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Unified Investigation of Spectrum Sensing Schemes for Cognitive Radio Networks

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Abstract: A better Quality of Service (QoS) is the prime objective for the wireless applications and which can be satisfied by proper management of the available spectrum. In recent time Cognitive Radio (CR) is arise as promising technology to support spectrum management dynamically. Spectrum sensing is an important issue in dynamic spectrum management. There are number of spectrum sensing techniques presented in frequent literatures. This paper consist of the comparative analysis of different eigenvalue based spectrum sensing techniques is presented. The Maximum Minimum Eigen value detection, Energy detection, Mean Eigen value detection and Roys Largest root test are considered for the evaluation. Closed form analysis of equation is traced and from that it is confirmed that Maximum Minimum eigen value gives better execution and can be useful for spectrum sensing for dynamic spectrum management perspective.

Keywords: Cognitive Radio, Eigen Value Detection, Energy Detection, Roys Largest Root Test, Dynamic Spectrum Management.

I. INTRODUCTION

Wireless networks are organized by a fixed spectrum allocation policy, i.e. the spectrum is regulated by lawmaking agencies and is assign to license holders or services on a long term basis for ample geographical location. Figure 1 shows the signal strength allocation over a large part of the wireless spectrum. Moreover it shows that the significant spectrum utilization is only in some portions of the spectrum while a major amount of the spectrum remains idle. According to Federal Communications Commission (FCC) [1], only 15% to 85% of the assigned spectrum utilised according to its temporal and geographical variations. Even though the fixed spectrum assignment policy generally served well in the past, there is impressive increase in the access to the limited spectrum for telecommunication services in the recent time period. This gain is efforts the powerfulness of the traditional spectrum policies. The small-scale available spectrum and the inadequacy in the spectrum usage necessitate a new communication model to exploit the existing wireless spectrum expedient [2]. To solve these current spectrum inefficiency problems intelligent spectrum access is proposed. DARPAs conceptualization on Dynamic Spectrum Access network, the NeXt Generation (xG) program aims to implement the policy based intelligent radios known as cognitive radios [3]. Cognitive radio is a new era of designing wireless communications systems which aims to improve the utilization of the radio frequency (RF) spectrum.

The main challenges with CRs or secondary users (SUs) are that it must sense the signal from PU without any interference. In this paper we focus on the spectrum sensing techniques that are dependent on primary transmitter detection [4].

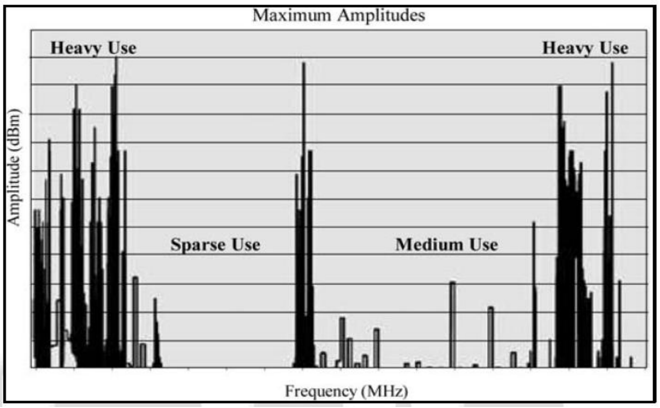

Fig. 1: Spectrum Utilization

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The focus of this work is on the comparative study of an important spectrum sensing detection techniques are addressed: the energy detection (ED)[5-8], the maximum minimum eigen value detection (MMED)[9-13], the Mean eigen value detection (MED)[12-13], and the eigen value-based generalized likelihood ratio test (GLRT)[14-15].
The rest of paper is presented as follows. Section II and III presents the spectrum sensing techniques. In Section IV presents the simulation model and section V include the simulation set up and Section VI the summary of simulation setup to the signal model.

