Performance Evaluation of Spectrum Sensing Techniques based on Eigenvalue in Cognitive Radio Networks

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Abstract—**Spectrum management is required to control the transmission of radio waves to avoid interference and mixing among wireless users. Intelligent Transceiver i.e. Cognitive Radio is the key enabling technology to support spectrum management dynamically. To sense the spectrum is very important & main issue in dynamic spectrum management. There are many spectrum sensing techniques presented in numerous literature's. Here in this paper the comparative study of different spectrum sensing techniques based on eigenvalue are presented. The Maximum Minimum Eigenvalue Detection, Energy Detection, Mean Eigenvalue Detection and Generalized Likelihood Ratio Test are considered for the evaluation. The simulation results are elaborated with respect to the performance measurement matrices like Probability of detection, Probability of false detection and Probability of missed detection. Closed form analysis of equation derived and from that it is considered that Maximum Minimum eigenvalue gives better performance and can be useful for spectrum sensing for dynamic spectrum management perspective.**

Keywords - **Eigenvalue detection, Energy detection, Dynamic spectrum management.**

I. INTRODUCTION

Today's wireless networks are regulated by a fixed or static spectrum allocation policy, i.e. the spectrum is regulated by governmental agencies and is assigned to license holders or services on a long term basis for large geographical areas. Also, a large part of the allotted spectrum is used sporadically as illustrated in Fig. below, where the signal strength distribution over a large portion of the wireless spectrum is shown. The spectrum usage is concentrated on some portions of the spectrum while a significant amount of the spectrum remains unused. As per Federal Communications Commission (FCC) [5], temporal and geographical variations in the utilization of the assigned spectrum range from 15% to 85%. Although the fixed spectrum assignment policy generally served good in the past years, there is an extensive increase in the access to the limited spectrum for mobile services in the recent years. This increase in the access is weakening the effectiveness of the traditional spectrum policies and rules. The limited available spectrum and the inability in the spectrum usage necessitate a new communication paradigm to exploit the existing wireless spectrum opportunistically [4]. Dynamic spectrum access is proposed to solve these current spectrum inability problems. DARPAs approach on Dynamic Spectrum Access network, the so-called NeXt Generation (xG) program aims to implement the policy based intelligent radios known as cognitive radios [5]. Cognitive radio is a new paradigm of designing wireless communications systems which aims to enhance the utilization of the radio frequency (RF) spectrum. With the advent of the cognitive radio (CR) paradigm [2], cognition-inspired dynamic spectrum access techniques come into action by exploring the unused portions of the spectrum in time and space, while causing zero or very minimum harm in the system that owns the license. Among the enormous variety of cognitive assignments that a CR can do, spectrum sensing is the function of detecting holes (whitespaces) in frequency bands licensed to primary wireless networks, for opportunistic use by the secondary network. Recent advances in random matrix theory have spurred the adoption of eigenvalue-based detection techniques for spectrum sensing in cognitive radio. These techniques use the ratio of the largest and the smallest eigenvalues of the received signal covariance matrix to find the presence or absence of the primary signal.

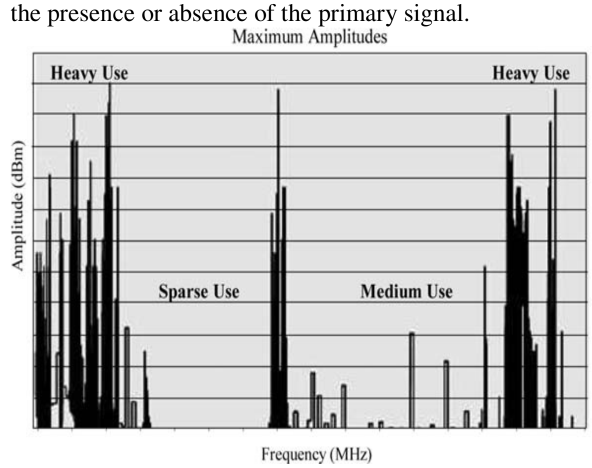

Fig.a. Spectrum Utilization

The spectrum sensing issue has gained new aspects with cognitive radio & opportunistic spectrum access approach. It is one of the most challenging issues in cognitive radio systems. Two main characteristics of the cognitive radio can be defined as:

i. Cognitive Capability

Cognitive capability refers to the ability of the radio technology to capture or sense the information from its radio environment. This capability cannot simply be realized by monitoring the power in some frequency band of interest but more sophisticated techniques are required in order to capture the temporal and spatial variations in the radio environment and avoid interference to other users.

