INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

ORIGINAL ARTICLE

Implementation of cooperative spectrum sensing using cognitive radio testbed

R Aswatha[1]*, V Seethalakshmi[1], K Murugan[1], N Sathishkumar[1], A Reethika[1], S Gunanandhini[1]

1 Department of Electronics and Communication Engineering, KPR Institute of Engineering and Technology, Coimbatore, 641407, India

OPEN ACCESS

Received: 01-04-2020

Accepted: 23-04-2020

Published: 16-05-2020

Editor: Dr. Natarajan Gajendran

Citation: Aswatha R, Seethalakshmi V, Murugan K, Sathishkumar N, Reethika A, Gunanandhini S (2020) Implementation of cooperative spectrum sensing using cognitive radio testbed. Indian Journal of Science and Technology 13(13): 1355-1366. https://doi.org/10.17485/IJST/v13i13.94

***Corresponding author**.
R Aswatha
Department of Electronics and Communication Engineering, KPR Institute of Engineering and Technology, Coimbatore, 641407, India
aswathajrkrishnan@gmail.com

Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

Abstract

Objectives: To implement energy detection and eigenvalue based cooperative spectrum sensing in NI-USRP hardware platform and to obtain its performance.Cooperative spectrum sensing is to be implemented using OR and AND fusion rules. **Methodology:** The hardware is implemented using one primary user transmitter and two cognitive radio users. The implementation is done using LABVIEW and detection performance is analyzed. In cooperative spectrum sensing (CSS), CR system shares its own sensing information with other sensing nodes and utilizes the sensing outcomes of others to give a decision. **Findings:** Energy detection performs well in high SNR region and eigenvalue based detection performs well even with low SNR region. Energy detector detects the signal completely with SNR greater than 10dB. Eigenvalue detector detects signal completely at SNR of -9dB. Detection probability with OR Cooperative rule is better than AND rule. It increases with number of samples and signal-to-noise ratio. It is found that cooperative spectrum sensing performs well than the non-cooperative sensing by decreasing the chances of miss detection. **Novelty:** CSS is robust in sensing errors due to hidden node or fading channels and also it decreases the probabilities of false alarm as well as probabilities of miss detection.

Keywords: Cognitive radio; Cooperative spectrum sensing; Primary users; Secondary users; Energy detection

1 Introduction

Spectrum sensing is the primary task in cognitive radio technique to detect the primary users in a frequency band. Energy detection is a method of spectrum sensing which detects the primary user in high SNR regions. Eigenvalue detection is independent of noise power so that PU signal can be differentiated from the noise signal even at low SNR values. The sensing performance can be estimated based on two metrics: False alarm probability (P_{fa}) and detection probability (P_d). The false alarm probability condition occurs when a CR user assumes that PU is present when spectrum is unused. Detection probability is when CR user identifies presence of PU correctly. Interference of cognitive radio user occurs when detection of PU is missed. Cooperative spectrum sensing is an efficient method of detecting the spectrum holes by consolidating the sensing information from multiple CR users. Sensing performance is improved by cooperative spectrum sensing.

1.1 Related works

The sensing performance can be improved by making a cooperative decision from multiple cognitive radio users spatially located at various places[1]. Cooperative spectrum sensing is done using local sensing, gathering information about presence or absence of primary user and finally data fusion. Based on the method used to share sensing information between different cognitive users, cooperative spectrum sensing is categorized based on sensing method as distributed, centralized and relay-assisted. The detection probability is improved by CSS.

In cooperative spectrum sensing, sensing time and number of cognitive radio users are to be limited to increase the detection probability[2]. Participation of all secondary users in a network and utilization of full length frame size do not produce optimal detection probability. By varying network size, throughput and frame duration, the detection probability can be improved.

Centralized cooperative sensing is a method that has been implemented by[3], in which cognitive radio user continuously monitors spectrum and sends one bit locally sensed data to a centralized fusion centre. One of the cognitive radio user acts as fusion centre. The local sensing is done by tuning all the cognitive radio users to a selected frequency band which is termed as sensing channel. The collected information is sent to fusion centre by tuning cognitive radio users to a separate frequency band called control channel. The different fusion rules that can be incorporated are AND, OR and MAJORITY rule.

Accuracy of energy detector is based on selection threshold. In[4] derived decision threshold which is dependent on root finding algorithm. Analytical expressions of detection probabilities, miss-detection and false alarm based on the two witness rules which is combination of OR and AND rules are derived. Probability of interference with primary user is reduced.

In[5] described about the effect of samples count on threshold value calculation. As sample count is increased threshold also increases. The performance analysis on the detection probability for different SNR values is analyzed and found that the detection probability increases with SNR.

The centralized cooperative spectrum sensing for different hard decision schemes like AND, OR and MAJORITY rule has been presented in[6]. Here AND rule is implemented with low threshold value, OR rule is implemented with high threshold value and MAJORITY rule is implemented with average threshold value. The total error should be very less for good spectrum decision. It is observed that OR rule provides better results than other two fusion rules.

2 Implementation of energy detection and eigenvalue based cooperative spectrum sensing in usrp test bed

2.1 Energy detection

Energy detection based spectrum sensing method is very effective due to less complexity and it does not require prior knowledge of the primary user signal like frequency, modulation type etc. The energy detector detects primary user signal by comparing energy of received signal with a threshold value[7]. Transmitted signal at primary user is denoted as s(t) and received signal at cognitive radio user is given by,

$$X(t)=\left\{\begin{array}{ll} n(t) & ;H_0 \\ h(t)\cdot s(t)+n(t) & ;H_1 \end{array}\right\} \tag{1}$$

where, h(t) is channel gain of the sensing channel, n(t) is the zero-mean additive white Gaussian noise(AWGN). Signal detected at secondary user can be modeled as a binary hypothesis testing given as,

- Hypothesis 0 (H_0): signal is absent
- Hypothesis 1 (H_1): signal is present

Energy detector takes decision about presence or absence of primary signal based on the amount of energy in received signal samples. In order to calculate energy of received signal samples, the received signal samples are squared and summed over observation time interval. Then, integrated output is compared with a predefined threshold.

