Original Research Paper

Enhanced Hybrid Spectrum Sensing Method Using TCDT and IEDT for Cognitive Radio

[1]Neha Chaudhary, [2]Rashima Mahajan, [1]Richa Adlakha, [1]Ashish Grover
[3]Dipali Bansal and [4]Sunny Bhatia

[1]*Department of Electrical and Electronics Engineering, Manav Rachna International Institute of Research and Studies, Faridabad, India*
[2]*Department of Computer Science and Engineering, Manav Rachna International Institute of Research and Studies Faridabad, India*
[3]*Department of Electronics Engineering Department, Manav Rachna University, Faridabad, India*
[4]*Department of Mechanical Engineering, Manav Rachna International Institute of Research and Studies, India*

Article history
Received: 20-10-2023
Revised: 11-12-2023
Accepted: 09-07-2024

Corresponding Author:
Neha Chaudhary
Department of Electrical and Electronics Engineering, Manav Rachna International Institute of Research and Studies, Faridabad, India
Email: nehachaudhary.set@mriu.edu.in

Abstract: The development of efficient spectrum sensing techniques has witnessed progressive growth for optimum utilization of spectrum resources in cognitive radio. The primary objective of spectrum sensing is the identification and proper utilization of the spectrum holes. Nowadays, due to the advancement of wireless technologies, the demand for spectrum is also increasing and thus in turn, the requirement for better spectrum sensing techniques. An attempt has been made to further improve the performance of spectrum sensing techniques for efficient primary user detection by implementing hybrid spectrum detection (a combination of two different spectrum sensing techniques). This study is comprised of an improved energy detector for message signals with a lower range of SNR and a third-order cyclostationary detection spectrum sensing technique for signals with a high value of SNR. A detailed comparative analysis of the implemented hybrid spectrum sensing technique with the individual spectrum sensing techniques and the existing hybrid spectrum sensing technique has been made A proposed scheme using Third order Cyclostationary-Detection Technique (TCDT) and Improved-Energy-Detection Technique (IEDT). Here, MATLAB software has been used for the implementation of TCDT with a low value of Signal-to-Noise Ratio (SNR) and IEDT has been employed for the signals with a high value of SNR. Simulation results of validation of the proposed hybrid spectrum sensing technique with conventional hybrid approaches reveal that the proposed technique outperforms the conventional hybrid spectrum sensing methods as it can improve the probability of detection from 17-45% with SNR values -15 to -25. It has also been analyzed that the probability of mis-detection decreases approximately from 18-47% with the SNR value range from -15 to -25. With a 0.1 value of the probability of a false alarm, there is a 47% deduction in the detection rate. Therefore, the proposed method possesses the capability to optimize the use of spectrum holes (unused frequency bands) for future cognitive radio.

Keywords: Spectrum Sensing, Probability of Misdetection, Hybrid Spectrum Sensing Techniques, Primary User Detection

Introduction

Spectrum scarcity is one of the problems due to the increasing number of users and limited allocation of spectrum in wireless communication. A Cognitive-Radio Network (CRN) is one of the promising solutions to this spectrum scarcity problem. The bands unused by the Primary Users (PU) are utilized by the Cognitive- Radio-User (CRU) in the cognitive radio networks without affecting the primary user administration. Therefore, to increase the capability of available spectrum band usage, the designated band of the primary user can be utilized by other users in the absence of the primary user. Cognitive radio users can sense the status of the primary user. In case, certain spectral bands have not been occupied by the primary users, then the cognitive radio user may become active and utilize those spectral bands. On the other hand, if the primary user returns in that case based on the priority, the cognitive radio user empties that occupied band to avoid any unsafe barrier. Proper utilization of the spectrum band without interference from the primary user can be achieved by better detection of the primary user.

Problem Statement Formulation

Radio Frequency spectrum is getting crowded due to the increased demand for wireless applications. There is a need for an efficient, flexible, and reliable utilization of the available spectrum. The problem of the proposed research is to implement sensing techniques for better utilization of radio spectrum over a wide range of SNR, with a minimal false alarm rate and maximum detection rate with reduced system complexity.

Literature Review

Many spectrum sensing techniques are available for the detection of PU like cyclostationary detection, matched filter detection, and conventional-energy detection (Chaudhary and Rashima, 2023a).

Figure 1 shows the classification of spectrum sensing techniques. From the different spectrum sensing techniques, conventional-energy-detection is the preferable technique because of its less complexity, uncertainty towards the noise, and its pertinence to unidentified PU signals. Distinguishing noise from the primary signal cannot be achieved by conventional energy detection at a low signal-to-noise ratio. Detection of the primary users is better in improved energy detectors as compared to conventional energy detectors (Sani *et al*., 2021). Figure (2) represents the block diagram of the energy detector spectrum sensing technique.

Cyclostationary Detection (CD) works as a suboptimal detector because of its capability to differentiate between noise and primary user signals. Figure (3) presents the block diagram of the cyclostationary feature detection technique. Cyclostationary detection is also applicable for signals with low SNR because it could reject the noise. However, complexity in the case of cyclostationary detection is higher than in energy detection (Alnwaimi and Boujema, 2020; Chaudhary and Mahajan, 2021a).