II. SPECTRUM SENSING TECHNIQUES

With Cognitive Radio being used in a number of applications, the area of spectrum sensing has become increasingly essential. As Cognitive Radio technology is being used to provide a method of using the spectrum more efficiently, spectrum sensing is primal to this application. The quality of Cognitive Radio systems to access lean areas of the radio spectrum, and to keep observation the spectrum to ensure that the Cognitive Radio system does not cause any unjustified interference relies totally on the spectrum sensing elements of the system.
For the overall system to operate more effectively and to furnish the required improvement in spectrum efficiency, the Cognitive Radio spectrum sensing system must be able to effectively detect any other transmissions, identify what they are within the Cognitive Radio so that the required action can be taken. Spectrum sensing can be basically reduced to an identification problem, modeled as a hypothesis test. The sensing equipment has to just settle between for one of the two hypotheses as follows:

$$H1: X(n) = S(n) + W(n)$$
$$H0: X(n) = W(n) \qquad (1)$$

Where,
S (n) is the signal transmitted by the primary users.
X (n) Being the signal received by the secondary users.
W (n) Is the additive white Gaussian noise with variance
Hypothesis 'H0' bespeak absence of primary user and that the frequency band of interest only has noise whereas 'H1' points towards presence of primary user.
Declaring H1 under H0 hypothesis, leads to Probability of False Alarm (Pf).
Pf = Pr (H1 / H0)
Declaring H1 under H1 hypothesis, leads to Probability of Detection (Pd).
Pd = Pr (H1 / H1)
Declaring H0 under H1 hypothesis, leads to Probability of Missing (Pm).
Pm = Pr (H0 / H1)

III. EIGEN VALUE BASED SPECTRUM SENSING TECHNIQUE

A. Energy Detection
For the detection of unknown deterministic signals corrupted by the additive white Gaussian noise, an energy detector is derived in [15], which is called conventional energy detector. In this technique receiver does not have much information about the Primary user, the value of white Gaussian noise is known . Calculating the energy of received signal, received signal can detect effortless [16-18]. Energy detection technique can be implemented efficiently because the receiver does not necessitate any prior information to detect the PU signal. In this technique input signal is received by analog to digital then output of A/D converter x(n) is passed to square law circuit and fed to summation block. The output of summation/Integrator y(n) is compared to a pre-defined threshold. This comparison is used to discover the presence or absence of the PU signal.
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).

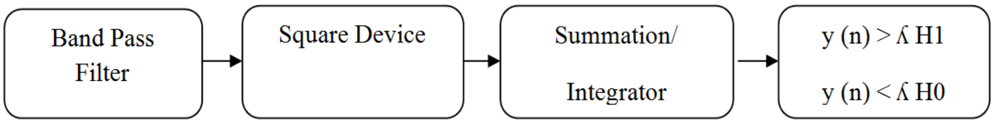

Fig. 2: Block Diagram of Energy Detector

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B. Maximum to minimum eigenvalue detection

Energy detection is the robust method and does not need any information of the signal to be detected. However, energy detection relies on the knowledge of accurate noise power, and inaccurate estimation of the noise power leads to high probability of false alarm [19,20]. Thus energy detection is susceptible to the noise uncertainty. Energy detection is not prime for detecting correlated signal, which is the case for most practical applications. To defeat the shortcomings of energy detection, we utilize new technique based on the eigenvalue of the covariance matrix of the received signal. An Eigenvalue-based scheme does not require prior information of the transmitted signal. Also in some eigenvalue-based schemes, the knowledge of noise variance is not needed. In this sensing technique, the test statistic is computed from the eigenvalues of the received signal covariance matrix.

C. Maximum to minimum eigenvalue detection

The novel modification in method of spectrum sensing based on eigenvalue, maximum eigenvalue to minimum eigenvalue ratio detector [9] 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 compute the distributions of these ratios and find the detection thresholds for the proposed detection techniques. The probability of false alarm and probability of detection are also derived by using the RMT. Mean eigenvalue detection 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. 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 continuation. Based on some latest random matrix theories (RMT), we can quantize the ratio and find the threshold. RMT is also useful to found the probability of false alarm.
The Mean eigenvalue ratio detector (MERD) method overcome the inconvenience of maximum eigenvalue to minimum eigenvalue ratio detector and perform better for probability of false detection, overcome noise level variation difficulty, and in addition have the advantages of maximum eigenvalue to minimum eigenvalue ratio detector & energy detection method.
Mean Eigenvalue Ratio Detection (MERD) steps
Step1. Compute

$$R(Ns) = 1/Ns \sum_{n=L}^{L-1+Ns} x^{\wedge}(n)\, x^{\wedge} + (n), \qquad (3)$$

