Joint Scheduling Algorithms for LTE-A CoMP System

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Abstract — **This paper investigates a novel type of Joint Scheduling algorithm for LTE-A CoMP system in a time and frequency selective fading channel. Two algorithms named SEB (Spectrum Efficiency Based) and JSB (Joint Score-Based) are proposed. Based on the spectrum efficiency optimization and the spectrum efficiency & users' fairness co-optimization, we formulate the optimization problems and give out the greedy-algorithm-based solutions. They try to select the best user and the best transmission method (CoMP or Non-CoMP) dynamically on every different time and frequency band to get better performance. It is proven by the simulation that 1) the best spectrum efficient can be achieved when SEB is used, especially when the channel quality is poor; 2) when taking the users' fairness into account, JSB outperforms other scheduling algorithms.**

Index Terms—**CoMP resource allocation, spectrum efficiency optimization, Score –Based scheduling**

I. INTRODUCTION

To meet the dramatic capacity and high transmission speed demand in Long Time Evolution Advanced (LTE-A), both intra-cell and inter-cell interference (ICI) should be managed appropriately. To deal with the intra-cell interference, Orthogonal Frequency Division Multiplexing (OFDM) has been proven a key technology. How to eliminate the inter-cell interference is still a crucial problem [1]. Although the authors in [2][3] propose soft or fractional frequency reuse as solutions to reduce inter-cell interference, the spectral efficiency is limited. ICI Coordination (ICIC) is also considered to eliminate ICI, which allocate orthogonal channel resources to the cell-edge users in each Transmit Time Interval (TTI)[4]. But the spectral efficiency of ICIC system is still not sufficient. To better manage the ICI and improve the system capacity, Coordinated Multipoint Transmission/Reception (CoMP) is proposed [5].

So far, CoMP has been demonstrated as an efficient approach to improve the cell-edge user's throughput and the whole cell throughput [6-9]. There are two types of CoMP, Coordinated Scheduling/Beam-forming (CS/CB) and Joint Processing/Transmission (JP/JT)[10]. Both of them implement a spatial reuse of radio resources, while JP/JT CoMP is studied more widely since it usually achieves larger capacity gain than CS/CB[11]. The researchers have focused on various aspects of JT/JP CoMP, such as information feedback, resource allocation and, scheduling.

Current investigations on resource allocation and scheduling schemes in CoMP system can be categorized into two strategies as follows:

1) The most commonly proposed is a Resource-Divided-Users-Divided (RDUD) strategy. As illustrated in [12], the cell-center users and the cell-edge users should firstly be divided by a threshold, which is normally a certain value of long-term-averaged Signal to Interference and Noise Ratio (SINR). Each cell-edge user has a BS cooperative cluster which is also called a CoMP Cooperating Set and composes of the cells transmitting data to this user [13]. Generally, the clustering schemes can be classified into static ones and dynamic ones. In static clustering, the fixed combinations of BSs should be maintained for a long period [14][15], with benefits of less signal overhead and lower complexity. But it leads to a limited gain of performance due to the time-variant of wireless channel as well as users' location. With regard to the dynamic clustering, ref. [16-18] propose that each user select its cooperation BSs based on average channel quality to achieve better performance. Hence, these clustering schemes may result in overlap of clusters and higher complexity. Ref. [19] proposes a multi-layered clustering method as a trade-off solution. After clustering, the system schedules RBs to the cell-center users and the cell-edge users separately. Normally, a specific CoMP frequency zone is always defined firstly for the cell-edge uers [20]. Due to the frequent fluctuations in the number of cell-edge users, a flexible allocating of CoMP frequency zone is supposed to be adopted. In ref. [7], a central unit (CU) is installed as a central scheduler to get all the User Equipments (UEs)' Channel State Information (CSI) and dynamically allocate resource. Another method is to further divide the CoMP frequency zone into several smaller partitions, each of which will be assigned to a certain cooperative cell, guaranteeing sufficient coordinated resource distributed in a cluster [17]. The typical scheduling algorithms, such as

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Proportional Fairness (PF) and Round Robin (RR), then can easily implement in different frequency zone for all kinds of users. ***However, CoMP frequency zone is not always allocated accurately in RDUD strategy [21], the throughput gain of CoMP is not sufficient.***