Through this capability, the portions of the spectrum that are unused at a specific time or location can be identified. Consequently, the best spectrum and appropriate operating parameters can be selected.

ii. Reconfigurability

The cognitive capability provides spectrum awareness whereas Reconfigurability enables the radio to be dynamically programmed according to the radio environment. More specifically, the cognitive radio can be programmed to transmit and receive on a variety of frequencies and to use different transmission access technologies supported by its hardware design [18].

II. SPECTRUM SENSING

Cognitive radio is the key technology for future wireless communication. An important requirement of the Cognitive Radio Network (CRN) is to sense the spectrum holes. Spectrum sensing is one of the most important functions in implementing cognitive radio, which empower secondary users to identify & utilize vacant spectrum resource allocated to primary users. A cognitive radio is designed to be aware of and sensitive to the changes in its environment. The spectrum sensing function empowers the cognitive radio to adapt to its environment by detecting spectrum holes. The most effective way to detect spectrum holes or white space is to identify the primary users that are receiving data within the communication range of a CR user. Spectrum sensing is used to determine the state. A cognitive radio user can allocate only an unused portion of the spectrum and the activity of the primary (licensed) users. A cognitive radio detects an unused spectrum or spectrum holes i.e. monitors the available spectrum bands, acquire their information.

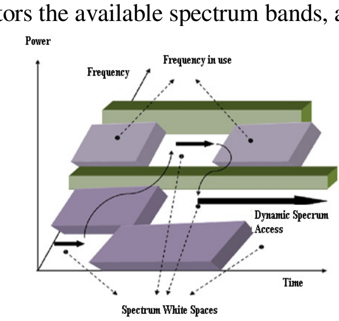

Fig.b. Concept of Spectrum Hole

Spectrum sensing can be simply reduced to an identification problem, modeled as a hypothesis test. The sensing equipment has to just decide between for one of the two hypotheses as follows:

$$H_1 : X(n) = S(n) + W(n)$$

$$H_0 : X(n) = W(n)$$

Where,

'$S(n)$' is the signal transmitted by the primary users.

'$X(n)$' is the signal received by the secondary users.

'$W(n)$' Is the additive white Gaussian noise with variance σ_W^2

Hypothesis 'H_0' indicates absence of primary user and that the frequency band of interest only has noise whereas 'H_1' points towards presence of primary user. Thus for the two state hypotheses numbers of important cases are:-

- H_1 turns out to be TRUE in case of presence of primary user i.e. P (H_1 / H_1) is known as Probability of Detection (P_d).
- H_0 turns out to be TRUE in case of presence of primary user i.e. P (H_0 / H_1) is known as Probability of Missed-Detection (P_m).
- H_1 turns out to be TRUE in case of absence of primary user i.e. P (H_1 / H_0) is known as Probability of False Alarm (P_f)

Mathematically,
P_d (Probability of detection) = P (H_1 / H_1),
P_f (Probability of false alarm) = P (H_1 / H_0), and
P_m (Probability of missed detection) = P (H_0 / H_1).

III. EIGEN VALUE BASED SPECTRUM SENSING TECHNIQUES

A. *Energy detection*

For the detection of unknown deterministic signals corrupted by the additive white Gaussian noise, an energy detector is derived, which is called conventional energy detector. In this technique receiver does not have much information about the PU, only the value of white Gaussian noise is known. Calculating the energy of received signal, received signal can detect easily [16, 17]. Energy detection technique is simple and 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 A/D converter then output of A/D converter x(n) is passed to square law circuit and fed to summation block. The output of summation or Integrator y(n) is compared to a pre-defined threshold . This comparison is used to discover the presence or absence of the PU signal.

B. *Eigenvalue based 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 defective estimation of the noise power leads to high probability of false alarm [16]-[17]. 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 overcome the shortcomings of energy detection, we use new methods based on the eigenvalue of the covariance matrix of the received signal.