In Cooperative-Spectrum-Sensing (CSS), various Cognitive Radio Users (CRUs) cooperate with each other for spectrum sensing and better detection of the primary user takes place (Amrutha and Karthikeyan, 2017; He *et al*., 2018). The concept of a fusion scheme is used in CSS, where each user sends their sensing decision to the fusion center and finally, the presence or absence of the primary user is decided on the basis of sensing decisions as processed by the fusion center (Arjoune and Kaabouch, 2019; Chaudhary and Rashima, 2023b).

Literature analysis reveals that the effective utilization of available RF spectrum is still an area of concern. Continuously monitoring the radio environment and filling the gap of the frequency bands accordingly could enhance the efficiency of the spectrum. The design and selection of the technique are dependent on the type of application and user system. Thus, spectrum sensing is still an open area of research and by exploring and enhancing the different sensing algorithms, the probability of opportunity detection can be enhanced.

In this research, a hybrid scheme for primary user detection (which is the combination of an improved energy detector and third-order cyclostationary detection) has been implemented with reduced complexity and better detection of the primary user.

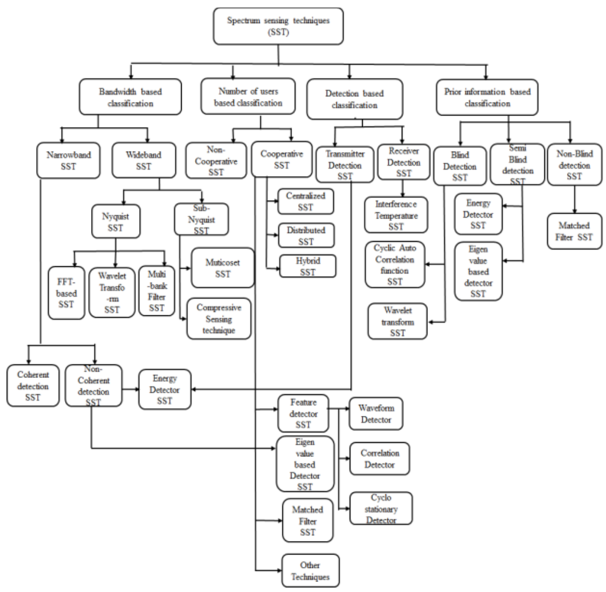

Fig. 1: Classification of spectrum sensing

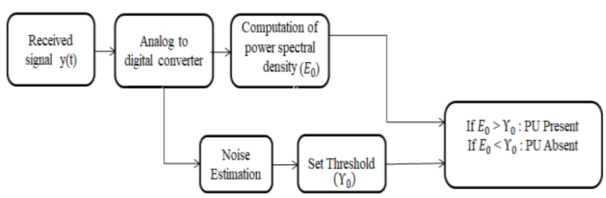

Fig. 2: Block diagram of energy detector

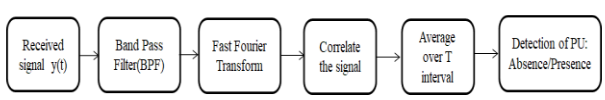

Fig. 3: Block diagram of cyclostationary feature detection technique

The motivation for this study was to improve the performance of primary user detection, where existing spectrum sensing methods fail to find out the existence of the primary users at a low value of signal-to-noise ratio. In the conventional methods, the signal received from the cognitive users was sent to the energy detector to check the existence of the primary user. The energy detector technique compares the amplitude of received signal energy with a set threshold value to identify the primary user (Bhowmick *et al*., 2019). Later on, the cyclostationary detection method is applied if the energy present in the received signal is less than the value of the set threshold. The complexity level of Cyclostationary Detection (CD) is higher as compared to the Energy Detector-based Spectrum Sensing Technique (EDSST), also if CD is applied to each of the cognitive users, then the analytical complexity of the detector further increases (Raghu and Elias, 2019).

The solution to overcome the complexity level is to introduce the hybrid spectrum sensing technique where the CD is only introduced by the cognitive radio user when the primary user is not detected by the EDSST (Wan *et al*., 2019). This study has resulted in better detection of the primary users at low SNR, where EDSST is not able to detect the primary user. In this research, initially, the detection of the primary user is performed by the improved energy detector-based spectrum sensing over the wide range of SNR, else detection can be performed by the cyclostationary detection over the varied series of SNRs. This hybrid scheme is applied to a cooperative environment where the OR fusion rule is existing. The whole module involves:

- Primary user detection using a hybrid spectrum sensing technique which is the combination of the improved EDSST and TCDT
- Evaluation of different values of the EDSST's parameters including the probability of false alarm and probability of detection for the cooperative spectrum sensing method and the single user of the cognitive radio
- Comparative analysis of the performance parameters of the hybrid scheme used for primary user detection
- Analysis of the performance parameters such as signal-to-noise ratio and threshold for hybrid scheme and individual schemes

Materials and Methods

This section includes the details of the methodology used to implement conventional energy detection, improved energy detection, cyclostationary detection, and cooperative spectrum sensing followed by the hybrid spectrum sensing method using the Improved Energy Detector Technique (IEDT) and order Cyclostationary spectrum sensing Technique (TCDT).

