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Modeling multiuser spectrum allocation for cognitive radio networks☆

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ABSTRACT

Spectrum allocation scheme in cognitive radio networks (CRNs) becomes complex when multiple CR users concomitantly need to be allocated new and suitable bands once the primary user returns. Most existing schemes focus on the gain of individual users, ignoring the effect of an allocation on other users and rely on the 'periodic sensing and transmission' cycle which reduces spectrum utilization. This paper introduces a scheme that exploits collaboration among users to detect PU's return which relieves active CR users from the sensing task, and thereby improves spectrum utilization. It defines a Capacity of Service (CoS) metric based on the optimal sensing parameters which measures the suitability of a band for each contending user and takes into consideration the impact of allocating a particular band on other band seeking users. The proposed scheme significantly improves capacity of service, reduces interference loss and collision, and hence, enhances dynamic spectrum access capabilities.

1. Introduction

The use of cognitive radio (CR) technology allows radio devices to opportunistically access the radio frequency (RF) spectrum in an unlicensed fashion. The RF operation of a CR (i.e., secondary/unlicensed user) involves three major mechanisms: spectrum sensing, spectrum use, and spectrum switching. Spectrum sensing is used to find white spaces (vacant band) in licensed bands and does not interfere with the licensed networks' activities. The most widely accepted method for detecting white spaces is energy detection based cooperative spectrum sensing [1]. After finding a suitable white space, the secondary user starts using that band and continues until it detects the return of the primary user (PU). At that point, it quickly evacuates the band to inflict minimum interference on the primary system [2]. Finally, the secondary user (SU) has to find and switch to another vacant band to resume transmission. However, finding a vacant band, assessing its suitability to SU's need and switching smoothly to that band to continue uninterrupted transmission are the most critical factors affecting this mechanism.

Early works on spectrum allocation primarily focused on a simple scenario where a single SU requires finding and switching to the most appropriate band from a number of available vacant bands. Recent works have focused on a more complex but general scenario where multiple SUs require multiple bands for seamless transmission. The critical task in this scenario is to find currently unused licensed bands and allocate them among these users efficiently. In such band allocation, candidate bands'

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suitability in meeting respective SU's requirement as well as throughput achievable should be taken in consideration. Existing researches often use 'periodic sensing' (i.e., an SU senses and transmits in alternate cycle) and assume a priori knowledge on PU usage pattern. But 'periodic sensing' reduces spectrum utilization due to the time wasted in sensing and the usage pattern of PUs is most likely to vary over time. Another issue is the possible conflict arising from the selection of the same band at the same time by two or more users and has also generally been ignored in literature. Therefore, the following issues need to be addressed for real world implementation of CR networks: (i) improving sensing scheme and spectrum utilization removing the drawbacks of 'periodic sensing', such scheme should not depend on the known PU usage pattern; (ii) allocation of vacant bands among multiple users concomitantly in a way that meets individual SU's requirement while maximizing utility gain; and (iii) resolution of any conflict when the same band is equally suitable for multiple SUs.

In this paper, we introduce a collaborative spectrum band allocation framework for cognitive radio networks where multiple users simultaneously seek spectrum bands for transmission. Our framework allocates spectrum bands to both types of users - new incoming users and ongoing users who are already using some other bands and need to change bands quickly due to the return of the corresponding licensed users. To develop this framework, we first propose a sensing model based on energy detection where non-active users (i.e., users that are not using any licensed band currently) are split into two groups, sensing and idle, based on some appropriate criteria. By selectively keeping the idle group silent and engaging the sensing group into cooperative spectrum sensing, the scheme achieves accurate sensing results and allows continuous spectrum utilization by active users, eliminating the necessity and essentially the drawbacks of periodic sensing [2]. We then define two parameters to determine suitability of a band once it is found vacant via spectrum sensing. One is named suitability throughput gain (STG) which is a measure of throughput of a utilized spectrum band and its suitability to a specific user, and the other is interference loss (IL) which we formulate to reflect the loss due to inflicted interference on the primary user. In order to maximize STG keeping IL below a certain level, we formulate a maximization problem to optimize the sensing time-bandwidth product and decision threshold of a set of energy detectors working in parallel for spectrum sensing over multiple spectrum bands. Based on STG and IL, a combined decision is taken to allocate unique spectrum bands to all the secondary users currently requesting for bands. In this respect, our proposed framework offers: (i) devising a collaborative spectrum sensing model that offers accurate sensing and better spectrum utilization, (ii) allocation of spectrum bands among multiple users aiming to maximize the spectrum efficiency and gain, and (iii) a solution to mitigate the collisions among users in selecting spectrum bands.

This paper is organized as follows. Section 2 presents the related background literature along with their limitations and the necessity of the proposed framework. Section 3 describes the network structure and the sensing model incorporated in our proposed framework. The parameters influencing the formulation of the optimization problem and their impact on the allocation scheme are discussed in Section 4. Section 5 formulates the optimization problem to maximize the suitability throughput gain and the solution is analyzed. The proposed spectrum allocation techniques based on the solution is presented in Section 6 and their performances are analyzed in Section 7. Finally, the paper is concluded with some remarks in Section 8.

2. Related works

In spectrum allocation, the most common practice in the literature is selecting a band from a set based on its service properties. The spectrum pooling technique is considered to be the first approach for selection of a band. In this approach, spectrum bands from different owners (military, trunk radio, etc.) are merged into a common pool. From this pool, an SU may temporarily use a licensed band during its idle periods. To select the most appropriate band, a covariance matrix based cooperative detection method is used. The optimal capacity of the spectrum pool as well as two update strategies were investigated in [3] to determine the relationship between the optimal capacity of the spectrum pool and the system efficiency. One limitation of spectrum pooling is its size; if the pool is too small, then possibility exists that none of the bands in the pool will have a vacant band. Conversely, if the pool is too large, the usage of the vacant band will depend solely on the sensing ability of the SU and in this case the need to form a pool is questionable.

Another approach is to adjust the sensing parameters and to consider long term channel selection probability to find an appropriate band for an individual CR. In [4], a bank of narrowband energy detectors is jointly optimized to maximize the opportunistic throughput capacity and limit interference to the primary system. Long term channel observation is incorporated in a probability-based channel selection scheme in [5]. This scheme allows the CR to select a channel which has a lower probability of being interrupted by PU transmission. Analysis in [6] suggests that probability-based scheme require shorter system time (interval between data arrival at system to transmission) than sensing-based scheme at low SU traffic load and vice versa. However, one major shortcoming of this scheme is that a CR may select a band that has low PU transmission probability but is currently engaged.

A Least Cost First Serve (LCFS) scheduling algorithm for selecting a band from the available spectrum bands was proposed by Lee and Akyildiz in [7]. Assuming separate sensing and transmission periods, this scheme represents the sensing and transmission duration as functions of the average false alarm probability and optimizes them to maximize the opportunistic sensing capacity. Once the parameters are optimized, an opportunity cost is calculated for each band and the current time slot is assigned to the band with minimum opportunity cost. However, a major drawback of this scheme is that the PU transmission characteristics must be known to the CR system. Another limitation is that this approach assumes periodic sensing which reduces the spectrum utilization.

Some recent literature propose schemes to accommodate multiple SUs in multiple available bands. In that effort, an adaptive spectrum allocation method for centralized CR networks (with a secondary base station/ scheduling server and common control