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MULTIPLE SPETRUM SENSING TECHNIQUES FOR COGNITIVE RADIO

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ABSTRACT

Utilization of electromagnetic radio frequency spectrum with efficient way, we required to check the spectrum to determine whether it is being used by primary user (PU) or not. The term cognitive radio (CR) finds unused spectrum and allocate to secondary user without interfering to PU. The focus of this paper is on the comparative study of an important spectrum sensing detection methods namely Energy detection (ED), Matched filter detection (MFD), Cyclostationary feature detection (CFD), Maximum eigenvalue to Minimum eigenvalue ratio detector (ERD) and one proposed modification in Maximum eigenvalue to Minimum eigenvalue ratio detector is Mean eigenvalue ratio detector (MERD). Comparative analysis has been carried out in terms of probability of false alarm Pf, probability of detection alarm P_d, and probability of miss detection P_m using MATLAB simulation. The ERD method performs better for P_d than remaining techniques, but performance poor for P_f, and it is limitation in CR system because it can be create interference with PU. The proposed MERD method performs better for probability of false detection (Pf) than ERD and also has the advantages of ERD &ED method.

Keywords: Cognitive Radio System, PU, SU, SNR, Cyclostationary, Detection Alarm, False Alarm.

I. INTRODUCTION

According to Federal Communications Commission (FCC), temporal and geographical variations in the utilization of the assigned spectrum range from 15% to 85%. Although the fixed spectrum assignment policy generally served well in the past, there is a dramatic increase in the access to the limited spectrum for mobile services in the recent years. This increase is straining the effectiveness of the traditional spectrum policies. The limited available spectrum and the inefficiency in the spectrum usage necessitate a new communication paradigm to exploit the existing wireless spectrum opportunistically. Dynamic spectrum access is proposed to solve these current spectrum inefficiency problems and so called Next Generation program aims to implement the policy based intelligent radios known as cognitive radios.

The Cognitive Radio technology will enable the user to determine which portion of the spectrum is available, detect the presence of primary user (spectrum sensing), select the best available channel (spectrum management), coordinates the access to the channel with other users (spectrum sharing) and migrate to some other channel whenever the primary user is detected (spectrum mobility)[3]. Cognitive Radio will enable the user to determine the presence of primary user, which portion of spectrum is available, in other words to detect the spectrum holes or white spaces and it is called spectrum sensing, select the best available channel or to predict that how long the white spaces are available to use for unlicensed users also called spectrum management, to distribute the spectrum holes among the other secondary users which is called spectrum sharing and switch to other channel whenever primary user is detected and this functionality of CR called spectrum mobility[4].Among these function Spectrum Sensing is considered to be the one of the most important critical task to establish Cognitive Radio Networks.

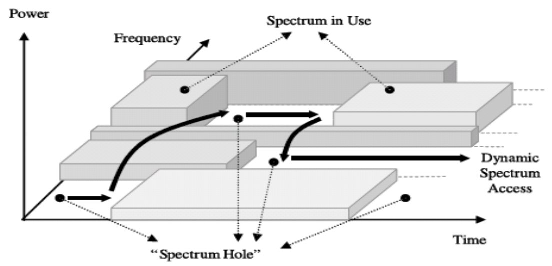

Figure.1 Illustration of spectrum hole

Cognitive Radio is characterized by the fact that it can adapt, according to the environment, by changing its transmitting parameters, such as modulation, frequency, frame format, etc. [4]. The main challenges with CRs or secondary users (SUs) are that it should sense the PU signal without any interference. This work focuses on the spectrum sensing techniques that are based on primary transmitter detection [5]. The focus of this work is on the comparative study of an important spectrum sensing detection methods namely Energy detection (ED), Matched filter detection (MFD), Cyclostationary feature detection (CFD), Maximum eigenvalue to Minimum eigenvalue ratio detector (ERD) and one proposed modification in Maximum eigenvalue to Minimum eigenvalue ratio detector is Mean eigenvalue ratio detector (MERD). Comparative analysis has been carried out in terms of probability of false alarm Pf, probability of detection alarm P_d, and probability of miss detection P_m

II. SPECTRUM SENSING TECHNIQUES

In non-cooperative sensing we have to find the primary transmitters that are transmitting at any given time by using local measurements and local observations. The hypothesis for signal detection at time t can be described as [1].

$$x(n) = \begin{cases} w(n), & H_0 \\ s(n) + h(n) + w(n), & H_1 \end{cases} \quad (1)$$

Where,

x (n) =Signal received by CR user,

w (n) =Additive white Gaussian noise,

s (n) =PU Signal,

h (n) =Channel gain

Here, H_0 and H_1 are defined as the hypotheses of not having and having a signal from a licensed user in the target frequency band, respectively. In non-cooperative sensing generally three methods are used for sensing.

