CHAPTER 4

A DISTRIBUTED SCHEDULING APPROACH
FOR QOS IMPROVEMENT IN
COGNITIVE RADIO NETWORKS

This chapter presents the improved scheduling approach with its operation and simulation analysis of the system. It also elaborates with the scheduling approach with other improvements of the overall network.

4.1 INTRODUCTION

In cognitive radio networks, spectrum allocation for primary and secondary users is the most important task. During the active state of a primary user, part of the spectrum is used by the primary user, and the remaining unallocated part will be in a busy state. This unallocated and unused spectrum increases the delay and latency in Cognitive Radio Networks (CRN); however, allocating unused channels to other users may increase collision. Moreover, allocation of the unused spectrum channel is a difficult task in cognitive radio networks.

Generally, a cognitive radio network uses multicast and broadcast transmission. Multicast transmissions allow multi-hop and multi-path transmissions; all nodes within the cognitive radio network use multiple paths to reach the destination. In a broadcast network, the server node transmits the data to the cooperative nodes, and these nodes forward the data to the destination node. Due to this use of multicasting and broadcasting, the collision probability is high in cognitive radio networks.
Scheduling is therefore also an important task within cognitive radio networks, both for single channel and multi-channel schemes. Scheduling is used to reduce the collision probability, and also to decrease the delay, which increases network performance. The network performance is analyzed using the quality of service parameters of latency, jitter, collision probability, drop rate, throughput, delivery rate, end-to-end delay and overhead ratio. The overhead ratio is increased in cognitive radio networks, due to multi-channel allocation. Overhead also occurs due to the high collision rate, which is triggered by multiple data transmissions between multiple users.

Cognitive radio networks have two types of architecture, known as centralized architecture and distributed architecture. In a centralized architecture, the central server node forwards and amplifies the data to the remaining nodes in the network. In a distributed architecture, all the nodes are located in a distributed and decentralized manner, and are not under the control of a central node. In a centralized architecture, the central node allocates the scheduling in each node for data transmission.

4.2 PROPOSED WORK

The proposed scheme is known as QoS Improvement Proper Scheduling (QIPS) for distributed cognitive radio networks, and enables effective communication between the users in the network. This distributed type of network has a decentralized architecture, with all nodes being randomly distributed; the proposed scheme creates the distributed network architecture and then divides it into different regions. After this division, one node is selected as the base station for each region in the network, and this base station is used to allocate proper scheduling of the primary user and secondary users in its region.
Proper scheduling is based on real-time and non-real-time applications, with first priority being given to real-time applications and secondary priority to non-real-time applications.

The scheme proposed here has been analyzed under three different data traffic conditions: File Transfer Protocol, Transmission Control Protocol and Hypertext Transfer Protocol.

File Transfer Protocol uses a constant bit rate for data packet transmission, while Transmission Control Protocol uses the User Datagram Protocol, and Hypertext Transfer Protocol uses a variable bit rate.

i. **Selection of base station**

The selection of the base station is based on connectivity among the nodes; that is, the node which has the most links will be selected as the base station in order to give the most efficient communication. Links are counted with the help of control messages. Each node broadcasts control messages to its neighbor nodes, and the node with the highest number of replies is chosen as the base station.

Cx sends RTS to Nn

where Nn represents the neighbor nodes

and x=1, 2….8 gives the number of nodes in Region 1

Nn acks CTS to Cx

Here, CTS acknowledgements are counted in the routing table. Each node receives its own acknowledgement, and by adding all the
acknowledgments, the number of links for each node is calculated. Following this, the numbers of links for each node are compared, and the node with most links is selected as the base station.

Figure 4.1a shows that the bipartite network architecture consists of a number of nodes with saturated vertex of I and unsaturated vertex of J. The distributed network is partitioned into two different regions, Regions 1 and 2. All the nodes in the network are connected to the cognitive radio base station, which is used to perform constant scheduling for each node in the network.

![Bipartite network architecture](image)

**Figure 4.1a Bipartite network architecture**

For example, from Figure 4.1b, it can be seen that Region 1 has 4 nodes, represented by 1, 2, 3 and 4.

C1=2 links, C2=3 links, C3 =1 links, C4=2 links
This can be calculated by the acknowledgements received from the neighbor nodes.

If \( C_x >> C(x+1) \)

\( C_x \rightarrow \text{base station} \)

Else

\( x++; \)

End

The node with the highest number of links is found using a for loop condition. Following this, the mobility of this node is changed to 0 m/s for stable conditions. Due to this stability, resilience is achieved and link failure is avoided. Communication between Regions 1 and 2 is possible via the base stations.

