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Research Article

Design and Development of Hybrid Spectrum Access Technique for CR-IoT Network

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ABSTRACT

The radio spectrum is an underutilized natural resource with significant untapped potential. The rapid proliferation of Internet of Things (IoT) devices is driving a dramatic increase in radio spectrum demand. These devices can utilize cognitive radio (CR) technology to access the bandwidth left unused by licensed spectrum users, also known as primary users (PUs), to meet end users spectrum requirements efficiently. However, because PUs are given priority, CR-enabled Internet of Things (CR-IoT) devices, also known as secondary users (SU), must frequently communicate with one another in an opportunistic manner or under stringent power constraints. This can complicate CR-IoT device communication, render it unstable, and restrict its throughput. This paper proposes a hybrid spectrum access algorithm that combines underlay and interweave spectrum access methods to address this issue. When a PU is detected, under the proposed scheme, CR-IoT devices utilize underlay spectrum access. In contrast, when no PU is detected, CR-IoT devices employ interweave spectrum access. In addition, a proposed iterative algorithm permits CR-IoT devices to adapt their sensing thresholds, and sensing time based on the Signal-to-Noise ratio (SNR) received from Pus to strike a balance between achievable throughput and fairness among PUs and CR-IoT devices in extremely noisy channel. Simulation results demonstrate that the throughput for CR-IoT devices increases by 28% in proposed scheme when compared to the conventional spectrum access schemes.

1. INTRODUCTION

The explosive growth of the Internet of Things is thus creating a massive demand for wireless spectrum. The problem is that most of the available spectrum is already licensed to telecoms and other users, making it difficult for unlicensed users like IoT devices to access the spectrum even if it is free. This creates artificial spectrum scarcity. We need to find new flexible ways to access and use the licensed radio spectrum more efficiently. One promising approach is a cognitive radio technology, which can be used to dynamically scan for unused licensed spectrum. CR-enabled IoT devices (i.e. CR-IoT devices) can opportunistically exploit channels that are unoccupied or under-utilized by licensed spectrum users, known as the primary users (PUs). This opportunistic channel exploitation frees up communication room for the growing tsunami of IoT devices that may crowd the unlicensed spectrum [1-5].

This paper will explore the design and development of a dynamic spectrum access technique for CR-IoT devices. The proposed hybrid spectrum access technique will allow CR-IoT devices to automatically detect and utilize underutilized licensed spectrum bands, thus improving spectral efficiency and reducing network congestion of IoT devices in the unlicensed spectrum. Through this research, we aim to help meet the increasing demand for wireless spectrum for IoT devices by providing an innovative and adaptable solution. This paper proposes a spectrum access algorithm that uses hybrid underlay/interleave spectrum access strategy to satisfy the interests of both PUs and CR-IoT devices. The proposed scheme uses an iterative algorithm that permits CR-IoT devices to adapt their sensing thresholds, and sensing time based on the received Signal-to-Noise Ratio (SNR) from primary users. The desirable outcome is a balance between CR-IoT communication stability, CR-IoT throughput, interference to PU and fairness [6-10].

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2. LITERATURE REVIEWED

2.1 Hybrid Spectrum Access (HAS)

Hybrid spectrum access is a recent technique that combines interweave opportunistic spectrum access with underlay simultaneous spectrum access. This allows devices to take advantage of the benefits of both methods simultaneously. A hybrid CR-IoT device first senses the licensed spectrum and then chooses the appropriate spectrum access mode based on the channel status. Various research papers have already been written on the hybrid spectrum access technique, covering it from a variety of methods and perspectives. A portion of these works is reviewed here [11-15].

