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Enhanced Cognitive Radio Energy Detection Algorithm Based on Estimation of Noise Uncertainty

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ABSTRACT:
With rapid growth of wireless devices, the Scarcity of Spectrum resources arises ,due to the improper and inefficient usage of available spectrum band. This problem can be alleviated by Cognitive radio . The major functions of the cognitive radio rely on efficient sensing of available spectrum and Spectrum sensing techniques have been used to enhance the detection performance. Among these techniques, Energy detection is considered to be the implemented in practice because of less complexity.

KEY WORDS: Cognitive Radio, Spectrum Sensing, Energy detection, Noise Uncertainty

INTRODUCTION:
Cognitive radio is a novel technology which improves the spectrum utilization by allowing secondary users to borrow unused radio spectrum from primary licensed users or to share the spectrum with the primary users. As an intelligent wireless communication system, cognitive radio is aware of the radio frequency environment, selects the communication parameters (such as carrier frequency, modulation type, bandwidth and transmission power) to optimize the spectrum usage and adapts its transmission and reception accordingly. By sensing and adapting to the environment, a cognitive radio is able to able to fill in the spectrum holes and serve its users without causing harmful interference to the licensed user. To do so, the cognitive radio must continuously sense the spectrum it is using in order to detect the re-appearance of the primary user . Once the primary user is detected, the cognitive radio should withdraw from the spectrum instantly so as to minimize the interference.

DEFINITION:
According to Mitola [3], CR is defined as The point in which wireless personal digital assistants (PDAs) and the related networks are sufficiently computationally intelligent about radio resources and related computer-to-computer communications to: (a) detect user communications needs as a function of use context, and (b) to provide radio resources and wireless services most appropriate to those needs. However the concept of CR is not limited strictly to wireless devices such as PDAs.
Simon Haykin defines Cognitive Radio, it as follows [1]: "Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment (i.e., outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind:
highly reliable communications whenever and wherever needed efficient utilization of the radio spectrum.
Cognitive radio is a excellent tool for solving two major problems :
Interoperability (talking to legacy radios using a variety of incompatible waveforms)

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APPLICATION:

A typical cognitive radio operation is representated as a simplification to the cognition cycle. A cognitive cycle by
which a cognitive radio interact with environment is

1. **Radio-scene analysis, which encompasses the following**:
2. Estimation of interference temperature of the radio environment;
3. Detection of spectrum holes.
4. **Channel identification, which encompasses the following**:
5. Estimation of channel-state information (CSI)
6. Prediction of channel capacity for use by the transmitter.
7. **Transmit-power control and dynamic spectrum management**
8. Tasks 1) and 2) are carried out in the receiver, and task 3) is carried out in the transmitter. Through interaction with the RF environment, these three tasks form a cognitive cycle,

COGNITIVE RADIO APPLICATIONS, ADVANTAGES AND DRAWBACKS:

The cognitive radio does the same advantages and disadvantages of SDR. The cognitive has the more benefits than a conventional radio. The following are the applications, advantages and disadvantages of cognitive radio.

Some of the important applications of CR are as follows:

Improving spectrum utilization & efficiency Improving link reliability Less expensive radios Advanced network topologies Enhancing SDR techniques Automated radio resource management

ADVANTAGES OF CR:

1. Cognitive radios are expected to be powerful tools for mitigating and solving general and selective spectrum access issues
2. Improves current spectrum utilization (Fill in unused spectrum and move away from occupied spectrum)
3. Improves wireless data network performance through increased user throughput and system reliability
4. More adaptability and less coordination required between wireless network.

DRAWBACKS OF CR:

1. Security
2. Software reliability
3. Keeping up with higher data rates
4. Regulatory concerns
5. Fear of undesirable adaptations
6. Significant research remains to be done to realize commercially practical cognitive radio.

