DATA ALLOCATION WITH MULTI-CELL SC-FDMA FOR MIMO SYSTEMS

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ABSTRACT

Joint resource allocation algorithm is used for dynamic user grouping, multi-cell cooperation and resource block allocation for single carrier frequency division multiple access (SC-FDMA) uplink in multi cell virtual MIMO systems. To develop the dynamic multi-cell user grouping criteria using minimum mean square equalization and adaptive modulation with bit error rate constraint. The main advantage of this system is to formulate and solve a new performance maximization problem. Furthermore, to reduce the computational complexity significantly, especially in the case of large numbers of users and RBs, the system present an efficient iterative Hungarian algorithm based on user and resource partitions to solve the problem by decomposing the large scale problem into a series of small scale sub-problems, which can obtain close-to-optimal solution with much lower complexity. The simulation results show that the joint resource allocation algorithm with dynamic multi-cell user grouping scheme achieves better system throughput with BER guarantee than fixed user grouping algorithm.

Keyword : - *Data allocation , user grouping, spectral efficiency, multiple input multiple output(MIMO) etc….*

1. INTRODUCTION

MIMO (multiple input, multiple output) is an antenna technology for wireless communications in which multiple antennas are used at both the transmitter and the receiver. The antennas at each end of the communications circuit are combined to minimize errors and optimize data speed.

MIMO is one of several forms of smart antenna technology, the others being MISO (multiple input, single output) and SISO (single input, multiple output).MIMO is a method for multiplying the capacity of a radio link using multiple transmission and receiving antennas to exploit multipath propagation.

In wireless the term "MIMO" referred to the use of multiple antennas at the transmitter and the receiver. In modern usage, "MIMO" specifically refers to a practical technique for sending and receiving more than one data signal simultaneously over the same radio channel by exploiting multipath propagation.

MIMO is fundamentally different from smart antenna techniques developed to enhance the performance of a single data signal, such as beam forming and diversity.

MIMO increases receiver signal-capturing power by enabling antennas to combine data streams arriving from different paths and at different times. Smart antennas use spatial diversity technology, which puts surplus antennas to good use. When antennas outnumber spatial streams, the antennas can add receiver diversity and increase range.

More antennas usually equate to higher speeds. A wireless adapter with three antennas can have a speed of 600 Mbps. An adapter with two antennas has a speed of 300 Mbps. The router needs multiple antennas and must fully support all features of 802.11n to attain the highest speed possible.

Eg1: As per Kong, the density of X increases with Y [3].

Eg 2: It is reported that X increase with Y [2].

2. DYNAMIC USER GROUPING FOR MULTI-CELL SC-FDMA UPLINK

The Block diagram of the Multi-cell Virtual MIMO for SC-FDMA uplink system contains transmitter and receiver blocks of SC-FDMA system and central controller for multi-cell co-operation as shown in fig-1.

