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Gini Index Test Metric Based Collaborative Sensing of Spectrum for Cognitive Networks

Gini Index Test Metric Based Collaborative Sensing of Spectrum for Cognitive Networks

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Abstract. The key confront for a cognitive radio network is to identify the presence of primary users consistently so as to curtail the intrusion to license approved communications. Consequently, sensing of spectrum is a main significant requisite of a cognitive network. Nevertheless, because of the ambiguity in the channel, local interpretations don't provide a trustworthy solution and therefore collaboration is needed between the users. Collaborative spectrum sensing is a competent scheme to enhance the spectrum utility in wireless networks, which utilizes cooperation between multiple nodes to prevail over the inadequacy of single-node to improve the performance of detection. In this paper, a detailed investigation, simulation and comparative analysis of collaborative scheme for sensing the spectrum of cognitive networks based on Gini Index test metrics is done and the results are compared with various other detecting schemes. The simulation is accomplished by means of Matlab R2014 software.
Keywords: Cognitive Radio Networks, Collaborative Spectrum Sensing, Gini Index,

1. Introduction

Sensing of spectrum is a vital part of cognitive radio. The essential assignments of spectrum sensing are to identify the primary users and also to recognize accessible spectrum bands. Spectrum sensing is accountable for a cognitive radio system to persuade two elemental necessities [1]. First and foremost, a cognitive radio network must spot the white spaces also known as spectrum holes to assure a quality of service demands of secondary users. Secondly, the cognitive network requires making sure that any secondary user do not provide any dangerous intrusion to frequency bands the primary users' [5]. At present, shadowing, multi-path fading, and receiver uncertainty problems are the major issues in networks of cognitive radio. Cooperative sensing of the spectrum is a competent approach to enhance spectrum utilization in wireless networks, by improving detection performance and saving energy with the help of cooperation among various nodes to conquer the shortcomings of single-node. Commonly, spectrum sensing elucidations are largely categorised as collaborative and non-collaborative [2]. Further particularly, collaborative solutions depend on various secondary users to share the occupancy details of the spectrum via local independent evaluations and calculations which are accomplished by cluster based architectures [5]. Spectrum accessibility is measured by leveraging spectrum utility data from various cluster heads. Collaborative sensing schemes in addition are exploited to evaluate the highest transmit power in cognitive networks which in turn satisfies the constraints on the interference [9].

2. RELATED WORK

H. Liu et al in [1], presented an imbalanced data method of Weighted Gini index feature selection. Lemes et al in [2], has proposed a mapping for the Gini Index detector test statistic using artificial neural networks. Swati Goswami et al in [3], has explained the application of Gini Index for network graphs. Zhu et al in [4], has analyzed Collaborative Wireless Sensor Networks and its Applications in detail. Dayan Adionel Guimarães in [5] has proposed Gini Index Detector (GID) for collaborative sensing of spectrum [5]. Authors in [6] & [7] have surveyed the various research and developments in the cognitive networks and also has analyzed the various spectrum sensing schemes for cognitive networks. Haykin S et al in [8], has described the various modern wireless communications. Proakis, J.G, in [9], has described the various digital communications. Rappaport,T. in [10], has described Wireless Communications Principles and its Practice.Thangalakshmi, B et al in [11] & [12], has reviewed the cognitive networks and also proposed a method of sensing the spectrum of cognitive networks based on matched filter detection [12]. Guimarães, Dayan A. in [13], has presented a Hybrid Spectrum Sensing Test Statistic using the Gershgorin Theorem and on the Gini Index. TY - CHAP et al in [14] has presented collaborative method of sensing the spectrum for cognitive networks using NS2. Kamran Arshad et al in [15], has explained the optimization schemes for collaborative sensing of spectrum for cognitive radio networks. T. Manna et al in [16], has presented a collaborative sensing of spectrum in real cognitive radio network [16]. K. Arshad et al in [17], has analyzed collaborative spectrum sensing for cognitive radio. Masahiro Sasabe et al in [18], has proposed a collaborative sensing of spectrum techniques based on incentive of the user in cognitive radio networks. Arshad, Kamran et al in [19], has proposed optimization schemes for collaborative sensing of spectrum for cognitive radio networks. Authors in [20], [21] & [22] have presented a detailed report and analysis on multidimensional correlations based collaborative sensing of spectrum in cognitive radio networks using. M. Meena et al in [23] & [25] , has explained a sensing of spectrum along with allocation of resource for efficient data transmission in cognitive radio networks with 5G. Bharathy G.T et al in [24], has proposed an approach for coverage area restoration based on energy - efficiency during the failure of sensor nodes.