Conventional Energy Detection Technique (CEDT)

The received signal for any arbitrary Cognitive radio user has been represented by Eq. (1) as follows:

$$r(t) = \begin{cases} a(t);\ 0 < t < t_0\ H_0 \\ c_f m(t) + a(t); 0 < t < t_0\ H_1 \end{cases} \tag{1}$$

Here, (it) represents the received signal at Cognitive Radio User (CRU): Observation time is denoted by t_0; transmitted signal by the primary user is denoted by $m(t)$, and channel coefficient is presented by c_f; $a(t)$ is the additive white Gaussian noise with zero value of mean and variance is σ^2. The presence and absenteeism of the primary user are denoted by H_1 and H_0, respectively. Figure (4) shows the flow chart of the CEDT.

Probability of Detection and Probability of False Alarm Equations in CEDT

Expression for the probability of false alarm (P_{fa}) and actual probability of detection (P_{ad}) for conventional energy detection technique over the AWGN (Additive White Gaussian Noise) type channel at various CRU have been expressed using the Eqs. (2-3), respectively:

$$P_{fa(CEDT)} = P_{rec}(R > \lambda\,|H_0) = \frac{(m,\lambda/2)}{(m)} \tag{2}$$

$$P_{ad(CEDT)} = P_{rec}(R > \lambda\,|H_1) = Q_{mac}\sqrt{2\gamma},\ \sqrt{\lambda}\,) \tag{3}$$

In Eqs. (2-3), λ indicates the sensing threshold, and the complete and incomplete gamma function is represented by □(.) and □(.,.) respectively. Gamma functions are used for continuous monitoring of the signal. Marcum Q-function is represented by Q_{mac} (.,.), which is a normally distributed function used for performance analysis and characterized by a tail-type curve.

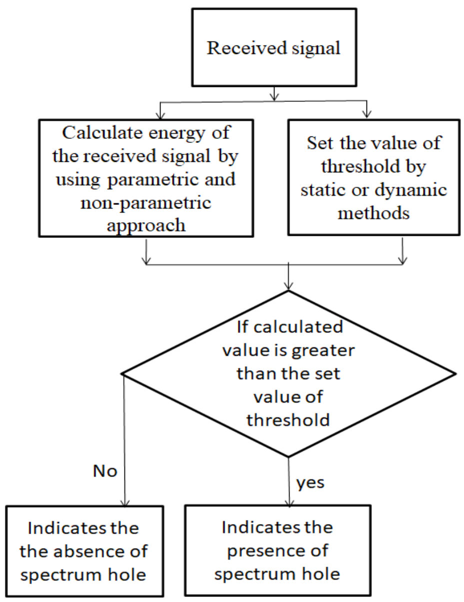

Fig. 4: Flow chart of the CEDT

Improved-Energy-Detection Technique (IEDT)

In this type of spectrum sensing technique, the energy of the received signal for the k^{th} order of cognitive user is represented as per Eq. (4):

$$R = |r_k|^{ip}, ip > 0 \tag{4}$$

ip is the improvement parameter for an improved energy detector. For hypotheses H_0 and H_1, the cumulative distribution function (CDF) for the IEDT has been represented as Eqs. (5-6), respectively (Gaiera *et al*., 2019; Priya *et al*., 2019).

Probability of Detection and Probability of False Alarm Equations in IEDT

From the Eqs. (5-6), the expression for the probability of false alarm (P_{fa}) and actual probability of detection (P_{ad}) for IED is given as in Eqs. (7-8):

$$F_{R|H_0}(r) = \frac{\sqrt{2}r^{\frac{1-ip}{ip}}}{ip\sqrt{\pi\sigma_n{}^2}} exp\left(-\frac{r^{\frac{2}{ip}}}{2\sigma_n{}^2}\right), r > 0 \tag{5}$$

$$F_{R|H_1}(r) = \frac{\sqrt{2}r^{(1-ip)/ip}}{ip\sqrt{\pi\sigma_n{}^2}} exp\left(-\frac{r^{2/ip}}{2\sigma_n{}^2}\right)\left(-\frac{r^{2/ip}}{2(\sigma_n{}^2+\sigma_s{}^2)}\right), r > 0 \tag{6}$$

$$P_{fa(IEDT)} = \frac{1}{\sqrt{\pi}} \square \left(\frac{1}{2}, \frac{\lambda^{2/ip}}{2\sigma_n{}^2}\right) \tag{7}$$

$$P_{ad(IEDT)} = \frac{1}{\sqrt{\pi}} \square \left(\frac{1}{2}, \frac{\lambda^{2/ip}}{2(\sigma_n{}^2+\sigma_s{}^2)}\right) \tag{8}$$

For the improved energy detector, false alarm probability varies with respect to the threshold value (λ) and noise variance ($\sigma_n{}^2$). Also, for better detection of the user, threshold value, noise variance, and signal variance ($\sigma_s{}^2$) play a significant role.