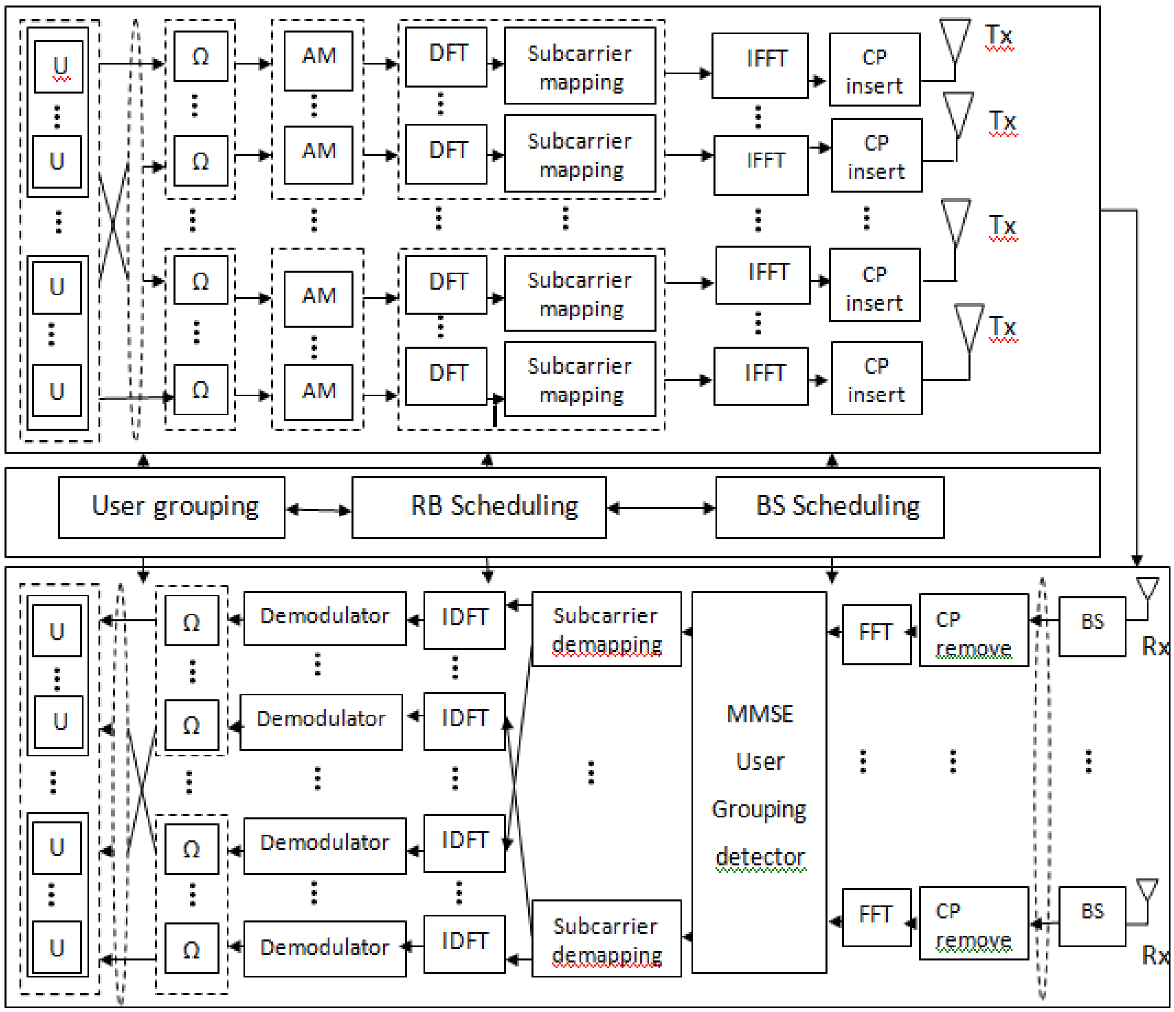

Fig-1 Block diagram of the Multi-cell Virtual MIMO for SC-FDMA

The user groups are scheduled on different RBs and receiving BSs in our scheme. Considering the time-frequency correlation, all subcarriers in one RB have assumed the same CSI which can be obtained by taking the average of the CSIs of the subcarriers within the RB. To keep procedures simple, to drop the subscripts of subcarrier/RB and receiving BS in the description of user grouping. For a multi-cell SCFDMA uplink with L cells and U active users, to write the group set according to the number of users scheduled in one group, that is

$$\Omega = \{\Omega_1^{NU},.., \Omega_m^{NU},..,\Omega_{Nr}^{NU}\} \quad (1)$$

Let $\Omega_m^{NU} = \{\Omega_{m,i}^{NU}\}$, $0 < i \leq |\Omega^{NU}|$ $\Omega_{m,i}^{NU} = (u_1, u_2, \cdots, u_m)$ denote the i-th user group corresponding to user index combination form $(u_1, u_2, \cdots, u_m)$ where $1 \leq u_1 < \cdots < u_m \leq LU$ and $1 \leq m \leq N_r$. Then, the group index i of $\Omega_{m,i}^{NU}$ can be expressed as

$$i = \left\{ \sum_{j=1}^{m-1} \Delta j + (u_m - u_{m-1}),\ m-1 \right. \tag{2}$$

where $\Delta_j = \binom{LU-uj-1}{m-j+1} - \binom{LU-(uj-1)}{m-j+1}$

Assume that L = 1, U = 20, m = 4 and the receiving antennas at BS is Nr = 4. Let B_m be m-user grouping matrix. Taking 4-user grouping as an example, B^4 can be written as follows,

$$\begin{array}{c} \text{Group index} \quad 1 \quad 2 \quad \ldots \quad 4222 \quad \ldots \quad |\Omega_4^{NU}| \\ B^4 = \begin{bmatrix} 1 & 1 & \cdots & 0 & \cdots & 0 \\ 1 & 1 & \cdots & 0 & \cdots & 0 \\ 1 & 1 & \cdots & 0 & \cdots & 0 \\ 1 & 0 & \cdots & 0 & \cdots & \cdots \\ 0 & 1 & \cdots & 0 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & 1 & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & \cdots & 0 & \cdots & 1 \end{bmatrix} \end{array} \tag{3}$$

The maximum capacity of virtual MIMO from user group *Ωg* to *l*-th receiving BS can be expressed as,

$$\Psi_{g,l} = \log_2 \det \left(INr + \frac{Es}{|\Upsilon\Omega g|\,\sigma 2} Hg,l\, Hg,l\, H \right) \tag{4}$$

To achieve the maximum system capacity, the receiving BS selection and dynamic user grouping criterion can be written as

$$\text{Group} - \text{Capacity}\ (\Upsilon, L) = \underset{g,l}{\arg\max} \{\Psi_{g,l}\} \tag{5}$$