The following are steps the involved in spectrum sensing based on energy detection

- The received signal by CR user is sampled at definite time intervals.
- The samples are squared to measure the received energy.
- The average energy of all samples is measured and compared with decision threshold.

The threshold formula for energy detection is given by,

$$\lambda=\left(Q^{-1}\left(P_F\right)+\sqrt{N}\right)\sqrt{N}\,2\,\sigma^2{}_w \tag{2}$$

where, N= number of samples, σ_w =variance of the noise signal P_F = False alarm probability. If received signal energy is greater than the threshold λ, energy detector makes a decision as primary user is present and if the energy of received signal is less than threshold the decision is taken as absence of primary user. The threshold is increased by increasing number of samples and SNR. As the threshold increases, the false alarm probability decreases[8].

2.2 Eigenvalue detection

Spectrum detection based on eigenvalue is of two types Maximum Minimum Eigenvalue (MME) detection and Energy with Minimum Eigenvalue (EME) detection. In MME detection, ratio of maximum to minimum eigenvalue of received signal samples is compared with a predefined threshold. In EME based detection ratio of average energy and minimum eigenvalue, it is compared with a predefined threshold for the detection of primary user. In this paper MME detection is implemented. Eigenvalues are determined by calculating covariance matrix of received signal samples. In eigenvalue detection technique PU signal can be differentiated from noise signal even at low SNR values.

Following are the steps involved in Maximum-Minimum Eigenvalue (MME) based detection.

Step1: Computation of sample covariance matrix of received signal

$$R_r(N_s) = \sum_{n=L}^{N_s-L+1} r(n) * (r(n))^H \quad (3)$$

Where, r(n) is received signal samples.

Step2: Obtain max and min eigenvalues of matrix $R_r(N_s)$, (i.e) λ_{max} and λ_{min}. The second step of sensing process is to find maximum and minimum eigenvalues of sample covariance matrix based on their magnitude.

Step3: Decision: if $\lambda_{max} / \lambda_{min}$>threshold of MME, Signal exists; otherwise signal doesn't exist. The last step of the sensing algorithm is the threshold calculation and decision-making. In this stage, ratio of maximum to minimum eigenvalue is compared with predetermined threshold to make decisions where, threshold of MME is always greater than 1.[9]

The threshold formula for maximum minimum eigenvalue based detection is given by,

$r1=(\sqrt{Ns}+\sqrt{L})^2 / (\sqrt{Ns}-\sqrt{L})^2$

$r2=1+((\sqrt{Ns}+\sqrt{L})^{-2/3} / (Ns*L)^{1/6})*F_1^{-1}(Pfa)$

$threshold\_MME=r_1*r_2$ (4)

where, Ns is the number of received signal samples; L is smoothing factor and F_1^{-1} is Tracy-Widom distribution of order 1.

2.3 Cooperative spectrum sensing

Cooperative spectrum sensing is done by gathering spectrum sensing information by multiple CR users. Cooperative spectrum sensing network consists of primary users, secondary users and a fusion centre. Secondary user monitors spectrum continuously and sends sensed data to a fusion centre. One of the cognitive radio user acts as fusion centre. The cognitive radio users are considered as secondary users. The fusion can be done in three ways centralized, distributed and relay-assisted. In centralized cooperative spectrum detection all the cognitive radio users send sensed data to a fusion centre. Here all CR users are tuned to a selected licensed frequency band to determine the presence of primary signal which is called as sensing channel. Distributed cooperative sensing do not relay on a fusion centre for making sensing decision. In distributed cooperative spectrum detection every cognitive radio user is connected with all other cognitive radio users in a network. Relay-assisted cooperative sensing is a combination of centralized and distributed sensing methods. Spectrum sensing decision is done by a fusion centre. In relay assisted cooperative spectrum detection some cognitive radio users act as relays to transfer the sensed data to other cognitive radio user. This is multi-hop cooperative sensing.

2.4 Block diagram of proposed cooperative spectrum sensing

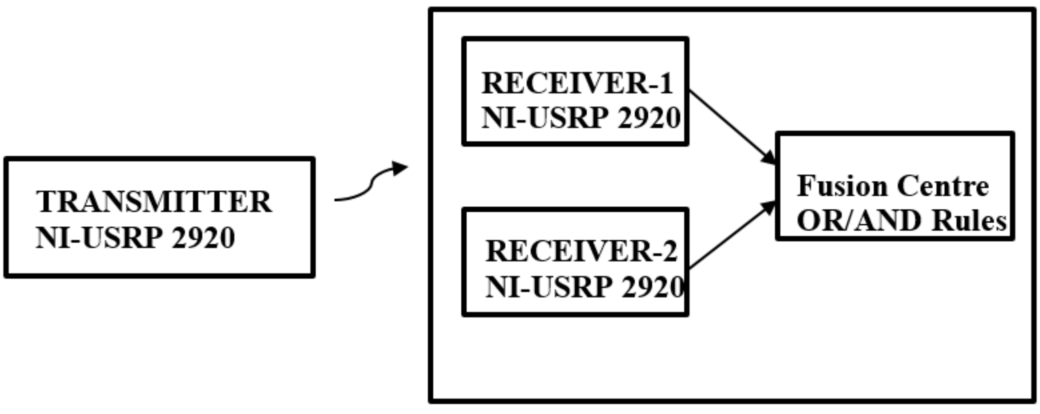

Fig 1. Block diagram of proposed cooperative spectrum sensing

Figure 1 shows the block diagram of proposed cooperative spectrum sensing where centralized fusion is incorporated. The transmitter is the primary user. The receiver 1 and 2 are the secondary users. Transmitter is used to transmit a base band signal using NI-USRP 2920. The receivers continuously monitor primary user signal and sends one bit of sensed data to a fusion centre. Fusion is done based on OR and AND fusion rules.

2.4.1 Logical AND rule

According to this rule only if all the secondary users report as primary users with logical one decision, fusion centre declares that frequency band as occupied by primary user

2.4.2 Logical OR rule

According to this rule even if one of the secondary users send local decision as one, fusion centre confess its result as one and it declares that the primary user has occupied the frequency band.

