Scientific Journal Impact Factor (SJIF): 1.711
e-ISSN: 2349-9745
p-ISSN: 2393-8161
International Journal of Modern Trends in Engineering and Research
www.ijmter.com

DYNAMIC SPECTRUM ALLOCATION TO MAXIMIZE EFFICIENCY IN COGNITIVE RADIO NETWORKS

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Abstract-A cognitive radio network is composed of secondary users, referred to as cognitive users, which are allowed to use a given licensed spectrum in an effective manner, and also band as long as there are no primary (or) licensed, users occupying this band in their neighborhood. This limited spectrum access strategy leads to heterogeneity in spectrum availability among secondary users .The first objective is maximizing the network coverage area, in terms of the total number of clients served, and at the same time reduce the communication coordination function. To address this type of problem, we proposed a received based spectrum allocation strategy that reduces the need for a common control channel, thus reduce the coordination function.
Keywords: Spectrum allocation, Cognitive radio networks, Spectrum utilization.

I. INTRODUCTION

A cognitive radio is software defined radio that is able to identify idle frequency channels, or so called spectrum holes, through spectrum sensing. Furthermore, a cognitive radio is able to identify the best available spectrum to meet certain quality-of-service requirements through spectrum analysis. Spectrum mobility is another functionality of a cognitive radio which enables it to change its frequency of operation, and therefore enables dynamic spectrum access. In general terms, a “cognitive radio” is defined as a radio that can change its transceiver parameters based on interaction with the surrounding environment.

A. The Communication Coordination Function and Spectrum Allocation

Although the technology of cognitive radios gives SUs more flexibility and adaptability (by allowing them to change their communication parameters dynamically), it makes the coordination of the communication process much more complicated. This complexity arises from the fact that SUs might be operating on different frequency channels at different times. This requires the communicating pair of SUs to negotiate their channel availability and decide on one channel for communication. But, the negotiation itself must take place over a common channel that is known to the communicating pair a priori; this channel is usually referred to as the common control channel (CCC). At the network level, this CCC has to be common network wide to guarantee network operation.

A recent paradigm that assigns the task of spectrum sensing to a dedicated sensor network infrastructure frees SUs from the burden of spectrum sensing, and consequently from the need for a CCC to coordinate the sensing process. In effort to completely alleviate the need for a CCC, we propose a spectrum allocation mechanism that does not require a CCC to coordinate the communication process.

II. SPECTRUM ALLOCATION FOR MAXIMIZED COVERAGE

The spectrum allocation problem in cognitive radio networks (CRNs). We aim at finding an allocation strategy that guarantees quality of service (in terms of link reliability), maximizes network coverage, and alleviates the need for a common control channel to coordinate the communication process. The allocation of a particular spectrum to a cognitive client(CC) is considered feasible if the MC can establish connectivity with the backbone network in both upstream and downstream directions, and has the SINR (signal to interference and noise ratio) of the uplink and the downlink with its parent cognitive router (CR) within a predetermined threshold. A receiver-based spectrum allocation model that achieves the aforementioned objectives is proposed in this paper. The last phase is spectrum allocation to MCs, i.e., downlinks. First of all, the MCs to be considered in the phase are only the ones that have reliable uplinks with their parent MRs after the second phase. Therefore, in lines [15-16] of Algorithm, we set Ai $\forall_i \in B \cup G$ to those MCs that have reliable uplinks with MR x. Similar to what we did with uplinks, we need to process potential downlinks in ascending order of their maximum channel gains.

However, the case now is different. Each MC may have several channels available, i.e., Lj > 1 for j $\in$ A. This provides us with multiple choices for each downlink, in contrary to the uplink case where each uplink has only one choice, i.e., the channel assigned to the MR of that uplink. Therefore, for each MC j, we will find |Lj | maximum channel gains each on one of the channels in Lj. Let P be the set of all possible (MC, channel) pairs defined as follows:

$$P = \{(x, k): x \in \cup_{j \in B \cup G} Aj, k \in Lx\}.$$

Recall that this set is evaluated after removing MCs that cannot be served on the link. Therefore, all MCs represented by at least one pair in P have passed the second phase, i.e., can be served reliably on the uplink. Let pr(x) denote the parent MR of MC x. Then for each pair (x, k) $\in$ P, the maximum channel gain λ(x, k) is calculated as follows:

$$\lambda(x,k) = \max \{ \max_{j:(j,k)\in P, pr(x)\neq p(j)} \psi_{ij}^{k} \quad \max_{j \in B \cup G \setminus \{pr(x)\} : \exists (m,j) \in (k)} \psi_{ij}^{k} \}$$

