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Analysis of hybrid schedulers for CoMP resource allocation in LTE-Advanced SU-MIMO systems

Wei-Teng Hsu
Iowa State University

Analysis of hybrid schedulers for CoMP resource allocation in LTE-Advanced SU-MIMO systems

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Wei-Teng Hsu

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Morris Chang, Major Professor

Degang James Chen

Ahmed El-Sayed Kamal

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DEDICATION

I would like to dedicate this thesis to my father Hai-Chang Hsu and to my mother Pei-Hsuan Hsieh without whose support I would not have been able to complete my master's program. I would also like to appreciate this small town Ames where ISU id located at, and everything happened to me in the past several years. They made me realized something I did have and something I did not have, something I should keep and something I should forget. Consequently I know more about myself, and more about others. I start from here, from now on, and from the circumstance. Thank you everybody and everything.

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ABSTRACT

Coordinated Multi Point transmission and reception (CoMP) has been considered as a promising technique to enhance system throughput performance by reducing inter-cell interference (ICI) in cell edge area. Past studies showed that Joint Processing (JP) transmission mode is capable to provide much better throughput performance benefits than Coordinated Scheduling/Beamforming (CS/CB) both in homogeneous and heterogeneous networks; however, the robust strategy of resource block (RB) allocation and scheduling algorithms has to be specifically designed for CoMP-JP in a MIMO-OFDMA system. In this paper, an intuitive algorithm will be investigated in order to reach the highest overall system throughput but keep same level of fairness performance at same time. We first analyze the threshold of reference signal strength to determine the operating region for CoMP-JP user selection, and then calculate the robust ratio of RB allocation for CoMP and non-CoMP users. In final stage, the hybrid schedulers adopted specifically for the unique characteristics of CoMP and non-CoMP users will be analyzed and compared. Our results show that the threshold of reference signal strength (λ, θ) should both be set at -1dB for CoMP operating region, and the parameter to the ratio of CoMP users should be set at $\gamma = 0.9$ for robust RB allocation.

CHAPTER 1. INTRODUCTION

The specification for the Universal Mobile Telecommunication System (UMTS) Long-Term Evolution (LTE) which is based on Global System for Mobile Communications (GSM) has been regarded as a revolution technique and is already a mature standardization currently. To meet or exceed IMT-Advanced requirements of downlink peak data rate 1Gb/s and efficiency 15b/s/Hz Sawahashi et al. (2010), several new schemes such as Carrier Aggregation (CA) and Enhanced Relay Nodes techniques have been involved as part of Release 10 in The 3rd Generation Partnership Project (3GPP) standard since 2008, which is well-known as LTE-Advanced. However, the issues of spectrum inefficiency and significant inter-cell interference (ICI) in cell edge area are still unavoidable impacts to overall system performance.

To provide more flexible schemes for bandwidth allocation in LTE specification, full frequency reuse which is known as frequency reuse factor 1 is being used; however, the LTE system is more sensitive in Inter-Cell Interference (ICI) and thus has lower throughput performance in cell edge area. The idea of Coordinated Beamforming (CB) was first introduced in the mid-nineties, which calculates the values of power level and beamforming coefficients to achieve some threshold of Signal-to-Interference-Plus noise Ratio (SINR) or to maximize the minimum SINR Lee et al. (2012). Later, another concept of coordinated resource allocation, Relative Narrowband Transmit Power (RNTP), was proposed in 3GPP Release 8 to make up the deficiency of frequency reuse technique. RNTP technique generates a bitmap Information Element (IE) of quantized transmission power per physical resource block (PRB) and is signaled between neighbor eNodeBs over the X2 interface 3GPP (2012d). The purpose is to inform neighbor eNodeBs that which specific PRBs will be allocated high transmission power so the neighbor eNodeBs should reduce their transmission power over those PRBs. Hence, RNTP provides LTE systems an auxiliary function for coordinated power control to mitigate

ICI especially in cell edge area. However, the above technique still cannot afford the heavy traffic of data transmission nowadays. An evolutional mechanism of Coordinated Multi Point transmission and reception (CoMP) which is one of promising techniques to efficiently improve throughput in cell edge area proposed in 36 series Docomo (2008).

In conventional design, a UE is connected to a cell of single base station (BS) during a given time slot; this cell will then become the UE's serving cell and the only one cell transmitting data burst to the UE during a certain period of time. Consequently, the UE communicates to only its serving cell including control signals, data downloading and data uploading before cell reselection or handover event is triggered. While in CoMP scenario the UE is allowed to communicate with several different cells which may or may not be geographically collocated in neighbor area. In CoMP operation, a CoMP cooperating set is defined as a cluster consist of several coordinated cells geographically adjacent to or logically linked to each other in backhaul network 3GPP (2010a), and these coordinated cells will then share information of scheduling and Radio Resource Management (RRM) with each other. Also, CoMP transmission points are further defined as a set of cells which are simultaneously assigned to participate one PDSCH transmission for certain UEs 3GPP (2009). Hence, the CoMP transmission points should be a subset of a CoMP cooperating set. For downlink data transmission in LTE-Advanced systems, two types of CoMP mechanisms, Joint Processing (JP) and Coordinated Scheduling/Beamforming (CS/CB), were introduced in 3GPP Release 10 3GPP (2010a).