CONCEPT OF COGNITIVE RADIO:

SPECTRUM SENSING:

Spectrum sensing is the most important components in cognitive radio as its ability to sense and aware the parameters related to the radio channel characteristics. Spectrum sensing acts to detect the presence or absence of a primary user signal in cognitive radio system [3]. This element enables SU to access unoccupied spectrum band.

The fundamental nature of spectrum sensing is a binary hypothesis-testing problem

Ho: primary user is absent

H1: primary user is in operation

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The input metric in the spectrum sensing is given by

1. Probability of correct detection, *Pd*– which quantifies the probability of a SU detecting that incumbent is present.
2. Probability of false alarm, *Pf* - which quantifies the probability of SU declaring that a incumbent is
3. present in the spectrum when the spectrum is in fact free.

4. Probability of miss detection, *Pm*- which quantifies the probability of SU declaring that the spectrum is free but the fact is there is incumbent present .

The probability of correct detection, Pd and probability of false alarm, Pf is important for the evaluation of detection performance is defined as

$$Pd=P\{decision =H1/H1\}=P(Y>T/H1)$$
$$Pf=P\{decision =H1/H0\}=P(Y>T/H0)$$

Where Y is the decision stastics and t is the decision threshold.

TECHNIQUE OF SPECTRUM SENSING CAN BE CATEGORIZED INTO THREE GROUPS WHICH ARE:

1. Transmitter detection – the detection based a signal from primary transmitter through the local interpretation of SUs.
2. Cooperative detection – SUs shares their sensing information and combined the decision for a better and precise detection.
3. Interference-based detection – detection using interference temperature model.

Transmitter Detection Techniques:

Transmitter detection is based on the discovery of a weak signal from a primary transmitter through the local observations of CR users. The basic hypothesis model for transmitter detection technique is defined as:

$$X(n)=\{ \begin{array}{ll} w(n)\ldots\ldots H0 \\ y(n)+w(n)\ \ldots. H1 \end{array} \}$$

Where *x(n)* is the received signal, *y(n)* is the transmitted signal and *w(n)* is the noise. *Ho* is a null hypothesis states that there is no PU in a certain frequency band. While *H1* indicates that PU is exists in that frequency band.
There are three different techniques that generally used in transmitter detection which are matched filter detection, energy detector and cyclostationary feature detection . One of the simplest techniques that decides the present and absent of PU based on the energy of the observed signal is energy detector . Not as matched filter, this technique doesn't need any priori information from PU.

MATCHED-FILTER DETECTION:

is best technique for detecting PU in Gaussian noise channel as it enlarges the accepted (SNR) signal to noise ratio as in comparison with other detection techniques. The advantage of this technique is that it needs very lower time, have large gain for processing and minimum samples number to gain needed level of missed detection probability and false alarm probability. The sensing device in matched filter detection has to gain coherency and demodulation of PU legal user signal, hence cognitive user requires to have the prior instructions of PU at both the physical and (Medium Access layer) MAC layer. Also, the technique demands devoted receiver for each legal PU user signal and therefore possess very much power consumption due to which this is least used in radio spectrum awareness for cognitive radio.

ENERGY DETECTION:

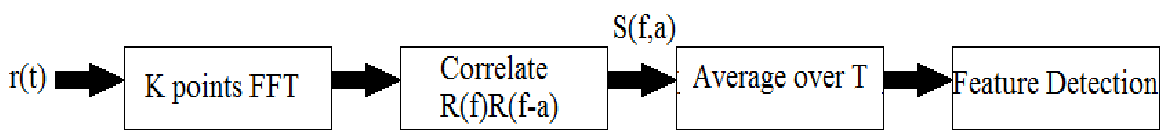
is the most common technique used in detection of primary transmitter due to its less implementation and computational complexities. In this technique the detector performs non-coherent detection and therefore don't require any prior knowledge of the primary transmitter. The signal Y (f) is obtained by passing the received signal y (t) through band pass filter and Fast Fourier Transform. The energy gained of signal is then calculated by integration and summing the information Y (f) over detection interval of time. The primary user is then encountered by correlating energy of received signal with the range of threshold. The threshold decision confides upon the level needed for Fake alarm and is much inclined to the uncertainty in Noise signal. This technique cannot differentiate between noise and primary signal and therefore has very low attainment under less SNR. Also this technique is unsuitable for the detection of Spread Spectrum signals as very complex signal processing algorithms are used for its detection.

