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An Improved Proactive Handoff Scheme (IPHS) for Target Channel Selection in Cognitive Radio Network

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ABSTRACT

In recent years, one of the challenges of spectrum allocation and utilization was fixed spectrum allocation which lead to spectrum scarcity and underutilization. In an attempt to address this challenge, Cognitive Radio Network (CRN) which uses Dynamic Spectrum Access (DSA) was proposed. It allows licensed users' or Primary Users' (PUs) spectrum to be shared with unlicensed users or Secondary Users (SUs). DSA could be achieved by developing an effective channel selection scheme for SUs spectrum handoff. Selecting an appropriate channel for the SUs to continue their interrupted transmission is a challenging task. Several researchers have used different techniques such as Novel Proactive Handoff Scheme (NPHS) to enhance accurate channel selection for spectrum handoff by considering only channel occupancy. These techniques still suffer some set back like high number of spectrum handoff and delay in channel selection. This paper presents an Improved Proactive Spectrum Handoff Scheme (IPHS) for accurate target channel selection in CRN. The improvement is achieved by considering channel signal quality in addition to channel occupancy as a criteria for the selection of a backup channel for spectrum handoff. Simulation results showed that the IPHS reduced the number of spectrum handoff by 15% and 26% as compared to NPHS and IEEE 802.11 scheme respectively. The average delay was also reduced by 13% and 35% as compared to NPHS and IEEE 802.11 scheme respectively.

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1. INTRODUCTION

Radio resources usage and regulations on radio emissions are controlled by government agencies like the Federal Communication Comission (FCC). Spectrum is assigned to licensed owner known as Primary Users (PUs) using Fixed Spectrum Access (FSA), on a long term basis for geographical regions and other users are prohibited from using the spectrum leading to spectrum scarcity. According to FCC, 15% to 85% of spectrum assigned to PUs are under utilized (Kumar & Kumar, 2020). Efficient channel utilization can be achieved by Dynamic Spectrum Access (DSA) technique (Aggarwal *et al.*, 2019). Cognitive Radio Network (CRN) has proven to be efficient in spectrum utilization due to its DSA techique (Alias, 2016). CRN enables unlicensed users known as Secondary Users (SUs) to use the PUs spectrum opportunistically (Bharathy *et al*, 2021).

CRN addresses the challenge of spectrum scarcity and spectrum underutilization associated with FSA by allowing SUs to have access to PUs spectrum without causing interference to PUs transmissions (Buttar, 2019). In order for the CRN to be able to achieve this, it requires four important functionalities: (i) Spectrum sensing, (ii) Spectrum management, (iii) Spectrum sharing and (iv) Spectrum handoff (Hindia, *et al*, 2020).

Spectrum sensing enables SUs to detect the presence of PUs. It also enables SUs to locate vacant time slots i.e spectrum holes, to transmit their data. Spectrum decision allows the SUs to select the best spectrum hole out of the sensed spectrum. Spectrum sharing involves allocating and coordinating spectrum access among SUs. Spectrum handoff enables SUs to switch between channels when PUs appears on licensed channels (Bharathy *et al*, 2021).

There are three basic ways in which SUs can access the PUs spectrum. These are: (i) spectrum overlay, (ii) spectrum underlay and (iii) spectrum interweave. In the spectrum overlay, SUs can only transmit when the PU is not transmitted on the licensed channel. In spectrum underlay, SUs can transmit concurrently with the PU provided their transmit power set below the interference temperature limit. In interweave approach, SUs can only use those spectrum that have not been used by PUs for a long period of time (Mishra & Vidyarthi, 2019).

Spectrum handoff is the process of transfering an ongoing communication between two SUs from one channel to another when the licensed owner appears on a channel (Tlouyamma & Velempini, (2021). Spectrum handoff scheme is in two categories based on target channel selection. This includes reactive and proactive handoff scheme. In reactive handoff scheme, the target channel is selected the moment handoff trigger occurred, while in proactive handoff scheme the target channel is selected prior to the occurrence of handoff trigger. The proactive handoff scheme was adopted in this work due to its advantage of low latency compared to the reactive handoff scheme (Thomas, & Menon, 2017).