Although the system performance can be siginificantly improved by CoMP, the computational complexity for coordinated scheduling algorithm will also be impacted. For the purpose to get better beamforming and precoding decision in PHY layer, low complexity computation schemes for CoMP resource allocation have to be discussed in future researches. In this paper, we propose an intuition and efficient system level strategy for grouping and scheduling in CoMP-JP mode. The rest of this paper is organized as follows. An overview of CoMP mechanism and related issues are provided in Section II and Section III respectively. The proposed scheme is given in Section IV. The simulation environment will be introduced in Section V and the simulation results and analysis will be showed in Section VI. Section VII concludes our discussion.

CHAPTER 2. OVERVIEW OF CoMP TECHNIQUES

In downlink CoMP transmission including both CS/CB and JP transmission, the control channels including physical downlink control channel (PDCCH) are transmitted only from serving cell, while the data burst on PDSCH is transmitted from one or more coordinated cells in CoMP operation sets. Hence, the channel knowledge has to be shared with several neighbor eNodeBs, and the knowledge exchange may somehow consume backhaul bandwidth resources. Reducing the operational overhead is also a challenge for CoMP transmission and it may significantly impact the system performance in PHY layer. This issue is beyond our research purpose, in this paper we focus on the throughput and fairness performance tradeoff influenced by PHY resource allocation and scheduling algorithms but we assume that the backhaul network has efficient bandwidth to transmit control signals.

2.1 Coordinated Scheduling/Beamforming (CS/CB)

For CS/CB operation, the data burst is only available at serving cell but the scheduling/beamforming decisions are made with coordination among cells corresponding to the CoMP cooperating set 3GPP (2010a). The serving cell utilizes the feedback information and precoding matrix indicator (PMI) reported from UEs to find out the recommended precoder for opportunistic beamforming and interference avoidance.

In order to enhance throughput performance in edge area, the beamforming calculation at each coordinated transmission point should focus on eliminating the intercell interference and a robust spatial signal processing, such as Zero-forcing Beamforming (ZFBF), should be implemented. Thus, CS/CB operation will efficiently minimize other-cell-interference (OCI) especially at same frequency of scheduled resource blocks (RB). Although the interference-

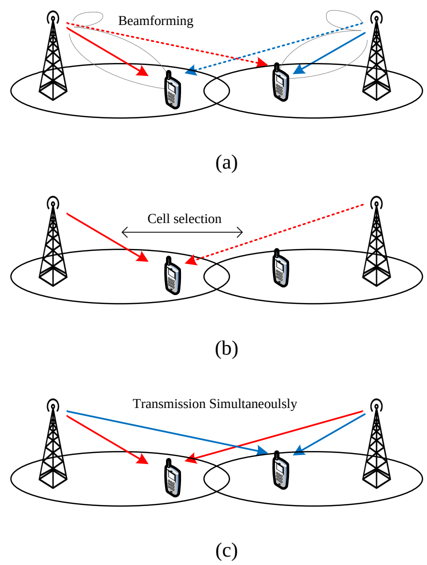

Figure 2.1 Schemes of CoMP (a) Coordinated scheduling/beamforing (b) Dynamic cell selection (c) Joint transmission

suppression-based CB might improve the system performance more, it requires more complexity, CSI accuracy, and feedback overhead Lee et al. (2012).

2.2 Joint Processing (JP)

CoMP-JP is simply based on the concept of simultaneous transmission coherently or non-coherently from one or multiple coordinated transmission points. Consequently, the data burst has to be available at each CoMP transmission point in advance to implement CoMP-JP transmission. According to the number of CoMP transmission points, CoMP-JP can be further categorized into dynamic cell selection (DCS) and joint transmission (JT). Figure 2.1b and 2.1c shows the main principle of two CoMP-JP schemes. For a DCS operation, UEs receive desired signal on PDSCH from only one transmission point, while in JT operation a UE may receive desired signal from multiple transmission points simultaneously without knowing any information in advance.

