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Localized Algorithm for Channel Assignment in Cognitive Radio Networks

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ABSTRACT
Cognitive Radio has been emerged as a revolutionary solution to migrate the current shortage of spectrum allocation in wireless networks. In this paper, an improved localized channel allocation algorithm based on channel weight is proposed. A factor of channel stability is introduced based on link environment, which efficiently assigns the best channels to the links. Based on the framework, a conflict resolution strategy is used to make the scheme adaptable to different network conditions. Calculations indicate that this algorithm can reduce the conflicts, increase the delivery rate and link assignment rate compared with the basic channel assignment algorithm.
Keywords–CRNs, channel assignment, dynamic spectrum access, localized algorithm

I. Introduction

With the development of wireless communications, the demand for spectrum resources is growing, and the traditional method of spectrum allocation is challenged greatly with the reason of low utilization of the spectrum. CR (cognitive radio) technology is considered to be the best solution to solve this problem [1][2].

In the cognitive radio network, the secondary (unlicensed) users (SUs) are allowed to opportunistically access any idle frequency that is originally allocated to the Primary (licensed) users (PUs) but currently not occupied. A Graph-coloring model was put forward by Wei Wang. This model abstracts the spectrum allocation problem into a graph-coloring problem [3]. Greedy Algorithm and Fair Algorithm were present based in this model. A spectrum aware channel assignment algorithm is addressed [6] to minimize the interference to PR nodes, maximize the connectivity and to minimize the interference between CR nodes due to channel reuse. Demand-based spectrum allocation algorithm was proposed by Y. Ding to satisfy the requirement of actual networks [12]. In order to reduce the complexity of the algorithm and time cost, parallel algorithm of spectrum allocation[16] is introduced to realize the quick spectrum allocation, while it cannot guarantee the access fairness. Some other works study the cross-layer optimization, considering both network and link layers [17].

In this paper, a localized channel allocation algorithm based on channel weight is proposed. A function for calculating channel stability is introduced based on link environment. Conflict probability and then channel weight is calculated which efficiently assigns the best channels to the links. The delivery rate and link assignment rate are increased as compared to the basic channel assignment algorithm. Our goal is to minimize the interference between nodes due to channel reuse and maximize the Connectivity.

II. Channel Allocation Model

The channel allocation model is described by a graph G (V, E) where V denotes the set of vertices corresponding to CR nodes and E denotes the set of edges corresponding to possible communication links. In addition, the allocation model in this article is described by several matrices. In our model, we assume that environmental conditions such as user location, available spectrum are static during the time it takes to perform channel assignment. In this model, an edge exists between two CRs if they can directly communicate in the absence of any PR activity. Two links are adjacent if they share one end node. Conflicts exist if two adjacent links are assigned the same channel. For the i^{th} CR, denoted by v_i, its one-hop neighborhood $N(v_i)$ is the set of all CRs it can communicate with based on G(V, E). We also define $C(v_i) = \{C_1, C_2 \ldots .. C_k\}$ to indicate the set of idle channels sensed by v_i. Here $C(v_i) \subseteq C$ where C denotes the set of total available channels in the network. C_u is not equal with C, due to the different interference ranges of primary users at different locations. The matrices and parameters needed is shown as follows:

- **Available Channels:** The available channels for link uv is defined as $C_u \cap C_v$, denoted as C_{uv}.

- **Group (cluster):** A group or cluster is a special 2-level tree with one independent set node, and a set of adjacent links associated with that node. In each cluster, each link is ‘‘handled’’ by the parent node, called host or head.

- **Vertex Vector:** V is the vertex of the graph, which represents N cognitive users.

- **Edge Matrix:**E= {e_{ij}|e_{ij} ∈ {0,1}, i, j=1,2,……N} is a *N*by *N*binary matrix, representing all edges of the graph. An edge is available between nodes i and j if e_{ij}= 1. And if e_{ij} = 0, the opposite.