1. Energy Detection

Energy detection is a non-coherent detection method that is used to detect the primary signal. [3]. It is a simple method in which it is not required a priori knowledge of primary user signal, it is one of popular and easiest sensing technique of cooperative sensing in cognitive radio networks [2-3]. If the random Gaussian noise power is known, then energy detector is optimal choice. In energy detector as shown in Figure 2. the band pass filter selects the specific band of frequency to which user wants to sense. After the band pass filter there is a squaring device which is used to measure the received energy. The energy which is found by squaring device is then passed through integrator which determines the observation interval, T. Now the output of integrator, Y is compared with a value called threshold, λ and if the values are above the threshold it will be considered that primary user is present otherwise absent.

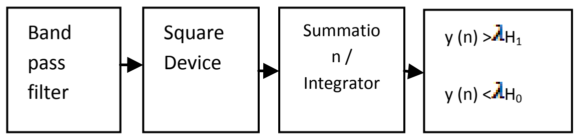

Figure. 2 Block Diagram of Energy Detector

Calculation of the energy of input received signal is done as follow

$$E = \sum_{n=1}^{N} | x(n) |^2 \qquad (2)$$

Where,

x (n) = Received input signal.

E = Calculating the Energy of received input signal or some time denoted by y (n).

At the end of the above diagram the threshold decision block shown and its decision has been made on the base of two hypotheses are related to the detection of primary user signals, first one is null hypothesis H_0 and the alternative hypothesis H_1. H_0 is the case in which a primary user signal is not present in primary spectrum, and H_1 describe the case in which a primary signal is available.

2. Matched Filter Detection

It is a known fact that the detector using a matched filter is able to perform efficiently and optimally when a user operate at secondary sensing node can perform a coherent detection of the primary signal [4]. However, within spectrum sensing to use the matched filter, the secondary sensing node must be synchronized to the primary system and it must be able to demodulate the primary signal.

Accordingly, the prior information about the primary system must be known to secondary sensing node such as the preamble signalling for synchronization, pilot patterns for channel estimation, and even modulation orders of the transmitted signal. The best way to detect signals with maximum SNR is to use a matched filter receiver. Its most important skill is the low execution time, but to know the signal proprieties is needed. This method includes the demodulation of the signal. This means that the receiver should agree with the source, estimate the channel conditions and to know the signal nature.

As shown in Figure 3. Matched filter is a linear filter which works on phenomena of maximizing the output signal to noise ratio. Matched filter detection is then applied when the cognitive radio user having information about the type of primary signal. Matched filter operation is equivalent to correlation in which the unknown signal is convolved with the filter whose impulse response is the mirror and time shifted version of a reference signal. The operation of matched filter detection is expressed as

$$y(n) = \sum_{n=0}^{(N-1)} x(n) \times xp * (n) \qquad (3)$$

Where,

x (n) = Input transmitted signal.

x_p*(n) = Conjugate of Known Pilot data.

y (n) = Received signal.

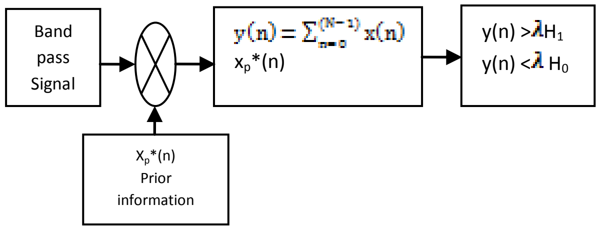

Figure.3 Block diagram of matched filter detector

Detection by using matched filter is useful only in cases where the information from the primary users is known to the cognitive users.

