SPECTRUM-AWARE DISTRIBUTED CHANNEL ASSIGNMENT FOR COGNITIVE RADIO WIRELESS MESH NETWORKS

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ABSTRACT

In Cognitive Radio Networks, the application throughput is not only affected by primary user activity but also by numerous environment factors such as interference. Therefore, channel assignment for cognitive radio networks should not only consider channel idle time but also an error rate perceived on the channel. The spectrum-aware channel assignment is vital to efficiently utilize the network resources. In this paper, we propose Spectrum-aware Channel Assignment (SaCA) algorithm for multi-radio, multi-channel cognitive radio networks. We have simulated our proposed algorithm in OMNeT++, an open source discrete event simulator, and compare its performance with the spectrum-unaware channel assignment (SuCA) algorithm. The performance of channel assignment is evaluated for packet delivery ratio and number of channel switches by varying the number of primary users, number of channels and primary user activity ratio. The performance of SaCA is better for large number of channels, primary users and higher primary user activity ratio in the network. In comparison with SaCA, average packet delivery ratio more sharply decreases with increase in number of primary users for SuCA.

Keywords: Cognitive Radio Networks, Channel Assignment, Dynamic Spectrum Access, Wireless Mesh Networks

1.0 INTRODUCTION

Dynamic Spectrum Access (DSA) has emerged as a new communication paradigm to cope with underutilization problem of fixed spectrum allocation in wireless networks. In fixed spectrum allocation, license holders are allocated a spectrum on a long term basis for large geo-graphical regions. Temporal and spatial utilization varies from 15% to 85% [1]. Fixed spectrum assignment policy has been adopted for a long time in the past, but due to scarcity of spectrum and underutilization of allocated spectrum, it is considered as an inefficient spectrum assignment mechanism. On the other hand, DSA is based on cognitive radio technology that has an ability to change its transmitter parameters based on the interaction with its operating environment [1]. Cognitive radio technology can identify allocated but currently unused spectrum and select the best available spectrum using cognitive capability and reconfiguration [2].

Wireless Mesh Networks comprising mainly of Mesh routers, Mesh Gateways and Mesh clients, are envisioned to expand internet access in urban and rural areas. Mesh routers provide route between different mesh clients whereas Mesh Gateways are used to interconnect different wireless networks such as cellular networks and WiFi. The Mesh Client (MC) could be a stationary workstation, or mobile user that communicates across the internet. WMNs provide promising services to the end user in the form of a broadband home networking, community and neighborhood networks [3]. Nevertheless, the performance of such nodes is restricted due to limited availability of bandwidth to each node in close proximity of large number of nodes. This problem can be mitigated by using cognitive radios in such devices to find currently unused spectrum in the locality other than the available unlicensed spectrum [4]. These technologies have been incorporated in COgnitive Mesh NETwork (COMNET) algorithmic framework [4], thus recognizing spectrum-aware self-managed mesh network. Cognitive Radios are playing an important role in communication paradigm shift by significantly alleviating the artificial spectrum scarcity caused by wrong spectrum policy management. They reduce the effect of user saturation in unlicensed spectrum while improving the network capacity of unlicensed networks. The availability of increased spectrum resources enables a number of applications to improve their performance and contribute in emergence of novel applications. Multiple heterogeneous spectrum opportunities are available on temporal and spatial basis which require similar transmissions on all or some of available nodes. As the available channels have different primary user activity intensity and data error rates, so it requires intelligent channel assignment decisions. Channels with high idle time and less error rates should be selected. In this manner, node can suffer less channel switching delay and retransmissions.

Channel Assignment is the process of allocating available channels to radio interfaces on a node to enhance network capacity and reduce the interference. Improvement in channel assignment algorithms is vital to get better throughput by exploiting radios and channels diversity in cognitive radio networks. Channel Assignment is an NP-Hard and its NP-Hardness is proven in [24]. Channel Assignment solution mainly focusses on Connectivity and Interference. Connectivity can be affected by sudden changes in available spectrum such as primary user activity and interference which may affect paths used by existing flows. To improve the packet delivery ratio of nodes across Cognitive Radio Network, we have proposed a spectrum-aware channel assignment algorithm for cognitive radio wireless mesh networks. We define the spectrum-awareness as the algorithm capability to know the spectrum characteristics such as primary user activity duration and error rate. The algorithm computes ranking function values on the basis of channel characteristics and assigns the channel with higher ranking function value to different interfaces.

The rest of the paper is organized as follows. Section 2 discusses the background to provide the basic knowledge of dynamic spectrum access and cognitive radio networks. Section 3 presents the related work along with the discussion of its relevance with and difference to our work. In section 4, System Model is discussed. Spectrum-aware channel assignment algorithm is presented in section 5. Section 6 discusses the extension in OMNeT++ for simulating the CRNs. Simulation setup is explained in section 7. Section 8 discusses the result by highlighting the performance difference in SuCA and SaCA. Finally, we conclude our paper by summarizing the performance evaluation of the proposed channel assignment algorithm. Table 1 shows the list of acronyms used in the paper.

Table 1 List of Acronyms

Symbol	Description
CC	Control Channel
CR	Cognitive Radio
CRN	Cognitive Radio Network
DDMAC	Distance Dependent Medium Access Control
DSA	Dynamic Spectrum Access
IEEE	Institute of Electrical and Electronics Engineers
i.i.d.	Independent and Identically Distributed
MAC	Medium Access Control
MC	Mesh Client
MCS	Maximum Channel Selection
MRP	Markov Renewal Process
NP	Non-Polynomial
p.d.f.	Probability Distribution Function
PU	Primary User
SaCA	Spectrum-aware Channel Assignment
SINR	Signal to Interference plus Noise Ratio
SU	Secondary User
SuCA	Spectrum-unaware Channel Assignment
WiFi	Wireless Fidelity
WMN	Wireless Mesh Network

2.0 BACKGROUND

This section elaborates the concept of DSA and CRNs to help us grasping better understanding of DSA and CRN. Furthermore, it explains the channel assignment in CRNs. Lastly, it presents advantages of exploiting multiple radios multiple channels in CRNs.

