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Fairness-Capacity Tradeoff for SC-FDMA/SDMA Transmission Scheme

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***Abstract*—In this paper, we propose a fairness-controlled multiuser scheduling and resource allocation (RA) algorithm for uplink spatial division multiple access (SDMA)/ single carrier frequency division multiple access (SC-FDMA). In fact, with the aim of improving the spectral efficiency (SE) and at the same time controlling the network fairness, a sub-optimal power projection method based on users' spatial correlation is employed, which chooses the users for each resource block (RB). We assume a single-input multiple-output (SIMO) scheme with correlation at receive antenna. By changing the maximum allowed number of simultaneously accessing users, we can choose the desired balance between SE and the fairness. Numerical analysis verifies that the proposed scheme improves the SE considerably at the target defined fairness level. We also investigate the variations in fairness for different system design parameters, i.e., RB size, number of receive antenna, etc.**

***Index Terms*—SC-FDMA, SIMO, SDMA, Multiuser Scheduling, Spatial Correlation, Resource Allocation, Uplink, Spectral Efficiency, Fairness.**

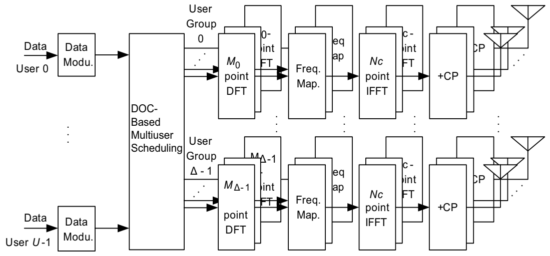
I. Introduction

Wireless communication is facing an increasing demand for a better performance and QoS guarantee. As a result, adaptive resource allocation and scheduling algorithms are proposed to improve the spectral efficiency (SE). Single-carrier frequency division multiple access (SC-FDMA) [1], [2] transmission is a novel technique used in the uplink of the 3GPP long term evolution (LTE) [3]. SC-FDMA has the advantage of reduced peak-to-average power ratio (PAPR) [4] compared to orthogonal frequency division multiple access (OFDMA), which reduces the complexity in the design of user terminal. Multiple-input multiple-output (MIMO) techniques can improve the SC-FDMA scheme significantly by allowing spatial diversity and assigning more than one user to each resource block (RB). Combining MIMO SC-FDMA with multiuser scheduling techniques can further improve the SE, especially in dense environments with larger number of users. However, this improvement in SE may cause degradation in fairness index. In fact, there exists a tradeoff between SE and fairness. All the recent scheduling algorithms either look into enhanced fairness or enhanced SE. The works which consider at the same time, controlling the SE-fairness tradeoff is scarce and often consider scenarios such as downlink OFDMA. Controlling the balance between these two factors is an important issue for users and network providers and must be taken into consideration jointly. This motivates us to think about a new method to improve and at the same time tradeoff between total capacity and proportional fairness.

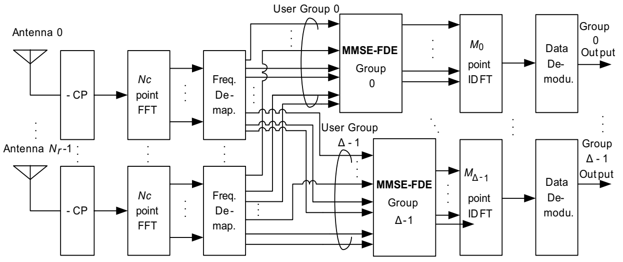
The authors in [5] consider a joint subcarrier, bit, and power allocation algorithm to minimize the total transmit power subject to bit error rate (BER) and rate constraints in downlink OFDMA. This algorithm has high computational complexity. Based on this work many other research works are proposed to reduce the complexity. In [6], authors introduced a priority based sequential scheduling criteria to achieve a better capacity compared with previous works at the cost of losing much proportional fairness among users. In [7], authors propose the use of codebook aided algorithms for joint user pairing and RA in virtual MIMO (V-MIMO) SC-FDMA. They consider two criteria for user pairing, i.e., V-MIMO channel capacity and bit error rate after equalization. This work is based on user pairing with a pairing criteria different than ours. Moreover, their RA algorithm is not adaptive with system parameters.

