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AN IMPROVED CHANNEL RANKING ALGORITHM FOR SPECTRUM HANDOFF IN COGNITIVE RADIO AD-HOC NETWORK.

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ABSTRACT

The rapid increase in wireless communication technology in the past decade has led to scarcity of spectrum. Thus the world is moving away from fixed Spectrum Access (FSA) techniques to Dynamic Spectrum Access (DSA) techniques. Cognitive Radio (CR) is one of the spectrum access technique that makes use of DSA by allowing Secondary Users (SUs) to make use of the Primary Users (PUs) channels opportunistically. The SUs have to vacate the PUs channels when the PUs arrive on their channels in order to avoid interference with the PUs transmission. The process whereby the SUs switch their communication to another vacant channels when the PUs arrives on their channels is known as spectrum handoff. Finding other vacant channels for the interrupted SUs to continue their transmission is a challenging task. Several researchers have used different technique to select the best channel by considering channel occupancy as a criterion, but these technique still suffer some challenges such as high number of handoff, delay and low throughput. Therefore this paper presents an Improved Channel Ranking Algorithm (ICRA) that rank channel based on channel occupancy and channel signal quality. The channel with the highest rank is selected as the next target channel. Simulation was carried out using Network Simulator (NS) and the results obtained were plotted using MATLAB. The results showed that the ICRA reduced the number of handoff by 14% and 25% compared to Novel Proactive Handoff Scheme (NPHS) and IEEE 802.11 scheme, it also reduced the packet delay by 12% and 34% when compared to the NPHS and IEEE 802.11 scheme. Furthermore, the ICRA increased the throughput by 8% and 97% when compared to the NPHS and the IEEE 802.11 scheme, it also improved the packet delivery ratio by 15% and 96% when compared to the NPHS and IEEE 802.11 scheme.

Keywords: Cognitive Radio, Channel ranking, Channel occupancy, Channel signal quality, Primary users.

1. INTRODUCTION

Electromagnetic spectrum available for wireless communication is a finite resources and the demand is increasing drastically over the last decade due to the increase in the number of wireless communication devices, which leads to demand for more channels (Sumith*et al.*, 2018). Spectrum are assigned to licensed users using the Fixed Spectrum Access (FSA) techniques. According to Federal Communication Commission (FCC), spectrum assigned to the licensed owners otherwise known as Primary Users (PUs) are underutilized by the PUs, thereby leading to temporal and special spectrum underutilization (Slimeni et al., 2020). Efficient spectrum utilization can be achieved by using

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Dynamic Spectrum Access (DSA) technique (Hinal et al., 2018).

Cognitive Radio (CR) is identified as one of the techniques of DSA that enable the unlicensed users known as Secondary Users (SUs) to make use of the spectrum holes (white space) of PUs opportunistically, as illustrated in Figure 1 (Groveret al., 2018).

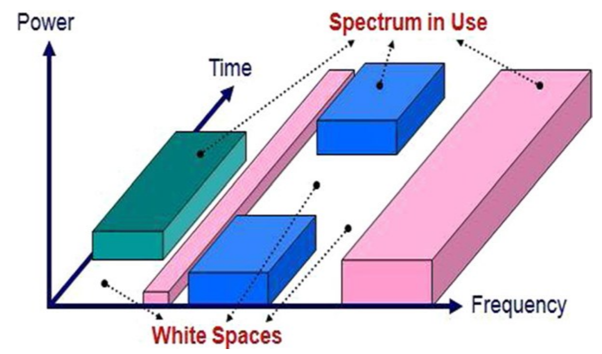

Figure 1. The concept of spectrum white space (Hindiaet al., 2020).

There are four important management frameworks in Cognitive Radio Network (CRN), as shown in Figure 2, which are required for efficient spectrum management.