2.5 USRP test bed implementation

The NI USRP 2920 is used for hardware implementation which is programmed with NI Labview software. The following are the steps involved in the testbed implementation,

Step 1: USRP transmitter (TX1) transmits packet at 2.2GHz

Step 2: Receiver (RX1) is fixed to receive signal from transmitter at a frequency of 2.2GHZ using antenna port1 of receiver.

Step 3: Energy and threshold are calculated for 1000 samples of the received signal.

Step 4: Channel is considered as vacant if energy of the signal is less than fixed threshold.

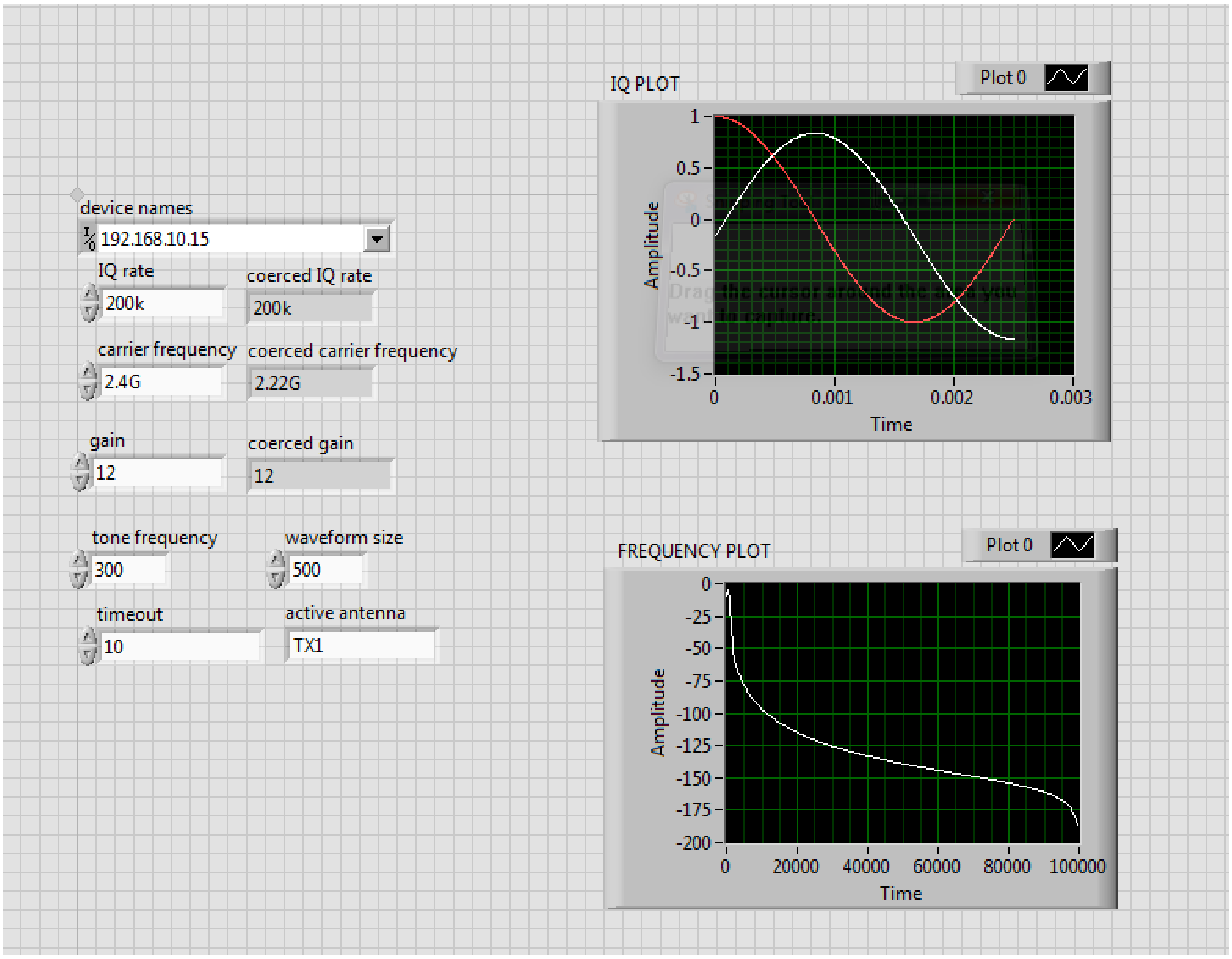

Fig 2. Front panel of baseband transmitter

Figure 2 shows the front panel of baseband transmitter, a primary user. Continuous sine waveform of 300Hz frequency is converted to array to the sample data which forms the real part of the data being transmitted. Same waveform is phase shifted and it is converted to an array of sample values to form the imaginary part of the data being transmitted. AWGN noise is summed up with original data and transmitted. Spectrum of the transmitted signal is displayed which is obtained by applying FFT to the data values. From array of clusters the data values are unbundled to separate real and imaginary part and IQ plot is plotted. 90 degree phase shift between the in phase and quadrature component is displayed in IQ plot.