- **Channel Availability Matrix:** A={a_{ik}| a_{ik}∈ {0,1}, i=1,2,….E, k=1,2,……M} is a E by M binary matrix representing the channel availability. Channel k is available for link i ifa_{ik} = 1. And if a_{ik}= 0, the opposite.

- **Channel Assignment matrix**: X={x_{ik}| x_{ik} ε{0,1}, i=1,2…..N, k=1,2,……M} is a E by M binary matrix which represents the final distribution of E links to M channels, and x_{ik}=1 indicates that link i shares the k^{th} channel. And if x_{ik}=0, link i cannot use the k^{th} channel.

- **Condition:**
  If a_{ik}= 0
  then x_{ik}= 0
  For any link i,
  $x_{ik}x_{ij}$= 0 (for all k ∈ neighbors of node i)

Maximize

$$\sum_{i=1}^{E} \sum_{k=1}^{M} x_{ik}$$

where $x_{ik} \le a_{ik}$

III. Channel Allocation Algorithm

3.1. LACR Algorithm

LACR is a localized scheme, which calculates channel weight for all common channels based on maximum connectivity and minimum interference within CR nodes. Some assumptions of LACR are as follows: First, a common channel, which enables CR nodes to transmission information, is used. Second, each node should maintain lists of locally available channels that are not occupied by primary users. Third, in our algorithm, the communication range equals the interference range and each link is only assigned with a single channel.

3.2. Channel Weight Calculation

Link Degree (D_{uv}) of any link uv between u and v is defined as the number of adjacent links of a link uv or the number of neighbors of u and v.
For any link uv, if N_u is the neighbor set of node u and N_v is the neighbor set of node v, then link degree is:
$D_{uv}=|N_u|+|N_v|$

Connection Degree (G_{uv}): If for a particular link uv using channel m, connection degree is the set of adjacent links having same channel.
If $g_u = \{x|x \in e_{uw}$ and $m \in C_{uw}\}$ and $g_v = \{x|x \in e_{vw}$ and $m \in C_{vw}\}$
then
$G_{uv}(m) = g_u \cup g_v$

where e_{uw} : adjacent edges of node u
e_{vw} : adjacent edges of node v
C_{uw} : the channel set of link uw.
C_{vw} : the channel set of link uw.

For any channel m, used by link uv, L_{uv} gives the sum of reciprocal of total number of channels of all the links of the connection degree set as defined in (1)

$$L_{uv}(m) = \sum_{uw \in g_u} \frac{1}{|C_{uw}|} + \sum_{vw \in g_v} \frac{1}{|C_{vw}|} \quad (1)$$

For all channels C_{uv} of a particular link uv:

$$L_{uv}(C_{uv}) = \sum_{c \in C_{uv}} L_{uv}(c)$$

For any link uv using a particular link m:

$$\text{Conflict Probability } p_{uv}(m) = \frac{Luv(m)}{\sum_{c \in C_{uv}} L_{uv}(c)} \quad (2)$$

For a group of nodes in a subset, the sum of probabilities is 1.

$$\sum_{uv \in S_u} \sum_{m \in C} p_{uv}(m) = 1$$

The channel weight of channel m over link uv is calculated as: $w_{uv}(m) = \frac{1-p_{uv}(m)}{D_{uv}}$ (3)

3.3. Algorithm Description

The algorithm is divided into two phases. Maximum independent set is calculated for a network and nodes in the set are called MIS nodes. The MIS nodes are marked as head nodes and 2-level trees each with one head node (MIS nodes) are formed with a set of adjacent links associated with that node. In each cluster, the head node handles each link and this process is called a “partition based on