In JT operation, therefore, the signal strength in edge area will be significantly enhanced if the UE can be served by multiple coordinated cells simultaneously. Fig.2.2 shows poten-

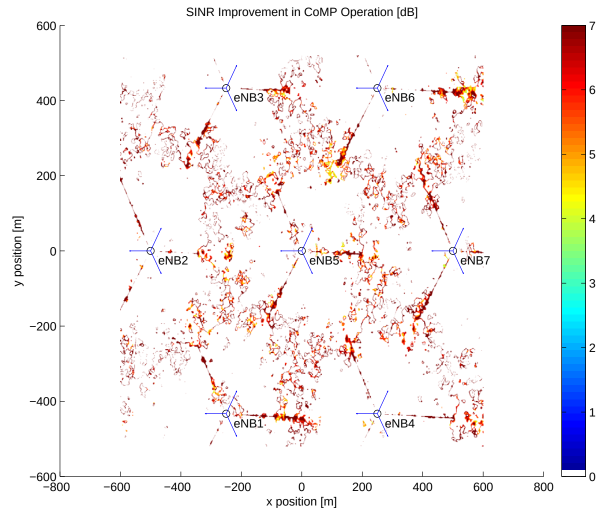

Figure 2.2 Potential SINR Improvement in 2-Cell CoMP Joint transmission

tial SINR improvement JT operation in a 21-cell LTE-Advanced environment. The color of scattering points depicts the degree of SINR improvement when the JT is applied at every scattering point in ground. It is not difficult to find SINR will be enhanced more than 5 dB in cell edge area and in the middle of two antenna emission direction. However, in a scenario of m transmission points JT environment, there are likely m cells occupying same frequency, e.g. same indices of RBs, for transmitting desired signal to one signel UE simultaneously; in other words, the consumption of bandwidth resource will be m times larger than conventional signal transmission if streams sent from m transmission points simultaneously in JT mode. To enhance the system throughput performance, therefore, the efficiency of JT operation should be undoubtedly larger than m times of non-JT operation. We can find a general hint for finding approximate value of required SNR improvement from table 2.1 and fig.2.3. Table 2.1 shows a list of Channel Quality Indicator (CQI) efficiency and corresponding CQI index and fig.2.3 shows the curve of SNR-to-CQI mapping. Considering a two transmission points JT mode, the SNR improvement should be approximately larger than 4 dB to obtain twice CQI efficiency; also, if the origin SNR is larger than 3 dB it requires at least 7 dB improvement to get double CQI efficiency. However, the stochastic simulation model in fig.2.2 shows that 7 dB SINR improvement hardly happened under a CoMP-JT environment. Hence, the user selection in

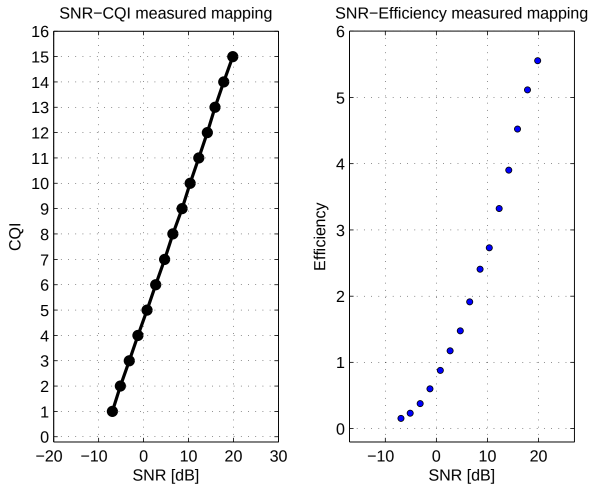

Figure 2.3 SNR-CQI and SNR-Efficiency measured mapping on 10% BLER

JT mode should be focused on UEs which feedback received signal strength indication (RSSI) lower than 3 dB.

On the other hand, UEs receive relatively stronger signal due to diversity gain in non-coherent transmission; while in coherent transmission the coordinated transmission points will be able to give an accurate scheduling decision by calculating channel state information (CSI) feedback. However, the operation of coherent transmission has much higher requirements of fast synchronization and short backhaul delay; besides, the more transmission points involved in a session of CoMP-JP transmission, the more traffic load will be incurred in backhaul network.

Table 2.1 CQI Table

CQI index	**Modulation**	**Code Rate x 1024**	**Efficiency**
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

CHAPTER 3. ISSUES AND PREVIOUS WORKS

In spite of the significant cell-edge throughput improvement in CoMP transmission, there are still several challenges, such as feedback efficiency, backhaul networking, multi-user selection, and scheduling algorithms, should be solved before CoMP operation can be integrated in next generation LTE-Advanced systems Irmer et al. (2011). Previous research works regarding CoMP were mainly focused on beamforming and ICI mitigation. In Jang et al. (2011) the researcher claimed that the CoMP region should be defined in $0.34 \cdot radius$ of a cell, and an algorithm with stream degree of freedom ξ for user selection to mitigate the ICI for CoMP-CS/BS operation. A scheme of ICI cancelation with zero-forcing precoding is used to suppress downlink inteferences from other cells in Zhang and Andrews (2010), while in Choi et al. (2011) several schemes of power allocation with adaptive modulation were investigated. The result showed that the exhaustive style of power constraint per Base Station (BS) will reach the highest data rate but consumed higher computing complexity.

