Fair Resource Allocation for Multiuser MIMO Communications Network

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Abstract—This paper studies the fairness optimization of dynamic multiuser multicarrier allocation in the cellular downlink of MIMO orthogonal frequency division multiple access (OFDMA) systems. The varying capacity demands of different users motivate the fairness problem. In the resource allocation approaches that maximizing the sum rate or minimizing the total power often leads to poor fairness among users. The allocation is prone to starvation situation for the users with deep fading subchannels. Hence, this work considers the fairness issue and proposes to maximize the minimum rate surplus, where the rate surplus is defined as the difference between the demand data rate and the resulting allocated data rate. The fairness is inverse proportional to the gap of the maximum rate surplus to the minimum rate surplus among all users. In this work, the design of the precoding and decoding matrices for the MIMO structure is also developed. To solve the optimization problem, an iterative algorithm is proposed to optimize the subcarrier assignment with low complexity. Simulation results on multiuser MIMO environment show that the proposed algorithm strikes the balance between sum rate and fairness. Comparing with the state-of-the-art works, the proposed algorithm shows an advantage in keeping the sum rate while the fairness is significantly improved.

Index Terms—Resource allocation, fairness, power allocation, multiuser diversity, wireless broadcasting, multi-carrier communications.

I. INTRODUCTION

The orthogonal frequency division multiple access (OFDMA) is broadly used in the present and next generation wireless communication systems. The OFDMA is not only preferred in several current communication systems, but is also a strong candidate for many next generation cellular standards. The latest generation cellular system, i.e. IMT-Advanced (IMT-A), has to meet the high spectral efficiency requirements set by the ITU-R [1]. The wireless standards, such as 3GPP-LTE [2], or LTE-Advanced (LTE-A) [4], have envisioned OFDMA-based technology due to the robustness to frequency selective fading channels and the flexibility to radio resource allocation. The 3GPP-LTE employs OFDMA in the downlink (DL) and DFT-Spread-OFDM, i.e. single-carrier frequency division multiple access (FDMA), in the uplink (UL). Due to the characteristics of independent channel fading under the multiuser OFDMA systems, many dynamic resource allocation schemes have been developed. As different devices (or users) may have quite different data rate demands, a fairness issue of the resource allocation based on specific requirement is raised.

The resource allocation optimization formulations in the literatures can be categorized into two classes. One is rate adaptive approach [5], and the other is margin adaptive approach [6]. The rate adaptive methods aim to maximize the sum rate of users in the system subject to the transmit power, whereas the margin adaptive methods aim to minimize the sum transmit power with constraint on the minimum transmit rate for each user. The common idea of solutions to these methods is to allocate the subchannel (i.e. subcarrier) and the transmit power to the users with higher channel gain. In other words, the users with poor channel gain may be unable to receive any data in condition of the large variation of path loss among users. Hence, the allocation that penalizes the user with poor channel condition is unfair.

The max-min problem and the sum rate maximization problem with proportional fairness constraint and minimum rate requirement are studied in [3] [7]–[10]. The formulation of a max-min problem is used to maximize the worst data rate, which finds a fair data rate among the users. The proportional fairness problem recently appear in the works discussing the resource allocation problem, since it takes different rate requirements of different devices into account. However, the fairness constraint may not be satisfied unless the amount of the resource (i.e. the number of the subcarriers, or the limit of sum of transmit power, ..., etc.) is abundant. Besides, the minimum rate requirement for each user of a rate adaptive problem cannot guarantee a feasible solution when the rate requirement is too high and the capacity outage could occur.

In this work, we develop a new fairness optimization formulation, which maximizes the worst surplus among the users in a downlink MIMO OFDMA cellular network. The surplus is defined as the difference between the demand data rate and the allocated data rate. The demand rate is an expected data rate for each user and varies with different demands of the users. Different with previous works, the demand rate component appears in the objective function of a max-min problem. It provides a fairness criterion as a result of equal surpluses and guarantees a feasible solution, although the demand rate may not be always satisfied (i.e. the allocated rate is greater than or equal to the target rate). Exploiting the formulation,
an optimization of joint beamforming and subchannel, power allocation for MIMO system is discussed in this paper. The design of the precoding and the decoding matrices for the MIMO structure are relevant to the constraint of the number of transmit data streams. Leverage an alternative maximization algorithm (AMA) [11], users can utilize the same subcarrier and avoid the inter-user interference (IUI). Furthermore, an iterative algorithm with low complexity is proposed to find the solution. The main contributions of this paper are summarized as follows:

1) The resource allocation algorithm applied on MIMO system is optimized to the joint power allocation and subcarriers assignment with the design of precoding/decoding matrices.