Channel selection is one of the basic challenges of spectrum handoff in CRN (Thomas, & Menon, 2017). Channel selection schemes can be categorized into three (Grover *et al.*, 2018): (i) Centralized scheme, where the central node obtains the link and local spectrum information such as load on each channel and capacities of available channels from all other nodes. The central node makes the decision about channel selection to all channel and then disseminate the information to all nodes in the network, (ii) Distributed channel selection scheme which makes use of information from all nodes in the network in order to make the decision of which channel to be selected for a particular link. This scheme is more robust compared to others because channel selection does not depend on one entity i.e., single node. Therefore, degradation in the performance of one of the nodes does not affect performance on all over the network. This was the reason why it is adopted in this work. (iii)

Decentralized channel selection scheme makes use of a cluster based wireless network. In this scheme, a node from a cluster is made a cluster head to compute the interface of all other nodes in the cluster using the local information of the cluster. After this, all the cluster head cooperate and distribute information to determine the inter-cluster channel selection.

This paper, presents an Improved Proactive Spectrum Handoff Scheme (IPHS) that takes into consideration channel signal quality (which is a limitation in the works of previous researchers). This scheme is used in addition to channel occupancy in the selection of back up channel for spectrum handoff. Selecting a channel with poor signal quality will increase the number of spectrum handoff, and invariably leads to more delay. The rest of the paper is structured as follows. Section two (2) reviews of related works, section three (3) consists of research methodology, section (4) presents results and discussion and section (5) is conclusion.

2. RELATED WORKS

Aggarwal et al., (2019) proposed a probability-based centralized device for spectrum handoff in cognitive radio networks. The proposed scheme made use of a reactive central cognitive device that takes over the cognitive function of the SUs. It consists of a queue that prioritized the handoff request and a probabilistic algorithm that performed spectrum sensing. When a handoff trigger occurred, the SUs demand a channel from the central cognitive device, which then senses the available spectrum and allocate a channel to the SUs that request a channel. Simulation result revealed that the probability-based centralized cognitive device for spectrum handoff had a better performance when compared with the traditional reactive and proactive sensing spectrum handoff scheme in terms of accuracy of target channel selection and handoff latency. However, the scheme leads to inefficient spectrum utilization due to the fact that the channel occupancy was not considered based on time slots.

A novel proactive handoff scheme (IPHS) with cognitive receiver based target channel selection for cognitive radio ad hoc network has been proposed by Rajpoot & Tripathi (2019). The past channel usage information at the transmitter and the receiver are used to calculate the state back transition probability. This was used to rank the available channels base on their occupancy probability and the channel with the maximum probability of not being occupied in the previous transmission. It was selected as next target channel for spectrum handoff. The simulation result showed that this scheme achieved target channel selection more accurate when compared with the traditional reactive handoff schemes. However, channel signal quality was not considered in the work. Considering channel occupancy alone as the only criterion for the selection of a suitable channel can affect the accuracy of target channel selection due to the fact that selecting a channel with poor signal strength can increase the number of handoff which can result in increased latency.

Rodrigues et al., (2020) proposed a deep reinforcement learning based optimal channel selection for cognitive radio vehicular ad hoc network. The scheme made use of Road Side Sensing Units (RSU_S) located on different parts of the road segment that sense the channels within their sensing range and share their sensed information with other RSU_S. Each RSU used the information to calculate the probability of primary user activity in previous transmission and the channel with the least probability of PU arrival was selected as the next target channel. This was made available to any vehicle on request. Simulation result showed that the scheme achieved a better result compared to other channel selection schemes. However, in their work, they assumed the channel capacity of all the channels to be fixed by assuming a constant SNR for all the channels which limited the criteria for channel selection. This resulted to poor channel selection, thereby increasing the number of handoff and delay in channel selection.