However, previous research works did not propose a general threshold for intuitional determination of user selection. In this paper we propose a realistic analysis of user selection and scheduling algorithms which can be used on both CoMP cells and non-CoMP conventional cells in a LTE-Advanced system. The main processes of analysis are introduced as following, and the strategies will be showed in Section. IV.

3.1 Selection of CoMP Transmission Points

To implement the CoMP-JP operation, a cluster of several coordinated eNodeBs should be either selected by UE location, which is known as UE-specific CoMP cooperating set, or selected by a network installation plan, which is known as Network-decided CoMP cooperating set 3GPP

(2009). No matter what cooperating set is deployed, the network backhaul shall be setup and a coordinating equipment should be ready for mechanism of resource allocation. In current LTE network deployment, however, the Radio Network Controllers (RNC) equipment is already removed from current Evolved Universal Terrestrial Radio Access (E-UTRA) architecture, so the function of dynamic resource allocation has to be done in MAC Layer on eNodeB itself or on a equivalent Control plane equipment such as mobility management entity (MME), but not on a centralized huge controller anymore 3GPP (2012d)3GPP (2012a). Genreally speaking, the more CoMP transmission points are involved in a session of transmission, the more complexity of algorithm should be considered and the more data loading will be exchanged in X2 backhaul Ghosh et al. (2010)Papadogiannis et al. (2011)

3.2 Categorizing of Subscribers

The main purpose of CoMP transmission is both to enhance throughput performance in edge area and to keep fairness performance of overall system, consequently the overall UE channel conditions and system traffic should be both considered. From the Network-decided system point of view, firstly UEs have to be divided into several levels according to the feedback of channel condition, such as Received Signal Strength Indicator (RSSI) or Reference Signal Received Power (RSRP); thus, the controlling equipment can further determine if the UE should be served with CoMP transmission or not. Furthermore, all coordinated eNodeBs in CoMP cooperating set will utilize channel state information (CSI) reported by all UEs to execute a dynamic scheduling algorithm for intercell radio resource management Irmer et al. (2011). In a general macrocell cellular system with UEs location uniformly distributed, a grouping scheme with more CoMP users will result in higher fairness performance but lower system throughput. Hence, the threshold should be set at the operating point that all UEs could benefit more than conventional transmission. In this paper we separate UEs into two groups, center UEs and edge UE, for CoMP JT mode; moreover, edge UEs which are served by multiple CoMP transmission points defined as CoMP UEs. The session handling equipment will then collect the data of system traffic in CoMP cooperation set to process the resource allocation in next step.

3.2.1 Scheduling and Link Adaptation

The strategy of RB allocation and scheduling algorithm is the key factor impact the overall system performance the most in MIMO-OFDMA LTE-Advanced system, and the first challenge is to allocate limited bandwidth resource to CoMP transmission and non-CoMP transmission respectively. The more RBs assigned to CoMP transmission results in higher fairness performance but lower system throughput. Furthermore, multiple times of bandwidth consumption has also to be considered in JT mode. In Wang et al. (2010) the author claimed that the bandwidth ratio for CoMP users should be 1.6 times the CoMP users number ratio. For example, 48% bandwidth should be allocated for CoMP transmission if there are 3 CoMP UEs out of 10 UEs. However, such allocation might result in severe throughput unbalance problem if there are more CoMP users than expected in one cooperation set. Therefore, the ratio of RB allocation has to be computed dynamically in a CoMP environment.

To achieve tight time delay requirement of control information sharing on X2, fast radio resource management including centralized and autonomous deployment has to be considered in a LTE-Advanced system Sawahashi et al. (2010); besides, a robust scheme of scheduler can help the system to mitigate ICI or even to turn ICI to be a useful signal for certain registered UE Fang and Thompson (2011)Marsch and Fettweis (2011). Consequently, the strategy has to be specifically designed for CoMP characteristics by utilizing CSI feedback in order to assign modulation and coding scheme (MCS) and determine the precoding schemes efficiently. Also, in order to balance overall system performance the coordinated scheduling strategy for non-CoMP users should be dedicated to fairness while the scheduler for CoMP user should focus on throughput.

CHAPTER 4. THE PROPOSED SCHEME

In this section, a complete algorithm for CoMP-JT resource allocation is introduced and system simulation results will be showed to prove our schemes in Section. VI. The CoMP was mainly designed to solve ICI problem, consequently the key factors are mainly on the resource allocation for UEs in cell edge area, but the session handling equipment should also keep the balance of the whole system performance. On the other hand, the handover mechanism should be also considered in discussion. To successfully implement CoMP transmission, the user selected for CoMP transmission has to be discovered before handover process start. We are interested in the operating area where a UE should be transmitted in CoMP operation, and we are eager to find out the best operating point and threshold by a realistic simulation. As per the discussion in Section III, firstly we find out the SINR threshold for the boundary of cell edge UEs and cell center UEs. In second stage, an exponential function of the ratio of cell edge and cell center UEs is proposed to allocate the RBs to CoMP and non-CoMP users. In the final stage we propose a dichotomy style of hybrid-scheduler for CoMP JT transmission.