2) An optimization of maximizing minimum surplus is proposed, which considers a fairness issue with different data rate requirement and guarantees a feasible solution.

3) To solve a max-min surplus problem, the proposed iterative algorithm is developed with low complexity. The simulations show that the algorithm outperforms other approaches on both sum rate and fairness index.

The rest of the paper is organized as follows. In Section II, we describe a multiuser MIMO OFDMA communication system and formulate the maximizing minimum surplus optimization problem. In Section III, an iterative multiuser bit allocation scheme is proposed. The numerical simulations and results are shown in Section IV, based on a multipath model of the MIMO system. Finally, we conclude in Section V.

II. SYSTEM MODEL AND PROBLEM FORMULATION

A. System Model

Suppose that there are \( N \) subcarriers in each user and the downlink MIMO channel between the BS and the \( k \)-th user is characterized by \( H \in \mathbb{C}^{N_t \times N_r} \), with \( N_t \) transmit and \( N_r \) receive antennas. Each element in \( H \) follows the spatial channel model and can be described as

\[
h(f) = \sum_{p=1}^{N_p} g_p e^{-j\phi_p e^{-j2\pi d_p f} e^{-(a_0+\alpha_1 f^2)} d_p},
\]

where \( g_p, N_p \) and \( d_p \) stand for path gain, the number of paths and path length, respectively. The \( \phi \) is the propagation speed of transmission signal. The first exponential term is the correlation feature, the second is the delay portion and the third is the attenuation portion, where \( \phi_p \) is the correlation factor and \( a_0, \alpha_1 \), and \( L \) are the attenuation parameters. We assume that the perfect channel state information (CSI) is available at BS and each user. Then, the received signal of the \( k \)-th user at subcarrier \( n \) can be represented as

\[
y_{k,n} = H_{k,n} x_{k,n} + \sum_{l=1, l \neq k}^{K} H_{l,n} x_{l,n} + z_{k,n}.
\]

The first term of right-hand side is the desired signal transmitted from the BS and the second term is the inter-user interference (IUI) composed of the signals of other users. The additive white Gaussian noise (AWGN) with zero mean and unit variance is denoted as \( z_{k,n} \). The input signal vector \( x_{k,n} \in \mathbb{C}^{N_t} \) transmitted at BS is constructed by a superposition of \( d_{k,n} \) data streams, i.e

\[
x_{k,n} = \sqrt{p_{k,n}} \sum_{j=1}^{d_{k,n}} s_{k,n}^{j} = \sqrt{p_{k,n}} \mathbf{V}_{k,n} s_{k,n},
\]

with the precoding matrices \( \mathbf{V} \in \mathbb{C}^{N_t \times d_{k,n}} \) which maps the data streams of \( s_{k,n} \in \mathbb{C}^{d_{k,n}} \) onto \( N_t \) transmit dimensions. On the other hand, the \( k \)-th user decodes the desired signals by multiplying the decoding matrix \( \mathbf{W} \in \mathbb{C}^{N_r \times d_{k,n}} \), and the signal through receiver combing is given by

\[
\bar{y}_{k,n} = \mathbf{W}_{k,n}^{\ast} y_{k,n}.
\]

B. Problem Formulation

The optimization problem of maximizing sum rate assigns each subcarrier to the user with the best channel gain to noise ratio. However such an allocation rule may penalizes the users with poor channel conditions [13]. Besides, to aim at specific data rate requirements of user, we need a fair resource scheme to make a better use of spectrum and improve the efficiency. Hence, this paper investigates the formulation of multi-user MIMO OFDMA resource allocation applied to cellular networks, subject to the constraints of the number of data streams on spatial domain and the power spectral density (PSD) mask for each user. The proposed algorithm aims to maximize the minimum surplus, and allocate the power and data streams with fairness according to the quality of each link. The optimization problem is formulated as below.

