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Spectrum Sensing Techniques for Cognitive Radio-Based Communication

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Abstract: **-- Cognitive radio (CR) is a new archetype wireless communication system which is use for efficient utilization of radio frequency (RF) spectrum or RF channel for opportunity to wireless communication. The motivation behind cognitive radio is the insufficiency of the existing frequency band and rising demand due to the up-and-coming wireless applications for mobile users. Cognitive radio is advanced technology for dynamic spectrum detection and for the use of unutilized spectrum. The secondary user (SU) devices enthusiastically sense to the primary user (PU) and use the spectrum band if it is accessible without affecting their performance. In this paper we intend methodology and comparative sensing schemes for Cyclostationary feature detection techniques and Co-operative Eigen value based spectrum detection in CR. The performance of various wireless fading channels is evaluated by analyzing it's operating characteristics. The study of the performance outcome shows that, at low signal to noise ratio (SNR) sensing is improved in Eigen value based detection method because it does not require any prior information about primary signals. For simulation we used MATLAB software.**

Keywords - Cognitive Radio, Spectrum Sensing, Dynamic Spectrum Management, Probability of detection, SNR, RF, PU, SU.

I. INTRODUCTION

In wireless communication technique frequency band is inadequate resource. At present, the electromagnetic spectrum for wireless communication systems follows the permanent allocation policy. In this policy, those who are purchasing a given segment of the frequency band obtain the permit for exclusively use of it, in malice of actually not occupying that segment during all instance and in the whole exposure region. These stable allocation strategies, along with the huge growth in wireless communications systems and services have led to spectrum congestion and under utilization at the equivalent occasion. Due to static allocation or fixed spectrum sharing its utilization is meager. Thus to overcome the spectrum barren utilization of allocated frequency channel, it is necessary to discover efficient communication model through which frequency spectrum can be utilized when white space hole is obtainable as depicted in Figure 1.[1]. To resolve this difficulty, the Dynamic Spectrum Access (DSA) scheme has been developed and it is recognized as CR.

The specific to entrance the spectrum is generally defined by frequency, space, transmit power, spectrum owner, type of use, and the duration of authorize. Habitually, a permit is assigned to one holder, and the use of spectrum by this holder must confirm to the specification in the permit. In the current spectrum permitting method, the permit cannot change the type of use or transfer the right to other holder. This restricts the use of the frequency spectrum and results in low utilization of the frequency spectrum [2]. Fundamentally, due to the current static spectrum permit method, spectrum holes take place. Spectrum hole is defined as a spectrum band that can be utilize by unlicensed users, which is a basic reserve for cognitive radio (CR) systems. [3].

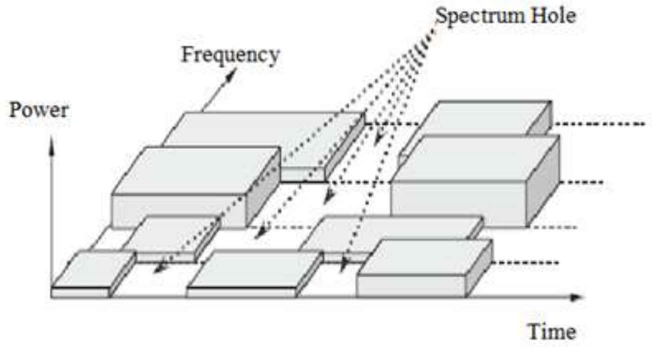

Figure 1. Utilization of Spectrum White Space (Holes)

The main challenges with secondary user's (SU) are that it should sense the primary user (PU) signal without any stumbling block. This operation is totally depend on spectrum detection techniques in which we analyzed the outcomes of probability of false alarm (Pf), probability of detection alarm (Pd) and probability of miss detection (Pm) at low SNR. The basic and simple detection techniques are Matched filter detection, Cyclostationary feature detection, Co-operative Eigen value based detection.

Matched filter detection and Cyclostationary feature detection method requires prior information of PU while sensing also it's realization is complex [4]. At low SNR the Co-operative Eigen value based detection method better than Energy detection method or other detection methods. The sensing time of Eigen value based detection method is very small also it's realization is easy.

