https://doi.org/10.51630/ijes.v4i1.72

AN IMPROVED CHANNEL SELECTION ALGORITHM (ICSA) FOR SPECTRUM HAND-OFF IN COGNITIVE RADIO AD HOC NETWORK

M. S. TEKANYI, JAMES A. OROKPO*, H. A. ABDULKAREEM, TOBORE O. ALEXANDER

Department of Electronics and Telecommunication Engineering, Ahmadu Bello University Zaria, Nigeria

**Corresponding author: orokpoaudu360@gmail.com*

(Received: 12 December 2022; Accepted: 15 January 2023; Published on-line: 01 March 2023)

ABSTRACT: The exponential growth in wireless communication technology has led to spectrum scarcity. Because of this, the world has moved from Fixed Spectrum Allocation (FSA) Strategy to Dynamic Spectrum Allocation (DSA) Strategy. Cognitive Radio (CR) is a rapidly growing technique that makes use of DSA, where the licensed users, otherwise known as Primary Users (PUs), share their channel with the unlicensed users, known as Secondary Users (SUs). The SUs can use the PUs channel when they are not being used for transmission, but they have to vacate to another vacant channel when the PUs arrive in their channel. Switching to another vacant channel on the arrival of the PUs to their channels is known as spectrum hand-off. Finding another suitable vacant channel for the SUs to continue their interrupted transmission is challenging. Several researchers have used different techniques to address the challenge of target channel selection for spectrum hand-off by considering channel occupancy alone. Still, they suffer challenges like the high number of spectrum hand-offs, high delay, and low throughput. Therefore, this research focuses on developing an Improved Channel Selection Algorithm (ICSA) that considers channel occupancy serially with signal quality requirements for selecting a particular backup channel for spectrum hand-off. The simulation was carried out using Network Simulator (NS), and the results were plotted using Matlab. The results showed that the ICSA had better performance when compared with the Novel Proactive Hand-off Scheme (NPHS) regarding the number of hand-offs, average delay, and average throughput.

KEY WORDS: Cognitive Radio (CR), Channel Occupancy, Primary Users (PUs), Secondary Users (SUs), Channel Selection

1. INTRODUCTION

Federal Communication Commission (FCC) allocates spectrum to licensed users known as Primary Users (PU) using the Fixed Spectrum Access (FSA) technique [1, 2]. According to FCC investigation, utilization of licensed spectrum assigned to PUs varies from 15% to 85 % [3] and resulting in underutilization of the licensed spectrum [4]. This unused spectrum is known as spectrum holes [5].

Efficient spectrum utilization could be achieved by using Dynamic Spectrum Access (DSA) technique. In the DSA technique, SUs access the PU channels opportunistically [6]. To do this, the CR employs four functionalities: (i) Spectrum sensing, (ii) Spectrum management, (iii) Spectrum sharing, and (iv) Spectrum hand-off [7].

Spectrum sensing enables the SU to detect the presence of the PU in order not to interfere with its transmission. Spectrum management involves the selection of the best channel based on spectrum sensing information. Spectrum sharing involves allocating and coordinating spectrum access among SUs. Spectrum hand-off enables the SUs to vacate the channel when a PU arrives and switch to another vacant channel to continue its transmission [8].

Spectrum hand-off is when SUs switch their transmission from one channel to another when the PU arrives on its channel [9]. The spectrum hand-off scheme is grouped into two categories based on channel selection: reactive and proactive. In the reactive scheme, the channel is selected the moment the hand-off trigger occurs; in the proactive hand-off scheme, the target channel is selected before the occurrence of the hand-off trigger. The proactive scheme has the advantage of low delay compared to the reactive scheme, which is why it was adopted in this work [10].

This paper presents an Improved Channel Selection Algorithm (ICSA) that serially considers channel occupancy and signal quality in selecting a particular backup channel for spectrum hand-off. The rest of the paper is structured as follows. Section II reviews related works, section III reviews the system model, section IV is the research methodology, section V is an improved channel selection algorithm, section VI is results and discussion, and section VI gives the conclusion.

2. RELATED WORKS

The following are related works: Quadri (2018) proposes a channel ranking and selection scheme based on channel occupancy and SNR for the cognitive radio network [11]. The channel ranking technique was developed by defining a channel utility function that considers SNR and channel occupancy. The channels are then ranked simultaneously using the SNR and channel occupancy. The simulation showed that this scheme achieved better results than other channel ranking schemes. However, occupancy-based channel ranking often assigns high ranks to poor signal quality channels with low channel occupancies. A better result could be achieved by ranking the channel in two stages: stage by channel occupancy and channel quality.