The success of the hybrid spectrum scheme heavily depends on its ability to accurately detect the presence or absence of a PU. As such, attempts have been made to improve hybrid spectrum sensing. [1] uses a Q-learning algorithm to improve the sensing results and resource allocation for CIoVs. With this machine learning algorithm, a CIoV can make decisions that get the highest reward. In this case, the reward is picking the best channel, allocating bandwidth and power in a reasonable way, and making sure there are few sensing errors. In addition, a trained artificial neural network (ANN) was used to make decisions regarding PU channel occupancy [2]. Alternatively, [3] used a cluster-based cooperative spectrum sensing method to find the channel's status [16-20].

Recent work by the authors of [4] has proposed an iterative algorithm for interweave CR-IoT devices that incorporate a dynamic sensing threshold and sensing time. However, the CR-IoT device is still vulnerable to decreased throughput, degraded QoS, and unstable communication when a PU is present, even with this solution in place. Due to the aforementioned gap, we propose a hybrid interweave/ underlay scheme for CR-IoT devices. In this scheme, the CR-IoT device operates in underlay spectrum access mode when a PU is present, and then switches to interweave spectrum access mode when the PU is absent. In this way, CR-IoT devices can maintain high throughput and QoS regardless of whether the PU is present [21-24].

2.2 Contributions of the Paper

In brevity, the main contributions of this paper are as follows:

- A hybrid spectrum access scheme is proposed for CR-IoT devices to maintain their throughput even in the presence of a PU.
- An adaptive sensing threshold is used to limit the effect of noise uncertainties, hence reducing sensing errors in low SNR situations.
- A closed-form expression for the throughput achievable by CR-IoT devices using hybrid spectrum access is derived.

3. PROPOSED CR-IOT SYSTEM

Fig. 1 illustrates the proposed CR-IoT communication scenario where the licensed primary user (PU) is communicating over the licensed channel while CR-IoT devices form an ad-hoc network and use the PU's licensed spectrum in an opportunistic manner. Fig. 2 shows the proposed frame structure for the devices. The frame structure comprises sensing and transmission times, t_s and t_t, respectively.

The CR-IoT devices assumed to be fitted with an energy detector capable of adapting its sensing threshold (δ) value as per the received SNR from the licensed PU. This process of detecting the status of a channel can be modeled as a binary hypothesis testing problem. The outcome of the energy detector is characterized as either hypothesis 0 (H_0) for the absence of primary user or hypothesis 1 (H_1) for the presence of primary user. Mathematically,

$$y(n) = \begin{bmatrix} w(n) & ; H_0 \\ s(n) + w(n) & ; H_1 \end{bmatrix} \quad (1)$$

The test statistic, which is a numerical summary of the sampled received signal $y(n)$, is used to determine whether the hypothesis should be rejected or accepted. The test statistic is represented as:

$$T_d = \sum_{n=1}^{N} |y(n)|^2 \quad (2)$$

If $T_d > \delta$, the PU is present in the channel and underlay spectrum access is used for CR-IoT transmission. Alternatively, if $T_d < \delta$, represents PU absence from the channel and interweave spectrum access is used for CR-IoT transmission.

If H_1 is true and we declare it, this is a detection(P_d). If H_1 is true and we do not declare it, this is a miss detection(P_{md}). If H_0 is true and we do not declare it, this is a false alarm$\left(P_f\right)$. P_d And P_f can be represented mathematically as:

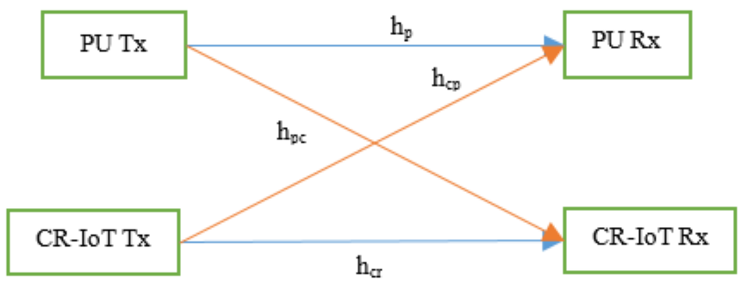
$$P_f = Prob\left(SNR_p > {}^{\delta}/_{H_0}\right) \tag{3}$$