II. SYSTEM MODEL

In the situation of spectrum sensing, the detection technique aims the extracting from the received signal a test statistic from which the spectrum tenancy is known. A summary of some of these techniques is given enlisted:

1. Matched Filter Detection**:** Matched filter is linear filter used to provides coherent detection [5]. This technique maximizes the signal-to-noise ratio (SNR) of the received signal and is considered the best possible one if the CR has prior information about primary transmitted signal characteristics, such as the modulation order type and the pulse shape. If the channel is mixed Additive White Gaussian Noise (AWGN) then knowledge of the channel impulse response is desired. The main challenging practical restriction of matched filter is related to the need of estimating or knowing a prior the above mentioned information [6]. In case such information is not sufficiently truthful, the spectrum sensing performs inadequately.

2. Energy Detection**:** The Energy Detection (ED) technique is the most advantageous one if prior information about the primary transmitted signal is unclear. If the random Gaussian noise power is known, then energy detector is optimal choice. Calculating the energy of received signal, received signal can detect easily[7]. The result shows, which is the test statistic and it is compared with a decision threshold so that the absence or presence of the primary signal is provisional. As this decision threshold depends on the thermal noise variance and even small noise variance estimation errors can lead to noticeable performance poverty.

3. Cyclostationary Feature Detection**:** Cyclostationary feature detection is a lot optimized technique that can easily separate the noise from the user signal. When the primary transmitted signal exhibits cyclostationarity then it can be detected by exploring the periodic behavior of the cyclostationary factor. As compare to energy detection this method is stronger to noise uncertainty[8]. Even though a cyclostationary signal can be detected at lower signal-to-noise ratios (SNR) compared to other detection strategies, cyclostationary detection is more complex than ED. It performs very well for superior noise on channels.

4. Co-operative Eigen value-Based Detection **:** This method determines the presence or absence of primary user. Primary user information is not required in this technique. They do not require prior information on the transmitted signal so the available spectrum sensing detection techniques, Co-operative Eigen value - based schemes are receiving a lot of awareness[9] . In few Eigen value - based schemes, the information of noise variance is not needed either. In Eigen value spectrum sensing the test value is calculated from the Eigen values of the received signal covariance matrix. In this paper we focus on the co-operative Eigen value - based detection. The subsequent techniques are addressed – first one maximum minimum Eigen value detection (MMED) also known as the Eigen value ratio detection (ERD), the Eigen value-based generalized likelihood ratio test (GLRT), the maximum Eigen value detection (MED) and the energy detection (ED). Even though ED is not an completely Eigen value-based detection technique but it can be implemented using Eigen value information.

In above spectrum sensing techniques, each technique had its own benefit and drawback. Matched filter detection method has improved SNR but it required prior information of primary user [10]. Energy detection method did not require prior information, but at low SNR, the performance is reduced. Cyclostationary feature detection method perform better than both, but it's implementation is complex. So we inspect our proposed system Co-operative Eigen value based detection with Cyclostationary feature detection method.

III. COMPARATIVE ANALYSIS FOR SPECTRUM SENSING TECHNIQUES

1. Cyclostationary Feature Detection :

In Cyclostationary Feature Detection technique, CR can single out between noise signal and user signal by evaluating its periodicity. Cyclostationary feature detection is a more beneficial technique that can simply separate the noise signal from the user signal. Cyclostationary feature detection technique is complex and takes large time in computation but it provides better performance than energy detection [11]. In this detection, transmitted signal are tied with sine wave carriers, all of which have a fixed periodicity, their mean and autocorrelation show signs of periodicity. Through spectral correlation function, it is probable to split out noise signal from transmitted signal and thereby sense if PU is present. The functional block diagram of the cyclostationary feature detection is shown in Figure 2.

The input signal is given to the Band Pass Filter (BPF) for measuring energy in the region of the associated band and then output of BPF is given to N-point FFT. FFT Computes the signal and correlation is done by correlator and pass to integrator. The output from the Integrator block is then compared to a threshold. This relationship is used to identify the presence or absence of the PU signal.

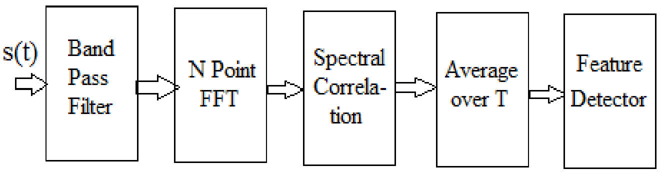

Figure 2 . Cyclostationary Feature Detector

Supplementary signal processing is required to better discriminate between a modulated signal and noise. One approach is to better access and classify the energy in-band and to take advantage of the cyclostationary nature of modulated signals. The detectors are called Cyclostationary Feature Detectors.

