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RESEARCH ARTICLE

Zhiwei LI, Chunyan FENG, Tiankui ZHANG, Jieying ZHENG

Power allocation scheme for multicell interference coordination in OFDMA systems

Abstract To coordinate inter-cell interference, a multicell adaptive power allocation scheme is proposed for downlink orthogonal frequency division multiple access (OFDMA) cellular systems. This scheme uses the difference of the signal to interference plus noise ratio (SINR) between the co-subchannels of adjacent cells to balance SINR for coordinating the transmit power in the co-subchannels. The scheme can improve edge user performance, reduce interference between the co-subchannels of adjacent cells and improve radio resource utility. Simulation results show that the scheme can balance system performance and ensure system throughput.

Keywords orthogonal frequency division multiple access (OFDMA), power allocation, inter-cell interference, interference coordination

1 Introduction

At present, all kinds of single-cell resource allocation algorithms for orthogonal frequency division multiple access (OFDMA) systems can adequately solve various issues in a single district. However, in multicell systems where the frequency reuse factor is 1, the single cell algorithm cannot be directly used because of interference between the co-subchannels of adjacent cells [1]. Although the multicell algorithm based on non-cooperative game theory can effectively reduce interference between the co-subchannels of adjacent cells [2], the performance of marginal users is very poor and thus fairness of the algorithm is unsatisfied. Therefore, a multicell adaptive power allocation based on signal to interference plus noise ratio (SINR)—MAP-BSINR is proposed in this article. By balancing the SINR between the co-subchannels of adjacent cells and using interference coordination, the algorithm can improve system fairness, reduce the interference between co-subchannels of adjacent cells and ensure system throughput.

2 Optimization object

In OFDMA systems, assume that the system bandwidth is B. A subchannel is made up of a group of sequential subcarriers [3], and the number of subchannels is assumed to be N. Each bandwidth of the subchannel is then $B_n = B/N$, with an index of $1-N$. Furthermore, assume that one subchannel can only be assigned to one user in one schedule. Consider I adjacent cells with the same-frequency interference. Each cell owns K active users, and the subchannels with the same index in different cells are considered as subchannels with the same frequency. Subsequently, suppose that the channel state information (CSI) can be transmitted to base station without any error or delay by control channels. Additionally, suppose that the CSI mainly includes the information of $g_{i,k,n}$ and $g_{j,k,n}^{i}$, where $g_{i,k,n}$ denotes the channel gain from the kth user to the nth subchannel of the ith cell, and $g_{j,k,n}^{i}$ denotes the gain from the same user to the interference subchannel of the other cells.

The optimization object based on system fairness and throughput is then submitted as

$$\max \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{n=1}^{N}\alpha_{i,k,n}c_{i,k,n},$$

$$\text{s.t.}\begin{cases}\displaystyle\sum_{k=1}^{K}\sum_{n=1}^{N}\alpha_{i,k,n}p_{i,k,n}\leqslant p_i^{\text{total}},\\ \overline{R}_{i,1}:\cdots:\overline{R}_{i,K}=r_{i,1}:\cdots:r_{i,K},\\ \displaystyle\sum_{k=1}^{K}\alpha_{i,k,n}=1.\end{cases}\tag{1}$$

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Zhiwei LI (✉), Chunyan FENG, Tiankui ZHANG, Jieying ZHENG
Institute of Communication Networks Integrated Technology, Beijing University of Posts and Telecommunications, Beijing 100876, China
E-mail: lihere11@gmail.com

Here, the first restricted condition is the power requirement of each base station, with p_i^{total} as the maximal power; the second one is the fairness requirement; and the last is the subchannel allocation requirement. $\alpha_{i,k,n} = 1$ denotes that the nth subchannel of the ith base station is assigned to the kth user; $\alpha_{i,k,n} = 0$ denotes the opposite situation; $c_{i,k,n}$ denotes the throughput when the nth subchannel of the ith base station is assigned to the kth user; and $\overline{R}_{i,k}$ denotes the average rate of the kth user in the ith cell.

When the requirement of bit error rate (BER) is constant, the following formula can be obtained according to the Shannon equation:

$$c_{i,k,n} = B_n \text{lb}\left(1+\frac{\gamma_{i,k,n}}{\Gamma}\right), \tag{2}$$

where $\Gamma = -\ln(5 \times \text{BER})/1.5$ [4].

