협동 전송 방식을 이용한 OFDMA 시스템에서의 자원 관리에 관한 연구

Resource Allocation in OFDMA System with User Cooperation

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Abstract

Orthogonal frequency division multiple access (OFDMA) has emerged as one of the core multiple access schemes in 4G to mitigate the problems of frequency selectivity and inter-symbol interferences. In OFDMA, cooperative transmission can be adopted in transmission between each user and base station. Cooperative transmission can provide better channel environments and additional transmitter diversity. In this paper, we formulate a user and subcarrier assignment problem in OFDMA system with user cooperation and propose an efficient scheme to solve it.

Keywords: OFDMA. Cooperative network

I. Introduction

With the increasing popularity of data traffic over wireless systems, the design of next generation wireless networks emphasizes efficient use of wireless resources to provide maximum data throughput over the shared link channel.
Orthogonal frequency division multiple access (OFDMA) is a promising multiple access sheme for 4G wireless broadband networks. It has been designed to mitigate the problems of frequency selectivity and inter-symbol interferences[1].

In OFDMA, adaptive subcarrier allocation combined with adaptive bit loading and power control is performed. In this system, the optimization of subcarrier and power allocation for different users is an effective way to take advantages of dynamic channel fluctuations and get multi-user diversities[2].

Multiuser cooperation has recently emerged as a candidate for improving performance of wireless communication systems. Cooperative transmission uses multiple nodes as a virtual macro antenna array, and creates multiple independently fading communication paths between the source and the destination. By using it, users in deep fading can transmit in association with relayers and get better channel gain. In addition, the broadcasting nature of wireless channels provides an opportunity for multi-node diversity among users[3].

Subcarrier and power allocation in OFDMA uplink system have been studied a lot[1], [2], [4]. User cooperation is an emerging issue and many researchers have tried to adopt user cooperation in existing wireless network[5]. However, the research on OFDMA network with user cooperation is very recent field and resource allocation in the system have been studied a little[6], [7].

In this paper, we consider an OFDMA system which allows cooperative transmissions among users and base station. To increase capacities of wireless data networks, Cooperative transmission can offer substantial gains to the system performance.

We formulate subcarrier for sender-relayer pairs and power allocation problem for OFDMA uplink system. Then, we propose a heuristic method to solve the problem. Our method converts relay-assisted OFDMA system to simple

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OFDMA system and make it possible to apply existing resource allocation methods for OFDMA system.

The rest of the paper is organized as follows: In section II, the system model is given. We formulate the optimization problem in section III. We provide an algorithm to solve the problem in section IV. Finally section V concludes the paper.

II. System model

We consider a broadband OFDMA uplink system with two-hop relaying. Each user can be a sender or relayer who relays another user's data to base station. For simplicity, we assume that relaying method is a simple amplify-and-forward and sender and relayer use same subcarrier. Only one relayer can be assigned to one sender.

In OFDMA system, we should determine sender and sender's transmission power. However In such a system, we should determine who will transmit, who will relay his/her data. In addition, subcarrier should be assigned to that transmission.

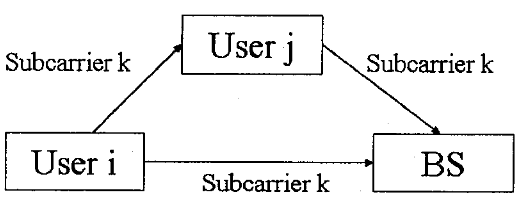

Figure 1: single-sender & single-relayer case

Before formulating the user and power allocation problem, we consider single-sender and single-relayer case[3]. Suppose that user i sends data by k subcarrier and user j relays it as Figure 1. There exist two paths from sender to base station, one path is direct (i-BS) path and the other is relay (i-j-BS) path. We define the channel gain of each link as follows.

g_{iB}^k : the channel gain from user i to base station at k subcarrier.
g_{ij}^k : the channel gain from user i to j at k subcarrier.

When we denote p_i^k as i's transmission power and p_j^k as relayer j's transmission power, SNRs of direct path and relay path are

$$\gamma(i-BS) = p_i^k g_{iB}^k \quad (1)$$

$$\gamma(i-j-BS) = \frac{p_i^k p_j^k g_{jB}^k g_{ij}^k}{p_j^k g_{jB}^k + p_i^k g_{ij}^k} \quad (2)$$

and SNR for user i's transmission is $\gamma_i^k = \gamma(i-BS) + \gamma(i-j-BS)$. Hence, when we use adaptive modulation and coding (AMC), we have

$$r_i^k = \log_2\left(1 + p_i^k g_{iB}^k + \frac{p_i^k p_j^k g_{jB}^k g_{ij}^k}{p_j^k g_{jB}^k + p_i^k g_{ij}^k}\right) \quad (3)$$

by shannon capacity[8].