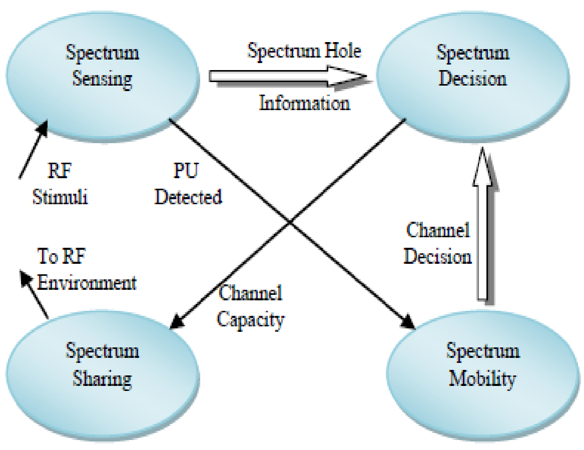

Figure 2: Cognitive Radio Management Framework (Dubey, 2018)

The first block in Figure 2 is spectrum sensing, the CR senses the spectrum to determine the spectrum holes. In addition, it capture its transmission information like occupancy status, signal strength, modulation and coding scheme, interference level, frequency and bandwidth and other characteristics of the channel. Spectrum decision involves the CR selecting the best spectrum (hole) out of the sensed spectrum. While spectrum sharing involves allocating and coordinating spectrum access among SUs and spectrum handoff or mobility involves the SUs vacating the PUs channel on the arrival of the PUs to other vacant channels (spectrum holes) in order to maintain seamless communication (Tiwari & Rastogi, 2016). Spectrum handoff aspect of the CR management frameworks is the focus of this research work.

Spectrum handoff is the process of transferring an ongoing communication between two SUs from one channel to another when the PU appears on its channel (Groveret al., 2018). Spectrum handoff schemes generally can be grouped into two category, reactive and proactive handoff scheme. The reactive handoff scheme commence search for next backup channel immediately handoff trigger occurs and as such this scheme takes a longer time to secure a vacant channel thus leading to much delay. In proactive handoff scheme, the target channel is selected prior to the occurrence of the handoff trigger, this scheme has the advantage of low delay and it is the reason why it is considered in this work (Goudaet al., 2018). Target channel selection is one of the basic challenges of CR network, selection of a channel is carried out on the basis that the channel remains idle for a long time and to avoid multiple interruptions with the SUs (Thomas & Menon, 2017**)** (Karandi & Manvi, 2015). For this reason this paper present an Improved channel Ranking Algorithm (ICRA) for spectrum handoff in CR ad-hoc network. This algorithm used channel occupancy and channel signal quality serially to rank available channel and the channel with the highest rank is selected as the next target channel.

The rest of the paper is organised as follows; section 2 is the review of related works, section 3 gives the system model, section 4 presents the methodology, section 5 presents the simulation and results and section 6 is the conclusion.

2. REVIEW OF RELATED WORKS

Goudaet al., (2018) proposed a reactive spectrum handoff combined with random target channel selection in CR networks with prioritized SUs. The proposed scheme was modeled using a mixed preemptive and non-preemptive resume priority. Target channels was chosen at random from the pool of available channels. Single and multi-user class CR network was considered. The scheme was implemented on heavy and light load network. Numerical and simulation results showed that the proposed scheme was able to reduce the handoff latency for both class of users in case of a light load network. However, for a heavy load network, the latency was high because the SU has to stay on the same channel. Rajpoot & Tripathi, (2019) proposed a NPHS with cognitive receiver based target channel selection for CR network. The proposed scheme made use of the joint probability of the channel usage information from the CR transmitter and CR receiver to rank available channels based on their occupancy. The channel with the highest probability of not being occupied by PU in previous transmission was selected as the next target channel. Simulation results showed that the developed scheme had better result when compared to other channel selection schemes in terms of average number of handoff, average delay, and throughput. However, channel signal quality was not considered as criterion for the selection of a particular backup channel. Selection of a channel with poor signal quality increases the number of handoff which leads to more delay and reduced throughput of the system. Alozieet al., (2022) proposed an intelligent process for spectrum handoff in CR network. This work used Proactive Fuzzy-Based Backup Channel Selection Scheme (PFBBCSS) that considered channel occupancy and transmission range as parameters for the selection of a particular channel for spectrum handoff. Simulation was carried out using MATLAB and results obtained showed better performance in terms of delay and throughput compared with traditional channel selection scheme. However, channel signal quality was not taken into consideration as requirement for the selection of a particular backup channel. From the literatures reviewed above, only channel occupancy was considered as parameter for the selection of a particular backup channel, considering channel signal quality in addition to channel occupancy do give better channel selection.