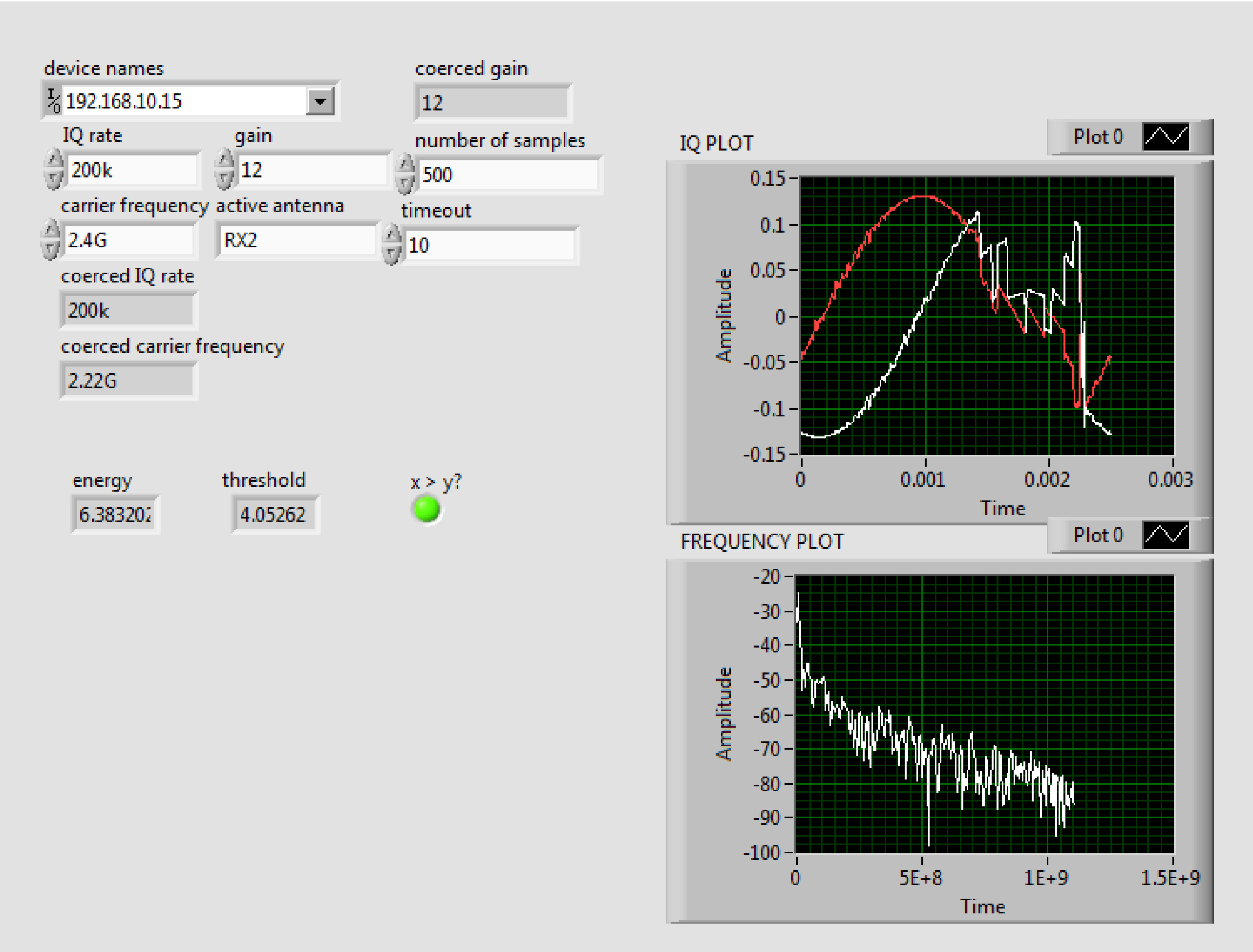

Fig 3. Front panel of baseband receiver.

Figure 3 shows front panel of baseband receiver. Data values of received signal are fetched from USRP fetch block and energy detection is applied to data values. Threshold value calculation is done using MATLAB script by fixing Signal to Noise Ratio and P_{fa}. Obtained energy is compared with threshold and decision is displayed using LED icon. Received signal energy and threshold is displayed in front panel. The decision indicating primary user signal presence is given by LED display. If obtained energy is greater than threshold the LED blinks and if energy is less than threshold the LED does not blink. Green color in LED icon shows the presence of primary user. The spectrum and IQ plot of the received signal are displayed in the baseband receiver.

Figure 4 shows the front panel of cooperative spectrum sensing receiver based on energy detection. Two receivers are built simultaneously to perform cooperative spectrum sensing. Energy is calculated and compared with threshold value at both the receivers to estimate primary user signal. OR and AND fusion rules are carried to perform cooperative spectrum sensing decision. The detection probability is done by calculating number of correct detections out of total number of detections. Energy of received signal at both the receivers and threshold are displayed in the front panel. OR and AND fusion decisions are also displayed. Total OR detection and AND detection are calculated to determine the detection probability. Different number of trails are carried out to optimize the detection performance. Spectrum and IQ plot of both the receivers are displayed.

Figure 5 shows front panel of eigenvalue based cooperative spectrum sensing receiver. Two eigenvalue receiver blocks are incorporated in a single loop. Covariance matrix is used for calculation of Eigenvalues. Ratio of maximum to minimum eigenvalue is obtained and compared with the threshold. If the ratio is greater than threshold the presence of signal is

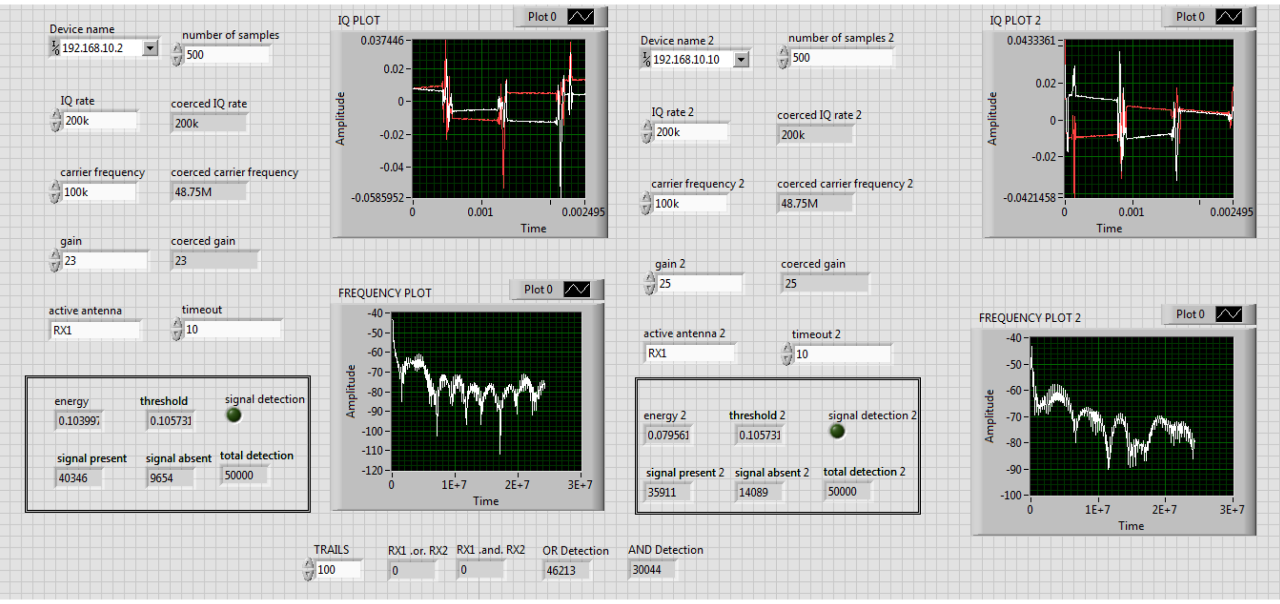

Fig 4. Front panel of cooperative spectrum sensing receiver based on energy detection

