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ADAPTIVE RESOURCE ALLOCATION FOR WIRELESS MULTICAST MIMO-OFDM SYSTEMS

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Abstract-Multiple antenna orthogonal frequency division multiple access (OFDMA) is a promising technique for the high downlink capacity in the next generation wireless systems, in which adaptive resource allocation would be an important research issue that can significantly improve the performance with guaranteed QoS for users. Moreover, most of the current source allocation algorithms are limited to the unicast system. In this paper, dynamic resource allocation is studied for multiple antenna OFDMA based systems which provide multicast service. The performance of multicast system is simulated and compared with that of the unicast system. Numerical results also show that the proposed algorithms improve the system capacity significantly compared with the conventional scheme.

Index Terms- Adaptive resource allocation, MIMO, multicast service, OFDM, water-filling.

I. INTRODUCTION

The next-generation wireless networks are expected to provide broadband multimedia services such as voice, web browsing, video conference, etc. with diverse Quality of Service (QoS) requirements [3]–[5], [7]. Multicast service over wireless networks as in Fig. 1 is an important and challenging goal oriented to many multimedia applications such as audio/video clips, mobile TV and interactive game [3]–[5], [7], [11].

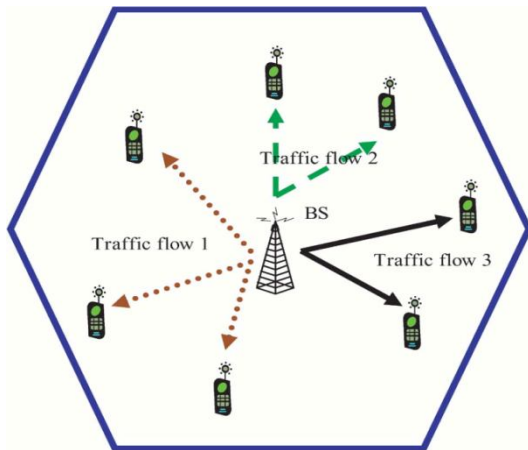


Fig. 1. Cellular structure of multicast transmission system.

There are two key traffics, namely, unicast traffics and multicast traffics, in wireless multimedia communications. Current studies mainly focus on unicast traffics. In particular, dynamic resource allocation has been identified as one of the most efficient techniques to achieve better QoS and higher system spectral efficiency in unicast wireless networks. Furthermore, more attention is paid to the unicast OFDM systems. Orthogonal Frequency Division Multiplexing (OFDM) is regarded as one of the promising techniques for future broadband wireless networks due to its ability to provide very

high data rates in the multi-path fading environment [16]. Orthogonal Frequency Division Multiple Access (OFDMA) is a multiuser version of the popular OFDM scheme and it is also referred as multiuser OFDM. Multiple input multiple output (MIMO) technologies have also received increasing attentions in the past decades. Many broadband wireless networks have now included MIMO technology in their protocols including the multicast system [3]. Compared to single input single output (SISO) system, MIMO offers the higher diversity which can potentially lead to a multiplicative increase in capacity. In multiuser OFDM or MIMO-OFDM systems, dynamic resource allocation always exploits multiuser diversity gain to improve the system performance [8]–[10], [6], [15] and it is divided into two types of optimization problems: 1) to maximize the system throughput with the total transmission power constraint [9]; 2) to minimize the overall transmit power with constraints on data rates

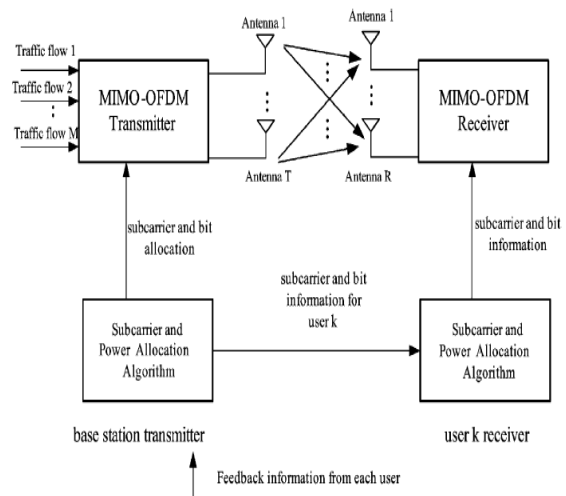


Fig. 2. Block diagram of multiple antenna OFDM multicast system.

