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Low Overhead Spectrum Allocation and Secondary Access in Cognitive Radio Networks

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ABSTRACT

Cognitive radio networks spectrum access, which allows secondary users opportunistically access unused licensed channels to exploit instantaneous spectrum availability, is a promising approach to achieve efficient spectrum utilization and mitigate spectrum scarcity. In order to reduce spectrum handoff overhead, this paper propose two heuristic spectrum allocation and reallocation methods based on graph coloring method. For a given network topology, the proposed spectrum allocation method first generates an interference graph based on the network topology and interference constraints. Then for secondary access on a graph coloring algorithm is cooperative spectrum reallocation among secondary users to minimize spectrum handoffs. Obtained results demonstrate that graph coloring method and algorithms are a promising concept that can enhance the performance of secondary spectrum usage.

Keywords- *Graph coloring problem; Cognitive radio network; Spectrum allocation*

1. INTRODUCTION

Cognitive radio (CR) is one of these concepts, which requires mobile terminals to be aware of their **environments** in order to take intelligent decisions [1]. This awareness is ensured by radio measurements, thus increasing the importance of measurement exploitation in wireless networks in the cognitive radio context. However, most of the channels actively transmit the information only for short a large portion of the assigned spectrum is used sporadically. This implies that the inefficient radio spectrum usage has been a serious bottleneck for deployment of larger density of wireless devices. With the dramatically increasing demands of the scarce radio spectrum for wireless services in recent years, cognitive radio has drawn great attention in the world for its ability of operating in licensed bands without a license. In a cognitive radio network (CRN), secondary (unlicensed) users (SUs) may coexist with active primary (licensed) users (PUs) of a primary radio network (PRN) either on a non-interfering access basis [2] or an interference-tolerant access basis [3]. Secondary spectrum usage allows unlicensed users (secondary users) to operate in frequency bands allocated to licensed systems (primary users) by detecting the unused spectrum portions (spectrum holes) without causing any deterioration to primary users [4]. The secondary spectrum usage can be classified into two main categories: frequency overlay and frequency underlay [5]. The underlay model stands for a simultaneous transmission of secondary users with primary users at the condition that the generated interference doesn't exceed the noisy floor of the PU. Whereas, the frequency overlay consists in transmitting in opportunistic manner on the detected spectrum opportunities at a given time and location.

In the literature in this area, approaches to regulating spectrum allocation can be broadly classified into two strategies: centralized and distributed schemes[6]. Such as IEEE 802.22 [7] adopt a centralized scheme, where a central controller allocates spectrum to all nodes. In particular, in 802.22 a cognitive radio network consists of multiple cells. Within each cell, there is a base station (BS) that supports a set of fixed wireless subscribers called customer premise equipments (CPEs). The spectrum of interest is divided into a set of non-overlapping channels which a BS can use to serve its corresponding CPEs. The spectrum is actually licensed to a set of primary users, e.g. TV services. An 802.22 network is shown in Figure 1.