In this paper, we propose a novel multiuser scheduling and RA technique for uplink single-input multiple-output (SIMO) SC-FDMA, which can tune to the desired level of fairness by changing the maximum number of simultaneously accessing users. We first present the signal processing at the transmitter and receiver side as well as the user's output signal-to-interference ratio (SINR) at the base station (BS). Later, we introduce our fairness-controlled scheduling and RA algorithm, which schedules users for each RB using a low-complexity algorithm based on the concept of users' mutual degree of correlation (DOC). Our proposed algorithm determines the optimal RB size and the number of simultaneous users which should access the uplink, using a concatenated probabilistic neural network (PNN) structure. The PNN is first trained offline and then runs in online mode. Simulation results are provided to evaluate the SE-fairness tradeoff performance of our algorithm based on different system design parameters.

The remainder of this paper is organized as follows. In Section II, SIMO SC-FDMA uplink signal transmission scheme is presented along with the SINR expression after equalization at the receiver. Section III discusses our proposed fairness-controlled multiuser scheduling and RA algorithm. Section IV discusses the simulation results and the evaluation of our algorithm. Finally, section V concludes the paper.



(a) Transmitter structure



(b) Receiver structure

Fig. 1. SIMO SC-FDMA transceiver structure.

II. MULTIUSER SC-FDMA UPLINK SIGNAL TRANSMISSION

The Multiuser SIMO SC-FDMA uplink transceiver is illustrated in Fig. 1. We use fast Fourier transform (FFT) sample-spaced discrete-time signal representation. A block transmission of M_δ symbols using N_r-antenna receive diversity reception is considered.

At the u_δth ($u_\delta = 0,\ldots,U_\delta$–1) user transmitter of δth RB, the M_δ-symbol block $\{s_{u_\delta}(n); n = 0,\ldots,M_\delta - 1\}$ is transformed by M_δ-point discrete Fourier transform (DFT) into the frequency-domain signal $\{S_{u_\delta}(k); k = 0,\ldots,M_\delta–1\}$ and then mapped over ($N_c = M_0 + M_1 + ... + M_{\Delta-1}$) subcarriers. We assume a total of ($U = U_0 + U_1 + ... + U_{\Delta-1}$) users in the system.

In this paper, we consider a localized spectrum mapping for the multiuser SIMO SC-FDMA transmitter. The frequency-domain signal after spectrum mapping is transformed back to the time-domain signal by applying N_c-point inverse FFT (IFFT). Last N_g samples of each N_c-sample block are copied as a cyclic prefix (CP) and inserted at the beginning of each block to make the received symbol block to be a circular convolution of the transmitted symbol block and the channel impulse response in order to avoid inter block interference (IBI). We assume that the CP is longer than the maximum path delay of the signal.

The CP-inserted signal block is transmitted over a frequency-selective fading channel. At the BS receiver, the received signal block at the n_rth receive antenna $\{r_{n_r}(n); n = 0,\ldots,N_c - 1\}$ after the removal of the CP is transformed by applying N_c-point FFT into the frequency-domain signal $\{R_{n_r}(k); k = 0,\ldots,N_c - 1\}$. Spectrum de-mapping is done to restore each user's spectrum. However, the MUI is present since we schedule each RB for transmission of more than one user. A simple MMSE-FDE is performed to suppress the MUI and recover the signal. Finally, a block of M_δ soft decision variables is obtained by applying M_δ-point inverse DFT (IDFT) to the frequency-domain signal.