The above equation finds the maximum channel gain λ(x, k) on channel k between MC x and any other MC that has channel k available or a MR that was assigned channel k in the first phase. Then, we process the pairs in P in ascending order of their maximum channel gains. For each pair (x, k), we add the downlink (pr(x), x) to the current set of reliable downlinks on channel k, Q_d^r(k) (initially empty), and the uplink (x, pr(x)) to the current set of reliable uplinks on channel k',Q_d^r(k') (which is initially empty) where k' is the channel assigned to pr(x), i.e,L(r)[x, k'] = 1. Using the PCA algorithm, if both the uplink and the downlink can be served reliably without breaking the reliability of any link in Q_d^r(k) and Q_d^r(k'), then this MC is added to the set of reliable MCs A^r and the downlink and the uplink are admitted to the set Q_d^r(k) and Q_d^r(k') respectively. Otherwise, the two links will be removed from Q_d^r(k) and Q_d^r(k') and the MC will not be added to A^r. Once an MC is added to A^r by one of its pairs, other pairs of this MC in P will be ignored. This process is presented in algorithm .The algorithm that combines all the three phases together is presented in Algorithm which we call the heuristic receiver-based spectrum allocation (HRBA) algorithm.

Algorithm: HRBA: Heuristic Receiver Based Spectrum Allocation
Input: L; B; G; Ax∀x ∈ B ∪ G; Lx∀x 2 B ∪ G ∪ A.
Output: Set of reliable MCsA^r; transmission powers; channel allocation to MRs L(r); channels Allocation to MCs ¯L(r).
//Phase 1: allocate 1 channel to MRs.
L(r) = GRA (B ∪ G, Lx∀x ∈ B ∪ G);
R =∅;

P_i^k = 0, ∀x 2 B ∪ G ∪ A, k ∈ Lx;
//Phase 2: find the set of reliable uplinks.
For all k ∈ L do
Qu(k) = {e : r(e) ∈ B ∪ G, t(e) ∈ Ar(e), k ∈ Lt(e),L(r)[r(e), k] = 1};
if Qu (k) ≠ ∅ ; then
For e ∈ Qu (k) find λe;
Q_u^r (k)≠ ∅;
For all e ∈ Qu (k) in ascending order of λe do
if PCA (Q_u^r (k) ∪ {e},∅, k) = 1 then
Q_u^r(k) = Q_u^r (k) ∪ {e};
//Phase 3: allocate channels to MCs.
Ai =∅, ∀x 2 B ∪ G;
Ax = {j: (j, x) ∈ Sk∈L Q_u^r (k)}, ∀x ∈ B ∪ G;
Find the set P;
For each pair (x, k) in P find λ(x, k);
Q_u^r(k) =∅, Q_u^r (k) =∅;
Let $\bar{L}$ (r) is an |A| × K matrix initially set to 0;
for all (x, k) ∈ P in ascending order of λ(x, k) do
if x ∈ A^r then
Continue;
k' := {k : L(r)[pr(x), k] = 1};
Q_u^r(k) = Q_u^r(k) ∪ {(pr(x), x)};
Q_u^r(k') = Q_u^r(k') ∪ {(x, pr (x))};
x = PCA (Q_u^r(k),Q_d^r (k), k);
y = PCA (Q_u^r(k'),Q_d^r (k'), k');
if x=1 and y=1 then
A^r = A^r ∪ {x};
$\bar{L}$ (r) [x, k] = 1;
else
Q_d^r(k) = Q_d^r (k) \ {(pr(x), x)};
Q_u^r(k') = Q_u^r (k0) \ {(x, pr(x))};

III. DYNAMIC APPROACHES BASED ON SPECTRUM ALLOCATION

A cluster-based approach was proposed such that the network is clustered into 1-hop clusters based on channel availability. Nodes that belong to the same cluster use the same control channel. Inter-cluster communication takes place through gateway nodes that operate on multiple control channels. Therefore, the channel allocation problem was mainly the allocation of control channels.