4.1 Criteria of User Selection

In the first stage, all registered UEs are categorized into cell edge UEs and cell center UEs based on the signal strength received from each neighbor cell in a CoMP cooperating set. We assume that every registered UE has already connected and registered to a serving cell, and each UE has an individual active set consists of the channel condition of several neighbor cells. Consider a common scenario of a mobile UE showed in fig.4.1, the UE may send a measurement report to start a handover request when the signal strength from neighbor cell 1 has been stronger than the signal from serving cell for a period of time Time-to-trigger (TTT)

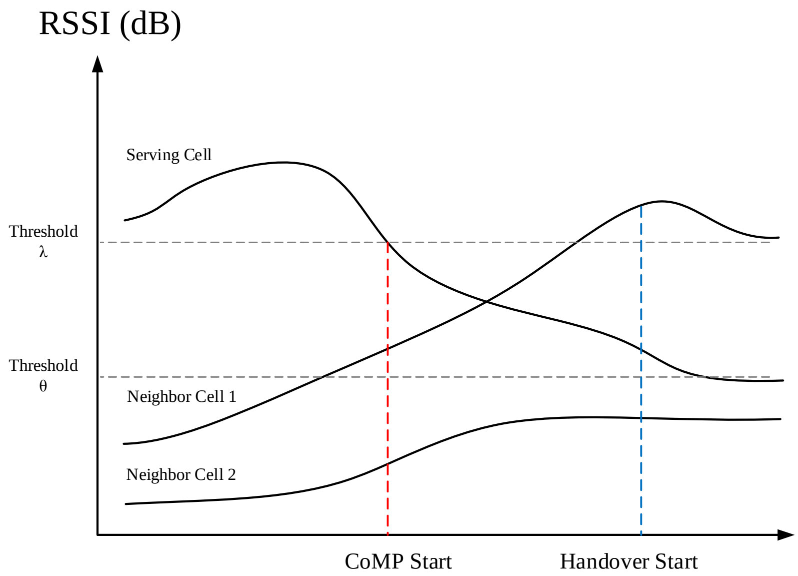

Figure 4.1 A common scenario of channel conditions

3GPP (2012c), where neighbor cell 1 represents the top-ranked neighbor cell in the UE's active set. Hence, the CoMP transmission should be undoubtedly started at certain moment before handover process triggered. Let $RS_{k,0}$ denotes the reference signal strength between k-th UE and serving cell and $RS_{k,1}$ denotes the reference signal strength between k-th UE and neighbor cell 1, we claim that $RS_{k,0}$ has to be lower than a threshold λ and $RS_{k,1}$ has to be higher than a threshold θ depicted in fig.4.1. UEs' channel conditions within this range are considered to be CoMP UEs and will be served in CoMP transmission. According to the hint in fig.2.3, the λ should be set lower than 4 dB and θ should be set lower than 2 dB. Furthermore, the higher λ and lower θ will result in more CoMP users in a cooperating set.

4.2 Weighted Resource Block Allocation

For the purpose to enhance the fairness performance, the schemes should take all registered UEs into consideration especially UEs which receive very weak signals in cell edge area. Besides, the RB allocation should be highly related to the number of users in a realistic LTE system. Here, we propose an exponential function of user ratio for dynamic frequency allocation. Let $\mathcal{U}_b$ denotes the set of UEs connected to b-th serving cell, $\mathcal{U}_b^C$ and $\mathcal{U}_b^{NC}$ denote the set of CoMP users and non-CoMP users categorized by the criteria in Section IV.3 respectively, where $\left|\mathcal{U}_b^C\right| = K_b^C$

and $\left|\mathcal{U}_b^{NC}\right| = K_b^{NC}$. Thus, we have the union set $\mathcal{U}_b = \mathcal{U}_b^C \cup \mathcal{U}_b^{NC}$, and the total number of registered UEs served by b-th cell is $K_b = K_b^C + K_b^{NC}$. Consider a multi-user downlink channel with N_b RBs per TTI in b-th cell, the RBs assigned for CoMP users is

$$N_b^C = N_b \cdot (\frac{K_b^C}{K_b})^\gamma \tag{4.1}$$

where γ the parameter to control the ratio of RB allocation. Since the number of RB is less than 100 in LTE systems, the offset of RB allocation must be in the level of dozens. Hence, we claim that the function should be a concave continuous function of $\frac{K_b^C}{K^b}$. The exponential function can reflect the change of CoMP user number and would not be fluctuate too much once γ is fixed.