Ali et.al (2018) used two backup channel models to select channels for spectrum hand-off in the cognitive radio networks [12]. The proposed scheme was modeled using M/M/1 queuing model to determine the waiting time for the SU on the queue. The SUs use the backup channels to resume transmission whenever a primary user shows up on the immediate channel. The target channel selection depends on the shortest queue, which will cause the shortest delay. The simulation results showed that the proposed scheme gave the shoend-to-end delay valueue compared to traditional random channel selection schemes. However, the channel signal quality was not considered in selecting the target channel, which can degrade the usefulness of the selected channel.

A Novel Proactive Hand-off Scheme (NPHS) proposed with cognitive receiver-based target channel selection for the cognitive radio networks [1]. The proposed scheme made use of the joint probability of the channel usage information from the Cognitive Radio Transmitter ($CRTs$) and Cognitive Radio Receiver (CRs) To rank available channels based on their occupancy. The channel with the highest probability of not being occupied by the Primary User (PU) in the previous transmission was selected as the next target channel. Simulation results showed that the developed scheme had better results when compared to other channel selection schemes in terms of the average number of hand-offs, average delay, and throughput. However, channel signal quality was not considered a criterion for selecting the particular backup

https://doi.org/10.51630/ijes.v4i1.72

channel. The selection of a channel with poor signal quality increases the number of hand-offs, leading to more delay and reduced system throughput.

A report also proposed an optimal channel selection scheme for improved performance in the cognitive radio network [5]. This scheme used two techniques, channel grouping and ranking, to select an appropriate channel. The ranking is based on descending order of the channel's idling probability. Grouping ensured that channels in each group were sensed simultaneously. These two techniques reduce sensing delays and maximize the throughput of the SU. The simulation was carried out using Matlab, and the result showed that the developed scheme had better performance when compared to the generalized predictive channel selection scheme in terms of sensing time delay and throughput of SU. However, the channel signal quality was not considered in this work.

From the literature reviewed, only channel occupancy was considered the criterion for selecting a particular channel for spectrum hand-off. Selecting a channel with low occupancy but poor channel signal quality will lead to more hand-off, leading

3. SYSTEM MODEL

The system is modeled as an ad hoc network scenario; the cognitive radios are randomly distributed within the network. Each Cognitive Radio (CR) has three radios: transmitter, receiver, and control. Primary user free Channel Lists (PCL) formed by each CR are shared among available CRs. The PCL contains information about the status (active or idle) of the channels in previous transmissions. Let $DC1$, $DC2$, $DC3$… DCN is the total number of the primary channel and the total number of CR nodes, M. The PCL is shared among these CR nodes, enabling them to form a matrix. The matrix contains the nodes' PCL and the PCL received from other CR nodes. The matrix is denoted by $X^{[m]}$ and it is represented by eq. 1:

$$X^{[m]} = \begin{bmatrix} X^{[m]}_{(1,1)} & \cdots & X^{[m]}_{(1,n)} \\ \vdots & \ddots & \vdots \\ X^{[m]}_{(m,1)} & \cdots & X^{[m]}_{(m,n)} \end{bmatrix} \quad (1)$$

Where: m is the range $1, 2, 3, \dots, M$, and $X^{[m]}_{i,j}$ represents j^{th} channel value of i^{th} node at M^{th} CR node. For ease of understanding, $X^{[m]}_{i,j}$ have binary values. When $X^{[m]}_{i,j} = 0$, it means that j^{th} channel of i^{th} CR node is free from PU activity and is available for cognitive users. Also, when $X^{[m]}_{i,j} = 1$, it means that j^{th} channel of i^{th} node is free of PU activity, so not available for cognitive users.

The node channel matrix formed at each CR node is given by [1]:

$$X = \left[X^{[1]}, X^{[2]}, \dots, X^{[M]}\right] \quad (2)$$

https://doi.org/10.51630/ijes.v4i1.72

4. METHODOLOGY

The following methodology was adopted in the development of the Improved Channel Selection Algorithm (ICSA):