3. Cyclostationary Feature Detection

In cyclostationary feature detection technique [6], CR can distinguish between noise and user signal by analyzing its periodicity. Cyclostationary feature detection is a much optimized technique that can easily isolate the noise from the user signal. In Cyclostationary feature detection, modulated signals are coupled with sine wave carriers, repeating spreading code sequences, or cyclic prefixes, all of which have a built-in periodicity, their mean and autocorrelation exhibit periodicity which is characterized as being cyclostationary[6]. Noise, on the other hand, is a wide-sense stationary signal with no correlation. Using a spectral correlation function, it is possible to differentiate noise energy from modulated signal energy and thereby detect if PU is present. The block diagram for the cyclostationary feature detection is shown in Figure 4.

Here, input signal received by BPF and is used to measure the energy around the related band, and then output of BPF is fed to FFT. Now FFT is computed of the signal received and then correlation block correlate the signal and pass to integrator. The output from the Integrator block is then compared to a threshold [4]. This comparison is used to discover the presence or absence of the PU signal.

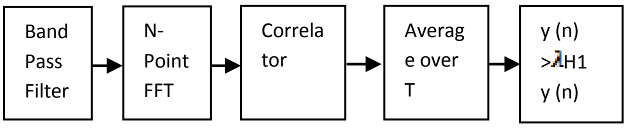

Figure 4. Cyclostationary Feature Detector

Now, considering a deterministic complex sine signal s (t) and passed it through an Additive white Gaussian noise (AWGN) channel which may be expressed as

$s(t) = A\cos(2\pi f_o t + \theta)$, (4)

Where,

A = Amplitude of input signal.

f_0 = Frequency,

θ = Initial Phase.

Transmission of s (t) through an AWGN, having zero mean, results to x (t) = s (t) + n (t). Thus, the Mean function of x (t) will be

$Mx(t) = E[x(t)]$, (5)

$Mx(t) = E[s(t + n(t))]$, (6)

$Mx(t) = E[s(t)]$ (7)

Where,

x (t) = Received signal.

s (t) = Transmitted Input signal.

E = Expectation operator.

$M_x(t)$ = Mean function of x (t) and also a Periodic function with period T_0.

As discussed earlier, modulated signal x (t) is considered to be a periodic signal or a cyclostationary signal in wide sense if it's mean and autocorrelation exhibit periodicity as follows [1],

$M_x(t) = M_x\, s(t + t_0)$ (8)

Similarly, the auto-correlation function of x (t) is also periodic with period T_0

$Rx(t,u) = R_x(t+T_0, u + T_0)$, (9)

4. Maximum Eigenvalue to Minimum Eigenvalue Ratio Detector

Energy detection does not need any information of the signal to be detected and is robust to unknown dispersive channel. However, energy detection relies on the knowledge of accurate noise power, and inaccurate estimation of the noise power leads to SNR wall and high probability of false alarm [7]. Thus energy detection is vulnerable to the noise uncertainty. Finally, while energy detection is optimal for detecting independent and identically distributed signal , it is not optimal for detecting correlated signal, which is the case for most practical applications.

To overcome the shortcomings of energy detection, we use new methods based on the eigenvalues of the covariance matrix of the received signal [8]. It is shown that the ratio of the maximum or average eigenvalue to the minimum eigenvalue can be used to detect the presence of the signal. Based on some latest random matrix theories (RMT) [8], we quantify the distributions of these ratios and find the detection thresholds for the detection algorithms. The probability of false alarm and probability of detection are also derived by using the RMT. The methods overcome the noise uncertainty problem and can even perform better than energy detection when the signals to be detected are highly correlated. The methods can be used for various signal detection applications with-out knowledge of the signal, the channel and noise power. Furthermore, different from matched filtering, the methods do not require accurate synchronization. Simulations based on randomly generated signals, wireless micro-phone signals and captured digital television (DTV) signals are carried out to verify the effectiveness of the methods. It is shown that the ratio of the maximum eigenvalue to the minimum eigenvalue can be used to detect the signal existence. Based on some latest random matrix theories (RMT), we can quantize the ratio and find the threshold. The probability of false alarm is also found by using the RMT. The method overcomes the noise uncertainty difficulty while keeps the advantages of the energy detection.

