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Efficient Centralized Cooperative Spectrum Sensing Techniques for Cognitive Networks

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Abstract: Wireless Communication is a system for communicating information from one point to other, without utilizing any connections like wire, cable, or other physical medium. Cognitive Radio (CR) based systems and networks are a revolutionary new perception in wireless communications. Spectrum sensing is a vital task of CR to avert destructive intrusion with licensed primary or main users and discover the accessible spectrum for the efficient utilization of the spectrum. Centralized Cooperative Spectrum Sensing (CSS) is a kind of spectrum sensing. Most of the test metrics designed till now for sensing the spectrum is produced by using the Sample Covariance Matrix (SCM) of the received signal. Some of the methods that use the SCM for the process of detection are Pietra-Ricci Index Detector (PRIDE), Hadamard Ratio (HR) detector, Gini Index Detector (GID), etc. This paper presents the simulation and comparative performance analysis of PRIDE with various other detectors like GID, HR, Arithmetic to Geometric Mean (AGM), Volume-based Detector number 1 (VD1), Maximum-to-Minimum Eigenvalue Detection (MMED), and Generalized Likelihood Ratio Test (GLRT) using the MATLAB software. The PRIDE provides better performance in the presence of variations in the power of the signal and the noise power with less computational complexity.

Keywords: Cognitive radio network; collaborative spectrum sensing; sample covariance matrix; pietra-ricci index detector; cooperative spectrum sensing; generalized likelihood ratio test; maximum-to-minimum eigenvalue detection; volume-based detector number

1 Introduction

Drastic expansion in the number of wireless communication users and applications has to lead an increase in the number of wireless standards and is anticipated to persist more rapidly in the future. Accordingly, the regulatory agencies, scientists, engineers, and wireless device manufacturers all have to face the challenge of implementing proficient wireless communication systems. Some of the difficulties faced are spectrum limitation, efficient spectrum utility, interferences, spectral crowding, etc. An approach of licensed spectrum leads to the wastage of spectrum resources. A set of new technologies takes advantage of the unlicensed spectrum such as Wi-Fi, Ultra-Wideband, Software-Defined Radio, and CR. Spectrum is immensely underutilized if the spectrum band is allotted to a particular company by the regulatory bodies. The CR idea has developed as a possible solution to the Radio Frequency spectrum shortage, discovering the variable nature of the spectrum work in space and time. It can adjust a dynamic policy of spectrum access in that uninhabited frequency bands can be speculatively utilized through Secondary Users (SUs).

To identify the existence of the Primary User (PU) signals, the SUs relate a procedure known as spectrum sensing, feasibly helped through a database of RF spectrum occupancy. Spectrum sensing can be prepared self-sufficiently through every SU. The former is exposed to issues that minimize the power

of PU signal detection, shadowing, multipath fading, and hidden terminals [1]. The perception of CR comes from analyzing the future spectrum implications. Spectrum sensing is an important technique in CR network. Cooperation enhances the spectrum occupation decisions accuracy. In centralized CSS with data fusion that is measured the received signal samples; otherwise, derived quantities are communicated to a Fusion Center (FC) here, a test indicator is built and made the decision of global. Such a decision is noticed to the SUs that will participate for the band if it is empty, through means of several multiple access approaches [2].

This paper introduces the PRIDE for centralized data fusion CSS. This PRIDE test measurement is simply calculated from the components of the received signal SCM that creates it lesser complex. This approach contains the detectors GID, HR, AGM, VD1, MMED, and GLRT. The rest of the paper is structured as follows. Section 2 explains the related works. The CR Network explanation is presented in Section 3. Section 4 explains the sensing of spectrum in cognitive networks. Section 5 presents the types of centralized CSS. Several detectors are described in Section 6. Section 7 presents the simulation parameter. Numerical results are given in section 8. Finally, the conclusions are present in Section 9.

2 Related Works

A collaborative spectrum sensing for CR network is explained in [3]. Detailed analysis and comparison of various spectrum sensing techniques and have presented a scheme for coverage area restoration when the failure of nodes is presented in [4,5]. A novel GIID for cooperative cognitive networks is designed in [6]. A concept of multidimensional correlations in cooperative cognitive networks is explored in [7]. The GLRT is derivative by several primary data, and secondary data comprise noise. The GLRT is exposed to be the invention of Kelly's GLRT. These detectors offer a respectable adjustment between the denial of mismatched signals and the recognition of matched signals. It also comprised in the null hypothesis is explained in [8].