4.1. Channel occupancy estimation using k/SBTP

The k/State Back Transition Probability (k/SBTP) is the probability that the occupancy of the Primary User (PU) channel is the previous transmission. k/SBTP means that $k+1$ consecutive time slots, including k prior and current time slots of a particular channel, are free from PU activity. Fig. 1 shows how to calculate $k/SBTP$. The current time slot is denoted by T_0 while previous consecutive time slots are denoted as $T_{-1}, T_{-2}, T_{-3}, \ldots$For example, the $1/SBTP$ $(k=1)$ gives the result that T_0 and T_{-1}(current and previous) the time slot of a particular channel is idle. Since each channel has total p time slots, total $p-1/SBTP's$ can be calculated. Here two functions $Func$ $(idle\ time\ slot)$ and Sum $(idle\ time\ slots)$ are used for the calculation of $k/SBTP$. The $Func$ $(idle\ time\ slots)$. Returns value one if k consecutive time slots are idle for the channel and the function Sum $(idle\ time\ slots)$ returns the summation of the $Func$ $(idle\ time\ slots)$ [1, 13].

$Func_1$ and $Func_2$ are calculated as given by [1]:

$$\frac{1}{SBTP}: Func_1(T_0, T_{-1},) = \begin{cases} 1\ if\ T_0, T_1\ are\ idle \\ \\ 0\ other\ wise \end{cases} \tag{3}$$

$$\frac{2}{SBTP}: Func_2(T_0, T_{-1}, T_{-2}) = \begin{cases} 1\ if\ T_0, T_{-1}, T_{-2} \\ \quad are\ idle \\ \quad 0\ oter\ wide \end{cases} \tag{4}$$

Likewise, we can calculate $Func_3(idle\ time\ slots)$, $Func_k(idle\ time\ slots)$. The equation for $Func_k(idole\ time\ slots)$ can be written as [1]:

$$\frac{k}{SBTP}: Func_k(T_0, T_{-1}, \cdots, T_{-1}) = \begin{cases} 1\ if\ T_0, T_{-1}, \ldots, T_{-k} \\ \quad are\ idle \\ 0\ other\ wise \end{cases} \tag{5}$$

Where $k = 1, 2, 3, \ldots (p-1)$ represents the maximum consecutive time slots. The summation of all $Func$ $(idle\ time\ slots)$ is obtained using the Sum $(idle\ time\ slots)$. So $\forall\ k$, is given by [1] as:

$$Sum_k(T_0, T_{-1}, \ldots, T_{-k}) = \sum_{i=1}^{p-1} Func_i\ (T_0, T_{-1} \ldots, T_{-k}) \tag{6}$$

where $i \epsilon p$ and $k = 1, 2, 3, \ldots, (p-1)$

A channel with the highest number of prior consecutive idle time slots from the current slot will achieve the highest weight in the above equation. This weight is used to obtain $k/SBTP$ as given by [1] as:

$$P_k(T_0, T_{-1} \dots, T_{-k}) = \frac{Sum_k(T_0, T_{-1} \dots, T_{-k})}{p-1} \tag{7}$$

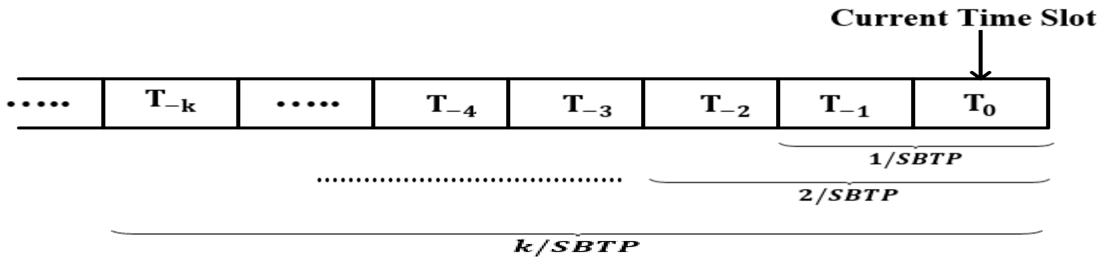

Fig. 1. Primary channel time slot division [1]

The k/SBTB at both the transmitter and the receiver sides is calculated using the following equation:

$$P_{Tx} = P_k(P_0, T_{-1}, \dots, T_{-k}) \tag{8}$$

$$P_{Rx} = P_k(P_0, T_{-1}, \dots, T_{-k}) \tag{9}$$

The joint probability of both the transmitter side and the receiver side is calculated using:

$$P_{joint}(T_0, T_{-1}, \dots, T_{-k}) = P_{Tx} \times P_{Rx} \tag{10}$$

4.2. Estimation of channel signal quality (SNR) using Eigenvalue Based Covariance Matrix

Channel signal quality of channels that have the same channel occupancy is estimated using [14]:

$$\gamma = \frac{\left(\sum_{j=1}^{L} \sum_{i=1}^{N} |x_{i,j}|^2\right)}{NL\hat{\sigma}_z^2} \tag{11}$$

Where: γ is the SNR, $x_{i,j}$ represent the received signal sample, N denotes the received signal sample, L is the length of the eigenvalues, $\hat{\sigma}_z^2$ represent the noise estimated variance.