$$P_d = Prob\left(SNR_p > {}^{\delta}/_{H_1}\right) \tag{4}$$

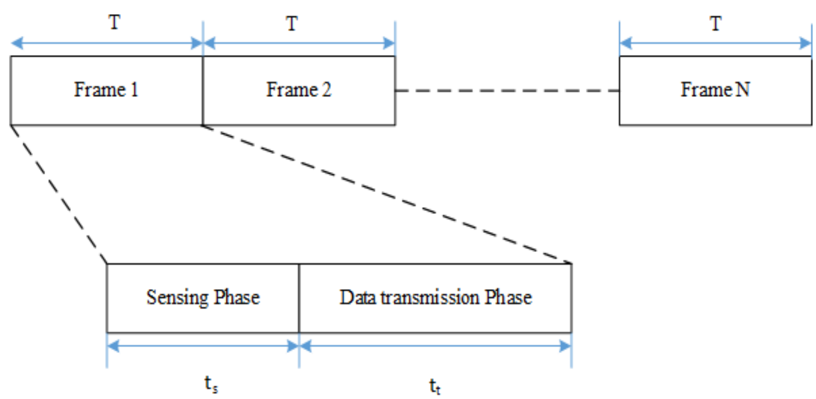
Where the SNR_p represents the received SNR from PU from CR-IoT device. Mathematically both parameters can be represented as:

$$P_f(\delta,) = Q\left[\left(\frac{\delta}{\sigma_n^2} - 1\right)\sqrt{t_s f_s}\right] \tag{5}$$

$$P_d(\delta, t_s) = Q\left[\left(\frac{\delta}{\sigma_n^2} - SNR_p - 1\right)\sqrt{\frac{t_s f_s}{2SNR_p + 1}}\right] \tag{6}$$



(a)



(b)

Fig.1. (a) Proposed System model (b) Frame design

3.1 Proposed Hybrid Spectrum

A decision-making algorithm considers the sensing outcomes and chooses the appropriate spectrum access scheme. $P(H_0)$ and $P(H_1)$indicate state of the channel as idle and busy, respectively. The algorithm chooses interweave spectrum access with maximum transmission power P_{Inter}, when the spectrum is idle. In contrast, it selects underlay spectrum access, in which transmission occurs in reduced power P_{under}, when the spectrum is busy. The four main cases arise as per outcomes:

Case 1: It represents a scenario when PU is absent but CR-IoT device detects it accurately with no false alarm with probability $P(H_0)(1 - P_f)$. Spectrum access is achieved using interweave with a maximum transmission power of P_{Inter}. The achievable throughput is:

$$C_1 = \frac{T - t_s}{T} log_2\left(1 + \frac{P_{inter}}{\sigma_n^2}\right) P(H_0)(1 - P_f) \quad (7)$$

Case 2: It represents a scenario when PU is and CR-IoT device fails to detect its presence with probability $P(H_1)(1 - P_d)$. Spectrum access is achieved using interweave with a maximum transmission power of P_{Inter}. The achievable throughput is:

$$C_2 = \frac{T - t_s}{T} log_2\left(1 + \frac{P_{inter}}{\sigma_n^2}\right) P(H_1)(1 - P_d) \quad (8)$$

Case 3: It represents a scenario when PU is absent, but CR-IoT device detects its presence. This case's probability is $P(H_0)(Pf)$. Spectrum access is achieved using underlay with a reduced transmission power of P_{under}. The achievable throughput is:

$$C_3 = \frac{T - t_s}{T} log_2\left(1 + \frac{P_{under}}{\sigma_n^2}\right) P(H_0)(Pf) \quad (9)$$

Case 4: It represents a scenario when PU is present in the

channel, and CR-IoT device also detects it accurately with probability $P(H_1)(P_d)$. Spectrum access is achieved using underlay with a reduced transmission power of P_{Under} the achievable throughput is:

$$C_4 = \frac{T - t_s}{T} log_2\left(1 + \frac{P_{under}}{\sigma_n^2}\right) P(H_1)(P_d) \quad (10)$$

Total achievable throughput of the proposed system will be given by

$$C = C_1 + C_2 + C_3 + C_4 \quad (11)$$

An iterative algorithm is proposed (Table 1) to implement hybrid spectrum access method while adapting sensing threshold to optimize sensing time.

