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Spectrum sharing optimization with QoS guarantee in cognitive radio networks ☆

Saleem Aslam, Kyung Geun Lee *

Department of Information and Communication Engineering, Sejong University, Seoul, Republic of Korea

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A B S T R A C T

In this paper, we propose an optimized spectrum sharing scheme based on the Hungarian Algorithm to guarantee the quality of service (QoS) for individual cognitive radio (CR) users belonging to different CR cells. The proposed scheme is most favorable for overlapping cells where the users are demanding channels for heterogeneous applications such as chatting, web browsing, or voice and video streaming. The spectrum sharing optimization with the QoS guarantee (SSO-QG) is an optimal scheme that can operate in throughput enhancement mode, high reliability mode and collision avoidance mode based on the weight assigned to the corresponding QoS parameters in accordance with the demands of different applications. Simulation results show that the proposed scheme outperforms the existing schemes in terms of forming the optimal sharing pattern and meeting the stringent QoS requirements fairly enough according to the demands of the cell. Moreover, it reduces collisions with primary users.

1. Introduction

The radio spectrum is considered to be the most important part of the wireless communication industry. Day by day innovations in the communication industry further increase the value of wireless media. Each emerging technology requires the spectrum band for its operation. However, wireless media is limited in terms of physical boundaries. Contrary to this, the Federal Communication Commission (FCC) shows very low utilization regarding usage of the allocated spectrum [1]. Recently, the CR has appeared on the screen to deal with issues of spectrum scarcity and limited spectrum utilization. The cognitive radio networks (CRNs) opportunistically utilize the spectrum band of the primary users (PUs) or the licensed users with the promise to cause negligible interference. The CR performs the spectrum sensing, spectrum decision, spectrum switching and spectrum sharing functions for its communication [2]. The spectrum sensing helps the CR to locate the free spots in the radio spectrum whereas the spectrum decision function assists the CR to analyze and select the best channels within the sensed spectrum band. The analysis is either based on the signal to the interference ratio of the channels [3] or based upon the activity of the PU [4].

After selecting the best channels, the next prime task is their allocation among CRs. From sharing perspective, many classification models have been proposed in the literature such as centralized or distributive, underlay or overlay and intra-network or inter-network [5–9]. In the centralized scheme, a central entity (spectrum server or spectrum broker) is responsible for the allocation of the spectrum whereas in the distributive approach, CRs exchange control information among them and collectively decide about the usage of the available spectrum. Subsequently, the overlay sharing scheme utilizes the available spectrum during the absence of the PUs whereas the underlay sharing model allows the CRs to perform communication in

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* Corresponding author. Address: Sejong University, 98 Gunja dong, Gwajin-Gu 143-747, Seoul, Republic of Korea. Tel.: +82 10 4179 8419.
E-mail addresses: saleem83@nrl.sejong.ac.kr (S. Aslam), kglee@sejong.ac.kr (K.G. Lee).

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parallel with the PUs by complex and robust implementation [9]. The scope of the intra-network spectrum sharing scheme is limited owing to the allocation of the available spectrum among the CRs operating under a single CR base station. All CRs in the intra-network put their requirements of the spectrum band to the central entity (spectrum server), which allocates the channels among CRs in an optimized way. However, the scope of the inter-network is significantly wider than intra-network because in an inter-network multiple CR base stations are involved in the sharing process.

In [10] Si et al., propose an internetwork sharing scheme for CRN. The authors adopt the concept of spectrum polling to aggregate the spectrum from multiple operators. The given scheme allocates the spectrum among CRs by considering the key factors of spectrum efficiency and pricing. However, this scheme is more confined towards the pricing objective and the reward of a spectrum to the CR networks decreases with the increase of the active CR operators. The objective function matures and converges to the optimal solution quickly. However, the scheme lacks in considering the key factors of the interference with the PUs and QoS of individual CR networks.