The BER for an AWGN channel with MQAM and ideal coherent detection is bounded by,

$$BER^{\varphi} \leq 0.2\, e^{\frac{-1.5SNR}{2\varphi-1}} \tag{6}$$

The transmission efficiency of the virtual MIMO is

$$R_{g,l} = \sum_{u \in \Upsilon\Omega g} \varphi\, u,l \tag{7}$$

Then, the user grouping criterion based on MMSE equalization and AM techniques can be obtained as

$$\text{Group-MMSE-AM}(\Upsilon, L) = \underset{g,l}{\arg\max} \{R_{g,l}\} \tag{8}$$

2.1 JOINT USER GROUPING AND RESOURCE ALLOCATION IN MULTI-CELL SC-FDMA UPLINK

For multi-cell SC-FDMA uplink system, adjacent time frequency RBs which can only belong to one receiving BS should be assigned to one user group. Assume that *NRB* consecutive RBs are available to be allocated to users. To determine the allocation pattern number J the resource pattern matrix T is expressed as follows

$$\begin{array}{c} \text{Pattern} \quad 1 \quad 2 \quad \cdots \quad \cdots \quad \cdots \quad \cdots \quad \cdots \quad J\text{-}1 \quad J \\ T_{NRB \times J} = \begin{bmatrix} 0 & 1 & \cdots & 1 & 0 & \cdots & 1 & 0 & \cdots & 0 & 1 \\ 0 & 0 & \cdots & 1 & 1 & \cdots & 1 & 1 & \cdots & 1 & 1 \\ 0 & 0 & \cdots & 0 & 1 & \cdots & 1 & 1 & \cdots & 1 & 1 \\ 0 & 0 & \cdots & 0 & 0 & \cdots & 0 & 1 & \cdots & 1 & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \cdots & 0 & \vdots & \cdots & \vdots & 1 \\ 0 & 0 & \cdots & 0 & 0 & \cdots & 0 & 0 & \cdots & 1 & 1 \\ 0 & 0 & \cdots & 0 & 0 & \cdots & 0 & 0 & \cdots & 1 & 1 \end{bmatrix} \end{array} \tag{9}$$

2.2 SOLUTION ALGORITHM TO THE JOINT RESOURCE ALLOCATION PROBLEM

The optimization problem in above equation is a typical binary integer programming problem. So it can be converted to Office Assignment Problem (OAP) and use a linear programming (LP)-based BNB algorithm to solve the problem.

Especially when the number of cells, users and RBs becomes large. In order to reduce the complexity, the problem into a series of lower degree dimension sub-problems can be decomposed which can be modeled as bipartite graphs. Based on the consideration of constraints and , we regroup the elements in set Ω to create the complete user group set $\Omega^{CUG} = \{\Omega i^{CUG}\}$ so that each subset Ωi^{CUG} contains the groups with all users but has no duplicate users. Similarly, the complete RB pattern set $T^{CRP} = \{T_j^{CRP}\}$ can be created so that each subset T_j^{CRP} contains the RB pattern with all RBs but has no duplicate RBs.

Consider a multi-cell uplink virtual MIMO system with L co-ordinated BSs (i.e. L cells), where each cell contains one BS equipped with Nr receiving antennas, U single antenna users as shown in figure 4.2.

The propagation factor from u-th user of the j-th cell to the m-th antenna of the BS in the l-th cell is denoted as $h_{m,l,u,j} = \sqrt{\beta_{m,l,u,j}}\gamma_{m,l,u,j}$, where $\gamma_{m,l,u,j}$ is small scale fading factor, which is independent and identically distributed zero mean, circularly-symmetric complex Gaussian CN(0,1) random variables, and $\beta_{m,l,u,j}$ is large scale fading coefficient which models the geometric attenuation and shadow fading that are assumed to be constant over a coherence time and known a prior.