EIGEN VALUE BASED DETECTION:

depends upon the Random Matrix theory. This technique is also non-coherent as no prior knowledge is required of the primary user. The advantage of this technique is that it is not implementationally and computationally complex. The maximum Eigen value of signal is obtained to compare it with predefined threshold for the detection of primary user signal. The maximum Eigen value is calculated by passing the received through autocorrelation and covariance matrix.

CYCLOSTATIONARY FEATURE DETECTION:

depends on the permanent prolixity in the legal PU transmitter. Cyclostationary nature is generated by the repetition in the signal or numeric like autocorrelation or mean. The unique factor of these signals is that it shows strong within largely spread spectral parameters of signal. Spectral Cyclic Correlation Function (SCF) which is a two dimensional function is used in the detection of primary user since the signal after modulation have no correlation components



The advantage of this technique is that the required signal can be differentiated from noise signal as modulated signal possess cyclostationary feature with spectral correlation function while noise is not correlated. Primary transmitted signal in this technique can be detected also with -ve signal-to-noise-ratio. The main disadvantage of technique is that, It is very computationally complicated and needs large time for observation

Spectrum sensing problem as described below:

$$H_0 \; denotes : y(n) = w(n) \rightarrow (PU \; unavailable)$$
$$H_1 \; denotes : y(n) = x(n) + w(n) \rightarrow (PU \; available)$$

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Here, $y(n)$ is the signal received by primary user, n= 1, 2, 3…N where N is complete primary legal user's observing period length. $x(n)$ denotes the sample of primary legal user signal. $w(n)$ denotes the sample of AWGN (Additive White Gaussian Noise) having variance σ_n^2. Hypotheses H_0 say about the absence of primary user and Hypotheses H_1 say about the presence of primary user. The samples of noise are related to variance in way as mentioned:

$$w(n) \in N(0, \sigma_n^2)$$

In energy detection technique considering fixed threshold, it analyzes the availability of primary user in the spectrum range. If the energy which is received of primary user comes out to be greater than the fixed threshold which was predetermined, the spectrum frequency band is considered to be busy and declares Hypotheses H_1. And if the energy received comes out to be less than the predetermined fixed threshold value, the spectrum can be declared as idle and hypotheses H_0 is considered in this case.

The statistic to be tested is given as:

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

Here, y(n) denotes the received energy of primary signal, D(y) is the decision variable. The statistic to be tested follows central distribution chi-square beneath hypotheses H_0 and non-central distribution beneath hypotheses H_1. While considering the region having low signal-to-noise-ratio, the sample number needed to gain certain performance in probability of false alarm and probability of detection should always be more than a single sample. Following this observation, the very known Central Limit Theorem can be used to analyze the statistic to be tested as the Gaussian distribution which is described below:

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

P is the average signal power of Primary user. We can describe probability of false alarm and probability of detection as below if we take into consideration only the Additive White Gaussian Noise (AWGN):

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

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

P_d Denotes the probability of detection and P_{fa} denotes the probability of false alarm. Q(.) is the standard Gaussian CDF(cumulative distribution function) and γ is the predetermined fixed threshold.

The desired predetermined fixed threshold which is used for in comparison with the energy received by PU can be calculated by:

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

From the value of threshold evaluated above, it can be foreseen that the threshold not only depends on probability of false alarm but also on the noise variance. As the signal changes, noise variance also changes but due to the fixed value of threshold, the performance of Energy detector therefore does not come out to be optimum. Also, a small change in noise variance can highly provide a harmful impact on the value of threshold. So, there is a need to change the value of threshold considering the effect of noise uncertainty. Here, comes the effect for the dynamic threshold energy detection.