2) Another strategy, which can be named as Users-Divided-Only (UDO) based on PF algorithm has been proposed in ref. [21]. In contrast with RDUD, it keeps frequency band un-pre-allocated, and treats all UEs equally in every RB. The fairness of users would be well guaranteed, even though the users are also partitioned to cell-center users and cell-edge users. This scheme obtained better throughput of cell-center users and cell-edge users. ***However, the pre-defined transmission mode of users would restrict the flexibility of resource allocation and reduce the potential user diversity gain.***

Based on the above analysis, this paper studies a type of Non-Division (ND) joint scheduling algorithm, which aims to achieve the maxim spectrum efficiency as well as the cell-edge's users' throughput. Two algorithms named SEB and JSB are proposed based on the spectrum efficiency optimization and on the spectrum efficiency & users fairness co-optimization. The rest of this paper is organized as follows. Section II discusses the system model. Section III introduces SEB joint scheduling algorithm and gives the simulation results. Section IV presents JSB joint scheduling algorithm and gives the simulation results, which taking the users' fairness into account as well as the spectrum efficiency. Finally, section V draws our conclusions.

II. System Model

We consider a cellular OFDM system with the topology below (Fig.1). This is a centralized CoMP architecture recommended by 3GPP [22], which has a CU in a cooperative cluster, and a cell refers to a "sector".

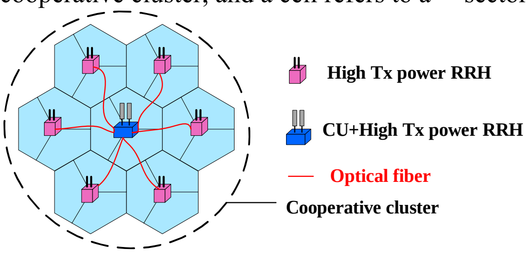

Figure 1. System Architecture

We assume SU-MIMO JP CoMP is implemented, and Adaptive Modulation & Coding (AMC) is used in each RB with the same and constant power. While adopting centralized scheduling, we assume the whole network as a cooperative cluster.

Assume sector m as the primary severing sector of UE j (Let j denote the unique ID of this UE); the SINR of UE j on RB$_i$ can be given by

$$SINR_{ji} = \begin{cases} \dfrac{p_{ji,m}\,|h_{ji,m}|^2}{\sum_{n\neq m} p_{ji,n}\,|h_{ji,n}|^2 + N_0} & (\text{Non-CoMP}) \\ \dfrac{p_{ji,m}\,|h_{ji,m}|^2 + \sum_{n\neq m, n\in C_{ji}} p_{ji,n}\,|h_{ji,n}|^2}{\sum_{n\notin C_{ji}} p_{ji,n}\,|h_{ji,n}|^2 + N_0} & (\text{CoMP}) \end{cases} \quad (1)$$

where $p_{ji,m}$ represents the transmitting power of sector m on RB$_i$, $h_{ji,m}$ represents the corresponding channel gain, C_{ji} represents the cooperative cluster of UE j on RB$_i$, and N_0 represents the noise power.

Assume that the achievable rate of UE j on RB$_i$ is R_{ji}, which can be depicted as a function of SINR according to

$$R_{ji} = f(SINR_{ji}) \quad (2)$$

III. Spectrum-Efficiency-Based (SEB) Joint Scheduling Algorithm

A. Concept

Let U_m denote the UE set of sector m. Assume M as the number of sectors, and I as the number of RBs (As the frequency reuse factor in LTE-A is set to 1, all sectors have I RBs on the same frequency band). Let $Y=[y_{ji,m}]$, set $y_{ji,m}$=1 if RB$_i$ of sector m is allocated to UE j ; otherwise $y_{ji,m}$=0. The system throughput is given by

$$TH(Y) = \sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j\in U_m} y_{ji,m} R_{ji} \quad (3)$$

In order to optimize the spectrum efficiency, we have

$$\text{MAX } TH(Y) = \sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j\in U_m} y_{ji,m} R_{ji} \quad (4)$$

s.t.

$$\sum_{j\in U_m} y_{ji,m} \in \{0,1\}, m = 1,2,\ldots,M; i = 1,2,\ldots,I \quad (5)$$

$$y_{ji,m} \in \{0,1\}, j = 1,2,\ldots,J; i = 1,2,\ldots,I \quad (6)$$

Function (5) means no more than one user would occupy one RB in a sector.

