-22-

PERFORMANCE OF ENERGY-EFFICIENT COOPERATIVE SPECTRUM SENSING FOR DETECTING LICENSED USERS IN ASPECTRUM SHARING SYSTEM USING EIGENVALUE DETECTOR

Adedeji A. A and Akinrinmade E.A

Department of Mechatronics Engineering, Osun State College of Technology Esa Oke, Nigeria
adedejibukky06@gmail.com

Abstract
Licensed User (LU) detection is a critical operation in Spectrum Shearing System (SSS) to prevent Licensed User (LU) from harmful interference. However, channel impairment such as multipath fading, shadowing, and path loss affect the sensing accuracy of SSS. Non-Cooperative SS (NCSS) used to solve this problem suffers from receiver uncertainty resulting in a high Probability of Missing (PM) that causes interference, while Cooperative SS (CSS) used to solve the problem of NCSS also suffers from large reporting overhead resulting in long sensing time, bandwidth inefficiency and energy inefficiency. Hence, this work proposes an Energy-Efficient CSS (EECSS) for signal detection in a CRN using cluster and Eigenvalue Detector (EVD). Secondary Users (SUs) 'L' numbers (4, 5, 6) are jointly used to carry out SS and each SU performs local sensing using EVD. The multiple copies of PU signals were received through 'P' (2, 3, 4) Secondary User (SU) antennas. The received signals are then used to form a square matrix to determine the ratio of maximum to minimum eigenvalue and used as test statistics to determine the idleness of the spectrum. SU selection is carried out based on the Signal Noise Ratio (SNR) of the received signal to determine the SUs that participate in the local sensing at that time. The 'L' number of SUs is used to form 'N' (3, 4, 5) clusters to reduce the reporting overhead between SUs. The local sensing results from individual SU are combined at the Cluster Head (CH) using the majority fusion rule to determine the sensing result at each cluster. Global sensing result is determined by combining the sensing results from individual clusters using the OR fusion rule. The model is simulated using MATLAB R2018a and evaluated using Probability of Detection (PD) and Sensing Time (ST). The results obtained showed that EECSS gives better performance with higher PD and lower ST values when compared with NCSS and conventional CSS. The EECSS technique proposed can be used for signal detection in wireless communication systems.
Keywords*: Eigenvalue Detector (EVD), Probability of Detection (PD), Sensing Time (ST), Secondary User (SU), Primary User (PU), and Cluster.*

1. INTRODUCTION

The tremendous increase in the usage of wireless communication services has led to an exponential increase in demand for frequency spectrum resulting in spectrum scarcity [1, 2, 3, 4]. The scarcity of spectrum is not only due to insufficient spectrum but also to underutilization of allocated spectrum [5]. To solve the problem of spectrum scarcity which is majorly due to underutilization of allocated spectrum, Spectrum Sharing System (SSS) was proposed. Cognitive Radio (CR) is a technique in which a transceiver intelligently detects communication channels which in use and not in use. This then instantly allows transmitting terminals to opportunistically make use of idle spectrum while avoiding busy ones [6, 7, 8]. The radio comprises two users namely: Primary User (PU) and Secondary User (SU). PU is the licensed user that owns the privileges to the assigned spectrum and SU is the unlicensed user that makes use of the frequency spectrum only when PU is not active [9]. CR is a technique that solves the problem of spectrum scarcity by exploiting the idle spectrum bands assigned to PU [10]. Spectrum Sensing (SS) which is the process by which SU scans through the spectrum to detect the presence of PU and identifies empty spectrum spaces is one of the important requirements of the CRNs [11, 12]. The difficulty in sensing PU is called the hidden PU problem

which is one of the challenges encountered during SS in CR-based systems [13, 14]. The sensing accuracy, which is the ability of SU to sense PU without interference, depends on fading channel between PU and SU. The Sensing of PU is affected by channel impairments such as path loss, multipath fading, and shadowing resulting in fluctuation of the received signals and causing poor reception of the signal [15].

SS is achieved using only one CR known as Non-Cooperative Spectrum Sensing (NCSS) or a group of CRs known as Cooperative Spectrum Sensing (CSS) [5]. NCSS suffers from receiver uncertainty which occurs when SU is outside the transmission range of the PU as a result of multipath propagation. CSS, on the other hand, solves the challenges of NCS and achieves a reliable detection that mitigates interference from SU to PU. In addition, CSS allows SUs to jointly carry out spectrum sensing to ameliorate the sensing credibility even at a very low PU signal strength. However, CSS suffers from large reporting overhead resulting in long sensing time and energy inefficiency. Several detection techniques such as Energy Detector (ED), Eigenvalue Detector (EVD), Cyclostationary Detector (CD), and Match Filter Detector (MFD) have been proposed in the literature to detect the presence of PU [16]. ED and EVD are blind detectors that do not require any prior information about the PU while CD and MFD is a non-blind detector that requires full information about the PU [17, 18]. Also, ED suffers from noise uncertainty which makes the detector have poor performance under low SNR. This is due to the noise variance which is not accurately known at the low Signal Noise Ratio (SNR) and the selection of threshold in ED depends on the noise variance which cannot be accurately estimated thereby resulting in unreliable detection. Therefore, in this work CSS with reduced reporting overhead resulting in low sensing time and energy efficiency is proposed using EVD and cluster.

2. LITERATURE REVIEW

2.1 Non-Cooperative Spectrum Sensing

Non-Cooperative Spectrum Sensing (NCSS) is a sensing method in which only one CR performs the sensing and makes decisions on its own. In this method, PU signals are detected independently by SU and decide on whether the spectrum is idle or occupied. In NCSS, individual SU works on its own and automatically configures itself according to PU detection. [19]. Single Antenna (SA) and Multiple Antenna (MA) are two antennas configuration used for *NCSS. In SA, only one antenna is used at both PU and SU, while MA involves a single antenna at PU and multiple antennas at SU. Multiple antennae in NCSS perform relatively better than single antennae and this is due to an increase in PU signal strength in multiple antennae [20; 21, 22]*. The efficiency of MA in NCSS is shown in terms of detection rate using a two-stage sensing method. In this scheme, SU has 'M' receiving antennas and each antenna receives 'L' samples of signals. PU transmits PU signal through the channel resulting in multiple copies due to obstructions in the channel. These multiple copies of signals are then received by multiple antennas of SU for sensing operation [21, 23]. NCSS suffers from receiver uncertainty that occurs when SU is outside the transmission range of license users resulting in harmful interference from SU to PU as shown in Fig. 1 [5].

