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Spectrum Sensing Techniques in Cognitive Radio Networks

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Abstract- Now a days, the available radio spectrum is divided between the licensed and unlicensed frequencies. But due to this, some frequency bands get occupied all the time and some are occupied for less time. This is leading to wastage of frequency spectrum. Again, in recent years, there has been huge growth in wireless communication devices and applications. To fulfill this demand of spectrum, we should use spectrum efficiently because it is limited source. Cognitive Radio is the recent paradigm that enables a more flexible and efficient system to manage the available frequency spectrum. It can allot the vacant frequency bands to CR users (called Secondary Users) opportunistically and vacate the band whenever needed by licensed users. Hence spectrum sensing is the basic task of cognitive radio system which helps to make decision that whether PU(Primary User) is occupying a particular frequency band or not. Here, in this paper, we are going to discuss four spectrum sensing techniques i.e. Energy detection method, Matched Filter Detection method, Cyclostationary Detection method and Maximum to Minimum Eigen Value Ratio method. We have also presented a performance analysis of these four methods on the basis of probability of detection (Pd), probability of False Alarm (Pf) and Probability of Missed Detection (Pm). We have simulated the results by using MATLAB 2012a.

Keywords-Cognitive Radio(CR), Spectrum Sensing, Primary User, Secondary User, Probability of Detection, Probability of False Alarm, Probability of Missed detection.

I. INTRODUCTION

The available electromagnetic spectrum is getting overloaded day by day due to static licensing scheme and new emerging wireless application requirements. We can see in fig .1 that the frequency spectrum is allotted to the licensed users for large region, but not occupied all the time. This underutilization problem should be solved by some means and the solution is Cognitive Radio Technology (CR). CR's are designed to provide reliable communication for users and also effective utilization of radio spectrum.

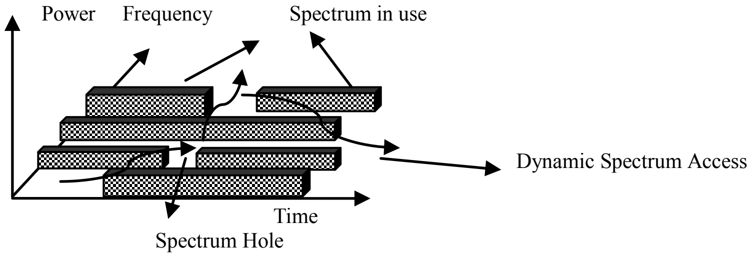

Figure 1. Concepts of a spectrum hole [8]

FCC defines CR as," A radio or system that senses its operational electromagnetic environment and can dynamically adjust its radio operating parameters to modify system operation, such as maximize throughput, mitigate interference, facilitate interoperability and access secondary markets" [1].
In fig.1 we can see the unoccupied frequency bands which are allocated to, but in some locations and at sometimes not utilized by licensed users and therefore can be accessed by secondary users (unlicensed). These unoccupied frequency bands are called as spectrum holes [1]. The two main objectives of CR system are [1],

1. To achieve highly reliable and efficient wireless communication.
2. To make improvement in utilization of frequency spectrum.

Spectrum Sensing is the most challenging task of CR system. Its goal is to determine the status of spectrum and it has to periodically monitor the activity of PU. If the band is vacant then this band can be utilized by the CR user.

II. CONCEPT OF SPECTRUM SENSING

As we have seen previously, spectrum sensing enables opportunistic access of spectrum. One of the main aim of spectrum sensing is transmitter detection. Spectrum sensing can be said as art of performing measurements on the part of spectrum and forming a decision related to measured data. Transmitter detection is nothing but identifying whether primary user is present or not.

Spectrum sensing and estimation is the first step to implement CR system.

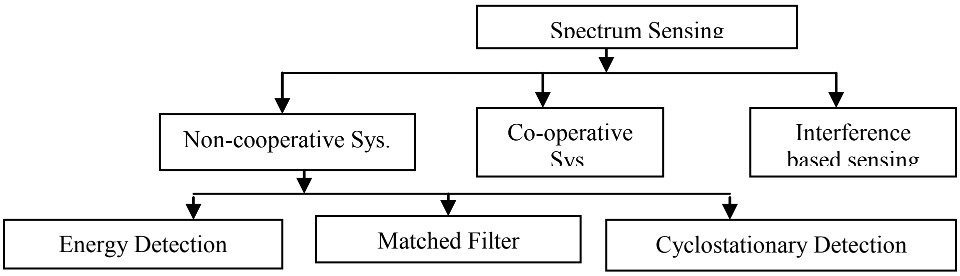

Figure 2. Classification chart for spectrum sensing [1]