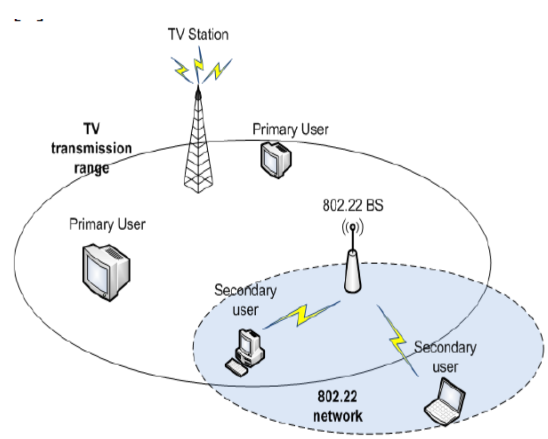

Figure 1: An 802.22 cognitive radio network

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In the process of coordination between PU and SU, a SU has to change the spectrum it's using when the primary user starts to occupy the spectrum. We denote the change from one spectrum band to another as spectrum handoff. In the context of dynamic spectrum sharing, spectrum need to be reallocated varying with time, which results in spectrum handoff. Frequently spectrum handoff will cause serious system overhead listed as follows: (1) it consumes extra energy to accomplish the process of spectrum sensing, spectrum choosing, and spectrum accessing; (2) it introduced more communications cost on exchanging control messages; (3) it also cause interruption and delay of services[8,9]. The subject of secondary spectrum usage has been a hot research topic for some time now. The goal of this article is to present an interesting solution to spectrum allocation and secondary spectrum usage reallocation based on graph coloring method and heuristic algorithms. The proposed technique helps achieve two goals in cognitive radio networks: efficient utilization of spectrum opportunities and fair allocation of spectrum resources among secondary users. The rest of the paper is organized as follows. Section 2 proposes CR network spectrum allocation method. Section 3 describes the secondary spectrum usage allocation algorithm of an 802.22-type cognitive radio network. Conclusions are drawn in Section 4.

2. SPECTRUM ALLOCATION

The spectrum allocation can be reduced to a graph coloring problem(GCP).

Definition 1:

Given the spectrum allocation can be represented by a *Conflict Graph* $G = (V;E)$ where V is a set of vertices denoting the users that share the spectrum, the available spectrum mapped to the color list at each vertex, and E is a set of undirected edges between vertices representing interference constraint between two vertices defined by C.[10]

For any two distinct vertices $u, v \in V$, an edge between u and v, is in E if and only if $C_{u;v} = 1$.

Figure. 2 illustrates an example of GCP graph. There are 5 colors available. The numbers outside the brackets attached to each node denote the colors assigned to that node, while the numbers inside the brackets denote the available color list of each node.

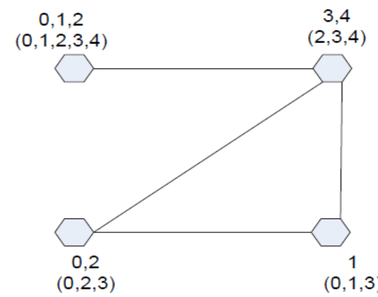

Figure. 2 . An example of GCP graph

A GCP graph is to color each vertex using a number of colors from its color list, and find the color assignment that minimize communication system interference. The coloring is constrained by that if an edge exists between any two distinct vertices, they can't be colored with the same color. Most importantly, the objective of coloring is to maximize spectrum allocation utility. The solution to this graph coloring problem is to maximize spectrum allocation utility for a given graph, *i.e.* a given topology and channel availability. Efficient algorithms to optimize spectrum allocation for a given network topology exist. In this research, the presented a heuristic method that produce good coloring solutions. The algorithm starts from empty color assignment and iteratively assign colors to vertices to approximate the optimal assignment. In each stage, the algorithm labels all the vertices with a non-empty color list according to some policy-defined labeling. The algorithm picks the vertex with the highest valued label and assigns the color associated with the label to the vertex. The algorithm then deletes the color from the vertex's color list, and from the color lists of the constrained neighbors. The color list and the interference constraint of a vertex keep on changing as other vertices are processed, and the labels of the colored vertex and its neighbor vertices are modified according to the new graph. The algorithm can be implemented using a centralized approach who observes global topology and makes decisions. The algorithm described in next subsection spectrum allocation for a given topology.

2.1 Heuristic Algorithm for Spectrum Allocation

Given a network of secondary users, we first construct a interference or conflict graph $G(V;E)$. In centralized networks such as IEEE 802.22, the base stations are the vertices of the graph. If two BSs interfere with each other on the same frequency band (e.g. within certain distance), then there is an edge between them. Then the goal

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of spectrum allocation is to minimize the number of distinct spectrum slices required while assigning different spectrum slices to any two vertices connected by an edge. The above problem is a typical graph coloring problem, which is NP-hard. Specifically, a vertex coloring is an assignment of labels or colors to each vertex of a graph such that no edge connects two identically colored vertices. The most common type of vertex coloring seeks to minimize the number of colors for a given graph. The minimum number of colors with which the vertices of a graph *G* may be colored is called the chromatic number, denoted by $X(G)$.