3. COGNITIVE RADIO NETWORK

Cognitive Radio (CR) is a structure of wireless communication in which a transceiver can wisely identify which communication channels are in usage and which are idle. CR technology makes it feasible to reuse precious spectrum resources without altering the available spectrum allocation policy. The intention of cognitive radio network is to utilize the spectrum in a vibrant way by permitting radio terminals to function in a preeminent frequency band. Fundamentally in wireless network, it comprises of both primary and secondary base station. Generally base station is a radio receiver/transmitter it functions as a centre of the wireless network. The primary user send and receive the spectrum through primary base station and it is called primary base station and the secondary user(cognitive user) transmit and receive the spectrum through secondary(cognitive) base station and it's called secondary transmission. Figure 1 and 2 shows the diagrammatic depiction of sensing of spectrum and collaborative sensing of spectrum respectively.

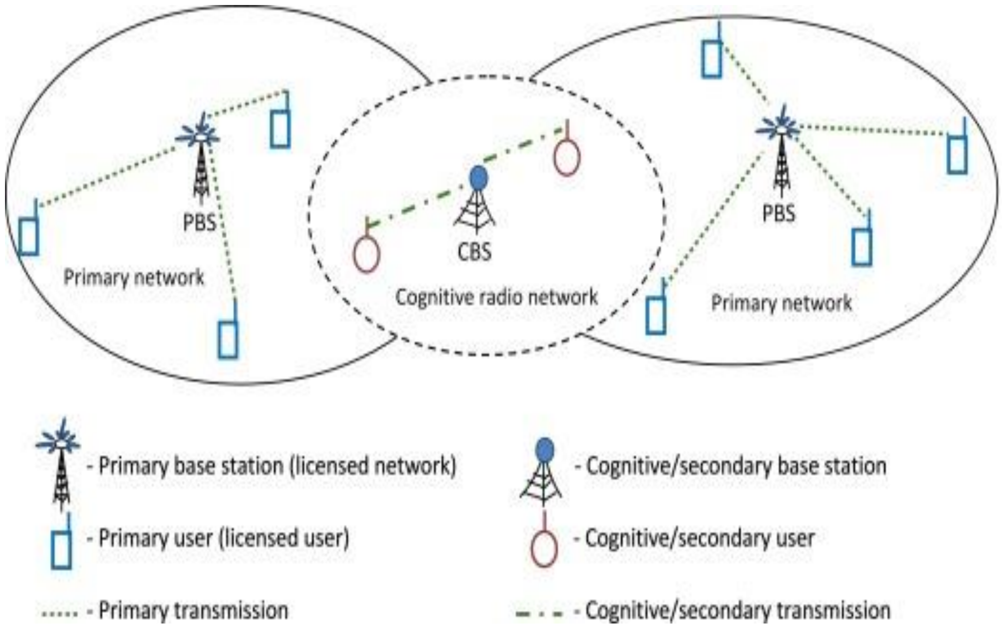

Figure. 1 Spectrum Sharing in Cognitive Networks

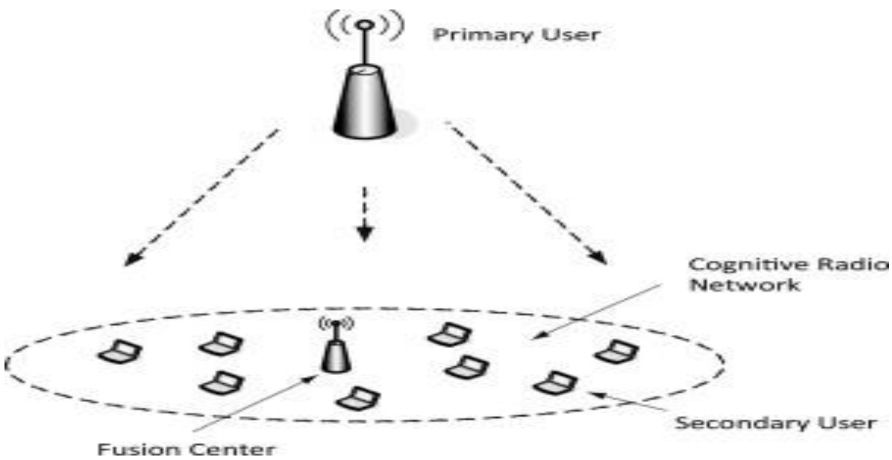

Figure 2. Spectrum Sensing in Cooperative CR

4. MODEL OF COGNITIVE RADIO NETWORK

Consider a M user cognitive network and a fusion center for detecting the existence of the primary user. Each cognitive network performs the spectrum sensing by analysing the received signal individually for the presence of signal alone or signal added with noise and takes decision based on the binary hypothesis equation as follows.

$$x_i(t) = \begin{cases} n_i(t), & \mathcal{H}_0, \\ h_i s(t) + n_i(t), & \mathcal{H}_1, \end{cases} \qquad (1)$$

where, S(t) is the primary user signal, n(t) is the noise and hi is the gain of the channel. H_0 and H_1 are the sensing states for absence and presence of signal respectively. There are four possible cases for the detected signal:

1. Stating H_1 under H_1 hypothesis, providing Detection Probability (Pd)
2. Stating H_0 under H_1 hypothesis, providing Missing Probability (Pm)
3. Stating H_1 under H_0 hypothesis, providing False Alarm Probability (Pf)
4. Stating H_0 under H_0 hypothesis

Each CR calculate its SNR, which provides the ratio of the signal power to the noise power and is given by,

$$\gamma_i \triangleq \frac{\mathrm{E}\left[|h_i|^2\right]\sigma_s^2}{\sigma_n^2} \qquad (2)$$

5. COLLABORATIVE SPECTRUM SENSING

Spectrum sensing can be carried out either individually by each cognitive radio, or with the cooperation among various cognitive users intending enhanced performances. The earlier method suffers from issues such as multipath fading, shadowing which combats the detection power [13]. Cooperation among CR's enhances the precision of the decisions on the occupancy condition of the band being sensed compared to the non-collaborative sensing. In centralized collaborative sensing [13] based on data fusion, the detection schemes for sensing the spectrum includes the Energy Detection (ED) [5], Matched Filter Detection (MFD) [5], [7], [12] Cyclostationary Feature Detection [5] (CFD) and the Eigen Value Detection (EVD) [5, 2, 3] are largely extensively utilized. The MFD and CFD are complicated to realize, as they require a prior knowledge on primary user signal or channel information which is not effortlessly accessible to the secondary users. The ED and the EVD does not require these types of information, hence it is categorised as blind techniques. The figure 1and 2 shows the diagrammatic representation of cooperative spectrum sensing scheme. The fusion center collects data from each SU's and shares the data with all the SU's. The optimum decision is taken using Neyman - Pearson criterion given by,

$$\frac{f(\mathbf{D} \mid \mathcal{H}_1)}{f(\mathbf{D} \mid \mathcal{H}_0)} \underset{\mathcal{H}_0}{\overset{\mathcal{H}_1}{\gtrless}} \lambda, \qquad (3)$$