The SINR of the ith user of the nth subchannel in the kth cell is given as

$$\gamma_{i,k,n} = \frac{g_{i,k,n} p_{i,k,n}}{\sum\limits_{j=1,\, j\neq i}^{I} g^{i}_{j,k,n} p_{j,k,n} + \sigma^2}, \tag{3}$$

where σ is white noise and $p_{i,k,n}$ is the transmit power of the kth user of the nth subchannel in the ith cell.

To obtain the optimal result of Eq. (1), all users of all subchannels in all base stations have to be considered. Thus, the data amount required in calculation is very large, which results in complex algorithm. Consequently, only the sub-optimal solution can be obtained by MAP-BSINR.

3 MAP-BSINR algorithm

To reduce algorithm complexity, the system resource was divided into two steps by MAP-BSINR. First, every single cell allots subchannels under the condition of equal power. Second, allot subchannels among the cells based on the result of the subchannel allocation [5].

3.1 Algorithm description

Subchannel allocation is independent and its result is the base of power allocation, i.e., power allocation can inherit features of subchannel allocation. Therefore, for better optimization, the MAP-BSINR uses proportional fairness (PF) algorithm of equal power in subchannel allocation.

To improve system fairness, the transport power of fringe users is increased. However, this will result in the chain reaction of ‘increasing transport power—increasing interfering—increasing transport power’ in the multicell system. Thus, MAP-BSINR aims to balance SINR when ensuring the maximum system throughput [6].

After the subchannel allocation, $\alpha_{i,k,n}$ is determined, where $c_{i,k,n}$, $\gamma_{i,k,n}$ and $p_{i,k,n}$ can be simplified as $c_{i,n}$, $\gamma_{i,n}$ and $p_{i,n}$. For Eqs. (1) and (2), the overall throughput of the multicell system can be expressed as follows:

$$c_{\text{total}} = \sum_{n=1}^{N} B_n \text{lb}\left(\prod_{i=1}^{I}\left(1+\frac{\gamma_{i,n}}{\Gamma}\right)\right). \tag{4}$$

From Eq. (4), it can be deduced that

$$\max c_{\text{total}} = \sum_{n=1}^{N} B_n \text{lb}\left(\max\left(\prod_{i=1}^{I}\left(1+\frac{\gamma_{i,n}}{\Gamma}\right)\right)\right). \tag{5}$$

For Eq. (5), the following can be obtained:

$$\max c_{\text{total}} \Rightarrow \sum_{n=1}^{N} \max \prod_{i=1}^{I}\left(1+\frac{\gamma_{i,n}}{\Gamma}\right), \tag{6}$$

i.e., as long as $\prod\limits_{i=1}^{I}(1+\gamma_{i,n}/\Gamma)$ in every group is the maximum value, the highest system throughput can be obtained. Then, assume $S_n = \sum\limits_{i=1}^{I}(1+\gamma_{i,n}/\Gamma)$. Because there must be a maximum value in each group, we can assume that S_n exists and is constant. Based on the theorem of the mean for inequation, if only

$$1+\gamma_{1,n}/\Gamma = 1+\gamma_{2,n}/\Gamma = \cdots = 1+\gamma_{I,n}/\Gamma,$$

i.e., $\gamma_{1,n} = \gamma_{2,n} = \cdots = \gamma_{I,n}$, we can then obtain

$$\max \prod_{i=1}^{I}(1+\gamma_{i,n}/\Gamma) = (S_n/I)^I.$$

Hence, the conclusion is

$$\begin{aligned} &\gamma_{1,n} = \gamma_{2,n} = \cdots = \gamma_{I,n} \\ &\Leftrightarrow \max \prod_{i=1}^{I}(1+\gamma_{i,n}/\Gamma) \Leftrightarrow S_n. \end{aligned} \tag{7}$$

Therefore, to improve system throughput, we must ensure that S_n is close to $\overline{S}_n = \sum\limits_{i=1}^{I}\left(1+\overline{\gamma}_{i,n}/\Gamma\right)$ as much as possible, where $\overline{\gamma}_{i,n}$ is the result of the simplified $\overline{\gamma}_{i,k,n}$ after the subchannel allocation. With increasing difference among $\overline{\gamma}_{1,n}, \overline{\gamma}_{2,n}, \ldots, \overline{\gamma}_{I,n}$, the extension of $\Delta_n = S_n - \overline{S}_n$ is also increased, i.e., Δ_n can guarantee the plus of the system throughput with a lower numerical value. Meanwhile, through S_n, we can confirm the $p_{1,n}, p_{2,n}, \ldots, p_{I,n}$ and the throughput limit in this group.