Cyclostationary-Detection Technique (CDT)

In this type of sensing technique, the mean of the signal is periodic with respect to the period T_1. Also, with the help of synchronized averaging, it is easy to calculate the periodicity of the signal. The sampling interval for the sampled value of $r(t)$ is taken as (t-kT_1,….t-T_1,…. t+T_1,…. T+kT_1), time is represented by t and k is taken as integer (Chaudhary and Mahajan, 2021b). The mean of signal $r(t)$ over the AWGN channel is computed using the Eq. (9):

$$M_r(t)_T = \triangleq \frac{1}{2I_c+1}\sum_{k=-I}^{I} r\,(t + k\,T_1) \tag{9}$$

In Eq. (9), observation time is represented by $T \triangleq (2I_c + 1)\,T_1$, and the collected cyclic prefix is represented as I_c. Figure 1 shows the workflow of the cyclostationary detection-based spectrum sensing technique, where the received signal is passed through the bandpass filter and by using Eq. (9) the mean of the signal is computed. Further, with the help of Eqs. (10-13), Probability-Density-Function (PDF) has been calculated and further analysis parameters i.e., $P_{fa(CDT)}$ and $P_{ad(CDT)}$ are obtained with the help of Eqs. (14-15).

Probability of Detection and Probability of False Alarm Equations in CDT

For the hypothesis H_0 and $H_{1,}$ the Probability-Density-Function (PDF) of mean function $M_r(t)_T$ is computed as per Eqs. (10-11) (Chaudhary and Mahajan, 2022):

$$P_{M_r(t)_T}(t{:}\,H_0) \sim C_{I_c}\left(0, \frac{\sigma_n{}^2}{2I_c+1}\right) \tag{10}$$

$$P_{M_r(t)_T}(t{:}\,H_1) \sim C_{I_c}\left(\mu, \frac{\sigma_n{}^2}{2I_c+1}\right) \tag{11}$$

Complex Gaussian distribution, which is circularly symmetric in nature is represented by $C_{I_c}(\mu, \sigma^2)$, here mean is μ and the variance is σ^2. For hypothesis, H_0 and H_1, the envelope of $M_r(t)_T$ has been obtained using the Eqs. (12-13) as follows:

$$P(r{:}\,H_0) = \begin{cases} \frac{r}{\sigma_b{}^2}\,exp(-\frac{r}{2\sigma_b{}^2}) & r \geq 0 \\ 0 & r < 0 \end{cases} \tag{12}$$

$$P(r{:}\,H_1) = \begin{cases} \frac{r}{\sigma_b{}^2}\,exp[-\frac{(r^2+b^2}{2\sigma_b{}^2}]\,I_0\left(\frac{br}{\sigma_b{}^2}\right) & r \geq 0,\ b \geq 0 \\ 0 & r < 0 \end{cases} \tag{13}$$

Here, $\frac{\sigma_n{}^2}{2I_c+1}$. $b^2 = \sigma_b{}^2$ is called the non-centrality parameter and the modified bessel function is represented by I_0 (.), probability of false alarm, and probability of detection have been computed using Eqs. (14-15), respectively:

$$P_{fa(CDT)} = exp\left(-\frac{\lambda^2}{2\sigma_b{}^2}\right) \tag{14}$$

$$P_{ad(CDT)} = Q_{mac}\left(\frac{\sqrt{2\gamma,}}{\sigma}, \frac{\lambda}{\sigma_b}\right) \tag{15}$$

In Eqs. (14-15), the sensing threshold is represented by λ, the signal-to-noise ratio is represented by γ, and the marcum Q-function is represented by Q_{mac} (.,.).

Hybrid Detection Technique

Better detection of the primary user can be achieved by the combination of two different spectrum sensing techniques. An attempt has been made to combine the Improved Energy Detection Technique (IEDT) and order Cyclostationary Detection Technique (TCDT) which reduces the complexity level and improves the detection of the primary users as compared to the previous research (Sivagurunathan *et al*., 2012; Yu *et al*., 2020). In a hybrid scheme, at first, the signal is received by an improved energy detector. If the IEDT can find the PU, then the result is PU present, otherwise, the signal is passed through the TCDT and it checks the status of the PU to get the final decision. Figure (5) represents the flowchart of the hybrid spectrum sensing method using TCDT and IEDT for cognitive radio.

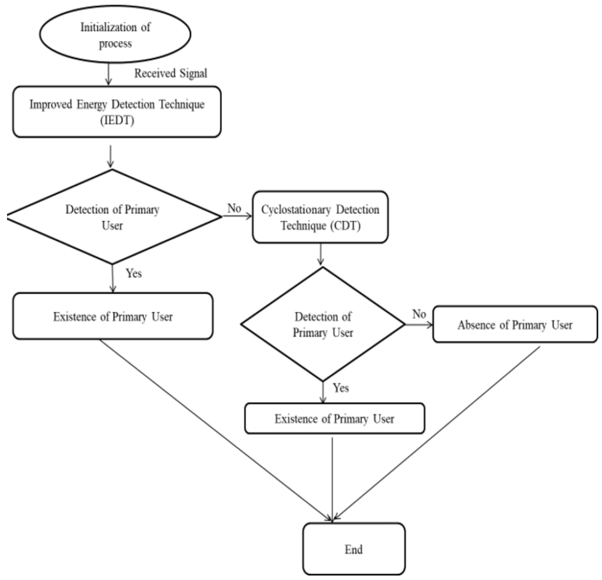

Fig. 5: Flow chart of the hybrid spectrum sensing

The fusion center has the main role of providing the final decision, where each cognitive radio user gives their own decision to the fusion center. To obtain the final decision, the OR rule has been applied across the fusion center, and the cooperative spectrum sensing technique is incorporated for better detection of the primary user (Sudhamani *et al*., 2021; Sarala *et al*., 2019).