In cluster head first approach, a node imitating the cluster formation process is the cluster head and then other nodes having similar spectrum holes join with the cluster one by one. In this approach the network is formed by interconnecting the clusters and, the neighbor discovery is not of importance in this approach. The cluster head first approach is quite different as compared to cluster first approach and is extensively dependent on neighbors.

The implementation in works as follows: A node forms a cluster on a particular channel. In other words, the cluster head and control channel are known at the first step itself. A node that initiates the clustering process is the cluster head .The cluster head invites the immediate nodes to join the cluster who observe similar spectrum holes. The aforementioned invitation is send on one of the idle channels. This channel is the master channel i.e. control channel. The clusters are formed on this control channel, which simply means there is exactly one control channel per cluster. The whole network is constructed using combining such clusters. The clusters formed are always non overlapping meaning that one node will be a member of exactly one cluster.

The clusters formed are based on the control channel. A node which senses multiple idle channels such that more than one of these channels act as control channels in different clusters. This implies that such a node has the privilege of being a member of more than one cluster at a time. Such nodes are gateway nodes, in the sense that they provide a link for inter cluster communication. This leads classification of nodes into three categories, namely, cluster heads, gateway nodes and ordinary nodes.

The nodes in the clusters are classified based on the role they perform in the cluster. In cluster first approach, the nodes can either be cluster heads or ordinary nodes. The cluster heads carry out the functionality of controlling and coordinating the cluster. This controlling and coordinating occurs through the use of control spectrum allocated in that cluster originating from cluster head. In cluster head first approach, the nodes are classified as cluster head, gateway nodes and ordinary nodes. The gateway nodes are meant for the ease of inter cluster communication. The cluster head can only communicate to another cluster head if they are immediate neighbors of each other. This has to be realized through the use of a common idle channel other than the control channel of those individual clusters. A message sent on control channel is intended for the cluster members for efficient intra cluster coordination and communication. Hence the inter cluster coordination should be carried out on a spectrum that is not allocated as the control channel. The only requirement is that the gateway node should must have the control channels of both clusters in its idle spectrum list.

IV.NETWORK MODEL ANALYSIS

The cluster first and cluster head first approaches are applied to the network shown in Fig.1. The cluster formation process for one node to illustrate the working of both the approaches is elaborated and the formed clusters are indicated in Fig.2 and Fig.3 for cluster first and cluster head first approach respectively.

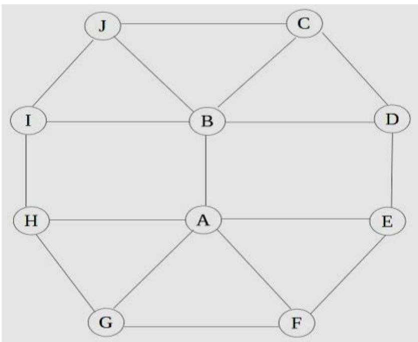

Fig.1.Network model

List of adjacent channels sensed by each CRS

A={1,2,3,7,9}	B={4,5,6,8,10}
C= {4, 6, 7}	D= {3, 5, 7}
E= {2, 4, 10}	F= {1, 3, 10}
G= {2, 9, 10}	H= {1, 8, 10}
I= {6, 7, 9}	J = {5, 7, 8}

It is assumed that the list of immediate neighbors is available with all the nodes and the spectrum holes do not change during the process of clustering. The working of node A for cluster first approach is explained here. Node A has five nodes as immediate neighbors, namely, B, E, F, G, and

H. The list of idle channels sensed by A is 1, 2,3,7,9. The intersection of each node's channel list is obtained as the next step. So, the number of common channels of nodes B,E,F,G,H with A are 1(2),2(3,7),3(1,7,9),4(1,3,7,9) respectively where numbers in brackets indicate the channel numbers. The node A has sensed 5 idle channels and if A was to be the only member of the cluster the product of nodes in the cluster and the common idle channels in the cluster would be 5. In the next step, A and G forms a cluster with 4 common idle channels. Since the intersection is highest and sequential (in the event for tie breaking). The common channels are 1,3,7,9. Cluster members are 2 and idle channels for that cluster are 4. The product of which is 8. The node H also joins the cluster in the next step because it also has the same common channels with A. So, the number of node becomes 3 and the common idle channels are 4. The product is 12. The nodes B and E do not have any common channel with this cluster so such nodes would obviously reduced the product and resulting into smaller clusters with very less common idle channels in each cluster. Of the products 5, 8 and 12; 12 is the highest. So, Let us assume that node is elected as cluster head. On similar lines, the clusters are formed control channel from a list of possibilities is selected and cluster heads for respective clusters are elected. The cluster heads could be A, B, C, E and F for their respective clusters. The clusters formed and the idle channels of those clusters are indicated in Fig.2.