4.3 Proposed Schedulers

Unlike previous LTE specification, CoMP transmission costs multiple times bandwidth resource on scheduled transmission blocks; besides, CoMP UEs and non-CoMP UEs have different characteristics of channel conditions. Hence, a robust scheduling mechanism specifically engineered for CoMP-JP is required. We claim that different schedulers have to be applied on each group to reach the best balance of system throughput and fairness. From the system point of view, CoMP UEs have similarly much poorer channel condition in edge area than non-CoMP UEs; thus, the channel capacity is much lower than CoMP users. Consequently, the scheduling strategy for CoMP UEs has to mainly enhance throughput, such as Best CQI Scheduler or Resource Fair Scheduler, while for non-CoMP UEs the scheduler has to take care about fairness more, such as Proportional Fair Scheduler or Round Robin Scheduler. Hybrid-schedulers consist of several well-know schedulers are discussed in the following, we use ψ_n to denote the index of UE that was picked at n-th RB per TTI.

Algorithm 1 Proposed Scheme for CoMP-JT

Require: $N_b > 0$
  $K_b^{NC} = K_b$, $K_b^C = 0$
  for $b = 1$ to B **do**
    if $RS_{k,0} < \lambda$ **then**
      k-th UE is candidate of CoMP user
      if $RS_{k,1} > \theta$ **then**
        k-th UE is qualified to be CoMP user
        $K_b^{NC} = K_b^{NC} - 1$
        $K_b^C = K_b^C + 1$
      end if
    end if
  end for
  $K^C = \sum_b K_b^C$

4.3.1 Maximum CQI Scheduler

The basic concept of Maximum CQI Scheduler (MC) is to find UEs which have the best channel condition at frequency of each RB in every TTI. The MC scheduler sorts CQI reported by all registered UEs in a CoMP cooperating set and allocates all available RBs to the qualified UEs to reach the maximum system throughput. However, this will be more than likely ignore other UEs' demands and fail to consider fairness performance especially UEs which are located in cell edge area with poor channel conditions. Here, we regard MC scheduler as the upper bound of system throughput and the lower bound of fairness performance when it is applied on scheduling CoMP transmission. Let vector $\mathbf{CQI}_k \in \{1, \cdots, CQI^{\max}\}^{N_b \times 1}$ denotes CQI reported by k-th user for the total N_b RBs. In LTE system, CQI values ranging from 1-15 mapping to modulation schemes QPSK, 16QAM, and 64QAM and efficiency ξ from 0.1523 to 5.5547. Thus, the $CQI^{\max}$ is set as 15, and the MC scheduler can be expressed as

$$\psi_n = \arg\max_{\{k\}} \sum_l \xi_{n,k,l} \tag{4.2}$$

where $\xi_{n,k,l}$ denotes the CQI efficiency of k-th UE on l-th layer and ψ_n the index of UEs which has the highest CQI efficiency on n-th RB.

4.3.2 Resource Fair Scheduler

The goal of Resource Fair Scheduler (RF) is to maximize the throughput of scheduled UEs under the condition of equal allocated resource for each UE, say, physical RBs in LTE system Schwarz et al. (2010). Hence, RF scheduler consists of two stages. In the first stage the scheduler is formulated to find maximum throughput based on Sum-Rate Maximization scheduler, while in the second stage it allocates available resources equally to each UE. Let the binary vector $\mathbf{b}_k \in \{0,1\}^{N\times 1}$ indicates RBs which are allocated to k-th user, this is to say, $\mathbf{b}_k(n) = 1$ when the n-th RB is allocated to k-th user. In this paper we assume that a RB can be allocated to only one UE in Single User MIMO (SU-MIMO) transmission, thus we have

$$\mathbf{b}_j^T \cdot \mathbf{b}_i = 0 \quad \forall i \neq j \tag{4.3}$$

where $(\cdot)^T$ denotes transpose of matrix. The k-th user throughput can be expressed as $T_k = C(\mathbf{CQI}_k, \mathbf{b}_k) \cdot \|\mathbf{b}_k\|_1$, where C is the function of data rate mapping from CQI. Thus, the RF scheduler in the first stage is formulated as

$$\{\mathbf{b}_1^*, \cdots, \mathbf{b}_k^*\} = \arg\max_{\{\mathbf{b}_1,\cdots,\mathbf{b}_k\}} \sum_{k=1}^{K} T_k \tag{4.4}$$

subject to:

$$\mathbf{b}_j^T \cdot \mathbf{b}_i = 0 \quad \forall i \neq j$$

$$\mathbf{b}_k(n) \in \{0,1\}^{N\times 1} \quad \forall n, k$$

In the second stage, RF scheduler allocates resources equally to each UE by adding a constraint