Based on the requirements, unsaturated vertices will be shifted to saturated vertices. This conversion will again be made through the base station. Through the use of control messages, information is passed to the base station that the spectrum is free in a link.

ii. Selection of Primary User

This algorithm illustrates the process of the proposed scheme. The input is a distributed network with a number of nodes and links. The expected output is a bipartite network, scheduling data to the primary and secondary users.
Figure 4.1b Flow of selection process in distributed network
Algorithm: Selection process in Distributed network

Input: Distributed network architecture with nodes, D (N, L)
Output: Bipartite network transmission through primary and secondary users
Create D(N,L) with N as nodes, L as links
Bipartition $D(N, L) = S \times U$
Set S $\rightarrow$ Region 1
Set U $\rightarrow$ Region 2
Calculate $N_i$, $\forall N_i \rightarrow$ node degree where, $i=1, 2, 3 \ldots L$
Create $B_{si} \rightarrow$ N has high $N_i$;
for each region $R_x$, $x=1, 2 \ldots n \ \forall$ number of regions and base station
Connect $B_{si}$ to $N_n$, $\forall N_n \rightarrow$ neighbor nodes
$B_{si}$ finds $P_u$; $P_u$ represents primary users
If $Bw(N_n)k >> Bw(N_n)k+1$;
Bw-bandwidth; $k=1, 2 \ldots n$;
k represents the number of neighbor nodes that are connected to the base station
If $Cr(N_n)k >> Cr(N_n)k+1$; Cr represents coverage range
$(N_n)k$ is assigned as $P_u$ \ \forall $P_u$ as primary users should have high bandwidth and high coverage range.
Else
$(N_n)(k+1$ is assigned as $S_u$ \ \forall $S_u$ represents secondary users
The remaining neighbor nodes are assigned as secondary users.
end
If $P_u$ is busy
$Dt\{(P_u)i, B_{si}\}$;
i.e., Data transmission takes place between primary user and base station in $i^{th}$ region
Else if $P_u$ is idle
End
$Dt\{(S_u)i, B_{si}\}$\ \forall Data transmission between secondary user and base station in $i^{th}$ region.
Free channels are utilized by secondary users.

Initially, partitioning of the network into different regions is performed using Theorem 1. Following this, the network is created, with each region having a primary user, a number of secondary users and a base station,
selected based on the highest number of node degrees. The base station is connected to the remaining neighbor nodes in its respective region, and calculates the bandwidth and coverage range for each node.

Bandwidth is defined as the ratio of transmission rate to the network interface.

\[ Bw = \frac{Tr}{Ni} \quad (4.1) \]

\[ Cr = A(Nni) \quad (4.2) \]

Where, Bw is bandwidth; Tr is transmission rate; Ni is the network interface; Cr is the coverage range; A(Nni) is the area covered by neighbor nodes; and N represents the nodes. Coverage range is defined as the area covered by the node.

Based on Equations 4.1 and 4.2, the primary user is selected. This is calculated by the base station with the aid of control messages.

After calculating the bandwidth and coverage range of the neighbor nodes, the base station checks which node has the highest bandwidth and coverage range, and this node is assigned as the primary user.

The remaining neighbor nodes connected to the base station are assigned as secondary users. If the primary user is in the busy state, this means that the primary user is accessing the channel for data transmission to the base station. When the primary user is in the idle state, secondary users can access the free channel for data transmission.
iii. Proper scheduling

In the proposed QoS improvement proper scheduling scheme, scheduling for each user is done with the aid of the base station. This scheduling is based on real-time and non-real-time data applications. First priority is given to real-time data in the scheduling. The priority user is a real-time data user denoted by \( u \) and with a traffic rate of \( t \).

The channel is allocated for real-time and non-real-time data based on the \( S_j \) service coefficient condition. The service coefficient is defined as the ratio of number of users (\( N_u \)) to free channels (\( F \)) which can be allocated to the real-time users.

\[
S_j = \begin{cases} 
1 + e^{-F/N_u}, & Sa \rightarrow real-time \ users \\
1, & Sa \rightarrow non-real-time \ users 
\end{cases}
\]  

(4.3)

If the first condition is satisfied, scheduling access (\( Sa \)) priority is given to real-time users. Otherwise, if the service coefficient value is unity, scheduling access (\( Sa \)) priority is given to the non-real-time users. Following this, free channels should be allocated to real-time data.

iv. Spectrum allocation

In general, data channels are divided into the two categories: busy and free channels. These types of channels can be identified using control messages, which use the control channels in identifying the status of data channels. Free channels are denoted as \( F \), while busy channels are denoted as \( B \).
If the data channel is busy, the source node will wait for a predetermined threshold time, before repeating the request to obtain the status of the channel using control messages.

\[ Dch(B) = Wt \ll \tau, Sn \cup Cm \]  

(4.4)

Where, \( Dch(B) \) denotes that the data channel is busy; \( Wt \) is the waiting time; \( \tau \) represents the threshold time; \( Sn \) represents the source node; \( Cm \) represents control messages.