B. Suboptimum SEB Joint Scheduling Algorithm

The problem mentioned above is a typical nonlinear programming whose optimum solution is difficult to obtain while we can get the suboptimum solution by using greedy algorithm. Let J denote the number of UEs.

```
Greedy Algorithm
Y = zeros(J,I,M)  *
for i=1:I do
   for m=1:M   do
      for k=1:card(U_m)   do
         j = U_m(k)
         T= zeros(J,I,M)
         T(j,i,m) = 1
```

```
            Ω_j = TH(Y+T) − TH(Y)
        end for
        for n=1:m-1 do
            T = zeros(J,I,M)
            j = index(1,Y(:,i,n)) **
            T(j,i,m) = 1
            Ω'_n = TH(Y+T) − TH(Y)
        end for
        j* = arg max Ω_j
        n* = arg max Ω'_n
        if Ω_j* ≥ Ω'_n*
            Y(j*,i,m) = 1
        else
            j = index(1,Y(:,i,n*))
            Y(j,i,m) = 1
        end if
    end for
end for
```

* ***zeros(a,b,c)*** creates an a-by-b-by-c array of zeros

** ***Index(a,b)*** returns the index of element a in array b;*Y(:,i,n)* is a vector composed of all elements in the i_{th} column and n_{th} depth of *Y*

In the above algorithm, *RBs* will be allocated in turn. As for each RB in each sector and for each UE, Ω'_n and Ω_j are calculated, while Ω_j denotes the profit of allocating the RB to UE *j* with Non-CoMP transmission and Ω'_n denotes the profit of allocating the RB to UE *j* with CoMP transmission. If the maximum value of Ω_j is more than the maximum value of Ω'_n, RB *i* is allocated to UE as a CoMP transmission channel, otherwise, as a Non-CoMP transmission channel. For the fairness of all the sectors, the loop sequence of sectors should be adjusted at the beginning.

C Simulation Results

The performance of this algorithm can be analyzed by using CoMP system-level simulation platform. The specific simulation parameters are listed in Table I.

TABLE I.

SIMULATION PARAMETERS

Parameter	**Value**
Frequency	2.0GHz
Bandwidth	10MHz
Thermal noise density	-174dBm/Hz
Noise figure of receiver	9(dB)
Number of antennas	2×2
Transmission mode	CLSM
Simulation duration	10×100 TTIs
Distance between eNBs	500 m
Number of sectors	19 eNBs, 57 sectors
Minimum coupling loss	70 dB
Large scale fading	128.1+37.6log10(R)
Shadow fading	lognormal, space-correlated, μ=0,σ=10(dB)
Small scale fading	PedB model
eNB transmit power	43 dBm
User distribution	Uniform distribution 10UEs/sector
UE's speed	5 km/h
Antenna pattern	$A(\theta)=-\min[12(\frac{\theta}{65})^2, 20\text{ dB}]$
Traffic model	Full buffer

Fig. 2 presents the CDF curves of normalized user throughput for LTE-A CoMP with different scheduling schemes. RDUD RR represents CoMP with Round Robbin algorithm under RDUD strategy, UDO PF represents CoMP with joint PF algorithm under UDO strategy proposed in [21], and SEB represents the proposed scheme in this section. All these schemes have no upper limit of UE SINR. Table II. exhibits the corresponding simulation results.

It can be seen that the SEB can maximize the system throughput, but the performance of cell edge users is poor, which means it does not provide any guarantee of users' fairness.