Probability of Detection and Probability of False Alarm Equations Hybrid Detection Technique

For additive white Gaussian noise, the actual probability of detection using a hybrid scheme, where cognitive radio users have undergone *CD* has been computed by Eq. (16):

$$P_{ad(CDT)} = 1 - P_{ad(IEDT)} = P_{md(IEDT)} \tag{16}$$

Let us consider that L is the total number of available cognitive radio users. The number of users who undergo CD is considered as the Binomial Random Variable (BRV) and expressed by Eq. (17):

$$P\ (j) = \sum_{j=0}^{L} \binom{L}{j} \left(P_{(CDT)}\right)^{J} \left(1 - P_{(CDT)}\right)^{L-J} \tag{17}$$

Here, *j* is the number of the Cognitive-Radio-Users (CRUs) that are undergoing Cyclostationary Detector (CD) from the total value i.e., *L* and *P* (*j*) is the probability for the same.

Cooperative Spectrum Sensing Technique (CSST)

In this sensing technique, primary user detection takes place because of the cooperation between the different cognitive radio users. Each user sends the respective decision to the fusion center and shall be combined using the OR fusion rule (Ejaz *et al*., 2018).

Probability of Detection and Probability of False Alarm Equations in CSST

The probability of detection under a hybrid scheme depends upon the probability of detection for IEDT and TCDT under the additive white Gaussian noise (Ranjeeth and Anuradha, 2019) as given below in Eq. (18):

$$P_{ad(HDT)} = 1 - (1 - P_{ad(IEDT)})(1 - P_{md(CDT)}) \tag{18}$$

Missed probability of detection for the hybrid scheme is computed using the Eq. (19) as follows:

$$P_{md(HDT)} = 1 - (1 - P_{ad(HDT)}) \tag{19}$$

The probability of a false alarm for the hybrid scheme has been computed using Eq. (20) as given below:

$$P_{fa(HDT)} = 1 - (1 - P_{fd(IEDT)})(1 - P_{fd(CDT)}) \tag{20}$$

The overall probability of actual detection (Q_{ad}), probability of false alarm (Q_{fa}), and probability of missed detection (Q_{md}) at the fusion center point over additive white Gaussian noise with the implementation of the or rule has been computed as per Eqs. (21-23), respectively:

$$(Q_{ad}) = 1 - (1 - P_{ad,HDT})^{L} \tag{21}$$

$$\left(Q_{fa}\right) = 1 - (1 - P_{fa,HDT})^{L} \tag{22}$$

$$(Q_{md}) = 1 - (1 - P_{ad,HDT})^{L} = (P_{md,HDT})^{L} \tag{23}$$

The main goal of the spectrum sensing technique is to minimize the rate of missed detection. Individual spectrum sensing techniques have their merits and demerits. So, the hybrid scheme is one of the solutions to achieve better detection of users with comparatively fewer false alarms and missed detection rates.

Results and Discussion

In this research, a hybrid scheme which is the combination of the Improved Energy Detector (IEDT) spectrum sensing technique and Third order Cyclostationary Detection spectrum sensing Technique (TCDT) has been implemented. All the simulations have been performed in MATLAB workspace. The performance of the implemented algorithm for the detection of primary users has been analyzed for QAM-modulated signals.

To evaluate the performance of the implemented hybrid spectrum sensing technique, the different parameters were set including input signal samples as 1000 at different Signal-to-Noise Ratios (SNR) i.e., -15, -20, and -25 dB, and frequency range from 1800-2300 MHz. Comparisons of the implemented hybrid scheme with the Conventional Energy Detector (CED) technique and Cyclostationary Detector (CD) technique have been analyzed for the different values of the probability of a false alarm.

Figure (6) represents the graphical variation of the probability of misdetection (P_{md}) with respect to the set values of probability of false alarm (P_{fa}), where the P_{fa} range has been considered from 10^{-4} and the input number of the sample as 1000. It has been observed from the simulations results that the probability of misdetection is minimal for the proposed hybrid spectrum sensing technique as implemented in this study which consists of the Improved Energy Detector Technique (IEDT) and 3rd order Cyclostationary Detector Technique (TCDT) as compared to the other hybrid scheme combinations and individual spectrum sensing techniques reported in the existing schemes in the literature.

From Table (1) at $P_{fa} = 10^{-4}$, the value of P_{md} for individual first-order cyclostationary detection is obtained as 0.35, the value of P_{md} for individual conventional energy detector is obtained as 1, the value of P_{md} for hybrid scheme (CD + CED) is found to be 1, the value of P_{md} for hybrid scheme (CD + IEDT) is found to be 0.56 whereas the minimal value of P_{md} is obtained for the hybrid scheme (TCDT + IED) i.e 0.1 which shows the 46% improvement and misdetection can be reduced by this new proposed hybrid scheme for $P_{fa} = 10^{-4}$ and 25% improvement rate for the $P_{fa} = 10^{-1}$

Figure (7) represents the probability of misdetection vs SNR analysis, where different values of SNR i.e., -15, -20, and -25 dB have been considered. It has been observed from the simulations that the probability of misdetection rate is very high for individual implementation of spectrum sensing technique and already existing hybrid spectrum sensing is better than the individual spectrum sensing technique but new hybrid schemes show better results as compared to all previously existing techniques.