Assume that we are interested in the frequency band with central frequency Fc and bandwidth W. We sample the received signal at a sampling rate higher than the Nyquist rate. Assume that there are M≥1 receivers (antennas). The received discrete signal at receiver is denoted by xi (n) (I = 1, 2…., M). There are two hypothesises hypothesis H_0: there exists only noise (no signal); (2) hypothesis H_1: there exist both noise and signal. At hypothesis H_0, the received signal at receiver i is

$$xi(n) = \sum_{j=1}^{P}\sum_{k=0}^{Nij} hij(k)\, sj(n-k) + \eta i(n), \qquad (10)$$

where $s_j(n)$ (j = 1, 2,…, P) are P≥1 source signals, $h_{ij}(k)$is the channel response from source signal j to receiver i,Nijis the order of channel hij(k), and ŋi(n)is the noise samples. Based on the received signals with little or no information on the source signals, channel responses and noise power, a sensing algorithm should make a decision on the existence of signals. Let Pd be the probability of detection, which is at hypothesis H1, the probability of the algorithm having detected signal. Let Pfa be the probability of false alarm that is at Ho, the probability of the algorithm having detected the signal. Obviously, for a good detection algorithm, Pd should be high and Pfa should be low. The requirements of the Pd and Pfa depend on the applications.

Maximum Minimum Eigenvalue Detection

Letting N_j = max (N_{ij}), zero padding h_{ij} (k) if necessary, and defining

x (n) = [x1(n), x2(n)…3M(n),]T, (11)

h_j (n) = [h1j (n h_{2j} (n),hMj(n),)T, (12)

ŋ (n) = [ŋ 1(n),ŋ 2(n),…ŋ M(n),]T, (13)

We can express (41) into vector form as

$$x(n) = \sum_{j=1}^{p} \sum_{k=0}^{Nj} hj(k)sj(n-k) + \eta(n), \quad n = 0,1 \ldots$$

Considering L consecutive outputs and defining

x^(n) = [xT(n),xT(n-1),…xT(n-L+1),]T, (14)

ŋ^(n) = [ŋ T (n),ŋ T(n-1),…ŋ T(n-L+1),]T, (15)

s^(n) = [s1 (n),…s1 (n-N1-L+1),… sp(n),…sp(n-Np-L+1)T,

We get

x^ (n) = Ḧ = [Ḧ1, Ḧ2,…ḦP,] (16)

The following assumption for statistical properties of transmitted symbols and channel noise are assumed (A1) Noise is white.

(A2) Noise and transmitted signal are correlated.

Let R (Ns) be the sample covariance matrix of the received signal, that is,

$$R(Ns) = 1/Ns \sum_{n=L}^{L-1+Ns} x^n x^{+(n)}, \qquad (17)$$

Where Ns is the number of collected samples. If Ns is large, based on the assumption, we can verify that

R (Ns) = ḦRsḦ+ +σ2Ŋ IML, (18)

Where Rs is statically covariance matrix of the input signal. Rs=E(s^ (n) s^ (n)) σ2Ŋ is the variance of the noise, and IML is the identity matrix of order ML.

Let λ^max and λ^min be the maximum and minimum eigenvalues of R and ρ^max and ρ^min are the maximum and minimum eigen values of ḦRsḦ+. Then λ_{max}= ρ_{max} + σ2Ŋ and λ_{min}= ρ_{min} + σ2Ŋ. , p^max = ρ^min if and only if ḦRsḦ+ = δIML, δ is positive number. In practice, when signal present, it is very unlikely that ḦRsḦ+ = δIML. Hence if there is no signal λ^max/ λ^min= 1; otherwise, λ^max/ λ^min>1. The ratio of λ^max/ λ^mincan used to detect the presence of signal.

Maximum Minimum Eigenvalue Detection steps

Step1. Compute

$$R(Ns) = 1/Ns \sum_{n=L}^{L-1+Ns} x^n x^{+(n)}, \qquad (19)$$

Step2: Obtain the maximum and minimum eigenvalues of the matrix R (Ns) that is λ_{max} and λ_{min}.