The following is a step by step heuristic algorithm of CR spectrum allocation.

Input: CR network initialization.

Output: A valid coloring of the communication graph.

Step 1: Arrange the vertex by decreasing order of degrees.
Step 2: Choose the first uncolored vertex from the set.
Step 3: Color the chosen vertex with the least possible color.
Step 4: Merge the vertex with the first non-adjacent vertex.
Step 5: Color the chosen vertex with the same color. If there is no more non-adjacent vertex, return to Step 2.
Step 6: If the entire vertex are colored, stop. Otherwise, return to Step 2.

2.2 Simulation Results of Spectrum Allocation

In the following, we simulate the heuristic algorithm based on graph coloring method for spectrum allocation. The demonstrate the steps of the heuristic algorithm with a CR network example(see figure 3). The input graph is shown below in figure 3 with n = 100 vertices. The algorithm required coloring of the vertices respectively.

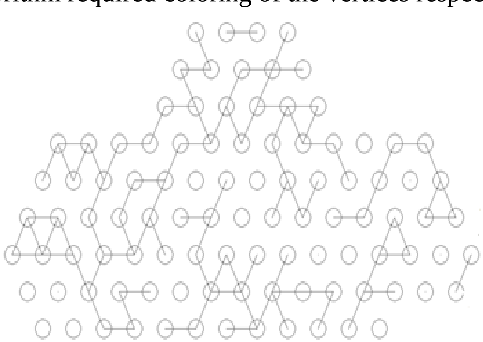

Figure. 3 Example GCP graph

From the example graph, it is required 7 color for coloring the graph. It means that required 7 channels for this topology of CR network(in figure 4).

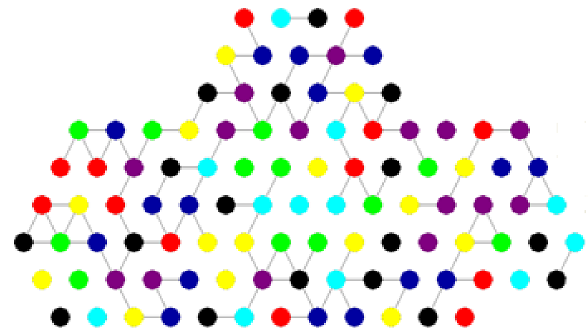

Figure. 4 Spectrum allocation on the GCP graph

3. REALLOCATION SECONDARY SPECTRUM ACCESS

Once the spectrum has been allocated, secondary users need a operation to coordinate their access in a cognitive radio network. To address this problem, we target at minimizing the number of (PU/SU) users affected by spectrum handoff in spectrum reallocations. Based on the aforementioned spectrum allocation information, the secondary spectrum usage access(see the marked with red circle in figure 5.) can evaluate the additional request generated by the secondary users on the surrounding CR network, and also the minimum spectrum handoff without causing any harmful interference on primary users.

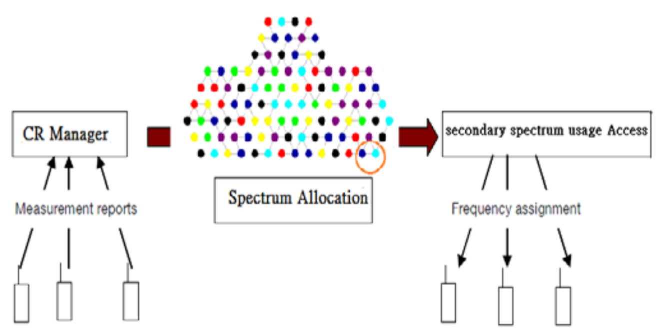

Figure. 5 secondary spectrum usage access in CR network

The basic idea of our heuristic secondary spectrum access reallocation is simple. It consists of two main components. In the first step, we assign all exclusive channels to the node since they could not be used by other neighbors. If the exclusive channels cannot satisfy user

