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Game-Theory-Based on Downlink Spectrum Allocation in Two-Tier Networks

Yu Zhang, Ye Tian, Fang Ye Yixuan Kang

Abstract—The capacity of conventional cellular networks has reached its upper bound and it can be well handled by introducing femtocells with low-cost and easy-to-deploy. Spectrum interference issue becomes more critical in peace with the value-added multimedia services growing up increasingly in two-tier cellular networks. Spectrum allocation is one of effective methods in interference mitigation technology. This paper proposes a game-theory-based on OFDMA downlink spectrum allocation aiming at reducing co-channel interference in two-tier femtocell networks. The framework is formulated as a non-cooperative game, wherein the femto base stations are players and frequency channels available are strategies. The scheme takes full account of competitive behavior and fairness among stations. In addition, the utility function reflects the interference from the standpoint of channels essentially. This work focuses on co-channel interference and puts forward a negative logarithm interference function on distance weight ratio aiming at suppressing co-channel interference in the same layer network. This scenario is more suitable for actual network deployment and the system possesses high robustness. According to the proposed mechanism, interference exists only when players employ the same channel for data communication. This paper focuses on implementing spectrum allocation in a distributed fashion. Numerical results show that signal to interference and noise ratio can be obviously improved through the spectrum allocation scheme and the users quality of service in downlink can be satisfied. Besides, the average spectrum efficiency in cellular network can be significantly promoted as simulations results shown.

Keywords—Femtocell networks, game theory, interference mitigation, spectrum allocation.

I. Introduction

IT can be seen that frequency band resources in being are usually controlled under government management statically in [1]. Value-added multimedia services (data [2], voice [3], image [4], etc.) in cellular network has been growing up increasingly in peace with the evolution of telecommunications technology. And during this process, spectrum band was divided for employment of various communication systems. However, wireless services communicate only in certain subareas, which means that the spectrum in different frequency domain, time domain and spatial domain of extreme unbalanced, leading to frequency spectrum become tense scarce resources. Facing exponential growth of mobile application data [5], the traditional cellular network technology has reached its breakthrough point and the traditional cellular structure is facing unprecedented challenges [6].

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Cognitive radio technology is applied in data telecommunications network to improve spectrum efficiency [7]. Accordingly, it is allowable for unlicensed users to employ space spectrum without jamming usage of licensed users in cognitive radio network, which clears that there are existing two types of interference viz., interference between licensed users and unlicensed users and interference between unlicensed users and unlicensed users (the focus of our research), to be studied.

Game theory is a mathematical tool of microeconomics, for the analysis of multiple interactions between policy decision entities [8], and recently is adopted for resource allocation scheduling in cognitive radio networks. Cognitive radio is essentially an autonomous agent that learns its environment and optimizes its performance by modifying its cross-task parameters. The competitive behavior and purpose of cognitive users in the network can be well responded by the game theoretic framework. And in this structure, cognitive radio plays the role of game player, while their actions are available transmission parameters which will have effects on the performance of neighbors and their own. Some different game theoretic models for cognitive radio networks have been showed in [9], which has proposed a precise potential game formula on the signal to interference-and-noise ratio (SINR) and waveforms selections for cognitive radio framework. Different convergence conditions for game theoretic models of cognitive radio network have been discussed in [10]. Reference [11] has defined two different utility functions for selfish users and cooperative users in the spectrum sharing games. A specific channel assignment game model under Wi-Fi and Wi-Max network has been presented in [12], which advanced a new interference factor for overlapped spectrum allocation.

In this work, we establish an exact potential game for sub-channel allocation of cognitive radio network in the same layer and propose an interference model based on distance weight factor to reduce co-channel interference in the same layer network so as to promote spectrum efficiency. Reference [11] has been discussed with regard to the spectrum allocation mechanism of the cognitive radio network in order to analyze performance of cognitive radios. According to the proposed mechanism, interference exists only when users employ the same channel for data communication.

The remaining schedules are as follows: Section II introduces cognitive radio network system model. Section III presents game theory briefly and set up of a potential game model for dynamic spectrum allocation. Section IV is the simulation results of data analysis. Eventually, it is a summary of the paper.

II. System Model

Condider a cognitive network made up of N cognitive transmitter-receiver pairs of nodes in a circular cell of radius L as shown in Fig.1. We set the base stations with service radius r as the transmitters and the users as the receivers.