A novel hybrid scheme by applying [9] in Theorem and [10] test metric-based spectrum sensing is described in [11]. PRIDE utilized for cooperative sensing of the spectrum is discussed in [12]. The PRIDE is frequently utilized in social sciences and economics for evaluating inequality. The index is altered to the scenario of CSS. The PRIDE employs the index to differentiate the received signal sample covariance matrices shapes in the conditions of existence and nonexistence of the primary sensed signal is illustrated in [13]. The HR test is a vigorous signal detection analysis of multivariate. It is dedicated to the precise recognition function of the HR for healthy spectrum sensing is described in [14]. The recent different modern wireless communications are explained in [15].

A survey on CSS in CR networks is reviewed and presented in [16]. The optimization algorithms for the cooperative sensing of the spectrum in CR networks are explained in [17]. An artificial neural network-based Gini index test metric detector is described in [18]. A scheme for imbalanced data using a weighted Gini index is presented in [19]. A CR system for efficient spectrum utilization is modeled in [20,21]. Collaborative sensing of spectrum in a real CR network is presented in [22]. The various digital communication techniques are explained in [23].

A detailed description of various wireless communications principles practices is presented in [24]. The CR network and a spectrum sensing scheme based on matched filter detection are reviewed in [25,26], respectively. The collaborative wireless sensor network and also its applications are explained in [27]. Deficiency and Signal existence cases are distinguished through VD1. The Gaussian noise postulation detectors' decision thresholds are accurately computed through the random matrix theory. VD1 analyzed the spectrum sensing capable of offering the desirable properties of noise and constant false-alarm rate [28].

3 CR Networks

Primary/Main user and SU/Cognitive user are vital parts of a CR networks. PU: A user with privileged priority or rights on the utilization of a precise fraction of the spectrum. SU: A user who has a lower priority. The chief tasks of CRs are: controlling power, spectrum sensing, wideband, and spectrum management. Identifying unemployed spectrum and sharing the same by avoiding dangerous intrusion to other user and this mechanism is named as spectrum sensing and sharing. Fig. 1 illustrates the CR networks. CR network is a combination of three type of networks: such as primary networks, CR network with infrastructure and without infrastructure. Unlicensed Band contains CR user and Licensed Band I consist of PU, CR user, primary base station, CR base station and spectrum border. Licensed Band II contains CR user, primary base station, and PU.

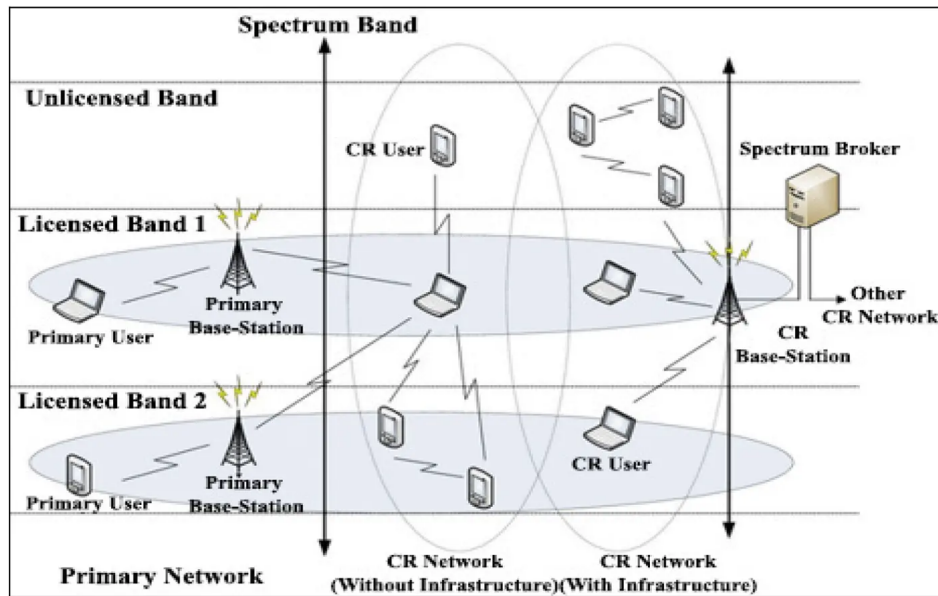


Figure 1: Illustration of cognitive network

4 Sensing of Spectrum in Cognitive Networks

Fig. 2 illustrates the spectrum sensing. It consists of a PU, number of SUs, and a FC. The SUs access the PU channel then SU reports the PU signal information from the FC.