Channel ranking based on SNR estimation is achieved using:

$$U_{SNR} = \frac{1}{2} + \frac{1}{2}\left(\tan h\left(\frac{\gamma}{2}\right)\right) \quad (12)$$

where: γ is the SNR U_{SNR} represent channel ranking by SNR

4.3 Channel selection based on the estimated occupancy and channel

Channel selection based on the estimated channel occupancy and channel signal quality is achieved using the following:

$$\delta_m = \begin{cases} 1 \ P_{joint}(T_0, T_{-1}, ..T_{-k}), \ \ U_{SNR} \\ \quad\quad are\ idle \quad\quad\quad max \\ 0\ other\ wise\ (not\ idle) \end{cases} \quad (13)$$

Where $P_{joint}(T_0, T_{-1}, ..T_{-k})$ is channel ranking based on occupancy and U_{SNR} Is channel ranking based on SNR estimation.

5. IMPROVED CHANNEL SELECTION ALGORITHM

Fig. 2 shows the flow chart of the Improved Channel Selection Algorithm (ICSA); the red portion is where improvement was carried out. It starts with calculating 1/SBTP to check if two consecutive time slots of a particular channel are free of Primary User (PU) activity, using the PCL stored at each CR node (Equation 2). The 1/SBTP of all channels is then compared with a local threshold where the $Thres$, which has an initial of 0. The $2/SBTP$ is only calculated for channels with 1/SBTP more significant than the local threshold. For the calculation of 2/SBTP, the threshold is increased to 1/SBTP for each channel.

Table 1: Example of channel ranking based on channel occupancy and SNR

Sr.No	1/SBTP	2/SBTP	…	6/SBTP	7/SBTP	SNR	Ranked by SNR
1	0.01 (DC 7)	0.04 (DC 7)	…	0.36 (DC4)	0.49 (DC4)	19	Ranked 1
2	0.01 (DC 2)	0.04 (DC 2)	…	0.36 (DC 1)	0.49 (DC 1)	8	Ranked 2
3	0.01 (DC 1)	0.04 (DC 1)	…	0.36 (DC 10)	0.49 (DC 10)	6	Ranked 3
4	0.01 (DC 4)	0.04 (DC 9)	…	0.36 (DC 7)	0.49 (DC 7)	-15	Ranked 4
5	0.01 (DC 6)	0.04 (DC 4)	…	0.36 (DC 2)	0.36 (DC 2)	-	-
6	0.01 (DC3)	0.04 (DC 10)	…	0.09 (DC 9)	0.09 (DC 9)	-	-
7	0.01 (DC 5)	0.04 (DC 3)	…	0.04 (DC 8)	0.04 (DC 8)	-	-
8	0.01 (DC 8)	0.04 (DC 8)	…	0.04 (DC 3)	0.04 (DC 3)	-	-
9	0.01(DC 10)	0.01 (DC 6)	…	0.01 (DC 6)	0.01 (DC 6)	-	-
10	0.01 (DC 9)	0.01 (DC 5)	…	0.01 (DC 5)	0.01 (DC 5)	-	-

The process continues until channel/channels with the maximum probability of not being occupied by PU in the previous transmission are obtained. If, at the final stage of calculation of the SBTP, only one channel has a maximum k/SBTP, it is selected as the next backup channel. Otherwise, that channel's Signal Noise Ratio (SNR) is estimated, and the channel with the maximum SNR is selected as the next backup channel. Otherwise, the next target channel

https://doi.org/10.51630/ijes.v4i1.72

is selected randomly if more than one channel has maximum SNR. Table 1 shows an example of how channels are ranked using the joint probability (k/SBTP) of the Cognitive Radio Transmitter CRTs and Cognitive Radio Receiver (CRRs), and the channels with maximum k/SBTP are ranked based on the channel signal quality (SNR).

