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Optimal resource allocation scheme for cognitive radio networks with relay selection based on game theory

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Abstract

In this paper, we present a non-transferable utility coalition graph game (NTU-CGG) based resource allocation scheme with relay selection for a downlink orthogonal frequency division multiplexing (OFDMA) based cognitive radio networks to maximize both system throughput and system fairness. In this algorithm, with the assistance of others SUs, SUs with less available channels to improve their throughput and fairness by forming a directed tree graph according to spectrum availability and traffic demands of SUs. So this scheme can effectively exploit both space and frequency diversity of the system. Performance results show that, NTU-CGG significantly improves system fairness level while not reducing the throughput comparing with other existing algorithms.

Keywords cooperative relaying, cognitive radio networks, relay selection and resource allocation, coalition graph game

1 Introduction

Nowadays facing the problem between increasing bandwidth demands and underuse of licensed spectrum, cognitive radio (CR) has been proposed as possible approach for secondary users (SUs). Due to the possible changing environment sensed by different SUs in different location, a common available channel for a pair of SUs may be difficult to confirm. In order to solve above problem, cooperative relay has been introduced into CR networks [1]. With the assistance of other SUs, some of non-common spectrum bands can be bridged to exploit more spectrum opportunities. Then how to get optimal resource allocation with consideration on feasible relay selection scheme has attracted extensive interests recently for higher spectrum utilization [2–4].

In this paper, we study the optimal resource allocation with relay selection for a downlink orthogonal frequency division multiplexing (OFDM) cognitive radio network (CRN). The main contribution is to model this problem as a NTU-CGG, and propose a low-complexity algorithm for coalition graph formation to maximize SUs' utility while guaranteeing their fairness.

The rest of the paper is organized as follows. Sect. 2 describes the system model and problem formulation. Sect. 3 shows a low-complexity algorithm for coalition graph formation. Simulation results locate in Sect. 4, and conclusions are in Sect. 5.

2 System model and problem formulation

Consider a downlink OFDMA cooperative CRN with K idle channels. A cognitive access point (AP) is located at the center while N SUs are randomly located. AP is in charge of the transmission and knows each SU's location. Define w_i^k, $i=1,2,...,N$, as an indicator, where $w_i^k=1$ means that channel k is available at SU i, and 0 reversely. w_0^k denotes the availability of channel k at AP.

Our observation shows there are many SUs' idle spectrum, which can be utilized to relay AP's data and improve performance significantly. The downlink slot comprises two subslots, with $w_{0ij,1}^k$, $w_{0ij,2}^k$ as the channel allocation indicators, and $w_{0ii,1}^k=1$ denotes that channel k is the direction channel for SU i, otherwise $w_{0ii,1}^k=0$;

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$w^k_{0ij,1}=1$, $w^k_{0ij,2}=1(i \neq j)$ indicate the assignment of channel k to SU i and SU j pair in subslot 1 and 2 respectively. We assume that the channel state keeps constant in one slot.

In this work, we model the problem as a coalition graph game [5], which the SUs will interact for forming coalitions. With each coalition $S \subseteq \mathbb{N}=\{1,2,...,N\}$, a SU, selected as coalition-head, receives the data from AP and relays it to other SUs. So this problem is equal to coalition-head selection and links form problem. Given a coalitional structure $C_{\mathrm{s}}=\{S_1,S_2,...,S_l\}$, defined as a partition of $\mathbb{N}$, $\forall i \neq j$, $S_i \cap S_j = \varnothing$, each coalition consists of several SUs, i.e., $S_i=\{S_{i,0},S_{i,1},...,S_{i,N_i}\}$. A link, consists of multi-channels, is formed between $S_{i,0}$ and $S_{i,j}$. The throughput between AP and $S_{i,j}$ on allocated channel consists of two parts:

$$R^{(1)}_{i,j}=\sum_k\left(R^k_{0i_ji_j,1}w^k_{0i_ji_j,1}+R^k_{0i_ji_j,2}w^k_{0i_ji_j,2}\right) \tag{1}$$

$$R^{(2)}_{i,j}=\sum_{j,j\neq i}\frac{1}{2}\min\left\{\sum_k R^k_{0ij,1}w^k_{0ij,1},\sum_k R^k_{0ij,2}w^k_{0ij,2}\right\} \tag{2}$$

where $R^k_{0i_ji_j,1}$, $R^k_{0i_ji_j,2}$ denote the direct transmission rate, and $R^k_{0ij,1}$, $R^k_{0ij,2}$ denote the corresponding relaying transmission rate .