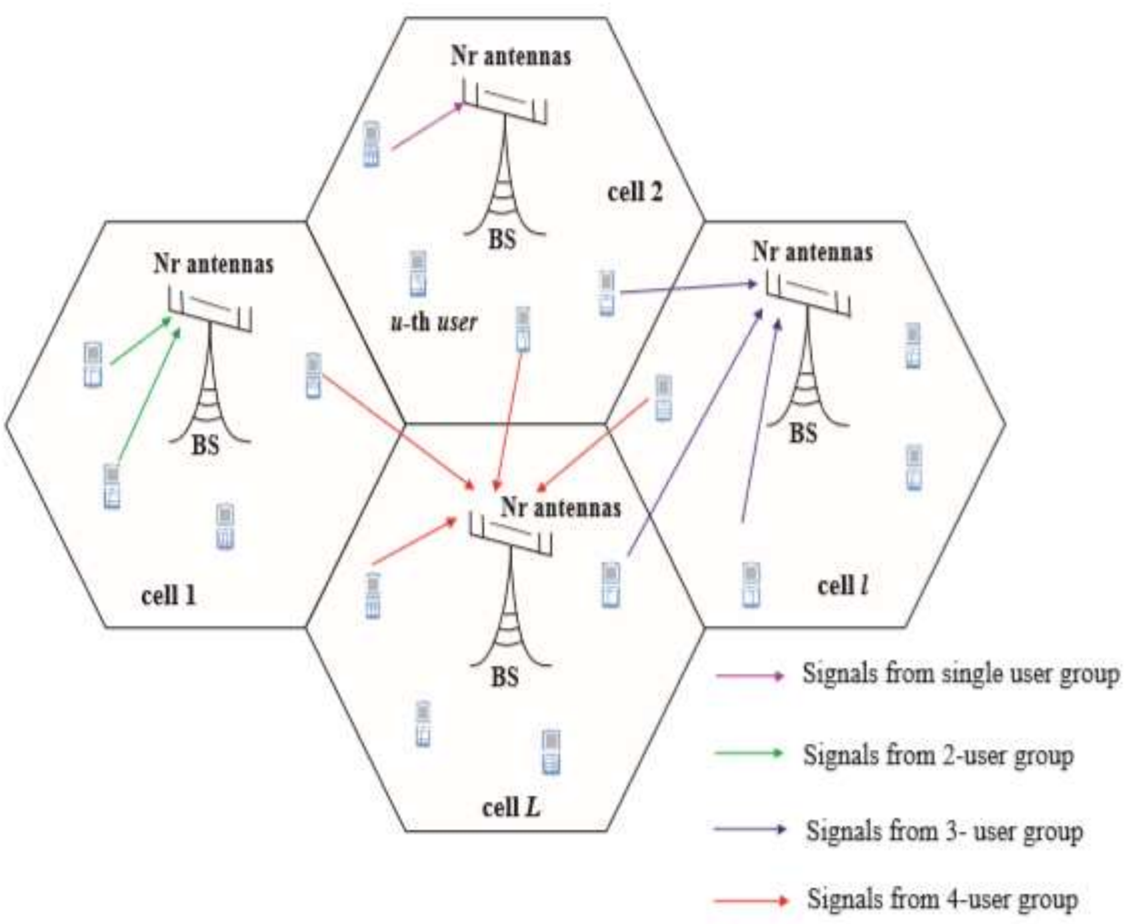

Fig-2 Illustration of the multi-cell uplink virtual MIMO system with uniform distribution of users (U) and co-ordinated BSs (L=4).

2.2.1 Construction of the Complete RB Pattern Set T^{CRP}

If there are NRB RBs available to be allocated, the size of the RB pattern set T^{CRP} will be $2^{\wedge NRB-1}$. Considering a NRB-RB sequence with the order of RB1,RB2,⋯ ,RB_{NRB}, to insert a underline between each of RBs to construct a new sequence,

$$\omega= \{RB_1,\_ ,RB_2,\_,...,\_ ,RB_{NRB}\} \tag{10}$$

Only 0 and 1 can be put on these underlines. Putting 0 on the underline between RB_i and RB_{i+1} means that RB_i and RB_{i+1} are assigned to the same RB pattern and vice versa. Through changing the values put on these underlines, all pattern subset T_j^{CRP} can be obtained and the size of the RB pattern set $|T^{CRP}|=2^{NRB-1}$ can be derived by multiplication principle.

Define j to be the index of subset T_j^{CRP} in T^{CRP}, then, j equals the value of the binary sequence inserted into sequence ω corresponding to T_j^{CRP}. Assume there are NRB = 6 RBs in the system, which are RB1,RB2, · · · ,RB6. Given the inserted binary sequence (1, 1, 0, 0, 1), the sequence ω is shown as follow

$$\omega= \{ RB_1 ,\underline{1} , RB_2 , \underline{1} ,RB_3,\underline{0},RB_4,\underline{0}, RB_5,\underline{1} , RB_6\} \tag{11}$$

2.2.2 Construction of the Complete User Group Set Ω^{CUG}

The integer partition of LU users can be divided into many groups and each group contains many users. Then, by the operation of user permutations and combinations based on the partition result, all the complete user subset can obtain. The total user number in one cluster is LU and the receiving antennas number at each BS is Nr. The total user number in one cluster is LU and the receiving antennas number at each BS is Nr. Generating the integer partition of LU Call the Procedure to complete the integer partition operation of LU and obtain the partition matrix Q whose sum of each row vector equals LU. Here, the integer partition operation of LU means listing all possible values of n1,n2,⋯ ,nLU, which meet the requirement of the following equation,

$$n1 + n2 + \cdots + ni + \cdots + nLU = LU \tag{12}$$

where $0 \le ni \le ni+1 \le Nr$ $(1 \le i \le LU - 1)$. Generating the user group set Ω^{CUG} based on the integer partition of LU Let q^i be the i-th row vector of Q. Then, obtain set qi = {qi,1,qi,2,⋯ ,qi,W} by deleting the 0 elements in q^i, where $0 < qi,1 \le qi,2 \le \cdots \le qi,W \le LU$, $W \le LU$.