Among the existing spectrum sensing detection techniques [13], eigenvalue-based schemes are receiving a lot of attention [14]-[15], mainly because they do not require prior information on the transmitted signal. In some eigenvalue-based schemes, the knowledge of noise variance is not needed either [15]. In eigenvalue spectrum sensing, the test statistic is computed from the eigenvalues of the received signal covariance matrix.

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 [19].

In this paper the following techniques are addressed: the Energy Detection (ED), the Maximum Minimum Eigen Value Detection (MMED), the Mean Eigen value Detection (MED), and the Eigen value -Based Generalized Likelihood Ratio Test (GLRT).

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 $Y \in X^{mxn}$. Also 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,

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

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,

$$T_{GLRT} = \frac{\lambda_1}{\frac{1}{m}\sum_{i=1}^{m}\lambda_i}$$

$$T_{MMED} = \frac{\lambda_1}{\lambda_m}$$

$$T_{MED} = \frac{\frac{1}{m}\sum_{i=1}^{m}\lambda_i}{\lambda_m}$$

$$T_{ED} = \frac{1}{m\sigma^2}\sum_{i=1}^{m}\lambda_i$$

Where *σ* 2 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) Find Eigenvalue of each covariance matrix
5) Calculate Test Statistics for each method
6) Compare Test statistics with threshold
7) Decide presence & absence of primary user based on hypothesis.

VI. SIMULATION RESULT

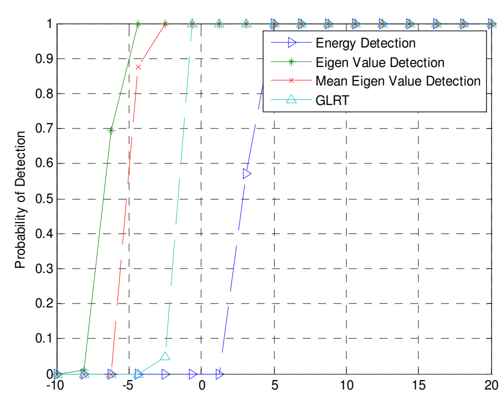

Fig 1. Comparative result analysis of P_d Vs SNR

Figure 1 shows the comparative result of the probability of detection Vs SNR. It shows that the Eigenvalue based detection method performs better than the other detection methods.

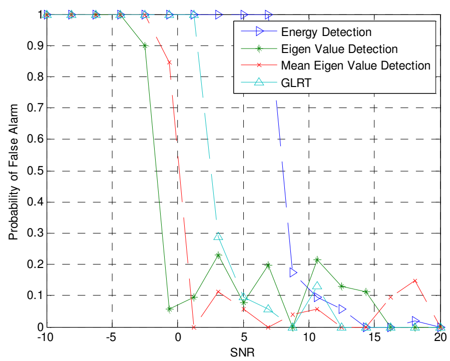

Fig 2. Comparative result analysis of P_{fa} Vs SNR

Figure 2 shows the comparative result of the probability of false alarm for different SNR values. From graph we conclude that Eigenvalue detection gives better results for low SNR Values.

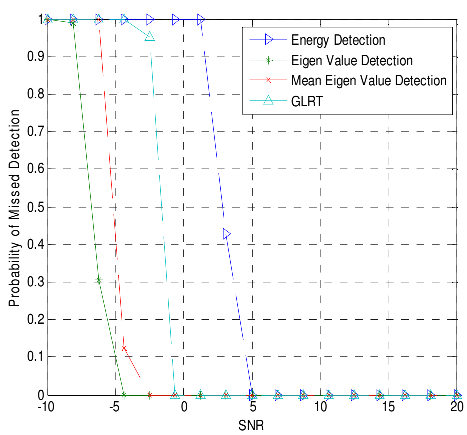

Fig 3. Comparative result analysis of P_m Vs SNR

Figure 3 depicts that Eigenvalue detection method is better for the probability of miss detection at lower SNR

VII. CONCLUSION

In this paper we have evaluated the performance of Spectrum Sensing Techniques based on Eigenvalue such as Energy Detection, Maximum Minimum eigenvalue based Detection method ,Mean eigenvalue detection, Generalized Likelihood Ratio Test. Test. On the basis of different performance matrices like Probability of Detection, Probability of False Alarm and Probability of Missed Detection. From the comparative results we can conclude that the Maximum Minimum Eigenvalue Based Detection method performs better than all other eigenvalue based detection methods.

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