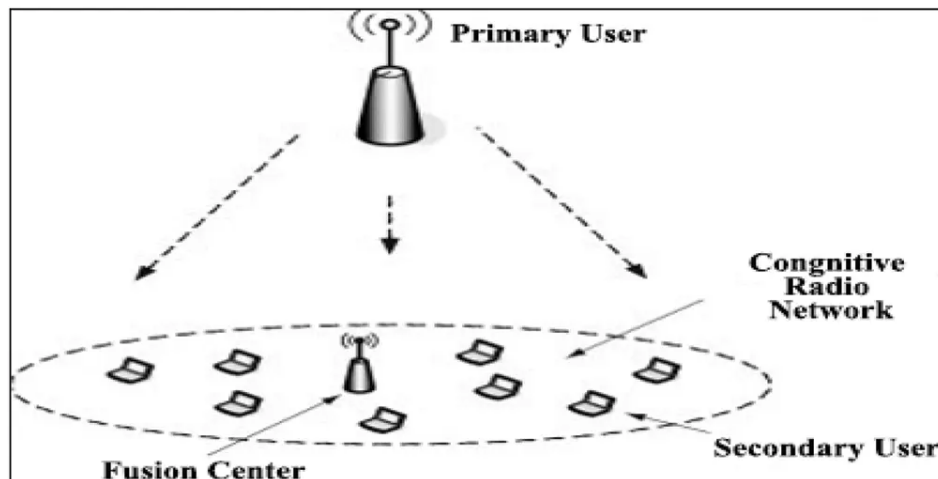


Figure 2: Illustration of spectrum sensing

The main base station transmits the spectrum to the fusion center, where the spectrum is sensed and shared to the cognitive users, i.e., the secondary base stations. Spectrum sensing is broadly categorized as single spectrum user sensing, cooperative sensing of the spectrum and interference-based sensing of the spectrum.

4.1 Single User Spectrum Sensing

It facilitates the cognitive user to identify the existence/non-existence of PU and consequently decides the communication approach.

4.2 CSS

Cooperative sensing of the spectrum is utilized to prevail over the channel effects and makes the most of the site diversity to identify even a feeble primary signal. The existence of a malicious user depreciates the detection performance of cooperative sensing of the spectrum. Fig. 3 illustrates the CSS. From this Fig. 3 the SU sense and detect the PU by the local spectrum. Next, the SU access the PU signal and report this information to the FC. Finally, the FC makes a global decision to check the information received SU is reliable or an attacker.