2.1. Dynamic Spectrum Access

In traditional wireless networks, frequency is allocated and controlled by fixed spectrum allocation policy. According to fixed spectrum allocation policy, the spectrum is assigned to licensee by governmental agencies for a long time period while covering large geographical regions. However, the allocated spectrum is utilized sporadically by licensee as shown in Fig. 1 which depicts the signal strength distribution over a large part of the wireless spectrum. The signal strength distribution trend in the figure shows that spectrum usage is high only in specific parts of the spectrum while the rest of portions of the spectrum remain unutilized. Temporal and spatial utilization varies range from 15% to 85% [1].

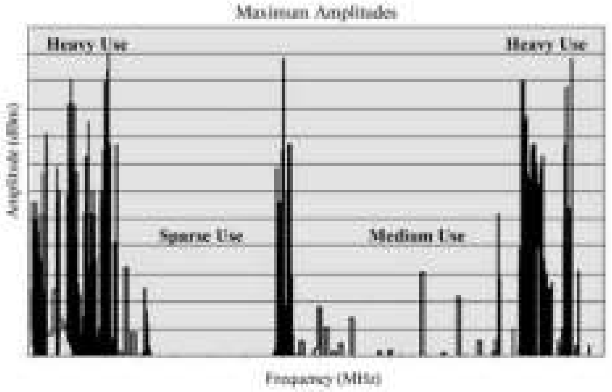

Fig. 1 Allocated Frequency Spectrum Utilization. [2]

Fixed spectrum assignment policy has been adopted for a long time in the past, but due to scarcity of spectrum and underutilization of allocated spectrum, it is considered as an inefficient spectrum assignment mechanism. The scarcity of available spectrum and the inefficient spectrum utilization arises a demand for a new communication paradigm to utilize the existing wireless spectrum opportunistically [30]. Thus, DSA has emerged as a new communication paradigm to cope with underutilization problem of fixed spectrum allocation in wireless networks. Dynamic Spectrum Access allows the user of spectrum to dynamically access the spectrum. There are three models employed to realize the DSA. These models are dynamic exclusive use model, open sharing model and hierarchical access model. The taxonomy of different models of DSA is presented in [31]. The taxonomy of dynamic spectrum access models is shown in Fig. 2. The dynamic exclusive use model provides the flexibility to exclusively use spectrum. The model employs two approaches namely dynamic spectrum allocation [34] and spectrum property rights [32], [33]. Open sharing model is also called spectrum commons [35], [36]; this model facilitates peer users with open spectrum sharing. Lastly, hierarchical access model permits the opportunistic usage of licensed spectrum among the secondary while avoiding the interference with primary user communication. There are two approaches to realize the hierarchical access model namely spectrum overlay [38] and spectrum underlay [37].

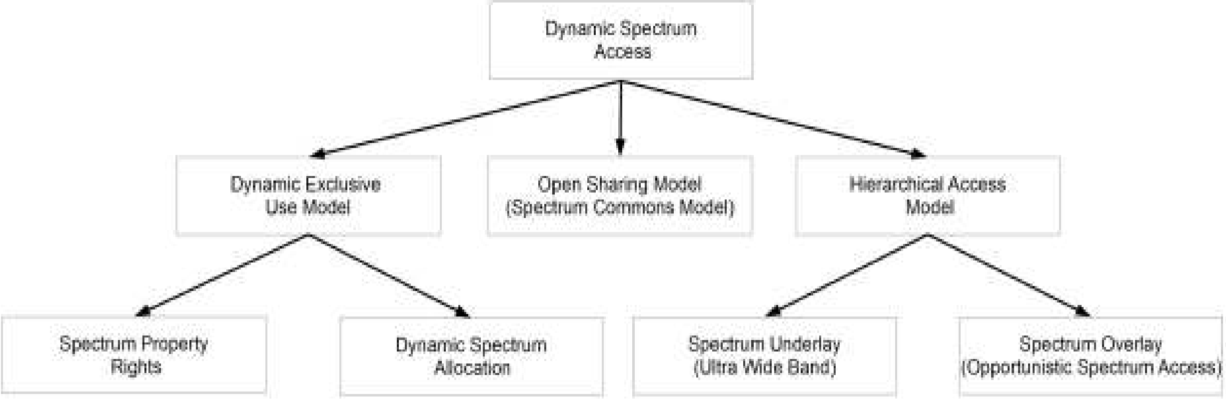

Fig. 2 Taxonomy of Dynamic Spectrum Access. [31]

2.2. Cognitive Radio Networks

Cognitive Radio is one of the enabling technologies for the DSA. Cognitive radio technology facilitates the secondary user in opportunistically using or sharing the spectrum. The flexibility is provided by dynamic spectrum access techniques to secondary user to select and operate the best available channel dynamically. Specifically, the cognitive radio technology performs the following functionality to enable the dynamic spectrum access namely spectrum sensing, spectrum management, spectrum sharing and spectrum mobility [2]. Spectrum sensing empowers the cognitive user to find the vacant portions of the spectrum and sense the licensed user's presence during the secondary user's activity. Spectrum management facilitates in the selection of the best available channel. Spectrum sharing enables the cognitive user to coordinate access to the channel with other users. On the licensed user detection, spectrum mobility is performed by vacating the channel. The functions employed by cognitive radios network during the cognitive life cycle are shown in Figure 3.