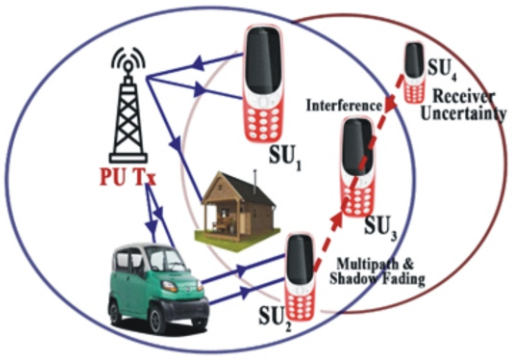


Fig. 1: Challenges of Non-Cooperative Spectrum Sensing [24]

2.1 Cooperative Spectrum Sensing

Cooperative Spectrum Sensing (CSS) is one of the sensing methods in which a group of SUs shares the sense information. Information from multiple SUs is incorporated together and analyzed for PU detection to increase the sensing capability of individual SU. The spectrum is continuously monitored by all the SUs to detect the free spectrum in the network and communicate with one another. When the free spectrum is available, SUs in the network send the sensed data to the Fusion Centre (FC) and the decision is made regarding the availability of the spectrum [24, 25]. The main idea of CSS is to enhance the detection rate by exploiting the spatial diversity in the observations of spatially located SUs. Through cooperation, CR users share their sensing information for making a combined decision more accurate than the individual decision. This provides a better scenario of the spectrum usage over the area where the CRs are located. CSS has been developed to solve the challenges of NCSS through spatial diversity since it is not possible for all spatially distributed SUs in a CR network to simultaneously experience fading that causes receiver uncertainty [19, 23]. Therefore, the combined effect of cooperative decision derived from the spatially collected observations overcomes the deficiency of individual observations at each SU and thereby improving the overall detection performance. CSS is an attractive and effective approach to address multipath fading and shadowing thereby mitigating the receiver uncertainty problem [21, 23]. It involves sharing of SUs observations between each other and communication exists between different SUs as shown in Fig. 2. Each SUs carried out its local sensing to determine the presence or absence of a PU signal. The observed information from individual CR is then shared among themselves to make a final decision based on the fusion rule [25, 28]. CSS reduce hidden node problem due to a higher number of receivers that provide more accurate transmissions in the specified area. An increase in the number of spectrum sensing nodes by cooperation enables the sensing to be more accurate and thereby providing an increase in detection rate. Signal detection is more accurate and reduces the number of false alarms by having multiple nodes performing the spectrum sensing [21].

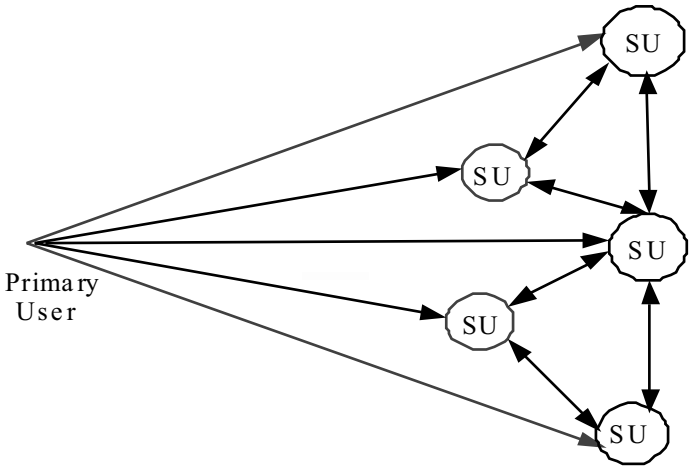


Fig. 2: Cooperative Spectrum Sensing [27]

2.3 Eigenvalue Detector

Eigenvalue Detector (EVD) is a non-coherent detector that is based on the maximum and minimum eigenvalues of the covariance matrix of the received signal. In EVD, the covariance matrix is first derived from the received signal. The maximum and minimum eigenvalues are then calculated from the covariance matrix. The ratio of maximum to minimum eigenvalue is compared with the set threshold to determine the presence or absence of the PU signal. Under H_0 hypothesis, the PU signal is present, otherwise, the PU signal is absent. Unlike ED, the threshold in EVD does not depend on the variance of the noise and thereby overcoming the problem of noise uncertainty. Also, EVD can detect a highly correlated signal, which is difficult to achieve in ED, thus making EVD have superior

performance compared to ED [30]. Under H_0hypothesis, the received signal $R_i(n)$ is given by [29] as

$$R_i(n) = \sum_{j=1}^{p} \sum_{k=0}^{N} h_j(k) x_j(k) + w_j(k) \quad (1)$$

where: P is the number of PU signal
$x_j$is the PU signals,
$h_j(k)$ is the channel response from the PU signal,
$w_j(k)$ is the noise sample.

The sample covariance matrix $'R_C'$ is given by [30] as

$$R_C(N) = \frac{1}{N} X^q X^{+(q)} \quad (2)$$

where: N is the number of collected samples
$X^q$is the square matrix
$X^{+(q)}$is the transpose of the matrix X^q

According to [30, 31], the characteristic equation of a square covariance matrix 'A' is given as

$$det(A - \beta I) = 0 \quad (3)$$

where: β is the eigenvalue
I is the identity matrix.

2 METHODOLOGY

Local spectrum sensing is carried out using Eigen Value Detector (EVD) and a Multiple antenna system is used at the SU to receive multiple copies of the PU signals. The ratio of maximum to minimum eigenvalues is obtained through the covariance matrix of the received signals and used as test statistics. The system model for the proposed technique is developed by incorporating "N" clusters and each cluster contains "L" SUs together with a Cluster Head (CH). The distance between SUs and CH in each cluster is determined using cluster radius. In this work, "L" SUs are used to carry out local spectrum sensing, and sensed decision from individual SU is sent to their respective CH in their respective cluster to make a global cluster decision. Also, the sensed decision from individual clusters is communicated among one another through CH to make the final decision. Extensive simulations using MATLAB R2018a are used to investigate the performance of the proposed technique.

