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...
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 Mt transmit
antennas and each user has Mr receive antennas. Let Hk,n represents the Mt × Mr channel frequency
response matrix of the kth user on the nth subcarrier, and
the matrix’s element, Hk,n[i,j] represents the channel frequency response from the jth transmit antenna to the
ith receive antenna. The rank of Hk,n is denoted by L
and L = rank(Hk,n) = min(Mr,Mt). The BS executes
SVD to users’ feedback channel information Hk,n:

\[ H_{k,n} = U_{k,n}S_{k,n}(V_{k,n})^H = \sum_{l=1}^{L} u^l_{k,n}s^l_{k,n}(v^l_{k,n})^H \]  

(1)

where \( u^l_{k,n} \) and \( v^l_{k,n} \) are the left and right singular vectors, with \( s^l_{k,n} \) 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 Wl,n and
Wl,n^H respectively. Then, Wl,n = v^l_{k,n}, Wl,n^H = u^l_{k,n},
k ∈ 1, 2, ..., 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:

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

(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:

\[ b_{l,n} = \lfloor \log 2(1 + SNR_{l,n}/\Gamma) \rfloor \]  

(3)

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

\[ \Gamma = -\ln(5*BERR_{target})/1.5 \]  

(4)

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

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

\[ R_n = \sum_{l=1}^{L} b_{l,n} \]  

(5)

IV. PROPOSED ALGORITHM

A. User and system utility functions

The resource allocation, in wireless systems, is mathematically formulated by an optimization problem. The
distributor processes this optimization at each time slot to
maximize the system throughput under the QoS require-
ments. 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 access.

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

\[ r_n = (r_{1n}, r_{2n}, ..., r_{Kn}) \]  

(6)

Let’s define \( Q \) to be the policy used for scheduling
users identified by theirs id in the set \( I_u = \{1, 2, ..., K\} \).
The policy \( Q \) gives us users which are allowed to receive
their packets. The scheduled users have their id in a
subset of \( I_u \) denoted \( Q(I_u) \). The cardinal (number of
elements) of the subset \( Q(I_u) \) 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,

\[ U_Q = \sum_{k \in Q(I_u)} U_k(w_k(t), r_k(t)) \]  

(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 \( U_Q \):

\[
U_Q = E(U_Q)
\]  

(8)

The optimal scheduling policy would be then,

\[
\max_Q U_Q
\]  

(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:

\[
\max_k \nabla U(W)^H\Gamma
\]  

(10)

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

\[
\arg \max_k r_k
\]  

(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:

\[
\max_k \nabla U(W)^H 1_K = \max_k D_k
\]  

(12)

where \( U_k(w_k) = \kappa D_k^{\alpha + 1} \) and \( 1_K \) is a vector of \( K \) elements equal to 1, and \( \alpha \) 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. \( G_1=\{ \text{users owing variance greater than a predefined threshold } g_{th} \} \) and \( G_2=\{ \text{the remainder users} \} \).

In order to guarantee user’s QoS, in each slot BS schedules users in \( G_1 \) according to maximum 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 maximum 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: the user that has the minimum 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 subcarrier \( b_{l,n} \) of subcarrier \( n \) is assigned to the \( k \)th 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 :

\[
\sum_{n=1}^{N_c} C_{k,n} R_{k,n} = \sum_{n=1}^{N_c} \sum_{l=1}^{L} C_{k,n}(b_{l,n})_k
\]  

(13)

where \( R_{k,n} \) is the support rate on the subcarrier \( b_{l,n} \) is the number of assigned bits on the \( l \)th subcarrier 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 \( P_n = P_{total}/N_c \), and the power of each subchannel is \( P_{n} = P_{total}/N_c/L \).

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: \( id_{min} = \arg \min_{k \in G_1} R_k \) 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: \( k_s = \arg \max_{k \in \mathcal{G}_s} R_k \)
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.
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,

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

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) 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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