Where D represents the individual decision of M users in the cognitive network. Numerator and the denominator represent the PDF of D under the hypothesis H1and H0, respectively. There are numerous methods to combine the decisions taken by the individual CR, which depends on the counting rules like AND rule, OR rule or K out of M rule.

$$y_c = \begin{cases} \sum_{i=1}^{M} D_i \geq K, & \mathcal{H}_1 \\ \sum_{i=1}^{M} D_i \leq K, & \mathcal{H}_0. \end{cases} \quad (4)$$

K = 1 represents OR rule, K = M represents AND rule

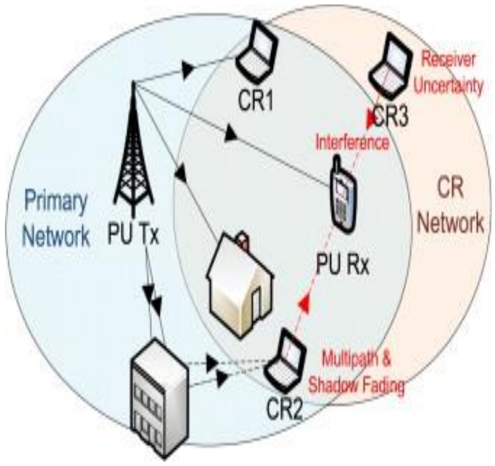

Figure 3. Cooperative Spectrum Sensing

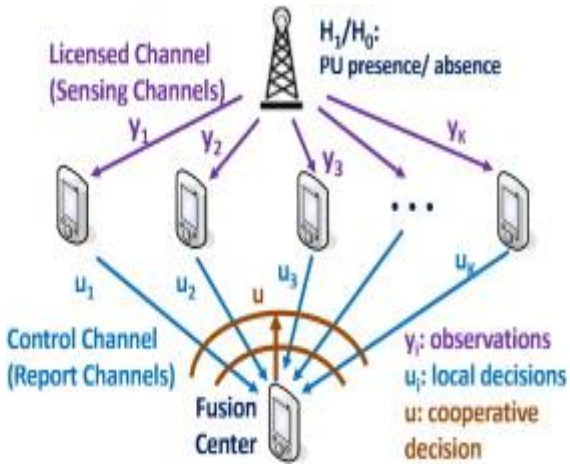

Figure 4. Cooperative Spectrum Sensing Model

6. COLLABORATIVE SPECTRUM SENSING MODEL

The two test metrics commonly utilized for assessing the performance of sensing the spectrum are the detection probability, P_d, and the false alarm probability, P_{fa}. The earlier is the probability to decide in favour of a band which is occupied, when it is actually occupied. The later is the probability to decide in favour of an engaged band, when it is actually unoccupied. A large value of P_d is required to decrease the interference produced by the cognitive network to the main (primary) network because of wrong (missed) detections. At the same time, a little value of P_{fa} is intended at for larger opportunistic data transfer could be carried out by the cognitive network because of the bands which are rarely stated as occupied when they are truly not in use. The Collaborative Sensing of Spectrum is achieved by using m cognitive SUs, each and every user gathering n samples of the signal received from s primary transmitters at each and every interval or instant of sensing. At the fusion center such samples from the matrix $\mathbf{Y} \in \mathbb{C}^{m \times n}$ given by,

$$\mathbf{Y} = \mathbf{H}\mathbf{X} + \mathbf{V}. \quad (5)$$

7. GINI INDEX DETECTOR

Gini Index is a numerical metric which is mathematically defined as one half of the absolute difference of the relative mean [5], that is the ratio among the mean absolute difference and the arithmetic mean [5], given by

$$G = (\sum_{i=1}^{N} \sum_{j=1}^{N} |x_i - x_j|)/(2N \sum_{i=1}^{N} x_i) \tag{6}$$

where G is greater than equal to 0. The Gini index is given s input to a test covariance matrix m.