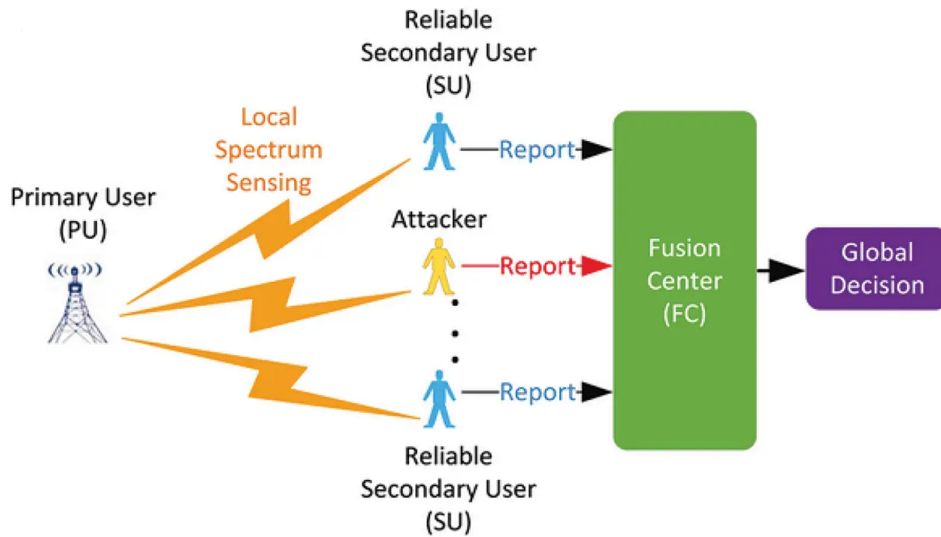


Figure 3: Illustration of CSS

4.3 Design Challenges for Spectrum Sensing

The design of the spectrum sensing techniques in CR experiences certain definite challenges, which include low sensing Signal to Noise Ratio (SNR) (the necessary sensitivity is as low as -20 dB), the uncertainty of the channel (characteristics of the channel is varying with time and is unknown), noise uncertainty (noise characteristics is unknown and vary with time), non-synchronization (difficulty in synchronizing the main signal and the received signal), interferences (interference may be from intended or unintended transmitters), etc.

5 Centralized CSS Types

In centralized cooperative sensing of the spectrum, a fusion center gathers sensing data from cognitive users. The FC identifies the accessible spectrum and transmits this data to various other cognitive users. Based on the method of data sharing between the cognitive users, they are classified into two broad categories, namely partially cooperative network (every cognitive user identifies the channel separately and straightforwardly sends its sensing data to the FC and totally cooperative network (cognitive users cooperatively sends each other's sensing data, and then transmits data to the FC. Figs. 4 and 5 illustrate a partially cooperative network and a totally cooperative network. Fig. 4 contains PU and CR users. In a partially cooperative network, CR users do not send the sensing data among other CR users. Fig. 5 comprises PU and CR users. In a totally cooperative network, CR users send the sensing data among other CR users.

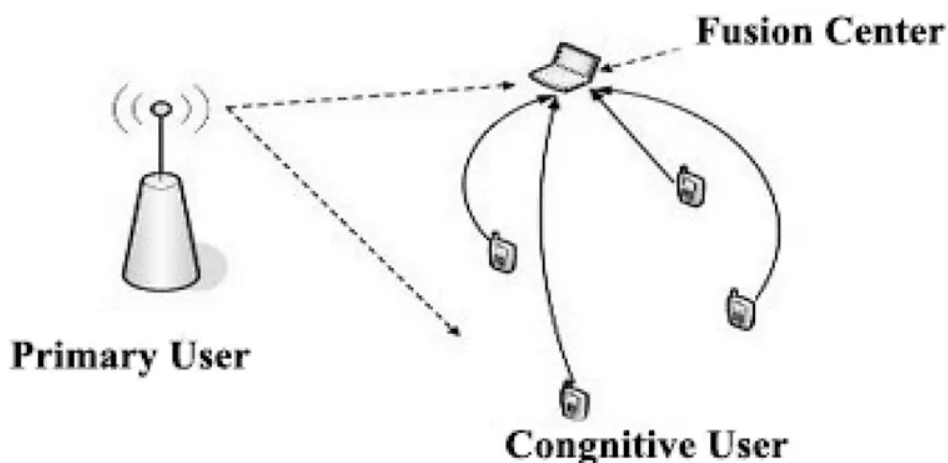


Figure 4: Illustration of partially cooperative network

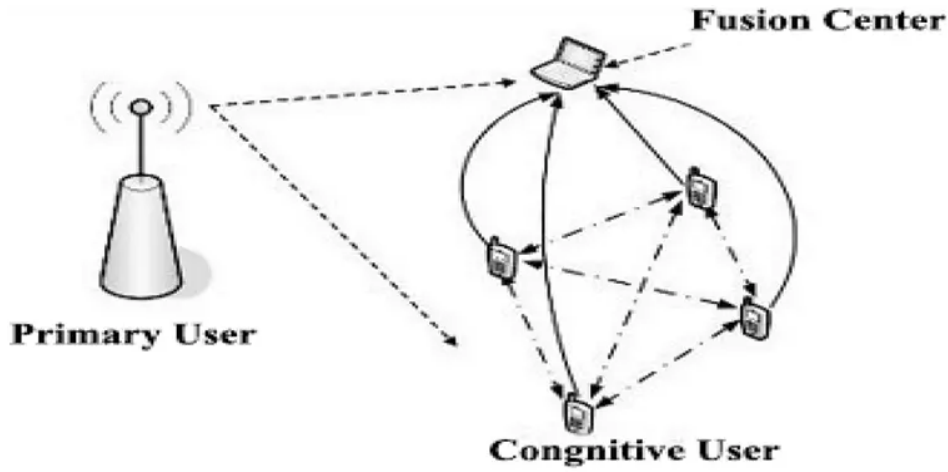


Figure 5: Illustration of totally cooperative network

The cognitive users collaborate by sharing their local examinations to the FC, to make an absolute decision on if H1 or H0 is correct. Two sets of fusion algorithms are hard information combining algorithm and soft information combining algorithm.

