Improvement in QoS for MIMO OFDM Multicast Systems

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ABSTRACT

Adaptive resource allocation in the next generation wireless systems is a key technique that can significantly improve the performance with guaranteed QoS to users. Moreover, most of the current resource allocation algorithms are limited to unicast systems. In this paper, adaptive resource allocation is studied for multiple antenna OFDMA based systems which provide multicast services. The optimal resource allocation solution is proposed with low complexity algorithms. The numerical result is shown that the performance of our proposed algorithm improve the system capacity significantly compared with existing one.

Key words: MIMO, OFDMA, Water-filling Algorithm, BER

1. 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. 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. 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. Orthogonal Frequency Division Multiple Access (OFDMA) is a multiuser version of the popular scheme and it is also referred as multiuser OFDM.

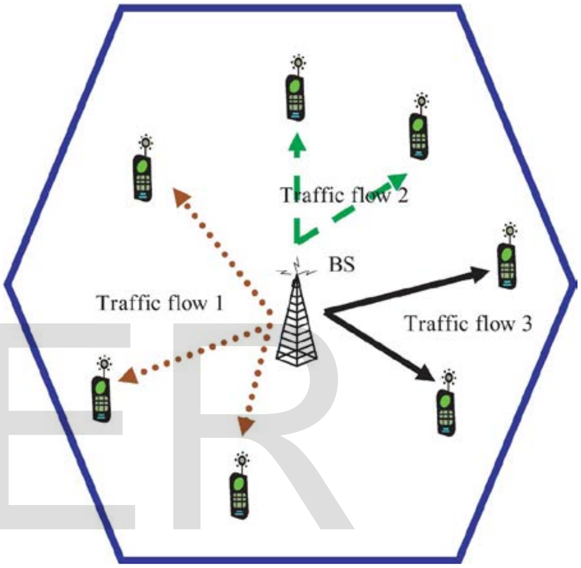

Fig. 1. Cellular structure of multicast transmission system.

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. 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 and it is divided into two types of optimization problems: 1) to maximize the system throughput with the total transmission power constraint and 2) to minimize the overall transmit power with constraints on data rates or Bit Error Rates (BER). multiuser OFDM systems.

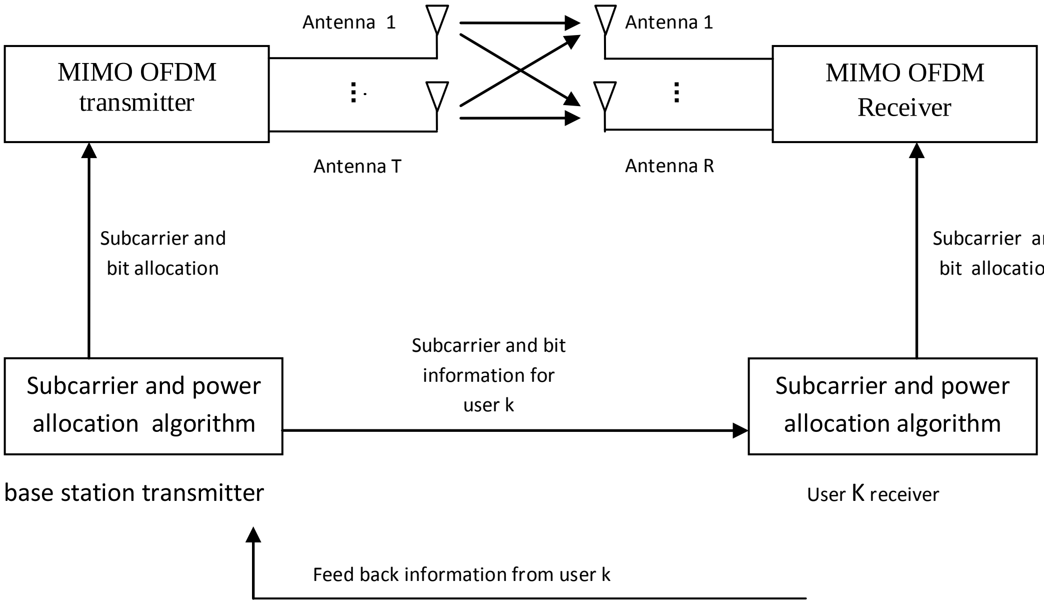

Fig.2 Block diagram of multiple antenna OFDM

To the best of our knowledge, most dynamic resource allocation algorithms, however, only consider unicast 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. 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.

