict primary user's absence or presence. The two thresholds value estimated is used to enlarge the value of P_d and reduce the value of P_{fa} i.e., when we expect the presence of primary user we use smaller

threshold and vice versa for the unavailability of primary user.

The remaining paper is sectioned as: Section 2 refers to the classical fixed energy algorithm. Section 3 detailed the proposed dynamic energy detection algorithm. Section 4 depicts the theoretical analysis of dynamic threshold energy detector. Section 5 gives the performance evaluations followed by conclusion in Section 6.

II. THE FIXED CLASSICAL ENERGY DETECTION ALGORITHM

A. *Spectrum Sensing Problem Formulation*

Binary Hypotheses testing method can be used to model the spectrum sensing problem where the situation of Primary user is defined with the help of two hypotheses as follows:

$$H_0 \rightarrow y(n) = w(n) \qquad (PU\ absent)$$
$$H_1 \rightarrow y(n) = x(n) + w(n) \quad (PU\ present)$$

Where n=1,2,…….N and N is the complete length of Primary user's observing period, hypotheses H_0 denotes the unavailability of primary user, hypotheses H_1 denotes the presence of primary user. $y(n)$ is the sample signal received, $w(n)$ is the samples of noise signal corresponding to additive white Gaussian noise (AWGN) with variance σ_n^2 , i.e., $w(n) \in N(0, \sigma_n^2)$. $x(n)$ is the samples of primary user signal and N is the total number of samples of received primary signal for carrying out the process of detection. Sometimes the technique of Spectrum sensing fails which results in probability of missed detections and probability of false alarms. The missed detection is occurred when primary user is present in frequency band and cognitive radio selects the hypotheses H_0 , due to which harmful interference can be caused to primary user. While, false alarm is occurred when the frequency band that is sensed is idle but cognitive radio selects hypotheses H_1 , which gives rise to the missed opportunities for using the spectrum and therefore resulting in less spectrum utilization. Depending upon these two definitions, we can summarize the results of any spectrum sensing technique by means of probabilities: probability of detection (P_d) and probability of false alarm ($P_{\downarrow}fa$) . For the good performance of cognitive radio, P_d should be maximized and P_{fa} should be minimized.

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B. *Fixed threshold Classical Energy Detection*

In general we cannot expect from cognitive radio to provide us with information about the primary user which is using the radio spectrum. There we can preferably use Energy detection because it can detect the presence of Primary user without any prior knowledge about it and its implementation is also simple. The fixed threshold energy detector evaluates the energy received from the primary user and compares it with predefined threshold. The channel is considered to be busy if the energy is greater than threshold else it is considered to be idle. The test statistic is provided as follows:

$$D(y) = \sum_{n=0}^{N} y(n)^2$$

Here *D(y)* denotes the decision variable. The above test statistic obeys central chi-square distribution under hypothesis H_0 and non-central chi-square distribution under hypothesis H_1 having N as degree of freedom. In the region of low SNR, the minimum samples required to obtain with particular performance must be greater than one sample. Due to this observation, we can deploy central limit theorem to evaluate test statistic as the Gaussian distribution which is following:

$$D(y) = \begin{cases} N\left(N\sigma_n^{2,2N\sigma_n^4}\right) & H_0 \\ N(N(P+\sigma_n^2), 2N([P+\sigma_n^2)]^2) & H_1 \end{cases}$$

Here, P denotes average power of signal. If we consider only noise which is AWGN, the probability of False alarm and probability of detection can be studied as:

$$P_{fa} = P_r(D(y) > \gamma | H_0) = Q\left(\frac{\gamma - N\sigma_n^2}{\sqrt{2N}\sigma_n^2}\right)$$

$$P_d = P_r(D(y) > \gamma | H_1) = Q\left(\frac{\gamma - N(P+\sigma_n^2)}{\sqrt{2N}(P+\sigma_n^2)}\right)$$

Here, Q(.) is the standard Gaussian cumulative distribution function and γ is the fixed threshold corresponding to which decisions are made. We can calculate the desired threshold by using:

$$\gamma = \sigma_n^2\left[Q^{-1}(P_{fa})\sqrt{2N} + N\right]$$

From the above equation, it is clearly evident that decision threshold is not only harmed by probability of false alarm ($P_{\downarrow}fa$) but also by the noise variance (σ_n^2), which can never be a constant value practically. So, a very small variation in σ_n^2 can highly affect the decision threshold causing unreliability in the detection of primary user.