3.1 Development of a Local Spectrum Sensing

The received signal '

$$Y = \sum_{i=1}^{P} \sum_{j=1}^{Q} X_i(j) + W_i(j) \quad (4)$$

where: P is the number of antennae
Q is the number of branches received by individual antenna
$X_i(j)$ is the PU signal
$W_i(j)$ is the AWGN present on the PU link

$$\boldsymbol{Y} = \begin{bmatrix} X_{1,1} & X_{1,2}\ldots\ldots & X_{1,Q} \\ X_{2,1} & X_{2,2}\ldots\ldots & X_{2,Q} \\ & & \vdots \\ X_{P,1} & X_{P,2} & X_{P,Q} \end{bmatrix} + \begin{bmatrix} W_{1,1} & W_{1,2}\ldots\ldots & W_{1,Q} \\ W_{2,1} & W_{2,2}\ldots\ldots & W_{2,Q} \\ & & \vdots \\ W_{P,1} & W_{P,2} & W_{P,Q} \end{bmatrix} \quad (5)$$

Using Equation (2), covariance 'Y_C' of the received signal for the proposed techniques is given as

$$Y_C = \frac{1}{P}(Y)Y^T \quad (6)$$

where:

P is the number of SU antenna

Y^T is the transpose of matrix Y

Using Equation (3), the maximum eigenvalue (β_{max}) and minimum eigenvalue (β_{min}) is obtained from Equation (6) as

$$det(Y_C - \beta I) = 0 \quad (7)$$

Solving Equation (6) and substituting into Equation (7) gives

$$det\begin{bmatrix} Y_{C1,1}-\beta & Y_{C1,2}\ldots\ldots\ldots\ldots & Y_{C1,Q} \\ Y_{C2,1} & Y_{C2,2}-\beta \ldots\ldots. & Y_{C2,Q} \\ & & \vdots \\ Y_{CP,1} & Y_{CP,2} & Y_{CP,Q}-\beta \end{bmatrix} = 0 \quad (8)$$

β with the highest value is the maximum eigenvalue and β with the lowest value is the minimum eigenvalue. Therefore, the test statistics 'T' is given as

$$T = \frac{\beta_{max}}{\beta_{min}} \quad (9)$$

The Probability of Detection at the local sensing is then expressed as

$$PD_{LEVD} = \Pr(T > 1) \quad (10)$$

3.2 Development of an Energy-Efficient Cooperative Network

The Energy Efficient Cooperative Network (EECN) is developed using clusters to reduce the reporting overhead between SUs that causes long sensing time and high-power consumption. SU selection is also carried out to opportunistically select SU that participates in local sensing at a particular time using the Signal-to-Noise Ratio (SNR) of the received signal at SU to reduce power consumption.

a. **Formation of Cluster**

In this work, "N" clusters are considered, and each cluster contains "L" SUs and a CH as shown in Fig. 3. The distance between an individual SU and a CH is determined using cluster radius '

$$R_C = \frac{\emptyset - 1}{\emptyset + 1} D_P \quad (11)$$

where: D_P is the distance between the PU and CH

$$\emptyset = 10^{\frac{0.1}{\delta}} \quad (12)$$

where: δ is the path loss exponent

in this work, the average values of path loss exponent for urban and suburban areas are given as 3.1 and 4.0, respectively. Solving Equation (12) using values of path loss exponent, cluster radius for the urban environment is obtained as

$$R_{C/urban} = 0.037D_P \quad (13)$$

While that of sub-urban is obtained as

$$R_{C/sub-urban} = 0.029D_P \quad (14)$$

Equations (13) and (14) are the distance between individual SU and CH for urban and suburban, respectively. At each cluster, the majority fusion rule is used to make decision on the presence and absence of PU at the CH due to its compromises between the spectrum management efficiency and PU protection.The global probability Q_{major} of this fusion is given by [5] as

$$Q_{major} = \sum_{K=R}^{L} \binom{L}{K} P_i^K (1 - P_i)^{L-K} \quad (15)$$

Using PD of local sensing and solving Equation (15) gives

$$PD_{CL,major} = 2^{K-1}(L + 2)(PD_{SU})^K(1 - PD_{SU})^{L-K} \quad (16)$$

where: PD_{SU} is the probability of detection for individual SU in a cluster

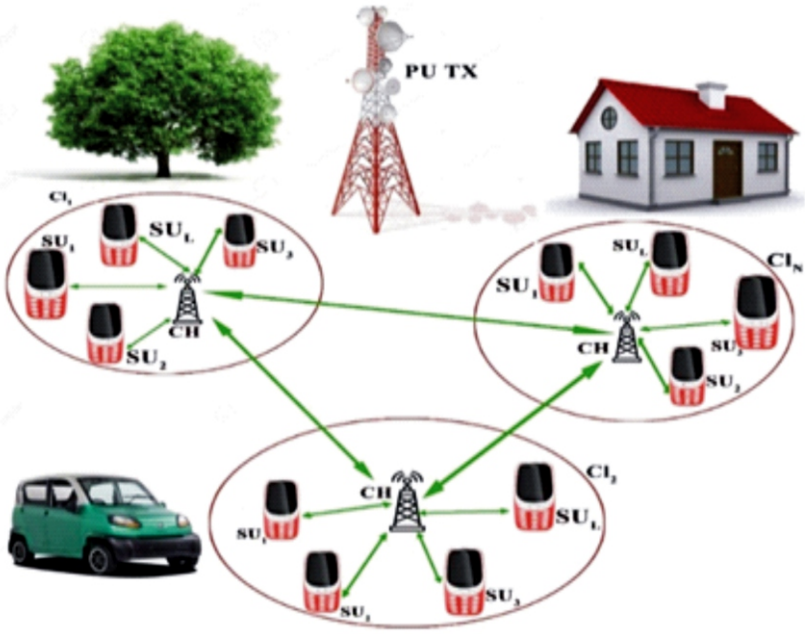


Fig. 3: Block Diagram of Energy Efficient Cooperative Spectrum Sensing

a. **Probability of Detection (PD)**

At the global decision, OR fusion rule is used due to its increase in PU protection.