If the data channel is free, the source node will transmit the real-time data to the destination node, using free channels.

\[ Dch(F) = Sc(Dt) \rightarrow De(Dt) \forall F \]  

(4.5)

Equation 4.5 shows the spectrum allocation to the source node. In this case, \( Sc(Dt) \) is the source which carries the data; \( \rightarrow \) shows that the transmission occurs from \( Sc(Dt) \) to \( De(Dt) \); \( De(Dt) \) is the destination receiving the data; \( D \) denotes data; and \( F \) represents the free channels.

v. QoS Improvement

To improve the quality of service in a distributed cognitive radio network, the following conditions should be fulfilled:

a. Proper scheduling should be observed

b. Priority in scheduling should be given to real-time data users

c. Collision should be avoided during high levels of traffic

d. Delay should be reduced even in high queuing conditions
e. Throughput should be increased

If any one condition is satisfied, a value of one is added to the QoS factor. In ideal conditions, the quality of service is equal to 5, since all five conditions are satisfied.

**Algorithm: QoS Improvement Proper Scheduling**

<table>
<thead>
<tr>
<th>Input: D(N, L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output: {Ps <em>Qs}</em>{D(N, L)}</td>
</tr>
<tr>
<td>Create D(N,L)</td>
</tr>
<tr>
<td>Bipartition D(N, L) = S * U</td>
</tr>
<tr>
<td>Set S→ Region 1</td>
</tr>
<tr>
<td>Set U→ Region 2</td>
</tr>
<tr>
<td>Create Bsi ¥ Ri, i=1, 2, ... n \ number of regions and base station</td>
</tr>
<tr>
<td>Connect Bsi to Ri(N), i=1, 2, … n \ number of regions and base station</td>
</tr>
<tr>
<td>Allocate Ps based on Service coefficient (from Equation 4.3)</td>
</tr>
<tr>
<td>Check Sj \ Service coefficient</td>
</tr>
<tr>
<td>If Sj=1</td>
</tr>
<tr>
<td>NRT \ Non-real-time data</td>
</tr>
<tr>
<td>Send to Queue</td>
</tr>
<tr>
<td>Repeat if</td>
</tr>
<tr>
<td>Else</td>
</tr>
<tr>
<td>RT \ Real-time data</td>
</tr>
<tr>
<td>Allocate Sa \ Scheduling channel access</td>
</tr>
<tr>
<td>Data transmission b</td>
</tr>
<tr>
<td>End</td>
</tr>
<tr>
<td>Ps * D (N,L) \ Successful proper scheduling is complete</td>
</tr>
<tr>
<td>Check Qs \ Quality of service</td>
</tr>
<tr>
<td>If Qs ≥ 5 \ Five conditions for QoS to be satisfied</td>
</tr>
<tr>
<td>{Ps <em>Qs}</em>{D (N, L)} \ QoS improvement and proper scheduling is done</td>
</tr>
<tr>
<td>Else repeat Ps \ Proper scheduling</td>
</tr>
<tr>
<td>End</td>
</tr>
</tbody>
</table>
The algorithm for the proposed QIPS scheme is stated as below. The input is a distributed cognitive radio network, and the expected output is the QIPS network with proper scheduling and bipartitioning.

This algorithm illustrates the process of the proposed scheme. Initially, a network is created with a random number of nodes. Following this, partitioning of the secondary user network into different regions is carried out using Theorem 1.

From these, each region is allocated one base station (one of the secondary users), a primary user and number of secondary users. The base station allocates proper scheduling for real-time and non-real-time data users within its respective partition.

Real-time data users are identified by the base station based on the service coefficient value, and a channel is allocated for the real-time data users. If non-real-time data users are identified, they are directed to the queue and allocated a free channel after the completion of the real-time data user’s transmission. If the scheduling is successfully achieved, the quality of service is analyzed. If the quality of service satisfies all five conditions, this will be given as the QIPS for distributed cognitive radio networks.