To guarantee the fairness for SUs, we adopt the fairness strategy in Ref. [4], and define the $S_{i,j}{}'s$ satisfaction level as:

$$\eta_{i,j}=\frac{R_{i,j}}{R^{\min}_{i,j}} \tag{3}$$

where $R_{i,j}$, $R^{\min}_{i,j}$ denote $S_{i,j}{}'s$ actual throughput and traffic demand. And the satisfaction factor is required nearly equal.

The system throughput can be transformed to the sum of logarithmic payoff of SUs jointing the coalition. So the core $\upsilon(S_i,C_{\mathrm{s}})$ of a graph game within the coalition $S_i \in C_{\mathrm{s}}$ can be expressed as [6]:

$$\upsilon(S_i,C_{\mathrm{s}})=\sum_{j=0}^{|N_i|}\ln\left(R_{i,j}-R^{\min}_{i,j}\right) \tag{4}$$

where $R_{i,j}$ is the payoff of $S_{i,j}$ when it joints the coalition S_i , and N_i is the number of SUs in the coalition i.

So the mathematical description of the balanced-core of optimal coalition graph formation can be described as follows

$$\left.\begin{aligned}
&U=\max\sum_{i=1}^{l}\upsilon(S_i,C_{\mathbf{s}})\\
&\text{s.t.}\\
&w^k_{0i_ji_j,t}\leqslant w^k_{i_j}w^k_0;\quad \forall i,j,k,t\\
&w^k_{0ij,t}\leqslant w^k_i w^k_j;\quad \forall i,j\neq i,k,t\\
&\sum_i w^k_{0ii,t}\leqslant 1;\quad \forall k,t\\
&\sum_i\sum_j w^k_{0ij,t}\leqslant 1;\quad \forall k,t\\
&P_0+N_{\mathrm{Num}}P_1\leqslant P^{\max}
\end{aligned}\right\} \tag{5}$$

where P_0 and P_1 stand for the total transmission power of AP and SU i respectively. $P^{\max}$ is the system total power constraint. N_{Num} is the number of coalition-heads.

However this optimization problem is combinatorial and nonlinear so that has a high computational complexity when the number of SUs or channels increases. In the following section, we will obtain a low-complexity heuristic algorithm to solve it.

3 Coalition graph game solution

3.1 Potential coalition-head selection

First, we consider the initial optimal single-channel allocation (OSCA) problem without cooperation. This problem can be transformed into a maximum weighted bipartite matching problem: take channel set $C=\{1,2,...,K\}$ and SUs set $\mathbb{N}=\{1,2,...,N\}$ as the disjoint bipartite subsets, and define the weight of edge e_{ki} connecting vertex k of C and vertex i of $\mathbb{N}$ as $e_{ki}=(1/N)P_0H^k_i$, where H^k_i denotes channel k gain between AP and SU i. Thus, to maximize the weight-sum is equivalent to maximize the total utility. Kuhn-Munkras algorithm [7] can be employed to solve the bipartite matching problem.

In this work, the SUs will interact for forming coalition. Within each coalition S_i, a SU, which completes its slot traffic demand in just one subslot, can be selected as the potential coalition-head. A mathematical description can be gained as

$$\mathrm{lb}\left(1+\frac{P_{i,k_i}H^{k_i}_i}{N_0}\right)>2R^{\mathrm{req}}_i \tag{6}$$

s.t.

$$\sum_i P_{i,k_i}\leqslant P_0 \tag{7}$$