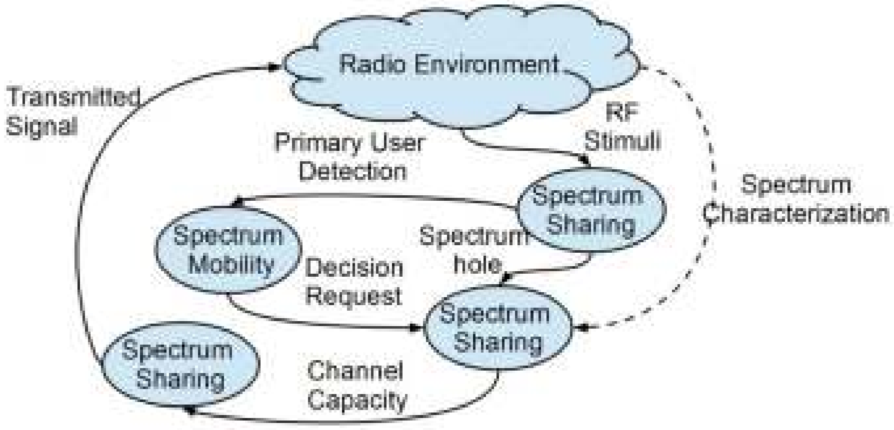

Fig. 3 Cognitive Life Cycle. [39]

2.3. Channel Assignment in Cognitive Radio Networks

Channel Assignment in CRNs is the process of assigning available channels to interfaces of similar CRN nodes in range [40]. The goal of the channel assignment is assigning a single channel to each link of CRN to maximize the network capacity [41]. The existing channel assignment algorithms for CRNs follow the centralized [42] and distributed [43], [44], [62], [63] approaches.

In centralized channel assignment, central entity such as server collects the available channels information from each node in the network, and then it runs the channel assignment algorithm considering the global information, and sends back the computed channels for each link to relevant secondary users. The centralized channel assignment approach suffers with high communication overhead. The approach is inefficient especially in highly dynamic network conditions which superannuate the information used in channel assignment rapidly. In contrast, distributed approaches [43], [44] for channel assignment are more faults tolerant and less costly. In CRNs, furnishing an efficient channel assignment is a challenging task due to highly dynamic communication resources. In addition, optimizing network capacity utilization while reducing the interference with PU is another common challenge. Channel assignment in CRNs follows the static and dynamic assignment approaches. The static channel assignment is used for control channel whereas dynamic channel assignment is usually done for the data channels.

2.4. Multiple Radio Multiple Channel Exploitation

Nowadays, mobile devices are equipped with multiple radios so benefits of using the multiple radios to improve network capacity is investigated by many researchers [45]-[61] in WMNs and in CRNs. Bahl et al. [45] investigates significant benefits of using multiple radio in wireless systems for capacity enhancement, energy conservation and mobility management. Kyasanur et al. [52] investigates the impact of multi-channel in wireless networks. Multiple radios tuned on orthogonal channels can transmit and receive simultaneously, so enhances the network throughput. Using multiple cognitive radios enables the wireless node to sense on one radio while transmitting on others.

3.0 RELATED WORK

In CRNs, research has been conducted for last several years. This section discusses several studies related to the research work related to channel assignment in WMNs and CRNs. Channel selection in CRNs has been studied by different authors in different perspectives. V. S. Rao et al. [6] proposes heuristics for allocating spectrum to CRNs. One of these heuristic is Clique Based Heuristic and the second one is Localized Heuristic which allocate the spectrum in Cognitive Radio Adhoc Networks. In [7], [19] channel selection for heterogeneous primary user band has been proposed. In [19], authors have devised maximum channel selection (MCS) problem as a binary integer nonlinear optimization problem. The objective of the optimization problem is to maximize the total channel utilization in secondary network. They further developed greedy channel selection which gives close-to-optimal numerical performance. L. Yang et. al. [10] has proposed a proactive spectrum access mechanism which incorporates past channel histories to predict intelligently future spectrum availability. The author advises two channel selection and switching approaches to alleviate disruptions to primary users. H. Bany Salameh, et. al. [20] proposes a distance de-pendent MAC protocol DDMAC for CRNs that try to raise the CRN throughput. DDMAC gives a new channel assignment algorithm uses the relationship of signal's attenuation model and distance while incorporating the traffic profile. There also exist works on channel selection for cognitive radio nodes which are discussed in [11], [14], [15], [17], [18], [21]. Some of these channel selection approaches provides the solution for multi radio nodes. Other than channel assignment work in CRNs, channel assignment solutions have also been proposed for WMN which are interference-aware [13], [16], [23], [24] and consider the Multi-Radio nodes in network. Our work is different than existing approaches in a way that we have considered not only channel idle duration but also error rate for a particular channel.

4.0 SYSTEM MODEL

4.1. Network Model

To study the problem, network in consideration is a Wireless Mesh Cognitive Radio Network. Nodes in the network support multi-radio, multi-channel. Network conditions are dynamic in terms of interferer activities which can be further parameterized. Interferer is a general interference source where primary user in CRNs can be taken as specific instance of the interference. In general, whenever interferer is introduced in a network, communication in wireless mesh network suffers. Successful communication depends on the SINR value at the receiver but in a CRNs, communication of a cognitive user should be stopped as soon as a primary user starts transmitting.