or Bit Error Rates (BER) [15]. To the best of our knowledge, most dynamic resource allocation algorithms, however, only consider unicast multiuser OFDM systems. In wireless networks, many multimedia applications adapt to the multicast transmission from the base station (BS) to a group of users. These targeted users consist of a multicast group which receives the data packets of the same traffic flow. The simultaneously achievable transmission rates to these users were investigated in [12] and [13]. Recently scientific researches of multicast transmission in the wireless networks have been paid more attention. For example, proportional fair scheduling algorithms were developed to deal with multiple multicast groups in each time slot in cellular data networks [2]. The dynamic resource allocation for OFDM based multicast system was researched in [1], however it focused on SISO system and can not be applied to MIMO system directly. On the other hand, the conventional scheme in current standards such as IEEE 802.16 or 3GPP LTE for multicast service considers the worst user very much, which may waste the resource. In this paper, we propose dynamic subcarrier and power allocation algorithms for MIMO OFDMA-based wireless multicast systems. In the proposed algorithms, the subcarriers and powers are dynamically allocated to the multicast groups. Our aim is to maximize the system throughput given the total power constraint. Let us assume that there are multiple multicast groups in a cell and each multicast group may contain a different number of users. The users included in the same multicast group are called co- group users and these can be located in different places in the cell.

This paper is organized as follows. Section II introduces the multiple antenna OFDMA based multicast system model and presents the optimization objective function. In Section III, the proposed resource allocation algorithm is described. Simulation results are illustrated in Section IV and conclusions are drawn in Section V.

II. SYSTEM MODEL

The block diagram of multiuser MIMO-OFDM downlink system model is shown in Fig. 2. It shows that in the basestation channel state information of each couple of transmit and receive antennas are sent to the block of subcarrier and power algorithm through the feedback channels. The resource allocation information is forwarded to the MIMO-OFDM transmitter. The transmitter then selects the allocated number of bits from different users to form OFDMA symbols and transmits via the multiple transmit antennas. The spatial multiplexing mode of MIMO is considered. The resource allocation scheme is updated as soon as the channel information is collected and also the subcarrier and bit allocation information are sent to each user for detection.

The following assumptions are used in this paper. The transmitted signals experience slowly time-varying fading channel, therefore the channel coefficients can be regarded as constants during the subcarrier allocation and power loading period. Throughout this paper, let the number of transmit antennas be T and the number of receive antennas be R for all users. Denote the number of traffic flows as M , the number of user as K and the number of subcarriers as N . Thus in this model downlink traffic flows are transmitted to users over subcarriers. Assume that the base station has total transmit power constraint Q . The objective is to maximize the system sum capacity with the total power constraint. We use the equally weighted sum capacity as the objective function. The system capacity optimization problem for muticast MIMO-OFDM system can be formulated to determine the optimal subcarrier allocation and power distribution:

$$\begin{aligned} \max C & \\ = \frac{1}{N} \sum_{k=1}^K \sum_{n=1}^N p_{k,n} & \left(\sum_{i=1}^{M_{k,n}} \log \left(1 + \frac{\lambda_{k,n} q_{k,n}}{N_0} \right) \right) \quad (1) \\ \text{subject to : } \sum_{n=1}^N \max_k & (q_{k,n}) \leq Q \\ q_{k,n} \geq 0 & \text{ for all } k, n \\ p_{k,n} \in \{0,1\} & \text{ for all } k, n \end{aligned}$$

Where C is the system sum capacity which can be derived based on [16] and the above assumptions; Q is the total available power $q_{k,n}$; is the power assigned to user in the subcarrier n ; $P_{k,n}$ can only be the value of 1 or 0 indicating whether subcarrier n is used by user K or not. $M_{k,n}$ is the rank of $H_{k,n}$ which denotes the MIMO channel gain matrix ($R * T$) on subcarrier n for user K and $\{\lambda_{k,n}^{(i)}\}$ $i = 1:M_{k,n}$ are eigenvalues of $H_{k,n} H_{k,n}^H$; K_n is the allocated user index on subcarrier n ; N_0 is the noise power in the frequency band of one subcarrier.