The noise uncertainty factor is given as below:

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

In generalized energy detector, we take the power as a positive integer p instead of taking it as 2 as was in Classical Energy Detector.

In CED, the test statistic is given as

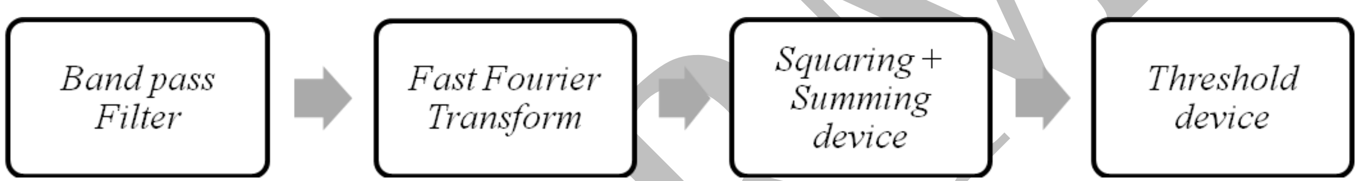
$$D(y) = \sum_{n=0}^{N} y(n)^2$$

While in GED, we take the test statistic as

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

Here, p is a positive integer ranging from 1, 2…n.
With p=2, the GED becomes the CED which is a special case.

BLOCK DIAGRAM OF ENERGY DETECTION TECHNIQUE:



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

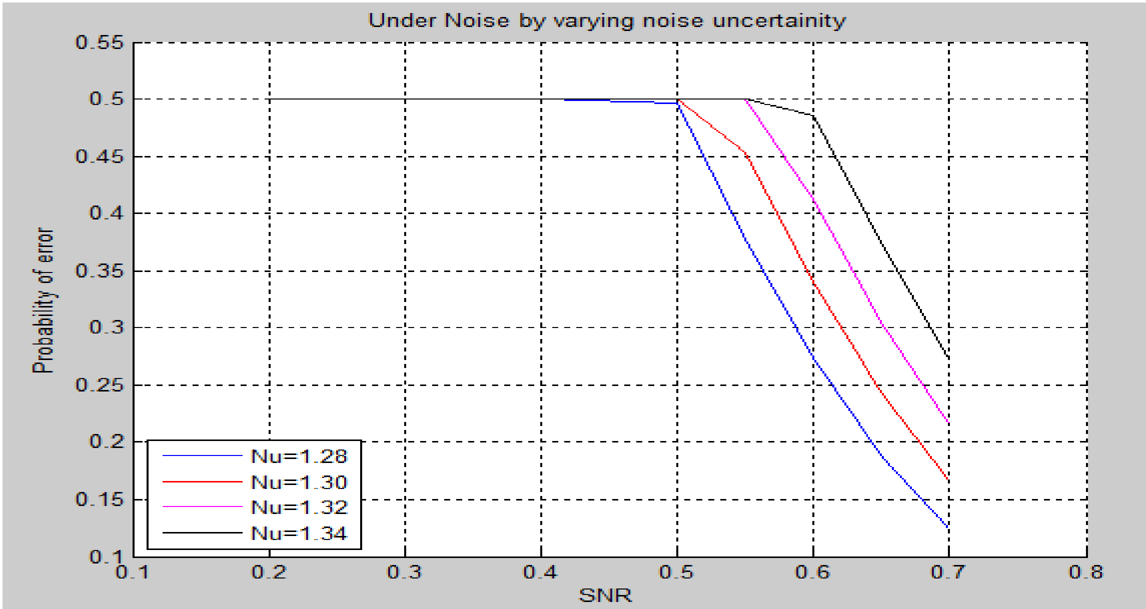
$$P_{fa} = P_r(D(y) > \gamma | H_0) = Q(\frac{\gamma - N\sigma_n^2}{\sqrt{2N}\sigma_n^2})$$

P_d Denotes the probability of detection and P_{fa} denotes the probability of false alarm. Q(.) is the standard Gaussian CDF(cumulative distribution function) and γ is the predetermined fixed threshold.