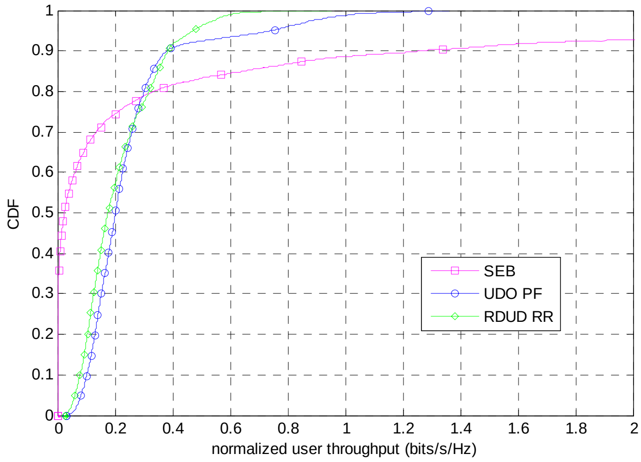

Figure 2. CDF of sector throughput for three schemes

TABLE II.

NORMALIZED SECTOR THROUGHPUT AND CELL-EDGE USER THROUGHPUT OF THREE SCHEMES

	SEB	UDO PF	RDUD RR
Normalized sector throughput (bits/s/Hz/sector)	5.21	2.49	2.12
Normalized cell-edge user throughput(bits/s/Hz)	0.0000	0.0830	0.0607

For further analysis, we simulate the spectrum efficiency with another two scenarios, one adopts the Maximum Carrier to Interference (Max C/I) scheduling algorithm in Non-CoMP system, and the other adopts SEB algorithm proposed in this section. The two scenarios have been simulated under different SINR limit, which is the upper-bound of the signal level that all UEs received. Fig. 3 and Table III. present the simulation results.

From the simulation results, we know that the proposed SEB algorithm is very "sensitive" to the signal level. That is, when the average channel quality of the sector is poor, SEB can obviously improve the spectrum efficiency as compared with the Non-CoMP system with Max C/I algorithm. This is because the gain of CoMP is larger than that of multi-user diversity under such conditions.

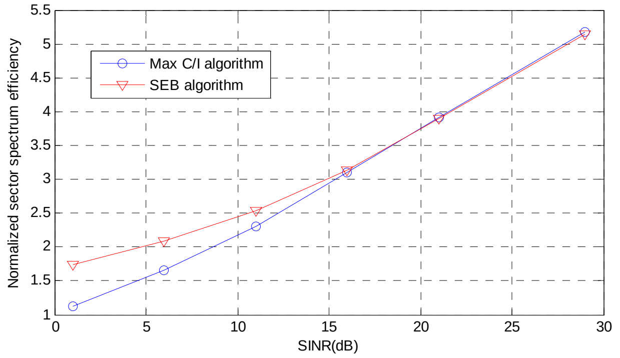

Figure 3. Simulation of two algorithms

TABLE III.

COMPARISON OF SECTOR SPECTRUM EFFICIENCY BETWEEN TWO ALGORITHMS

SINR of UEs	⩽ 1dB	⩽ 6dB	⩽ 11d B	⩽ 16d B	⩽ 21d B	⩽ 29d B
Spectrum efficiency with Max C/I algorithm （bit/s/Hz/sector）	1.12	1.65	2.30	3.09	3.91	5.18
Spectrum efficiency with SEB algorithm (bit/s/Hz/sector)	1.74	2.09	2.53	3.14	3.89	5.15

Although the SEB can maximize the system throughput, it does not provide any guarantee of users' fairness. Meanwhile, a large amount of channel quality feedback from UE is needed by the CU during the scheduling, so the considerable signaling overhead is a big problem. Therefore, we propose a more practical scheduling algorithm to solve these problems in the next section.

IV. JOINT SCORE BASED (JSB) SCHEDULING

A. Concept

To achieve better balance between efficiency and fairness, we change the *TH* in (3) to *TH'*, which can be expressed by the following.

$$TH'(Y) = \sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j\in U_m} y_{ji,m} R'_{ji} \quad (7)$$

where

$$R'_{ji} = \frac{R_{ji}}{\sum_{k=1}^{I} R_{jk} + \sum_{t=1}^{T} \overline{R_{jt}}} \quad (8)$$

$\overline{R_{jt}}$ stands for the average rate of all RBs of UE_j in T TTIs before time t. Then we have,

$$\text{MAX } TH'(Y) = \sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j\in U_m} y_{ji,m} R'_{ji} \quad (9)$$

s.t.

$$\sum_{j\in U_m} y_{ji,m} \in \{0,1\}, m = 1,2,\ldots,M; i = 1,2,\ldots,I \quad (10)$$

$$y_{ji,m} \in \{0,1\}, j = 1,2,\ldots,J; i = 1,2,\ldots,I \quad (11)$$

$$\sum_{m}\sum_{i} y_{ji,m} \le L_j, m = 1,2,\ldots,M; i = 1,2,\ldots,I \quad (12)$$

Equation (12) is to guarantee that no UE will be scheduled on too much RBs. L_j stands for the upper limitation of RB amount obtained by UE_j, which can be adjusted according to the fairness requirements.