From the related works above, channel occupancy was the only factor considered in the selection of a particular channel, considering channel signal quality in addition to channel occupancy do give better channel selection.

3. RESEARCH METHODOLOGY

The following are the steps adopted in the development of the Improved Proactive Handoff Scheme (IPHS).

1) Estimation of the occupancy of the PUs channels, ranking of the channels based on channel occupancy and selection of the channel with the maximum rank as a backup channel.
2) If there are more than one channel with the same channel occupancy based on the first stage ranking, then channel signal quality is estimated.
3) The channels in step two (2) above are then ranked based on channel signal quality or Signal to Noise Ratio (SNR).
4) The channel with the maximum rank is then selected as the next backup channel.

3.1. Channel occupancy estimation

The Cognitive Radio (CR) nodes are randomly deployed in the network. These nodes sense the Primary Users (PUs) channel that are within their sensing range and send their information to other nodes in the network. This information are stored in the form of matrix in each of the CR nodes as represented as (Rajpoot & Tripathi, 2019)

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

Where m represent $1, 2, 3, \cdots$ M. M denotes CR nodes (SU), N represents PU, $X^{[m]}_{i,j}$:jth channel value of ith node of Mth node. When $X^{[m]}_{i,j} = 0$ it means jth channel of ith CR is unoccupied by PU. When $X^{[m]}_{i,j} = 1$, it means jth channel of ith node is occupied by PU, so it can not be used by CR user.

The node matrix formed at each CR node for the whole network is represented by:

$$X = \left[X^{[1]}, X^{[2]}, \cdots, X^{[M]}\right] \tag{2}$$

The k State Back Transition Probability (SBTP) is calculated from the information stored in the nodes (Equation 2) using the exponential ON/OFF model. The SBTP is the probability that indicates the occupancy of the PU in the previous transmission. Where k stands for the value of the stages of SBTP. k/SBTP indicates that a total of k+1 time slots, including k prior and present time slots, are not occupied by the PU. **Figure 1** shows how k/SBTB is calculated. T_0 represents the current time slot, while previous consecutive time slots are represented by T_{-1},T_{-2},T_{-3}, …,. The 1/SBTP shows that time slots T_0 and T_{-1} are not occupied by the PU. Each channel has a total of p time slots, so a total of $p - 1/SBTP's$ can be calculated. $Fun\ c_k$ (idle time slots) and sum (idle time slots) are used to calculate the k/SBTP.

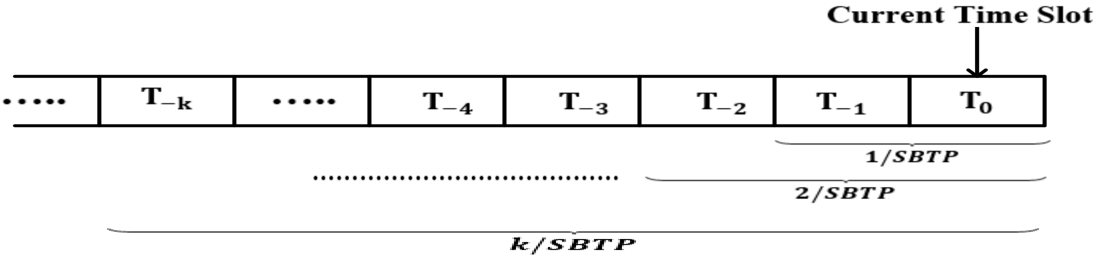

Figure 1: Primary Channel Time Slot Division (Rajpoot and Tripathi, 2019)

The function $Fun\ c_k$ (idle time slots) returns the value 1 if k consecutive time slots of a channel are found idle and function sum (idle time slots) returns the summation of the function $Fun\ c_k$ (idle time slots).