Step2: Obtain the mean and minimum eigenvalues of the matrix R (Ns) that is λ_{mean} and λ_{min}.
Step3: Decision:
If $\lambda_{mean} / \lambda_{min}$, > Threshold, then signal exist (“H_1” decision)
Otherwise,
$\lambda_{mean} / \lambda_{min}$, < Threshold, then signal does not exist (“H_0” decision)

D. Eigenvalue-based generalized likelihood ratio test

Generalized Likelihood Ratio Test is an effective detection technique for spectrum sensing in CR, with unknown parameters.
In the case of unknown parameters, such as R_s and σ_w^2, the solution to the detection problem is GLRT which obtains the maximum likelihood estimate (MLE) of unknown parameters under H0 and H1, i.e.,

$$\hat{\theta}_0 = arg \max_{\theta_0} P(X|H_0, \theta_0) \qquad (4)$$

$$\hat{\theta}_1 = arg \max_{\theta 1} P(X|H_1, \theta_1) \qquad (5)$$

where X is [x(0); x(1);……..; x(N - 1)], and $\hat{\theta}_0$ and $\hat{\theta}_1$ are the MLE of unknown parameters. The GLRT statistics [11] is given as

$$\frac{P(X|\hat{\theta}_1, H_1)}{P(X|\hat{\theta}_0, H_0)} \begin{matrix} >^{H_1} \\ < H_0 \end{matrix} \Upsilon \qquad (6)$$

Where, Υ is threshold determined from the given P_{fa}. The unknown parameters in the binary hypothesis problem given in (4) are h and σ_w^2 Under H_1 , and σ_w^2 under H_0.

IV. SYSTEM MODEL

Assume that there are m antennas in a CR, or m single-antenna CRs, each one collecting n samples of the received signal from p primary transmitters during the sensing period. Consider that these samples are arranged in a matrix

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$Y \in X^{mxn}$. Consider that the transmitted signal samples from the p primary transmitters are arranged in a matrix $X \in X^{pxn}$.Let $H \in X^{mxp}$ be the channel matrix with elements {hij}, i = 1, 2, …, m and j = 1, 2, …, p, representing the channel gain between the j-th primary transmitter and the i-th sensor (antenna or receiver). Finally, let **V** and $V_{IN} \in X^{mxn}$ the matrices containing thermal noise and IN samples that corrupt the received signal, respectively. The matrix of received samples is then,

{hij}, i = 1, 2, …, m and j = 1, 2, …, p, representing the channel gain between the j-th primary transmitter and the i-th sensor (antenna or receiver). Finally, let V and the matrices containing thermal noise and IN samples that corrupt the received signal, respectively. The matrix of received samples is then,

$$Y = HX + V + V_{IN}$$

In eigenvalue-based sensing, spectral holes are detected using test statistics computed from the eigenvalues of the sample covariance matrix of the received signal matrix **Y**. The sample covariance matrix is given as,

$$R = \frac{1}{n} YY^{\dagger}$$

The eigenvalues {λ1 ≥ λ2 ≥ … ≥λm} of **R** then computed, and assuming a single primary transmitter (p = 1), the test statistics for GLRT, MMED, MED, and ED are respectively calculated as follows,

$$T_{GLRT} = \frac{\lambda_1}{\frac{1}{m}\sum_{i=1}^{m}\lambda_i} \quad (7)$$

$$T_{MMED} = \frac{\lambda_1}{\lambda_m} \quad (8)$$

$$T_{MED} = \frac{\frac{1}{m}\sum_{i=1}^{m}\lambda_i}{\lambda_m} \quad (9)$$

$$T_{ED} = \frac{1}{n\sigma^2}\sum_{i=1}^{m}\lambda_i \quad (10)$$

Where, σ2 is the thermal noise power, which is known and with equal value in each secondary user.