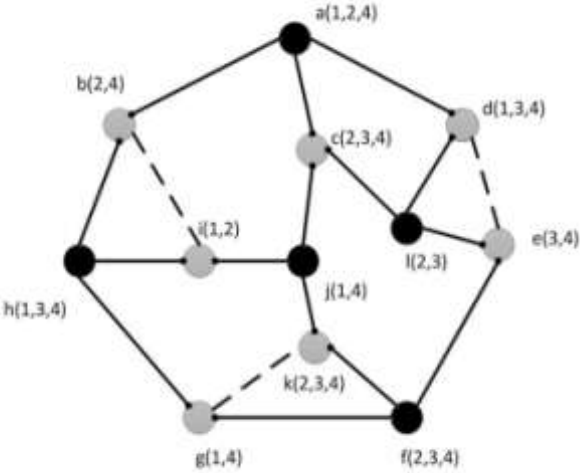
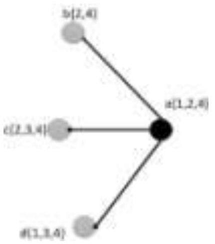


Figure 1: The example topology with independent set

independent set algorithm as shown in Fig. 1. This partition will form a set of ''clusters.'' Fig. 2(a) shows a group obtained because of independent set and fig. 2(b) shows the corresponding channel availability matrix.



links / channels	1	2	3	4
ab	0	1	0	1
ac	0	1	0	1
ad	1	0	0	1

Figure 2: (a)Network partition group after run of MIS, (b) Channel availability matrix of a Group

Then, in each cluster, initial assignment through maximal matching processing is performed, by assigning channels to links that minimize channel-conflict probability as shown in fig. 3.The two phases are:

- **Channel Allocation:** In channel allocation phase, the positions of N cognitive nodes are generated. The graph is partitioned according to the maximum independent set calculations. Weight is calculated and the channels are allocated to each partition by maximal matching in order to maximize the weight.

- **Conflict Resolution:** In conflict resolution phase, conflicts are solved by taking link priorities. Priority is based on the remaining number of channels. If $|U_{vw}|$ is the number of unused channels on vw, then it is used as a priority, with a smaller value corresponding to a higher priority. This strategy assigns a higher priority to links with fewer choices of channels.

Table 1: Conflict probability of every channel on each link.

$p_{ab}(2)$	$p_{ab}(4)$	$p_{ac}(2)$	$p_{ab}(4)$	$p_{ad}(1)$	$p_{ad}(4)$
0.33	0.67	0.33	0.16	0	1

Table 2: Weight of every channel on each link

$w_{ab}(2)$	$w_{ab}(4)$	$w_{ac}(2)$	$w_{ab}(4)$	$w_{ad}(1)$	$w_{ad}(4)$
0.33	0.16	0.33	0.16	1	0

Auction algorithm is used to find the maximum matching. Moreover, the Auction algorithm is a local greedy algorithm; it only needs the weight information on each adjacent link in one cluster. The number of channels and the number of links can be made equal by adding virtual nodes at either side, so that the number of channels and the number of links are the same. The bipartite must satisfy Hall's matching theorem [41] by adding virtual edges from the virtual nodes to apply perfect matching.