A. Spectrum Mapping and Transmit Signal

DFT output of the u_δth user is given by

$$S_{u_\delta}(k) = \sqrt{\frac{1}{M_\delta}} \sum_{n=0}^{M_\delta-1} s_{u_\delta}(n) \exp\left(-j2\pi k \frac{n}{M_\delta}\right). \tag{1}$$

The u_δth user's frequency-domain signal $\{S'_{u_\delta}(k);\ k = 0,\ldots,N_c - 1\}$ after spectrum mapping can be expressed as

$$S'_{u_\delta}(k) = \begin{cases} S_{u_\delta}(k - \sum_{s=0}^{\delta} M_s) & k = M_\delta,\ldots,2M_\delta - 1 \\ 0 & otherwise \end{cases}. \tag{2}$$

An N_c-point IFFT is applied to $\{S'_u(k)\}$ to obtain the transmit time-domain signal $\{s_u(n)\}$, which is given by

$$s_{u_\delta}(n) = \sqrt{\frac{1}{N_c}} \sum_{k=0}^{N_c-1} S'_{u_\delta}(k) \exp\left(j2\pi n \frac{k}{N_c}\right), \forall n \in \{-N_g, ..., N_c - 1\} \tag{3}$$

B. Channel Model

A frequency-selective fading is considered with the channel impulse response of u_δth user at n_rth antenna given by

$$h_{u_\delta,n_r}(\tau) = \sum_{l=0}^{L-1} h_{u_\delta,n_r} \mathbf{D}(\tau - \tau_{u_\delta,l}), \tag{4}$$

where the propagation channel is assumed to be an L-path block fading channel, each path being subjected to independent fading. h_{u_δ,n_r} and $\tau_{u_\delta,l}$ are respectively the complex-valued Rayleigh path gain and time delay of the lth path ($l = 0,\ldots,L$–1) between the u_δth user's transmitter and the n_rth ($n_r = 0,\ldots,N_r$–1) receive antenna of the BS. $\mathbf{D}(\tau)$ is the delta function. Please note that h_{u_δ,n_r} satisfies $\sum_{l=0}^{L-1} \mathbf{E}\{|h_{u_\delta,n_r}|^2\} = 1$, where $\mathbf{E} = \{.\}$ is the expectation operator.

The received signal at the n_rth antenna is given by

$$r_{n_r}(n) = \sum_{\delta=0}^{\Delta-1} \sum_{u_\delta=0}^{U_\delta-1} \sum_{l=0}^{L-1} \sqrt{P_{u_\delta}} h_{u_\delta,n_r} s_{u_\delta}(n - \tau_{u_\delta,l}) + n_{n_r}(n), \tag{5}$$

where P_{u_δ} is the transmit power of u_δth user, $n_{n_r}(n)$ is the zero-mean complex Gaussian noise with variance $2N_0/T_s$ with N_0 being the single-sided power spectrum density of the additive white Gaussian noise (AWGN) and T_s the symbol duration.

C. Received signal and spectrum de-mapping

N_c-point FFT is applied to $\{r_{n_r}(n); n = 0,\ldots,N_c - 1\}$ to transform it into the frequency-domain signal $\{R_{n_r}(k); k = 0,\ldots,N_c - 1\}$. $R_{n_r}(n)$ is given by

$$\begin{aligned} R_{n_r}(k) &= \sqrt{\frac{1}{N_c}} \sum_{n=0}^{N_c-1} r_{n_r}(n) \exp\left(-j2\pi k \frac{n}{N_c}\right) \\ &= \sum_{\delta=0}^{\Delta-1} \sum_{u_\delta=0}^{U_\delta-1} \sqrt{P_{u_\delta}} H'_{u_\delta,n_r}(k) S'_{u_\delta}(k) + N_{n_r}(k), \end{aligned} \tag{6}$$