\[
\max_{p_{k,n},d_{k,n},\mathbf{V}_{k,n},\mathbf{W}_{k,n}} \min_k \left( \sum_{n=1}^{N} r_{k,n} \right) - R_k \tag{6}
\]

subject to

\[
r_{k,n} = \log_2 \left( 1 + \frac{-1.5}{\ln(5) p_{k,n} g_{k,n}} \right) \tag{7a}
\]

\[
g_{k,n} = \left\| \mathbf{W}_{k,n}^{\ast} \mathbf{H}_{k,n} \mathbf{V}_{k,n} \right\|_F^2 \tag{7b}
\]

\[
\mathbf{V}_{k,n} \subseteq \text{null} \left( \left[ \mathbf{H}_{j,k}^{\ast} \mathbf{W}_{j,n} \right]_{j=1, K, j \neq k} \right) \tag{7c}
\]

\[
\mathbf{W}_{k,n}^{\ast} \mathbf{W}_{k,n} = \mathbf{V}_{k,n}^{\ast} \mathbf{V}_{k,n} = \{ 0 \} \cap \mathbb{C}^{N_t \times d_{k,n}} \tag{7d}
\]

\[
\sum_{k=1}^{K} d_{k,n} \leq N_t, \ \forall n \tag{7e}
\]

\[
d_{k,n} \in \{ 0, 1, \ldots, N_r \}, \ \forall n \forall k \tag{7f}
\]

\[
\sum_{k=1}^{K} p_{k,n} \leq \rho_n, \ \forall n \tag{7g}
\]
where $R_k$ is the demand data rate for the $k$-th user and $L_{d,n}$ is an $d_{k,n} \times d_{k,n}$ identity matrix. $\tilde{p}_n$ is denoted as the PSD mask for the $n$-th subcarrier, which is the limit of the sum transmitted power on the $n$-th subcarrier. In spatial domain, the number of the data streams is an integer that ranges from zero to $N_R$ and can not exceed the number of the antennas at transmitter or receiver, which is shown in (7f) and (7e), respectively. Besides, in order to avoid the inter-user interference (IUI), the precoding matrix should be orthogonal to the channel which is not the path to the correspond receiver, as represented in (7c), and null($A$) is the null space of a matrix $A$. That is, different from previous works that focus only on frequency domain, the proposed optimization problem that considers both frequency and spatial domain allows multiple users to share one frequency subchannel and gains almost $N_T$ times of sum data rates.

In summary, we try to find an optimal allocation of the number of data streams, $d_{k,n}$, the power, $p_{k,n}$, and the designs of the precoding and decoding matrix, $V_{k,n}$ and $W_{k,n}$, to maximize the minimum surplus of the difference between the achieved rate and the demand rate.

### III. RESOURCE ALLOCATION ALGORITHM

Obviously, the optimization problem above is non-convex and is NP-hard to derive the global optimum. Hence, we break the original problem into several smaller but associated problems, and proposed an iterative algorithm with lower complexity to derive the solution in this section.

First, the user with the minimum surplus has the higher priority to select a subcarrier. The selection of the subcarrier is according to the magnitude of channel gain of each user on each subcarrier. Then, we focus on spatial domain and try to maximize the sum of data rate on the selected subcarrier. The optimization problem of maximizing sum rate can be solved by two separate steps: 1) data stream assignment and 2) inter-user interference (IUI) Alignment. In the assignment, we talk about how to assign the data streams to the users, whereas in the alignment, the precoding and decoding matrices are designed and align the transmit data streams into the individual orthogonal subspaces.

#### A. Data Stream Assignment - Dominant Parallel Channel Gain Scheduling (DPCGS)

For a MIMO system, a BS is able to transmit at most $N_T$ data streams to the users and each user is able to decode $N_R$ data streams on one subcarrier. Hence, there are total $\binom{KN_R}{N_T}$ number of combinations of the assignment and one can maximize the sum of data rate.

In the optimization problem of maximizing sum rates on frequency domain, each subcarrier is assigned to the user whose channel gain is good for it and the transmit power is equal to the ceiling of the limit of the PSD mask. Similarly on spatial domain, the transmit space on one subcarrier can be divided into $N_T$ number of subspace (i.e. subchannel), and the user with better parallel channel gain deserves the subchannel, as shown in Fig. 1, where $G_n$ and $A_n$ are the sets of the SISO channel gains and MIMO parallel channel gains on subcarrier $n$, respectively. The derivation is shown as follow.