6 Detectors

6.1 PRIDE

Existing statistical metric, explicitly an index which is assessed of inequalities, named as the Pietra-Ricci index. This type of index is adjusted to the scenario of CSS. It applies the index to differentiate the shapes of the received signal sample covariance matrices in the conditions of existence as well as the nonexistence of the primary sensed signal. The PRIDE is simple, vigorous beside time-varying noise as well as received signal powers, reveals the constant rate of false alarm rate, and outperforms state-of-the-art detectors in several conditions. The Pietra-Ricci index is given by

$$P = \frac{\sum_i |x_i - x|}{2\sum_i |x_i|} \quad (1)$$

Here x_i is the earning of i^{th} person and x is the mean earning. The index P evaluates the segment of earning which is obtained by the fortunate (rich) segment of the inhabitants in examination and provided to the fewer fortunate (poor) segments in an attempt to avoid inequality. PRIDE test metric is represented as

$$T(\text{PRIDE}) = \frac{\sum_{i=1}^m |r_i|}{\sum_{i=1}^m |r_i - r|} \quad (2)$$

Here r_i denotes the i^{th} value of the vector obtained by placing all columns of R , r_j denotes the j^{th} value of the vector obtained by placing all columns of R and $i = 1$ to m , denotes the flat channel obtains between the i -th SU and the PU.

6.2 GID

The GID with less complexity is presented for CSS in CR networks. GID has a lesser computational complexity, they are vigorous against variations in the received signal as well as noise powers, they do not essential awareness about the features of the sensed signal as well as the noise power, significance that which are wholly blind detectors, also they have the property of continuous false alarm rate. The GID important feature is to provide high performance while the sensed signal has a leading propagation. The Gini index is a statistical dispersion metric extensively utilized in economic and social sciences to assess inequalities. GID test metric is represented as,

$$T(\text{GID}) = \frac{\sum_{i=1}^m |r_i|}{\sum_{i=1}^m \sum_{j=1}^m |r_i - r_j|} \quad (3)$$

6.3 HR Detector

The HR Detector utilizes a double-tuned transformer for converting the instantaneous frequency changes of the input signal to instantaneous amplitude changes. The precise distribution of the HR Detector metrics under the null hypothesis is written by using the Mellin transform. This expression is

difficult to be evaluated numerically; moment-based approximation under the null hypothesis is used. Specifically, that creates an intricate, however closed-form expression for the false-alarm possibility. A humbler and tight closed-form approximation for both the false-alarm and detection possibilities uses a moment-based HR Detector statistical dissemination approximation under both hypotheses. HRD test metric is represented as,

$$T(HR) = \frac{\det(R)}{\prod_{i=1 \text{ to } m} r(ii)} \quad (4)$$

Here, $\det(R)$ is the determinant of R and R is the Euclidean norm.

6.4 VDI

The VDI is used to identify the main users in a smart approach; a new viewpoint is planned for spectrum sensing. In the signal, existence and non-existence are obtained from the determinant of SCM or volume difference between the cases of presence signal and absence signal. With the usage of RMT, precisely yield the theoretical choice threshold for one of the detectors below the Gaussian noise assumption. VDI test metric is represented as,

$$T(\text{VDI}) = \log[\det(E^{-1}R)] \quad (5)$$

here $E = \text{diag}(d)$, $d = [d_1, d_2, \dots, d_m]$, $\text{diag}(d)$ is the diagonal matrix.

