Efficient and Fair Resource Sharing Algorithm for Multi-user MIMO-OFDM Systems

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Abstract— **In this paper, an efficient and fair algorithm for resource management in MIMO-OFDM systems is proposed. The system used for this analysis is the downlink of multi-user MIMO-OFDM system. Based on channel state information (CSI), the base station (BS) employs singular value decomposition (SVD) to transmit the MIMO channel into parallel subchannels for each subcarrier, and then subcarriers, are allocated according to a variance based algorithm. The proposed scheme is used to enhance the system capacity while satisfying the proportional fairness constraint. A selection of numerical results is presented to illustrate the performance of the proposed algorithm.**

Index Terms— **MIMO-OFDM, SVD, resource management, fairness.**

I. Introduction

MIMO-OFDM has recently been the subject of much interest because of its potential for meeting the stringent requirements of the next-generation broadband wireless communication systems.

Multiple Input Multiple Output (MIMO) systems can achieve significant increases in the system's capacity, bandwidth efficiency and result in a Quality of Service (QoS) improvement in the wireless environment [1] [2].

Over a multipath and frequency selective fading channel. Orthogonal Frequency Division Multiplexing (OFDM) is a very attractive solution for efficiently eliminating the detrimental effects of multipath delay spread [3].

Resource allocation in MIMO-OFDM systems has also been receiving increasing interest. An Optimizing power and resource Management for multi-user MIMO-OFDM systems is proposed in [4]. In this paper an adaptive multi-user resource allocation algorithm for MIMO-OFDM systems that involve adaptive multiple-access control, adaptive modulation, and power control is presented. The objective was to optimize the power efficiency while ensuring the fulfillment of each user's QoS requirements including the bit rate and BER (Bit error rate). The problem of finding a set of users most suitable for each subcarrier is solved in [5] by a resource scheduling algorithm for the downlink of MIMO-OFDMA systems using the well-known row pivoting method from computational linear algebra. In [6], a user selection algorithm for space division multiple access (SDMA) beamforming with imperfect CSI is proposed in MIMO-OFDM systems.

In this study we provide an algorithm for subcarriers of transmit antennas selection that maximizes the system throughput while providing Quality of Service (QoS) requirements. The scheduling schemes have to share the available subcarriers of a MIMO-OFDM system among competing streams of the system traffic.The scheduler in the BS uses the available channel state information (CSI) obtained via a feedback dedicated channel to allocate the subcarriers of transmit antennas to users selected from a maximization procedure of a predefined system utility function. Then, the goal of the packet scheduler can be specified to maximize the sum system performance. To optimize the resources'use under the requirements of the QoS, each spatial subchannel, equivalent to each subcarrier, can be assigned to the user that owns the best channel and verifies fairness criteria. If the user experiences a variance of his subchannel gains lower than a predefined variance threshold, he would be selected for receiving packets if he owns the min average throughput compared to other users in the same conditions. The selected user would combine a good channel condition and a low user performance. If the user has a variance of his subchannel gains greater than the variance threshold, he would be selected, if he has the max average throughput compared to other users in the same case. The user is allowed to select his best subcarrier on his best channel. Accordingly, the proposed algorithm can be seen as the opportunistic scheduling algorithm under adaptive weak control of the QoS requirements.

The remainder of the paper is organized as follows. A background is given in section II. The system model is introduced in section III. Our proposed scheduling algorithm is proposed in section VI. In section V, the system throughput according to this algorithm is analyzed by numerical simulations.

II. Background

In MIMO-OFDM systems, most of the existing algorithms of resource allocation have not taken user's QoS requirement into account. So they can not utilize the spatial resources efficiently or provide good services to users. In [7] a resource allocation algorithm for multi-user MIMO-OFDMA with precoding is proposed. This scheme can greatly reduce the amount of feedback information. An adaptive grouping approach based on the criterion of maximizing the total throughput is adopted in this study in order to keep the performance gain of MIMO precoding and

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remove the effect of feedback reduction. For this scheme fairness among users as a QoS requirement was not taken into account. Other algorithms for resource management in MIMO-OFDM systems have been provided to reach a compromise between throughput and QoS requirements. In [8] an adaptive spatial subchannel allocation algorithm for multi-user MIMO-OFDM systems is proposed. This scheme takes into account a concern of maximizing the overall data throughput of the system, while guaranteeing prescribed error performance, under the constraint of fixed transmit-power. However, in this work QoS requirements were not taken into consideration.