$$
\hat{D}_n = \arg \max_{D_n} \sum_{k=1}^{K} r_{k,n}
$$

$$
= \arg \max_{D_n} \sum_{k=1}^{K} \left\| W_{k,n}^* H_{k,n} x_{k,n} \right\|^2_F
$$

$$
= \arg \max_{D_n} \sum_{k=1}^{K} \text{tr} \left( W_{k,n}^* H_{k,n} V_{k,n}^* H_{k,n} W_{k,n} \right)
$$

s.t. $\sum_{k=1}^{K} d_{k,n} = N_T$

(8)

where $D_n = \{d_{1,n}, \ldots, d_{K,n}\}$ is the set of the number of the transmit data streams and $\text{tr}(A)$ denotes the trace of a matrix $A$. Exploiting singular value composition, $H_{k,n}=U_{k,n} \Sigma_{k,n} U_{k,n}^*$, where $\Sigma_{k,n} = \text{diag}(\lambda_{1,n}^k, \ldots, \lambda_{N_T,n}^k)$ is a diagonal matrix and $(\lambda_{1,n}^k)^2 \geq (\lambda_{2,n}^k)^2 \geq \cdots \geq (\lambda_{N_T,n}^k)^2$ is the parallel channel gains between the BS and the $k$-th user on the subcarrier $n$. To maximize the sum of data rate in (8), the precoding matrix, $V_{k,n}$, can be designed as the $d_{k,n}$ dominant column of $\hat{U}_{k,n}$, similarly, the decoding matrix, $W_{k,n}$, can be the $d_{k,n}$ dominant column of $\hat{U}_{k,n}$. Then, $W_{k,n}^* H_{k,n} V_{k,n}$ becomes $\text{diag}(\lambda_{1,n}^k, \ldots, \lambda_{d_{k,n}}^k)$ and further (8) becomes

$$
\hat{D}_n = \arg \max_{D_n} \sum_{k=1}^{K} \sum_{j=1}^{d_{k,n}} (\lambda_{j,n}^k)^2.
$$

(9)

s.t. $\sum_{k=1}^{K} d_{k,n} = N_T$, 

\[ \text{Fig. 1. In the SISO system, the subchannel is assigned to the user with the best channel. Each channel is used for transmitting only one data stream, i.e., } d_{k,n} = 1; \text{ In the MIMO system, the subchannels are assigned to the users with } N_T \text{ dominant parallel channel gains (i.e. DPCGS).} \]
which implies that the optimal solution is assigning $N_T$ data streams (i.e. subchannels of one subcarrier) to the users with dominant parallel channel gains in the set of $\mathbf{A}_n = \{ (\lambda_{1,n}^1)^2, \ldots, (\lambda_{1,n}^N)^2, (\lambda_{K,n}^1)^2, \ldots, (\lambda_{K,n}^N)^2 \}$. The process is also shown on Fig. 1.

B. Inter-User Interference Alignment

Back to the optimization problem of maximizing minimum surplus in Section II, because the demand rate, $R_k$, is a given value, the surplus in objective function grows with the gain of the sum rate. This implies that the signal power, $p_{k,n}$, and the channel gain, $g_{k,n}$, in (7a) are expected to be as larger as possible. Hence, in this subsection, we discuss the power allocation, $p_{k,n}$, and the design of the precoding matrix, $\mathbf{V}_{k,n}$, and decoding matrix, $\mathbf{W}_{k,n}$ for the user $k$ on subcarrier $n$ to maximize the sum rate after the assignment process of DPCGS. (Note that precoding and decoding matrices designed in DPCGS do not consider the IUI constraint of (7c).) The joint optimization problem is formulated as:

$$\max_{p_{k,n}, \mathbf{V}_{k,n}, \mathbf{W}_{k,n}} \sum_{k=1}^{K} \left\| \mathbf{W}_{k,n}^* \mathbf{H}_{k,n} \mathbf{x}_{k,n} \right\|_F^2$$

$$\text{s.t.} \quad \mathbf{V}_{k,n} \subset \text{null} \left( \left[ (\mathbf{H}_{j,n}^* \mathbf{W}_{j,n})_{j=1,\ldots,K,j\neq k} \right] \right)$$

$$\mathbf{W}_{k,n} = \mathbf{V}_{k,n} \mathbf{V}_{k,n} = \{ \mathbf{I}_{d_k,n}, 0 \}$$

$$\sum_{k=1}^{K} p_{k,n} \leq \bar{p}_n.$$  

(10)

(11a)

(11b)

(11c)

In this problem, the transmit signal power, $p_{k,n}$, can be individually and optimally solved via a water-filling algorithm, which main idea is to allocate more power to the user with stronger parallel channel gain, and less or even no power to the weaker one [14].

$$p_{k,n} = \frac{d_k}{\gamma - \frac{1}{\left\| \mathbf{W}_{k,n}^* \mathbf{H}_{k,n} \mathbf{V}_{k,n} \right\|_F^2}} + 1,$$  