TABLE I. ITERATIVE ALGORITHM

Input **:** $\zeta, f_s, SNR_p, T, P_d$ *and* P_f
Output **:** C, t_s
Step 1 : Set $t_s = 0$
Step 2 : Evaluate δ *using eq.* (9)
Step 3 : If PU is present
Then Transmission power= P_{Inter}
else Transmission power= P_{Under}
Step 4 : Calculate throughput C *using eq. (11)*
Step 5 : $t_s = t_s + 1$
Step 6 : reiterate steps 2-5 for all the values till $t_s = T$
Step 7 : Calculate Maximum C *obtained in step 4*
Step 8 : Find time index value corresponding to the maximum throughput calculate in step 7.
$t_s{}^* = argmax\{C(t_s)\}$
Step 9 : Find maximum C *using optimum sensing duration* $t_s{}^*$ *calculated in step 8.*
Step 10 : Return $t_s{}^*$ *and* C

4. RESULTS AND DISCUSSIONS

In this section, we have investigated the performance of the proposed scheme. The results are simulated in MATLAB 2013a with specification as per IEEE 802.22 standard. The proposed scheme is compared with conventional schemes also. The first scheme is labeled as Conv. and does not use sensing threshold adaption and hybrid spectrum access (HSA). Scheme 1, represents the scheme with sensing threshold adaption, but lacks HSA. Scheme 2 is the proposed scheme in which both the sensing threshold adaption with HSA are implemented.

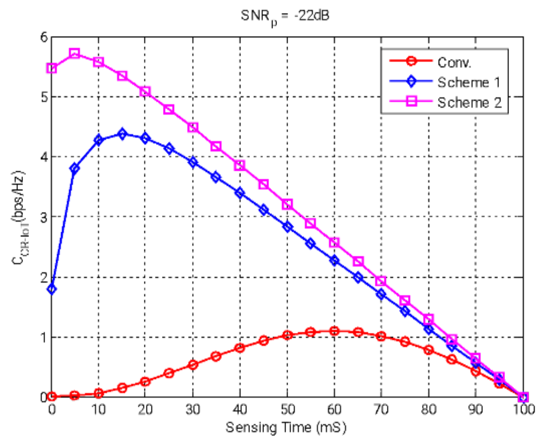


Fig.2. CR-IoT Throughput versus Sensing Time

Fig 2 shows the proposed system's throughput with respect to the sensing time. The total frame duration of 100ms. It is shown that the Conv. Scheme's maximum throughput of approximately 1bps/Hz after sensing the channel for 60ms. The Scheme 1 is able to attain the maximum throughput of 4.3 bps/ Hz with sensing time of 15ms. Moreover, the proposed scheme (scheme 2), attains a maximum throughput of 5.5 bps/Hz with sensing time of 5 ms as the proposed scheme makes out the sensing decision in less time and therefore more time is given for the data transmission. It is also be observed that throughput of the proposed scheme deceases as more time is given to sensing.