6.5 GLRT Detector

The random arrivals of primary user signals and the timing mismatch issue have to be taken into account for sensing the spectrum in CR networks. GLRT detector is utilized to prevail over that issue. The GLRT is derived by multiple primary data as well as a set of secondary data comprises noise. The GLRT is the accepted method; meanwhile, it has several tempting properties. For example, it is the uniformly most powerful test under definite conditions. GLRT test metric is represented as

$$T(\text{GLRD}) = \frac{\text{lamda}_{(1)}}{\sum_{i=1 \text{ to } m} \text{lamda}_{(i)}} \quad (6)$$

Here, $\text{lamda}_{(1)}$ denotes the Eigen values.

6.6 MMED

It can be utilized to identify the existence of the signal. Using the random matrix theory, the ratio can be quantized to find the threshold. Eigen values are a unique set of scalars associated with a linear system of equations. MMED test measurement to identify the presence of PUs signal; thus, it enhances the spectrum efficiency. MMID test metric is represented as,

$$T(\text{MMD}) = \frac{\text{lamda}_{(1)}}{\text{lamda}_{(m)}} \quad (7)$$

6.7 AGM

The arithmetic mean is greater than geometric mean, the causing the detector calculates the AGM of the sample covariance matrix Eigen values and equates with a threshold. AGM is represented as,

$$T(\text{AGM}) = \frac{\frac{1}{m} \sum_{i=1 \text{ to } m} \text{lamda}_{(i)}}{(\prod_{i=1 \text{ to } m} \text{lamda}_{(i)})^{1/m}} \quad (8)$$

7 Simulation Parameter Settings

The CSS is simulated for Ricean channel using R2014 MATLAB software by setting the following parameters given in [Tab. 1](#).

Table 1: Simulation parameter settings

S. No.	Parameter	Value
1.	Number of PU transmitters	5
2.	Number of SU receivers	200
3.	Average signal-to-noise ratio over all SUs, dB	-11
4.	Number of events for computing the empirical CDFs	2000
5.	Number of samples per SU	200
6.	Number of samples per QPSK PU symbol	1/10

Fig. 6 illustrates the flowchart of the coding. Here, the Rice factor is defined as the ratio of the specular power to dispersed power [29]. The algorithm steps are given below.

Step 1: Start the program.

Step 2: Initialize the parameters (Rice factor, Number of PU transmitters, Number of SU receivers, Number of samples per SU, Average signal-to-noise ratio over all SUs, and Fraction of noise power variations about the mean).

Step 3: Enable only the set of parameter values to be varied.

Step 4: Measure the test statistics for PRIDE, GID, HR, VD1, GLRT, MMED, and AGM detectors.

Step 5: By varying the parameter Rice factor the plot of Rice factor vs. detection probability is obtained.

Step 6: By varying the parameter Number of PU transmitters, plot the Number of PU transmitters vs. the probability of detection is obtained.

Step 7: Similarly, by varying other parameters plot of the corresponding varying parameter vs. probability of detection can be obtained.

Step 8: End the program.