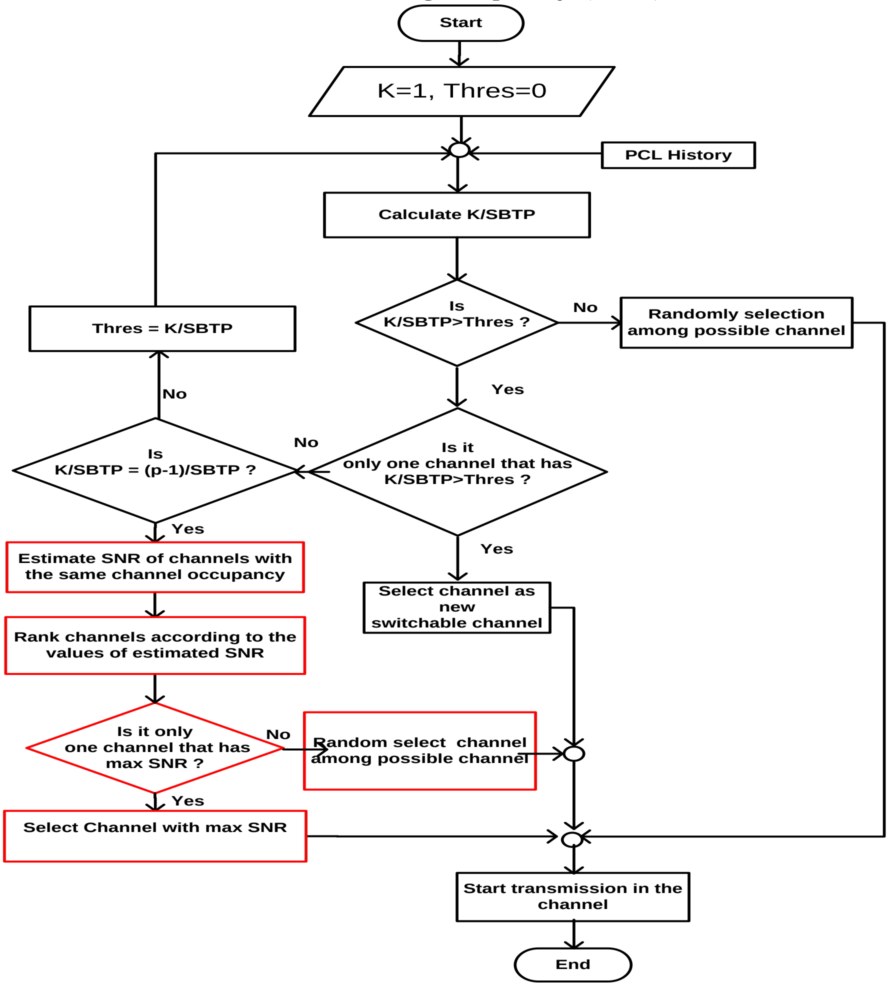

Fig. 2. Flow chart for the extended proactive hand-off scheme

6. SIMULATIONS AND RESULTS

This section discusses the results of the Improved Channel Selection Algorithm (ICSA), Novel Proactive Hand-off Scheme (NPHS), and IEEE 802.11 scheme [1]. The network performance was observed concerning the Number of Cognitive Radio (CR) nodes. The average number of hand-offs and average delay and throughput results were analyzed to measure the network's performance, t. Table 2 shows the parameters used for the simulation.

The percentage increase and decrease of the developed ICSA over both the NPHS and IEEE 802.11 scheme are given by equations (14), (15), (16), and (17), respectively.

$$Percentage\ improvemen = \frac{\sum_{n=1}^{N}\left(\frac{ICSA - NPHS}{NPHS}\right)}{N} \times 100\% \quad (14)$$

$$Percentage\ improvemen = \frac{\sum_{n=1}^{N}\left(\frac{ICSA - IEEE\ 802.11}{IEEE\ 8.2.11}\right)}{N} \times 100\% \quad (15)$$

$$Percentage\ reduction = \frac{\sum_{n=1}^{N}\left(\frac{NPHS - ICSA}{NPHS}\right)}{N} \times 100\% \quad (16)$$

$$Percentage\ reduction = \frac{\sum_{n=1}^{N}\left(\frac{IEEE\ 802.11 - ICSA}{IEEE\ 802.11}\right)}{N} \times 100\% \quad (17)$$

Where: n = the number of samples, and N is the total number.