3. SYSTEM MODEL

The system is modelled as an ad hoc network scenario, the CRs are randomly distributed within the network and each of the CR is equipped with three radios, the transmitter, the receiver, and control. PU Channel Lists (PCL) is formed by each CR and shared among available CRs. The PCL contains information about status (active or idle) of the channels in previous transmissions. The PCL is shared among the CR nodes and it enables them to form a matrix. The matrix contains the nodes' PCL as well as the PCL received from other CR nodes. The matrix is denoted by $X^{[m]}$ and it is represented in (Rajpoot & Tripathi, 2019) by (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 have values from 1, 2, 3…M, which are the CR nodes, $X^{[m]}_{i,j}$ represents j^{th}

channel value of i^{th} node at M^{th} CR node.

For ease of understanding, $X_{i,j}^{[m]}$ have binary values. When $X_{i,j}^{[m]} = 0$, it means that j^{th} channel of i^{th} CR node is free from PU activity and so is available for cognitive user. Also, when $X_{i,j}^{[m]} = 1$, it means that j^{th} channel of i^{th} node is free of PU activity so not available for cognitive user.

The node channel matrix formed at each CR node is given in (Rajpoot & Tripathi, 2019) by (2):

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

4. METHODOLOGY

The following are the methodology adopted in the development of the ICRA:

4.1. Estimation of channel occupancy using the state back transition probability

The k/State Back Transition Probability (k/SBTP) is the probability that indicate the occupancy of PU channel in previous transmission. k/SBTP means that k + 1 consecutive time slots including k prior and current time slot of a particular channel are free from PU activity. Figure 3 shows how to calculate k/SBTP, current time slot is denoted by T_0 while previous consecutive time slots are denoted as T_{-1}, T_{-2}, T_{-3},… For example, the 1/SBTP (k=1) gives the result that T_0 and T_{-1} (current and previous) time slot of a particular channel are 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 lots) are used for the calculation of k/SBTP. The *Func* (idle time slot) returns value 1 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) (Rajpoot & Tripathi, 2019):

$Func_1$ and $Func_2$ are calculated as given by (Rajpoot & Tripathi, 2019) and presented in (3) and (4):

$$1/SBTP: zFunc_1(T_0, T_{-1},) = \begin{cases} 1 \; if \; T_0, T_1 \; are \; idle \\ 0 \; other \; wise \end{cases} \quad (3)$$

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

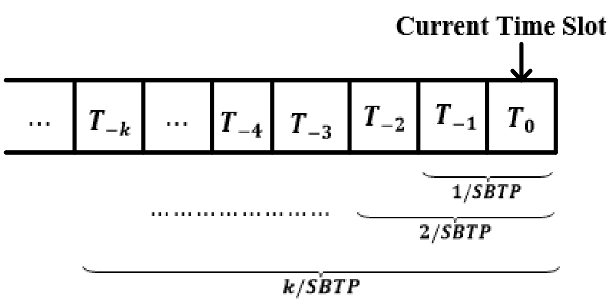

Figure 3. Primary Channel Time Slot Division (Rajpoot & Tripathi, 2019)

Likewise, we can calculate $Func_3$ (idle time slot)…$Func_k$ (idle time slots). The equation for $Func_k$ (idle time slots) is given by (Rajpoot & Tripathi, 2019) and presented in (5):

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

where k =1, 2, 3,…(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 (Rajpoot & Tripathi, 2019) and presented in (6):

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

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

A channel having highest number of prior consecutive idle time slots from current slot achieves highest weight in equation (6). This weight is used to obtain $k/SBTP$ as is given by (Rajpoot & Tripathi, 2019) and presented in (7):

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

The k/SBTB at both the transmitter and the receiver sides is calculated using (8) and (9) as given by (Rajpoot & Tripathi, 2019):

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

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

The joint probability of both the transmitter side and the receiver side is calculated using (10) (Rajpoot & Tripathi, 2019):

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

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 (11) (Maneshet al., 2017):

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

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

The channels are then ranked based on the estimated SNR using (12) (Quadri, 2018):

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

where: γ is the SNR

$\mathrm{U_{SNR}}$ represents channel ranking by SNR

4.3 Channel Selection Based on the estimated Channel Occupancy and Channel Signal Quality

Cannel selection based on the estimated channel occupancy and channel signal quality is achieved using (13):

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

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.