The test metrics of Gini Index Detector is given by

$$T_{\text{GID}} = \frac{2(m^2 - m)\sum_{i=1}^{m^2} |r_i|}{\sum_{i=1}^{m^2} \sum_{j=1}^{m^2} |r_i - r_j|} \tag{7}$$

where r_i is the i-th element of the vector r formed by mounting all columns of R.

A typical performance metric for analyzing the sensing of spectrum is the performance operating characteristics curve of the receiver called as ROC curve, for providing tradeoff between the detection probability P_d and the false alarm probability P_{fa} by changing the peak value of decision. The metric values are precisely evaluated with the help of area under the ROC curve (AUC) [5], in which the simulations are carried out by Monte Carlo simulations. For comparison the following detectors are used namely, Energy Detection (ED), Volume-based Detector 1 (VD1), Generalized Likelihood Ratio Test Detection (GLRT), Maximum Eigen value Detection (MED), Maximum-Minimum Eigen value Detection (MMED), Arithmetic to Geometric Mean (AGM) detector, Hadamard Ratio (HR) detector [5].

The test metrics for the above detectors are given in the table 1 where λ_1 , λ_2 , ...λ_m represents the Eigen values of R, det(R) gives the determinant value of R, yij are the values of Y, r_{ij} are the values of R, and E = diag(d), in which diag(d) is the diagonal matrix with diagonal d= [d_1,d_2, …… d_m] [5].

$T_{\text{GLRT}} = \frac{\lambda_1}{\sum_{i=1}^{m} \lambda_i}$	$T_{\text{MED}} = \frac{\lambda_1}{\sigma^2_{\text{avg}}}$
$T_{\text{AGM}} = \frac{\frac{1}{m}\sum_{i=1}^{m} \lambda_i}{(\prod_{i=1}^{m} \lambda_i)^{\frac{1}{m}}}$	$T_{\text{HR}} = \frac{\det(\mathbf{R})}{\prod_{i=1}^{m} r_{ii}}$
$T_{\text{MMED}} = \frac{\lambda_1}{\lambda_m}$	$T_{\text{ED}} = \sum_{i=1}^{m} \frac{1}{\sigma_i^2} \sum_{j=1}^{n} \|y_{ij}\|^2$
$T_{\text{GRCR}} = \frac{\sum_{i=1}^{m} \sum_{j \neq i} \|r_{ij}\|}{\sum_{i=1}^{m} r_{ii}}$	$T_{\text{VD1}} = \log\left[\det(\mathbf{E}^{-1}\mathbf{R})\right]$

Table1. Test Metrics of Various Detectors

8. SIMULATION SPECIFICATION REQUIREMENTS

The simulation of the collaborative sensing of spectrum is carried out using the Matlab software for Rician Channel with the following system specifications given in the table 2. Using the below mentioned parameters such as Number of Primary User transmitters, Number of Secondary User receivers, Number of samples per Secondary User and Number of samples per QPSK PU symbol, the Area Under Curve (AUC), Operating Characteristics of the Receiver (ROC) and a graph of SNR Vs Probability of Detection (P_d) is evaluated and plotted.

S.No.	Parameters	Value / Type
1.	s = Number of PU transmitters	5
2.	m = Number of SU receivers	20
3.	N = Number of samples per SU	50
4.	SNR = Average signal-to-noise ratio over all SUs, dB	-10
5.	Runs = Number of events for computing the empirical CDFs	1000
6.	Modulation	QPSK
7.	tau = Number of samples per QPSK PU symbol	n/10