Table 2: Simulation Parameters [1]

S/N	Parameter	Values
1	Simulator	NS-2.35
2	Topology dimension	$1000 \times 100\ (m^2)$
3	Maximum No. of CR nodes	100
4	No. of PUT_S	10
5	No. of PUR_X	10
6	Total No. of channels	11
7	Number of primary channels	10 (8 MHz bandwidth each)
8	No. of control channel	1 (902 MHz)
9	PUT_S transmission range	500 m
10	CR user's transmission range	250 m
11	Data rate	1 Mbps
12	Simulation time	50 s
13	Packet size	512 Bytes
14	Traffic type	CBR
15	Interference queue length	50 packets
16	Routing protocol	AODV

6.1. Number of Hand-offs versus Number of CR Nodes

Figure 3 plots the number of hand-offs against the number of CR nodes for the ICSA, NPHS, and IEEE 802 schemes. During simulation, an increase in the number of CR nodes leads to an increase in the number of hand-offs. An increase in the number of CR nodes leads to a corresponding increase in network activity as more users are interested in establishing communication using free Primary Users (PUs) channels. The graph shows that the number of CR nodes increases from 30 to 70. A gradual increase in the number of hand-offs for all the schemes due to the increased contention for the available channel. The number of CR nodes is further increased from 70 to 90; this is a massive increase in spectrum hand-offs for all the schemes due to the high increase in contention for available channels. Finally, when the number of CR is 90, the number of hand-offs for all the schemes begins to reduce because the network has reached its point of saturation due to the limited number of available PU channels. It was observed that the number of hand-offs reduced by 18% and 33% for ICSA when compared with NPHS and IEEE 802.11 scheme using equations (16) and (17). This is because channel signal quality was considered, in addition to channel occupancy, as a criterion for selecting a better available channel, which the NPHS and IEEE 802.11 scheme did not consider. Thus, considering channel signal quality during CR channel allocation reduced the spectrum hand-off rate, leading to better network performance for the developed ICSA.

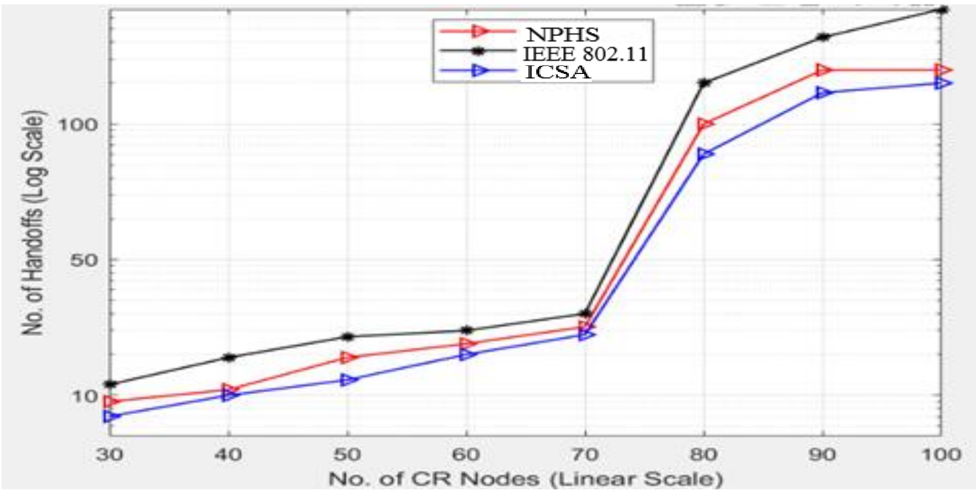

Fig. 3. Number of Hand-off versus Number of CR Nodes

6.2. Average Delay versus Number of CR Nodes

Fig. 4 plots the average delay against the number of CR nodes for ICSA, NPHS, and IEEE 802.11 scheme. Fig. 4 shows that the IEEE 802.11 scheme experiences a high average delay during channel selection. This was because it is a reactive scheme, and the channel's usage information is gathered when the hand-off trigger occurs. The NPHS and ICSA experience low average delay because they are proactive schemes, and target channels are selected before the hand-off trigger. The ICSA performs better than the other schemes because of the consideration of SNR, which further enhances the better selection of the channel, which leads to the reduced number of hand-offs, and hence, low average delay. The ICSA shows a 29% and 81% reduction in average delay compared to ICSA and IEEE 802.11 scheme, respectively, using equations (16) and (17).