Table 1 shows an example of how channels are ranked based on channel occupancy and channel signal quality (SNR). The joint probability (k/SBTP) of the Cognitive Radio Transmitter (CRTs) and Cognitive Radio Receiver (CRRs) for six stages (k=6) of calculation of k/SBTP and 101 time slots (p) per channel. SNR range of -20 dB to +20dB was used in this work, a SNR condition below negative 10dB is considered poor.

Table 1. Example of how to rank channels based on channel occupancy and channel signal quality (SNR) estimation

S/N	1SBTP	2/SBTP	…	6/SBTP	7/SBTP	SNR	Ranked by SNR
1.	0.01(C7)	0.04(C7)	…	0.36(C4)	0.49(C4)	18	1st
2.	0.01(C2)	0.04(C2)	…	0.36(C1)	0.49(C1)	7	2nd
3.	0.01(C1)	0.04(C1)	…	0.36(C10)	0.49(C1)	1	3rd
4.	0.01(C4)	0.04(C9)	…	0.36(C7)	0.49(C7)	-9	4th

5.	0.01(C6)	0.04(C4)	…	0.36(C2)	0.36(C2)	−	−
6.	0.01(C3)	0.04(10)	…	0.09(C9)	0.09(C9)	−	−
7.	0.01(C5)	0.04(C3)	…	0.04(C8)	0.04(C8)	−	−
8.	0.01(C8)	0.04(C8)	…	0.04(C3)	0..01(C3)	−	−
9.	0.01(C10)	0.01(C6)	…	0..01(C6)	0.01(C6)	−	−
10.	0.01(C9)	0.01(C5)	…	0.01(C5)	0.01(C5)	−	−

4.4 Improved Channel Ranking Algorithm

Figure 4 shows the flow chart of the ICRA, the portion marked red is the improvement. It starts with the calculation of 1/SBTP to check if two consecutive time slots of a particular channel are free from PU activity or not, using the PU PCL stored at each of the CR nodes (2). 1/SBTP of all channels is then compared with a local threshold which has an initial value of 0. $2/SBTP$ is only calculated for channels that have 1/SBTP greater than the value of the local threshold, for calculation of 2/SBTP, the value of the threshold is increased to the value of 1/SBTP for each channel. The process continue until channel (s) with maximum probability of not being occupied by PU in previous transmission is obtained. If at the final stage of calculation of the SBTP, only one channel has maximum k/SBTP, it is selected as the next backup channel, otherwise, SNR of those channel are estimated and the channel with the maximum SNR is selected as the next backup channel, otherwise, next target channel is selected randomly if more than one channel has maximum SNR.