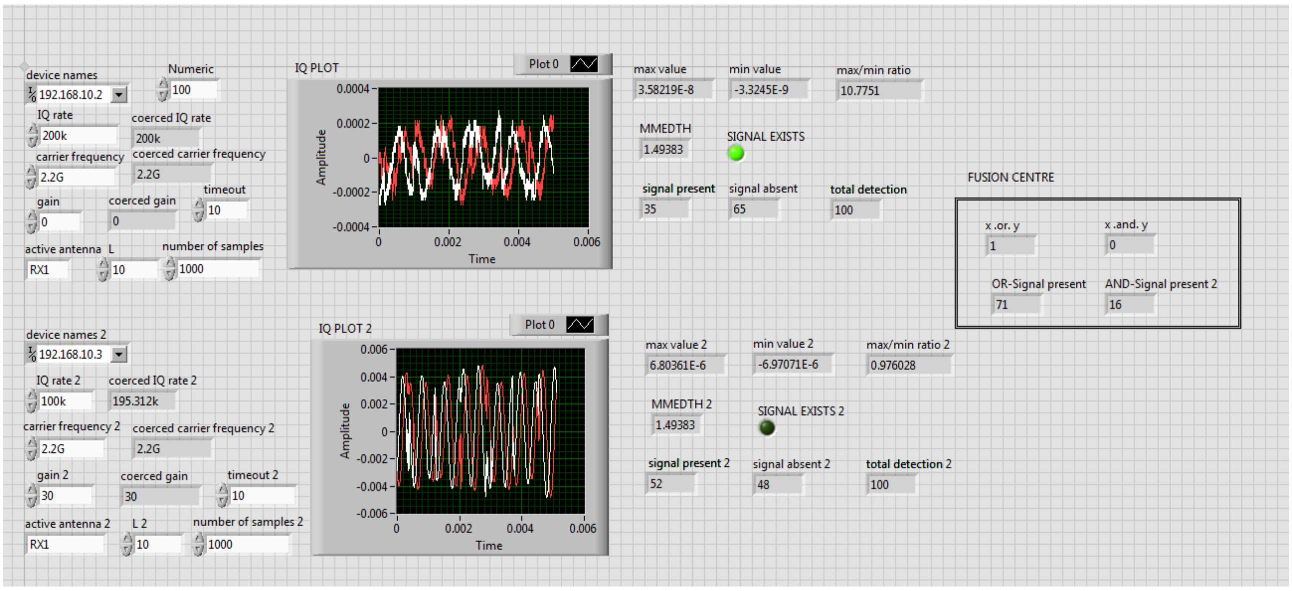

Fig 5. Front panel of eigenvalue based cooperative spectrum sensing receiver.

indicated by a blink of LED. The count for correct and wrong detections are made and indicated as signal present and absent. The OR/AND fusion rules and detection probability are carried out similar to cooperative spectrum sensing block based on energy detection method.

3 Results and Discussion

Cooperative spectrum sensing is implemented in the test bed and values of energy are acquired. Energy detection and eigenvalue based detection are performed by considering false alarm probability, detection probability, signal-to-noise ratio, smoothing factor and number of samples. The detection probability is estimated by varying number of samples, signal-to-noise ratio and false alarm probability. Following are ROC characteristics graph for different parameters.

3.1 Energy detection

The Figures 6 and 7 show a plot of number of samples vs. detection probability. SNR is kept constant as 10db and false alarm probability is kept as 0.01 and 0.1. Detection probability is calculated for theoretical values, single receiver, cooperative

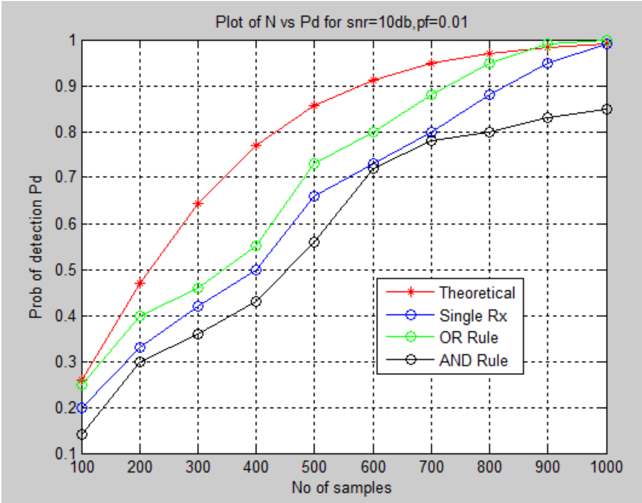

Fig 6. Plot of number of samples vs. detection probability for snr = 10db and Pf = 0.01

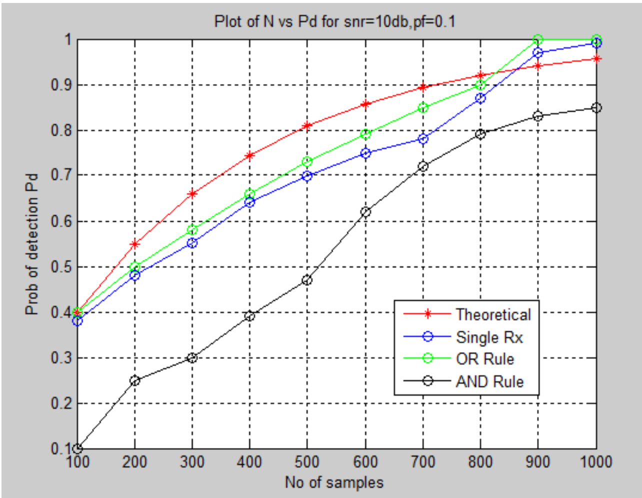

Fig 7. Plot of number of samples vs. detection probability for snr = 10db and Pf = 0.1

OR and AND fusion rules. As number of samples increases detection performance will be improved. It is observed that detection probability increases with increase in number of samples and false alarm probability. Detection probability is better with cooperative OR fusion rule than single receiver and cooperative AND fusion rule. Using OR fusion rule even if one CR user detects presence or absence of primary user signals, fusion centre considers it. Whereas using AND rule it is needed that all cooperating CR users should be declared as primary user. Therefore, by using OR rule, wrong decisions can be avoided and detection probability can be increased.