The calculation of $Fun\ c_1$ and c_2 are as follows (Rajpoot and Tripathi, 2019)

$$1/\mathrm{SBTP}: \mathrm{Fun}\ \mathrm{c}_1\ (\mathrm{T}_{0,}\mathrm{T}_{-1}) = \begin{cases} 1\ if\ T_0, T_{-1}\ are\ not\ occupied \\ 0\ other\ wise \end{cases} \quad (3)$$

$$1/\mathrm{SBTP}: \mathrm{Fun}\ \mathrm{c}_2\ (\mathrm{T}_{0,}\mathrm{T}_{-1}, \mathrm{T}_{-2}) = \begin{cases} 1\ \text{if}\ \mathrm{T}_0, \mathrm{T}_{-1}, \mathrm{T}_{-2}\ are\ not\ occupied \\ \quad 0\ \text{other wise} \end{cases} \quad (4)$$

Similarly, we can calculate Fun c_3 (idle time slots) until Fun c_k (idle time slots). The equation for calculating Fun c_k can be written as (Rajpoot and Tripathi, 2019):

$$\mathrm{k/SBTP: Fun}\ \mathrm{c_k}\ (\mathrm{T}_0, \mathrm{T}_{-1}, \dots, \mathrm{T}_{-k}) = \begin{cases} 1\ \text{if}\ \mathrm{T}_0, \mathrm{T}_{-1}, \dots, \mathrm{T}_{-k} \\ 0\ \text{otherwise} \end{cases} \quad (5)$$

The maximum consecutive time slots are indicated by k$= 1, 2, 3, \dots, (p-1)$. The sum (idle time slots) function is used to obtain the summation of all func (idle time slots) function. For all values of k, the $Sum_{\ k}$, is given (Rajpoot and Tripathi, 2019) as:

$$\mathrm{Sum}_{\ \mathrm{k}}\ (\mathrm{T}_0, \mathrm{T}_{-1}, \dots, \mathrm{T}_{-k}) = \sum_{\mathrm{i}=1}^{\mathrm{p}-1} \mathrm{Fun}\ \mathrm{c_i}\ (\mathrm{T}_0, \mathrm{T}_{-1}, \dots, \mathrm{T}_{-k}) \quad (6)$$

A channel having the highest number of time slots that are not occupied from the current time slot achieves the highest weight based on Equation (7). The weight is used to obtain the k/SBTP as given by Equation (7) (Rajpoot and Tripathi, (2019))

$$\mathrm{P_k}(\mathrm{T}_0, \mathrm{T}_{-1}, \dots, \mathrm{T}_{-k}) = \frac{\mathrm{Sum_k}(\mathrm{T}_0, \mathrm{T}_{-1}, \dots, \mathrm{T}_{-k})}{\mathrm{p}-1} \quad (7)$$

The k/SBTB at both the transmitter and the receiver sides is calculated using Equations (8) and (9) (Rajpoot and Tripathi, (2019))

$$\mathrm{P_{Tx}} = \mathrm{P_k}(\mathrm{P}_0, \mathrm{T}_{-1}, \dots, \mathrm{T}_{-k}) \quad (8)$$

$$\mathrm{P_{Rx}} = \mathrm{P_k}(\mathrm{P}_0, \mathrm{T}_{-1}, \dots, \mathrm{T}_{-k}) \quad (9)$$

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

$$\mathrm{P_{joint}}(\mathrm{T}_0, \mathrm{T}_{-1}, \dots, \mathrm{T}_{-k}) = \mathrm{P_{Tx}} \times \mathrm{P_{Rx}} \quad (10)$$

3.2. Channel signal quality (SNR) estimation using Eigenvalue Based Covariance Matrix

When there are more than one channel that have the same channel occupancy based on the first stage ranking, then channel signal quality of those channels are estimated using the Eigen Value Covariance Matrix. This is given by Equation (11) (Manesh et al., (2017))

$$\mathrm{X} = \frac{\left(\sum_{\mathrm{j}=1}^{\mathrm{L}} \sum_{\mathrm{i}=1}^{\mathrm{N}} |\mathrm{x_{i,j}}|^2\right)}{\mathrm{NL}\hat{\sigma}_{\mathrm{z}}^2} - 1 \quad (11)$$