In multiuser case, there may exist many senders and relayers in OFDMA uplink network. Each sender uses different subcarrier from others to avoid interferences. If cooperative transmission is allowed, sender should decide whether he/she will use relayer or not in the transmission of his/her data to BS.

III. Optimization problem

To formulate user-relay and subcarrier assignment problem, we classify each transmission into direct transmission and relay transmission. Direct transmission means that user directly sends data to BS without any relayer's help. In relay transmission, sender transmits data with a relayer's help. Then, we can define assignment index w_i^k and ζ_{ij}^k as

$$w_i^k = \begin{cases} 1, & i\, user\, transmit\, with\, k\, channel\, just\, directly \\ 0 & ,otherwise \end{cases}$$

$$\zeta_{ij}^k = \begin{cases} 1, & i\, user\, sends \text{ and } j\, helps\, with\, k\, channel \\ 0 & otherwise \end{cases}$$

SNR of direct transmission is same as (1) and that of relay transmission can be calculated as (1)+(2).

Suppose that there are K users and N subcarriers in the network. Then, user-relay and subcarrier assignment problem can be formulated as

(P)
Max

$$\sum_{k=1}^{N}\sum_{i=1}^{M}\sum_{j=1}^{M}[w_i^k SNRD(p_i^k) + \zeta_{ij}^k SNRR(\overline{p_i^k}, \overline{p_j^k})] \quad (4)$$

s.t.

$$\sum_{i=1}^{M} w_i^k + \sum_{j=1}^{M}\sum_{k=1}^{N}\zeta_{ij}^k \le 1, \ \forall k \quad (5)$$

$$\sum_{k=1}^{N}(p_i^k+\overline{p_i^k}) \le \overline{P_i}\ ,\forall i \qquad (6)$$

$$w_i^k, \zeta_{ij}^k = 0\,\text{or}\,1, p_i^k, \overline{p_i^k} \ge 0 \qquad (7)$$

where $SNRD(p_i^k)=\log_2(1+p_i^k g_{iB}^k)$,

$$SNRR(\overline{p_i^k},\overline{p_j^k})=\log_2(1+\overline{p_i^k}g_{iB}^k+\frac{\overline{p_i^k}\,\overline{p_j^k}g_{ij}^k g_{jB}^k}{\overline{p_i^k}g_{ij}^k+\overline{p_j^k}g_{jB}^k}).$$

Equation (4) is Objective function which maximizes total throughput of the network and (5) means that each subcarrier should be assigned to one sender or sender-relayer pair. Power of each user has a limitation $\overline{P_i}$ in (6).

IV. Proposed scheme

Above optimization problem (P) is not easy to solve because $SNRR(\overline{p_i^k},\overline{p_j^k})$ varies according to the change of sender's and relayer's power $\overline{p_i^k},\overline{p_j^k}$. In this section, we propose a method for assigning subcarriers to users and relayers and allocating power.

In the optimization problem (P), it is most efficient to distribute sender's and relayer's power to maximum SNR within given fixed power. Let

$$\acute{SNRR}(\breve{p}_{ij}^k)=\max SNRR(\overline{p_i^k},\overline{p_j^k}) \qquad (8)$$

where $\breve{p}_{ij}^k=\overline{p_i^k}+\overline{p_j^k}$.

Our main idea is to establish an imaginary path which is directly connected from sender to BS and has same SNR and power consumption as relaying path

In [5], Anghel et al. solved optimal power allocation for SNR maximization in single-sender and single-relayer case. If there is given power P, optimal power distribution is calculated as

$$\overline{p_i^*}=P-\overline{p_j} \qquad (9)$$
$$\overline{p_j}=\alpha g_{ij}/g_{iB}-1/g_{jB}$$

where p_i, p_j are sender's and relayer's powers, g_{ij}, g_{iB} are channel gains. For simplicity, we let $\overline{p_i^*}=k\overline{p_j^*}$, then we can set imaginary channel gain $\breve{g}_{iB}$ as

$$\overline{p_i^k}g_{iB}^k+\frac{\overline{p_i^k}\,\overline{p_j^k}g_{ij}^k g_{jB}^k}{\overline{p_i^k}g_{ij}^k+\overline{p_j^k}g_{jB}^k}=\breve{p}_{ij}^k\overline{g_{iB}^k}=(\overline{p_i^k}+\overline{p_j^k})\overline{g_{iB}^k}$$
$$\overline{g_{iB}^k}=\left(\frac{1}{1+k}\right)\left(\frac{kg_{ij}^k g_{jB}^k}{g_{ij}^k+kg_{jB}^k}\right). \qquad (10)$$

By using $\breve{g}_{iB}$ and $\breve{p}_{ij}^k$ instead of g_{ij}, g_{iB} and p_i, p_j, we can modify all the relaying transmissions into simple direct transmissions. Thus, subcarrier and power allocation problem can be solved in same way as OFDMA uplink system without cooperation.