In the network, activity of an interferer follows different probabilistic distributions. It is uniformly distributed among different channels where all the interferers are uniformly distributed in the network space. Interferer's activity can be modeled as continuous-time alternating ON/OFF Markov Renewal Process (MRP) [11], [15], [26]. This model has been used extensively in the cognitive radio research literature [9], [10], [11], [12], [15], [25], [26], [27]. The paper [28] has estimated and validates the primary user ON/OFF activity model for occurrence of the primary user signal in IEEE 802.11b.

4.2. Primary User Modeling

The activity of a primary user in our network is modeled with an On-Off process. Arrival rate for primary user to enter into ON state on channel 'c' is represented by λ_c which follows the Poisson distribution.

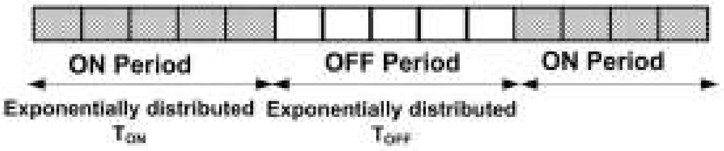

Fig. 4 ON-OFF Time line

We are assuming multiple channels in the system and Primary User (PU) selects a particular channel 'c' with uniform probability $\frac{1}{|C|}$ where |C| is the number of channels in the system. Primary User remains in ON state for a period exponentially distributed with mean $\mathrm{E}[T_{ON}^{(c)}]$ and in OFF state for a period exponentially distributed with mean $\mathrm{E}[T_{OFF}^{(c)}]$. *ON* and *OFF* durations are assumed as independent and identically distributed (i.i.d). The activity of primary user in an area can be modeled with an aggregated *ON-OFF* process. *ON* period is the time interval in which node 'u' detects the presence of PU on a particular channel. During the *OFF* period, node 'u' detects no PU activity on a particular channel in a case when the PU is only a primary user on the channel sensed by node 'u'. We illustrate the subsequent *ON-OFF* process of primary user by one parameter: the average duration $T_{ON}^{(c)}$ is the primary user *ON* period for channel 'c'. The average *ON* duration $T_{ON}^{(c)}$ follows an exponential distribution whose p.d.f. is $f_X(t) = \lambda_X \times e^{-\lambda_X t}$ and the average *OFF* duration $T_{ON}^{(c)}$ also follows an exponential distribution whose p.d.f. is $f_Y(t) = \lambda_Y \times e^{-\lambda_Y t}$. We can further compute channel utilization by primary user on channel 'c' in the interference range of secondary users.

$$u(i,c) = \frac{\mathrm{E}[T_{ON}^{(i,c)}]}{\mathrm{E}\left[T_{ON}^{(i,c)}\right] + \mathrm{E}[T_{OFF}^{(i,c)}]} \; where\ i \in set\ of\ SUs\ \&\ c \in C \tag{1}$$

5.0 CHANNEL ASSIGNMENT ALGORITHM

In CRNs, channel assignment is required to be spectrum-aware. Spectrum-awareness refers to the fact that the selection criteria should consider PU activity on the spectrum. Furthermore, channel assignment should also consider the channel error rate to reduce the number of retransmissions on channel. We have proposed channel assignment algorithm which is run by each node in a distributed manner while considering spectrum conditions.

In CRNs, Secondary Users (SUs) need to exchange cooperative spectrum sensing information, spectrum-aware routing information, channel coordination information and other management information which mainly exchange through Control Channel (CC). Control channel is mainly classified into two categories: Overlay and Underlay; furthermore Overlay mechanism is classified into In-band and Out-of-band. In Overlay CC approaches, the CC is used by SUs if it is not used by PUs; on the other hand, in underlay CC approaches, same channel can be allocated for CC to SUs while it is used by PUs. B. F. Lo et. al. [29] have discussed CC taxonomy, designs, and challenges. Out-of-band for control channel has been used in many techniques by many researchers [29]. We assume overlay mechanism for CC in In-band forms.

In our channel assignment strategy, each node computes the function for channel ranking in terms of primary user duration and channel error rate. During the channel assignment process no changes occur in the network. The channel ranking function is computed as:

$$f(i,c) = \frac{1}{\left(1-u(i,c)\right)} \times \frac{1}{\left(1-P_{err(c)}\right)} \qquad where\ c\ \in C\ \&\ i \qquad \in\ SU \tag{2}$$

In the above equation, $P_{err(c)}$ is error rate of channel ‘c’. Each node exchanges corresponding ranking function with its neighbors.

5.1. Spectrum-aware Channel Assignment Algorithm-(SaCA)

In wireless networks, channel assignment plays an important role in improving network throughput and for efficient utilization of spectrum resources. Channel Assignment algorithm for CRNs should not only be spectrum-aware but also primary user-aware. Spectrum awareness means that algorithm should take care of any changes on the spectrum of communication; the change can be onset of primary user. Primary user-awareness means that channel assignment should incorporate the information of primary user activity on the spectrum in channel selection decision. Whenever primary user arrived on channel, spectrum handover should be triggered and alternative spectrum hole should be assigned to interface. In our work, we have proposed channel assignment algorithm which is primary user aware and also incorporate error rate. We have studied the channel assignment problem in CRNs by considering packet drops due to primary user activity and error rate of wireless communication on that channel.

The algorithm takes following input: node id ‘n’ , set of radios ‘R’ , set of available channels ‘C ’, set of available channels on neighbors C_N , set of channel ranking function values of node ‘n’ f(n,C), its all neighbors f_N (n,C) respectively and set of neighbors, N .