Diffusion of s(t) through an Additive White Gaussian Noise having zero mean, thus the Mean function of x(t) will be

$$M_x(t) = E[x(t)] \qquad (1)$$

$$M_x(t) = E[s(t) + n(t)] \qquad (2)$$

$$M_x(t) = E[s(t)] \qquad (3)$$

Where, x(t) = Received signal.
S(t) = Transmitted input signal.
E = Expectation operator.
$M_x(t)$ = Mean function of x(t) and also cyclic function with period T_0

Now, consider complex sine signal s(t) is passed through an Additive White Gaussian Noise (AWGN), then it is expressed as

$$s(t) = A\cos(2\pi f_0 t + \theta), \qquad (4)$$

Where, A = Amplitude of input signal
Fo = Frequency
θ = Initial Phase

The modulated signal x(t) considered as Cyclostationary signal & its autocorrelation function as follows

$$R_x(t,u) = R_x(t + T_0, u + T_0), \qquad (5)$$

Replacing t and u in autocorrelation equation, express in Fourier series is as follows

$$R_x\left(t+\frac{\tau}{2}, t-\frac{\tau}{2}\right) = R_x\left(t+\frac{\tau}{2}+T_0, t-\frac{\tau}{2}+T_0\right) \quad (6)$$

Now, Periodic frequency is assumed to be known in the receiver. Autocorrelation of periodic signal is obtain by

$$R_x^{\alpha}(\tau) = \frac{1}{T}\int_{-1/T}^{+1/T} R_x\left(t+\frac{\tau}{2}, t-\frac{\tau}{2}\right) e^{-j2\pi f\tau}\, dt, \qquad (7)$$

The Fourier transform of the cyclic autocorrelation function is defined as the Spectral Correlation Function (SCF) can be measured by the normalized autocorrelation between two spectral component of x(t) [12]. SCF can be express as

$$S_x^{\alpha} = \lim_{T\to\infty}\left[\lim_{\Delta t\to\infty}\frac{1}{\Delta t}\int_{-\Delta t}^{+\Delta t}\frac{1}{T}X_T\left(t, f+\frac{\alpha}{2}\right)X_T^{*}\left(t, f+\right.\right.$$
$$\alpha 2dt \quad (8)$$

Where, finite time fourier transform is

$$X_T(t,u) = \int_{t-\frac{T}{2}}^{t+\frac{T}{2}} x(u)e^{-j2\pi u}\, du \qquad (9)$$

Cyclostationary detection requires a huge computation and sensing time hence it is complicated to implement and it reduces the flexibility of CR.

Now we study the $P_{f,}\ P_{m,} and\ P_d$ for this method. In Cyclostationary feature detection method according to the Central Limit Theorem , the probability distribution function (PDF) of both hypothesis $H_0\ and\ H_1$ can be expressed as

$$P_{M_x\,(t)_T}(t\!:H_0) = C_N\left(0,\frac{\sigma_\omega^2}{2N+1}\right) \qquad (10)$$

$$P_{M_x\,(t)_T}(t\!:H_1) = C_N\left(\mu,\frac{\sigma_\omega^2}{2N+1}\right) \qquad (11)$$

Where
H_0 = Primary signal is Absent
H_1 = Primary signal is Present
C_N = Circularly complex Gaussian distribution
μ = Mean

Therefore, an approximate false alarm frequency (P_f) of cyclostationary feature detector can be obtain as

$$P_f = Pr(H_1|H_0) \qquad (12)$$

Now, probability of primary user (PU) detection alarm (P_d) for the cyclostationary feature detector method can be calculated by given equation

$$P_d = P_r(H_1|H_1)$$

$$P_d = Q\left(\frac{\sqrt{2\gamma}}{\sigma_\omega},\frac{\lambda}{\sigma_A}\right) \qquad (13)$$

Where,
Q(,) = Generalized Marcum Q-function
γ = Signal to Noise ratio
σ_ω^2 = Noise Variance