Table 1. Example on how to rank and select channel base 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)	-12	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)	-	-

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

3.3. Ranking the channel based on the estimated SNR

Channel ranking based on the estimated SNR is achieved using Equation (12) (Adnan Quardri, 2018**)**

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

Where: X is the SNR, $\mathrm{U_{SNR}}$ represent channel ranking by SNR

3.4. Channel selection based on the estimated occupancy and channel signal quality (SNR)

Channel selection based on the estimated occupancy and channel signal quality (SNR) is achieved using Equation (13)

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

Where δ_m represent the channel availability for transmission based on the estimated channel occupancy and channel signal quality (SNR). **Table 1** shows channels with different values of channel occupancy (k/SBTP) with four channels ranked as channels with maximum channel occupancy. The SNR of the four channels are estimated and ranked based on their SNR values. Hence, the channel with the maximum SNR is selected as the backup channel for spectrum handoff.

Table 2. Simulation Parameters (Rajpoot & Tripathi, 2019)

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 $\mathrm{PUT_S}$	10
5.	No. of $\mathrm{PUR_X}$	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.	$\mathrm{PUT_S}$ transmission range	500 m
10.	CR users 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 que length	50 packets
16.	Routing protocol	AODV

3.5. Performance Evaluation

The percentage reduction in number of handoff and average delay is achieved using the percentage reduction formula:

$$= \frac{\sum_{n=1}^{N}\left(\frac{\mathrm{NPHS} - \mathrm{IPHS}}{\mathrm{NPHS}}\right)}{\mathrm{N}} \times 100\% \qquad (14)$$

$$= \frac{\sum_{n=1}^{N}\left(\frac{\mathrm{IEEE\ 802.11} - \mathrm{IPHS}}{\mathrm{IEEE\ 802.11}}\right)}{\mathrm{N}} \times 100\% \qquad (15)$$

Where n represents number of samples and N is the total number of sample.

In order to ensure that the method is valid, simulation was performed using parameters shown in **Table 2**.

4. RESULTS AND DISCUSSION

In this section, the results of the Improved Proactive Handoff Scheme (IPHS), the Novel Proactive Handoff Scheme (NPHS) of Rajpoot and Tripathi, (2019), and the IEEE 802.11 scheme are discussed. The performance of network was observed with respect to packet rate. In order to measure the performance of the network, the results for average number of handoff and average delay were analyzed.

4.1. Average Number of Handoff versus Packet Rate

Figure 2 shows the plot of handoff number at different packet rate for IPHS, NPHS and IEEE 802.11 scheme. Here, the IPHS was compared with NPHS and IEEE 802.11 schemes to determine the scheme with less number of average handoff. It was observed from **Figure 2** that the IEEE 802.11 scheme experiences more number of handoff when compared to the IPHS and NPHS. This can be occurred because the IEEE 802.11 is a reactive scheme, where the occupancy of the channel is calculated the moment the handoff trigger occurred.

The other schemes are proactive, in which the occupancy of the channels are calculated prior to the occurrence of the handoff trigger. Also, it was observed that the IPHS had lesser number of handoff when compared to NPHS. This is due to the consideration of both channel occupancy and Signal to Noise Ratio (SNR) to validate the quality of the channel before handoff are executed.

The use of these parameters further led to the selection of a more efficient channel for transmission by cognitive radio nodes. Hence, IPHS has relatively the lowest number of handoffs for different packet rates. The IPHS showed 15% reduction in number of handoffs when compared to NPNS and 26% reduction when compared to IEEE 802.11 scheme based on Equations (14) and (15).