Algorithm 1: Spectrum-unaware Channel Assignment Algorithm

```
Input: [n, R, C, $C_N$, N]
$X \leftarrow R$
$Z \leftarrow C$
while $R / X \neq R$ do
    Select any $c \in Z \cap C_N$
    $C(x) \leftarrow c$
    $X \leftarrow X/\{x\}$
    $Z \leftarrow Z/\{c\}$
end
Output: C(R)
```

Algorithm 2: Spectrum-aware Channel Assignment Algorithm(with PU history)

```
Input: [n, R, C, $C_N$, f (n, C), $f_N(n, C)$, N]
$X \leftarrow R$
$Z \leftarrow C$
while $R/X \neq R$ do
    compute: $\hat{c} \leftarrow arg\ min_{\forall c \in Z}$ h(c)
    $index_{cn} \leftarrow 0$
    foreach $k \in N$ do
        if $\{c\} \cap C_k \neq \emptyset$ then
            $t_c(index_{cn}) \leftarrow \max(f(n, c), f_k(n, c))$
            incr $index_{cn}$
        endif
    endfor
    $h(c) \leftarrow \min(t_c)$
    $C(x) \leftarrow \hat{c}$
    $X \leftarrow X/\{x\}$, where $x \in X$
    $Z \leftarrow Z/\{\hat{c}\}$
endwhile
Output: C(R)
```

Table 2 Notations' Definitions of Spectrum-aware Channel Algorithm

Symbol	Description
n	The node which is running algorithm
N	Set of Neighbors
$index_{cn}$	Index for each channel neighbors
C	Set of available channels on node ‘n’
f (n, C)	Set of channel ranking function values of node ‘n’
f_N (i, C)	Set of channel ranking function values of all neighbors of node ‘i’
C_N	Set of available channels of neighbouring nodes
R	Set of Radios on node ‘n’
X	Set of Radios on which channel is not assigned yet
$\hat{c}$	Channel for which function h(c) gives maximum value
Z	Set of channels which are not assigned yet
C(R)	Set of channels tuned to set of radios R

5.1.1. Example Illustration

In order to illustrate Algorithm 2, we take network topology depicted in Figure 5. Available Channel List for each node along with function value is shown in table 3. We take into account node ‘d’ to explain the spectrum-aware channel assignment. There is only one neighbor ‘c’ of node ‘d’ and it has channel 2 and 1 in common with node ‘c’.

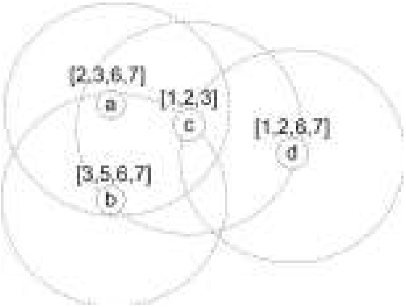

Fig. 5 Topology for Example Illustration

It computes $h(2) = \min(t_2\ (0.7)) = \min(0.7) = 0.7$ and $h(1) = \min(t_1(1)) = \min(0.6) = 0.6$. In first iteration, it selects channel ‘1’ as function gives lower value than that of channel ‘2’. It assigns the channel ‘1’ on one of its radio on which channel has been interrupted by PU. In next iteration, it selects channel ‘2’ as it is the only unassigned common channel. Node ‘c’ computes $h(3) = \min(t_3(1),\ t_3(1)) = \min(0.2, 0.2) = 0.2$, $h(2) = \min(t_2(1), t_2(1)) = \min(0.7, 0.7) = 0.7$ and $h(1) = \min(t_1(0.6)) = \min(0.6) = 0.6$. Channel ‘3’ is selected and assigned due to its lowest value. In next iteration, its selects channel 2 due to its lower value of function. Similarly, node ‘a’ selects channel 3 and 6 due to lowest values of these. Finally, node b selects channel 3 and 6 after running the algorithm.

Table 3 Available channel lists and corresponding function value

a					**b**			
C	7	6	3	2	7	6	5	3
f(c)	0.8	0.5	0.2	0.7	0.8	0.5	0.6	0.2
c					**d**			
C	1	2	3		7	6	2	1
f(c)	0.6	0.7	0.2		0.8	0.5	0.7	0.6

6.0 EXTENSION in OMNeT++

To evaluate the performance of SaCA, the proposed algorithm, we have extended the OMNeT++ simulator to simulate the CRNs. We introduce two new nodes, primary user and secondary user, in OMNeT++ along with our proposed channel assignment module. The topology diagram of implemented CRN is shown in Figure 6.