(12)

where $a^+ := \max (a, 0)$ and $\gamma$ is the Lagrange multiplier chosen such that the power constraint is met:

$$\sum_{k=1}^{K} p_{k,n} = \bar{p}_n.$$  

(13)

The optimization problem in (10) and (11) is still a non-convex problem over $2K$ variables (i.e., $\mathbf{W}_{1,n}, \ldots, \mathbf{W}_{K,n}, \mathbf{V}_{1,n}, \ldots, \mathbf{V}_{K,n}$). An iterative inter-user interference alignment (IIIA) is developed to provide the solution for the matrices. The concept of IIIA is that if $2K - 1$ of the variables are temporarily fixed, the remaining variable of the objective function can be optimized, then, alternating between the variables and keeping the operation until converge [11]. The proposed IIIA is summarized in Table I.

| Table I Proposed Iterative Inter-user Interference Alignment(IIIA) |

1) Initialization
By given the result of the assignment, i.e. $D_n = \{ d_{1,n}, \ldots, d_{K,n} \}$, $\mathbf{V}_{k,n}$ is fixed arbitrarily for all $k$.

2) Maximum Ratio Combining
$$\mathbf{W}_{k,n} = \arg \max \mathbf{W}_{k,n}^* \mathbf{H}_{k,n} \mathbf{V}_{k,n},$$
subject to $\mathbf{W}_{k,n}^* \mathbf{W}_{k,n} = \{ \mathbf{I}_{d_k,n}, 0 \}$, for all $k$. It is a convex problem with an optimal solution.

3) Inter-user Interference alignment

$$\mathbf{V}_{k,n} = \mathbf{null} \left( \left[ (\mathbf{H}_{j,n}^* \mathbf{W}_{j,n})_{j=1,\ldots,K,j\neq k} \right] \right)^*.$$  

4) Repeat step 2 and 3 until convergence.

C. Maximizing Minimum Surplus Resource Allocation

In [5], a max-min problem is formulated, and a suboptimal solution is developed by the greedy method with low complexity. Since the surplus problem is an extension of a max-min problem, we take the advantage of the algorithm proposed in [5] and apply to the MIMO structure by combining with the assignment and alignment method. The proposed algorithm develop a low complexity derivation to solve the maximizing minimum surplus problem, which is summarized in Table II:

| Table II Maximize Minimum Surplus Resource Allocation (MMSRA) |

1) Initialization
(a) set $r_k = 0$ and $d_{k,n} = 0$ for all $k = 1, \ldots, K$.
(b) $\mathbf{A} = \{ \mathbf{A}_1, \ldots, \mathbf{A}_N \}$, where
$$\mathbf{A}_n = \{ (\lambda_{1,n}^1)^2, \ldots, (\lambda_{1,n}^{N_R})^2, (\lambda_{K,n}^1)^2, \ldots, (\lambda_{K,n}^{N_R})^2 \}.$$  

(c) $\mathbf{A} = \{ 1, \ldots, N \}$.

2) for $k = 1$ to $K$
(a) find $n$ satisfying $(\lambda_{1,n}^1)^2 \geq (\lambda_{k,n}^1)^2$ for all $m \in \mathbf{A}$.
(b) do DPCGS for found subcarrier $n$, i.e.
$$\text{for } i = 1 \text{ to } N_T$$
$$\{ j, l \} = \arg \max \{ (\lambda_{i,n}^j)^2 \}$$
$$\mathbf{A}_n = \mathbf{A}_n - \{ (\lambda_{i,n}^j)^2 \}$$
$$d_{i,n} = d_{i,n} + 1$$
end
(c) do IUI Alignment for found subcarrier $n$, i.e.
derive $\mathbf{V}_{l,n}$ and $\mathbf{W}_{l,n}$ via IIIA, $\forall l$
derive $p_{i,n}$ via water-filling method, $\forall l$
(d) update $\mathbf{A}$ and $r_l$ for all $l=1,\ldots,K$, i.e.
$$\mathbf{A} = \mathbf{A} - \{ n \}$$and $r_l = r_l + r_{i,n}$
end
while $\mathbf{A} \neq \emptyset$.