The size of Ω_{qi}^{CUG} can be derived as follows

$$\Xi_i = \frac{\binom{LU}{qi,W}\binom{LU-qi,W}{qi,W-1}\cdots\binom{LU-\sum_{w=2}^{W} qi,W}{qi,1}}{\xi 1!\,\xi 2!\ldots\xi r!\ldots\xi Nr!} \tag{13}$$

where ξ_r, $1 \le r \le Nr$ is the number of elements in qi = {qi,1,qi,2,⋯ ,qi,W}, which is equal to r.

2.2.3 Size Analysis of Complete User Group Set Ω^{CUG}

The size of complete user group set Ω^{CUG} mainly depends on the partitions of LU users. In the following, the partition number of LU users with the group user number limit Nr, then, discuss the size of complete user group set Ω^{CUG}. Let P_Nr (LU) be the partition number of LU with no parts greater than Nr,

$$P_{\le}^{Nr}(LU) = \sum P_{\le}^{Nr-1}(m) \times b_{LU-m,} P_{\le}^{Nr-1}(0) = 1 \tag{14}$$

The accurate complexity analysis of the algorithms solving the joint resource allocation problem is difficult, the maximum dimension of allocation vector and the full search number in the optimization used to simply analyze the algorithm complexity for BNB algorithm.

2.3. IHA URP ALGORITHM

The Hungarian method is based on the theorem that is stated below.

If a constant is added (or subtracted) to every element of any row (or column) of a given n-by-n cost matrix in an assignment problem, then the assignment which minimizes the total cost for the new matrix will also minimize the total cost matrix. In this regard, $C_{ij} \ge 0$ is the cost of assigning the i th candidate to the j th task to build the input cost matrix.

Once the algorithm's mathematical aspects have been discussed, the procedure outlined by the Hungarian method to find an optimal solution consists of the following steps:

- Step 1: To identify and subtract the minimum number in each row from the entire row.
- Step 2: To identify and subtract the minimum number in each column from the entire column.
- Step 3: Cross all zeros in the matrix with as few lines (horizontal and/or vertical only) as possible.
- Step 4: Test for optimality:
    - If the minimum number of covering lines is n, an optimal assignment of zeros is possible and we are done.
    - If the minimum number of covering lines is less than n, an optimal assignment of zeros is not yet possible. And in this case, is necessary to proceed to Step 5.

- Step 5: To determine the smallest entry not covered by any line. Subtract this entry from each uncovered row, and then add it to each covered column. Return to Step 3.

Thus, the fact of following the previous steps will enable us to solve the assignment problem by obtaining an optimal one-to-one allotment.

After the generation of complete RB pattern set and complete user group set, iterative Hungarian algorithm can be used to obtain the resource allocation. However, according to the size of complete user group set Ω^{CUG} grows rapidly with the increase of user and RB numbers so that the computational complexity is still unbearable. Actually, when given a complete RB pattern subset, only one complete user group subset which belongs to a user partition can be selected as the best match. So, we can compress resource allocation using greedy strategy. Inspired by these ideas, we present an efficient sub-optimal IHA URP algorithm to solve problem with the following two phases:

- Initial phase:

The integer partitions of LU and NRB can be obtained. Since RBs must be adjacent in one pattern, complete RB pattern set T^{CRP} can be obtained as well.

- Running phase:

Complete user group set compression and joint resource allocation First, compress the size of Ω^{CUG} according to the user partition results by greedy algorithm. When given a complete RB pattern subset T_j^{CRP}, to get P_Nr (LU) best matched complete user group subsets based on partition results. Then, perform joint resource allocation. Select the complete user group subset and complete RB group subset with maximal sum-rate from the results of previous process.

2.3.1 Generation of the Best Matched Complete User Group Subset from a User Partition

Given a partition qi = {qi,1, · · · , qi,W } and a complete RB pattern subset T_j^{CRP} ={ T^{CRP},1 , · · · ,T_j^{CRP},V}, the best matched complete user group subset can be generated using Hungarian algorithm with greedy strategy.