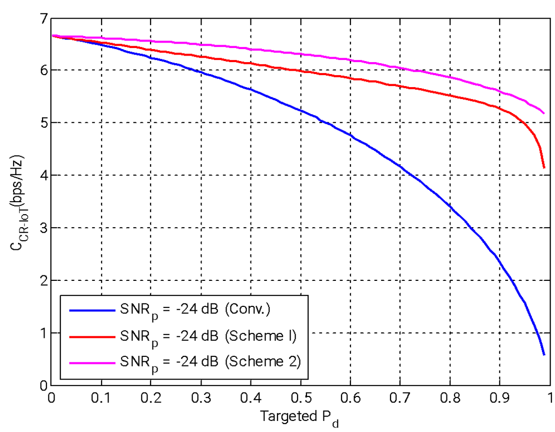


Fig.3. CR-IoT Throughput versus targeted Probability of detection

Fig. 3 shows the CR-IoT throughput performance as a function of detection probability. The results are simulated for received SNR equals to -24 dB which reflects an extremely noisy channel. It can be observed that all schemes perform equally well when the target P_d is 0, however, the conventional schemes' throughput decreases drastically as the requirement of the improved detection increases. For example, when P_d is equals to 0.97, the CR-IoT throughput decreases to 1bps/Hz. The scheme 1 is able to attain high throughput as it capable to attain the targeted $P_d$value within less sensing time. Thus significant time is allocated to data transmission. Furthermore, the proposed scheme 2 is able to achieve more throughput over conventional schemes because it exploits the available transmission opportunities by transmitting the data in hybrid mode unlike scheme 1 that transmits when no data is transmitted by PU. Refer to figure 4.

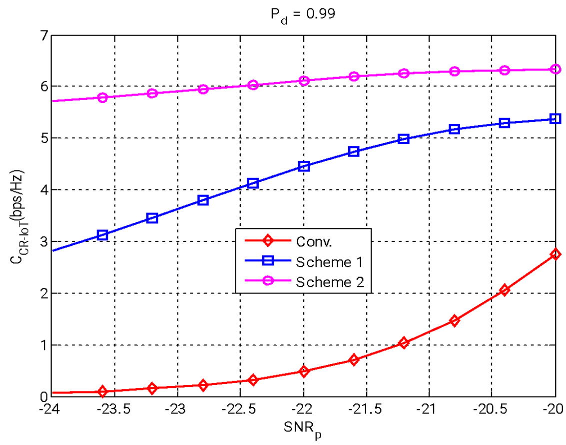


Fig .4. CR-IoT Throughput versus Received SNR from PU.

Considering highly noisy channel, the SNR values taken in simulation set up varies from 24 dB to 20dB. It has been observed that the CR-IoT throughput improves as the received SNR from PU increases. The improved SNR helps in making sensing decision in less time, and thus more time is allocated for data transmission.

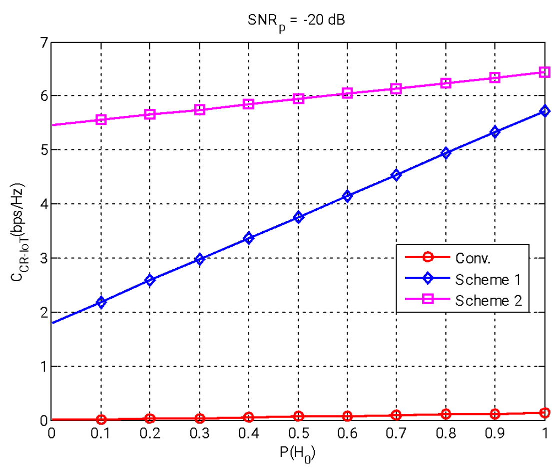


Fig.5. CR-IoT Throughput versus Probability of PU Absence from licensed channel

Figure 5 shows the CR-IoT throughput with respect to the probability of PU absence from the licensed channel. It is evident that CR-IoT's throughput increases as the probability of finding PU absent from the channel increases. It can be observed that scheme 1 and scheme 2 outperform the conventional scheme due to the sensing threshold adaptation by them. Further, scheme 2 outperforms scheme 1 on detecting channel idle or busy it transmits in HSA mode.