The optimum solution of the above problem is even harder to obtain. As a result, we also give a greedy solution, which is inspired by the time slot score based scheduling proposed in ref. [23] and named Joint Score Based (JSB) Scheduling. In JSB scheme, the scheduler scores for every UE of each RB according to every RB's relative channel quality and the amount of UE's obtained RBs in order to achieve balance of fairness and efficiency.

B. Joint Score Based (JSB) Scheduling

Fig. 4 shows the interaction procedure of JSB in terms of a specific UE_j. Assume UE_j needs 3 sectors' cooperating and $s_{1,j}$ is the ID of its primary serving sector, $s_{2,j}$ and $s_{3,j}$ are the IDs of its cooperative sectors. Num_j stands for the number of transmission sector for UE_j on each RB, CQI_j stands for the corresponding Channel Quality Indicator (quantized value of SINR) on each RB of UE_j and needs at most 5 bits on every RB.

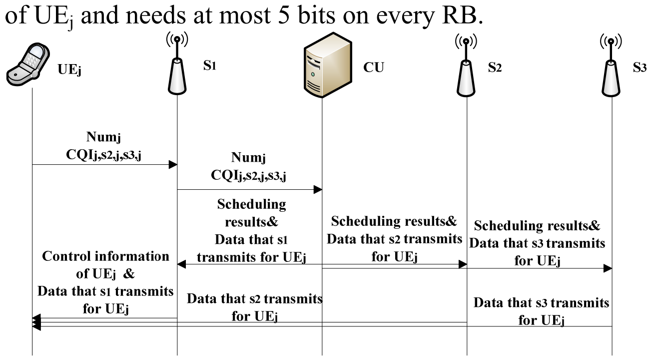

Figure 4. Interaction process of JSB

Seen from Fig 4., the additional feedback for JSB is limited.

The specific procedure of JSB is described below.

1) Phase 1: UE measuring and determining the feedback

In this phase, the UE determine what should feedback to the CU. Take UE_j as an example. Let $s_{2,j}$ and $s_{3,j}$ denote the strongest and the second strongest interfering sector within the cooperative cluster, $s_{1,j}$ denote its serving sector. The determination of feedback can be described in Algorithm 1.

Algorithm 1 Determination of Feedback
for *i=1:I* ***do***
[CQI₁ rate₁] = ***rate_cal****(j, i, s₁,ⱼ)* *
[CQI₂ rate₂] = ***rate_cal****(j, i, s₁,ⱼ, s₂,ⱼ)*
[CQI₃ rate₃] = ***rate_cal****(j, i, s₁,ⱼ, s₂,ⱼ, s₃,ⱼ)*
if *rate₁ > rate₂/2 && rate₁ > rate₃/3*
Num_{j,i} = 1 **
CQI_{j,i} = CQI₁

```
    else if  rate_1 < rate_2/2  &&  rate_2/2 > rate_3/3
       Num_{j,i} = 2
       CQI_{j,i} = CQI_2
    else
       Num_{j,i} =3
       CQI_{j,i} = CQI_3
    end if
end for
feedback_j = { Num_j , s_{1,j} , s_{2,j} , s_{3,j} , CQI_j }
```

* **rate_cal(j,i,m,n...)** calculates the CQI and rates of the *i*th RB of UE_j with the transmission of $sector_m$, $sector_n$...

** Single-sector transmission, equivalently, Non-CoMP

In Algorithm 1, $rate_2$ and $rate_3$ respectively mean the rate which can be obtained when two or three sectors cooperating. So they are divided by 2 or 3 to evaluate the real rate of each RB.

