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An effective dynamic spectrum access algorithm for multi-hop cognitive wireless networks

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ABSTRACT

Spectrum utilization, as a current hot research topic, has been paid extensive attention to in cognitive wireless networks. However, due to the complexities and dynamic properties in wireless networks, how to enhance effectively the spectrum utilization is still the main challenge to encounter at present. In this paper, we propose an effective dynamic spectrum access algorithm to improve the spectrum utilization and reliable communication in the multi-hop cognitive wireless network. Considering the inherent nature of licensed users, we adopt the Pareto distribution to model their behaviors. Accordingly, cognitive users can accurately sense the white spectrum. Different from the general dynamic spectrum access, we exploit the acknowledge information to provide the reliable transportation of data packets in multi-hop cognitive wireless networks. Moreover, to achieve the high spectrum utilization, we use the graph theory to perform the reasonable channel allocations. The time and frequency division multiplexing technologies are adopted to propose our practical strategies of channel allocations and switches. Consequently, we can solve the problems of channels sensing, channel allocations, channel accesses and channel switches. Simulation results indicate that the algorithm proposed can effectively reduce the overhead of channel sensing and switching, and improve the spectrum utilization.

1. Introduction

With wireless technologies advancing and new service appearing rapidly, the wireless communications are expected to be applied more extensively. This requires more wireless spectrum resource. However, most of the allocated spectrums are not made full use of. This has led to a massive waste of spectrum resource. According to FCC's investigation, 70% of the allocated spectrums are not exploited sufficiently [1]. The traditional static spectrum allocation policy is not capable of efficiently improving spectrum utilization. It has become a research hotspot how to effectively raise the utilization of the scarce spectrum resource [2–4]. A feasible and practical spectrum allocation scheme is critical to decide whether the current spectrums can be utilized efficiently. This has drawn more attention from network researchers and operators [5–7].

Due to dynamic characteristics of spectrum availability, cognitive users must be able to track environmental information and to capture these variations. Cognitive users need to seek for new spectrum access opportunities self-adaptively if the licensed users appear or the current spectrum environment deteriorates [8–10]. Moreover, cognitive users must guarantee the normal activities of licensed users when accessing the network. At the same time, cognitive users should quickly monitor the spectrum resources' availability. It should also restrain the interference on other cognitive users when there only exist limited access opportunities. In such a case, the overall utility of cognitive system can be maximized [11–13]. Thereby, a flexible spectrum access approach is significantly important to use the allocated spectrum resources efficiently.

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This paper, which takes advantage of graph coloring theory and the combined frequency-division and time-division multiplexing technologies, proposes an effective dynamic spectrum access algorithm (for short GFTDSA) to improve the spectrum utilization as well as network performance. As mentioned by current studies, network traffic holds the self-similarity and heavy-tailed distribution properties. What's more, the non-voice traffic, which has become the main network behavior, is now increasing gradually in new 3G and 4G networks [14–16]. The characteristic of heavy-tailed distribution of network traffic is dominant. Network traffic reflects the inherent nature of licensed users. Pareto distribution can precisely describe the self-similarity and heavy-tailed distribution features of network traffic and users' behaviors. First, this paper divides each channel into several independent time slots. The idle status of channels is supposed to follow Pareto distribution. Then we exploit Bayes formula to solve the problem of channel sensing and channel access. In the meanwhile, we use graph coloring theory to perform dynamic channels allocation. Although traditional graph coloring theory can reduce the collision probability between licensed users and cognitive users, it often lowers the channel utilization. Especially when the licensed users and cognitive users are close to each other, the cognitive users are not often able to effectively use the channels of licensed users. Therefore, we propose to combine graph coloring model with the channel allocation scheme to improve the utilization of channels. By abstracting the available channels and the interference condition between users as a binary matrix, we allocate dynamically the channel resources to cognitive users from a global point of view. As a result, we can improve the utilization of channels and network performance more effectively while avoiding the interference on licensed users. We also combine the frequency division and time division multiplexing technologies with graph coloring theory. Accordingly, the graph coloring theory is exploited to carry out the frequency division and time division-based channel allocation. The spectrum utilization of networks can be further improved. We can make sure that the cognitive users can get approximate channels through our channel allocation and switch strategies. Simulation results indicate that the algorithm proposed can not only allocate the channels better and hold the higher spectrum utilization, but also it can achieve better network performance and lower channel switch overhead.

The rest of this paper is organized as follows. Related work is introduced in Section 2. Section 3 describes system model. Our method is derived in Section 4. Section 5 presents in detail the simulation results and analysis. We conclude our work in Section 6.

2. Related work

Dynamic spectrum access is currently a hot research problem. This has attracted extensive attention from network researchers. Xue et al. [2] proposed a dynamic switch scheme based on the hypothesis of the idle time slot probability. This scheme reduced the switch frequency and improved the channel utilization. However it did not consider the channel allocation problem. Zhang et al. [3] brought forward a joint admission control and energy distribution algorithm. This algorithm built a joint admission control and energy distribution scheme. Xing et al. [22] studied the QoS and interference constraint for dynamic spectrum access. But authors in [3,22] did not consider the case of multiple licensed users and multiple cognitive users. This needs to get all channel information among all licensed users and cognitive users for the centralized power control. This means that plenty of cooperation between licensed users and cognitive network is needed. Some studies have adopted the distributed scheme to realize cooperation and resource sharing. The adaptive spectrum allocation was studied by bargaining with the local union [5–10]. The distributed schemes can achieve the best tradeoff between fairness and efficiency in the cooperative game. However, they have high computation complexity. Hoang et al. [11] put forward the hybrid distribution/centralized control algorithm with two stages. Cognitive users first updated power adaptively until the moment that the interference on licensed user had achieved the upper limit that they could bear (or the transmission power upper limit of cognitive users). The second stage exploits bilateral maximum weighted matching to solve the channel allocation problem. However, this method allocated each channel only to one cognitive user. Each cognitive user could only occupy at most one channel. Authors in [12–16], respectively, proposed the network coding model, probability density model, integer nonlinear programming model, game model and learning model. Only if dynamic spectrum access succeeds in solving the problems of channel allocation, channel access and channel switch, it can largely improve spectrum utilization.

In dynamic spectrum access process, the channel allocation method should be able to adapt the dynamic change of licensed users for channel usage in the real-time way. When all cognitive users are competing for limited channel resources, we should consider to maximize the efficiency of cognitive networks. In the process of dynamic spectrum access, the traditional channel allocation methods cannot meet the communication requirement of cognitive users since the random distribution of cognitive users and the competition for channels among different cognitive users and licensed users adds time-space complexity of the network topology. Consequently, the usage of spectrum resources become complicated.

The existing researches on spectrum allocation methods include graph theory, game theory, microeconomics theory and so on. The graph theory method models the spectrum allocation as a graph coloring problem. It can solve spectrum utilization, fairness, and throughout problem in cognitive networks via optimization scheme [17]. The game theory constructs the behaviors between cognitive users into a game model. Then it uses the game to make the optimal resource allocation [18]. Microeconomics theory makes use of its auction theory to realize spectrum lease [19,20]. These existing researches show that the spectrum allocation mainly has the following several key problems [21], namely NP optimization problem under the nonlinear interference restraints, system fast convergence problem, consistency problem that whether the simulation assumptions accord with real situations, and computation problem that network scale has larger impact on the computation, convergence and convergence rate.

When licensed users do not use their licensed spectrum at some certain time, cognitive users can exploit it to communicate with each other. When licensed users are to use their