Table 2. Simulation Parameters

9. SIMULATION RESULTS

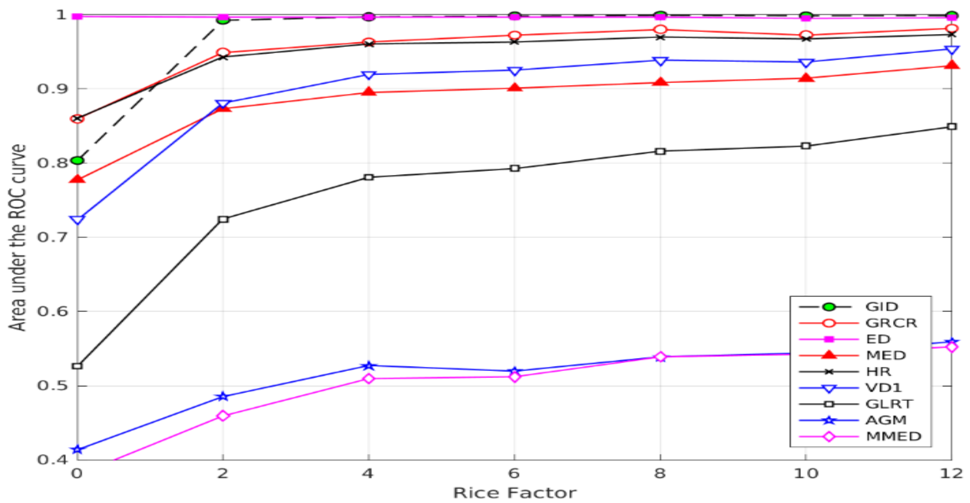

Figure 5. AUC of Gini Index detector compared with for various other detectors

The figure 5 simulated in Matlab platform using the above mentioned system requirement specifications, provides the comparison of various detector types for collaborative spectrum sensing under Rician channel. The result shows that the Gini Index detector provides a better output compared to other detectors when the Rice factor K > 2

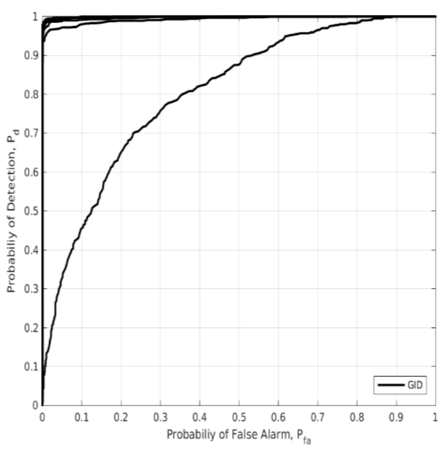

Figure 6. ROC of Gini Index Detector

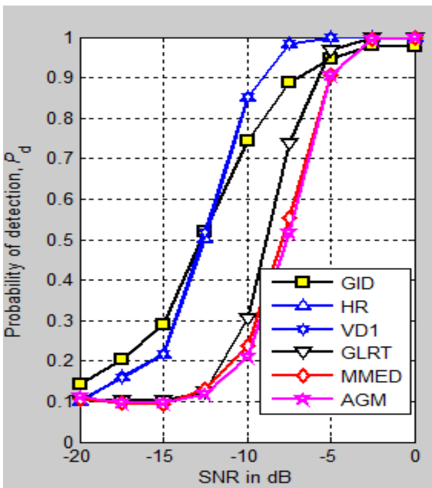

Figure 7. SNR Vs Probability of detection

The figure 6 illustrates that the detection probability Pd, increases with the increase in the false alarm probability Pfa. The figure 7 illustrates the graph of SNR Vs Detection Probability. The result shows that the Gini Index detector performs better at lower SNR values compared to other detectors.

10. CONCLUSION AND FUTURE WORK

This paper presents the result of Gini Index Test metric based collaborative spectrum sensing technique in Rician channel and its comparison with various other techniques like Energy Detection (ED), Volume-based Detector 1 (VD1), Generalized Likelihood Ratio Test Detection (GLRT), Maximum Eigen value Detection (MED), Maximum-Minimum Eigen value Detection (MMED), Arithmetic to Geometric Mean (AGM) detector, Hadamard Ratio (HR) detector and the Gershgoring Radii and Centers Ratio (GRCR) detector. As a future scope this work can be extended to other channels for more efficient results for 5G applications.

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