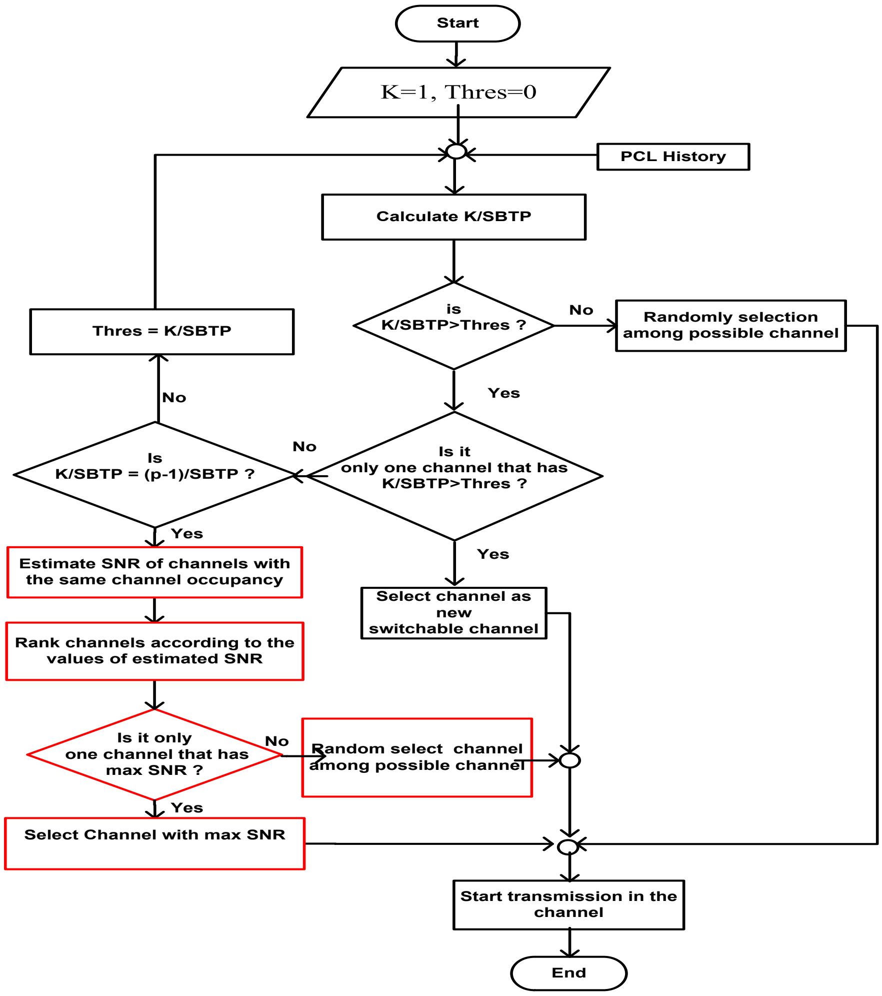

Figure 4. Flow chart for the Improved Channel Ranking Algorithm

5. SIMULATION AND RESULTS

The simulation parameter used for this work are as shown in Table 2.

Table 2: simulation parameters (Rajpoot & Tripathi, 2019)

S/N	Simulation Parameters	Values
1.	Simulator	Network Simulator (NS)
2.	Routing Protocol	AODV
3.	Topology dimension	1000 × 100 (m^2)
4.	Max. No. of CR nodes	100
5.	No. of PUTx	10
6.	No. of PURx	10
7.	Total No. of channels	11
8.	No. of PU channel	10 (8 MHz bandwidth each)
9.	No. of control channel	1 (902 MHz)
10	PUTx transmission range	500 m
11.	CR users transmission	250 m

	range	
12.	Data rate	Mbps
13.	Interference queue length	50 packets
14.	Simulation time	50 s
15.	Packet size	512 Bytes
16.	Traffic type	CBR

Also presented in this section are the results of the ICRA, NPHS, and the IEEE 802.11 Scheme. The performance of the network is observed with respect to variable packet rate. To measure the performance of the network, results for average number of handoff, average delay average throughput and packet delivery ratio were evaluated. The ICRA was then compared with the NPHS and the IEEE 802.11 scheme of (Rajpoot & Tripathi, 2019) to find the percentage increase or decrease for the performance metrics.

5.1 Number of Handoff versus Packet Rate

Figure 5 is a plot of number of handoff against packet rate for ICRA, NPHS and IEEE 802.11 scheme. From the results it is observed that, the IEEE 802.11 scheme experienced more number of handoff compared to ICRA and NPHS. This is because the IEEE 802.11 scheme is a reactive scheme, channel usage information is only gathered the moment handoff trigger occurs. Also, the ICRA experience less number of handoff when compared to the NPHS and IEEE 802.11 scheme because of the consideration of channel signal quality in addition to channel occupancy as criteria for the selection of a particular backup channel. The ICRA showed 14% and 25% reduction in number of handoff when compared to the NPHS and IEEE 802.11 scheme (Rajpoot & Tripathi, 2019).