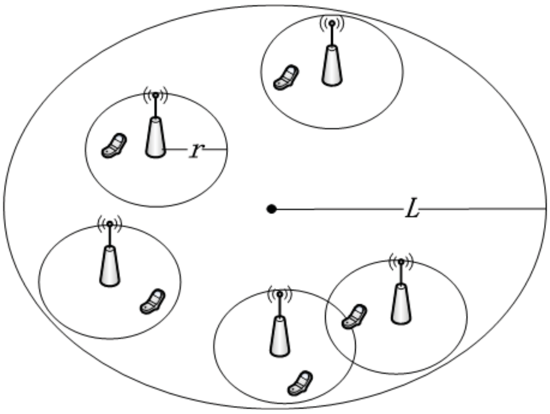

Fig. 1 System model

The SINR measured at the receiver i interrelated with transmitter i can be represented as follows:

$$SINR_i = \frac{p_i \mathrm{H}_{ii}}{\sum p_j \mathrm{H}_{ji} \mathrm{I}(s_j, s_i) + N_0} \quad (1)$$

where p_i is the transmission power at transmitter i and H_{ii} is channel gain between transmitter i and receiver i. $\mathrm{H}_{ji}(j \neq i)$ is channel interference gain from transmitter j to receiver i. While N_0 is Additive White Gaussian Noise in the channel. Besides, $\mathrm{I}(s_j, s_i)$ is an interference function we propose that indicates interference created by transmitter j and transmitter i. It is defined as follows when transmitter i and j are transmitting over the same channel.

$$\mathrm{I}(s_i, s_j) = 1 - \lambda * \log(dis) \quad (2)$$

where dis is the distance from transmitter i to j. Equation (2) shows that the interference between transmitters is inversely proportional to the distance and the interference is interacted to each other on the same frequency channel as $dis(i,j) = dis(j,i)$. In order to maximize the SINRs of the users they serve, the transmitter will choose the channels that are not occupied or the one over which the commuters are far away from themselves. The transmitter determines transmission frequency channel based on the quality of the SINR. We suppose that there are K frequency sub-channels available for transmission (note that $K < N$). By selecting the transmission frequency in a distributed manner, the radio can effectively construct a co-channel dynamic interference diagram and a channel reuse distribution map with reduced co-channel interference.

III. Potential Game Theoretic Framework

In this work, we consider the downlink scenario in a two-tier femtocell network, where time is divided into fixed-length time slots and OFDMA is assumed in each slot. The channel allocation issue is modeled as a fundamental game, which can be expressed in a normal form as $G = \{N, \{S_i\}, \{u_i\}\}$, where N is the finite set of cognitive radio base stations (1,2,...,n), $\{S_i\}, i \in N$ is the set of channels available to station i,$S = S_1 \times S_2 \cdots \times S_n$ is the strategies space, and $\{u_i\}, i \in N$ is the set of utility functions that the stations wish to maximize. For every station i in the game G, the utility function $\{u_i\}$ is a function related to strategy s_i chosen by station i and for the current policy its opponents is $\boldsymbol{s}_{-i}$. The current strategies set mathematically can be expressed as $\boldsymbol{s} = \{s_i, \boldsymbol{s}_{-i}\}$. And the utility function of station i can be defined as

$$\begin{aligned} u\{s_i, \boldsymbol{s}_{-i}\} = &- \sum_{j=1, i\neq j}^{n} p_{ji} \mathrm{H}_{ji} \mathrm{I}(s_j, s_i) \\ &- \sum_{j=1, i\neq j}^{n} p_{ij} \mathrm{H}_{ij} \mathrm{I}(s_i, s_j), \forall i \in N \end{aligned} \quad (3)$$

Utility function u_i can be written in two parts:

$$u\{s_i, \boldsymbol{s}_{-i}\}\text{=-}I_{ni}\text{-}I_{in} \quad (4)$$

$$I_{ni}\text{=} \sum_{j=1, i\neq j}^{n} p_{ji} \mathrm{H}_{ji} \mathrm{I}(s_j, s_i) \forall i \in N \quad (5)$$

$$I_{in}\text{=} \sum_{j=1, i\neq j}^{n} p_{ij} \mathrm{H}_{ij} \mathrm{I}(s_i, s_j) \forall i \in N \quad (6)$$

where p_{ij} is the transmission power from transmitter i, H_{ij} is channel gain between transmitter i and receiver j and $\mathrm{I}(s_j, s_i)$ is the interference function. Equation (4) considers the interference value from the perspective of the channels, where I_{ni} indicates the interference amplitude of the neighbor nodes to transmitter i and I_{in} signifies the interference amplitude of transmitter i to its neighbor nodes over the same channel. Apparently the utility function in (3) can react interference in the entire network, so that every player in the choice of strategies, not only needs to consider their interference, but also takes into account the interference of its neighbors.