On the other hand, the color-graph based approaches also exploit the resource sharing problem in CRNs [11,12]. The base stations are represented as vertices of the graph. If the regions of the base stations are overlapping then the vertices are connected to each other. The connected vertices are represented using different colors. In graph theory, the chromatic number represents the minimum number of separate colors required to characterize the entire graph. For example, if the chromatic number of a network is υ then it represents the minimum number of colors required to represent an overlapping wireless regional area network. The main flaw in the given scheme is that it allocates an equal amount of bandwidth/data rate among same color areas without considering the requirement of the network.

A game theory based spectrum sharing scheme is presented in [13]. In this scheme, multiple CRs share the same spectrum poll. The authors proposed static and dynamic sharing models using an oligopoly market approach and improve the revenue of the PUs and reduce the transmission delay. Both models maximize the revenue of the primary network and the effects of the PU on the CRN are not considered. In [14], the authors propose a scheme to improve the efficiency of the sharing system. The authors utilize the model of the cellular network and assume an environment where multiple operators are offering their spectrum for wireless connectivity. A user can be connected to any operator in the given network, but the network selection is based upon the promise of the *best service*. Although the given scheme minimizes the delay and packet drops, it is lacking in consideration of the interference with the PU and the demands from the individual base station. Another game theory based distributed spectrum sharing scheme for heterogeneous CRNs is described in [15]. Although, this scheme shows better QoS provision using the external power scaling method, it is lacking in regard to considering the PU effects, and its network scope is very limited.

In [16,17], the authors propose a sharing scheme for multiple overlapping IEEE 802.22 wireless regional area networks (WRANs). The authors allocate the channels to the overlapping WRANs in such a way that the overlapping networks acquire different channels to reduce the interference among overlapping WRANs. The given scheme also provides fairness to the individual WRANs. Although, the schemes given in [16,17] optimally allocate the channel to reduce interference and improve fairness, these schemes do not consider the desired QoS parameters (data rate and bit error rate) of individual CR users. In addition, the effect of the PU activity on the QoS of the CR is not discussed.

To counter the PU activity, there are two popular schemes known as the reactive and proactive schemes. The reactive schemes monitor the PU arrival and direct the CRs to pause on the arrival of the PU [5,18,19]. Such periodic pauses cause severe degradation in the QoS of the CR. The proreactive schemes [20–22] categorize the channel based upon the concentration of the PU activity and hence these schemes offer better QoS to the CR. In [23–25], various QoS aware spectrum sharing schemes are introduced. Authors in [23] present a QoS aware scheme to meet the requirements of multimedia users in the CRNs. The scheme given in [24] is inclined towards the power and rate adjustment to meet the designated QoS. Although the scheme presented in [25] is adaptive in reporting data transmission policies to satisfy the QoS requirements, it lacks in explaining the behavior under heterogeneous traffic. Also, the PU factor is not incorporated inside the scheduling algorithm.

In this article, we propose an innovative inter-network spectrum sharing scheme based on the Hungarian Algorithm (HA) to allocate the available spectrum among different overlapping CR cells according to the respective demands. The proposed SSO-QG scheme guarantees the desired QoS to the individual CRs in terms of their data rate, the bit error rate and the PU activity for supporting their heterogeneous applications such as web browsing, internet chatting, voice and video streaming. The PU activity is incorporated in the sharing decision to reduce the collisions between CRs and PU. It helps to minimize the overall transmission delay for the data transmission of the CRs. The proposed scheme can be operated in three modes: (1) throughput enhancement mode (TEM), (2) high reliability mode (HRM) and (3) collision avoidance mode (CAM) based on the weight given to the corresponding QoS parameters. The SSO-QG scheme forms the optimal sharing schedules, guarantees the stringent QoS to the individual CR belonging to different CR cells and reduces the collisions with the PUs.

The rest of the paper is organized as follows: Section 2 describes the system model and proposed framework. Section 3 shows the problem formulation using the HA. Section 4 describes the simulation results. Finally, Section 5 concludes the findings of our paper.

2. System model

We consider a CRN which consists of multiple cells $C = \{c_1, c_2, \ldots, c_i, \ldots, c_p\}$ in which each cell has a different number of active CRs competing for the spectrum. Each CR $n_j \in N$ within the set of CR users $N = \{n_1, n_2, \ldots, n_j, \ldots, n_q\}$ *senses*