Now, optimization problem (P) can be modified as follows.

(P')

Max

$$\sum_i^M\sum_j^M\sum_k^N\left[w_i^k\log_2(1+p_i^k g_{iB}^k)+\delta_{ij}^k\log_2(1+\breve{p}_{ij}^k\overline{g_{iB}^k})\right]$$

$$\sum_{i=1}^M w_i^k+\sum_{j=1}^M\sum_{k=1}^N\zeta_{ij}^k\le 1,\ \forall k$$

$$\sum_{k=1}^N(p_i^k+\breve{p}_{ij}^k)\le\overline{P_i},\ \forall i,j$$

$$w_i^k,\zeta_{ij}^k=0\,\text{or}\,1, p_i^k,\breve{p}_{ij}^k\ge 0$$

Problem (P') is a subcarrier and power allocation problem in OFDMA uplink system. There exists M+M^2 number of users, which consists of M directly transmitting users and M^2 users using power $\breve{p}_{ij}^k$ and having channel gain $\breve{g}_{iB}$.

Kim et al. studied the optimal conditions of subcarrier and power allocation problem in OFDMA uplink system in [1]. According to [1], user and subcarrier pair i^*, j^*, k^* should be determined given by

$$i^*, j^*, k^*=\arg max[\max(p_i^k g_i^k, \breve{p}_{ij}^k, \overline{g_{iB}^k})] \qquad (11)$$

In (11), if $p_{i^*}^{k^*}g_{i^*B}^{k^*}>\breve{p}_{i^*j^*}^{k^*}\overline{g_{i^*B}^{k^*}}$, i^* user transmits by k^* subcarrier directly. In the other case, i^* user transmits using j^* relayer.

Given user-relayer and subcarrier allocation, optimal power can be allocated by water-filling algorithm. After optimal power $\breve{p}_{ij}^k$ is determined by water-filling, total power $\breve{p}_{ij}^k$ is distributed to sender i and relayer j as follows.

$$\text{If } \breve{p}_{ij}^{k} \geq 0,\ \overline{p_j^k} = \frac{\breve{p}_{ij}^{k}}{1+k},\ \overline{p_i^k} = \breve{p}_{ij}^{k} - \overline{p_j^k} \tag{12}$$

Thus, we can allocate power to every directly transmitting user and relaying user. However, in solving problem (P'), our method regards as if sender in relaying transmission used power $\breve{p}_{ij}^{k}$ even though he/she used $\overline{p_i^k}$ actually. In relaying, sender is recognized as he/she transmitted more power than he/she actually did and relayer is in opposite case. Hence, we should adjust power in order to make our solution be feasible to problem (P). We propose a heuristic algorithm to adjust power as follows.

<Heuristic: Power adjustment>

If $\sum_k p_i^k < \overline{P_i}$, let $\triangle = \overline{P_i} - \sum_k p_i^k$.

$S_i = \{k | w_i^k = 1\}$.

$k^* = \mathrm{arg}max_{k \in S_i} \begin{bmatrix} \log_2(1 + (p_i^k + \triangle) g_{iB}^k) \\ -\log_2(1 + p_i^k g_{iB}^k) \end{bmatrix}$.

Then $p_i^{k^*} = p_i^{k^*} + \triangle$.

If $\sum_k p_i^k > \overline{P_i}$, let $\triangle = \sum_k p_i^k - \overline{P_i}$.

$S_i = \{k | w_i^k = 1\}$.

$k^* = \mathrm{arg}min_{k \in S_i} \begin{bmatrix} \log_2(1 + p_i^k g_{iB}^k) \\ -\log_2(1 + (p_i^k - \triangle) g_{iB}^k) \end{bmatrix}$.

Then $p_i^{k^*} = p_i^{k^*} - \triangle$.

In this heuristic, if an user's power remains, remaining power is added to a subcarrier which was already allocated before. Among them, we choose a subcarrier so as to maximize the increment of the user's throughput. If an user's power exceeds power constraint, one of the already allocated subcarrier is selected so as to minimize the decrease of the throughput by eliminating excessive power.

Our method is a sub-optimal algorithm because power adjustment is needed after solving the problem (P'). However, our method is highly applicable because it converts the complex user-relay problem to simple and well-known problem.

V. Conclusions

In the paper, we formulated a resource allocation problem in OFDMA system with user cooperation and proposed sub-optimal algorithm to solve it. We substituted relaying transmission to direct transmission by using imaginary channel gain and made problem easier. Based on our method, many heuristc methods applied in OFDMA system can be adopted in relay combined system easily.

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