2) Phase 2: CU scheduling

Assume $Q_{j,i}$ *and* $Q'_{j\,i}$ are the current and the average quality of RB_i of UE_j, and $R_{j,i}$ is the possible transmission rate of UE_j on RB_i, and $rank_{j,i}$ is the rank of $Q_{j,i}$ in the set of Q_j and Q'_j, and U_m is the UE set of $sector_m$. Moreover, we use $used_j$ to denote the number of RBs "consumed" by each UE_j.

In this phase, CU calculates the value of *rank* for every UE on every RB, and then start greedy-algorithm based scheduling shown in Algorithm 2. The scheduling output is an RB-occupation table *OC*.

Algorithm 2 *greedy-algorithm based scheduling*

```
OC=zeros(I, M)
for m=1:M do
   U_m=[]
end for
for j=1:J  do
   if  max( Num_j )==1
      Insert( j , s_{1,j} )  *
   else if  max( Num_j )==2
      Insert( j , s_{1,j} , s_{2,j} )
   else
      Insert( j , s_{1,j} , s_{2,j} , s_{3,j} )
   end if
end for
for j=1:J  do
   for i=1:I  do
      Q_{j,i} = R_{j,i} / Num_{j,i}
   end for
   A = { Q_j , Q'_j }
   Sort(A)
   for i=1:I  do
      rank_{j,i} = Index( Q_{j,i} , A )
   end for
   Qm_j = mean( Q_j )
   In_queue( Qm_j , Q'_j )  **
end for
for m=1:M  do
   for i=1:I  do
      for k=1:card(U_m)  do
         j=U_m(k)
         Score_{j,i} = rank_{j,i} + used_j
      end for
      while OC(i,m)==0 do
         select j  for j=arg min_n Score_{n,i}  in U_m
         if  Score_{j,i} == Inf
            break
         end if
         if  Num_j ==1
            OC(i,m)=j
         else if  Num_j ==2
            if  OC(i,s_{1,j})+OC(i,s_{2,j})==0
               OC(i,[s_{1,j} , s_{2,j}])=j  ***
            else
               Score_{j,i} = Inf
            end if
         else
            if  OC(i,s_{1,j})+OC(i,s_{2,j})+OC(i,s_{3,j})==0
               OC(i,[s_{1,j} , s_{2,j} , s_{3,j}])=j
            else
               Score_{j,i} = Inf
            end if
         end if
         if OC(i,s)>0
            used_j = used_j + Num_j
         end if
      end while
   end for
end for
```

* **Insert(j,m,n,...)** insert UE_j into the UE set U_m ,U_n,… of $sector_m$,$sector_n$...

** when the circular queue is full, remove the tail and insert Qm_j

*** *A(i,[m,n,...])=j* means setting the elements in the i_{th} row and m_{th},n_{th},... column of matrix *A* to be *j*.

C. Simulation Results

Fig. 5 and Fig. 6 present the CDF curves of normalized user throughput for different schemes. Fig. 7 and Fig. 8 are the corresponding histograms. And the Table IV. exhibits the corresponding simulation results. JSB represents the proposed scheme in this section. SEB,UDO PF and RDUD RR represent the same schemes in Fig. 2. SB Non-CoMP represents the normal Score-Based algorithm which does not adopt any CoMP operation. All these schemes also have no upper limit of UE SINR.

It can be seen that JSB achieves better balance between fairness and efficiency than SEB. Furthermore, JSB gets the maximum sector throughput and cell-edge throughput compared with the typical RDUD and UDO strategy.