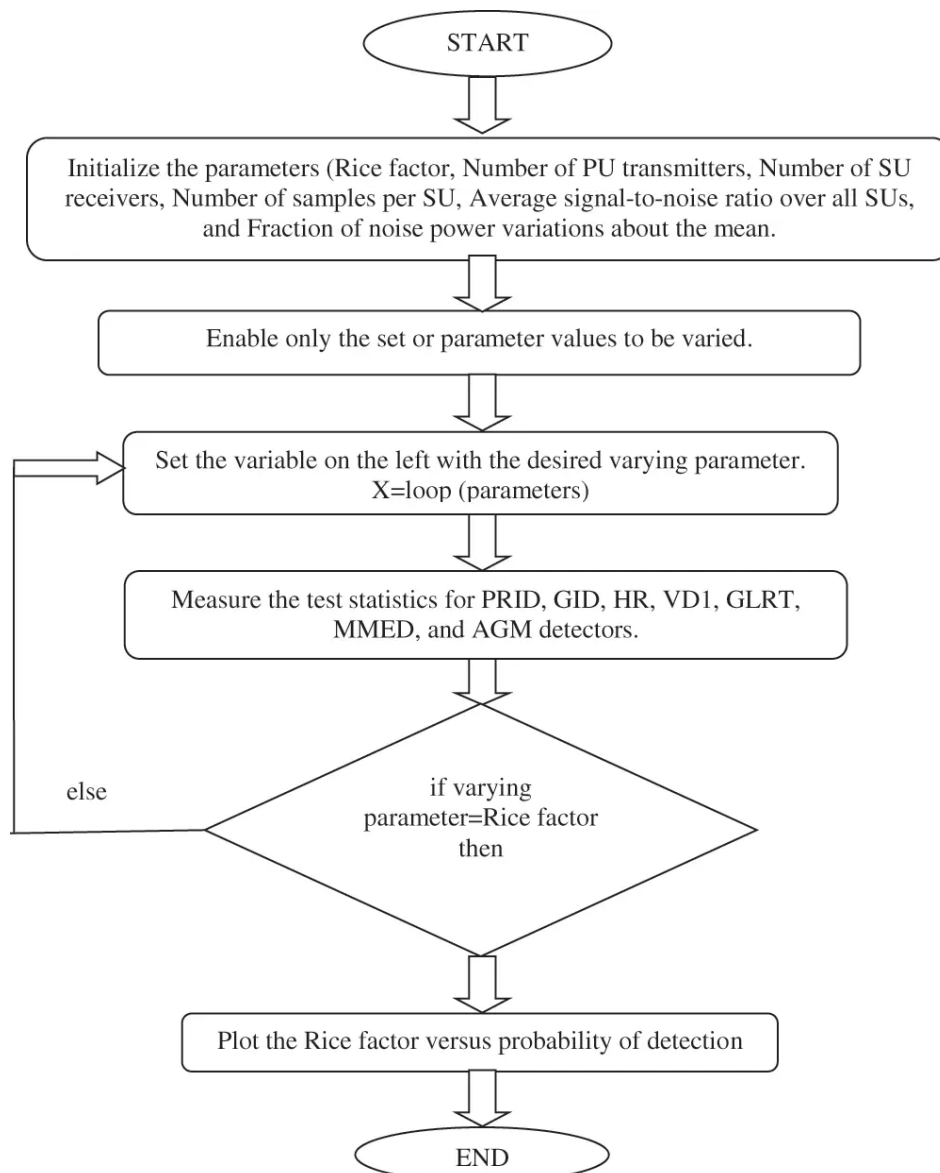
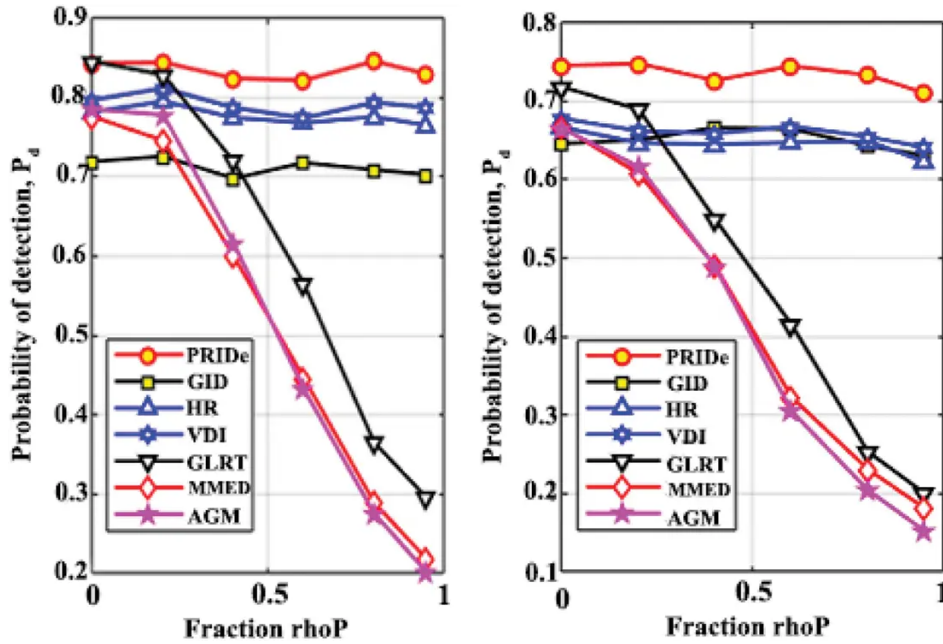