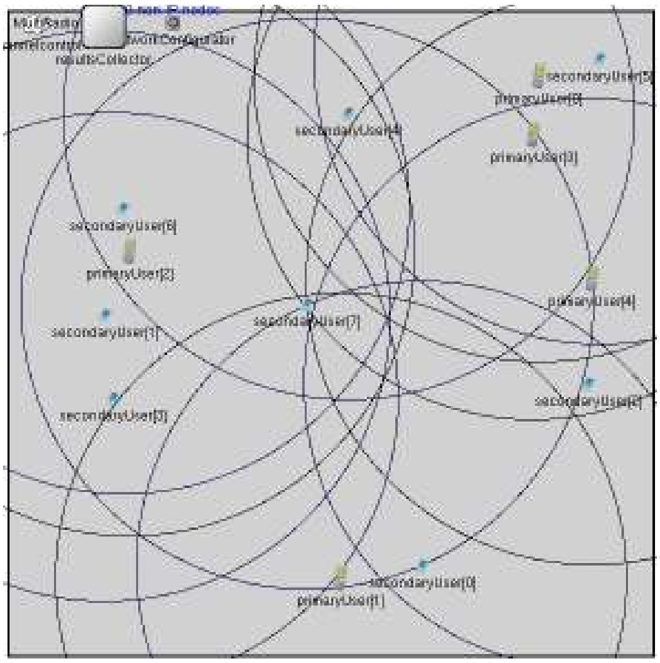

Fig. 6 Topology of Cognitive Radio Network implemented in OMNeT++

6.1. Primary Node Implementation in OMNeT++

We have implemented a “primaryUser” as primary node in OMNeT++ which is running its own application, PrimaryUserApp. Primary user activity is modeled by ON/OFF Markov Renewal Process where ON and OFF periods are exponentially distributed. Primary user selects a channel uniformly to communicate on. PrimaryUserApp generates and sends a packet in the start of primary user ON period to other primary users. The ON period duration is got by an exponentially distribution. Initially, in order to simplify and hide the complexities involve in sensing, we have added the information of ON period in primary user packet which is generated according to exponential distribution. When the primary user packets are received by the secondary nodes in the neighborhood, they set their flag of primary user activity true and schedule an event to be triggered after this time. During this period, the secondary user does not send any packet on primary user channel and call updateHostChannel() method of ChannelControlExtended to switch and configure the new available channel on the interface. The expiry of ON period timer again sets the primary user activity flag false for that channel on the secondary user. During the OFF period, the channel returns back to the available channel list of secondary users. On the other hand, primary node generates an exponentially distributed number which is used as an OFF period duration of primary user. The primary node uses the generated number for OFF period to schedule an event to be triggered on the expiry of OFF period. During the OFF period, PrimaryUserApp does not generate and send them to the neighboring nodes. The primary node repeats the whole process on the expiry of OFF period. The routing of primary nodes is also independent of the routing of secondary nodes. The primary nodes do not consider the secondary nodes as a neighbor while routing their packets. Besides, primary node does not receive secondary node packets, they just ignore after identifying them but consider the noise generated due to communication of secondary nodes.

6.2. Secondary Node Implementation in OMNeT++

The functionality implemented on secondary nodes is different than that of primary nodes in OMNeT++. The secondary nodes ignore the packets of primary nodes and do not sends them up. This functionality of identifying the primary user packets is implemented on radio sub-module of a node. The OMNeT++ facilitates in accessing the payload information packet on the radio so we have leveraged the flexibility to identify the primary user packets. Primary user packets are extracted in the radio module to find out the ON time duration. After extracting the information, the packet is just discarded. The routing module of secondary nodes does not consider the primary nodes in routing decision, so routing module implementation is also different than that of existing wireless nodes in OMNeT++. Secondary nodes run already existing applications supported by OMNeT++.

6.3. Channel Assignment Implementation in OMNeT++

The channel assignment in OMNeT++ is implemented as a second level module in MultiRadioHost. The channel assignment module consists of ChannelAssignment class, written in C++, and ChannelAssignment.ned file which implements the functionality of SaCA. The messages, ChannelAssignmentRequestMessage and ChannelAssignmentResultMessage, exchange during the channel assignment algorithms are also the part of the submodule. The messages are used to exchange the channel assignment request and resultant computed channels between interfaces and channel assignment modules. The channel assignment method is called from inside the AbstractRadioExtended class method changeChannel(). It is executed when average packet drop ratio increases on a certain channel or primary user appears on that channel. The secondary node architecture with SaCA sub-module is shown in Figure 7.

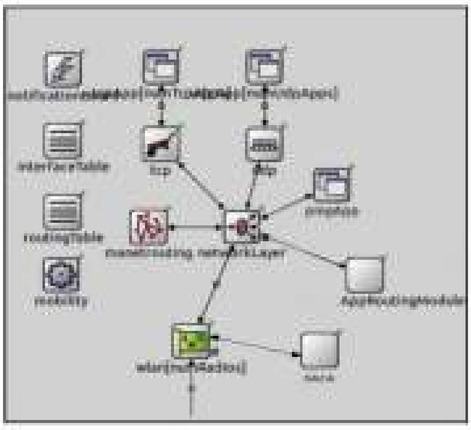

Fig. 7 Secondary Node Architecture in OMNeT++

Some parameters related to configuration are added to MultiRadio.ned and in omnetpp.ini to provide the configuration information of number of secondary nodes, number of primary nodes, number of radio interfaces supported by the secondary nodes and configuring the ON and OFF period.

7.0 SIMULATION SETUP

In order to evaluate the performance of proposed algorithm, we perform simulations in OMNeT++. The simulation is performed for a network area of 1000 * 1000 m^2. We take 12 secondary users and evaluate the performance of algorithm by varying the number of primary users, number of channels in the system and by changing the primary user activity duration in the network. For evaluation of performance, we have taken two parameters average packet delivery ratio and number of channel switches. We assume that every secondary node has 3 radio interfaces. The simulation is run for 1000 seconds and is replicated with 30 runs. The confidence level is taken 95% and we have used the statistical method of confidence interval to highlight the error margin in measurements. The initial parameter values for 5 seconds are discarded and have not included in our results to avoid the initial bias. The ON and OFF exponential parameter λ values are taken 2 for Fig. 8, Fig. 9, and Fig. 10.

8.0 RESULTS

The performance of SaCA is evaluated by comprehensive simulation study considering the effect of number of PU, number of channels and ON-OFF duration on packet delivery ratio and channel switches in the CRN. Packet delivery ratio decreases with the increase in number of PUs. SaCA outperforms SuCA as the number of PUs increases from zero. The algorithm even performs better than SuCA when the number of PUs reaches 25 which is shown in Fig. 8.