5. CONCLUSION

In this paper, adaptive sensing threshold based hybrid spectrum access scheme is proposed for CR-IoT devices. The proposed scheme adapts sensing threshold as per the received SNR from the licensed PU user to reduce sensing time with improved detection probability. Based on the sensing results, the proposed scheme transmits the data in underlay mode on detecting licensed PU over the channel and transmits in interweave mode when the licensed PU is not transmitting on the channel. The simulated results validate the efficacy of the proposed scheme and it has been observed that the achieves the 5.5 bps/Hz with the sensing time of 5ms. Even in low SNR regions, simulation results demonstrate that the proposed scheme increases throughput for CR-IoT devices by 28% when compared to the state-of-the-art spectrum access schemes with sensing threshold adaption.

Conflict of interest

None.

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References

[1] Y. Yang, Q. Zhang, Y. Wang, T. Emoto, M. Akutagawa, and S. Konaka, "Multi-strategy dynamic spectrum access in cognitive radio networks: Modeling, analysis and optimization," China Commun., vol. 16, no. 3, pp. 103–121, Mar. 2019, doi: 10.12676/j.cc.2019.03.010.

[2] A. A. Khan, M. H. Rehmani, and A. Rachedi, "Cognitive-Radio-Based Internet of Things: Applications, Architectures, Spectrum Related Functionalities, and Future Research Directions," IEEE Wireless Commun., vol. 24, no. 3, pp. 17–25, Jun. 2017, doi: 10.1109/MWC.2017.160040.

[3] I. Bala, A. Sharma, A. Tselykh, and B.-G. Kim, "Throughput optimization of interference limited cognitive radio-based internet of things (CR-IOT) network," J. King Saud Univ. - Comput. Inf. Sci., vol. 34, no. 7, pp. 4233–4243, 2022.

[4] I. Bala, M. S. Bhamrah, and G. Singh, "Capacity in fading environment based on soft sensing information under spectrum sharing constraints," Wireless Netw., vol. 23, no. 2, pp. 519–531, 2017.

[5] I. Bala, M. S. Bhamrah, and G. Singh, "Rate and Power Optimization under Received-Power Constraints for opportunistic Spectrum-Sharing Communication," Wireless Pers. Commun., vol. 96, no. 4, pp. 5667–5685, 2017.

[6] X. Liu, C. Sun, M. Zhou, B. Lin, and Y. Lim, "Reinforcement learning based dynamic spectrum access in cognitive Internet of Vehicles," China Commun., vol. 18, no. 7, pp. 58–68, Jul. 2021, doi: 10.23919/JCC.2021.07.006.

[7] I. Bala, M. S. Bhamrah, and G. Singh, "Investigation on Outage Capacity of Spectrum Sharing System using CSI and SSI under Received Power Constraint," Wireless Netw., vol. 25, no. 3, pp. 1047–1056, 2019.

[8] I. Bala, M. S. Bhamrah, and G. Singh, "Analytical Modeling of Ad Hoc Cognitive Radio Environment for Optimum Power Control," Int. J. Comput. Appl., vol. 92, no. 7, pp. 19–22, Apr. 2014.

[9] S. Macdonald, D. C. Popescu, and O. Popescu, "A Hybrid Framework for Spectrum Sharing in Cognitive Radio Systems With Dynamic Users," IEEE Commun. Lett., vol. 23, no. 10, pp. 1871–1874, Oct. 2019, doi: 10.1109/LCOMM.2019.2926461.

[10] J. Zhao, Q. Li, and Y. Gong, "Joint Bandwidth and Power Allocation of Hybrid Spectrum Sharing in Cognitive Radio - Invited Paper," in Proc. IEEE 87th Veh. Technol. Conf. (VTC Spring), 2018, pp. 1–5, doi: 10.1109/VTCSpring.2018.8417552.

[11] A. U. Khan, G. Abbas, Z. H. Abbas, M. Tanveer, S. Ullah, and A. Naushad, "HBLP: A Hybrid Underlay-Interweave Mode CRN for the Future 5G-Based Internet of Things," IEEE Access, vol. 8, pp. 63403–63420, 2020, doi: 10.1109/ACCESS.2020.2981413.

