Joint Spatial and Frequency Proportional Fairness Scheduling for MIMO OFDMA Downlink

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***Abstract*-For multiuser MIMO system, Zero Forcing Beamforming (ZFB) can be adopted to exploit the multiuser spatial multiplexing gain and diversity gain in downlink by spatial multiuser scheduling. On the other hand, multiuser joint subcarrier allocation can obtain multiuser diversity gain in frequency domain. In this paper, a novel joint Spatial and Frequency Proportional Fairness (SFPF) scheduler is proposed to achieve the spatial-frequency multiuser diversity gain for multiuser MIMO OFDMA based LTE TDD system while guarantees the multiuser fairness. To approach the multiuser capacity, Multiuser ZFB (Mu-ZFB) is adopted for spatial multiplexing of multiuser on the same subcarrier. To simplify the antenna selection of Mu-ZFB, three simplified multiuser antenna selection algorithms are proposed, optimal, random and suboptimal antenna selection and their performance is evaluated in a single cell scenario. The optimal algorithm can achieve the best performance but has the highest complexity. The random algorithm has the worst performance but the lowest complexity. The performance comparison in a multi-cell scenario shows that three algorithms of SFPF can obtain a similar system throughput when guarantee the user fairness. While the suboptimal algorithm is a tradeoff between the performance and the complexity.**

Key Word: Multiuser MIMO, ZFB, SFPF, Scheduling

I. INTRODUCTION

As fast increasing of data rate required by the mobile services, 2Mbps of 3G systems is not enough any more in several years. Recently, WiMAX based on OFDM has been proposed to provide wide area coverage for high data rate service, which can provide 75Mbps peak data rate in 20MHz bandwidth. To make 3G competitive in several years, Long Term Evolution (LTE) of 3G is issued in 3GPP. The basic idea of LTE is to implement the functions of B3G partially in current 3G or any available spectrum. The objective of LTE is to provide packet-based high-data-rate service with enhanced spectrum efficiency, coverage, capacity, and low latency and low cost. The data rate of 100Mbps in downlink and 50Mbps in uplink are expected for 20MHz channel.

To fulfill the requirements of 3G LTE, OFDMA is proposed for LTE downlink [1] for its excellent capability to mitigate the frequency selective fading of the mobile environment and provide high spectrum efficiency. Further, OFDMA provides a natural multiple access method by assigning different users with orthogonal subcarriers, and multiuser diversity gain in frequency domain can be exploited by multiuser subcarrier scheduling [2].

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By configuring multiple antennas at both ends of communication link, the MIMO channel capacity may be improved to be proportional to the minimum number of the antennas at the transmitter and receiver [3]. Exploiting the Channel State Information (CSI) at the transmitter, VBLAST can also approach the capacity of MIMO channel. Besides, spatial multiuser diversity and multiplexing can be exploited to achieve a better cell throughput. [4] [5] have proposed the improved round robin and greedy antenna scheduler respectively for multiuser downlink with VBLAST to exploit the spatial multiuser diversity.

For TDD system, the channel reciprocity between uplink and downlink can be used to implement the spatial multiuser scheduling very conveniently. In [10], the initial performance evaluation on TD-SCDMA LTE downlink has been performed based on the multiuser Per Antenna Rate Control with Antenna Selection (MU-PARC-AS). In this paper, Multiuser Zero Forcing Beamforming (Mu-ZFB) [11] is proposed to enhance the multiuser MIMO performance in downlink. The cost of the Mobile terminal and per bit data can be reduced because Mu-ZFB can achieve a higher system throughput, simplify the mobile receiver and move the complicated MIMO processing to the Node B where more powerful processing unit and hardware are available. To achieve the tradeoff between the user fairness and the system throughput, a Spatial-Frequency Proportional Fairness (SFPF) scheduler is proposed for None-Real Time (NRT) service. Three multiuser antenna selection algorithms for Mu-ZFB are proposed, optimal algorithm, random algorithm and suboptimal algorithm. The performance of these algorithms is evaluated. For 10MHz bandwidth, the system spectrum efficiency of ZFB with SFPF converges to 3.5bps/Hz and 5.8bps/Hz for 2×4 and 4×8 MIMO scenarios respectively considering the overhead of the special slots of TD-SCDMA LTE system. From the simulation results, multiuser diversity gain can be achieved by SFPF scheduling where more users lead to higher system spectrum efficiency. The optimal algorithm can achieve highest spectrum efficiency but has highest complexity. The random algorithm has the lowest spectrum efficiency but lowest complexity. The suboptimal algorithm is a tradeoff between the performance and the complexity.