As station makes a choice of strategies on its own and it will be influenced by other stations, we are interested in whether there is a final convergence point in the game called Nash Equilibrium (NE).

Definition 1. For pure strategies sets, strategy $s \in S_i$ a is a Nash equilibrium if and only if $\forall i \in N, \forall s_i \in S_i, \forall s^*_{-i} \in S_{-i}$, there is

$$u\{s_i^*, \boldsymbol{s}^*_{-i}\} \geq u\{s_i, \boldsymbol{s}^*_{-i}\} \quad (7)$$

Or it can be defined that when s_i^* satisfies the following formula, it is a Nash equilibrium.

$$\boldsymbol{s}_i^* \in \arg\max_{s_i \in S_i} u\{s_i, \boldsymbol{s}^*_{-i}\}, i \in N \quad (8)$$

For the spectrum allocation scheme, the Nash equilibrium issue can be turned to a maximization problem. In the Nash equilibrium strategies vector, it is impossible for any player to gain greater benefits by changing his own strategy. Therefore, the game achieves a stable state.

When the game meets a particular structure, we can use the difference of potential function to represent the increase

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or decrease of utility function.

Definition 2. A non-cooperative tactical game $G = \{N, \{S_i\}, \{u_i\}\}$ is a complete potential game, If there is an exact potential function $\mathrm{P} : \mathrm{s} \to \boldsymbol{R}$,for $\forall n \in G$,

$$\mathrm{P}(s_i, \boldsymbol{s}_{-i}) - \mathrm{P}(s_i{}', \boldsymbol{s}_{-i}) = u(s_i, \boldsymbol{s}_{-i}) - u(s_i{}', \boldsymbol{s}_{-i}) \quad (9)$$

and we can define the exact potential function as,

$$P\{s_i, \boldsymbol{s}_{-i}\} = \sum_{i=1}^{n} [-\frac{1}{2} \sum_{j=1, i\neq j}^{n} p_{ji}\mathrm{H}_{ji}\mathrm{I}(s_j, s_i) - \frac{1}{2} \sum_{j=1, i\neq j}^{n} p_{ij}\mathrm{H}_{ij}\mathrm{I}(s_i, s_j)] \quad (10)$$

Since we can prove that the potential function in (10) forms an exact potential game [11], (10) reflects the effect of each user's utility function on the performance of the overall network. As each user improves its own utility function, the whole system utility is also elevated. This potential function reflects the utility functions of all users and can satisfy the definition of exact potential game.

IV. Simulation Results

The flow chart of the algorithm is shown in Fig. 2. In this paper, we simulate a cognitive two-tier network

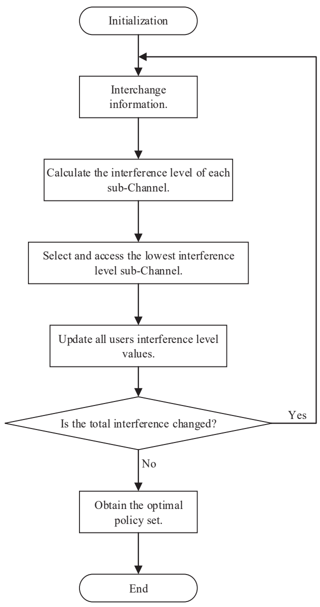

Fig. 2 The flow chart of the algorithm

with radius 400 m, where randomly distribute 40 cognitive transmitting-receiving pairs with service radius 30m and there is one active user in each femtocell at each slot. We consider that there are 4 frequency sub-channels available for transmission.

Fig.3 shows the attenuation of interference function as the distance between base stations increasing.