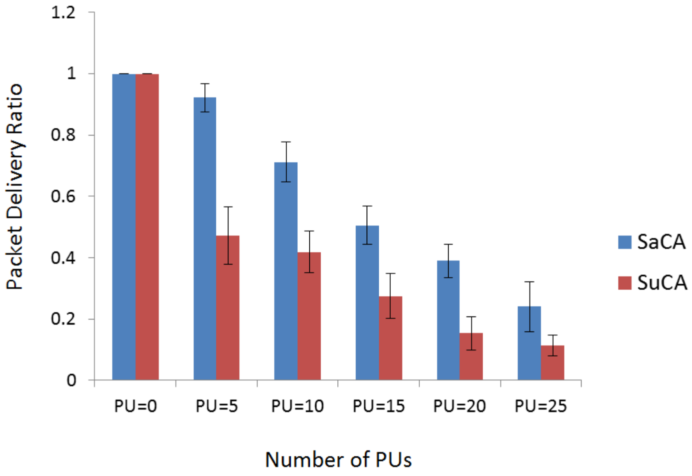

Fig. 8 Delivery Ratio Packet vs. Number of PUs

The packet delivery ratio of SaCA for PU = 0 is 0.999±1.94935E-16, PU = 5 is 0.921 ± 0.0463, PU = 10 is 0.711 ± 0.064, PU=15 is 0.504 ± 0.0618, PU=20 is 0.389 ±0.0542, PU=25 is 0.240±0.0818. The number of channels available in CRNs also affects the packet delivery ratio of secondary nodes in CRNs. The performance of SaCA and SuCA is illustrated in Fig. 9 in terms of packet delivery ratio. SaCA outperforms the SuCA even for increased number of channels in the network. The performance of SaCA is better for higher number of channels in the network due to less probability of PU on the assigned channel and maintains the performance for large number of PUs in the network.

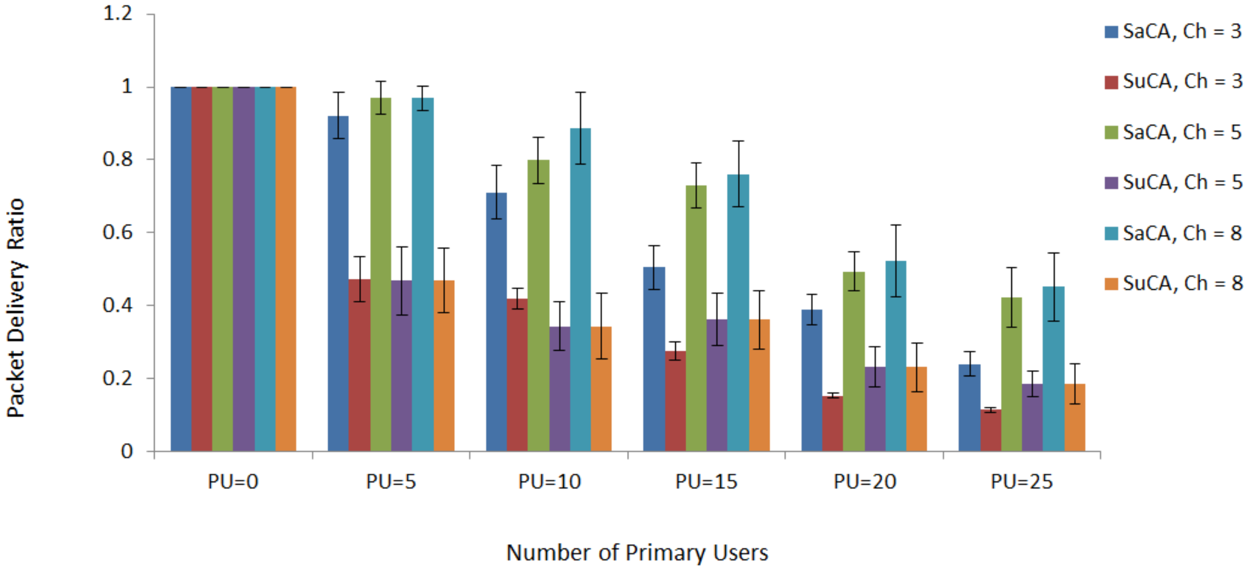

Fig. 9 Packet Delivery Ratio vs. Number of Primary Users

SaCA obtains the packet delivery ratio 0.999 ±0.0292 for PU=0, 0.969±0.0633 for PU=5, 0.888±0.0719 for PU=10, 0.761±0.0596 for PU=15, 0.523±0.0414 for PU=20, 0.451±0.0321 for PU=25. SaCA gets the packet delivery ratio 0.999±1.949E-16 for PU=0, 0.921 ± 0.046 for PU=5, 0.711 ± 0.064332 for PU=10, 0.504 ± 0.061 for PU=15, 0.389 ±0.054 for PU=20, 0.240±0.081 for PU=25 when the number of channels are 5 in CRN. It attains the packet delivery ratio of 0.999±1.94E-16 for PU=0, 0.969 ±0.033142 for PU=5, 0.79±0.098 for PU=10, 0.731 ±0.091 for PU=15, 0.493 ± 0.099 for PU=20, 0.4217 ±0.092 for PU=25 in case of 8 channels.

The performance of network is also affected by channel switching if the channel assignment in CRN does not incorporate the PU activity then the number of channel switches increase in the network. The effect of increasing the number of PUs in CRN is evaluated on the number of channel switching. The number of channel switches also increases when the number of channels are not sufficiently available in the network as shown in Fig. 10. The increase in number of channel decreases the number of channel switching in the network.