The different point of muticast optimization problem in (1) compared to the general unicast system is that there is no constraint of $\sum_{k=1}^K P_{k,n} = 1$ for all n , which means that many users can share the same subcarrier in multicast system because they may need the same multimedia contents. The capacity for user K , denoted as R_k , is defined as

$$R_k = \frac{1}{N} \sum_{n=1}^N P_{k,n} \left(\sum_{i=1}^{M_{k,n}} \log \left(1 + \frac{\lambda_{k,n}^{(i)} q_{k,n}}{N_0} \right) \right) \quad (2)$$

III. PROPOSED SUBOPTIMAL SUBCARRIER ALLOCATION AND POWER DISTRIBUTION

The optimization problem in (1) is generally very hard to solve. It involves both continuous variables

and binary variables. Such an optimization problem is called a mixed binary integer programming problem. Furthermore, since the feasible set is not convex the nonlinear constraints in (1) increase the difficulty in finding the optimal solution. Ideally, subcarriers and power should be allocated jointly to achieve the optimal solution in (1). However, this poses a prohibitive computational burden at the base station in order to reach the optimal allocation. Furthermore, the base station has to rapidly allocate the optimal subcarrier and power in the time varying wireless channel. Hence, low-complexity suboptimal algorithms are preferred for practical implementations. Separating the subcarrier and power allocation is a way to reduce the complexity, because the number of variables in the objective function is almost reduced by half. In an attempt to avoid the full search algorithm in the preceding section, we devise a suboptimum two-step approach. In the first step, the subcarriers are assigned assuming the constant transmit power of each subcarrier. This assumption is used only for subcarrier allocation. Next, power is allocated to the subcarriers assigned in the first step. Although such a two-step process would cause suboptimality of the algorithm, it makes the complexity significantly low. In fact, such a concept has been already employed in OFDMA systems and also its efficacy has been verified in terms of both performance and complexity. However, the algorithm proposed in this paper is unique in dealing with MIMO-OFDM based multicast resource allocation.

Before we describe the proposed suboptimal resource allocation algorithm, we firstly show mathematical simplifications for the following subcarrier allocation. It is noticed that in large SNR region, i.e. $\lambda_{k,n}^{(i)} q_n / N_0 \gg 1$, we get the following approximation:

$$\begin{aligned} & \arg \min_k \sum_{i=1}^{M_{k,n}} \log \left(1 + \frac{\lambda_{k,n}^{(i)} q_n}{N_0} \right) \\ &= \arg \min_k \prod_{i=1}^{M_{k,n}} \left(1 + \frac{\lambda_{k,n}^{(i)} q_n}{N_0} \right) \\ &\approx \arg \min_k \prod_{i=1}^{M_{k,n}} \left(\frac{\lambda_{k,n}^{(i)} q_n}{N_0} \right) \\ &= \arg \min_k \prod_{i=1}^{M_{k,n}} \lambda_{k,n}^{(i)} \text{ when } M_{1,n} = \dots = M_{k,n} = M \quad (3) \end{aligned}$$

Where $\arg \min_k \prod_{i=1}^{M_{k,n}} \lambda_{k,n}^{(i)}$ is named as product-criterion which tends to be more accurate when the SNR is high. On the other hand, in small SNR region, i.e. $\lambda_{k,n}^{(i)} q_n / N_0 \ll 1$, using $\log(1+x) = x$, we get

$$\begin{aligned} & \arg \min_k \sum_{i=1}^{M_{k,n}} \log \left(1 + \frac{\lambda_{k,n}^{(i)} q_n}{N_0} \right) \\ &\approx \arg \min_k \sum_{i=1}^{M_{k,n}} \left(\frac{\lambda_{k,n}^{(i)} q_n}{N_0} \right) \\ &= \arg \min_k \sum_{i=1}^{M_{k,n}} \left(\sum_{i=1}^{M_{k,n}} \lambda_{k,n}^{(i)} \right) \frac{q_n}{N_0} \\ &= \arg \min_k \sum_{i=1}^{M_{k,n}} \lambda_{k,n}^{(i)} \quad (4) \end{aligned}$$

Where $\arg \max_k \sum_{i=1}^{M_{k,n}} \lambda_{k,n}^{(i)}$ is named as sum-criterion which is more accurate when the SNR is low. These two approximations will be used in the suboptimal algorithm for the high SNR and low SNR cases, respectively. In this way, we can reduce the complexity significantly with minimal performance degradation.

The steps of the proposed suboptimal algorithm are as follows:

- Step 1 Assign the subcarriers to the users in a way that maximizes the overall system capacity;
- Step 2 Assign the total power to the allocated subcarriers using the multi-dimension water-filling algorithm.