Spectrum Sensing can be broadly classified in to three systems i.e. non co-operative, Co-operative and interference based as shown in fig.1. These systems can be implemented by using three methods i.e. Energy detection method, matched filter detection method and cyclostationary detection method. When we have no prior information of the transmitted signal then energy detection method can be preferred. It measures energy in radio resource and compares the value against threshold. Though this technique can be used to declare whether the PU is present or not, it can not identify the type of system or channel. It should have knowledge of noise level also.
Matched Filter Detection is using a template or a known signal to compare it with sensed signal. It will derive some decision statistic and compare with threshold value. Hence, in this method prior knowledge of signal is required. Cyclostationary detection is a statistical test method. It is based on an auto correlation of one or several cyclic frequencies. Hence this method can detect those signals which possess known cyclostationary properties.

The sensing device has to decide between one of the two types as follows.

$$x(n) = s(n) + w(n) \qquad : H1$$
$$x(n) = w(n) \qquad : H0$$

Where,

s(n) is the signal transmitted by Primary User.

w(n) is additive white Gaussian noise.

Hypothesis H0 indicates that PU is absent and hypothesis H0 indicates that PU is present. Thus according to this hypothesis, we can enlist following performance parameters.

- H1 turns out to be TRUE in case of presence of Primary User i.e. P(H1/H1) is known as probability of detection(Pd)
- H0 turns out to be TRUE in case of presence of Primary User i.e. P(H0/H1) is known as probability of missed detection(Pm)
- H1 turns out to be TRUE in case of absence of Primary User i.e. P(H1/H0) is known as probability of false alarm (Pf).
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III. SPECTRUM SENSING TECHNIQUES

Now, we are going to discuss different sensing techniques.

3.1 Matched Filter Detection:-

The detector using matched filter is able to achieve the optimum performance when secondary user can perform coherent detection, which is helpful in maximizing SNR. For this purpose secondary user should be synchronized with primary user and must even be able to demodulate the primary signal. That means secondary user should have prior information about primary user signal such as preamble, signaling for synchronization or even modulation orders. Block diagram of matched filter detection is as shown in fig. 2

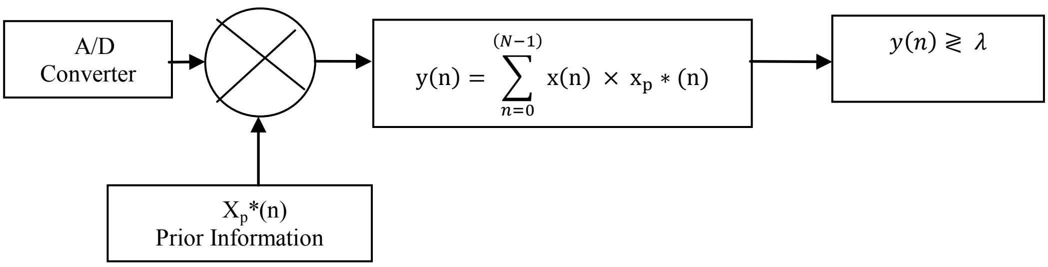

Figure 3. Matched Filter Detection

Here the i/p signal is received by A to D converter and then o/p x(n) is multiplied with prior information $x_p^*(n)$. Now this multiplied signal is fed to summation block and output of this block is compared with the threshold value which decides whether the PU is present or not.

The mathematical expression of matched filter detection method is written as,

$$y(n) = \sum_{N=0}^{N-1} x(n) * x_p^*(n)$$

Where, x(n) = Transmitted signal

$x_p^*(n)$ = Prior information signal(conjugate of known data)

y(n) = Received Signal

n= 0,1,2,3,4……N-1

Now probability of false alarm of MF technique can be calculated by,

$$Pf=P(H1/H0)$$

$$Pf=P[(y(n)>\lambda)/H0]$$

Where λ is threshold value.

During Pf ,i/p signal will be x(n)= w(n) and hence received signal will be

N-1

$$Y(n) = \sum_{n=0} w(n) * x_p^*(n)$$

Now, the probability of PU detection alarm for the Matched filter detection method can be calculated by the given equation,

$$Pd = P[H1/H1]$$

$$Pd = P[(y(n)>\lambda)/H1]$$

During the probability of detection i/p signal x(n) will be

$$x(n) = s(n)*h(n)+w(n)$$

and the received signal can be calculated as,

$$Y(n) = \sum_{n=0}^{N-1} [s(n)*h(n)+w(n)]* x_p^*(n)$$

Probability of Missed Detection can be given as,

$$Pm = 1-Pd$$

We can say that Matched Filter Detection method is costly and complex since prior knowledge of primary signal is required.