The organization of this paper is as follows. The system model of ZFB is introduced in section II; the Joint Spatial-Frequency PF scheduling is proposed in section III; the simulation parameters are given in section IV; the results are presented and analyzed in section V, and the conclusion are drawn in section VI.

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II. SYSTEM MODEL

The system model of the Mu-ZFB is presented as Figure 1. There are N_t and N_r antennas at the transmitter and receiver respectively. In this paper, the CSI is assumed to be known perfectly at the transmitter. The MIMO channel is assumed to be flat fading on every subcarrier. The CIR of the MIMO channel on a subcarrier can be expressed as:

$$\mathbf{H} = \left[H_{m,n} \right]_{N_r \times N_t} \tag{1}$$

Where $H_{m,n}$ is the channel impulse response between the transmitter antenna n and the receiver antenna m.

In this scheme, all the antennas of UEs are constructed as a virtual UE, which owns all the antennas from different UEs. And then the CIR of the virtual UE can be expressed as:

$$\mathbf{H} = \left[\mathbf{H}^1 \quad \dots \quad \mathbf{H}^i \quad \dots \quad \mathbf{H}^K \right] \tag{2}$$

Then the receiver antenna selection is executed to select out partial antennas to receive from the virtual UE. To guarantee the orthogonality among the independent data streams from the Node B, the selected receive antenna number should not be more than the antenna number at Node B. In this paper, the decremental antenna selection algorithm [7] has been adopted even it is much complex when the user number is large. Every time, one antenna is deleted from the receiver of the virtual UE, which contributes minimum to the total capacity, until every user only left one receiver antenna.

Then with the CIR selected, the Mu-ZFB can be applied. The beamforming weightmatrix is calculated as:

$$\mathbf{B} = \mathbf{H}^{\dagger} \left(\mathbf{H}\mathbf{H}^{\dagger} \right)^{-1} \mathbf{D} \tag{3}$$

Where $\mathbf{D} = diag\left(d_1, \dots, d_K\right)$ is the diagonal matrix which keeps the transmit power unchanged after beamforming, and $\dagger$ means the hermit transpose.

$$d_k = 1 \Big/ \sqrt{\left[\left(\mathbf{H}\mathbf{H}^{\dagger} \right)^{-1} \right]_{k,k}} \tag{4}$$

If M receiver antennas are selected, and $\mathbf{S} \in \mathbb{C}^{M \times 1}$ is the modulated symbol vector, the element s_k is the transmitted data symbol on the data stream k, the transmitted signal after beamforming is:

$$\mathbf{x} = \mathbf{BS} \tag{5}$$

And after the channel, the receiver signal at the virtual UE can be expressed as:

$$\mathbf{r} = \mathbf{Hx} + \mathbf{n} = \mathbf{HBS} + \mathbf{n} = \mathbf{DS} + \mathbf{n} \tag{6}$$

Because $\mathbf{D}$ is a diagonal matrix, the MIMO channel is decomposed into M SISO channel with channel gain d_k. The total power of the Node B can be allocated among the different data streams to maximize the total system capacity.