The Figures 8, 9 and 10 show a plot of number of samples vs. detection probability. False alarm probability is kept constant as 0.5. SNR is varied as -8db,-5db and 0db. From above plots it is observed that detection probability increases with increase in SNR. As SNR increases performance will be better and hence detection probability also increases.

The Figures 11, 12 and 13 show a plot of signal-to-noise ratio vs. detection probability. Number of samples is kept constant as 1000. False alarm probability is varied as 0.01, 0.05 and 0.1 As SNR increases the performance will be better and hence detection probability also increases. From the above plots it is observed that Detection probability increases with increase in SNR and false alarm probability.

3.2 Eigenvalue detection

Figures 14 and 15 show a plot of number of samples vs. detection probability. SNR is kept constant as -7dB and smoothing factor L as 10. From the above plot it is observed that detection probability increases with increase in number of samples and also with increase in SNR. As SNR increases performance will be better and hence detection probability also increases. Detection probability is plotted for single receiver, cooperative OR and AND fusion rules.

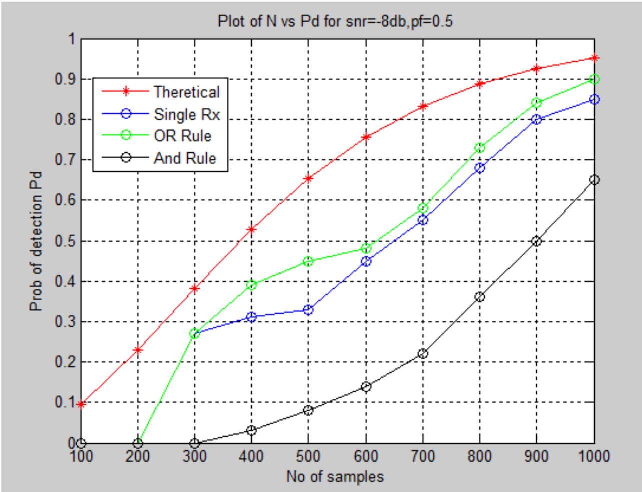

Fig 8. Plot of number of samples vs. detection probability for Pf = 0.5 and snr = -8db

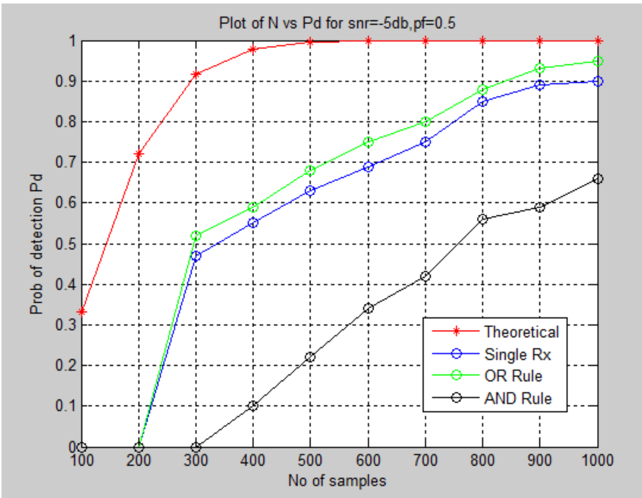

Fig 9. Plot of number of samples vs. detection probability for Pf = 0.5 and sn r= -5db

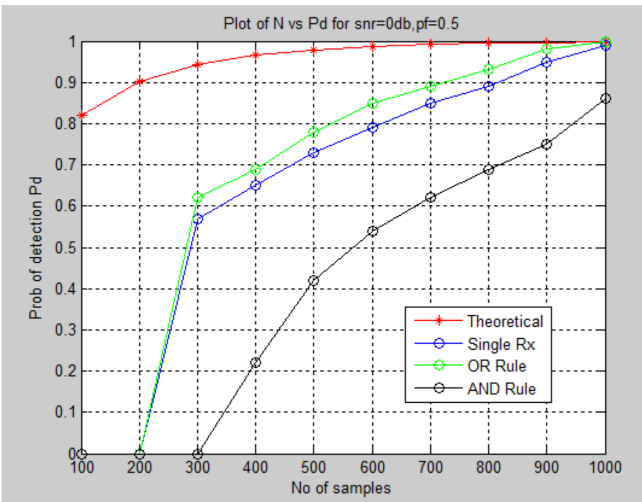

Fig 10. Plot of number of samples vs. detection probability for Pf=0.5 and snr=0db

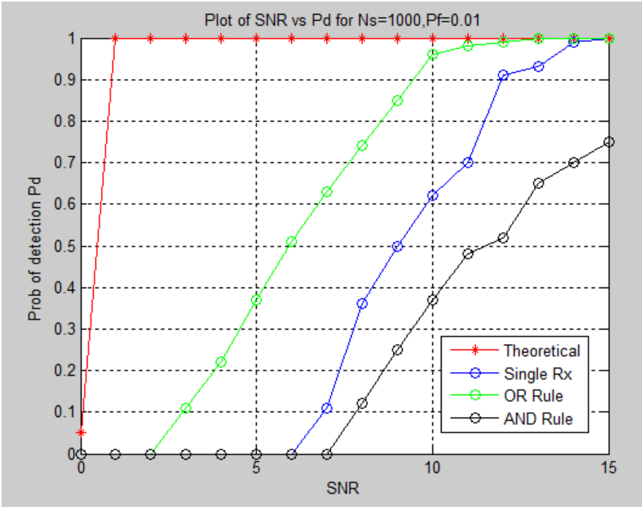

Fig 11. Plot of SNR vs. detection probability for number of samples=1000 and Pf=0.01