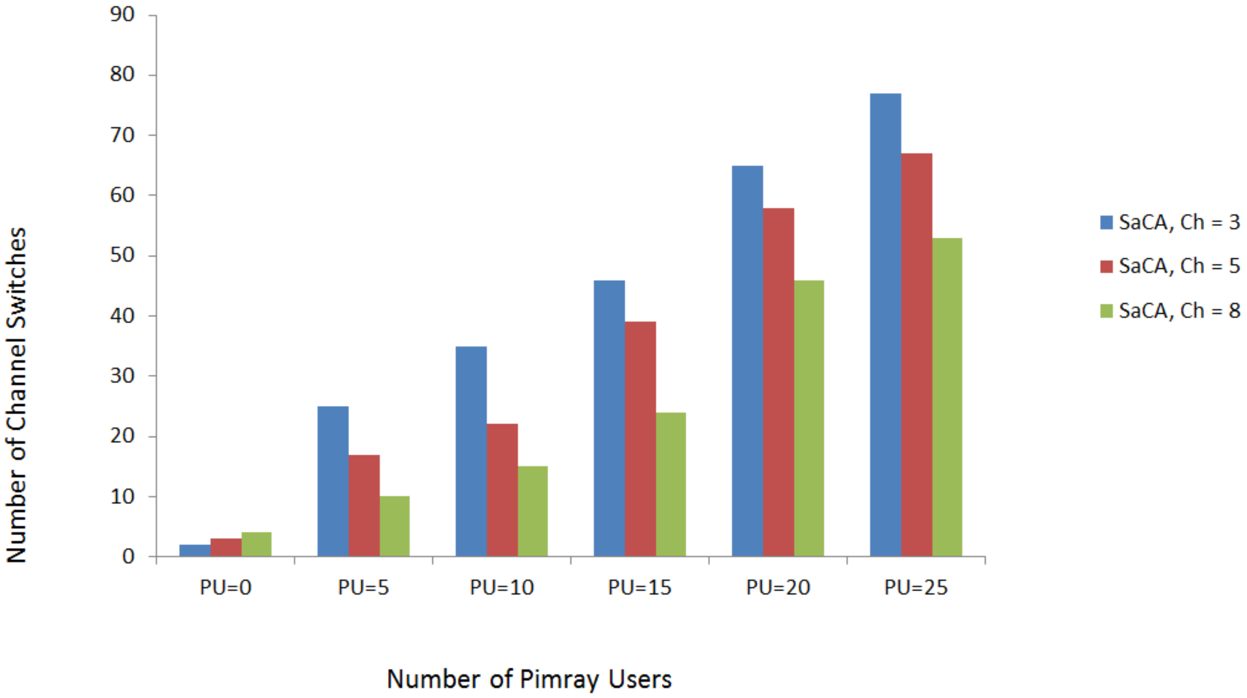

Fig. 10 Number of Channel Switches vs. Number of PUs

The packet delivery ratio is also affected by the primary user activity duration in CRNs. As the PU remains more idle then packet delivery ratio increases. The effect of PU activity duration is studied by taking the ON period λ value of 5 and varying the OFF period λ. The number of radios and channels for studying the effect of PU activity duration on packet delivery ratio are taken as 3 and 5 respectively. The number of SUs and PUs are 10 and 20 respectively in this simulation setup. Packet delivery ratio significantly increases when the OFF duration parameter value is 10 in Figure 11.

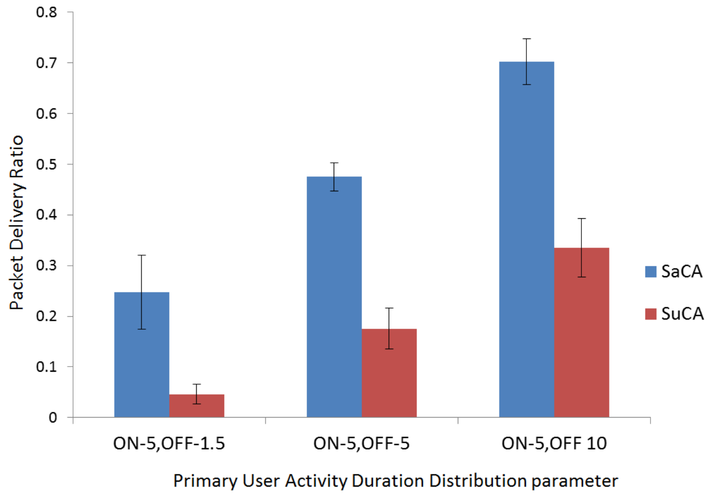

Fig. 11 Packet Delivery Ratio vs. Primary User Activity Duration

9.0 CONCLUSION

The proposed channel assignment algorithm which incorporates the primary user activity and other spectrum conditions such packet loss ratio has significantly improved the packet delivery ratio. The algorithm outperforms the traditional common channel assignment algorithm which suffers with more interference and PU activity. The result shows that the spectrum-aware channel assignment algorithm performance improves, as the number of available channels increases. The improvement is up to 41 % in average packet drop ratio for spectrum-aware channel assignment algorithm while increasing number of channels from 3 to 8. The main reason of increased packet delivery ratio is the high probability of vacant channel availability with less packet drop ratio in CRNs with the increasing set of channels in the system. The proposed algorithm also performed well with the increasing number of primary users as compared to traditional spectrum unaware channel assignment algorithm. Our evaluation shows that incorporation of primary user activity information and interference information improves the network delivery ratio.

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