If the total number of SUs is `N`and the total number of SUs that decide that spectrum is used is `R`, the global probability Q_{OR} is given as

$$Q_{OR} = R - (1 - p_i)^N \quad (18)$$

where: p_i is the probability of detection or probability of a false alarm for the i^{th} SU

In the OR rule, $R = 1$ since the spectrum is busy if at least one of the PUs decides that the spectrum is occupied. Therefore, equation (18) becomes

$$Q_{OR} = 1 - (1 - p_i)^N \quad (19)$$

Using Equation (19) and PD for the local sensing at each cluster, the global PD is given as

$$PD_{GL,OR} = 1 - \left(1 - PD_{CL,major}\right)^L \quad (20)$$

Substituting Equation (16) into (20) gives

$$PD_{GL,OR} = 1 - (1 - 2^{K-1}(L + 2)(PD_{SU})^K(1 - PD_{SU})^{L-K})^L \quad (21)$$

RESULTS AND DISCUSSIONS

The values of PD obtained for both EECSS, NCSS and conventional CSS are presented in Figs 5 to 8 at different configurations. Fig. 5 shows the PD versus SNR for both EECSS and conventional CSS at P of 5, N of 6, and SU antenna of 4. The PD values obtained for the EECSS are 0.6229, 0.6962, 0.7345, and 0.7941 at SNRs of 4, 8, 12, and 16 dB, respectively, as against the conventional CSS with PD values of 0.5945, 0.6705, 0.7189 and 0.7667 at SNRs of 4, 8, 12 and 16 dB. NCSS showed poor performance with PD values of 0.1407, 0.1832, 0.2410, and 0.2761 at SNRs of 4, 8, 12, and 16 dB respectively. The poor performance of NCSS is due to receiver uncertainty that affects the sensing accuracy. Also, EECSS has higher PD values when compared with conventional CSS and this is due to a reduction in reporting overhead that in turn increases the detection rate. Fig 6 depicts the PD versus SNR for EECSS, conventional CSS, and NCSS at SU antenna of 3 with P of 5 and N of 6. At SNR of 4, 8, 12, and 16, PD values obtained for EECSS are 0.5143, 0.5731, 0.6054, and 0.6534, respectively, as against 0.4897, 0.5528, 0.5922, and 0.6316 for conventional CSS. NCSS showed poor performance with PD values of 0.1410, 0.1923, 0.2381, and 0.2864 at SNRs of 4, 8, 12, and 16 dB, respectively. Also, Fig 8 depicts the PD versus SNR at SU antenna of 2 with P of 5 and N of 6 for both EECSS, conventional CSS, and NCSS. EECSS showed a better performance when compared with conventional CSS and NCSS with PD values of 0.3819, 0.4242, 0.4471, and 0.4843 at SNRs of 4, 8, 12, and 16, respectively. The PD values obtained for conventional CSS are 0.3633, 0.4088, 0.4380, and 0.4666 at SNRs of 4, 8,12, and 16 dB, respectively, as against 0.1189, 0.1599, 0.2019, and 0.2457 for NCSS. In all the configurations, NCSS showed poor performance with lower PD values when compared with EECSS and conventional CSS. The poor performance is due to hidden PU which occurs when SU is outside the coverage area of the PU signal. Also, in all the techniques, PD increases as the PU antenna increases and this is due to the fact the ratio of eigenvalue increases as the number of PU signals increases.

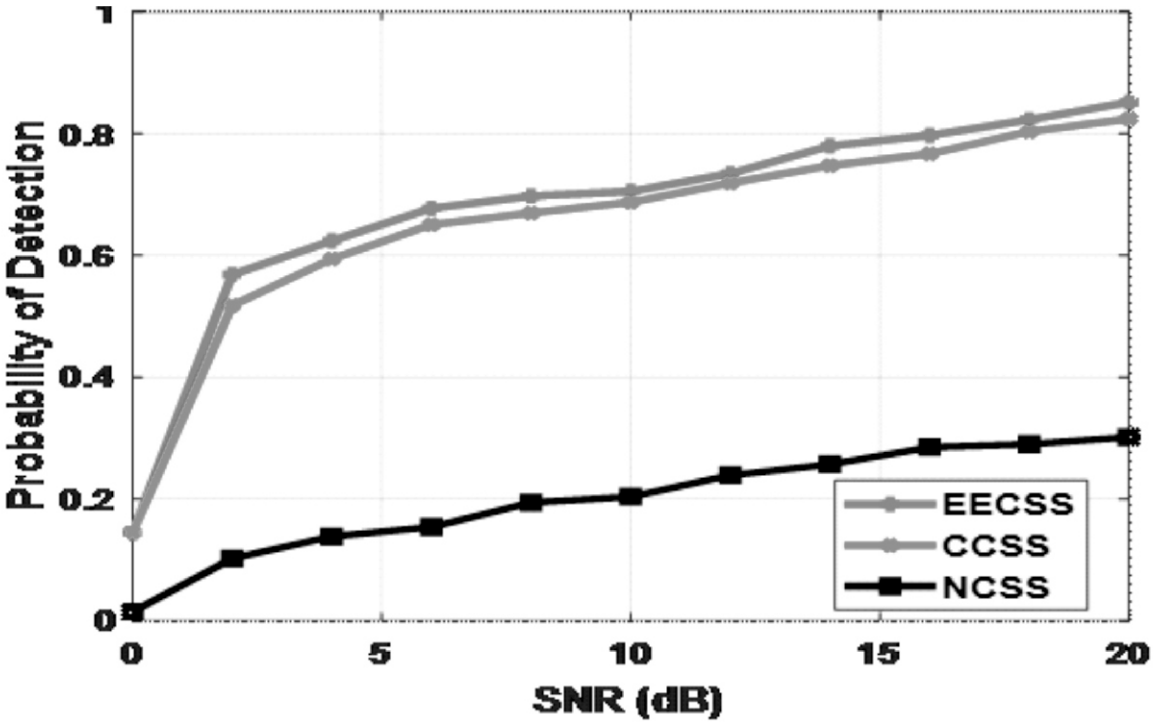


Fig. 5: Probability of Detection (PD) versus SNR for EECSS, CCSS, and NCSS at SU antenna of four