$$\|\mathbf{b}_k\|_1 = \frac{N}{K} \quad \forall k \tag{4.5}$$

if $\frac{N}{K}$ is an integer, otherwise several of UEs are picked randomly to get $\lfloor \frac{N}{K} \rfloor$ RBs while the other UEs get $\lceil \frac{N}{K} \rceil$ RBs. Hence, the final RF scheduler can be expressed as

$$\psi_n = \{k \,|\mathbf{b}_k^*(n) = 1\} \tag{4.6}$$

4.3.3 Proportional Fairness Scheduler

The general math expression for proportional-fair based scheduler can be formulated as a widely applied α-utility function Lan et al. (2010):

$$U_\alpha(x) = \begin{cases} \frac{x^{1-\alpha}}{1-\alpha} & \alpha \geq 0,\, \alpha \neq 1 \\ \log(x) & \alpha = 1 \end{cases} \tag{4.7}$$

In our case of RB scheduling, x denotes the expected throughput $\tilde{T}_{k,t}$ received by the k-th user at t-th TTI after RB allocated. The parameter α can be viewed as an index of fairness measurement by varying α from 0 to ∞. For $\alpha = 0$, the utility function maximizes the throughput but lose the fairness, while $\alpha \rightarrow \infty$ maximizes the minimum element, e.g. the least average throughput, but achieve the highest fairness performance. Here, we pick the special case of $\alpha = 1$ as Proportional Fairness Scheduler (PF). Let $T_{k,t}$ be the estimated throughput received by the k-th user at n-th TTI, the average throughput with an exponential window β can be described as

$$\bar{T}_{k,t} = (1 - \frac{1}{\beta})\bar{T}_{k,t-1} + \frac{1}{\beta}T_{k,t} \tag{4.8}$$

By a first-order Taylor expansion, the objective function of PF scheduler at t-th TTI is formulated as Kushner and Whiting (2004):

$$\begin{aligned} \{\mathbf{b}_1^*, \cdots, \mathbf{b}_k^*\} &= \underset{\{\mathbf{b}_1, \cdots, \mathbf{b}_k\}}{\arg\max} \{U'_\alpha(\bar{T}_{k,t-1}) \cdot T_{k,t}\} \\ &= \underset{\{\mathbf{b}_1, \cdots, \mathbf{b}_k\}}{\arg\max} \frac{T_{k,t}}{(\bar{T}_{k,t-1})} \end{aligned} \tag{4.9}$$

subject to:

$$\mathbf{b}_j^T \cdot \mathbf{b}_i = 0 \quad \forall i \neq j$$

$$\mathbf{b}_k(n) \in \{0,1\}^{N\times 1} \quad \forall n, k$$

Thus, the index of UE that was picked at n-th RB per TTI can be expressed as

$$\psi_n = \{k \,|\mathbf{b}^*_k(n) = 1\} \tag{4.10}$$

CHAPTER 5. SYSTEM MODEL AND SIMULATION ENVIRONMENT

Suppose that a LTE-Advanced system consists of several CoMP cooperating sets, these CoMP cooperating sets are perfectly predefined and network backhaul are completely built up in a system installation plan. In order to reduce the complexity of computing Block Error Ratio (BLER) and to implementation the overall system performance efficiently, a link performance models is used in our simulation in this paper Brueninghaus et al. (2005). Fig.5.1 shows a schematic block diagram of a system level simulator. The link measurement model is used for link adaption and resource allocation, while the performance model is used to determine if the UE successfully receive transport blocks under 10% BLER and to calculate throughput and fairness performance. We assume that the data streams cannot be scheduled to different UEs over particular time-frequency resource, say, RB in SU-MIMO LTE system. In addition, the following assumptions were made in the simulation to simplify the analysis.

- The X2 interface has efficient bandwidth to transmit required data sharing and control signals
- Equal power allocation
- All UEs are in RRC_CONNECTED status
- All UEs are in Full buffer traffic mode

5.1 Radio Environment

To setup an accurate and realistic simulation environment, we mainly follow the system simulation parameters for Scenario 1 in 3GPP specification 3GPP (2011a). Notice that the