- The performance measure matrix of T_j^{CRP} and Ω^{NU} qi for cell l can be constructed.
- Find the best match between resource pattern and user group by the operation (v_,w_, l_, g_) = arg max v,w,l,ˆg { bηv,w,l| v ∈ [1, V] , w ∈ [1,W] , l ∈ [1,L]},where v∗, w∗, l∗ and g∗ mean the resource pattern index, part of partition qi, the index of cell and the group index, respectively. Then the assignment index δj,i v∗,g∗,l∗ = 1, the pre-allocated users are $Y_{\Omega g}$∗.
- Delete v_-th row and w_-th column from the matrix when l values from 1 to L and put each of it into matrix respectively, then remove users YΩg from Y and update the group set {Ω_m^{NU} }according to new user set Y, and then, go to step 1 until the elements of matrix are empty.
- Then, the sum-rate of T_j^{CRP} and Ω_{qi}^{NU} in cell l equals Rj,I = ΣvΣgΣlbηv,w,l . δj,iv,g,l and the assignment index corresponding to them is δj,i. After 2NRB^-1.P<=Nr (LU) iterations, all best matches between {T_j^{CRP}} and {Ω_{qi}^{CUG}} for each cell, the sort operation is used to find the resource allocation result:

$$(j^*,i^*) = \arg\max\{ R_{j,i} | j \in [1,|T^{CRP}|],i \in [1,n]\} \tag{15}$$

The operations in initial phase are performed only once, so the running time of the proposed algorithm mainly comes from running phase. IHA URP algorithm, iterative processes are performed with compression operations where the assignment operations are performed by Hungarian algorithm with greedy strategy. As a combination optimization problem, the complexities of the processes are demonstrated by combination numbers and the iteration number. For the proposed IHA URP algorithm, the total complexity is

$$\binom{156}{6} \cdot 6! \cdot 32 \cdot 7+32 \approx 2.929\times10^{15}$$

The proposed IHA URP algorithm dramatically reduce the complexity. Moreover, since the sub-problems are independent, the solution operations for these $P^{\leq Nr}(LU)\times 2^{NRB-1}$ sub-problems can be run in parallel mode for fast processing in practice.

3. RESULT AND ANALYSIS

3.1 Simulation Outputs

The corresponding simulation represents 'Dynamic user grouping with multi-cell cooperation' algorithm outperforms 'Dynamic user grouping without multi-cell cooperation' algorithm and 'No user grouping without multi-cell cooperation' algorithm, which due to the former can achieve multi-cell selective gain and grouping multiplexing gain while the latter two algorithms cannot. The 'Dynamic user grouping with multi-cell cooperation' algorithm achieves much higher spectral efficiency than the 'Conventional fixed 2-user grouping' algorithm and 'Conventional fixed 2-user grouping algorithm as shown in fig-3.

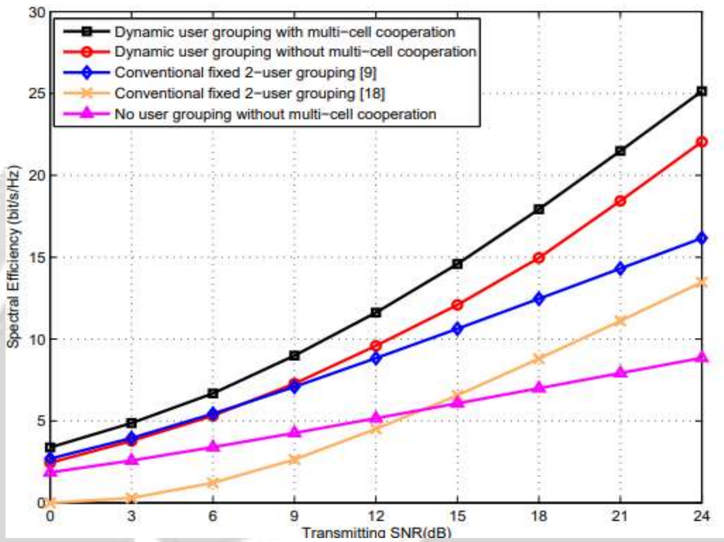

Fig-3 Simulation output of different resource allocation groups

The corresponding simulation represents that the spectral efficiency of 'Dynamic user grouping with multi-cell cooperation' algorithm always outperforms that of fixed 1-, 2-, 3-user grouping algorithms in both high SNR region and low SNR region. The performance gain comes from grouping multiplexing gain and multiuser selection gain. In the low SNR region, due to the BER constraint, the algorithms of small fixed grouping user number work well while the algorithms of large fixed grouping user number work well in high SNR region as shown in fig-4.