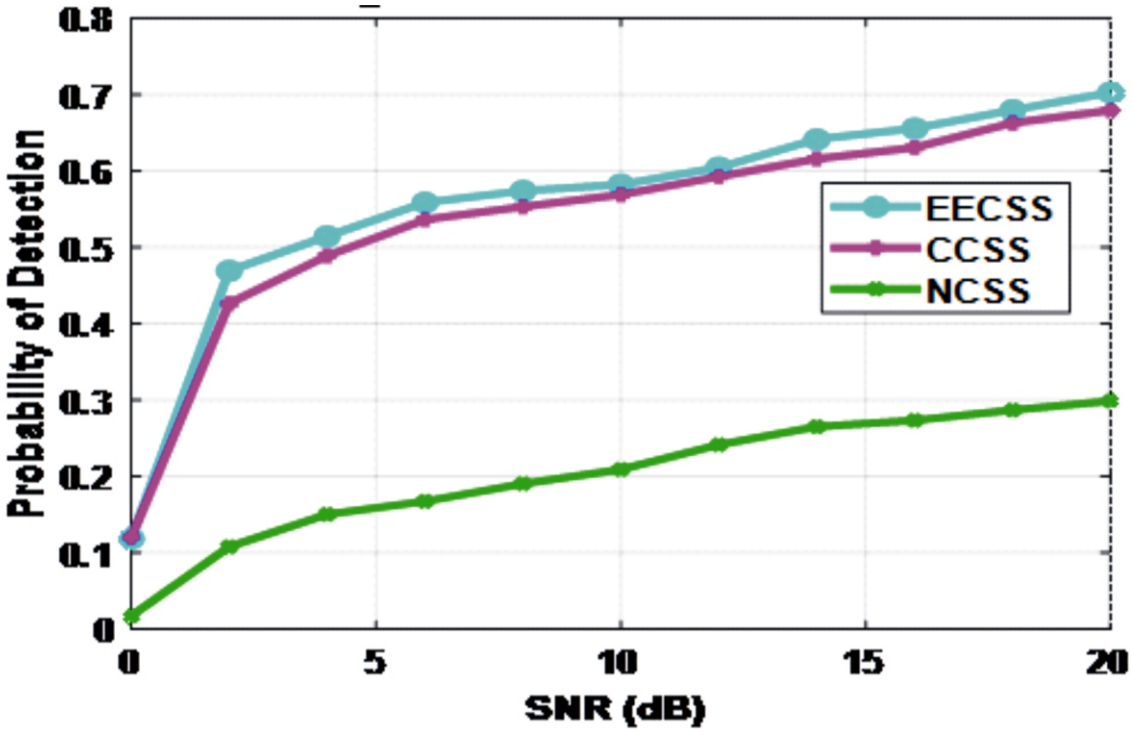


Fig.6: Probability of Detection (PD) versus SNR for EECSS, CCSS, and NCSS at SU antenna of three

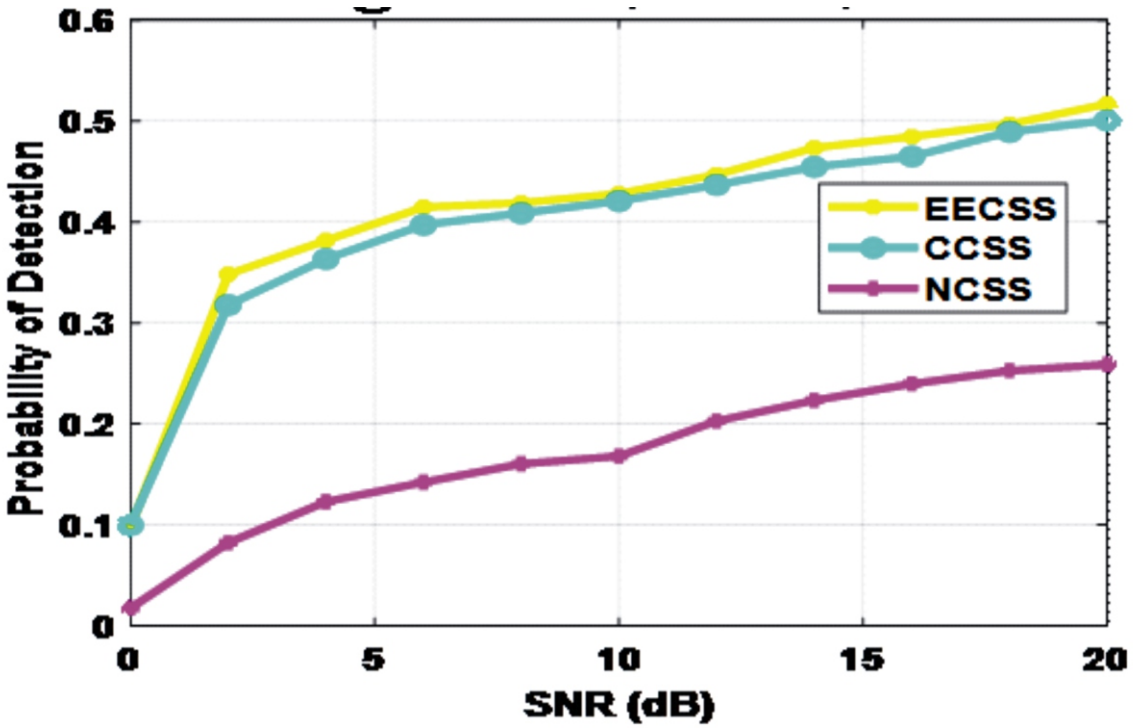


Fig. 7: Probability of Detection (PD) versus SNR for EECSS, CCSS, and NCSS at SU antenna of two