3.2 Energy Detection

It is the optimal method for spectrum sensing when information of licensed user is not available. In this case knowledge of noise power plays very important role. The block diagram for ED technique is shown in fig. 4.

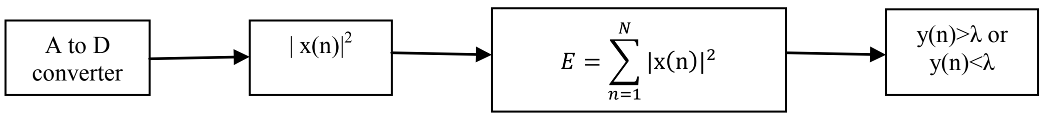

Figure 4. Energy Detection

During the probability of false alarm input signal x (n) will be,

$$x(n) = \omega(n) ; H_0$$

From equation and ,the received signal y(n) can be written as,

$$y(n) = E = \sum_{n=1}^{N} |\omega(n)|^2$$

Now the probability of false alarm for energy detection method can be calculated by

$$Pf = P[H_1/H_0]$$

Let the received signal in presence of PU is,

$$Y(n) = E = \sum_{n=1}^{N} | s(n)*h(n)+ w(n)|^2$$

The probability of missed detection can by given as,

$$Pm = 1-Pd$$

The two shortcomings of energy detection are,

1. The performance of system affects due to uncertainty of noise power.
2. It can only detect presence of signal but not the type of signal(e.g. whether the signal is from PU or SU).

3.3 Cyclostationary Detection

The transmitted signal from Primary User generally has periodic pattern. Any signal is said to be cyclostationary when it's mean and autocorrelation are periodic function and it can be used to detect presence or absence of PU. On the other hand noise is a wide-sense stationary signal without correlation. So this technique gives better results in presence of noise.

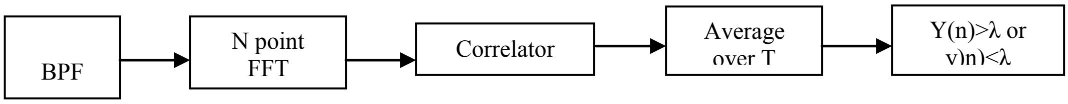

Figure 5. Cyclostationary Detection

Block diagram for Cyclostationary Detection is as shown in fig.5 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. This comparison is used to discover the presence or absence of the PU signal.

Transmission of s (t) through an AWGN, having zero mean, results to x(t) = s(t) + n(t).
Here, the power spectral density is a special form of spectral correlation function. However, cyclostationary detection requires a large computational capacity and significantly long observation times, so difficult to implement. Further, it cannot detect the type of communication, so it reduces the flexibility of CR.

Hence, for a particular threshold λ, an approximate expression for false alarm probability (Pf) is given as,

$$P_f = P\ [H_1/H_0]$$

Now, the probability of PU detection (Pd) can be calculated by the given equation,

$$P_d = P\ [H_1/H_1]$$

3.4 Maximum to Minimum Eigen value Ratio Detector

Though Energy Detection method does not need any information about PU signal, It's performance affects due to varying noise power. We can say that, ED method is optimal for detecting independent and identically distributed signal, but it is not optimal for detecting correlated signal.
To overcome shortcomings of ED technique, we can use Eigen Value Ratio Detection method where we can show that the ratio of maximum to minimum Eigen value of received signal's covariance matrix can be used to detect the presence or absence of PU signal. Based on RMT(Random Matrix Theory), we quantify the distribution of these ratios and find detection threshold. This method overcome the problem of noise uncertainty and can also detect correlated signals.

Maximum Minimum Eigen value Detection steps

Step1. Compute Eigen Values of Received Signal Matrix say Y.

$$R = 1/n*(Y*Y^{\dagger)}$$

Where, † is complex conjugate and transpose.

Step2: Obtain the maximum and minimum eigenvalues of the matrix R that is λ_{max} and $\lambda_{min.}$

Step3: Decision: Calculate test statistics as $T=\lambda_{max}/\ \lambda_{min}$ and compare with threshold.