III. THE DYNAMIC ENERGY DETECTION SCHEME

This proposed scheme considers the effect of noise uncertainty and hence results in better performance of CR dynamic energy detector in comparison to fixed threshold energy detector.

In this method, we calculate the two threshold values to calculate the effect of noise uncertainty and accordingly enlarge and reduce the value of P_{fa} and P_d respectively.

From the values of P_{fa} and $P_{d,}$ it can be observed that we can predict the availability or unavailability of primary user; we can increase or decrease the values of these probabilities by dynamically decreasing and increasing the used threshold. Therefore, we can introduce a dynamic energy detection scheme based on prediction of primary user. In the algorithm proposed, we calculate the energy of primary user and based on which we estimate the presence or absence of PU. Hence, we calculate the average energy of primary user during L consecutive N observational periods.

$$D_{av} = \frac{1}{L}\sum_{k=1}^{L} D(y)_k$$

Here, D_{av} is the average energy received of primary user, $D(y)_k$ is the received energy. Noise uncertainty factor is calculated at the same time by estimating the noise variances, and by dividing the maximum noise variance with the average value of noise variances and can be written as:

$$\rho = \frac{\max_{1\leq i\leq L} \left((\sigma)^2{}_{n_i}\right)}{\frac{1}{L}\sum_{i=1}^{L} \sigma^2{}_{n_i}}$$

Here, ρ is the noise uncertainty factor. Now, when the average energy D_{av} and factor of noise uncertainty ρ is calculated, we compare D_{av} with already defined threshold valueγ . If the average energy received (D_{av}) is greater than fixed threshold (γ) , then the presence of primary user can be estimated. To overcome the effect of noise uncertainty γ/ρ is used as value of threshold. While if average energy is less than fixed threshold, $\gamma\rho$ is used as threshold to overcome the effect of noise uncertainty.

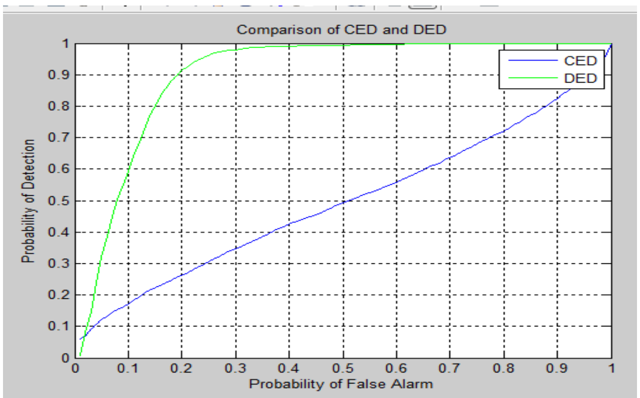
IV. ANALYSIS OF THE PROPOSED DYNAMIC ENERGY SCHEME THEORETICALLY

The different scenarios of modern algorithm here for dynamic energy detection is summarized in "fig.1".

"Fig.1". Theoretical analysis of proposed dynamic energy scheme

Case	1	2	3	4
Predicted State	H_1	H_1	H_0	H_0
Actual State	H_1	H_0	H_0	H_1
New threshold	γ/ρ	γ/ρ	$\gamma\rho$	$\gamma\rho$
Result	P_d increases	P_{fa} increases	P_{fa} decreases	P_d decreases

V. PERFORMANCE EVALUATION



Here, we can see that probability of detection is maximized and probability of false alarm is minimized for Dynamic energy detection than classical energy detection algorithm.

VI. CONCLUSION

The dynamic threshold energy detection is proposed in this paper for the spectrum sensing of Cognitive Radio. The proposed scheme depends on the current state of the primary user. Depending on this, dynamic thresholds are calculated considering effect of Uncertainty of Noise. The value of thresholds evaluated are used to increase the value of P_d and decrease the value of P_{fa} . The performance of dynamic energy detection technique is optimized against the values of parameters. The proposed dynamic energy detection scheme proved to be 3.5 times better than the classical energy detection scheme.

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