Figure 4.2 gives a flow chart showing packet scheduling traffic. Both real-time and non-real-time data are added to the queue. Following this, the queue size is checked; if it is higher than the threshold rate, it is assigned as a high traffic rate. If the queue size is lower than the specific threshold rate, it is assigned as a low traffic rate.
Prioritization of traffic is also known as service of class, and this differs from quality of service. In general, traffic can be divided into low, medium and high states. When traffic is low, prioritization is unnecessary. If the traffic data rate is high, prioritization is required to avoid packets being dropped and to reduce delay. The proposed QoS improvement proper scheduling scheme therefore allocates proper scheduling based on real-time and non-real-time data.

If the traffic rate is low, straight path can be used directly for data transmission. If the traffic rate is high, prioritization is required for real-time and non-real-time data. Using the service coefficient equation, real-time and non-real-time data are separated. Following the completion of real-time data
transmission, the traffic rate is reduced, and non-real-time data is then transmitted during low traffic conditions.

4.3 PERFORMANCE ANALYSIS

Simulation results were obtained using a network simulator with a random generation of 100 to 500 cognitive nodes. This proposed scheme has been analyzed under three different data traffic rates: File Transfer Protocol, Transmission Control Protocol and Hypertext Transfer Protocol. These use a constant bit rate, User Datagram Protocol and a variable bit rate respectively for data packet transmissions.

Table 4.1 Details of routing parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routing Protocol</td>
<td>AODV</td>
</tr>
<tr>
<td>Number of Nodes</td>
<td>100 to 500 Cognitive nodes</td>
</tr>
<tr>
<td>Mobility</td>
<td>20m/s</td>
</tr>
<tr>
<td>Topology Size</td>
<td>2000 X 2000 m</td>
</tr>
<tr>
<td>Frequency</td>
<td>1 to 3 GHz</td>
</tr>
<tr>
<td>MAC</td>
<td>802.11, 802.22</td>
</tr>
<tr>
<td>Traffic Type</td>
<td>CBR, UDP, VBR</td>
</tr>
<tr>
<td>Simulation Time</td>
<td>200 seconds</td>
</tr>
<tr>
<td>Queuing Time</td>
<td>50 seconds</td>
</tr>
<tr>
<td>Queuing type</td>
<td>Priority queue</td>
</tr>
</tbody>
</table>

The proposed scheme is compared with two existing approaches: the BRACER broadcast protocol for cognitive radio networks and the QoS-Based Prioritization Model (QBPM). To determine the performance of the
cognitive radio network, the quality of service parameters of overhead ratio, delivery rate, throughput, end-to-end delay, efficiency and collision probability are examined. Table 4.1 shows the details of the routing parameters and the range.

Figure 4.3 shows the overhead analysis. This is defined as the ratio of the number of data messages received to the number of control messages. If the number of control messages increases, the overhead will increase. Both the BRACER broadcast protocol and QBPM have a high overhead ratio, due to a relatively high usage of control messages for data transmission between the nodes in the network.

![Overhead ratio vs. Number of nodes](image)

**Figure 4.3 Overhead ratio vs. Number of nodes**

However, the proposed QIPS technique is able to reduce this overhead through a lower usage of control messages, by properly assigning the base station which controls channel assignments for the primary and secondary users. Each region is assigned a separate base station, which converts the distributed nature of the network into a partially-controlled network and hence reduces this overhead.
Figure 4.4 shows the packet delivery ratio, which is defined as the ratio of the number of packets received to the number of packets transmitted. The existing techniques, the BRACER broadcast protocol and the QBPM, have lower delivery rates, due to the high overheads occurring between the source and destination. The proposed QIPS scheme achieves a higher delivery rate by decreasing the collision and prioritizing real-time data, which leads to faster transmission of packets.

Figure 4.5 shows the end-to-end delay, which is defined as the time taken to transmit the data between source and destination, and which includes the slot waiting time during queuing. The BRACER broadcast protocol and QBPM have high end-to-end delay due to the use of broadcasting. Due to the use of QoS-based prioritizing, the remaining data may also be lost easily.

However, in the proposed QIPS scheme, this delay is reduced through the service coefficient condition used by the base station. The real-time data applications are served faster, and the queue is emptied more
quickly, leaving space for the non-real-time data, which is then transmitted in the next available slot after the transmission of the real-time data.

**Figure 4.5 End-to-end delay**

Network efficiency is defined as the ratio of number of data packets successfully received by the destination to the number of data packets successfully transmitted by the source after the simulation ends, and this is shown in Figure 4.6.