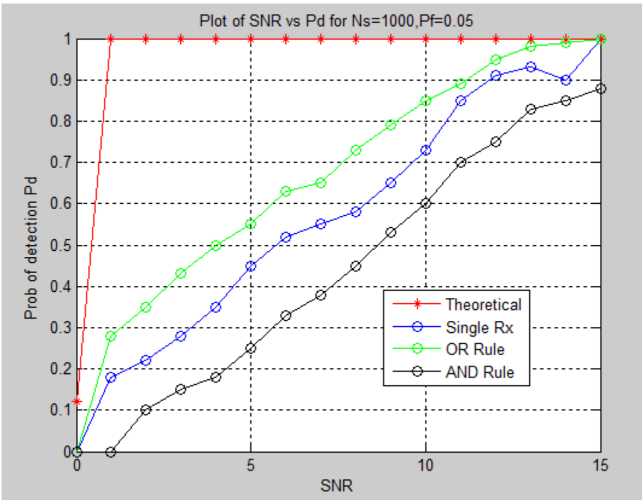

Fig 12. Plot of SNR vs. detection probability for number of samples=1000 and Pf=0.05

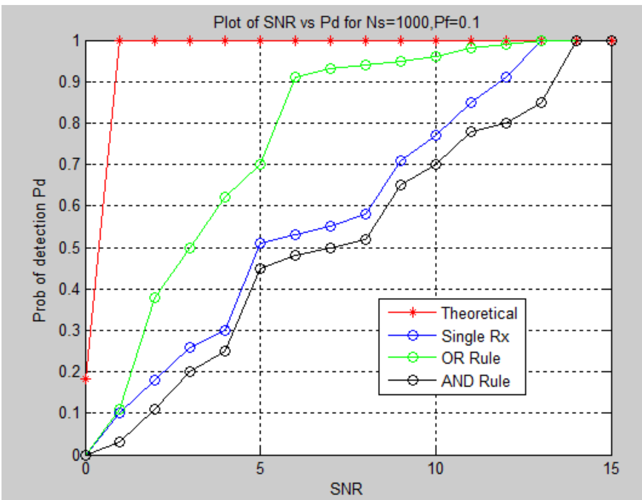

Fig 13. Plot of SNR vs. detection probability for number of samples = 1000 and Pf = 0.1

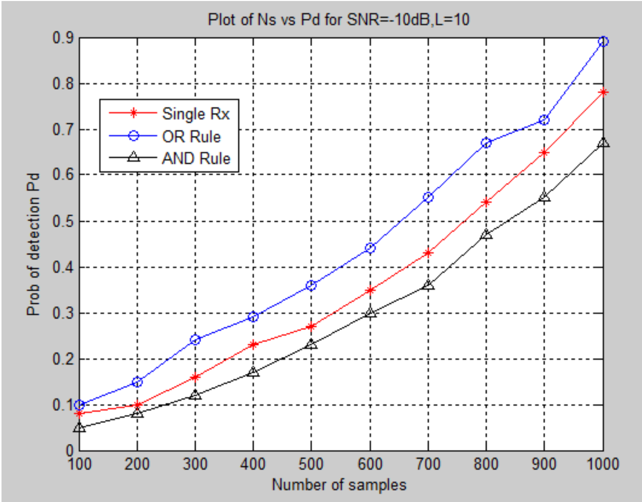

Fig 14. Plot of number of samples vs. detection probability for SNR=-10dB and L=10

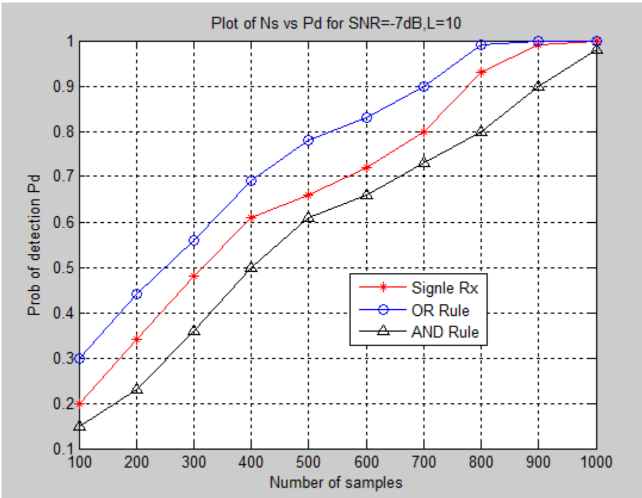

Fig 15. Plot of number of samples vs. detection probability for SNR = -7dB and L = 10

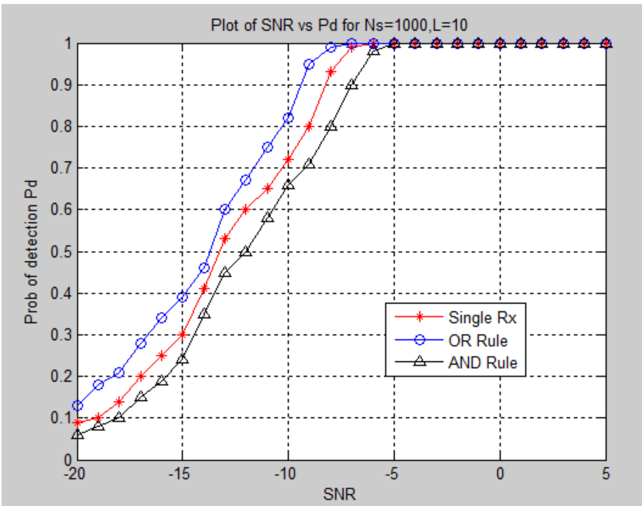

Fig 16. Plot of SNR vs. detection probability for number of samples = 1000 and L = 10

Figure 16 shows a plot of SNR vs. detection probability. Number of samples is kept constant at 1000. False alarm probability is varied as 0.01, 0.05 and 0.1. From the above plots it is observed that detection probability increases with increase in SNR and false alarm probability.