As shown in Table 1 we can compare four sensing techniques [1] [2]

IV. PERFORMANCE ANALYSIS

Here, we have taken Primary User (P) as 1 and Cognitive Radio Users as 6. SNR range is from -10 dB to 20 dB. For this range we have analyzed the performance of four techniques by taking λ=3 and Samples n=100.Figure 6 shows the graphical plot of probability of detection over different values of SNR for all four techniques discussed before.

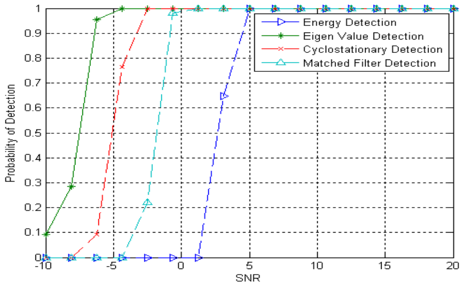

Figure 6. SNR vs Probability of Detection

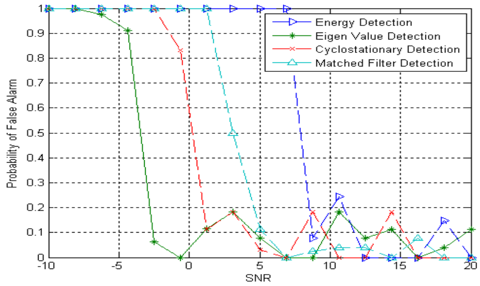

Figure 7. SNR vs Probability of False Alarm

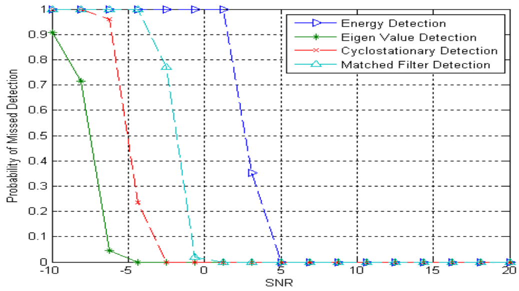

Figure 8. SNR vs Probability of Missed Detection

It is observed in Fig.6 that the probability of detection is more in maximum to minimum eigen value detection method than the other methods. It means that the Maximum to Minimum Eigen Value detection is better in this method at lower values of SNR. Cyclostationary feature detection and Matched Filter detection methods also giving promising results but not better than the maximum to minimum eigen value detection method. Energy Detection Method also has degraded performance at lower values of SNR.

Figure 7 shows the graphical plot of probability of False Alarm for different values of SNR for all four methods. We can observe that again Maximum to Minimum eigen value detection method has better performance. As probability of missed detection is complement of probability of detection, here we are getting complementary plot of probability of detection Vs SNR plot. Hence here also maximum to minimum eigen value detection method outperforms the other methods.

Figure 8 shows the graphical plot of probability of missed detection over different values of SNR for all different methods. If we increase number of samples, then we can observe that performance of cyclostationary Detection method improves and reaches nearly to Maximum to Minimum Eigen Value Detection Method. Performance of all other techniques will also improve with the increase in number of samples but simulation time will also increase.

V. CONCLUSION & FUTURE SCOPE

In this project work, we have presented performance analysis of four different sensing techniques in CR based on Probability of detection (Pd), Probability of False Alarm(Pf) and Probability of Missed Detection. Each technique has its own advantages and disadvantages.

In energy detection technique no prior information about the PU is required and it is also easy to implement, but it fails to perform at low SNR. Minimum SNR is essential for ED method for effective sensing. Cyclostationary feature detection needs to know the cyclic frequencies of the primary signal, which may not be available to the secondary users in practice. Also, it has high computational complexity. Matched filter detection is considered to be an optimal signal-detection method. However, it requires a prior knowledge of the primary user, e.g., modulation type, pulse shaping, and synchronization of timing and carrier. The Eigen value –based spectrum sensing techniques is found as the best amongst existing sensing methods as it does not require prior knowledge of the transmitted signal also information of noise variance is not necessary in this method. Maximum to minimum eigen value ratio detector methods overcome noise level variation difficulty, and also have the advantages of energy detection method.

The simulation results provide a performance evaluation of all the sensing techniques in cognitive radio systems, and it is validated from the simulation results that Maximum to Minimum Eigen Ratio Detector has best performance in case of probability of false alarm and Probability of Detection than that of other techniques. Based on this analysis, further research will focus on the developing the hybrid detection methods using more realistic approach with typical CR signal processing tasks to minimize the detection time.

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