To improve system fairness, it should be assured that fringe users can obtain much more power. To that end, in every subchannel group with the same frequency, the worst channel in SINR is assigned the maximal power among all subchannels with the same frequency in the group, and other channels are coordinated with each other based on Eq. (7).

Furthermore, to increase total system throughput, considering the SINR difference of every channel with the same frequency, the gain after the balance is more evident when the difference is large. Thus, increasing user power on the channel with the same frequency whose SINR difference is larger, is equal to increasing its S_n in this group, and the throughput plus will be more evident. Hence, MAP-BSINR utilizes the standard value ratio of SINR in every group of the same-frequency channels to confirm the maximal power in every group.

3.2 MAP-BSINR algorithm flow

Step 1 Channel feedback, including link plus information and SINR information on the assumed condition of equal power.

Step 2 In every cell, the PF algorithm is used.

Step 3 Simplify $\overline{\gamma}_{i,k,n}$, $\gamma_{i,k,n}$ and $p_{i,k,n}$ as $\overline{\gamma}_{i,n}$, $\gamma_{i,n}$ and $p_{i,n}$, and the procedure of power assignment is as follows:

1) Account the SNR difference $\{\sigma_1, \sigma_2, \ldots, \sigma_N\}$ of the subchannel with the same frequency in multicells, where $\sigma_n = \sigma(\overline{\gamma}_{1,n}, \ldots, \overline{\gamma}_{I,n})$;

2) Based on $\sigma_1 : \sigma_2 : \cdots : \sigma_N$, account the upper limit of the subchannel with the same frequency in each group:

$$p_n^{\text{thr}} = \frac{\sigma_n}{\sum\limits_{n'=1}^{N} \sigma_{n'}} p_{\text{total}};$$

$$3)\begin{cases} p_{i',n} = p_n^{\text{thr}}, \qquad \{i'\} = \arg\limits_{n}\ \min \overline{\gamma}_{i,n}, \\ \dfrac{g_{1,n} p_{1,n}}{\sum\limits_{j=1,\, j\neq i}^{I} g_{j,n}^{1} p_{j,n} + \sigma^2} = \cdots = \dfrac{g_{I,n} p_{I,n}}{\sum\limits_{j=1,\, j\neq i}^{I} g_{j,n}^{I} p_{j,n} + \sigma^2}; \end{cases}$$

4) In the system, the power in each cell is limited by

$$\begin{cases} \sum\limits_{n=1}^{N} p_{i,n} \leqslant p_i^{\text{total}}, \\ p_{i,n} \geqslant 0, \end{cases}$$

while the result of 3) may not be in the scope. To guarantee the validity of the algorithm, assume that the *n*th group is in this situation, then $p_{i'',n''} = p_{n''}^{\text{thr}}$, where $i'' = \arg\ \min\ \overline{\gamma}_{i,n''}$, and the power of the other $I - 1$ users in the subchannels with the same frequency is $p_{j,n''}^{j\neq i''} = 0$.

After searching all the subchannels with the same frequency in the above process, the transport speed of each channel is confirmed again based on the power gained by each user and the result of subchannel allocation.

Step 4 Send data and complete this attempt.

4 Simulational analysis

The simulation parameters are listed in Table 1.

Table 1 Simulation parameters

parameter	value
number of sectors in each cell	3
sector reuse factor	1
system bandwidth	10 MHz
number of subcarriers	600
number of subchannels	24
total power of base station	20 W
TTI	0.5 ms
simulation time	2000 TTI

To simplify computation, algorithm simulation is carried out among three sectors in one cell. The same-frequency interference among sectors and white noise are considered as the main interference. Other kinds of interferences are ignored. It is assumed that there is an equal number of users in each sector, the number remains unchanged and each subchannel can only be allocated to a specific user during one scheduling process.

The two factors, system fairness and total throughout, are compared and analyzed, while they are not weighted factors. The following formula proposed in Ref. [6] is used to measure the fairness:

$$\text{fairness index} = \frac{\text{Top 5\% user throughput in CDF}}{\text{average user throughput}} = \frac{\text{edge user}}{\text{system average}}. \tag{8}$$

The optimization objective of the MAP-BSINR algorithm is to improve system fairness and guarantee system throughput. Therefore, in the simulation, the PF algorithm combined with equal power allocation in a single cell is directly extended to be a multicell algorithm, and is considered as the comparison algorithm. This algorithm is called the multicell equal power PF algorithm and labeled as PF + EP. The simulation result shown in Fig. 1 demonstrates that the fairness index under various user scenes is improved significantly, mainly because it can be assured that more power will be allocated to users with poorer SINR, compared with other users in the same group in the same-frequency subchannel. Consequently, the priority of users with poorer SINR can be guaranteed. Thus, system fairness tends to a stable range with a gradual increase of users diversity effect.

