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A spectrum auction algorithm for cognitive distributed antenna systems

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ABSTRACT

Distribute antenna system (DAS) can provide high date rate transmission to satisfy the service requirements for the rapid growing wireless applications. Besides, the increasing deployment of wireless applications make the demand for spectrum resource grow rapidly, thus cognitive radio (CR) has emerged as a promising technology to improve spectrum utilization, and spectrum auction is a promising approach to allocate spectrum bands in CR. A few existing works considered the combination of DAS and CR to get better system performance, but they have never studied the spectrum auction in these systems. In this paper, we will study the spectrum auction problem for cognitive DAS to improve spectrum utilization. Cognitive DAS with antennas deployed in a distributed manner in the secondary system can achieve higher spectrum utilization and reduce interference between primary users (PUs) and secondary users (SUs), and thus we can get a better system performance. According to the performance of SUs that can be obtained in cognitive DAS, the SUs compete for PU's licensed spectrum bands through auction. The objective of the spectrum auction is to maximize social welfare, which is formulated as an integer programming problem to allocate spectrum bands to SUs who value them best. A Lagrangian relaxation algorithm is developed to obtain the optimal allocation. Finally, we demonstrate the performance of the cognitive DAS and the auction mechanism through simulations.

1. Introduction

Radio spectrum is becoming a scarce resource due to the increasing deployment of wireless communication technologies. Currently, spectrum is regulated by government agencies like the Federal Communications Commission (FCC), and it allocates spectrum by assigning exclusive licenses to users to operate their networks in different geographical regions [1]. Such a spectrum allocation approach is inefficient with many allocated spectrum blocks being unused, and many new wireless applications cannot find enough radio spectrum to operate on. Cognitive Radio (CR) has emerged as a promising solution to overcome the above dilemma. By allowing the secondary users (SUs) to access the spectrum that licensed to primary users (PUs), spectrum utilization efficiency can be improved dramatically in CR.

Spectrum auction is considered as an efficient way to allocate PUs' licensed spectrum bands among SUs, which can assign spectrum bands to SUs (buyers) who value them most. Truthfulness which can avoid the buyers' manipulation is an important factor in spectrum auction, and it has been studied in [2,3]. Unlike the traditional auction, spectrum resource is interference-limited rather than quantity-limited, so it is possible to award one band to multiple buyers without interference, which is called spectrum reuse [3–6]. The researchers of [3,4] proposed an auction mechanism that divides non-conflicting buyers into

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multiple groups, which not only can satisfy truthfulness but also improve spectrum reuse, but they did not consider the social welfare, which is the total valuation of the sold spectrum bands [5–7]. Besides, considering that the buyers may distort their valuations about spectrum bands, the author in [7] developed a collusion-resistant mechanism to suppress their dishonest behaviors. In most previous works, the buyers' valuations for spectrum bands are given by random numbers, which cannot express the specific preference of buyers. In [8], the author defined the valuation as a function concerning the quality of a spectrum band and how eagerly a buyer needed a spectrum band. Combinatorial auction has been considered in [9], which means buyers can bid for combinations of spectrum bands. In most earlier works, primary access rights on spectrum bands are pre-determined before the auction, but a user's requirement on spectrum access right relies on its Quality of Service (QoS) requirement. So a TRUMP auction mechanism to determine the primary or secondary access right depending on user's QoS was investigated in [10]. In truthful and strategy-proof auction mechanisms, the issue of privacy preservation remains open. The author in [11] presented a mechanism which provides protection for both valuation privacy and interference area privacy. Many works only focus on static auction, which may cause potential utility loss, and if a wining buyer locates in a place interfering with many other buyers, it may deprive many other transmission opportunities. To resolve this challenge, the authors in [12] designed an online double auction mechanism in which the sporadic nature of spectrum request and buyers' geographic feature were taken into consideration.

On the other hand, with the rapid growing of wireless applications, wireless systems are expected to provide high data rate transmission to satisfy the service requirements. However, apart from the spectrum band limitation mentioned above, another limitation is transmission power. Subject to the spectrum band and transmit power constraints, one approach to offer high data rate transmission is to shorten the radio transmission distance between the transmitter and receiver, and the distributed antenna system (DAS) is such a promising system for wireless communications [13]. By using multiple antennas, the DAS can improve transmission performance without increase of spectrum bandwidth. Unlike conventional centralized antenna systems (CAS) where all antennas are co-located at the cell center, the distributed antennas (DAs) in the DAS are separated geographically, and are connected to a central unit (CU) via optical fiber [13,14]. The DAs are the only simple antennas to transmit and receive signals for CU, while the CU carry out signal processing. The advantage of DAS is that it statistically reduces the distance between users and its access point, thus it not only decrease transmit power but also decrease co-channel interference, which can improve system performance. Besides, by deploying the antennas in a distributed manner in a cell, the DAS can expand the coverage to avoid dead point.

DAS has drawn great attention because of its advantage in recent years. In [15], the transmission schemes based on capacity and sum rate analysis in the DAS have been studied. Energy efficient and spectral efficiency in the DAS were considered respectively in [16] and [17]. Resource allocation is also a topic of particular interest for the DAS, and some works have proposed different methods for various resource allocations like sub-carrier allocation [18], power allocation [19], and bit allocation [20]. Different from the works that assume perfect channel state information at the transmitter, the author in [20] proposed bit allocation and paring methods for multi-user DAS with limited feedback. Besides, some works have attempted to enhance the system performance of the DAS by designing of antenna locations and antenna selection [21].

As CR can improve spectrum utilization dramatically, and DAS can increase system capacity, it is thus quiet natural to combine these two techniques to achieve higher spectrum efficiency. Different from the existing researches considering the secondary base station (SBS) covers the whole cell with co-located antennas, cognitive DAS deploys DAs at various locations, and connects DAs to the SBS over fiber for centralized signal processing. This system brings the benefits of much shorter wireless transmission distances, lower transmission power, and the possibility of utilizing multi-antenna transmission techniques. The lower transmission power makes the interference from SUs to PUs in a low level and transmitting by different antennas make it possible that multiple SUs at different locations could share the same spectrum band. In recent years, some works have focused on the combination of CR and DAS, which are expected to help solving the problem of bandwidth demand. In [22], SUs in different geographical locations as relay nodes to forward signals for PUs in deep fading was studied in cognitive DAS. Besides, due to the capacity and interference are influenced by antenna placement, the antenna location design was investigated in distributed-antenna based secondary systems in [23]. These works only considered the uplink scenario, while for the downlink, the authors in [24] proposed a joint antenna selection and power allocation algorithm to maximize the sum-rate of SUs in antenna-based spectrum-sharing systems.

In fact, an important aspect for cognitive DAS is how to allocate the PUs' licensed spectrum bands to SUs. However, researches on it remain largely open. Actually, spectrum allocation has been investigated for other cognitive radio models. In [25], MIMO multi-band underly CR network system analyzed the spectrum sharing and power allocation, which were modeled as a price-based non-cooperative game. The authors in [26] also studied the spectrum sharing between PUs and SUs in MIMO with CR network, but to maximize the sum-rate of the CR network, the SUs' transmissions were modeled as a cooperative game, and by well-designed individual utility and network utility functions, the bargaining solution was unique and Pareto optimal. As for cognitive DAS, only a few literatures are related to spectrum allocation. In [27], the authors investigated the SU access control problem in CR with fiber-connected distributed antennas, which was elaborated as selecting an appropriate group of SUs to access the spectrum bands licensed to PU. Then, the problem was formulated as a stochastic knapsack problem and solved by the branch and bound algorithm. The authors in [28] proposed schemes that considered economic and