Figs. 8 to 10 depict the Processing Time (PT) versus SNR for EECSS and CCSS at different configurations. The values of PT obtained at P of 5, N of 6, and SU antenna of 4 for EECSS and CCSS are shown in Fig. 8. The PT values obtained for EECSS are 4.0907, 3.9621, 3.7732 and 3.4931 s at SNR of 4, 8, 12 and 16 dB, respectively, as against 7.5595, 7.2996, 6.9259 and 6.3435 s for CCSS. The results obtained showed that EECSS gives lower PT values when compared with CCSS and this is due to the cluster used thereby reducing the reporting overhead. Fig 9 is PT versus SNR for EECSS and CCSS at SU antenna of 3, P of 5, and N of 6. It is shown that at SNR of 4, 8, 12, and 16 dB, the PT obtained for EECSS are 5.4689, 5.2667, 5.0355, and 4.6513 s, respectively, as against 10.0841, 9.7384, 9.2431 and 8.4571 s, for CCSS. The results obtained show that PT decreases with an increase in SNR for both EECSS and CCSS. This implies that as PU signal strength increases, the rate at which SU detects the presence of licensed users increases. Fig 10 shows the PT versus SNR for the EECSS and CCSS at SU antenna of 2, P of 5, and N of 6. The results obtained show that at SNR of 4, 8, 12, and 16 dB, the PT obtained are 8.5893, 8.2428, 7.8808, and 7.2907 s, respectively, for the EECSS as against 15.777, 15.2441, 14.4510 and 13.2367 s for CCSS. The results obtained are justifiable in that the cluster and SU selection used in the EECSS reduces the reporting overhead in the implementation, thereby reducing the PT. Also, for both EECSS and CCSS, the PT values increase as the SU antenna decreases and this is due to the fact ST reduces as SU signal strength increases.

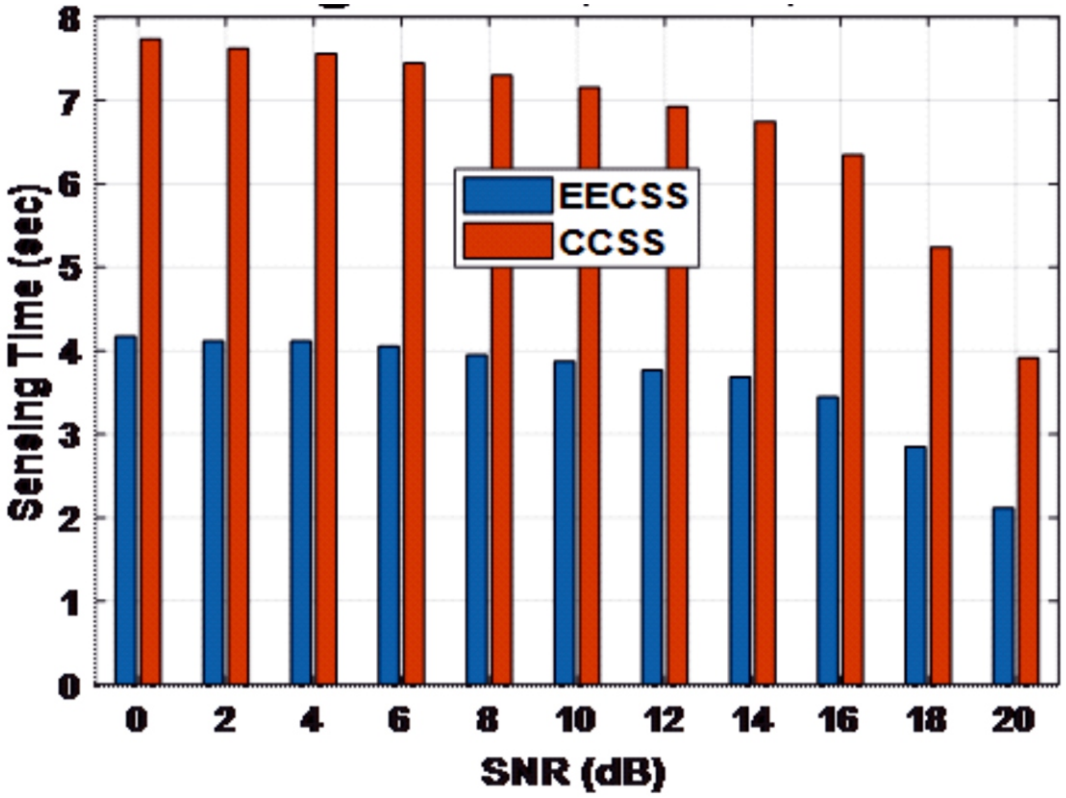


Fig. 8: Processing Time (PT) versus SNR for the EECSS and CCSS at the SU antenna of four

