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Dynamic subcarrier and power allocation based on cooperative game theory in symmetric cooperative OFDMA networks

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Abstract

In order to improve the efficiency and fairness of radio resource utilization, a scheme of dynamic cooperative subcarrier and power allocation based on Nash bargaining solution (NBS-DCSPA) is proposed in the uplink of a three-node symmetric cooperative orthogonal frequency division multiple access (OFDMA) system. In the proposed NBS-DCSPA scheme, resource allocation problem is formulated as a two-person subcarrier and power allocation bargaining game (SPABG) to maximize the system utility, under the constraints of each user's maximal power and minimal rate, while considering the fairness between the two users. Firstly, the equivalent direct channel gain of the relay link is introduced to decide the transmission mode of each subcarrier. Then, all subcarriers can be dynamically allocated to the two users in terms of their selected transmission mode. After that, the adaptive power allocation scheme combined with dynamic subcarrier allocation is optimized according to NBS. Finally, computer simulation is conducted to show the efficiency and fairness performance of the proposed NBS-DCSPA scheme.

Keywords cooperative relay, OFDMA, radio resource allocation, NBS, fairness

1 Introduction

Recently, cooperative communication has been considered as an efficient technique to achieve the cooperation diversity gain over wireless fading channels to enlarge system coverage and increase link reliability [1]. Cooperation allows multiple distributed terminals to share their antennas, creates a virtual multiple-antenna environment and thus achieves an increased rate or decreased outage probability. Every rational user will face the basic decisions, such as when and how to cooperate. To satisfy user requirement and optimize system performance, analyzing the behaviors of rational users and allocating energy and bandwidth have become challenges for radio resource management. Game theory has been proposed as a possible tool in modeling the interactions among the autonomous users. The bargaining theory, as a kind of cooperative game model, has been widely discussed for its efficiency and fairness performance [2–4].

For the three-node symmetric model, most of the previous works based on NBS were only involved with allocating one kind of resource, which means either bandwidth exchange with fixed user transmit power or power bargaining over the given orthogonal channels. For instance, a cooperative bandwidth allocation in a three-node symmetric system model with two users and an access point is formulated as a two-person bargaining game using NBS in Ref. [2]. In Ref. [3], a fair power sharing scheme using NBS between two selfish users is proposed in a similar model, in which the user utility is represented by the effective signal noise ratio (SNR). In Ref. [4], power allocation is formulated as a two-person bargaining game, where relay station tries to sell its data rate at some fixed price to the source station and the utility of the user station is the monetary value converted from the data rate.

Hence, in order to further enhance the efficiency of resource utilization, bandwidth allocation and power allocation are jointly considered and optimized in the paper. A scheme of dynamic cooperative subcarrier and power allocation based on NBS-DCSPA is proposed for radio resource allocation in the uplink of a three-node symmetric cooperative OFDMA system. Besides the increase of the

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system efficiency, the proposed NBS-DCSPA scheme can also improve user fairness. Simulation results prove that the sum-rate of the system, the rate of each user and the fairness are improved compared with the non-cooperative scheme.

The rest of this paper is organized as follows. In Sect. 2, the system model is given. In Sect. 3, the resource allocation problem is formulated as a two-person SPABG. The NBS-DCSPA scheme is proposed for joint optimization. In Sect. 4, computer simulation is conducted to show the effectiveness of the proposed NBS-DCSPA scheme. In Sect. 5, conclusions are drawn.

2 System model and transmission strategy

2.1 System model

A symmetric OFDMA cooperative communication system model made up of two user nodes (i.e. node 1, 2) and a base station (BS) node (i.e. node 3) is shown in Fig. 1. Each user may act as a source as well as a potential relay. BS is the common destination of both users. The amplify-and-forward (AF) cooperative protocol is used in two continuous time-slots. When a subcarrier is used for AF transmission by user n ($n\in\{1,2\}$), in the first time-slot, user n broadcasts data over this subcarrier. In the second time-slot, user $3-n$ forwards user n's data over the same subcarrier. At the destination, maximal ratio combining (MRC) is used by BS to achieve the diversity gain. When a subcarrier is used for direct transmission by user n, the link power is allocated averagely in the two continuous time-slots.