(a) find $k$ satisfying $(r_k - R_k) \leq (r_l - R_l)$, $\forall l=1,\ldots,K$
(b) use the found $k$ to find $n$ which satisfy $(\lambda_{k,n}^1)^2 \geq (\lambda_{k,n}^l)^2$ for all $m \in \mathbf{A}$
(c) do DPCGS for found subcarrier $n$
(d) do IUI Alignment for found subcarrier $n$
(e) update $\mathbf{A}$ and $r_l$ for all $l=1,\ldots,K$
end

IV. SIMULATION AND DISCUSSION

In this section, MMSRA is applied on MIMO system with $N_T = 4$ and $N_R = 2$. The simulation is based on the...
Fig. 2. Maximizing sum rate on spatial domain. Results for sum rate of combing different methods of data stream assignment with IIIA are shown for comparison. ES and AS are the abbreviations of the Exhausted Scheduling and the Arbitary Scheduling, respectively.

Fig. 3. Minimum surplus of MMSRA algorithm. The demand data rates of the users are assumed to be equal to 2 Mbits/s/transmission.

specification of ITU-R [1], where the bandwidth for data transmission is from 1MHz to 20 MHz and the subcarrier frequency space is 24.4140625 KHz. There are \( N = 942 \) subcarriers can be assigned to the devices. The channels between the BS and each user are assumed to be a simplified four-path model (i.e. \( N_p = 4 \)), which parameters are listed in Table III.

A. Data Stream Assignment and IUI Alignment

Firstly, we consider the problem of maximizing sum rate in (10) and simulate the resource allocation via the algorithms of DPCGS and IIIA. Fig. 2 shows the allocated sum rate for SNR ranging from 0 dB to 30 dB and compares several different works with the proposed method. The upper bound is achieved when the users cooperate with each other. It is equivalent to a single-user MIMO structure with \( N_T \) transmit antennas and \( K N_R \) received antennas. The exhausted scheduling (ES) of the data stream assignment is NP-hard, which derives all possible solutions and chooses the best. From Fig. 2, small difference is observed between ES and DPCGS, while the proposed DPCGS is formulated with lower complexity. In [15], data streams are assigned to the user whose row signal spaces are as close as possible to other users’ common nullspace. The algorithm named Best-User-First Subcarrier-User-Scheduling (BUF-SUS) allocates \( d_{k,n} = \min \{ N_R, (K - 1) N_R - N_T \} \) data streams to the user \( k \) sequentially until \( \sum_{k=1}^{K} d_{k,n} \geq N_T \). To maximize the sum of data rates, BUF-SUS considers the correlation of IUI among the users, whereas DPCGS

Fig. 4. Comparison the allocated sum rate between the formulations of the maximizing minimum sum rate and the maximizing minimum surplus. \( K = 4 \), \( SNR = 10dB \), \( R_1 = 2 \), \( R_2 = 2 \), \( R_3 = 6 \), \( R_4 = 6 \) Mbits/s/transmission.

Fig. 5. Fairness comparison of MMSRA algorithm with conventional Max-Min sum rate approach (i.e. BUF-SUS [15]). Users are divided into two groups, i.e. \( K = K_{g1} + K_{g2} \), the corresponding demand rates are \( R_{g1} = 2 \) and \( R_{g2} = 6 \) Mbps/transmission, respectively.
Table III Simulation Parameters of Fading Channel Model

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<th>attenuation parameters</th>
<th>( L \sim U(0, 1) )</th>
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<tbody>
<tr>
<td>( a_0 = 0 )</td>
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<td>( a_1 = 1.8 \times 10^{-10} )</td>
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<th>path parameters</th>
<th>( g_1 \sim U(0, 1) )</th>
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<tr>
<td>( g_2 \sim U(0.25, 0.5) )</td>
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<td>( g_3 \sim U(0.1, 0.25) )</td>
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<td>( g_4 \sim U(0.0, 0.1) )</td>
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\( d_p \sim U(200, 250) \text{ m, } \forall p = 1, \ldots, 4 \)

users and is defined as

\[
\text{Fairness} = \max_k \left\{ r_k - R_k \right\} - \min_j \left\{ r_j - R_j \right\}.
\]

V. Conclusion

This paper presents an optimal resource allocation algorithm for cellular MIMO-OFDMA systems. The formulation of maximizing minimum surplus considers a fairness issue and guarantee a feasible solution. The proposed iterative approach of MMSRA provides a derivation with low complexity, which finds out the bit allocation, power allocation and designs the precoding and receiving matrices for transmission. Simulation results indicate that the proposed algorithm can perform almost as well as an optimal bit allocation with exhausted searching. Although the rate requirements of each user are different, MMSRA derives a fair result of data rates.

**References**