Algorithm 1 : Adaptive Fairness-Controlled Scheduling and RA Algorithm for $\hat{U}/\Delta^* \geq 1$, i.e., introducing MUI.

```
Input:  Target $E_b/N_0$, $U$, $\mathbf{F}$, $N_c$, $N_r$ and $\mathbf{H}' \in \mathbb{C}^{N_c \times N_r \times U}$
Output: $\Delta^*$, $M_\delta^*$, $U_\delta^*$ and Allocation Vector $\mathcal{S}_\delta$
  $\hat{U} \leftarrow \mathcal{G}(E_b/N_0, \mathbf{F}, N_r)$
  $\Delta^* \leftarrow \mathcal{F}(E_b/N_0, \hat{U}, N_r)$
  $M_\delta^* \leftarrow N_c/\Delta^*$
Initialization: $\mathcal{B} = \{0, 1, ..., \Delta^* - 1\}$; $\mathcal{U} = \{0, 1, ..., U\}$;
$U_\delta^* \leftarrow \hat{U}/\Delta^*$
while do
    $\mathcal{S}_\delta \leftarrow \emptyset, \quad \forall \delta \in \mathcal{B}$
    for $\forall \delta \in \mathcal{B}$ do
        Find $u_\delta^* = \arg\max_{j \in \mathcal{U}} \| \mathbf{H}_j^\delta \|^2$, where
        $\mathbf{H}_j^\delta \in \mathbb{C}^{(\delta M_\delta^* + 1 : (\delta+1) M_\delta^*) \times N_r \times j}$ is a subspace of $\mathbf{H}'$
        $\mathcal{S}_\delta \leftarrow \mathcal{S}_\delta \bigcup \{u_\delta^*\}, \ \mathcal{U} \leftarrow \mathcal{U} \setminus \{u_\delta^*\}$
        while $|\mathcal{S}_\delta| < U_\delta^*$ do
            $\bar{u_\delta} = \arg\min_{j \in \mathcal{U}} \sum_{i \in \mathcal{S}_\delta} \left( \| \mathbf{H}_i^\delta (\mathbf{H}_j^\delta)^H \|^2 \ / \ \| \mathbf{H}_i^\delta \|^2 \| \mathbf{H}_j^\delta \|^2 \right)$
            $\mathcal{S}_\delta \leftarrow \mathcal{S}_\delta \bigcup \{\bar{u_\delta}\}, \ \mathcal{U} \leftarrow \mathcal{U} \setminus \{\bar{u_\delta}\}$
        end while
    end for
    Calculate the fairness factor $\mathbf{F}^*$ and $\epsilon = |\mathbf{F}^* - \mathbf{F}|$
    if $\epsilon \leq \epsilon^*$ then
        EXIT While
    else
        Adjust $\hat{U}$ accordingly
    end if
end while
```

where $H'_{u_\delta,n_r}(k)$ and $N_{n_r}(k)$ are respectively the channel gain and the noise due to the AWGN, given by

$$\begin{cases} H'_{u_\delta,n_r}(k) = \sum_{l=0}^{L-1} h_{u_\delta,n_r} \exp\left(-j2\pi k \frac{\tau_{u_\delta,l}}{N_c}\right) \\ N_{n_r}(k) = \frac{1}{N_c} \sum_{n=0}^{N_c-1} n_{n_r}(n) \exp\left(-j2\pi k \frac{n}{N_c}\right). \end{cases} \tag{7}$$

The spectrum de-mapping is applied to $\{R_{n_r}(k)\}$ to obtain the u_δth user's frequency-domain signal $\{R_{u_\delta,n_r}(k);\ k = M_\delta, \ldots, 2M_\delta - 1\}$ at δth RB, as well as the channel gain $\{H_{u,n_r}(k);\ k = M_\delta, \ldots, 2M_\delta - 1\}$ according to

$$\begin{cases} R_{u_\delta,n_r}(k) = R_{n_r}(k + \sum_{s=0}^{\delta} M_s) \\ H_{u_\delta,n_r}(k) = H'_{u,n_r}(k + \sum_{s=0}^{\delta} M_s) \end{cases}, \forall k \in \{M_\delta, \ldots, 2M_\delta - 1\}. \tag{8}$$

After FDE on each frequency to suppress the MUI and ISI, the received signal of desired user, u'_δ, in δth RB is given by

$$\begin{aligned} \hat{R}_{u'_\delta}(k) &= \sum_{n_r=1}^{N_r-1} W_{u'_\delta,n_r}(k) R_{u_\delta,n_r}(k) = \sqrt{P_{u'_\delta}} \hat{H}_{u'_\delta}(k) S'_{u'_\delta}(k) \\ &+ \sum_{u_\delta=0, u_\delta \neq u'_\delta}^{U_\delta-1} \sqrt{P_{u_\delta}} \hat{H}_{u_\delta}(k) S'_{u_\delta}(k) + \hat{N}_{u'_\delta}(k), \end{aligned} \tag{9}$$