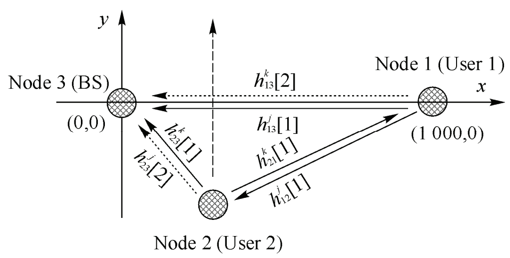

Fig. 1 Cooperative communication system model with two users and a BS

Let $h_{nm}^k[t]$ be the channel gain from node n to node m over subcarrier k in time-slot t ($n,t\in\{1,2\}$, $m\in\{1,2,3\}$, $k\in\{1,2,...,K\}$); p_n^k be the transmission power of node n over subcarrier k in one time-slot; P_n be the total power of node n in two continuous time-slots. K is the number of the subcarriers in the system. Slow fading is assumed to keep the same channel gain in two continuous time-slots, and therefore $h_{nm}^k[t]$ can be simplified as h_{nm}^k .

It is assumed that each user can communicate over several subcarriers, but none of the subcarriers can support the transmission for more than one user at the same time. So the subcarrier allocation variable a_n^k can be constrained as

$$a_n^k=\begin{cases}1; & \text{subcarrier } k \text{ is allocated to user } n\\ 0; & \text{otherwise}\end{cases},\quad \sum_{n=1}^{2}a_n^k=1;$$

$k\in\{1,2,...,K\}$, $n\in\{1,2\}$.

2.2 Equivalent direct channel gain

To simplify the subcarrier and power allocation in a cooperative communication system, the equivalent direct channel gain is introduced to convert AF transmission links to equivalent direct transmission ones.

The AF transmission rate of user n over subcarrier k can be approximately expressed as [5]

$$r_n^k(p_n^k,p_{3-n}^k)=\frac{1}{2}W\mathrm{lb}\left[1+\frac{p_n^k h_{n,3}^k}{\Gamma\sigma_k^2}+\frac{p_n^k h_{n,3-n}^k p_{3-n}^k h_{3-n,3}^k}{\Gamma\sigma_k^2(p_n^k h_{n,3-n}^k+p_{3-n}^k h_{3-n,3}^k)}\right] \tag{1}$$

where W is the subcarrier spacing; Γ is a constant representing SNR gap; σ_k^2 is the power of Gaussian noise over subcarrier k.

For a subcarrier (e.g., subcarrier k) used for AF link with a fixed link power constraint, applying Lagrange multiplier approach, the optimal source-relay power distribution can be obtained [5]:

When $h_{n,3}^k<h_{3-n,3}^k$,

$$\begin{cases}p_n^k=\dfrac{\eta_n^k}{1+\eta_n^k}p^k\\ p_{3-n}^k=\dfrac{1}{1+\eta_n^k}p^k\end{cases};\quad n\in\{1,2\} \tag{2}$$

where

$$\eta_n^k=\frac{h_{n,3}^k h_{3-n,3}^k+h_{3-n,3}^k\sqrt{h_{n,3}^k h_{3-n,3}^k+h_{n,3-n}^k h_{3-n,3}^k-h_{n,3-n}^k h_{n,3}^k}}{h_{n,3-n}^k(h_{3-n,3}^k-h_{n,3}^k)} \tag{3}$$

and p^k is the fixed link power over subcarrier k in two continuous time-slots.

The achievable rate of AF transmission for user n over subcarrier k can be expressed as

$$r_n^{k,\mathrm{AF}}(p^k)=\frac{1}{2}W\mathrm{lb}\left(1+\frac{p^k H_n^{k,\mathrm{AF}}}{\Gamma\sigma_k^2}\right) \tag{4}$$

where

$$H_n^{k,\mathrm{AF}}=\frac{h_{n,3}^k\eta_n^k(h_{n,3-n}^k\eta_n^k+h_{3-n,3}^k)+h_{n,3-n}^k h_{3-n,3}^k\eta_n^k}{(1+\eta_n^k)(h_{n,3-n}^k\eta_n^k+h_{3-n,3}^k)} \tag{5}$$