Step3: Decision: if $\lambda_{max} \geq \lambda\gamma\rho_{max}$, signal exist (“yes” decision); otherwise, signal does not exist (“No” decision), where λ ≥1is a threshold.

III. Proposed Work

The novel modification in method of spectrum sensing based on eigenvalue, maximum eigenvalue to minimum eigenvalue ratio detector [8] as discussed in previous section is proposed.

It is shown that the ratio of the mean eigenvalue to the minimum eigenvalue (MERD) can be used to detect the presence of the signal. Based on some latest random matrix theories (RMT), we quantify the distributions of these ratios and find the detection thresholds for the proposed detection algorithms. The probability of false alarm and probability of detection are also derived by using the RMT. The methods overcome the noise uncertainty problem and can even perform better than energy detection when the signals to be detected are highly correlated. The methods can be used for various signal detection applications with-out knowledge of the signal, the channel and noise power. Furthermore, different from matched filtering, the proposed methods do not require accurate synchronization. Simulations based on randomly generated signals are carried out to verify the effectiveness of the proposed methods. It is shown that the ratio of the mean eigenvalue to the minimum eigenvalue can be used to detect the signal existence. Based on some latest random matrix theories (RMT), we can quantize the ratio and find the threshold. The probability of false alarm is also found by using the RMT.

The proposed Mean eigenvalue ratio detector (MERD) method overcome the disadvantage of maximum eigenvalue to minimum eigenvalue ratio detector and perform better for probability of false detection (Pf) than all the remaining methods, also overcome noise level variation difficulty, and also have the advantages of maximum eigenvalue to minimum eigenvalue ratio detector & energy detection method. The proposed method is useful for detection of signal without prior knowledge of signals, channels and noise power.

Mean Eigenvalue Ratio Detection (MERD) steps

Step1. Compute

$$R(Ns) = 1/Ns \sum_{n=L}^{L-1+Ns} x^{\wedge}(n)\, x^{\wedge} + (n),$$

Step2: Obtain the mean and minimum eigenvalues of the matrix R (Ns) that is λ_{mean} and λ_{min}.

Step3: Decision:

If λ_{mean} / λ_{min}, > Threshold, then signal exist ("H_1" decision) Otherwise,

λ_{mean} / λ_{min}, < Threshold, then signal does not exist ("H_0" decision)

IV. SIMULATION RESULTS

We have assumed that the, the total number of samples = 100, number of events = 100, Number of CR users = 6, SNR range is from -10 dB to +20 dB with total 17 points for SNR, QAM modulation is employed for the simulation.

Probability of Detection Alarm -

Figure 5 shows the probability of PU detection alarm (Pd) with respect to SNR for the four cases. The probability of detection alarm should be as much as possible with respect to SNR. Figure 5 shows that eigenvalue detection is detecting PU signal at low SNR as compare to other three detection techniques.

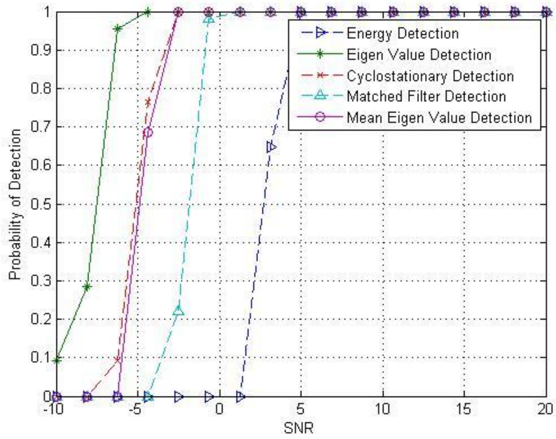

Figure 5: Probability of Detection vs. SNR for all Detection Methods

Probability of Miss Detection

Figure 6 depicts the probability of miss detection (Pm) with respect SNR for the all cases. Probability of miss detection should be as small as possible with respect to SNR. Figure 6 shows eigenvalue detection is superior to other techniques.