where $W_{u'_\delta,n_r}(k)$ is the MMSE-FDE equalization weight for u'_δth user on frequency k and is given by

$$W_{u'_\delta,n_r}(k) = \frac{P_{u'_\delta} H^*_{u'_\delta,n_r}(k)}{\sum_{u_\delta=0}^{U_\delta-1} P_{u_\delta} \left| H_{u_\delta,n_r}(k) \right|^2 + N_0}, \tag{10}$$

and we define

$$\mathbf{W}_{u'_\delta}(k) = \left[W_{u'_\delta,1}(k), .., W_{u'_\delta,N_r}(k) \right], \tag{11}$$

as the weight vector of u'_δth user on frequency k.

$\hat{H}_{u_\delta}(k)$ and $\hat{N}_{u_\delta}(k)$ are respectively the equivalent channel gain and the noise after FDE, given by

$$\begin{cases} \hat{H}_{u_\delta}(k) = \sum_{n_r=1}^{N_r-1} W_{u'_\delta,n_r}(k) H_{u_\delta,n_r}(k) \\ \hat{N}_{u_\delta}(k) = \sum_{n_r=1}^{N_r-1} W_{u'_\delta,n_r}(k) N_{u_\delta,n_r}(k). \end{cases} \tag{12}$$

Finally, the time domain estimate is obtained by applying M_δ-point IDFT to $S_{u'_\delta}(k); k = u'_\delta, \ldots, M_\delta - 1\}$ as

$$\begin{aligned} \hat{r}_{u'_\delta}(n) &= \frac{1}{M_\delta} \sum_{k=0}^{M_\delta-1} \hat{R}_{u'_\delta}(k) \exp\left(j2\pi n \frac{k}{M_\delta}\right) \\ &= \hat{s}_{u'_\delta}(n) + I(n) + \hat{z}(n). \end{aligned} \tag{13}$$

where $\hat{s}_{u'_\delta}$ is the desired signal, $I(n)$ is the ISI+MUI term and $\hat{z}(n)$ is the noise component. After calculating the power of each component in (13) based on a Gaussian approximation, the final SINR expression is given by

$$\gamma_{u'_\delta} = \frac{\frac{P_{u'_\delta}}{M_\delta N_0} \left| \sum_{k=0}^{M_\delta-1} \hat{H}_{u'_\delta}(k) \right|^2}{\sum_{u_\delta=0}^{U_\delta-1} \frac{P_{u_\delta}}{M_\delta N_0} \sum_{k=0}^{M_\delta-1} \left| \hat{H}_{u_\delta}(k) \right|^2 - \frac{P_{u'_\delta}}{M_\delta N_0} \left| \sum_{k=0}^{M_\delta-1} \hat{H}_{u'_\delta}(k) \right|^2 + \sum_{k=0}^{M_\delta-1} \left| W_{u'_\delta,n_r} \right|^2}. \tag{14}$$

III. ADAPTIVE SCHEDULING AND RA ALGORITHM

The detailed procedure for our scheduling and RA algorithm is presented in Algorithm 1 and Algorithm 2. We simplify the optimization by assuming that all RBs have the same size, i.e., $M_0 = ... = M_{\Delta-1} = N_c/\Delta$, and the number of users assigned on each RB is $U_0 = ... = U_{\Delta-1} = U/\Delta$. At first, based on the desired target fairness, the PNN algorithm gives a rough estimate of the number of simultaneous users, $\hat{U}$, which should be chosen for uplink connection. In the second step the PNN defines the optimum RB size, Δ^*, which depends on the assigned target SNR for the system, number of receive antennas and total number of users. The PNN algorithm, is trained first using a comprehensive gathered set of data in offline mode and then adaptively determines Δ^* and $\hat{U}$ in online mode. Based on values for Δ^* and $\hat{U}$, we propose two algorithms as explained in the following:

- If $\hat{U}/\Delta^* \geq 1$, i.e., each RB will be assigned one or more users which implies the existence of MUI. For this case, Algorithm 1 is proposed. In Algorithm 1, instead of assigning users randomly to each RB, we chose users based on their DOC metric as follows; For each RB, the first user is chosen as the one with the highest channel gain, the second users is chosen among remaining users with the lowest power projection metric with the first user. The third user is chosen as the one with the lowest sum mutual power projection with previous users and so on. At the end the fairness index will be calculated based on the achieved throughput of all the users in the system. If its difference with the actual fairness index is more than an allowed threshold then, $\hat{U}$ will be adjusted accordingly till desirable outcome is reached. We define the fairness index according to $\mathbf{F} = \left(\sum_{u=0}^{U-1} C_u\right)^2 / \left(U \cdot \sum_{u=0}^{U-1} C_u^2\right)$, where C_u is each user's achieved throughput. As the fairness becomes higher, $\mathbf{F}$ approaches 1. On the other hand, as the fairness becomes lower, $\mathbf{F}$ approaches $1/U$.

- If $\hat{U}/\Delta^* < 1$, i.e., each user will be assigned more than one RB which implies there is no MUI introduced to the system. For this case Algorithm 2 is proposed based on the similar concept in [8]. First, each RB is assigned to the user with the highest channel gain. In the second step, the algorithm tunes the total number of accessing users to $\hat{U}$ as follows; The user with the highest achieved throughput is chosen. If its total number of RBs is more than $\hat{U}/\Delta^*$, then its RBs with lowest throughput are taken and complemented to users which have the highest channel gain on those RBs. This process is continued until the number of RBs for the aforementioned user reaches $\hat{U}/\Delta^*$ and if its total number of RBs is less than $\hat{U}/\Delta^*$ then a reverse process is performed. At the next iteration user with the second highest throughput is chosen and the process is continued for exactly, $\hat{U}$, iterations. The rest of the process is similar to Algorithm 1.

IV. Computer Simulation

The simulation parameters are summarized in Table I.

Figs. 2 and 3 show the spectral efficiency and its related fairness index as a function of average received SNR for different Δs assuming $N_r = 6$ and $U = 32$ with our DOC-based multiuser scheduling algorithm. No target fairness index is assigned, i.e., all users may simultaneously access the uplink. We observe that the maximum value for SE is a function of target SNR, and RB size. This justifies the need for an adaptive algorithm, which chooses the right RB size based on actual system condition. We also notice that for $\Delta = 1$, fairness is maximum due to the equal opportunity for all users to access the uplink. However, fairness reduces for $\Delta > 1$ due to increased contention by users to access each RB.

TABLE I
Simulation Parameters

Transmitter	Data modulation	QPSK,
	Number of resource blocks	$\Delta = 1 \sim 8$
	FFT/IFFT size	$N_c = 256$
	Total Number of users	$U = 1 \sim 16$
	Total Transmit SNR	$E_s/N_0 = 0 \sim 20$dB
	Transmit Power Control	Slow TPC
Channel	Fading type	Frequency-selective block Rayleigh
	Power delay profile	$L = 16$-path uniform power delay profile
	Time delay	$\tau_{u,l} = l,\ l = 0 \sim L-1$
Receiver	Number of receive antennas	$N_r = 1 \sim 8$
	Equalization Type	MMSE-FDE
	Channel estimation	Ideal