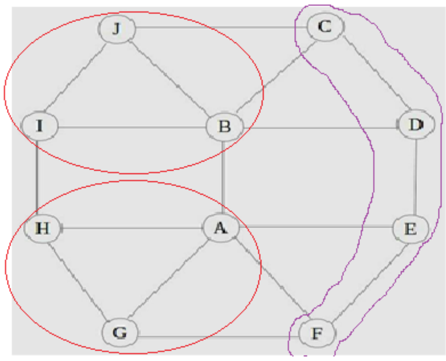

Fig.2. Clusters formed by cluster first approach

The working of node A in cluster head first approach is as follows: Node A initiates the cluster formation process. So, node is the cluster head of the cluster that will be formed. Node broadcasts invitation to its immediate neighbors for cluster formation on the lowest frequency channels, which is channel 1 in this case. The immediate neighbors H and G receive the invitation and join the cluster on channel 1. It is worth noting that the channel 1 is the only control channel for the cluster formed and moreover the cluster is formed on this channel. The other idle channels may or may not form clusters on them depending on the invitations received or themselves initiating the cluster formation process. Thus the cluster formed by A has two other members namely G and H and the control channel is 1 while the node A is the cluster head. The clusters formed with cluster heads and the idle channels of those clusters are indicated in Fig.3.

The overlapping clusters are formed due to the reason that a node is a member of one cluster on one channel and member of another cluster on another channel. Such nodes, as mentioned previously are gateway nodes. The cluster heads are B, E, F, G, I for their respective clusters and the gateway nodes are A, H, D. Node A is a member of a cluster on control channel 1 and member of other clusters on channels 2 and 5. Similarly H is a member of one cluster on channel 1 and member of another on channel 3. Also D has two memberships i.e. on channels 2 and 6.

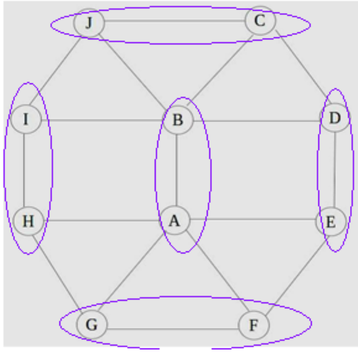

Fig.3. Clusters formed by cluster head first approach

4.1. Packet based Spectrum allocation: Spectrum allocation is performed on a per-packet basis by transmitter and receiver in a common control channel .The allocation does not apply to subsequent packets or other entities. Since different packets may be transmitted on different data channels, frequent switching between channels may be incurred, resulting in significant channel switching delay.

4.2. Link based Spectrum allocation: All packets on a wireless link between two nodes are transmitted on the same channel until the spectrum allocation decision expires. Each link in a flow can choose any one of the free spectrum. Note that existing spectrum allocation strategies for CR networks take the link-based approach. The major pitfall of a link-based approach is the significant channel switching delay incurred when a node serves two links on different channels.

4.3. Flow- and component-based Spectrum allocation: In flow-based spectrum allocation, all packets belonging to a flow are transmitted on the same spectrum. Different flows may operate on different channels. A component in the context of spectrum allocation is similarly defined as a connected sub-graph in the network flow graph, which is composed of nodes belonging to intersecting flows. In component-based spectrum allocation, all nodes within a component are assigned the same spectrum. If there are no intersecting flows, the component-based assignment is equivalent to the flow-based assignment.