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.

2. SYSTEM MODEL

The block diagram of multiuser MIMO-OFDM downlink system model is shown in Fig. 2. It shows that in the base station 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 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:

$$\max C = \frac{1}{N}\sum_{n=1}^{N} \rho_{k,n}\Big(\sum_{I=1}^{M_{K,N}} \log\big(1+\frac{\lambda^{i}_{k,n}q_{k,n}}{N_o}\big)\Big) \quad (1)$$

$$\text{Subjected to} \quad \sum_{N=1}^{N} \max(q_{k.n}) \leq Q$$

$$q_{k,n} \geq 0 \quad \text{for all k, n}$$

$$\rho_{k,n} = \{0,1\} \qquad \text{for all k, n}$$

Where C is the system sum capacity and the above assumptions; Q is the total available power; $q_{k,n}$ is the power assigned to user $\mathcal{K}$ in the subcarrier n ; can only be the value of 1 or 0 indicating whether subcarrier n is used by user $\mathcal{K}$ or not. $M_{k,n}$ is the rank of $H_{k,n}$ which denotes the MIMO channel gain matrix (R x T) on subcarrier n for user $\mathcal{K}$ and $\{\lambda^{(i)}_{k,n}\}_{i=1:M\,k,n}$ are eigen values of $H_{k,n}H^{+}_{k,n}$; k_n is the allocated is the allocated user index on subcarrier ; N_o 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 that a single carrier is assigned to a single user for all subcarriers , 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 , denoted as R_n , is defined as

$$R_n = \frac{1}{N}\sum_{k=1}^{K}\sum_{n=1}^{N} \rho_{k,n}\Big(\sum_{I=1}^{M_{K,N}} \log\big(1+\frac{\lambda^{i}_{k,n}q_{k,n}}{N_o}\big)\Big) \quad \ldots(2)$$

3. 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 sub-optimality 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., $\lambda^{(i)}_{k,n}q_n/N_o>>1$, we get the following approximation:

$$\arg_k \min \sum_{I=1}^{M_{K,N}} \log(1+\frac{\lambda^i_{k,n}q_{k,n}}{N_o})$$

$$= \arg_k \min \prod_{i=1}^{M_{k,n}} \log(1+\frac{\lambda^i{}_{k,n}q_n}{N_o})$$

$$= \arg_k \min \prod_{i=1}^{M_{k,n}} \frac{\lambda^i{}_{k,n}q_n}{N_o}$$

$$= \arg\min \prod_{i=1}^{M_{k,n}} \lambda^i_{k,n} \text{ when } M_{1,n}=\ldots=M_{k,n}=M \qquad (3)$$

Where $\prod_{i=1}^{M} \lambda^i_{k,n}$ is named as product-criterion which tends to be more accurate when the SNR is high.

In small SNR region

$$\arg_k \min \sum_{I=1}^{M_{K,N}} \log(1+\frac{\lambda^i_{k,n}q_{k,n}}{N_o})$$

$$= \arg_k \min (\sum_{i=1}^{M_{k,n}} \log(\frac{\lambda^i{}_{K,N}q_{k,n}}{N_o})$$

$$= \arg_k \min \sum_{i=1}^{M_{k,n}} \lambda^i_{k,n} \qquad (4)$$

where $\mathrm{argmax}_k \sum_{i=1}^{M_{k,n}} \lambda^i_{k,n}$ 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 $q=(q_1,q_2\ldots q_n)$ for each subcarrier, RA optimization problem of (1) is separable with respect to each subcarrier. The subcarrier problem with respect to subcarrier n is

$$\max R(n) = \sum_{k=1}^{K} \sum_{n=1}^{N} \rho_{k,n} (\sum_{I=1}^{M_{K,N}} \log(1+\frac{\lambda^i_{k,n}q_{k,n}}{N_o}))$$