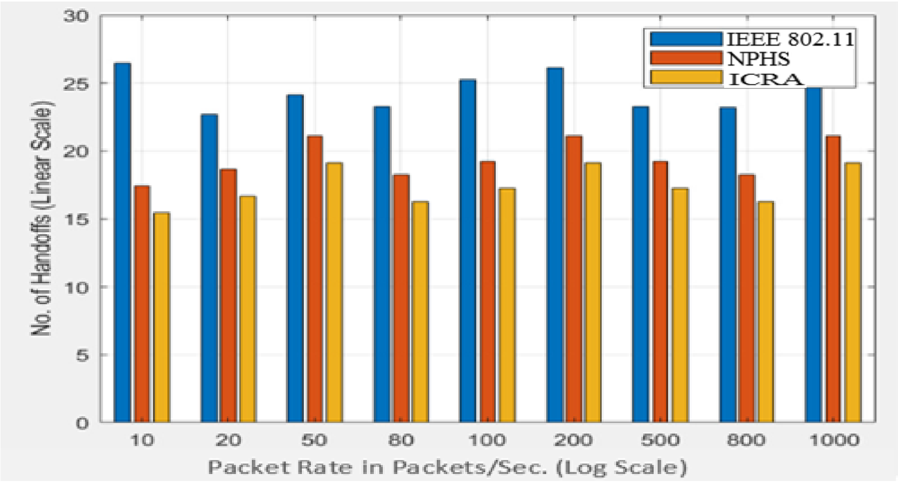

Figure 5: Number of Handoffs versus Packet Rates

5.2 Average Delay versus Packet Rate

Figure 6 shows the plot of average delay against packet rate for ICRA, NPHS and IEEE 802.11 scheme. From the result it is observed the IEEE 802.11 scheme experience more delay than the other scheme, this is because it is a reactive scheme, it only obtains information about the channel occupancy the moment handoff trigger occurs, also it appears to perform better than the other scheme initially because it select channels that appear promising which was used for transmission for a short period of time which later becomes unavailable due to the appearance of the PU. The ICRA and NPHS experience less number of handoff compared to the reactive scheme because they are proactive scheme, also the ICRA experience less delay when compared to the other scheme because of the consideration of channel signal quality in addition to channel occupancy as criteria for the selection of backup channel which leads to less number of handoff and less delay in the selection of backup channel. The ICRA experienced 12% and 34% reduction in average delay compared to the NPHS and IEEE 802.11 scheme (Rajpoot & Tripathi, 2019).

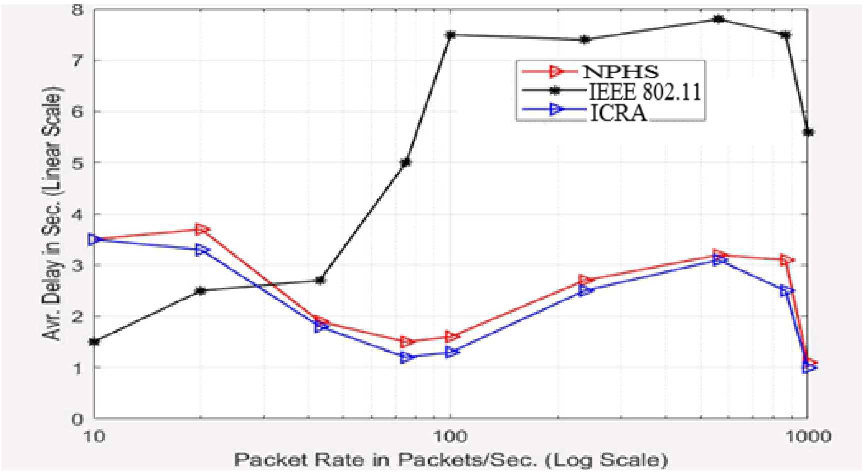

Figure 6: Average Packet Delay versus Packet Rates

5.3 Throughput versus Packet Rate

Figure 7 is a plot of average throughput at different packet rate for ICRA, NPHS and IEEE scheme. As observed from the plot, the average throughput for the network increases as the packet rate increases for all the schemes. This shows the efficiency of the schemes in ensuring proper utilization of the available channels by the CR nodes. It is observed that the performance of ICRA is better than NPHS and IEEE 802.11 scheme. This is due to the consideration of channel signal quality in addition to channel occupancy as criteria for the selection of a particular backup channel. The consideration of this factors reduces the number of spectrum handoff and delay in channel selection which ultimately increase the throughput of the network. The ICRA shows an average throughput improvement of 8% when compared to NPHS and 97%, when compared to IEEE 802.11 scheme (Rajpoot & Tripathi, 2019).