We believe that when the distance between two transmitters exceeds 300 meters, the value of the interference function

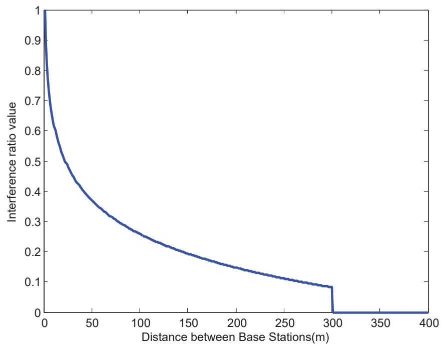

Fig. 3 Attenuation of interference function

becomes to zero, as the interference value has been represented by normalization in this case. From the perspective of the system, this can be done to better perform for the spectrum planning.

Figs.4 and 5 suggest SINRs improvement observed by receivers before and after the use of the allocation algorithm. In the initial situation, there are some users whose SINR is lower than 5dB. Even a small part of the users have SINRs below 0dB and the number of users whose SINRs are higher than 25dB is less than half of the total quantity. In the final allocation situation, the number of users whose SINRs are lower than 5 dB is reduced to zero and the overall user's communication quality is generally promoted. It can be seen in Fig.5 which achieves the state of Nash equilibrium the member at lower SINR has been reduced. Furthermore, Fig.6 illustrate the average spectrum efficiency comparison. The red line adopts the interference at each player as the utility function and the green line uses the throughput as the utility function. It can be seen that the proposed algorithm can improve the spectrum efficiency. In addition, while the number of users increases, the interference becomes more complex and the spectrum efficiency decreases.

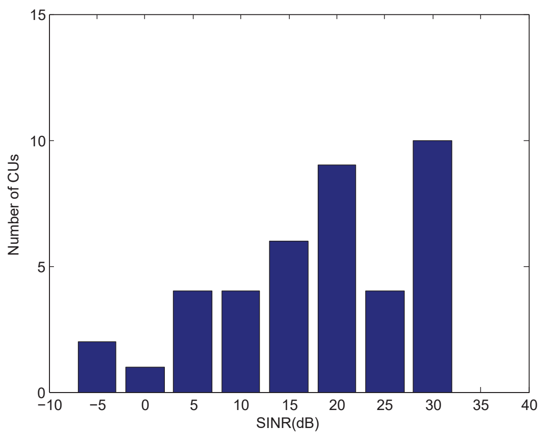

Fig. 4 SINRs histogram of users in initial assignment

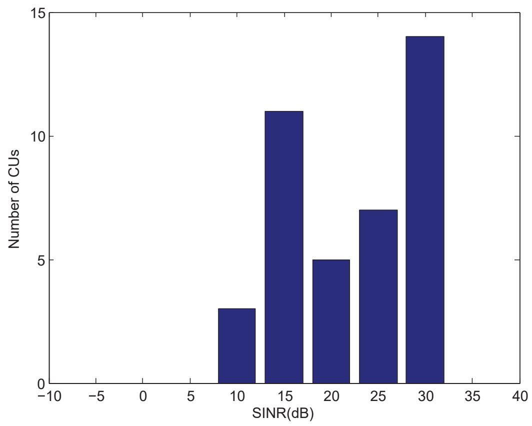

Fig. 5 SINRs histogram of users in final assignment

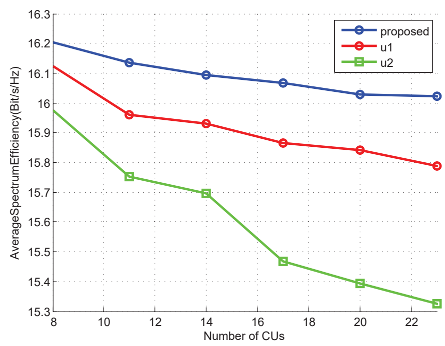

Fig. 6 Average spectrum efficiency comparison

V. Conclusion

A dynamic spectrum allocation model based on game theory for cognitive radio network is raised in this paper and we analyze the algorithm from the perspective of channel interference. We have focused on reducing co-channel interference the same layer and considered a negative logarithm interference function. In addition, the utility function reflects the interference on the view of frequency channel essentially. The simulation results show that the proposed interference model has better allocation results and it has a good effect on improving the spectral efficiency and improving the SINRs of users and the quality of service in downlink can be satisfied. This work focuses on implementing spectrum allocation in a distributed fashion.

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