[12] Y. Liu, X. Qin, Y. Huang, L. Tang, and J. Fu, "Maximizing Energy Efficiency in hybrid overlay-underlay cognitive radio networks based on energy harvesting-cooperative spectrum sensing," Energies, vol. 15, no. 8, p. 2803, 2022.

[13] A. Ali et al., "Hybrid Fuzzy Logic Scheme for Efficient Channel Utilization in Cognitive Radio Networks," IEEE Access, vol. 7, pp. 24463–24476, 2019, doi: 10.1109/ACCESS.2019.2900233.

[14] R. Rajaganapathi and P. M. C. Nathan, "Cluster-based Spectrum Access Scheme selection and Optimal Relay Link selection for hybrid overlay/underlay cognitive radio networks," Int. J. Commun. Syst., vol. 35, no. 2, 2020.

[15] I. Bala and K. Ahuja, "Energy-efficient framework for throughput enhancement of cognitive radio network," Int. J. Commun. Syst., vol. 34, no. 13, 2021.

[16] I. Bala and K. Ahuja, "Energy-efficient framework for throughput enhancement of cognitive radio network by exploiting transmission mode diversity," J. Ambient Intell. Hum. Comput., 2021, doi: 10.1007/s12652-021-03428-x.

[17] R. Sethi and I. Bala, "Performance Evaluation of Energy Detector for Cognitive Radio Network," IOSR J. Electron. Commun. Eng., vol. 8, no. 5, pp. 46–51, Dec. 2013.

[18] M. R. Amini and M. W. Baidas, "Availability-Reliability-Stability Trade-Offs in Ultra-Reliable Energy-Harvesting Cognitive Radio IoT Networks," IEEE Access, vol. 8, pp. 82890–82916, 2020, doi: 10.1109/ACCESS.2020.2991861.

[19] I. A. M. Balapuwaduge, F. Y. Li, and V. Pla, "Dynamic Spectrum Reservation for CR Networks in the Presence of Channel Failures: Channel Allocation and Reliability Analysis," IEEE Trans. Wireless Commun., vol. 17, no. 2, pp. 882–898, Feb. 2018, doi: 10.1109/TWC.2017.2772240.

[20] V. Rana, N. Jain, and I. Bala, "Resource Allocation Models for cognitive Radio Networks: A Study," Int. J. Comput. Appl., vol. 91, no. 12, pp. 51–55, Apr. 2014.

[21] R. Sethi and I. Bala, "Throughput Enhancement of Cognitive Radio Networks Through Improved Frame Structure," Int. J. Comput. Appl., vol. 109, no. 14, Jan. 2015.

[22] I. Bala, M. S. Bhamrah, V. Rana, N. Jain, and G. Singh, "Adaptive Power Control Scheme for the Cognitive Radio System Based on Receiver Sensitivity," in Computational Advancement in Communication Circuits and Systems, K. Maharatna et al., Eds. New Delhi: Springer, 2015, pp. 65–72, doi: 10.1007/978-81-322-2274-3_9.

[23] I. Bala, K. Ahuja, and A. Nayyar, "Hybrid Spectrum Access Strategy for Throughput Enhancement of Cognitive Radio Network," in Micro-Electron. Telecommun. Eng., D. K. Sharma et al., Eds. Singapore: Springer, 2021, pp. 137–145, doi: 10.1007/978-981-33-4687-1_11.

[24] V. Srivastava and I. Bala, "A Novel Support Vector Machine-Red Deer Optimization Algorithm for Enhancing Energy Efficiency of Spectrum Sensing in Cognitive Radio Network," in Mobile Radio Commun. 5G Netw., N. Marriwala et al., Eds. Singapore: Springer, 2022, pp. 35–44, doi: 10.1007/978-981-16-7018-3_3.