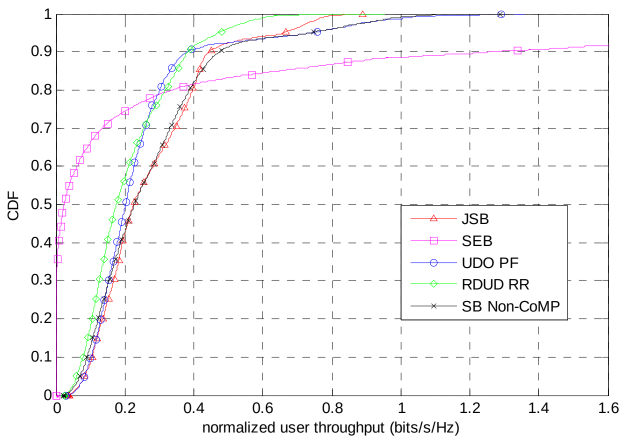

Figure 5. CDF of sector throughput for different schemes

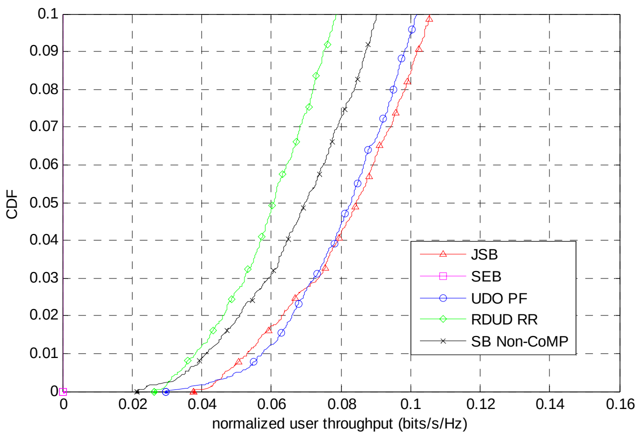

Figure 6. CDF of cell-edge user throughput for different schemes

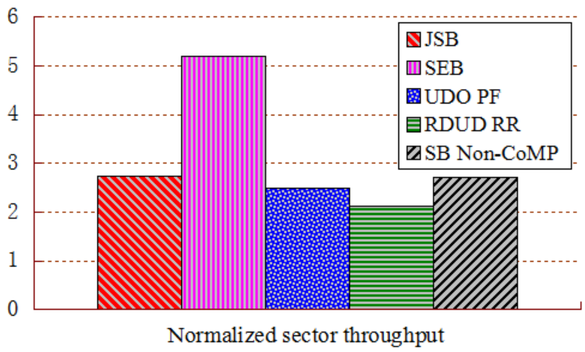

Figure 7. Normalized sector throughput for different schemes

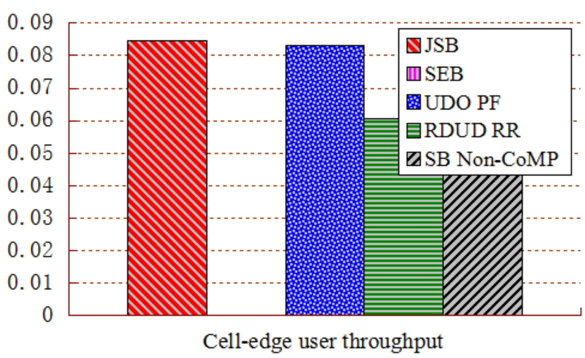

Figure 8. Cell-edge user throughput for different schemes

TABLE IV.

NORMALIZED SECTOR THROUGHPUT AND CELL-EDGE USER THROUGHPUT OF DIFFERENT SCHEMES

	JSB	SEB	UDO PF	RDUD RR	SB Non-CoMP
Normalized sector throughput (bits/s/Hz/sector)	2.73	5.21	2.49	2.12	2.72
Normalized cell-edge user throughput (bits/s/Hz)	0.0846	0.0000	0.0830	0.0607	0.0699

V. CONCLUSION

In this paper, a novel type of ND joint scheduling algorithm applied in LTE-A CoMP system is investigated. Firstly, the spectrum efficient optimization problem is formulated and Greedy Algorithm based solution (SEB) is proposed. It can get best spectrum efficient when compared with other CoMP scheduling algorithm, and exceeds Non-CoMP system with Max C/I algorithm especially when the channel quality is below 15dB. But it needs a large amount of feedback and is inferior to other CoMP scheduling algorithm in the cell-edge user's throughput because of its insufficient fairness. Then we improved it by Score Based scheduling idea as a Joint Score Based (JSB) algorithm, which only needs limited UE feedback and takes the fairness into account. From the simulation results, it is proven obviously superior to other CoMP scheduling algorithms, despite its overall throughput loss as compared with SEB.

All of these works are done in a centralized CoMP architecture, which is complex when the scale of the network increases. So our further work will extend to investigating distributed CoMP architecture.

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