Figure 6: Flow chart for simulation

8 Results and Discussion

8.1 Detection Probability (P_d) vs. Fraction of Signal Value About the Mean (ρ)

Fig. 7 illustrates the P_d against ρ urban area (left); rural area (right) for PRIDe, GID, HR, VD1, GLRT, and MMED. The plot of P_d against the fraction of the signal ρ which administer the variations in the power of noise and the signal, considering urban area (left) with an SNR of -10 dB, and considering rural area (right) with an SNR of -10.4 dB. It is obvious from the plot that the PRIDe provides a better output compared to all the other detectors because the detection probability is high and is constant throughout the mean variations. The result shows that the detectors PRIDe, HR, GID, and VD1 are vigorous beside these variations. The MMED, AGM, and GLRT detectors are not vigorous entirely. Furthermore, the PRIDe is significantly greater than the GID and a slightly greater to the HR and the VD1 for ρ .

**Figure 7:** Plot of P_d against ρ urban area (left); rural area (right)

8.2 Detection Probability vs. Average SNR

Fig. 8 shows the P_d against SNR urban area (left); rural area (right) for PRIDe, GID, HR, VD1, GLRT, and MMED detectors. The result considers an urban area (left) with a number of samples per SU as 200 and considering rural area (right) with a number of samples per SU as 160. The PRIDe attains better output for any given SNR value than the Gini Index Detector and all other detectors. Furthermore, the HR and the VD1 are slightly lesser than the PRIDe. The detector's GLRT, MMED and AGM provides meager performance, excluding very high SNRs.

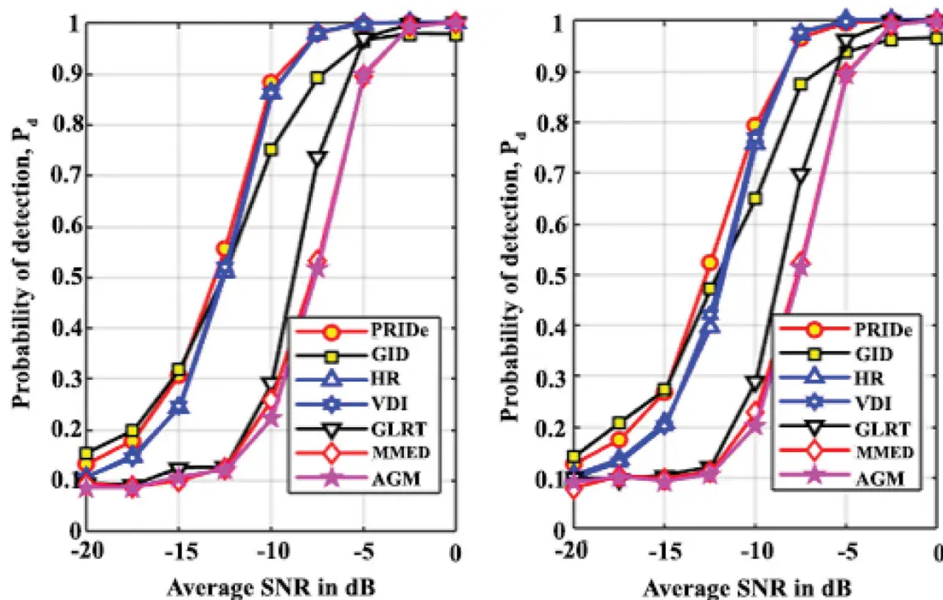


Figure 8: Plot of P_d against SNR urban area (left); rural area (right)

9 Conclusions

This paper presents the simulation and comparative performance analysis of PRIDe with various detectors like GID, HR, AGM, VDI, MMED, and GLRT. Spectrum sensing is a vital task of CR to avert destructive intrusion with licensed PUs and discover the accessible spectrum for the efficient utilization of the spectrum. Centralized CSS is a kind of spectrum sensing. On the whole, it is concluded that PRIDe CSS technique provides an efficient performance compared to GLRT, MMED, AGM, HR, and VDI detectors. In addition, it observed that the GID and the PRIDe are close to one another if the surroundings change from urban to rural. This is because of the fact that rural regions have a large value of Rice factor compared to urban areas. Furthermore, the PRIDe is vigorous against received signal and noise powers and performs detectors in several conditions.

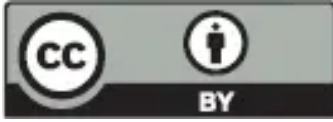
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