In this paper, we provide a variance based algorithm for subcarriers assignment to active users for a single cell MIMO-OFDM system. For users experiencing high variance, the user who has the max average throughput is allowed to select his best subcarrier on his best channel. As well we provide a solution that alleviates the condition on the fairness to increase the system sum rate. For users experiencing variances lower than the predefined threshold, the user with min QoS performance, i.e. the user with min average throughput compared to other users in the same conditions, is selected as most favorable candidate. The switching between the two groups of users is obtained according to a logical function indicating the group of the user which has critical performance. In this paper, the minimum average throughput is used to define the logical function. The main goal is to achieve high system throughput while providing fairness among users adaptively to the critical user performance.

III. SYSTEM MODEL

Here we investigate a multi-user MIMO-OFDM system with Nc subcarriers and K users. The BS has M_t transmit antennas and each user has M_r receive antennas. Let $H_{k,n}$ represents the $M_r \times M_t$ channel frequency response matrix of the kth user on the nth subcarrier, and the matrix's element , $[H_{k,n}]_{i,j}$ represents the channel frequency response from the jth transmit antenna to the ith receive antenna. The rank of $H_{k,n}$ is denoted by L and $L = rank(H_{k,n}) = min(M_t, M_r)$. The BS executes SVD to users' feedback channel information $H_{k,n}$:

$$H_{k,n} = U_{k,n} S_{k,n} (V_{k,n})^H = \sum_{l=1}^{L} u_{k,n}^l s_{k,n}^l (v_{k,n}^l)^H \quad (1)$$

where $u_{k,n}^l$ and $v_{k,n}^l$ are the left and right singular vectors, with $s_{k,n}^l$ denoting the singular values that are arranged in descending order. Denote the transmitting beamforming vector and receiving weight vector for the lth spatial subchannel of the nth subcarrier as Wt_n^l and Wr_n^l respectively. Then, $Wt_n^l = v_{k,n}^l$, $Wr_n^l = u_{k,n}^l$, $k \in 1, 2, \ldots K$, and each subcarrier can be divided into L parallel spatial subchannels with gain $(s_{l,n})^2$ and transmit power $P_{l,n}$ on the lth spatial subchannel.The signal to noise ratio (SNR) on the lth subchannel of the nth subcarrier can be express as:

$$SNR_{l,n} = \frac{P_{l,n}(s_{l,n})^2}{N_0 B / Nc} \quad (2)$$

where N_0 is the power spectrum density of the noise, *B* is the channel bandwidth, and N_c is the subcarrier number of the system.

According to the $SNR_{l,n}$ of each subchannel, the number of assigned bits can be decided by:

$$b_{l,n} = \lfloor \log 2(1 + SNR_{l,n}/\Gamma) \rfloor \quad (3)$$

Where $\lfloor x \rfloor$ denotes the floor function that takes the maximum integer less than or equal to x. Γ represents the SNR gap, and if M-ary quadrature amplitude modulation (MQAM) is employed, Γ is written as:

$$\Gamma = \frac{-\ln(5 * BER_{target})}{1.5} \quad (4)$$

where BER_{target} is the required Bit Error Rate (BER).

Then, the total number of bits that can be transmitted on the nth subcarrier is:

$$R_n = \sum_{l=1}^{L} b_{l,n} \quad (5)$$

IV. PROPOSED ALGORITHM

A. User and system utility functions

The resource allocation, in wireless systems, is mathematically formulated by an optimization problem. The scheduler processes this optimization at each time slot to maximize the system throughput under the QoS requirements. Each user, is represented by a utility function that depends, generally, on the average transmissible rate. The scheduling scheme would resolve at each transmission period the maximization of the system utility function that is chosen to be a concave function. This function expresses the user satisfaction in terms of average rate QoS requirements.

At each time slot, each user is assigned a utility function $U_k(w_k)$. Where, w_k can be the average rate $(w_k = R_k)$ or the latency $(w_k = D_k)$ of the user k. The user latency is defined as the number of time slots between two successive channel accesses.