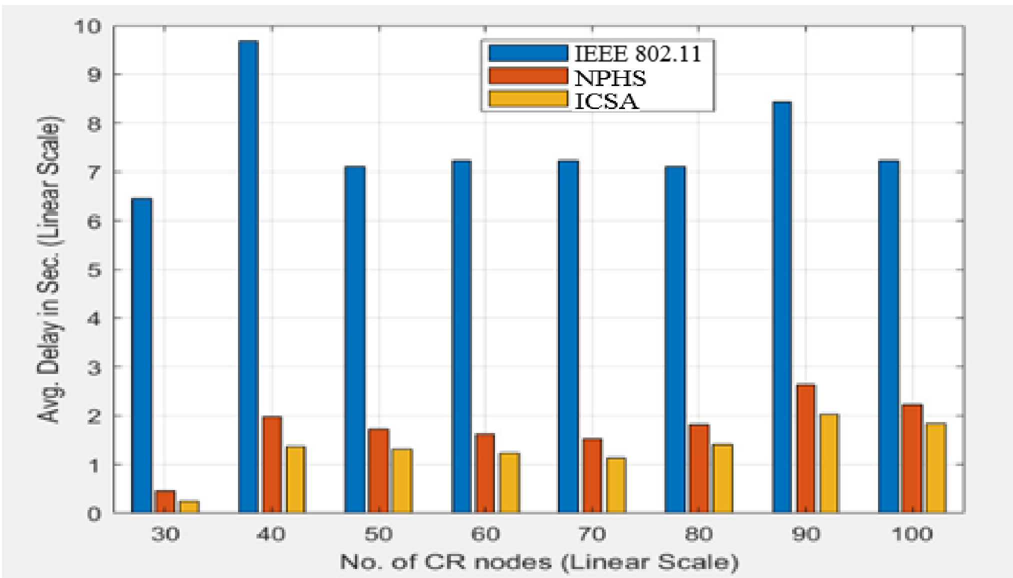

Fig. 4. Average Delay versus Number of CR Nodes

6.3. Throughput versus Number of CR Nodes

Fig. 5 plots the average throughput against the number of CR nodes for the ICSA, NPHS, and IEEE 802.11 schemes. From Fig. 5, it was observed that throughput increases with an increase in the number of CR nodes for the three schemes. This is because an increase in the number of CR nodes enhances the sensing accuracy of the PU channel, which leads to a better channel selection, thereby enhancing the average throughput of the CR network. It was observed that the ICSA had a better throughput than the other schemes because of the consideration of the SNR, which further enhances the selection process of a more accurate channel. The ICSA shows 25% and 89% improvement in throughput compared with NPHS and IEEE 802.11 scheme using equations (14) and (15).

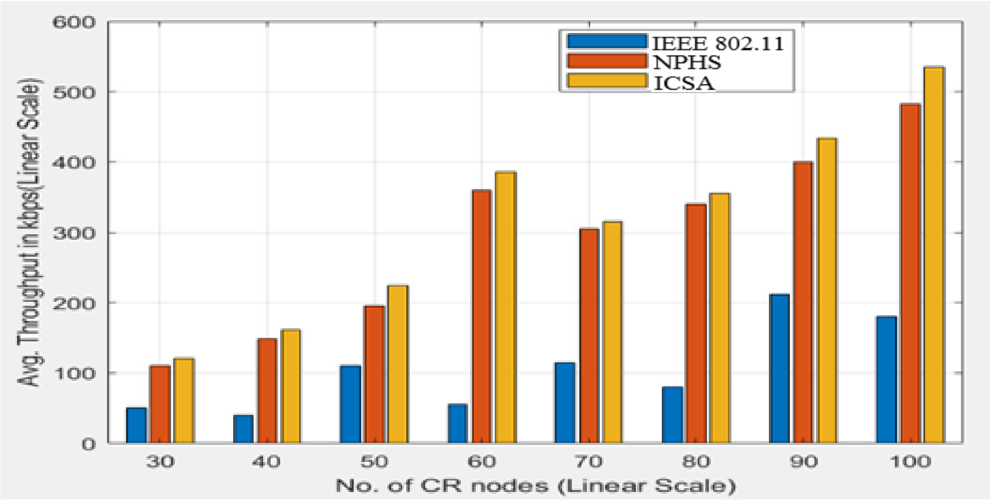

Fig. 5. Average Throughput versus Number of CR

7. CONCLUSION

This work developed an Improved Channel Selection Algorithm (ICSA) for target channel selection in cognitive radio networks. Channel occupancy and signal quality were considered serially in selecting a particular backup channel. The developed scheme experienced fewer hand-offs, reduced average delay, and improved throughput compared to other channel selection schemes.

ACKNOWLEDGEMENT

My profound appreciation goes to my institution for creating a favorable environment for this research's success.