And the probability of miss detection (P_m) for cyclostationary feature detector method can be calculated by using equation (13) as follows

$$P_m = 1 - Q\left(\frac{\sqrt{2\gamma}}{\sigma_\omega},\frac{\lambda}{\sigma_A}\right) \qquad (14)$$

2. Co-operative Eigen value-Based Detection :

The diagram shown in Figure 3. was the main reference for constructing such a implementation oriented model. A wideband band-pass filter (BPF) selects the overall spectrum range to be monitored. The low noise amplifier (LNA) pre-amplifies small signals and a down conversion (DC) process translates the received signal to in-phase and quadrature baseband signals. The local oscillator (LO) is part of the down-conversion circuitry. A variable gain amplifier (VGA) which is part of an automatic gain control (AGC) mechanism is dependable for maintaining the signal within the dynamic range of the analog-to-digital converter (ADC) [13].

The channel low-pass filter (LPF) selects the desired spectrum portion to be sensed. Filtering affects signal correlation and whitening process takes place to guarantee that noise samples are decorrelated when the test statistic is computed.

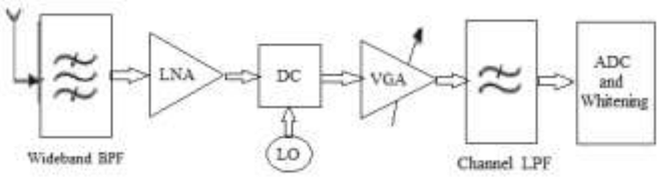

Figure 3. CR Receiver or Implementation Oriented Model

In this technique prior information of primary user is not necessary. This method was based on random matrix theory hence it is computationally very simple. Flowchart for this technique is shown in Figure 4.

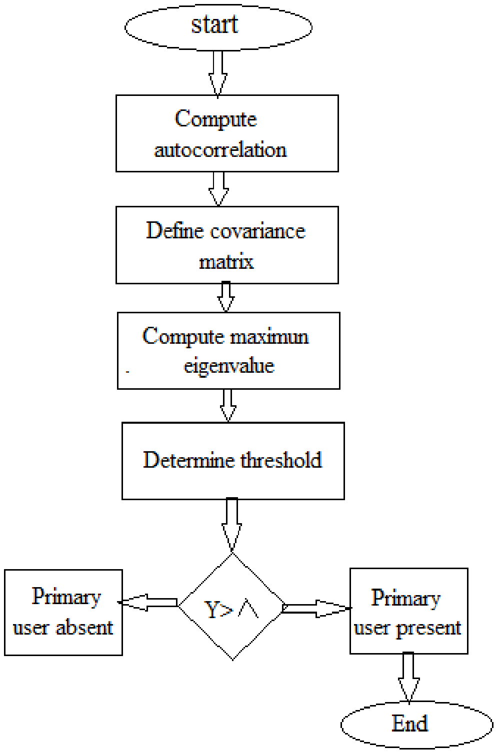

Fig. 4 Flow chart for Eigen value Based Detection

Received signal samples are autocorrelated to form covariance matrix. Maximum Eigen value of statistical matrix is compared with predetermined threshold value to find primary user occurrence [14]. Two important parameters associated with the assessment of the spectrum sensing performance are the probability of detection (P_d), and the probability of false alarm (P_{fa}) which are defined according to

$$P_{d=} P_r \{decision = H_1|H_1 \} = P_r \{T > \gamma \mid H_1\} \quad (15)$$

$$P_{fa=} P_r \{decision = H_1|H_0 \} = P_r \{T > \gamma \mid H_0\} \quad (16)$$

Where, P_r = Probability of given event
T = Detection dependent test statistic
γ = Decision threshold

Let **H** ∈ X^{m*p} be the channel matrix with elements $\{hij\}$, i = 1, 2, …, m and j = 1, 2, …, p, representing the channel gain between the jth primary transmitter and the ith sensor. Finally, let **V** and V_{IN} ∈ X^{m*n} the matrices containing thermal noise and IN samples that corrupt the received signal respectively. The matrix of received samples is then

$$Y = HX + V + V_{IN} \quad (17)$$

In Eigen value-based sensing, spectral holes are detected using test statistics computed from the Eigen values of the sample covariance matrix of the conventional signal matrix **Y**. A multi antenna device is used to make a decision upon the occupation of a given channel in a non-cooperative approach, or even in a centralized cooperative system with data-fusion, matrix **Y** is produced and the sample covariance matrix.