V. SIMULATION SETUP

The simulation setup is as follows,
1. Set the following parameters:
- P : number of primary users (1)
- m: number of Cognitive Radio users (6)
- n: number of samples of data collected from primary user (200)
- N: number of events per sample (200)
- P: probability of occurrence of IN noise (0.2)
- L: MA filter length (5)
- SNR_min: -10dB
- SNR_max: 20dB
- Gamma: Threshold value(3)

2. Calculate the received signal vector Y
3. Compute the sample Covariance matrix R
4. Compute the test statistics of all the methods
5. Compare test statistics with the predefined threshold value
6. Decide whether primary user present or absent

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VI. SIMULATION RESULTS

A. Probability Detection

Figure 3 shows the probability of PU detection (Pd) with respect to SNR for the four cases. The probability of detection alarm should be as much as possible with respect to SNR.

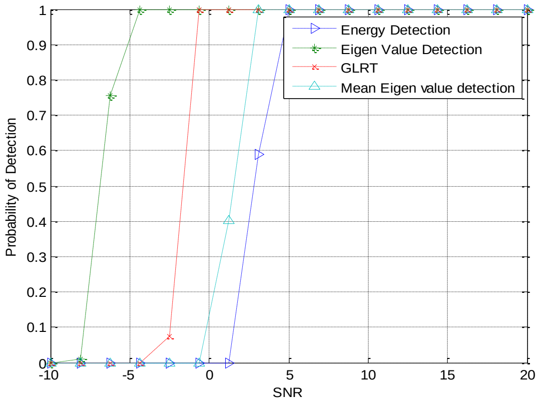

Fig. 3 Comparative graph of Probability of detection Vs SNR

B. Probability of false Alarm

In Fig. 4 the comparison of four spectrum detection 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.

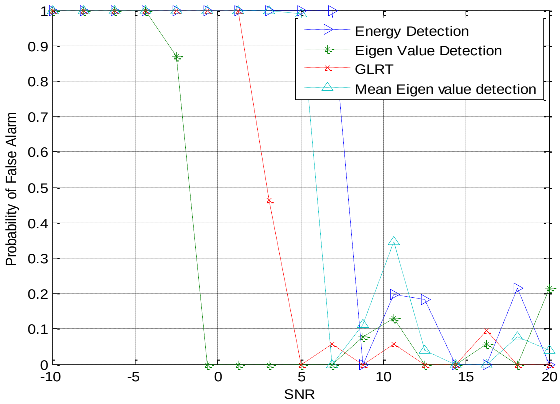

Fig. 4 Comparative graph of Probability of False Alarm Vs SNR

C. Probability of missed detection

Figure 5 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.

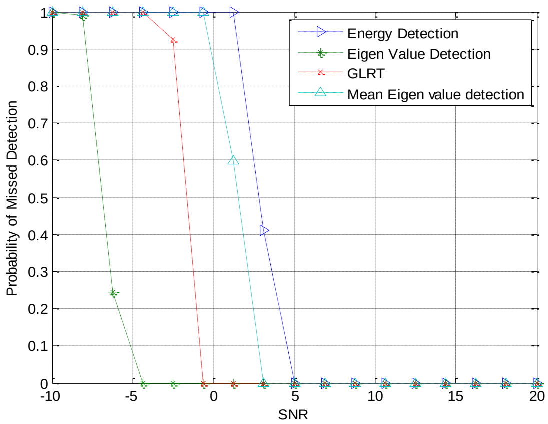

Fig. 5 Comparative graph of Probability of Missed Detection Vs SNR

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From figure 3, 4 and 5, it is clear that the Maximum Minimum Eigen value detection technique gives better results at lower values of SNR hence it perform better than the other techniques.

VII. CONCLUSION

From the simulations results it is concluded that, Maximum eigenvalue to Minimum eigenvalue ratio detector methods have the advantages of energy detection method and also overcome noise level variation difficulty. The Maximum eigenvalue to Minimum eigenvalue ratio detector method perform superior for probability of detection. But for s probability of false detection its performance is degraded and it is recorded as the drawback of this method. Secondly the mean eigenvalue ratio detector has shown very low probability of false detection so it overcome the limitation of Maximum eigenvalue to Minimum eigenvalue ratio detector. Finally, GLRT sensing algorithm significantly out performs numerous high-tech spectrum sensing methods in the presence of noise uncertainty, downside is its result perform with a small number of signal samples.

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