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demand, in the first component of the algorithm, we find the idle shared channels and assigned them to the node. Using idle shared channel will occupy the shared resources, but it won't affect the communication of other nodes. If both step 2 and step 3 in first component cannot provide enough channels for communication, we will apply the second component of the channel selection strategy to 'borrow' channels from neighbors, which will cause the affected neighbors to handoff to other channels or to initiate a new spectrum reallocation process. The algorithm is terminated when all spectrum demands are satisfied or there are no reconfigurable neighbors left. The pseudocode of the heuristic algorithm is illustrated in the following.

Input: A communication graph $G = (V;E)$ of m links.

Output: An interference-free link scheduling for local time frame.

Step 1: node.buffer = full
Step 2: *If* {node is sink } *then*
Among the eligible top-subtrees, choose the one with the largest number of total (remaining) packets, say top-subtree *i;*
Step 3: Schedule link (*root*(*i*), *s*) respecting interfering constraint
Step 4: *else*
Step 5: *If* {node.buffer = = empty} *then*
Choose a random child *c* of node whose buffer is full;
Step 6: Schedule link (*c*,*node*) respecting interfering constraint
Step 7: c.buffer = *empty*
Step 8: *node*.buffer = full
Step 9: end *If*
Step 10: end *If*

The idea behind the above heuristic algorithm regards as local time frame rescheduling[11]. Each node of *G* maintains a buffer and its associated state, which can be either full or empty depending on whether it contains a packet or not. Initially, all the buffers are full because every node has a packet to send. The first block of the algorithm in Step 2-3 gives the scheduling rules between the sink and the roots of the top-subtrees.

For a given local time frame, the root of an eligible top-subtree which has the largest number of total remaining packets is scheduled. If none of the top-subtrees are eligible, the sink does not receive any packet during that time slot. Inside each top-subtree, nodes are scheduled according to the rules in step 5-9. A subtree is defined to be active if there are still packets left in it (excluding its root) to be relayed. If a node's buffer is empty and the subtree rooted at this node is active, one of its children is scheduled at random whose buffer is not empty. The heuristic algorithm guarantees that in an active subtree there will always be at least one child whose buffer is not empty, and so whenever a node empties its buffer, it will receive a packet in the next time slot, thus emptying buffers from the bottom of the subtree to the top.

3.2 Simulation Results for Secondary Spectrum usage Access

The secondary spectrum usage access request is ask communication service, usually of high priority, that arrives to the CR network (see the marked with red circle in figure 6.) and must be reallocated immediately. As the schedule plans are elaborated periodically by the CR manager, these schedules cause a perturbation in the CR network. In this situation, the secondary users request interacts directly with the CR manager component to reallocation its schedule, using the heuristic algorithm and also the minimum spectrum handoff without causing any harmful interference on PUs. The problem appears if the SU's pocket request service(e.g. p11) has to be executed in a local time frame already occupied by other PUs' pockets(denoted p1~p10) , which requires a minimum spectrum handoff to relax these and to introduce new requests(in figure 7). Since each PU has an associated priority, CR manager network take this information into consideration. In the case that the SU request has maximal priority, i.e. it must be executed as soon as the current channels execution is completed, the heuristic algorithm tries to reallocation the operations that then make decisions, i.e. those reallocation that can probably be accommodated without delay (see figure 8) or need other extra resource or delay decision option to solve this situation with the minimum handoff in the existing spectrum resource providing.