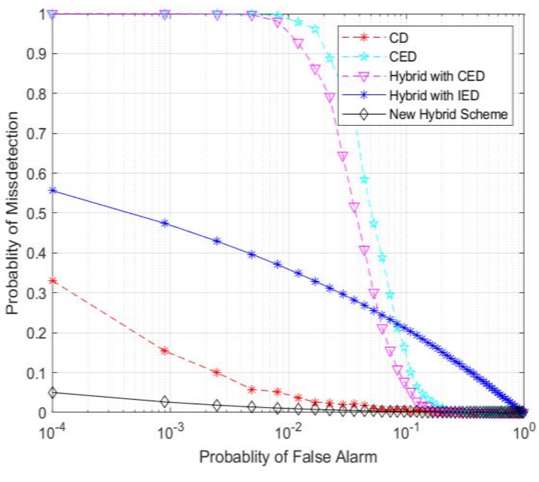

Fig. 6: Probability of misdetection vs probability of false alarm

Table 1: P_{fa} vs P_{md}

P_{fa}	P_{md} (CD)	P_{md} (CED)	P_{md} (hybrid scheme) (CD + CED)	P_{md} (hybrid scheme) (CD + IEDT)	P_{md} (new hybrid scheme) (TCDT + IEDT)
10^{-4}	0.35	1	1	0.56	0.1
10^{-3}	0.27	1	1	0.48	0.08
10^{-2}	0.08	1	0.98	0.39	0.05
10^{-1}	0.01	0.2	0.09	0.25	0

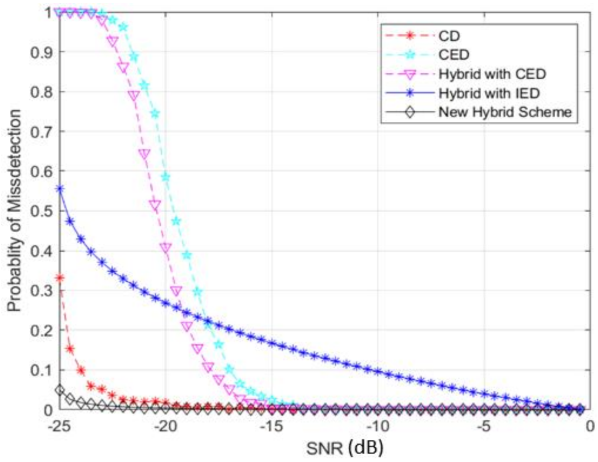

Fig. 7: Probability of misdetection vs SNR

It has been analyzed from Table (2) that the minimal value of P_{md} (as obtained with the new hybrid scheme: TCDT + IED) is 0.01 at SNR = -15 dB as compared to the other set of values of SNR i.e., -20 and -25 dB. From the results, it has been observed that at SNR = -25, the probability of misdetection is 0.57 for the (CD + IED) combination whereas for the new proposed scheme value is 0.1 so there is a 47% improvement and decrease in the misdetection rate, whereas at SNR = -20, the probability of misdetection is 0.28 for (CD + IED) combination whereas for new proposed scheme value is 0.02 so there is 26% improvement and decrease in the misdetection rate. Also, for SNR = -15, the probability of misdetection is 0.18 for the (CD + IED) combination whereas for the new proposed scheme value is 0.01 so there is a 17% improvement and decrease in the misdetection rate.

Figure (8) represents the actual probability of detection (P_{ad}) vs SNR analysis. It has been observed from the simulations results that P_{ad} is maximum with the implemented hybrid spectrum sensing technique (TCDT + IEDT) at SNR = -15 dB as compared to the other SNR values i.e., at -20 and -25 dB. Results reveal that an improvement of 5% has been achieved for the probability of detection with the new hybrid scheme even at low SNRs as compared to the other previously existing schemes (Patil *et al*., 2017).

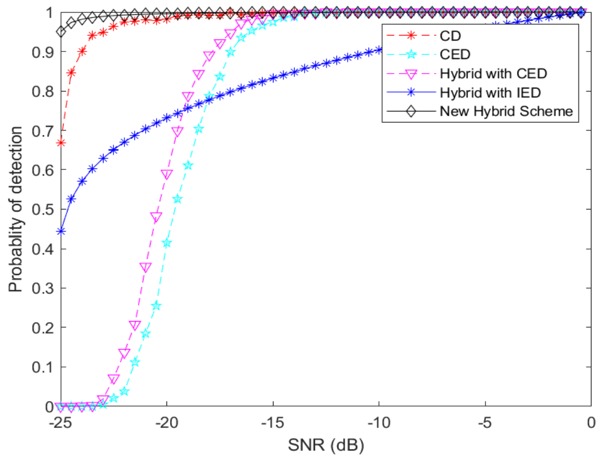

Fig. 8: Probability of detection vs SNR

Table 2: SNR vs P_{md}

SNR (dB)	P_{md} (CD)	P_{md} (CED)	P_{md} (hybrid scheme) (CD + CED)	P_{md} hybrid scheme) (CD + IED)	P_{md} (new hybrid scheme) (TCDT + IED)
-25	0.32	1.00	1.00	0.57	0.10
-20	0.02	0.63	0.39	0.28	0.02
-15	0.01	0.02	0.01	0.18	0.01