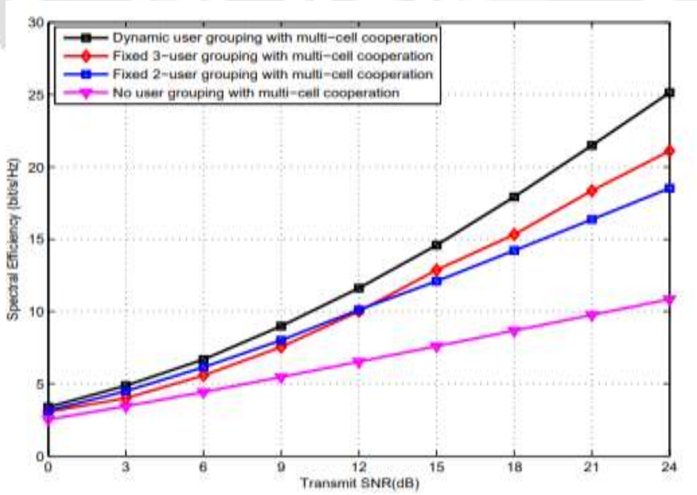

Fig-4 Simulation output of fixed user grouping algorithms

The corresponding simulation represents that the spectral efficiency rises when BER performance constraint drops, which mainly because the number of active grouping users becomes large. This leads to different spectral efficiency due to the different grouping user multiplexing gain and multiuser selection gain. So, the proposed ‘Dynamic user grouping with multi-cell cooperation’ algorithm can achieve trade-off between BER performance and spectral efficiency as required. as shown in fig-5.

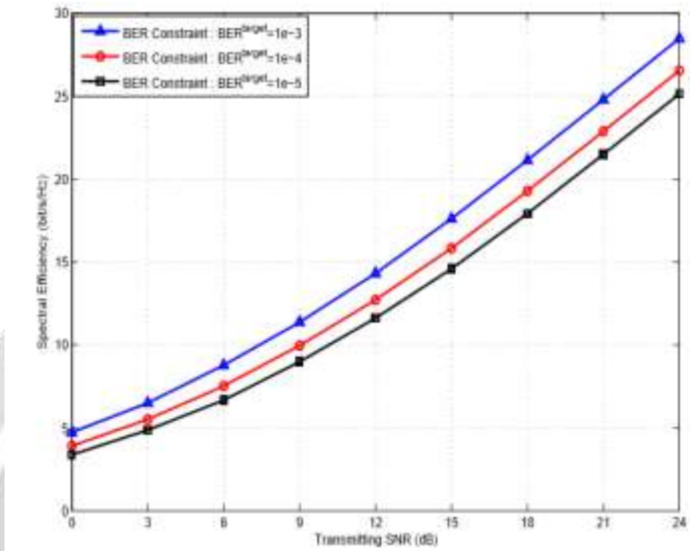

Fig-5 Simulation output of different BER constraints

The corresponding simulation represents both the algorithms with dynamic user grouping and the algorithms with fixed 2-user grouping have the phenomenon that spectral efficiency of the cluster consisting of 4 cells outperforms that of others. The conclusion is obtained that the more cells one cluster consists, the higher spectral efficiency is. Because the cluster consisting of more cells can achieve much higher RB selection gain, multiuser selection gain and multi-cell selection gain than the cluster with less cells. The cluster consisting of 4 cells has 32 users for grouping and 8 RBs for allocation which can achieve much higher selection gains than the cluster consisting of only 1 cell case as shown in fig-6.

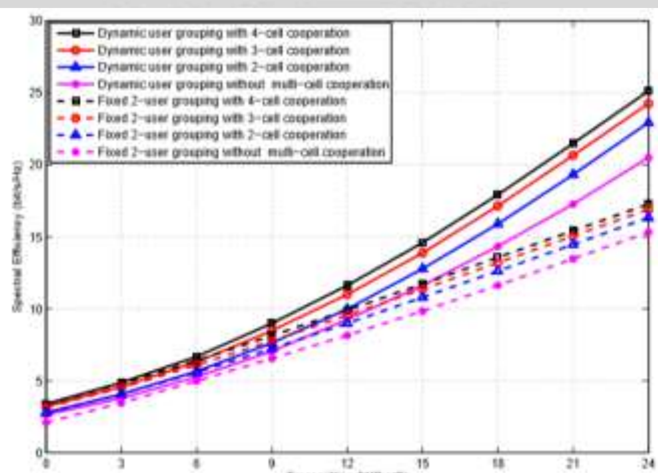

Fig-6 Simulation output of Spectral efficiency versus transmitting SNR for one cluster consisting of different number of cells

The corresponding simulation represents that the spectrum efficiency increases as the number of users increases. As expected, when the number of users increases, the overall spectral efficiency of each experiment improves due to the increased degrees of user freedom the number of users in one cluster increases over 28, the increase of spectrum efficiency gain becomes negligible that the 'Dynamic user grouping with multi-cell cooperation' algorithm has much larger spectral efficiency than 'Dynamic user grouping without multi-cell cooperation', 'Conventional fixed 2-user grouping [9]' and 'No user grouping with multicell cooperation' algorithms no matter smoothing window length is small or large. as shown in fig-7.