A. Step 1—Subcarrier Assignment

For a given power allocation vector $q = (q_1, q_2, \dots, q_n)$ for each subcarrier, RA optimization problem of (1) is separable with respect to each subcarrier. The subcarrier problem with respect to subcarrier is

$$\text{MaxR}(n) = \sum_{k=1}^K P_{k,n} \left(\sum_{i=1}^{M_{k,n}} \log \left(1 + \frac{\lambda_{k,n}^{(i)} q_n}{N_0} \right) \right)$$

Subject to: $\max_k \{q_{k,n}\} \leq q_n$

$$P_{k,n} = \{0,1\} \text{ for all } k,n \quad (5)$$

Then the multicast subcarrier allocation algorithm based on (3) for each subcarrier is given as follows.

- 1) For the t th subcarrier, calculate the current total data rate when the t th user is selected as the user who has lowest eigenvalue product

$$R(n) = N_{k,n} \sum_{i=1}^{M_{k,n}} \log \left(1 + \frac{\lambda_{k,n}^{(i)} q_n}{N_0} \right) \quad (6)$$

- 2) For the n th subcarrier, select the user index k_n which can maximize

$$K_n = \arg \max_k R(n) \quad (7)$$

Then we have

(8)

For the low SNR case, the product-criterion (3) is changed into the sum-criterion (4) for this step's subcarrier allocation.

B. Step 2 Power Allocation

The subcarrier algorithm in step 1 is not optimum because equal power distribution for the subcarriers is assumed. In this step, we propose an efficient power allocation algorithm based on the subcarrier allocation in step 2. Corresponding to each subcarrier, there may be several users to share it for the multicast service. In this case, the lowest user's channel gain on that subcarrier among the selected users in step 1 will be used for the power allocation. The multi-dimension water-filling method is applied to find the optimal power allocation as follows. The power distribution over subcarriers is

$$q_{*n} = \max(0, q_n)$$

where q_n means the power assigned to each antenna of subcarrier n and it is the root of the following equation,

$$\dots = 0, n = 1, 2, \dots, N, \quad (9)$$

where K_n is the allocated user index on subcarrier α ; λ is the water-filling level which satisfies $\sum_{n=1}^N M_{k_n, n} q_n^* = Q$ where Q and N are the total power and the number of subcarriers, respectively.

In case of $T = R = 1$, that is, a single antenna system, the optimal power distribution for the subcarriers is transformed into the standard water-filling solution:

$$\dots \quad (10)$$

Where $(x)^+ = \max(0, x)$ and $\lambda_{kn}^{(1)}$ is the same as $H_{kn}^{(1)}$ for a single antenna. The multi-dimension water-filling algorithm is an iterative method, by which we can find the optimal power distribution to realize the maximum of system capacity.

IV. SIMULATION RESULTS

In this section, simulation results are presented to demonstrate the performance of the proposed algorithm. The simulation parameters of the proposed system are given in

Table I.
The Simulation Parameters for the MIMO-OFDM Systems.

Number of subcarriers	64
Number of transmitter antenna	2
Number of receive antenna	2
Number of users	4
Bandwidth	1 MHz
Max. transmit power	1W
AWGN PSD	-100dBW/Hz - -80 dBW/Hz
BER	1e-3
Number of multipaths	6

wireless channel is modeled as a frequency selective channel consisting of six independent Rayleigh multipaths. Each multipath component is modeled by Clarke's flat fading model. The number of users is 4 and the number of antennas is $T = R = 2$. Each couple of transmit antenna and receive antenna is assumed to be independent to the other couples. Total transmit power is 1 W and AWGN power spectral density varies from 85 dBW/Hz to 60 dBW/Hz. The total bandwidth B is 1 MHz, which is divided into 64 subcarriers. The capacities in the following figures are averaged over 10000 channel realizations.

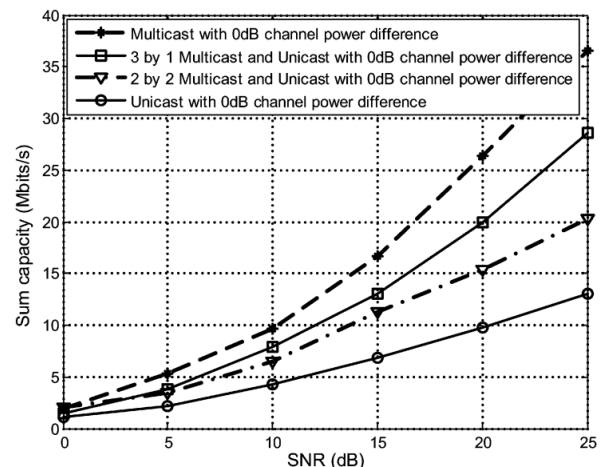


Fig. 3. Sum capacity comparison of multicast and unicast systems.