Table 3: SNR vs P_{ad}

SNR (dB)	P_{ad} (CD)	P_{ad} (CED)	P_{ad} (hybrid scheme) (CD + CED)	P_{ad} (hybrid scheme) (CD + IED)	P_{ad} (new hybrid scheme) (TCDT + IED)
-25	0.67	0.00	0.0	0.45	0.90
-20	0.98	0.56	0.8	0.72	0.94
-15	1.00	0.94	1.0	0.82	1.00

Table (3) shows the analysis of SNR vs P_{ad}. At SNR = -25, the probability of actual detection is 0.45 whereas the probability of actual detection for the new proposed hybrid scheme is 0.9, so there is a 45% improvement as compared to the previous existing work. At SNR = -20, the probability of actual detection is 0.72 whereas the probability of actual detection for the new proposed hybrid scheme is 0.94, so there is a 22% improvement also at SNR = -15 the probability of actual detection is 0.82 whereas the probability of actual detection for new proposed hybrid scheme is 1, so there is 18% improvement.

Conclusion

In this research, a hybrid spectrum sensing technique has been implemented, which consists of a combination of improved energy detector spectrum sensing and cyclostationary detection spectrum sensing technique. Performance analysis of existing individual spectrum sensing techniques i.e., (CD, CED) and previously existing hybrid schemes (CD + CED) and (CD + IED) with the new hybrid spectrum sensing technique (TCDT + IEDT) has been presented in this research. Previous existing work mentioned in the paper (Patil *et al*., 2017) has used first-order cyclostationary detection but in the new proposed scheme third order cyclostationary technique has been used also instead of a conventional energy detector here improved energy detector has been included which makes this hybrid scheme is better techniques. From the results and discussion section, it has been witnessed that the probability of detection increases from 17-45% with SNR values from -15 to -25. It has also been analyzed that the probability of mis-detection decreases approximately from 18-47% with the SNR value range from -15 to -25. Also, the effect on the probability of misdetection with a probability of false alarm is presented in the result and discussion where 46% is the maximum rate of decrease in the probability of misdetection This research focused on the fusion of two spectrum sensing techniques to identify the primary user more effectively with a wide range of signal-to-noise ratios in cognitive radio.

As observed spectrum sensing is still an open research area. The concept of Dual-Stage Sensing (DSS) possesses a great scope to improve detection by combining the effect of diverse Spectrum-Sensing Techniques (SST). Also, the performance of the implemented spectrum sensing method may be enhanced by the combination of the best sensing techniques.

Acknowledgment

I would like to express my deepest gratitude to the researchers who supported this study with all the necessary references.

Funding Information

The authors received no financial support for the research, authorship and/or publication of this article.

Author's Contributions

Neha Chaudhary: Formulated the research objectives, conducted the literature review and developed the methodology.

Rashima Mahajan: Conducted the literature review and contributed to the development of the methodology.

Richa Adlakha and Ashish Grover: Implemented the algorithm.

Dipali Bansal and Sunny Bhatia: Analyzed the end-to-end outcomes.

Ethics

By signing this document, I affirm that this article is original and has not been published elsewhere.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this study. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication, falsification, double publication and, or submission and redundancy have been completely witnessed by the authors.

References

Alnwaimi, G., & Boujemaa, H. (2020). Enhanced spectrum sensing using a combination of energy detector, matched filter, and cyclic prefix. *Digital Communications and Networks*, *6*(4), 534–541. https://doi.org/10.1016/j.dcan.2019.08.009

Amrutha, V., & Karthikeyan, K. V. (2017). Spectrum sensing methodologies in cognitive radio networks: A survey. *2017 International Conference on Innovations in Electrical, Electronics, Instrumentation and Media Technology (ICEEIMT)*, 306–310. https://doi.org/10.1109/icieeimt.2017.8116855

Arjoune, Y., & Kaabouch, N. (2019). A Comprehensive Survey on Spectrum Sensing in Cognitive Radio Networks: Recent Advances, New Challenges, and Future Research Directions. *Sensors*, *19*(1), 126. https://doi.org/10.3390/s19010126

Bhowmick, A., Roy, S. D., & Kundu, S. (2019). Cooperative Spectrum Sensing Under Double Threshold With Censoring and Hybrid Spectrum Access Schemes in Cognitive Radio Network. In *Sensing Techniques for Next Generation Cognitive Radio Networks* (pp. 164–188). IGI Global. https://doi.org/10.4018/978-1-5225-5354-0.ch010

Chaudhary, N., & Mahajan, R. (2021a). Identification of spectrum holes using energy detector based spectrum sensing. *International Journal of Information Technology*, *13*(3), 1243–1254. https://doi.org/10.1007/s41870-021-00662-6