III. SFPF SCHEDULING

In a multiuser MIMO OFDMA system, different users experience independent spatial and frequency selective fading, and thus the multiuser diversity can be exploited by multiuser scheduling. In this paper, the frequency domain multiuser diversity of OFDMA and spatial multiuser diversity of MIMO are jointly considered and a joint spatial-frequency subcarrier and antenna selection algorithm is proposed to exploit the multiuser diversity in spatial-frequency domain. To guarantee the user fairness, the SFPF algorithm is proposed firstly in this paper.

Assume the set of M_T selected receiving antennas from all the UEs is presented as C_n, the selected optimal antenna set can be obtained optimally as following:

$$C_n^{'} = \underset{C_n \in [1, M_T]}{\arg} \; \underset{U_n \in [1,K]}{\arg} \; \max \sum_{U_n} C\left(C_n, U_n\right) \tag{7}$$

Where $C\left(C_n, U_n\right)$ is the total capacity of the selected users and antennas. To find the optimal solution, all the possible sets are compared. It is too complicated to be implemented. The user and antenna assignment algorithm proposed above can approach the multiuser MIMO capacity without considering the user fairness. In a real system, a proper algorithm is to guarantee the user fairness which achieve the multiuser diversity gain as much as possible.

We propose a joint spatial and frequency proportional fairness scheduling as following:

$$\Pr_n^k(t) = \frac{R_n^k(t)}{T_k(t)} \tag{8}$$

Where R_n^k is the theoretical data rate on subcarrier n of user k, and T_k is the average transmission data rate of user k, and it is updated as equation (9).

$$R_n^k = B \log_2 \left(\det \left(\mathbf{I} + \rho \left(\mathbf{H}_n^k \right)^H \mathbf{H}_n^k \right) \right) \tag{9}$$

Where B is the subcarrier spacing Here we assume that only one antenna at most can be assigned to one user on a subcarrier. Then on subcarrier n, M_T users' group C_n is selected as following:

$$\underset{C_n \in [1,K]}{\arg} \max \sum_{k \in C_n} \Pr_n^k(t) = \underset{C_n \in [1,K]}{\arg} \max \sum_{k \in C_n} \frac{R_n^k(t)}{T_k(t)} \tag{10}$$

M_R users with highest priority are selected to transmit in next timeslot.

For ZFB, one antenna of every selected UE is chosen to maximize the total system capacity. Then the virtual MIMO channel matrix on subcarrier n between Node B and the selected antennas of the selected UE can be expressed as:

$$\mathbf{H} = \left[\mathbf{H}_n^{C_n(1)} \quad \dots \quad \mathbf{H}_n^{C_n(i)} \quad \dots \quad \mathbf{H}_n^{C_n(M_T)} \right] \tag{11}$$

Where $\mathbf{H}_n^{C_n(i)}$ is the selected channel of UE $C_n(i)$ on subcarrier n and $C_n(i)$ means the element i of C_n. Then equation (3) and (4) can be used to calculate the channel gain and the beamforming vector for Mu-ZFB.

The power allocated to different data streams is expressed as p_n^k, and $P_T = \sum_{n=1}^{N} \sum_{k \in C_n} p_n^k$. If the user k is not scheduled to share the subcarrier n , then $p_n^k = 0$. Based on $\mathbf{H}$, the data rate of the user $C_n(k)$ on subcarrier n can be calculated as:

$$R_n^{C_n(k)} = B\log_2\left(1+SNR_n^{C_n(k)}\right) \quad (12)$$

Where B is the subcarrier spacing. In fact, in our simulation, the data rate of every data stream is decided by the selected Modulation and Coding Scheme (MCS) adopted in this work according to the Signal to Interference and Noise Ratio (SINR) on the data stream of every subcarrier. By configuring proper SINR threshold for the switching among the different MCS, the highest system throughput can be achieved with Adaptive Modulation and Coding (AMC).

The total data rate of user k in the next scheduling period is:

$$R_k = \sum_{n=1}^{N} R_n^k \quad (13)$$

Where N is the subcarrier number. T_k can be updated with R_k after the scheduling:

$$T_k = \begin{cases} (1-\alpha)T_k + \alpha R_k, \textit{if user k is served}. \\ (1-\alpha)T_k, \quad \textit{else} \end{cases} \quad (14)$$

Where $0 < \alpha < 1$ is the forgetting factor.