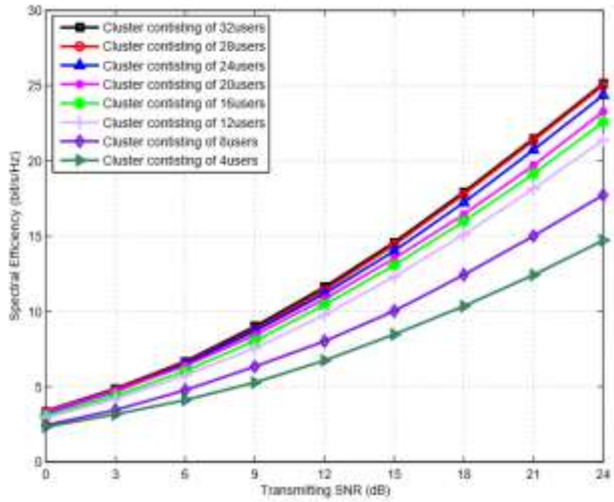

Fig-7 Simulation output of Spectral efficiency versus transmitting SNR for one cluster consisting of different user numbers.

The fig-8 represents that the fairness indices of those four algorithms are greater than 0.99 and close to 1. So when user fairness is taken into account by using the proportional scheduling, the fairness of each user in the system is guaranteed. It also represents that both fairness index and spectral efficiency curves for all algorithms tend to be stabilized when the length of smoothing window is greater than 70. So, it is suitable to set the smoothing window length 70 for practical use.

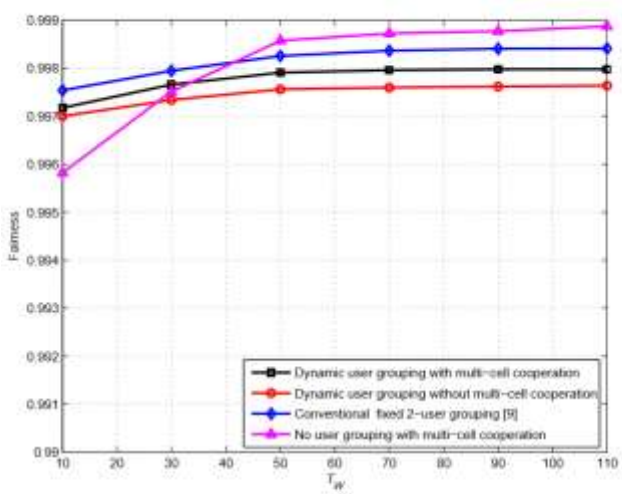

Fig-8 Simulation output of fairness index

The fig-9 represents that 'Dynamic user grouping with multi-cell cooperation' algorithm has much larger spectral efficiency than 'Dynamic user grouping without multi-cell cooperation', 'Conventional fixed 2-user grouping' and 'No user grouping with multicell cooperation' algorithms no matter smoothing window length is small or large. So the proposed algorithm has better trade-off between user fairness and spectral efficiency than others. It also represents that both fairness index and spectral efficiency curves for all algorithms tend to be stabilized when the length of smoothing window is greater than 70. So, it is suitable to set the smoothing window length 70 for practical use.

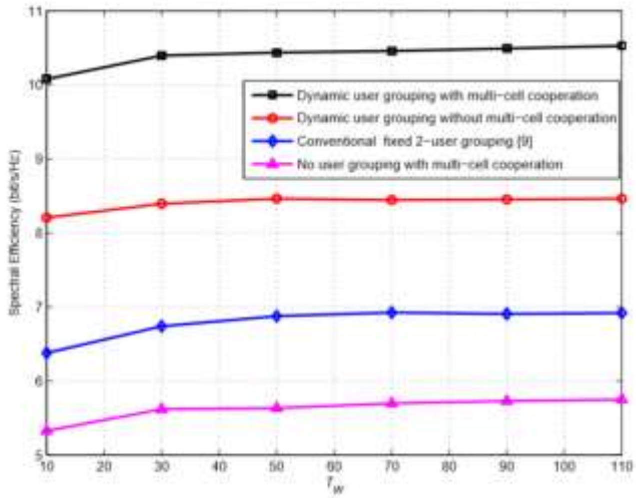

Fig-9 Simulation output of spectral efficiency

4. CONCLUSION

This technique proposed a dynamic user grouping and joint resource allocation algorithm for SC-FDMA uplink in multi-cell virtual MIMO systems. Multi-cell cooperation is to achieve maximum system overall throughput with MMSE equalization and AM techniques. In addition, to reduce the computation complexity, an efficient IHA URP algorithm for solution of the joint resource allocation problem. BNB algorithm is too complex for a practical implementation especially when the number of cells, users and resource block becomes large. The proposed algorithm has better trade-off between user fairness and spectral efficiency than others. After the generation of complete RB pattern set and complete user group set, iterative Hungarian algorithm is used to obtain the resource allocation. The simulation results demonstrated that the proposed algorithm attains better system throughput than both the traditional algorithms with fixed user grouping and the algorithms without multi-cell co-operation. The performance of IHA URP is close to that of BNB which has the optimal performance.

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