Subjected to: $\max(q_{k,n}) > q_n$

$$\rho_{k,n} = \{0.1\} \text{ for all k, n} \qquad (5)$$

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

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

$$R(n) = \sum_{I=1}^{M_{K,N}} \log(1+\frac{\lambda^i_{k,n}q_{k,n}}{N_o}) \qquad (6)$$

2) For the th subcarrier, select the user index K_n which can maximize

$$k_n = \arg_k \max(R(n)) \qquad (7)$$

Then we have

$$\rho_{k,n} = \begin{cases} 1 & \\ & \text{for } \prod_{i=1}^{M_{k,n}} \lambda^i_k > \prod_{i=1}^{M_{k,n}} \lambda^i_{k_n} \\ 0 & \end{cases} \qquad (8)$$

For the low SNR case, the product-criterion is changed into the sum-criterion 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,

$$\sum_{i=1}^{M_{k_n,n}} \frac{\lambda_{k_n,n}^{(i)}}{\lambda_{k_n,n}^{(i)} q_n + N_o} + \alpha = 0,\ \ n=1,2,\ldots..N, \qquad (9)$$

If T=1 ,R=1 then the optimal power allocation algorithms transform into standard water filling algorithm. 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.

4. SIMULATION RESULTS

In this section the performance of the MIMO-OFDM based multicast system has been analyzed over a slowly varying rayleigh fading channel .The assumptions used in this analysis are shown in the Table.1

Number of subcarriers	64
Number of transmitting antennas	2
Number of receiving antennas	2
Number of user	4
Bandwidth	1MHZ
BER	1e-3

Table 1 Parameters Used To Calculate Capacity

Using equations 1 and 2, the capacity of the MIMO OFDM system with subcarrier allocation algorithm has been calculated. The channel coefficients are regarded as constants during the subcarrier allocation and power loading period due to slowly fading Rayleigh channel. From the graphs it is observed that as the number of transmitting and receiving antennas increases the capacity increases due to diversity In figure 3 the capacity versus average SNR graph is shown for different antennas for a MIMO system. It is inferred that the capacity of MIMO system can be increased as the number of antennas increased.

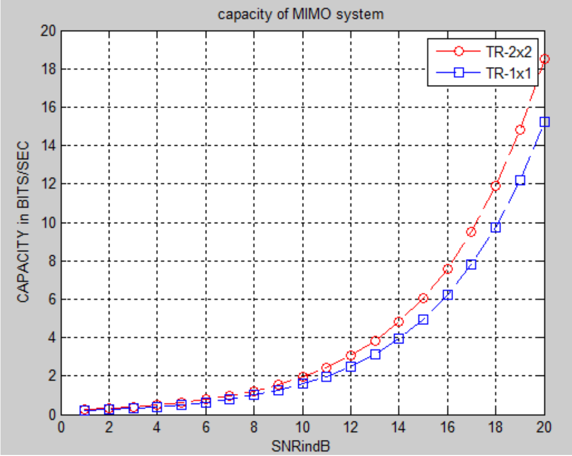

Fig.3 Capacity of MIMO system

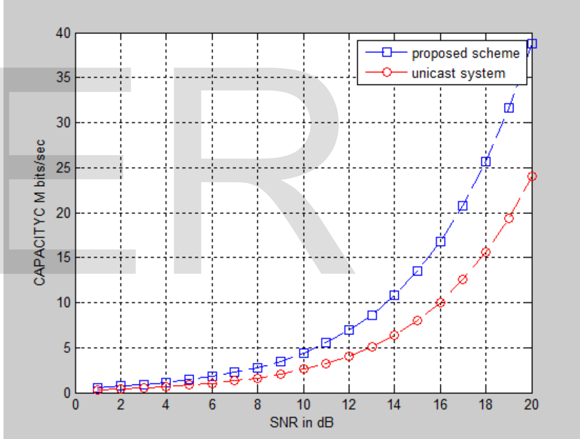

FIG.4 Capacity of Multicast system

In figure 4 the capacity versus average SNR of MIMO-OFDM is shown for the unicast and multicast systems. In both the systems two antennas at receiver and the transmitter are used. It is inferred that the capacity of the multicast system is more compared to the unicast systems for the same values of SNR. Multicast systems shows a better capacity at low SNR values.

5. 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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