$$R = \frac{1}{n} YY^{+} \quad (18)$$

The Eigen values $\{\lambda 1 \geq \lambda 2 \geq \ldots \geq \lambda m\}$ of **R** are then computed and assuming a single primary transmitter (p = 1), the test statistics for GLRT, MED, MMED and ED are respectively calculated as follows

$$T_{GLRT} = \frac{\lambda_1}{\frac{1\, tr\ (R)}{m}} \quad (19)$$

$$T_{MMED} = \frac{\lambda_1}{\lambda_m} \quad (20)$$

$$T_{MED} = \frac{\lambda_1}{\sigma_2} \quad (21)$$

$$T_{ED} = \frac{||Y||_F^2}{mn\sigma^2} = \frac{1}{M\sigma^2} \sum_{i=1}^{m} \lambda_i \quad (22)$$

All the Eigen value-based detection methods reply on the fact that in n the sample covariance matrix **R** in the presence of noise only is a diagonal matrix with all its non zero elements equal to σ 2. Thus **R** has Eigen values equal to σ 2 and multiplicity m. In the presence of a primary user, these recognition methods try to identify this situation- as one can see in GLRT the ratio between the largest Eigen value and the average of all the remaining ones is computed in MMED the ratio between the largest and the smallest Eigen values is computed in MED it is assumed that the noise variance σ 2 is known and the largest Eigen value is compared with σ 2.

IV. SIMULATION RESULTS

Fig. 5 and Fig. 6 shows the graph of Probability of Detection (P_d) versus SNR and Probability of Miss Detection (P_m) versus SNR respectively for various spectrum sensing techniques such as Energy detection, Cyclostationary feature detection, Matched filter detection and Eigen value based detection. By analyzing the characteristic of sensing techniques it is observed that the probability of signal detection takes very less time in Eigen value based detection techniques than other sensing type without any prior knowledge of PU. At low SNR the Co-operative Eigen value based detection method outperformed.

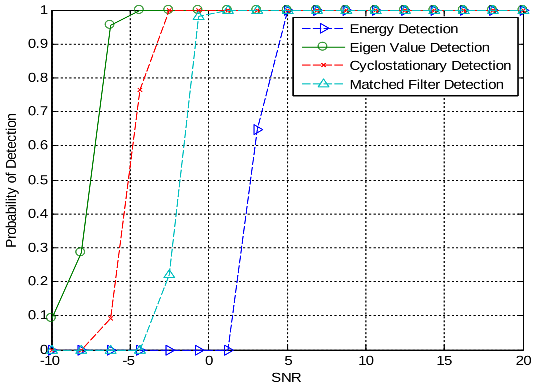

Fig. 5 Probability of Detection Versus SNR

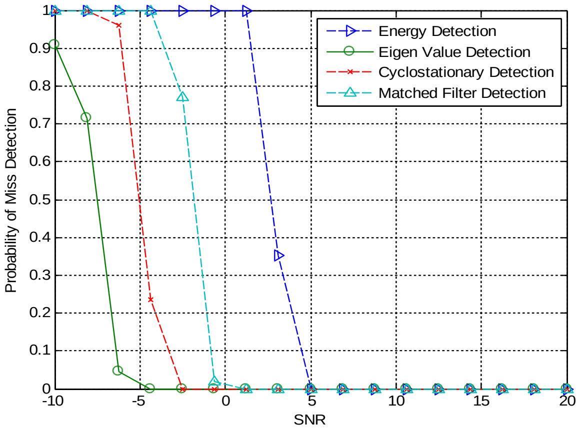

Fig. 6 Probability of Miss Detection Versus SNR

V. CONCLUSION

In this paper, we have discussed performance analysis of Cyclostationary feature detection and Co-operative Eigen value based detection techniques in terms of probability $(P_m, P_d$ and $P_{fa})$ for given signal-to-noise ratio. Cyclostationary feature detection method outperformed but it's dealing out time is very large and realization was composite. Also it requires prior information of PU while sensing.

At low SNR the Co-operative Eigen value based detection method outperform than Cyclostationary feature detection method or other detection methods without prior knowledge of PU. The sensing time of Eigen value based detection method is very small also it's realization is simple.

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