Algorithm 2 : Adaptive Fairness-Controlled Scheduling and RA Algorithm for $\hat{U}/\Delta^* < 1$, i.e., no MUI.

```
Input:   Target $E_b/N_0$, $U$, $\mathbf{F}$, $N_c$, $N_r$ and $\mathbf{H}' \in \mathbb{C}^{N_c \times N_r \times U}$
Output: $\Delta^*$, $M_\delta^*$, $U_\delta^*$ and Allocation Vector $\mathcal{S}_u$
  $\hat{U} \leftarrow \mathcal{G}(E_b/N_0, \mathbf{F}, N_r)$
  $\Delta^* \leftarrow \mathcal{F}(E_b/N_0, \hat{U}, N_r)$
  $M_\delta^* \leftarrow N_c/\Delta^*$
Initialization: $\mathcal{B} = \{0, 1, ..., \Delta^* - 1\}$; $\mathcal{U} = \{0, 1, ..., U\}$;
while  do
    $\mathcal{S}_u \leftarrow \emptyset,\ C_u \leftarrow \emptyset\ \forall u \in \mathcal{U}$
    for $\forall \delta \in \mathcal{B}$ do
        Find $u^* = \arg\max_{j \in \mathcal{U}} \| \mathbf{H}_j^\delta \|^2$,
        $\mathcal{S}_{u^*} \leftarrow \mathcal{S}_{u^*} \bigcup \{\delta\}$,
    end for
    Calculate each user achieved capacity, $C_u$
    $\mathcal{K} = \{0, 1, ..., U\}$;
    for $u = 1 : \hat{U}$ do
        Find $u^* = \arg\max_{u \in \mathcal{K}} C_u$,
        $\mathcal{K} \leftarrow \mathcal{K} \setminus \{u^*\}$
        if $|\mathcal{S}_{u^*}| = \hat{U}/\Delta^*$ then
            EXIT
        else if $|\mathcal{S}_{u^*}| > \hat{U}/\Delta^*$ then
            while $|\mathcal{S}_{u^*}| > \hat{U}/\Delta^*$ do
                Find $\delta^* = \arg\min_{\delta \in \mathcal{S}_{u^*}} \| \mathbf{H}_{u^*}^\delta \|^2$,
                Find $\bar{u}^* = \arg\max_{j \in \mathcal{U}} \| \mathbf{H}_j^{\delta^*} \|^2$,
                $\mathcal{S}_{\bar{u}^*} \leftarrow \mathcal{S}_{\bar{u}^*} \bigcup \{\delta^*\}$, Update $C_{\bar{u}^*}$
                $\mathcal{S}_{u^*} \leftarrow \mathcal{S}_{u^*} \setminus \{\delta^*\}$, Update $C_{u^*}$
            end while
        else if $|\mathcal{S}_{u^*}| < \hat{U}/\Delta^*$ then
            while $|\mathcal{S}_{u^*}| < \hat{U}/\Delta^*$ do
                Find $\delta^* = \arg\max_{\delta \in \mathcal{S}_u\ \forall u \neq u^*} \| \mathbf{H}_{u^*}^\delta \|^2$,
                Find the user $\bar{u}^*$ to which $\delta^*$ belongs to
                $\mathcal{S}_{u^*} \leftarrow \mathcal{S}_{u^*} \bigcup \{\delta^*\}$, Update $C_{u^*}$
                $\mathcal{S}_{\bar{u}^*} \leftarrow \mathcal{S}_{\bar{u}^*} \setminus \{\delta^*\}$, Update $C_{\bar{u}^*}$
            end while
        end if
    end for
    Calculate the fairness factor $\mathbf{F}^*$ and $\epsilon = |\mathbf{F}^* - \mathbf{F}|$
    if $\epsilon \leq \epsilon^*$ then
        EXIT While
    else
        Adjust $\hat{U}$ accordingly
    end if
end while
```

Fig. 4 shows the spectral efficiency as a function of average received SNR for different scheduling and RA schemes in the presence of a fixed fairness index, $\mathbf{F} = 0.8$. Our proposed adaptive scheme is compared with two extreme cases, i.e., SC-FDE ($\Delta = 1$) and pure SIMO SC-FDMA ($U = \Delta$), with and without the DOC-based scheduling technique. As we can see

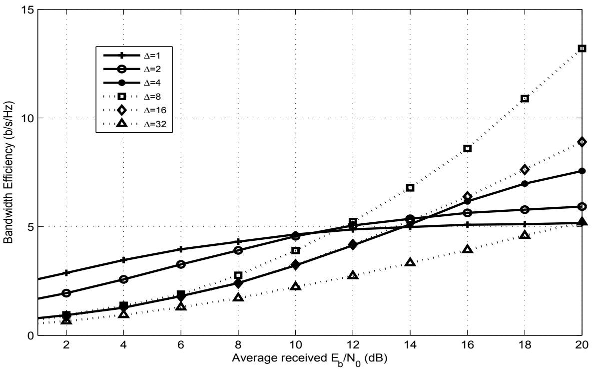


Fig. 2. Spectral efficiency *vs* average received SNR for different RB sizes and $N_r = 6$, $U = 32$ (with scheduling).