Then the total capacity of the system is expressed as:

$$C = \sum_{k=1}^{K} R_k = B\sum_{k=1}^{K}\sum_{n=1}^{N}\log_2\left(1+\frac{p_n^k\left(d_{n,k}\right)^2}{\left(\sigma_n^k\right)^2}\right) \quad (15)$$

For the SFPF scheduling, the multiuser antenna selection should be performed after the user set has been decided by (10). For multiuser antenna selection of Mu-ZFB, three simple algorithms have been proposed as following:

- **Algorithm 1: Optimal Multiuser Antenna selection（Opt）**

Step a: Try all the possible antenna assignment for user set C_n where every user is assigned one receiver antenna, find the antenna set A which achieves the highest multiuser capacity for Mu-ZFB on subcarrier n .

Step b: Based on $\mathbf{H}$ between receiver antenna set A and transmitting antennas, the gain on every spatial sub-channel of ZFB can be obtained as $d_k = 1/\sqrt{\left(inv\left(\mathbf{HH}^H\right)\right)_{k,k}}$, and the post SINR is calculated to select the proper MCS for every user correspondingly.

- **Algorithm 2: Random Multiuser Antenna Selection（Rand）**

Step a：For the selected M_T users, every user selects one antenna randomly from its M_R receiver antenna, and construct the receiver antenna set as A .

Step b: Based on $\mathbf{H}$ between receiver antenna set A and transmitting antennas, the gain on every spatial sub-channel of ZFB can be obtained as $d_k = 1/\sqrt{\left(inv\left(\mathbf{HH}^H\right)\right)_{k,k}}$, and the post SINR is calculated to select the proper MCS for every user correspondingly..

- **Algorithm 3: Suboptimal Multiuser Antenna Selection (Subopt)**

Step a: the MIMO channel matrix of M_T users selected constructs a generalized MIMO channel matrix, and one receiver antenna is selected, which maximize the MISO channel capacity between it and the transmitter antennas; Then delete the left receiver antennas of the selected user from the generalized MIMO channel matrix.

Step b: Select one receiver antenna from the left, and maximize the capacity of the MIMO channel between the selected receiver antenna and the transmitter.

Step c: Repeat step b until every user obtains one receiver antenna.

Step d: Based on $\mathbf{H}$ between receiver antenna set A and transmitting antennas, the gain on every spatial sub-channel of ZFB can be obtained as $d_k = 1/\sqrt{\left(inv\left(\mathbf{HH}^H\right)\right)_{k,k}}$, and the post SINR is calculated to select the proper MCS for every user correspondingly..

IV. Simulation parameters

In this paper, LTE TDD system is considered. The CSI is known perfectly at the transmitter by exploiting the channel reciprocity of TDD system. The MIMO channel model is 3GPP SCM [9], and the fixed Power Delay Profile (PDP) of Typical Urban (TU) is adopted. The user speed is 3km/h. The full buffer service model is assumed for every user. The frame structure from [8] is adopted in our simulation.

No H-ARQ is considered in link level simulation, but the chase combining is adopted in system level simulation. One sub-channel can be shared by multiple users according to the algorithms we proposed above. The estimation of the received SNR of every data stream from the spatial sub-channel of Node B on every sub-channel is based on the average on all 8 subcarriers. The scheduling is based on the sub-channel. The power of a sub-channel is allocated uniformly among the users who are sharing it.

Furthermore, to avoid the serious inter-cell interference, Soft Frequency Reuse is adopted in this work as that of [7] [10]. The other system simulation parameters are the same as that in [10].