Chaudhary, N., & Mahajan, R. (2021b). Spectrum Sensing Techniques in Cognitive Radio Networks: Challenges and Future Direction. *Proceeding of Fifth International Conference on Microelectronics, Computing and Communication Systems*, 451–458. https://doi.org/10.1007/978-981-16-0275-7_37

Chaudhary, N., & Mahajan, R. (2022). Comprehensive review on spectrum sensing techniques in cognitive radio. *Engineering Review*, *42*(1), 88–102. https://doi.org/10.30765/er.1677

Chaudhary, N., & Mahajan, R. (2023a). Performance analysis of cooperative spectrum sensing using double dynamic threshold. *IAES International Journal of Artificial Intelligence (IJ-AI)*, *12*(1), 478–487. https://doi.org/10.11591/ijai.v12.i1.pp478-487

Chaudhary, N., & Mahajan, R. (2023b). Spectrum sensing using 16-QAM and 32-QAM modulation techniques at different signal-to-noise ratio: a performance analysis. *IAES International Journal of Artificial Intelligence (IJ-AI)*, *12*(2), 966–973. https://doi.org/10.11591/ijai.v12.i2.pp966-973

Ejaz, W., Hattab, G., Cherif, N., Ibnkahla, M., Abdelkefi, F., & Siala, M. (2018). Cooperative Spectrum Sensing With Heterogeneous Devices: Hard Combining Versus Soft Combining. *IEEE Systems Journal*, *12*(1), 981–992. https://doi.org/10.1109/jsyst.2016.2582647

Gaiera, B., Patel, D. K., Soni, B., & Lopez-Benitez, M. (2019). Performance Evaluation of Improved Energy Detection under Signal and Noise Uncertainties in Cognitive Radio Networks. *2019 IEEE International Conference on Signals and Systems (ICSigSys)*, 131–137. https://doi.org/10.1109/icsigsys.2019.8811079

He, Y., Xue, J., Ratnarajah, T., Sellathurai, M., & Khan, F. (2018). On the Performance of Cooperative Spectrum Sensing in Random Cognitive Radio Networks. *IEEE Systems Journal*, *12*(1), 881–892. https://doi.org/10.1109/jsyst.2016.2554464

Patil, V., Yadav, K., Roy, S. D., & Kundu, S. (2017). Hybrid cooperative spectrum sensing with cyclostationary detector and improved energy detector for cognitive radio networks. *2017 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET)*, 1353–1357. https://doi.org/10.1109/wispnet.2017.8299984

Priya, C. G., Sri, S. S., Renganayagi, M., & Varsha, T. M. (2019). Average Information based Spectrum Sensing for Cognitive Radio. *2019 International Conference on Communication and Signal Processing (ICCSP)*, 0876–0880. https://doi.org/10.1109/iccsp.2019.8698106

Ranjeeth, M., & Anuradha, S. (2019). Throughput Analysis in Cooperative Spectrum Sensing Network using an Improved Energy Detector. *2019 21st International Conference on Advanced Communication Technology (ICACT)*, 483–487. https://doi.org/10.23919/icact.2019.8701974

Raghu, I., & Elias, E. (2019). Low complexity spectrum sensing technique for cognitive radio using Farrow Structure Digital Filters. *Engineering Science and Technology, an International Journal*, *22*(1), 131–142. https://doi.org/10.1016/j.jestch.2018.04.012

Sani, M., Tsado, J., Thomas, S., Suleiman, H., Shehu, I. M., & Shanuna, M. G. (2021). A Survey on Spectrum Sensing Techniques for Cognitive Radio Networks. *2021 1st International Conference on Multidisciplinary Engineering and Applied Science (ICMEAS)*, 1–5. https://doi.org/10.1109/icmeas52683.2021.9692412

Sarala, B., Devi, D. R., & Bhargava, D. S. (2019). RETRACTED ARTICLE: Classical energy detection method for spectrum detecting in cognitive radio networks by using robust augmented threshold technique. *Cluster Computing*, *22*(5), 11109–11118. https://doi.org/10.1007/s10586-017-1311-8

Sivagurunathan, P. T., Ramakrishnan, P., & Sathishkumar, N. (2021). Recent Paradigms for Efficient Spectrum Sensing in Cognitive Radio Networks: Issues and Challenges. *Journal of Physics: Conference Series*, *1717*, 012057. https://doi.org/10.1088/1742-6596/1717/1/012057

Sudhamani, C., Saxena, A., & Aswini, V. (2021). Improved Detection Performance of Energy Detection Based Spectrum Sensing in Cognitive Radio Networks. *International Journal of Sensors, Wireless Communications and Control*, *11*(9), 957–962. https://doi.org/10.2174/2210327911666210219115009

Wan, R., Ding, L., Xiong, N., Shu, W., & Yang, L. (2019). Dynamic dual threshold cooperative spectrum sensing for cognitive radio under noise power uncertainty. *Human-Centric Computing and Information Sciences*, *9*(1), 22. https://doi.org/10.1186/s13673-019-0181-x

Yu, S., Liu, J., Wang, J., & Ullah, I. (2020). Adaptive Double-Threshold Cooperative Spectrum Sensing Algorithm Based on History Energy Detection. *Wireless Communications and Mobile Computing*, *2020*, 1–12. https://doi.org/10.1155/2020/4794136