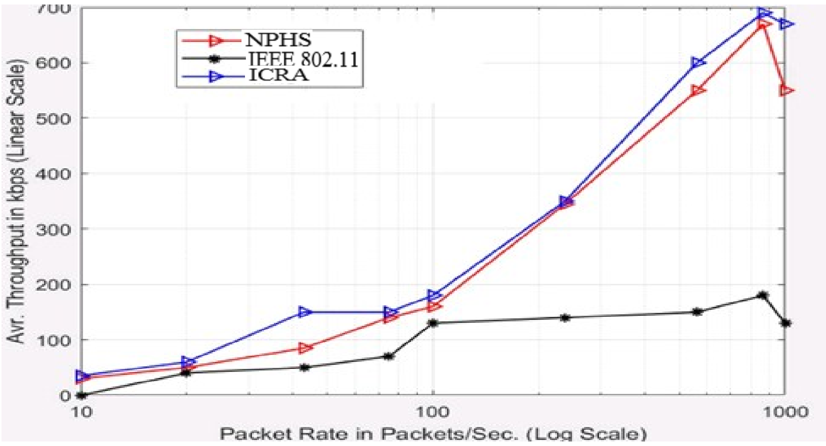

Figure 7: Average Throughput versus Packet Rates

5.4 Packet Delivery Ratio versus Packet Rates

Figure 8 is a plot of packet delivery ratio against packet rate in seconds. From the graph it can be seen that, the packet delivery ratio drops as packet rate increases. This is due to limited CR node processing capability as limited channel are available for packet transmission. Packet delivery ratio of ICRA is better than both NPHS and IEEE 802.11 scheme due to the consideration of the SNR of the channels which enhances the selection process of a better channel for the CR node transmission. The ICRA shows 15% and 96% improvement in packet delivery ratio when compared with NPHS and IEEE 802.11 scheme (Rajpoot & Tripathi, 2019).

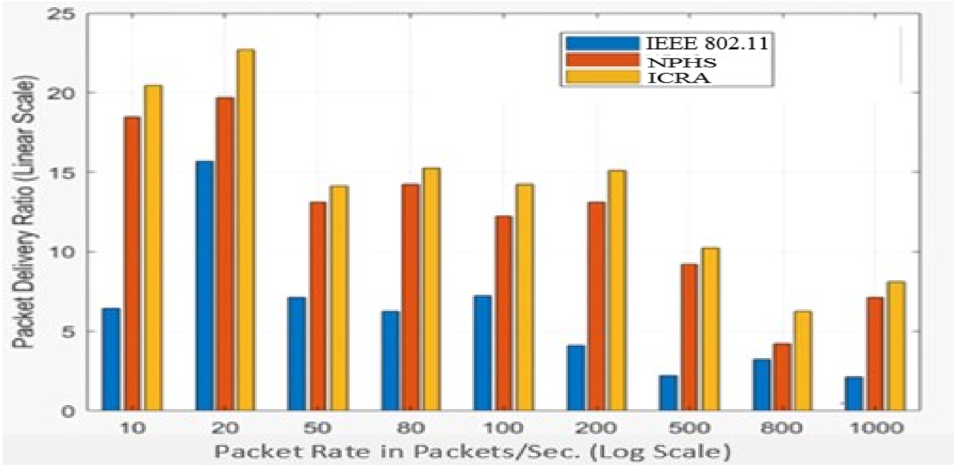

Figure 8: Average Packet Delay versus Packet Rates

6. CONCLUSION

Accurate target channel selection is an important aspect of spectrum handoff in CR network. It enables the interrupted SUs to have access to the best channel to continue their interrupted communication. The ICRA for spectrum handoff in CR ad-hoc network has been implemented by taking into consideration channel occupancy and channel signal quality as criteria for the selection of backup channel for spectrum handoff. Simulation was carried out using Network simulator. The results obtained showed that the ICRA experienced reduced number of handoff which led to low delay, increased throughput and high packet delivery ratio compared with the NPHS and IEEE 802.11 scheme.

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