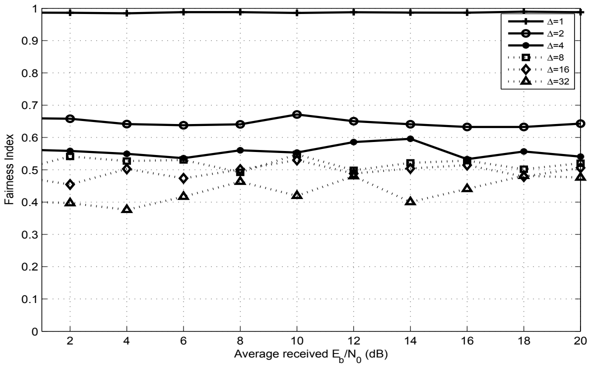


Fig. 3. Fairness index *vs* average received SNR for different RB sizes and $N_r = 6$, $U = 32$ (with scheduling).

our proposed adaptive scheme, which jointly selects the RB size and schedules the users, has the dominant performance for SNRs over 10dB. However, it has a similar performance with SC-FDE for SNRs below 12dB. By comparing SC-FDE and SIMO SC-FDMA ($U = \Delta$), we observe that SC-FDE has a better performance only for SNRs below 14dB, and for SNRs over 14dB its performance degrades due to increased MUI. Finally, Fig. 5 shows the spectral efficiency as a function of average received SNR for different Δs assuming $N_r = 2, 6$ and $U = 4$. As expected, SE increases by an increase in the number of receive antenna. However, for different N_rs, the maximum SE depends on the RB size.

V. Conclusion

We proposed an adaptive fairness-controlled multiuser scheduling and resource block allocation for uplink SIMO SC-FDMA system. A model for SIMO SC-FDMA system signal processing at the transmitter and receiver was first presented. Later, we derived the users's SINR, using a simple MMSE-FDE receiver. In order to design a low complexity algorithm for user scheduling, we proposed a grouping procedure based on the mutual degree of correlation between user's received channel vector. In order to control the fairness index, we control the simultaneous number of users which can access the system at the same time. Two algorithms were proposed for the scenarios with MUI and without MUI. Simulation results show that our algorithm improves the spectral efficiency, while keeping the fairness at the desired level.

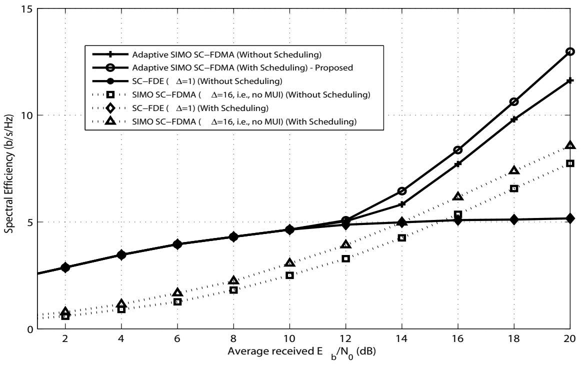


Fig. 4. Spectral efficiency *vs* average received SNR for different resource allocation scenarios, $N_r = 6$, $U = 32$ and target $\mathbf{F} = 0.8$.

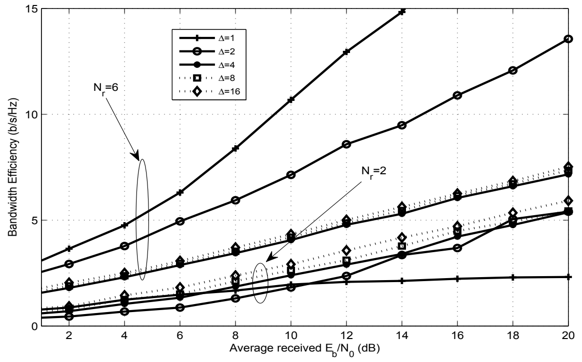


Fig. 5. Spectral efficiency *vs* average received SNR for different RB sizes and $N_r = 2, 6$, $U = 4$.

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