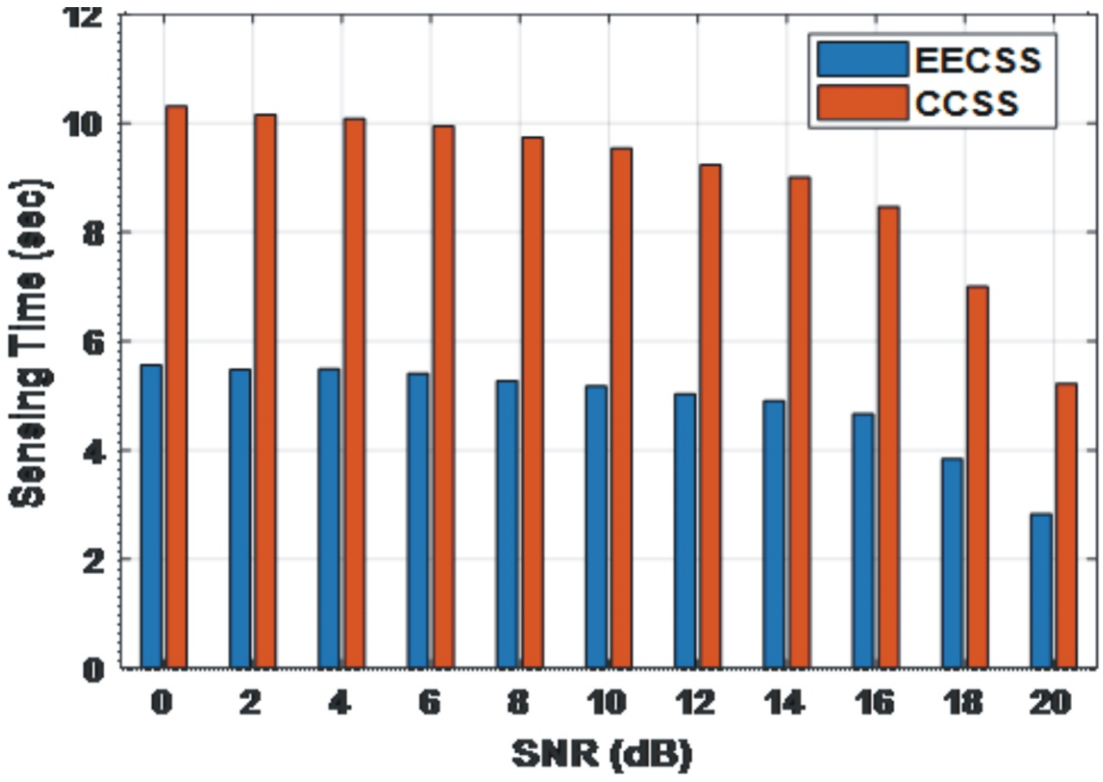


Fig. 9: Processing Time (PT) versus SNR for the EECSS and CCSS at the SU antenna of three

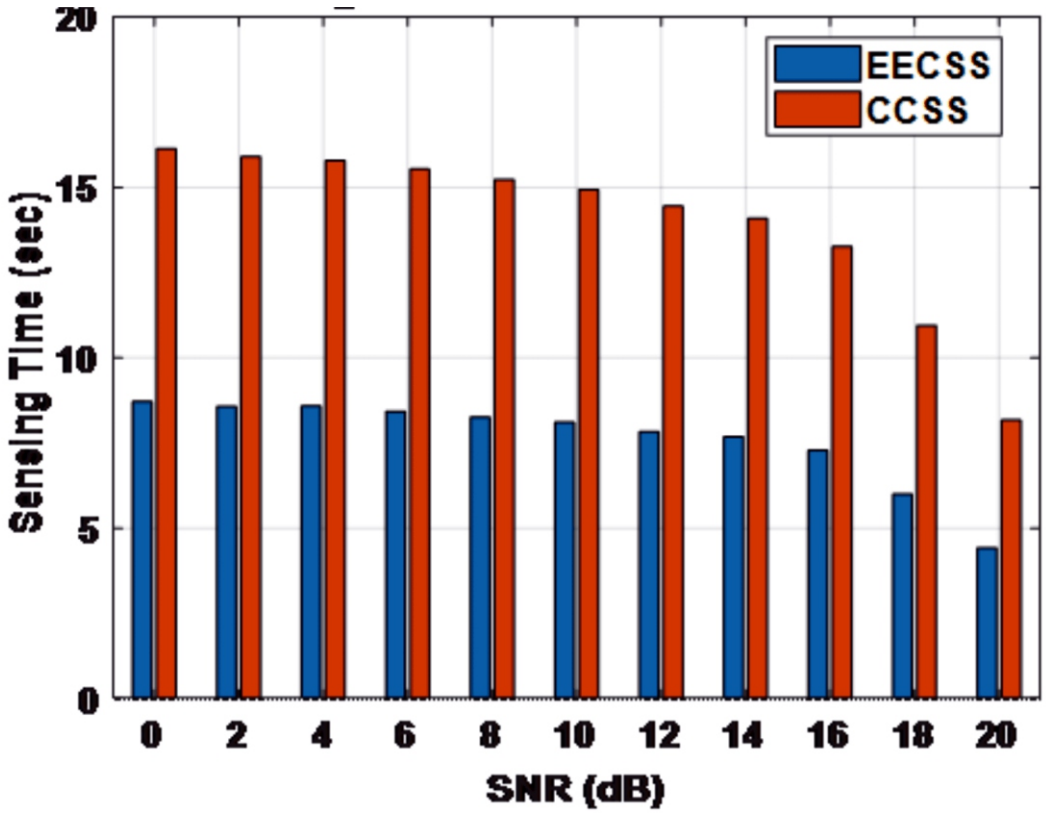


Fig. 10: Processing Time (PT) versus SNR for the EECSS and CCSS at the SU antenna of two

3 CONCLUSION

In this paper, an Energy Efficient Cooperative Spectrum Sensing (EECSS) technique for LU detection in SSS is proposed using Eigenvalue Detector (EVD) and cluster. The ratio of maximum eigenvalue to minimum eigenvalue at different antenna configurations is obtained and used as a test statistic to determine the presence of licensed users at each cluster. The local sensing results obtained at each cluster are combined using OR rule to determine the global sensing results. The technique has been simulated and evaluated using PD and PT. The results obtained show that the EECSS performs better than the CCSS due to higher PD and lower PT values. The proposed EECSS shows better performance with higher PD when compared with NCSS due to multiple SU that jointly carried out sensing operations. The better performance of the EECSS with higher PD and lower PT, when compared with CCSS, is due to cluster and SU selection used that reduce reporting overhead. Also, the results obtained depict the fact that PD increases as the number of clusters increases but PT decreases as the cluster increases. Therefore, the EECSS proposed has been shown to have a better performance by having a higher PD and lower PT than the conventional. The study shows the reporting overhead reduction and can be implemented in wireless communication systems for signal detection.

REFERENCES

[1] Kiilerich, P. N. Novel cooperative spectrum sensing methods and their limitations. Ph.D. dissertation submitted to Aalborg University, 2012. pp 1-35.

[2] Goldsmith, A.J. Wireless Communication" first Edition. Cambridge University Press. Cambridge, England. 2004. pp 445.

[3] Adeyemo, Z.K., Ojo, S.I., Abolade, R.O. and Oladimeji, O.B. Modification of a Square-Law Combiner for Detection in a Cognitive Radio Network, *International Journal of Wireless and Microwave Technologies*, 2019. 4(2): 32-45.

[4] Rappaport, T.S. Wireless communications: principle and practice, prentice hall communication, Chicago, 2002. pp 652.

[5] Noor, S. Combined soft hard cooperative spectrum sensing in Cognitive Radio networks, *Ph.D. dissertations* submitted to University of Windsor, 2017. pp 1-79.

[6] Nikhil, A. Rita M. Cooperative spectrum sensing using hard-soft decision fusion scheme*International Journal of Open Information Technologies*, 2017. 5(5):36-39.