The BRACER broadcast protocol and QBPM have lower efficiencies, due to high delays and drop rates. However, the proposed QIPS model increases network performance while reducing delay and drop rate. After the simulation ends, a trace file is generated in the network simulator, containing all the details of the simulation from beginning to end. Values were extracted from this file using AWK, and a graph was plotted. Here, successful transmission is achieved using service coefficients; in addition, the unused channels are immediately allocated to the secondary users by the base
station, leading to better spectrum efficiency, which in turn improves network efficiency.

Figure 4.6 Network Efficiency

Figure 4.7 shows the collision probability, which is defined as the ratio of the number of packets dropped to the number of packets transmitted. If the drop rate is high, collision will also be high, since the collision probability is proportional to the rate of dropped packets.

The BRACER broadcast protocol and QBPM have high collision probability; BRACER has high collision due to use of message broadcasting, and QBPM has a high drop rate due to the use of QoS-based scheduling. However, the proposed QIPS model reduces both the collision and the drop rate, due to the use of scheduling based on the service coefficient.
Figure 4.8 shows the throughput analysis. This is defined as the ratio of the number of control and data packets successfully received to the simulation time. This was analyzed after the simulation ended, i.e., at 200 seconds. The channel bandwidth allocated here was 2Mbps, and the proposed scheme used 1.7Mbps of the available spectrum. The BRACER protocol and QBPM have low throughput.

However, the proposed QIPS scheme increases the throughput using proper spectrum allocation, which is carried out with the aid of the base station in each region. The throughput is increased due to a reduction in drop rate, collision and overhead, and high network efficiency and delivery ratio.
Figure 4.8 Throughput analysis

Table 4.2 Comparison of QoS parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>BRACER</th>
<th>QBPM</th>
<th>QIPS-TCP</th>
<th>QIPS-FTP</th>
<th>QIPS-HTTP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivery rate (%)</td>
<td>60</td>
<td>50</td>
<td>80</td>
<td>82</td>
<td>83</td>
</tr>
<tr>
<td>Throughput (Mbps)</td>
<td>0.6</td>
<td>0.7</td>
<td>1.2</td>
<td>1.4</td>
<td>1.7</td>
</tr>
<tr>
<td>Delay (ms)</td>
<td>0.7</td>
<td>0.65</td>
<td>0.31</td>
<td>0.32</td>
<td>0.39</td>
</tr>
<tr>
<td>Network Efficiency (%)</td>
<td>69</td>
<td>75</td>
<td>92</td>
<td>94</td>
<td>96</td>
</tr>
<tr>
<td>Collision Probability (%)</td>
<td>60</td>
<td>70</td>
<td>12</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Overhead Ratio (%)</td>
<td>52</td>
<td>60</td>
<td>43</td>
<td>39</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 4.2 shows the comparison of the QoS parameters of delivery rate, drop rate, throughput, delay, network efficiency, collision probability and overhead ratio. The QIPS model gives increased throughput, network
efficiency and delivery rate through the use of different data traffic rates, and also gives decreased delay, drop rate, collision probability and overhead ratio. A delivery rate of 82%, a throughput of 1.5Mbps and a network efficiency of 94% are achieved by the proposed technique.

The computing complexity is based on the construction of the network, and depends on the size and structure of the network. The BRACER broadcast protocol has a high computational complexity of $O(\exp^{n \log n})$, where $n$ denotes the number of nodes in the network. Due to the use of message broadcasting, it uses multiple hops, and this generates an exponential of $n$, giving a high complexity.

QBPM has a complexity of $O(n \log n^2)$. This technique has a greater number of nodes, and in order to calculate prioritization, all the nodes in the network need to be analyzed. However, compared to the existing models, the QIPS scheme has a lower complexity of $O(2n)$. This method divides the network into two regions, and the complexity is therefore reduced in the QIPS technique.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Type of Algorithm</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>BRACER</td>
<td>$O(\exp^{n \log n})$</td>
</tr>
<tr>
<td>2.</td>
<td>QBPM</td>
<td>$O(n \log n^2)$</td>
</tr>
<tr>
<td>3.</td>
<td>QIPS</td>
<td>$O(2n)$</td>
</tr>
</tbody>
</table>

4.4 CHAPTER SUMMARY

In this chapter many scheduling problems which occur in distributed cognitive radio networks because of decentralized model are
discussed. To avoid these issues, a new scheme, QIPS, is proposed for distributed cognitive radio networks, in order to improve the QoS and to improve scheduling efficiency across the distributed network. This system converts a centralized network into many distributed networks with individual base stations, which can vary with the time and resource availability. The prioritized scheduling is apt for real time data. The algorithm is explained with transmission of three types of data traffic. Simulations were carried for a variable number of nodes. Five important QoS parameters were studied and compared with already existing methodologies. The results are tabulated and also graphically presented.