There are three algorithms, Max C/I, PF and MAP-BSINR in Fig. 2. They are all combined with equal power allocation. Figure 2 shows the simulation result of throughput. The Max C/I combined with equal power allocation is labeled as Max C/I + EP in the figure. The simulation shows that the throughput of PF + EP is less than that of MAP-BSINR. This happens because the user SINRs of each group of the same-frequency subchannel differ considerably. The difference can be fully used in the MAP-BSINR algorithm. However, the difference will be reduced with the gradual increase of users' diversity effect. Subsequently, the throughput gain will be reduced. The simulation result shows that the gain is still obvious when there are 200 users under the simulation condition assumed in this article. However, the MAP-BSINR algorithm is mainly used to improve fairness, and throughput improvement is additive. Moreover, the result shows that the throughput of the MAP-BSINR algorithm is more than that of the two others. This happens because the users' diversity effect is not obvious in the case of a smaller user number, thus the MAP-BSINR algorithm can guarantee a greater throughput gain. However, with the increase of user numbers, the users' diversity effect will be more obvious. Since the objective of the Max C/I algorithm is to maximize the throughput, which can more efficiently utilize the diversity effect, the increase yields a throughput of the MAP-BSINR algorithm less than that of Max C/I + EP.

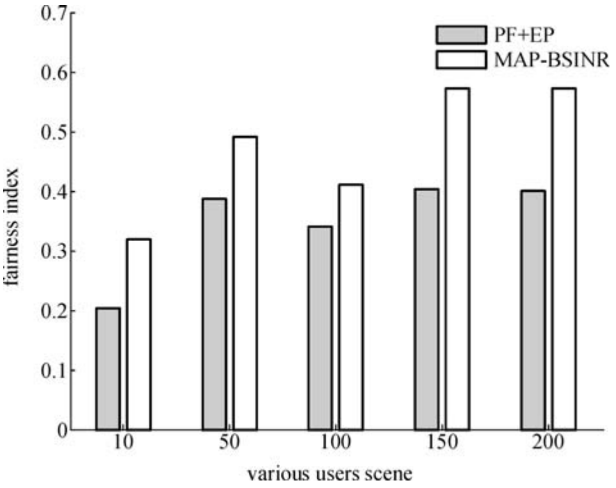

Fig. 1 Comparison of system fairness

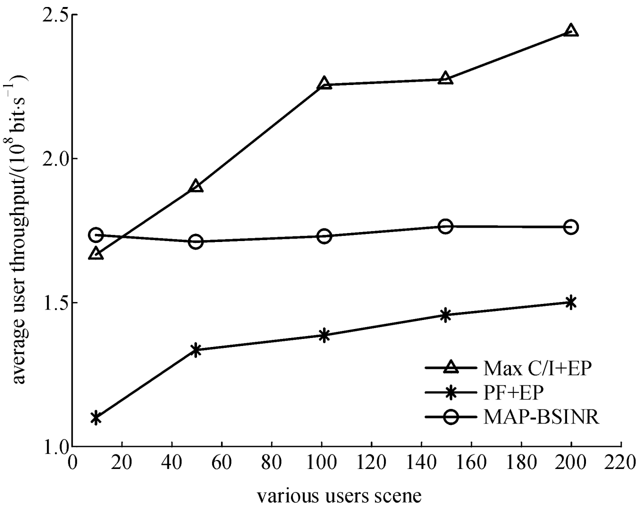

Fig. 2 Comparison of throughput

5 Conclusions

The MAP-BSINR algorithm can be used in multicell, multiuser OFDMA systems. Power allocation in the algorithm can be combined with various subchannel allocation algorithms according to the optimization objectives. The MAP-BSINR coordinates the transmit power in the same-frequency channel of cells. It improves fairness, reduces the cells' interference and guarantees the overall throughput. However, the initial power of the algorithm has a major impact on the overall throughput and edge user performance. To improve performance of this algorithm, more excellent initial power allocations shall be studied.

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