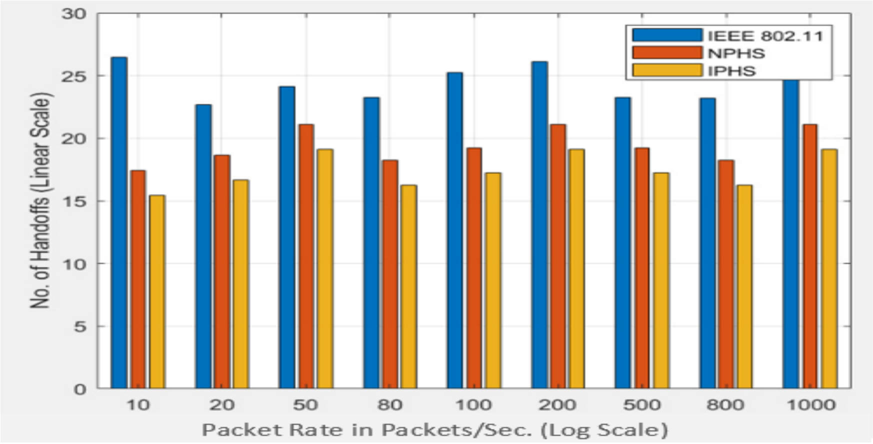

Figure 2: Number of Handoffs versus Packet Rates

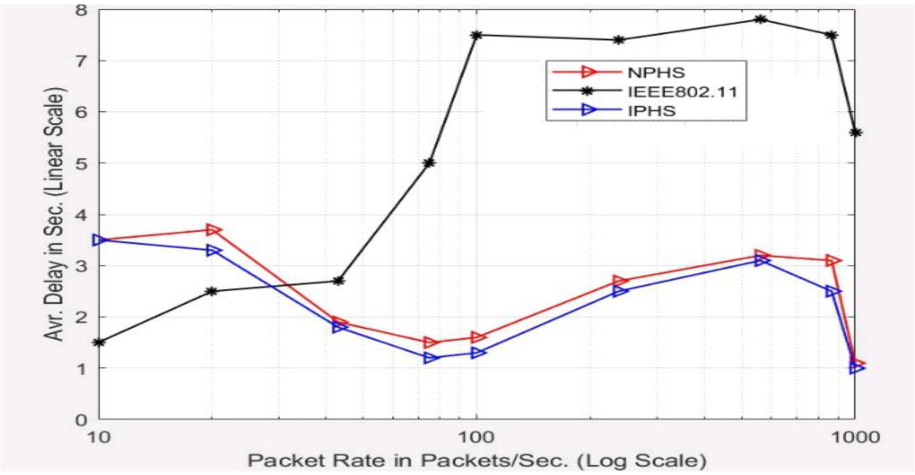

Figure 3: Average packet delay versus packet rates.

4.2. Number of Handoffs versus Number of CR Nodes

Figure 3 shows a plot of average delay at different packet rate for IPHS, NPHS and IEEE 802.11 schemes. In general, it was observed that an increase in packet rate leads to an increase in network average delay. When the packet rate is between 20 to about 70 packets per second, the average network delay drops for both IPHS and NPHS. This is due to the fact that the system has less packet to process for both schemes. There is a steady increase in average delay from 70 to 562 packet/sec., which is due to the increase in packet rate. In addition, there is a sudden drop in the average delay for IPHS, NPHS and, IEEE 802.11 schemes from 562 to 1000 packet rate, because of the successful delivery of sent packets. The IPHS showed 13% reduction in average delay compared to NPHS and 35% reduction compared to IEEE 802.11 based on Equations (14) and (15).

5. CONCLUSION

Due to inaccurate channel selection during spectrum handoff in Cognitive Radio Network (CRN), this research developed an Improved Proactive Handoff Scheme (IPHS) for accurate target channel selection in Cognitive Radio Network (CRN). The developed scheme is based on channel occupancy and channel signal quality serially as criteria for the selection of a particular channel. Simulation results showed that the developed scheme enhances the performance of CRN in terms of reduced number of handoff and average delay when compared with other channel selection schemes.

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