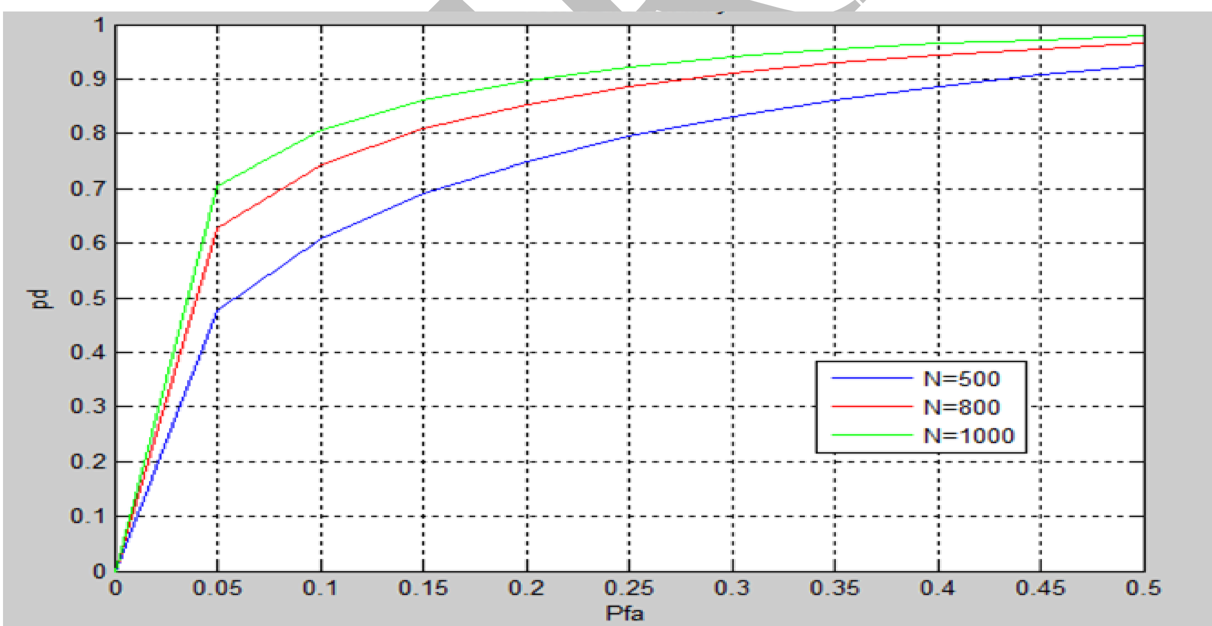
The desired predetermined fixed threshold which is used for in comparison with the energy received by PU can be calculated by:

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

Shows the effect of noise uncertainty in the probability of error. When the noise uncertainty factor increases the probability of error increases and SNR bound also gets increased.



Probability of Detection by varying N



Represents the probability of detection under without noise uncertainty. It is shown that the probability of detection increases with the increase in number of samples

CONCLUSION:

The dynamic threshold energy detection, improved energy detection and generalized energy detector is proposed in this paper for the spectrum sensing of Cognitive Radio. The proposed dynamic energy scheme depends on the current state of the primary user. Depending on this, dynamic thresholds are evaluated considering the effect of Noise Uncertainty. The 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.

In improved energy detector, we calculate the average of all the energies received for N samples consecutive L periods of observations. If the average energy is greater than the predetermined threshold, we calculate the energy of the previous sample and compare now it with threshold. This technique is used to reduce the probability of False Alarm.

In generalized energy detector, we take the power as a positive integer p instead of taking it as 2 as was in Classical Energy Detector. For different values of p, value of detection probability and false alarm probability is observed.

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