V. Simulation results

In our simulations, 2×4 and 4×8 MIMO scenarios are simulated. In Figure 1, the system spectrum efficiency vs. UE number is presented. From the simulation results, the multiuser diversity gain from frequency and spatial domain can be achieved by SFPF scheduling proposed, where more users lead to higher system spectrum efficiency. The optimal algorithm can achieve the highest spectrum efficiency but has highest complexity. The random algorithm has the lowest spectrum efficiency but the lowest complexity. While the Subopt algorithm is a tradeoff between the performance and the complexity.

In Figure 2, the CDF of the user data rates are compared for three algorithms proposed in this paper. From the results, the user fairness can be guaranteed very well, and the data rate difference among users is very little.

VI. Conclusion

In TD-SCDMA LTE system, MIMO OFDMA is adopted in downlink to provide high spectrum efficiency in wideband system. OFDMA provides a natural multiple access method by assigning different users with orthogonal subcarriers, and multiuser diversity gain in frequency domain can be exploited by multiuser subcarrier scheduling. For multiuser MIMO, ZFB can implement multiuser spatial multiplexing by precoding, and spatial multiuser scheduling can achieve the spatial multiuser diversity gain further. While for a multiuser MIMO OFDMA system, the joint spatial and frequency scheduling may improve the system spectrum efficiency by exploiting the multiuser diversity gain in both frequency and spatial domain. In this paper, a SFPF scheduler is proposed to exploiting such gain and three simple multiuser antenna assignment algorithms are proposed. From the simulation results, multiuser diversity gain can be achieved by SFPF where more users lead to higher system spectrum efficiency. Comparing the three multiuser antenna selection algorithms, the optimal algorithm can achieve the highest spectrum efficiency but has the highest complexity, and the random algorithm has the lowest spectrum efficiency but the lowest complexity, while the Subopt algorithm is a tradeoff between the performance and the complexity.

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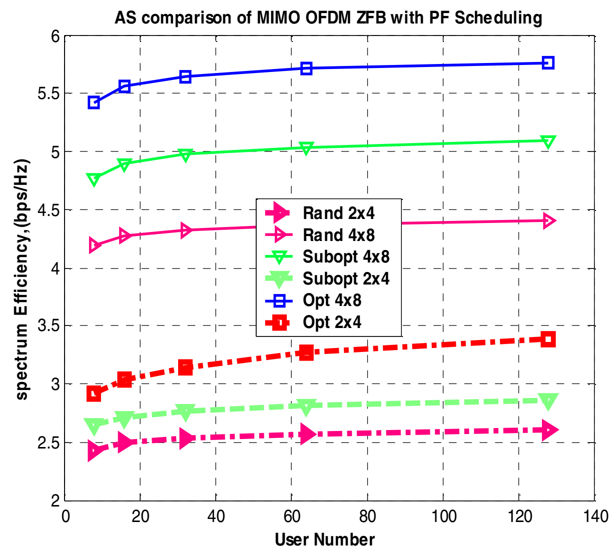

Figure 1 System spectrum efficiency vs. user number

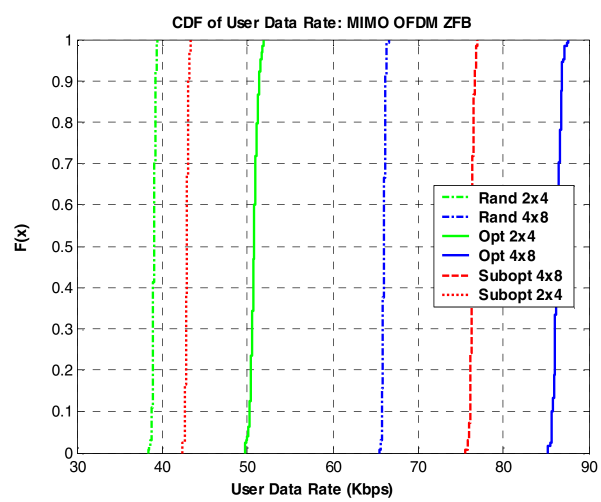

Figure 2 user data rate Vs. user number per cell