A. Comparison of Multicast and Unicast Systems:

In Fig. 3, the sum capacities of multicast and unicast schemes are shown for multiple antenna OFDM systems. Here it is supposed that there is no channel power difference between the users. In the multicast system, it is supposed that 4 users receive the same contents, while in the unicast system the contents of users are different from each other. 3 by 1 multicast and unicast system means that 3 users receive the same contents as one group and the left one user receives different content. And 2 by 2 multicast and unicast system means that 2 users receive the same contents as one group and the left two users are unicast users. It is noticed that the multicast scheme with the proposed method can achieve higher capacity than the unicast scheme or the mixed cases. The more multicast users exist, the higher system capacities can be achieved. For the Fairness of comparison, on each subcarrier the user with the

highest eigenvalue product is selected to use it in the unicast system.

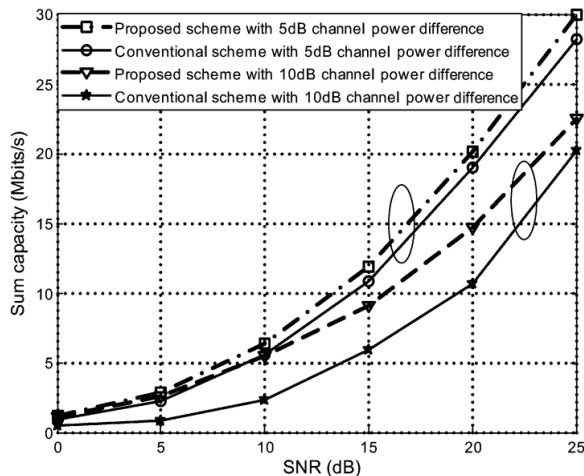


Fig. 4. Sum capacity comparison of proposed scheme and conventional one in multicast system when the SNR is high.

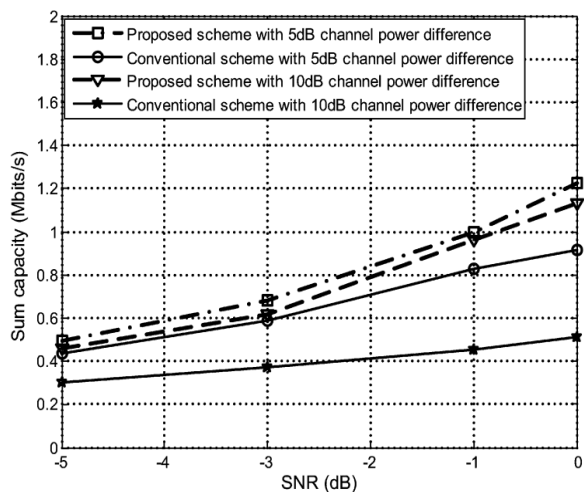


Fig. 5. Sum capacity comparison of proposed scheme and conventional one in multicast system when the SNR is low.

B. Comparison of Proposed Scheme and Conventional One

In this subsection, the sum capacities of the proposed scheme and conventional scheme for the multicast system are shown in Figs. 4 and 5 for the high SNR and low SNR cases, respectively. It is supposed that 4 users receive the same contents and there is 5 dB or 10 dB average channel power difference between the users. In the conventional scheme, on each subcarrier the user with the lowest eigenvalue product is selected as the baseline to transmit the information. From both Figs. 4 and 5, it is noticed that the proposed method can achieve higher capacity than the conventional one. The more average channel power difference between the users, the larger gains can be obtained. This means that the proposed adaptive subcarrier and power allocation algorithm is more effective in the presence of higher channel or link difference. This is because the drawback of the conventional scheme is more evident in the case of higher channel or link difference.

V. CONCLUSION

This paper presented a new method to solve the subcarrier and power allocation problem for multi-user MIMO-OFDM based multicast system. The optimization problem was formulated to maximize the system capacity with a total transmit power constraint. Due to the complexity of optimal algorithm, two step suboptimal algorithm was proposed. The proposed subcarrier allocation algorithm determined the number of users for each subcarrier based on the maximization criteria, in which the capacity of each subcarrier can be maximized. Then the proposed power allocation scheme adopted multi-dimension water-filling method in order to maximize the system capacity. Simulation results showed that the system capacity of the proposed scheme is significantly improved as compared with the conventional one.

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