At a given time slot, the instantaneous feasible transmission rates of the K active users on the nth subchannel is:

$$\vec{r_n} = (r_{1n}, r_{2n}, \ldots, r_{Kn}) \quad (6)$$

Let's define *Q* to be the policy used for scheduling users identified by theirs *id* in the set $Iu = 1, 2, \ldots, K$. The policy *Q* gives us users which are allowed to receive their packets. The scheduled users have their *id* in a subset of *Iu* denoted *Q(Iu)*. The cardinal (number of elements) of the subset *Q(Iu)* is less or equal to the number of the BS transmit antennas subcarriers. Each spatial subchannel is allocated to the user that maximizes the system performance. According to the policy *Q*, the system receives the performance,

$$U_Q = \sum_{k \in Q(Iu)} U_k(w_k(t), r_k(t)) \quad (7)$$

Our goal is to find a scheduling policy Q that maximizes the average system performance, which would be defined as the time expectation of U_Q:

$$\overline{U_Q} = E(U_Q) \quad (8)$$

The optimal scheduling policy would be then,

$$\max_{Q} \overline{U_Q} \quad (9)$$

Two trivial optimal scheduling policies are solution of (9): the opportunistic and the round robin policies. The opportunistic policy is optimal if only the system performance is the average sum rate. The scheduler in this case has to resolve at each time slot:

$$\max_{k} \nabla U(W)^H \vec{r} \quad (10)$$

where $U(k) = U_k(w_k) = \kappa R_k$, ∇U is the gradient of U, and κ is a positive constant. This is equivalent to allocate the considered resource to the user according to:

$$\arg\max_{k} r_k \quad (11)$$

The round robin policy is optimal if the fairness in channel access is considered, independently of other parameters. Accordingly, the optimization is obtained as follows at each time slot:

$$\max_{k} \nabla U(W)^H 1_K = \max_{k} D_k \quad (12)$$

where $U_k(w_k) = \kappa D_k^{1+\alpha}$ and 1_K is a vector of K elements equal to 1, and α is a real positive constant.

If we combine the advantages of these scheduling policies, we can construct a scheduling algorithm that provides high system throughput while taking into account the requirements of the fairness. Accordingly, in this paper we provide a scheduling algorithm that takes advantage of the two trivial scheduling policies solution of (9). In the following, we describe the proposed scheduling algorithm.

B. Scheduling algorithm

In this section, the proposed subcarrier allocation algorithm scheme is presented. The BS classifies users into two groups. G_1={users owing variance greater than a predefined threshold g_{th}} and G_2={the remainder users}.

In order to guarantee user's QoS, in each slot BS schedules users in G_1 according to max average throughput since they experience bad channel condition. This is equivalent to : if G_1 is considered for scheduling, a user of this group that experiences max average throughput is allowed to select his best subcarrier on his best channel. For users in G_2 BS uses a random selection since they experience low variance, then, any user from this group would have good channel conditions.

The switching between G_1 and G_2 is defined by a logical switching function SF: "the user with the minimum average rate is in G_1". If SF = True, the scheduler selects a user from G_1 according to policy defined by (11), else the selected user would be a member of G_2 and according to equation (12). As mentioned above, the considered QoS requirement is minimum average rate guarantee, thus, the selection of a user from G_2 would be modified to be: the user that has the min average rate compared to users in G_2, would be selected to receive packets on the considered subchannel.

Introduce Boolean variable $C_{k,n}$ with values 1 or 0, to denote whether the nth subcarrier is assigned to the kth user or not, since we do not allow more than one user to share an OFDM subcarrier, $C_{k,n}$ must satisfy $\sum_{k=1}^{K} C_{k,n} = 1$. The total data rate of user k can be written as :

$$\sum_{n=1}^{Nc} C_{k,n} R_{k,n} = \sum_{n=1}^{Nc} \sum_{l=1}^{L} C_{k,n} (b_{l,n})_k \quad (13)$$

where $R_{k,n}$ is the support rate on the nth subcarrier and $(b_{l,n})_k$ is the number of assigned bits on the l_{th} subchannel of subcarrier n.

The total power of the base station P_{total} is uniformly distributed on every subchannel of every subcarrier, i.e. the power on each subcarrier is $P_n = P_{total}/Nc$, and the power of each subchannel is $P_{l,n} = P_{total}/Nc/L$.

Our proposed subcarrier allocation algorithm is executed by the following steps and its flow chart is shown in Fig.1.

For each spatial subchannel do

1) Sort users is descending order of their variance
2) Define users of groups $G_1$and G_2
3) Process switching parameters: $id_{min} = \arg\min_{k \in Iu} R_k$ where R_k is the average throughput of user k.
4) If Switching function "SF=True", Group of users or scheduling: $S = G_1$ goto Step 5, else user's Group for scheduling: $S = G_2$, goto step 6.
5) Select a user to receive data identified by: $k_s = argmax_{k \in S} R_k$
6) Select a user for channel access identified by $n_s = id_{min}$
7) End

V. Simulation results

In this section simulation results are analyzed to show the performance of the proposed algorithm compared to the switched opportunistic scheduling algorithm (SOSA) [9]. The system considered for simulation is the downlink of a single cell that serves K mobile users. The presented results are obtained by processing the system average throughput vs. the number of active users.