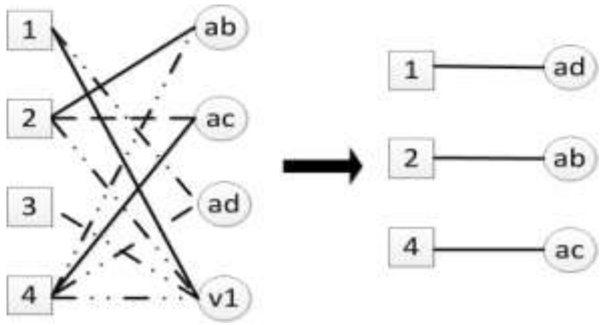


Figure 3: The channel assignment process

Algorithm for Channel Selection

Inputs: 'V' Number of nodes, 'C' total channels in the network, 'E' number of edges, 'k' is the size of maximum independent set
/*Initial Allocation Phase*/
Step 1:S= MIS (V, k) //Maximum Independent Set
Step 2:P ← Cluster formation according to the maximum independent set S
Step 3:for$\forall p_v \in$ P **do**
Step 4:for$\forall vu \in p_v$, $\forall m \in C_{vu}$, **do**
Step 5:calculate weight $w_{vu}(m)$
Step 6:calculate maximal matching between channels and adjacent links by the auction algorithm.
Step 7:for$\forall vu \in p_v$**do**
Step 8: update X_{vu}
/***Conflict Resolution phase */**
Step 9:for$\forall uv \in E'$ **do**
Step 10: **if** uv and any link in N_{uv} have conflicts **then**
Step 11:remove the channel from the link with the lower priority.
Step 12: **for**$\forall p_v \in$ P **do**
Step 13:for$\forall vu \in p_v$**do**
Step 14: **if** $X_{uv} > 0$ **then**
Step 15: $p_v \leftarrow p_v - \{vu\}$
Step 16: $E' \leftarrow E' - \{vu\}$, $C_{vu} \leftarrow C_{vu} - X_{vu}$
Step 17: **If**$\forall p_v$ satisfies $|C'_v| > 0$, and $X_{vu} = 0$ for $\forall vu \in p_v$**then**
Step 18:go to **step 2**

3.4. Example

Consider an example topology where all the nodes have single radio interface and there are 4 channels available. For simplicity, we assume that initially there is no PR activity on any of the available channels. The links show connectivity with different nodes. Fig. 1 shows the network when no channel is assigned to any node. Maximum independent set is calculated. Network is partitioned into groups according to the maximum independent set calculations, as shown in fig. 2. As there is no channel assigned in the network, so it calculates channel weight using equation (3) for each group. Here we take the channel assignment on a cluster with head node “a” for an example. We construct a bipartite graph, and add a virtual nodes on the link side to conduct the perfect matching. Auction algorithm is used to find the maximum matching.Each edge in the bipartite graph has a weight, as computed in Table2. The weight of virtual edges connecting virtual nodes is 0. Next, we conduct the maximum matching shown in Fig. 3. The other groups conduct their channel assignments in the same way. The number on each link is the channel assigned to it. Since link ge cannot get any channel, we use a dotted line to represent this link.

In this paper, we propose LACR, a highly efficient and localized algorithm that can adjust well with cognitive radio network and maximize the node connectivity. The algorithm is able to achieve the best-localized initialization by using partitions and maximal matching. Channels are assigned based on channel weight calculation and maximal matching is used with the goals of improving the efficiency while keeping the connectivity of the network. LACR, when compared to basic link-based algorithm, assigns channels efficiently, resulting in much reduced interference to radio nodes and increased link assignment rate.Link- based approach is a random channel assignment strategy in which channels are assigned randomly to links. These algorithms does not consider the ongoing PR activity. Since, our goal is to maximize connectivity and minimize the interference within CR nodes therefore we define the following performance metrics:

1**. Connectivity Rate:** This metric is defined as the ratio of the maximum reachable nodes over total number of nodes in the network.

2. **Link Assignment rate:** It is defined as the ratio of assigned links over possible links in the network.

- By varying the number of nodes randomly, when the number of SUs increases, at the same time, the connectivity rate and link assignment rate increasesfor the LACR algorithm as compared to link-based algorithm in which it is reduced with more nodes due to random assignment.
- By varying the number of channels, in LACR, as compared to link-based, the link assignment rate with radio nodes increases as there are more available channels for opportunistic spectrum access which causes minimum interference to other nodes. This is because LACR assigns those channels which have less conflict probability.

To conclude, the improved algorithm has good performance for the connectivity rate and link assignment rate.

IV. Conclusion

The proposed algorithm predicts the channel weight and it gives an approach for efficient and localized channel assignment that can adjust well with cognitive radio network, maximize the node connectivity, and based on minimum interference between CR nodes.Calculating the conflict probability and then weight provides the secondary user regarding the channel availability to determine whether to use the channel or not. This prediction enhances the channel enhances the communication of nodes.

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