[7] Ajay, K.G., Raju, U.G., Aravind, P. and Sushma, D. Intelligent Wireless Communication System of Cognitive Radio, *International Journal of Emerging Science and Engineering,* 2013. 1(4): 78-84.

[8] Vadivelu, R., Sankaranyanyanan, K. and Vijayakumari, V. Matched Filter Based Spectrum Sensing for Cognitive Radio at Low Signal Noise Ratio, *Journal of Theoretical and Applied Information Technology,* 2014. 62(1): 108-111.

[9] Ojo, F.K. and Fagbola, F.A. Spectrum Sharing in Cognitive Radio Work Using Good put Mathematical Model for Perfect Sensing, Zero Interference and Imperfect Sensing Non-Zero interference, *international Journal of Wireless Communication and Mobile Computing,*2015, 3(6): 58-59.

[10] Youssif, F. S. Cooperative spectrum sensing: performance analysis and algorithms, Ph.D. Dissertation submitted to the School of Electronic and Electrical Engineering, The University of Leeds, 2014. pp 1-16.

[11] Kaniezhil, R. and Chandraseker, C. Performance Analysis of Wireless Network with Opportunistic Spectrum Sharing via Cognitive Radio Nodes, *Journal of ElectronicScience and Technology*, 2012. 10(4): 99-208.

[12] Mansi, S. and Gajanan, B. Spectrum Sensing Techniques in Cognitive Radio Networks, *International Journal of Next Generation Networks*, 2011, 3(2): 37-40.

[13] Refik, F.U. Spectrum Sensing Techniques for Cognitive Radio Systems with Multiple Antennas, unpublished Master thesis in Electronics and Communication Engineering, Graduate School of Engineering and Sciences. 2010. pp 144.

[14] Ahmed, B. and Tamer, K. A Hybrid Spectrum Sensing Technique with Multiple Antenna Based on GRT, IEEE 9th International Conference on Wireless and Mobile Computing, Networking and Communication, Qatar University, 2013. pp 740.

[15] Adeyemo, Z. K., and Ojedokun, I.A. EGC Receiver using Single Radio Frequency Chain and Single Matched Filter over Combined Rayleigh and Rician Fading Channels, *ARPN Journal of Engineering and Applied Sciences,* 2014. 9(7): 992-994.

[16] Dong, X. J., Chen, Y.B., Yang, G.Y., Pang, X.S. and Yang, J.X. The optimization of improved energy detector in Cognitive Radio network, International Conference on Computer Information Systems and Industrial Applications, Yunnan Minzu University, 2015. pp 87-93.

[17] Manikandan, G., Mathavan, N., Suresh, M., Paramasivam, M. and Lavanya, V. Cognitive Radio spectrum sensing techniques: a survey, *International Journal of Advanced Engineering Technology*, 2016. 7(2):48-52.

[18] Guevara, O. O. Design of an optimal eigen value-based spectrum sensing algorithm for Cognitive Radio, Master thesis submitted to University of Nairobi, 2016.pp 12-47.

[19] Maninder, S., Pradeep, K. and Sandeep K. P. Techniques for spectrum sensing in Cognitive Radio networks: issues and challenges, *International Research Journal of Engineering and Technology*, 2016. 3(5):153-158.

[20] Kevin, C. Spectrum Sensing, Detection and Optimization in Cognitive Radio for Non-Stationary Primary User Signals, unpublished Ph.D. Thesis submitted to Queensland University of Technology, Network, and Communication, Faculty of Science and Engineering, 2012. pp 189.

[21] Suman, R., Rajeshwar, L. D. and Parmender, S. Spectrum Sensing in Cognitive Radio Using MIMO Techniques*, International Journal of Soft Computing and Engineering*, 2011. 1(5): 259-261.

[22] Suseela, B. and Sivakumar, D. Non-cooperative spectrum sensing techniques in cognitive radio-a survey, IEEE International Conference on Technological Innovations in ICT for Agriculture and Rural Development, 2015, pp 127-132.

[23] Komal, P., and Tanuja D. Review on: spectrum sensing in Cognitive Radio using multiple antennae, *International Journal of Innovative Science, Engineering and Technology*, (2016). 3(4):313-318.

[24] Lan, F.A., Brandon, F.L. and Ravikumar, B. Cooperative spectrum sensing in Cognitive Radio networks: A survey*, Elsevier on Physical Communication,* 2011. 4(3):40-62.

[25] Samrat, C. S. and Ajitsinh N J. Performance comparison of centralized cooperative spectrum sensing based on the voting rule in cognitive radio, *International Journal of Advanced Engineering Research and Science*, 2016. 3(5): 72-75.

[26] Maninder, S., Pradeep, K. and Sandeep K. P. Techniques for spectrum sensing in Cognitive Radio networks: issues and challenges, *International Research Journal of Engineering and Technology*, 2016. 3(5):153-158.

[27] Komal, P., and Tanuja D. Review on spectrum sensing in Cognitive Radio using multiple antenna, *International Journal of Innovative Science, Engineering and Technology*, 2016. 3(4):313-318.

[28] Hammadi, A.A., Altrady, O., Muhaidat, S., Al-Qutayri, M. and Al-Araji, S. Centralized Cooperative Spectrum Sensing with Multiple Antennas Over Imperfect Feedback Channels*,* IEEE International Conference on connected vehicles and espo, American University of Madaba, Jordan*,* 2014. pp 529-532.

[29] Nandkishor, P. S. and Priyanka, V. A. *Proportional study of Eigenvalue Based Spectrum Sensing Techniques for Cognitive Radio Networks, International Journal of Computer Networks and Wireless Communications,*2016.*6(3): 1-5.*

[30] Yonghong, Z. and Ying-Chang L. Eigenvalue-based spectrum sensing algorithms forCognitive Radio, *IEEE Transactions on Communications,* 2009. 57(6):1784-1788.

[31] Sruthy, V. and Sreeraj, K. P. Optimization of cooperative spectrum sensing to minimize the total error rate in cognitive radio networks, *International Journal of Advanced Research in Computer and Communication* Engineering, 2015. 4*(10):*28-31.