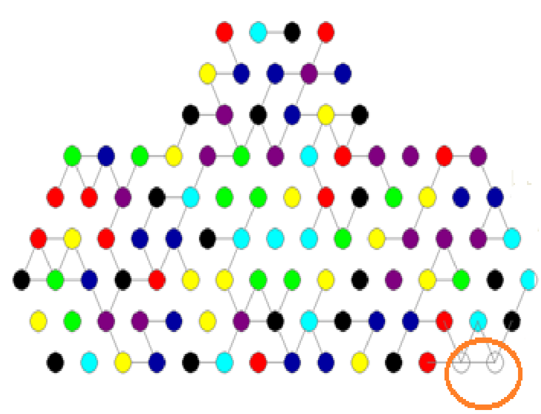

Figure. 6 Secondary users request on the CR GC graph

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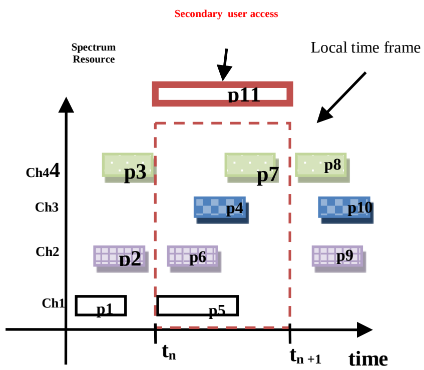
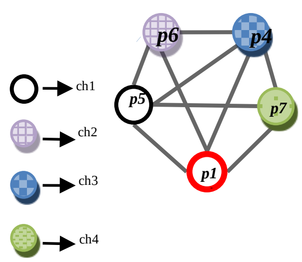
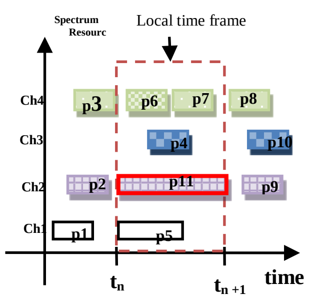


(a) Initial scheduling plan

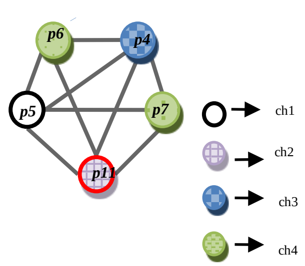


(b) Initial GCP plan

Figure. 7 Secondary users request on the GC graph



(a) Actual reallocation plan execution under local time frame



(b) Reallocation GCP plan

Figure. 8. Reallocation users request on the CR GC graph

The heuristic algorithm reallocation only one spectrum each round to the corresponding secondary user request, with repeatedly reallocation of spectrum until the full reallocation of all requests which is shown in figure 9.

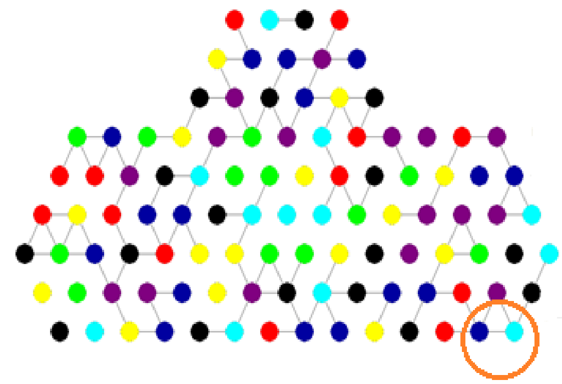


Figure. 9. Reallocation result for two requests of secondary users access

4. CONCLUSIONS

This paper first proposes a spectrum allocation algorithm based on graph coloring and interference minimize mechanisms. As a result, efficient and fair allocation of spectrum nodes can be achieved for PUs in cognitive radio networks such as 802.22 networks. We then describe a secondary users access and its heuristic reallocation algorithm for 802.22-type cognitive radio networks. Simulation results show two benefits of the proposed algorithms. On one hand, the spectrum allocation approach can dynamically improve the total system utility. On the other hand, cooperative spectrum reallocation decrease the number of spectrum handoff is an important factor impacting secondary user throughput. These promising results demonstrate that graph coloring based method constitute a viable solution for efficient secondary spectrum usage.

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