REFERENCES

[1] V. Rajpoot and V. S. Tripathi, "A novel proactive handoff scheme with CR receiver based target channel selection for cognitive radio network," *Physical Communication*, vol. 36, p. 100810, 2019/10/01/ 2019, doi: https://doi.org/10.1016/j.phycom.2019.100810.

[2] Ridhima and A. S. Buttar, "Fundamental Operations of Cognitive Radio: A Survey," in *2019 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT)*, 20-22 Feb. 2019 2019, pp. 1-5, doi: 10.1109/ICECCT.2019.8869190.

[3] A. Kumar and K. Kumar, "Multiple access schemes for Cognitive Radio networks: A survey," *Physical Communication*, vol. 38, p. 100953, 2020/02/01/ 2020, doi: https://doi.org/10.1016/j.phycom.2019.100953.

[4] M. H. D. N. Hindia, F. Qamar, H. Ojukwu, K. Dimyati, A. M. Al-Samman, and I. S. Amiri, "On Platform to Enable the Cognitive Radio Over 5G Networks," *Wireless Personal Communications*, vol. 113, no. 2, pp. 1241-1262, 2020/07/01 2020, doi: 10.1007/s11277-020-07277-3.

[5] J. Tlouyamma and M. Velempini, "Channel Selection Algorithm Optimized for Improved Performance in Cognitive Radio Networks," *Wireless Personal Communications*, vol. 119, no. 4, pp. 3161-3178, 2021/08/01 2021, doi: 10.1007/s11277-021-08392-5.

[6] M. Aggarwal, T. Velmurugans, M. Karuppiah, M. M. Hassan, A. Almogren, and W. N. Ismail, "Probability-Based Centralized Device for Spectrum Handoff in Cognitive Radio Networks," *IEEE Access*, vol. 7, pp. 26731-26739, 2019, doi: 10.1109/ACCESS.2019.2901237.

[7] D. M. Alias and G. K. Ragesh, "Cognitive Radio networks: A survey," in *2016 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET)*, 23-25 March 2016 2016, pp. 1981-1986, doi: 10.1109/WiSPNET.2016.7566489.

[8] R. V. Awathankar, M. S. S. Rukmini, and R. D. Raut, "To Mitigate with Trusted Channel Selection Using MOORA Algorithm in Cognitive Radio Network," *Iranian Journal of Science and Technology, Transactions of Electrical Engineering*, vol. 45, no. 2, pp. 381-390, 2021/06/01 2021, doi: 10.1007/s40998-020-00382-w.

[9] J. Thomas and P. P. Menon, "A survey on spectrum handoff in cognitive radio networks," in *2017 International Conference on Innovations in Information, Embedded and Communication Systems (ICIIECS)*, 17-18 March 2017 2017, pp. 1-4, doi: 10.1109/ICIIECS.2017.8275896.

[10] A. E. Gouda, S. I. Rabia, A. Y. Zakariya, and M. A. Omar, "Reactive spectrum handoff combined with random target channel selection in cognitive radio networks with prioritized secondary users," *Alexandria Engineering Journal*, vol. 57, no. 4, pp. 3219-3225, 2018/12/01/ 2018, doi: https://doi.org/10.1016/j.aej.2017.11.011.

[11] A. Quadri, "A Channel Ranking And Selection Scheme Based On Channel Occupancy And SNR For Cognitive Radio Systems," Electrical Engineering, University of North Dakota, 2018.

[12] S. Ali, M. Shokair, M. I. Dessouky, and N. Messiha, "Backup Channel Selection Approach for Spectrum Handoff in Cognitive Radio Networks," in *2018 13th International Conference on Computer Engineering and Systems (ICCES)*, 18-19 Dec. 2018 2018, pp. 353-359, doi: 10.1109/ICCES.2018.8639388.

[13] V. Rajpoot and V. S. Tripathi, "A Dedicated CCC based Data Channel Selection Scheme with Proactive Hand-off in Cognitive Radio Network," in *2018 5th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON)*, 2-4 Nov. 2018 2018, pp. 1-6, doi: 10.1109/UPCON.2018.8597034.

[14] M. R. Manesh, A. Quadri, S. Subramaniam, and N. Kaabouch, "An optimized SNR estimation technique using particle swarm optimization algorithm," in *2017 IEEE 7th Annual Computing and Communication Workshop and Conference (CCWC)*, 9-11 Jan. 2017 2017, pp. 1-6, doi: 10.1109/CCWC.2017.7868387.