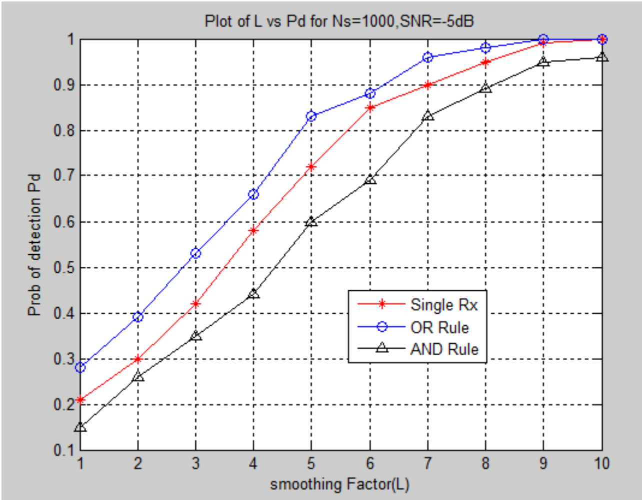

Fig 17. Plot of smoothing factor vs. detection probability for number of samples = 1000 and SNR = -5dB.

Figure 17 shows a plot of smoothing factor vs. detection probability. Number of samples is kept constant as 1000 and SNR as -5dB. From the above plots it is observed that detection probability increases with increase in smoothing factor.

3.3 Comparison between ED and MME

The effect of SNR on detection probability for ED and MME based detection is compared.

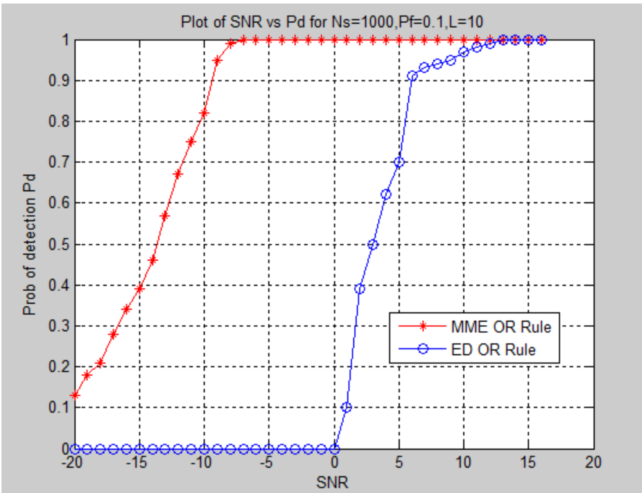

Fig 18. Plot of SNR vs. detection probability for number of samples=1000, Pf=0.1 AND L=10.

Figure 18 shows the Plot of SNR vs. detection probability for ED and MME. Cooperative OR fusion rule is considered for comparison since its detection probability is better than AND rule. With energy detection method signal is detected completely at SNR of 11dB. Whereas with MME detection signal is detected completely even at low SNR value of -9dB. The energy detector perform better in high SNR regions and MME based detector perform better even in low SNR regions. This is because ED requires knowledge of noise power whereas MME detection is independent of noise power.

4 Conclusion

Cooperative spectrum sensing based on energy detector is implemented on NI-USRP hardware platform. Energy detection performs well in high SNR region and eigenvalue based detection performs well even with low SNR region and it detects signal completely with SNR greater than 10dB. Eigenvalue detector detects signal completely at SNR of -9dB. Results are obtained and performance analysis is done on detection probability. ROC characteristics graphs are plotted for various parameters. It is found that cooperative spectrum sensing performs well than non-cooperative sensing by decreasing the chances of miss detection. It is also observed from detection probability with OR fusion that it is better than AND fusion rule. The same energy detector and eigenvalue based cooperative spectrum sensing can be extended for increase in number of cognitive radio users for better detection probability. Cooperative spectrum sensing can be done by incorporating different fusion algorithms.

Future work

The cooperative spectrum sensing can be done with different fusion algorithms. The number of cognitive radio users can be increased to analyze the performance.

Acknowledgement

The authors convey their gratitude to UGC- Major Research Project scheme through which the implementation in hardware platform became a possible task.

References

1) Akyildiz IF, Lo BF, Balakrishnan R. Cooperative spectrum sensing in cognitive radio networks: A survey. *Physical Communication*. 2011;4(1):40–62. doi:10.1016/j.phycom.2010.12.003.
2) Al-Doseri HF, Mangoud MA. Performance Analysis of Cooperative Spectrum Sensing under Guaranteed Throughput Constraints for Cognitive Radio Networks. *Journal of Computer Networks and Communications*. 2016;2016:1–9. doi:10.1155/2016/9706781.
3) Ajitsinh N, Jadhav S. Centralized cooperative and non cooperative spectrum sensing using energy detection in cognitive radio. *International Journal of Recent Scientific Research*. 2015;6(8):5764–5767.
4) Rahmabouraoui H. Fusion rules for cooperative censored energy detection: thresholds derivation based on analytical performance. *IEEE International Symposium on Signal, Image, Video and Communications*. 2016;10:98–102.
5) Suri A, Singh DJ. Evaluation of Probability of Detection using Energy Detection for Secondary User in Cognitive Environment with Variable Threshold & Sample Values. *International Journal of Advanced Research in Computer and Communication Engineering*. 2016;5(7).
6) Samratchandrakantshinde AN, Jadhav. Centralized Cooperative Spectrum Sensing with Energy Detection in Cognitive Radio and Optimization. *IEEE International Conference On Recent Trends In Electronics Information Communication Technology*. 2016;p. 1002–1006.
7) Ni S, Chang H. Adaptive Cooperative Spectrum Sensing Based on SNR Estimation in Cognitive Radio Networks. *Journal of Information Processing Systems*. 2019;15(3).
8) Mahendru G, Shukla A, Banerjee P. A Novel Mathematical Model for Energy Detection Based Spectrum Sensing in Cognitive Radio Networks. *Wireless Personal Communications*. 2020;110(3):1237–1249. doi:10.1007/s11277-019-06783-3.
9) Zeng Y, chang Liang Y. Eigenvalue-based spectrum sensing algorithms for cognitive radio. *IEEE Transactions on Communications*. 2009;57(6):1784–1793. doi:10.1109/tcomm.2009.06.070402.