Figure 2 shows the comparison of the throughput between the two algorithms. It can be observed in this situation that the throughput of the proposed scheme is higher than SOSA algorithm and the performance gap becomes larger as the number of active users increases.

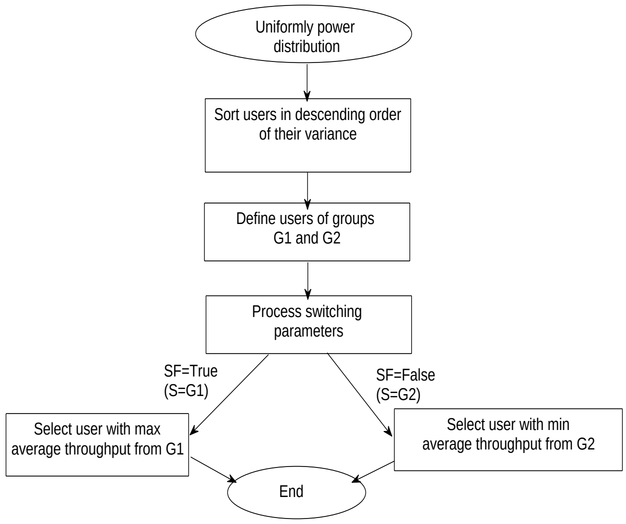

Figure 1. *Flow chart of the allocation algorithm*

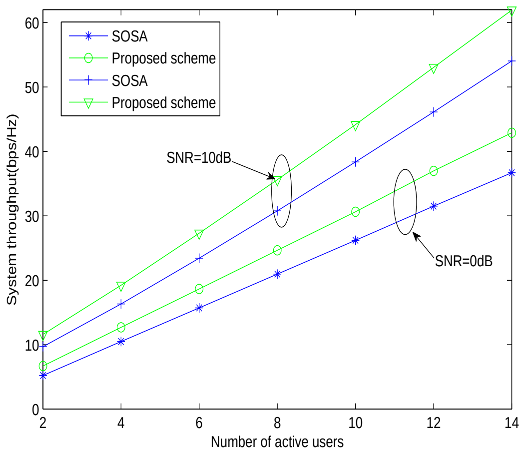

Figure 2. *Throughput versus the number of active users*

For SNR=0dB, the throughput of the proposed scheme is the highest. Which shows it performs well under low SNR

To measure the fairness degree as a QoS requirement, the Jain's fair index [10] is used as a metric for the fairness comparison of users' average throughputs (R_k). This index is given as follows,

$$JF(K) = \frac{\left(\sum_{k=1}^{K} R_k\right)^2}{K\sum_{k=1}^{N} {R_k}^2} \quad (14)$$

Figure 3 shows the fairness degree of the throughput in the cases of SOSA scheme and the proposed algorithm. We can conclude that both schemes provide quasi optimal (~ 1) fair degree. However the proposed algorithm outperforms the SOSA scheme.

VI. Conclusion

In this paper, a new resource allocation scheme is proposed for multi-user MIMO-OFDM systems. Based on channel state information (CSI), the base station (BS)

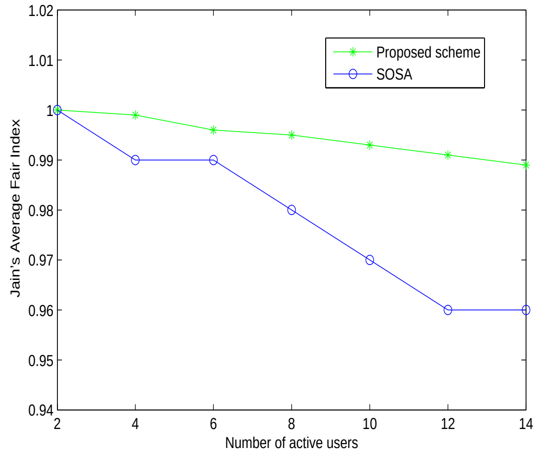

Figure 3. *Jain's average fair index*

employs singular value decomposition (SVD) to transmit the MIMO channel into parallel subchannels for each subcarrier, and then subcarriers, are allocated according to a variance based algorithm. We propose to achieve high system throughput while providing fairness among users adaptively to the critical user performance. Compared to the SOSA scheme, the proposed algorithm achieves a better performance

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