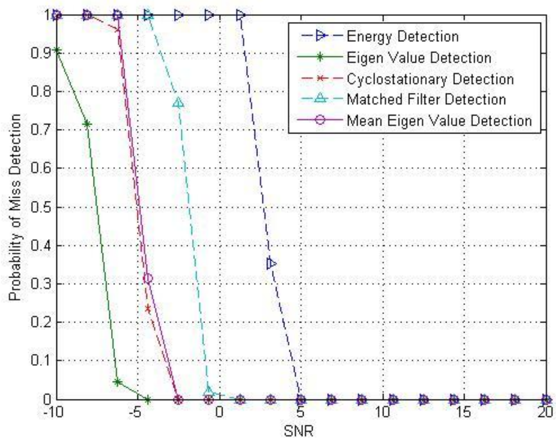

Figure 6: Probability of Miss Detection vs. SNR for all Detection Methods

Probability of False Alarm

In Figure 7 the comparison of four mentioned spectrum sensing techniques in terms of the probability of false alarm detection (Pf) with respect to SNR is done and plotted. The probability of false alarm should as minimum as possible with respect to SNR. It is observed that probability of false alarm for eigenvalue detection is better than remaining three techniques.

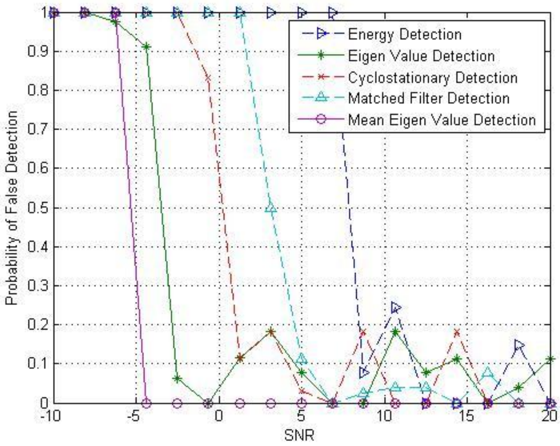

Figure 7: Probability of False Detection vs. SNR for all Detection Methods

Comparison of different spectrum sensing techniques on the basis of probability of detection, probability of false alarm, probability of miss detectionH_0 and H_1 are the sensing states for absence and presence of signal respectively. H_0 is the null hypothesis which indicates that PU has not occupied channel and H_1 is the alternative hypothesis. It can define in following cases for the detected signal.

Declaring H_1 under H_0 hypothesis which leads to Probability of False Alarm (P_f).

$$P_f = P_r (H_1 / H_0)$$

Declaring H_1 under H_1 hypothesis which leads to Probability of Detection (P_d).

$$P_d = P_r (H_1 / H_1)$$

Declaring H_0 under H_1 hypothesis which leads to Probability of Missing (P_m).

$$P_m = P_r (H_0 / H_1)$$

V. CONCLUSION

In this paper, we explain the spectrum sensing techniques, namely energy detection, matched filter detection, cyclostationary features based detection, eigenvalue detection and novel modification in eigenvalue detection proposed mean eigenvalue detection techniques with the help of MATLAB R2009b simulation. The comparison of all the sensing techniques with performance parameter Probability of Detection (Pd), Probability of Miss Detection (Pm), and Probability of False (Pf) Detection for different SNR values.

Each sensing technique has its own advantages and disadvantages. As, Matched filter detection improved SNR, but required the prior information of PU for better detection. Energy detection has the advantage that no prior information about the PU was required and also simple to implementation, but did not perform well at low SNR, there was a minimum SNR required after which it started working. Cyclostationary feature detection performed better than both, matched filter detection and energy detection. However, its processing time is large and implementation is complex. Maximum eigenvalue to Minimum eigenvalue ratio detector methods overcome noise level variation difficulty, and also have the advantages of energy detection method. The Maximum eigenvalue to Minimum eigenvalue ratio detector method perform better for Probability of detection, but its performance is poor for probability of false detection, and this is biggest limitation of Maximum eigenvalue to Minimum eigenvalue ratio detector because due to false detection the interference may be occurs between primary user and secondary user.

The mean eigenvalue ratio detector has very low probability of false detection means it overcome the limitation of Maximum eigenvalue to Minimum eigenvalue ratio detector, probability of detection is high, and also have the advantages of Maximum eigenvalue to Minimum eigenvalue ratio and energy detection method. Finally,simulation results shows that proposed mean eigenvalue ratio detector performs better than remaining techniques.

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