V.SIMULATION RESULTS

The performance of spectrum utilization is analyzed by taking parameter into account. From the obtained results it is inferred that the performance of spectral utilization is improved by cluster based and segment based approaches. The following are the parameters which taken into account for comparison:

1. Spectral Efficiency
2. Energy Efficiency

Formula to calculate spectral efficiency

$$\text{Spectralefficiency} = \frac{\text{Assigned link rate}}{\text{No of channel}} \qquad (1)$$

Assigned link rate is refers to the transmission of packet at link level.
Formula to calculate Energy efficiency

$$\text{EE} = \frac{\text{Data rate}}{\text{Total power}} \qquad (2)$$

Data rate is considered to be transmission of packets through the network based on transmission time and transmission power.

Table 1.Parameter settings

Total number of nodes	[10,40]
Communication range of each node	[50,70]
Total number of channels	[4,10]
Total number of primary users	10
Interference range of primary user	40

5.1. Number of Nodes Vs Assigned Link Rate

Assigned link rate is usually measured in bits/second. In the graph 1 assigned link rate is minimized by applying node based selection mechanism which is comparatively low if link based selection schemes are implemented in node level.

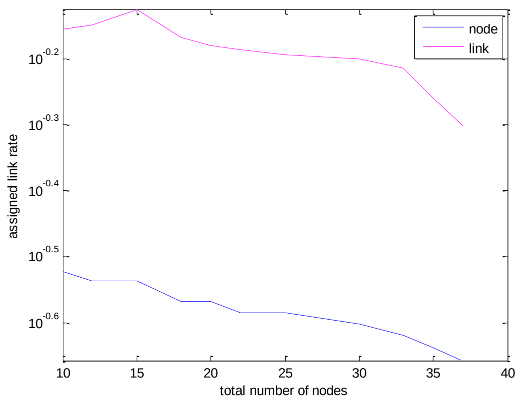

Fig.4. Nodes Vs Assigned link rate

The above graph shows the assigned link rate increase due to assigned links over possible links. By using link based selection.

5.2. Nodes Vs Number Of Rounds

The number of rounds needed by spectrum allocation. In the graph 2 number of rounds is decreased by applying link based selection which is comparatively high if node based selection are implemented in node level.

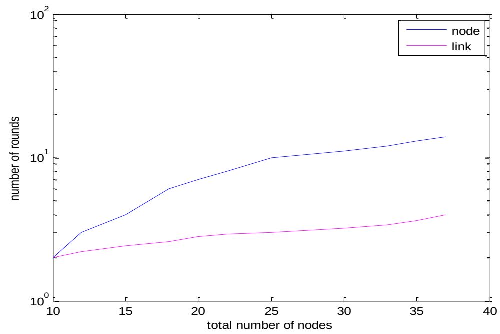

Fig 5. Nodes Vs Number of rounds

A small number of rounds indicate higher efficiency. Because the number of rounds needed by spectrum allocation.

5.3. Power Vs Energy Efficiency

Energy efficiency refers to time taken for the spectrum allocated for group of node. In the graph 3 Energy efficiency is increased by applying link based selection which is comparatively low if node based selection.

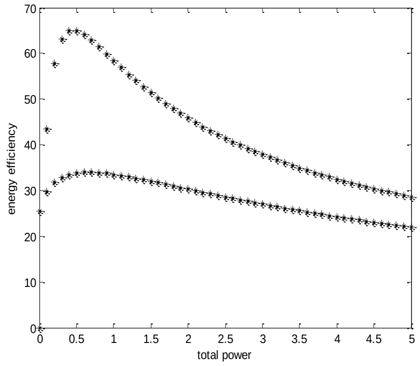

Fig 5. Power Vs Energy Efficiency

Transmission rate is increase the energy efficiency is reduced due to interference between the primary user as well as secondary user.

Table .2.Comparsion of rate and spectral Efficiency

RATE	SPECTRALEFFICIENCY
20.67	59.06
34.14	75.88
53.51	81.29
61.11	82.33
67.8	81.48
73.81	81.48
79.25	77.69
84.24	75.48

Transmission of each data rate is increased mean spectral efficiency is also decreased when the primary is considered through the spectrum allocation.

VI. CONCLUSION

The spectrum allocation (SA) problem is solved by using cluster based approach, segment based approach. In the cluster based algorithm assigned link rate is less when compare to segment based algorithm. Interference between the primary user and secondary user are reduced. Spectral efficiency and energy efficiency are maximized through the multi channel selection. Spectrum utilization is improved by using node-link based algorithm.

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