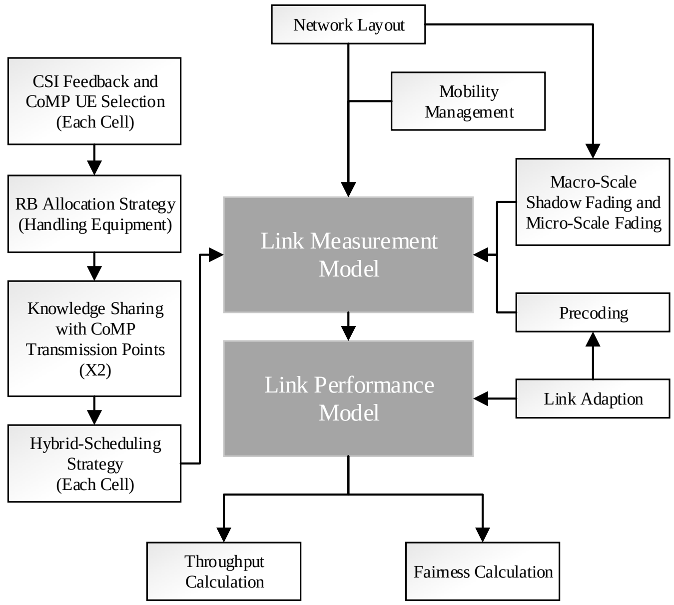

Figure 5.1 Link Performance Model

attenuation due to pathloss and shadow fading are position-dependent and time-invariant, while the channel model represent the impact of mobile movement and precoded MIMO signals modified by multipath.

5.1.1 Pathloss and Shadow Fading

The pathloss of the channel is defined as the reduction ratio of transmit power to receiver power due to the antenna gain and distance between a cell and UE. Furthermore, the propagation pathloss has the property of time-invariant but is related to only UE's position and height of antenna. For a CoMP simulation environment, propagation pathloss between each pair of cells and UEs should be considered and fedback to the serving eNodeB. Consider a macrocell propagation model in Urban Area with carrier frequency of 2000MHz and a base station antenna height of 15 metres, the propagation model is given by the following formula 3GPP (2010b)

$$L_{b,k} = 128.1 + 37.6 \cdot \log_{10}(R_{b,k}) \tag{5.1}$$

where R denotes the distance between the cell and the UE in kilometers. Also, the shadow fading is considered in our model to reflect the attenuation due to obstacles in the propagation path between cells and UEs. A slow fading is generally described as a log-normal distribution $LogF$ with mean 0 dB and standard deviation 10 dB 3GPP (2010b). Thus, the total macrocell propagation model can be expressed as $Pathloss_{b,k} = L_{b,k} + LogF_{b,k}$.

5.1.2 Channel Model

In this paper, a SU-MIMO LTE network with 7 eNodeBs will be considered, where each eNodeB has 3 cells and each cell has N_t antennas. Besides, each UE has N_r antennas and is connected to its serving cell which must be one of CoMP transmission points in a CoMP cooperating set. Generally we assume that the serving cell offer the strongest signal to the UE in the initial state. Suppose that the SU-MIMO system is built based on cyclic delay diversity (CDD) precoder, which is a useful approach to introduce virtual echoes and to increase the frequency selectivity of the channel in an Orthogonal Frequency Division Multiplexing (OFDM) based system. The channel model is defined by 3GPP (2011b):

$$\begin{bmatrix} y^{(0)}(i) \\ \vdots \\ y^{(P-1)}(i) \end{bmatrix} = W(i)D(i)U \begin{bmatrix} x^{(0)}(i) \\ \vdots \\ x^{(\upsilon-1)}(i) \end{bmatrix} \tag{5.2}$$

where the precoding matrix $W(i)$ is of size $P \times \upsilon$, $i = 0, 1, \cdots, M^{ap}_{symb} - 1$. P is the number of antenna ports used for transmission of a channel and υ is the number of transmission layers. $M^{ap}_{symb} = M^{layer}_{symb}$ denotes the number of modulation symbols to transmit per antenna port for a physical channel in our case, while the size of $D(i)$ and U should both be $\upsilon \times \upsilon$ introducing the large-delay CDD. Let $F^n_{b,k} = W^n_{b,k} D^n_{b,k} U^n_{b,k}$ be the product of WDU and $H^n_{b,k}$ the channel matrix, the received signal at the k-th user from b-th cell on the n-th RB is given by

$$y^n_k = H^n_{b,k} P^n_b F^n_{b,k} X^n_b + \sum_{i=1, i \neq b}^{B} H^n_{i,k} P^n_i F^n_{i,k} X^n_i + n^n_k \tag{5.3}$$

where $P_b^n = diag(\sqrt{P_{b,1}^n}, \sqrt{P_{b,2}^n}, \ldots, \sqrt{P_{b,N_t}^n})$ represents equal transmission power, which is assumed to be a constant in this paper. We further define $M = HPF$ and the estimated channel matrix at k-th user $G_{b,k}^n = [(g_{b,k,1}^n)^T, (g_{b,k,2}^n)^T, \ldots, (g_{b,k,\upsilon}^n)^T]^T$. Thus, the detected signal at the receiver on k-th UE can be expressed as

$$\begin{aligned}\hat{y}_k^n &= G_{b,k}^n y_k^n \\ &= G_{b,k}^n H_{b,k}^n P_b^n F_{b,k}^n X_b^n + G_{b,k}^n \sum_{i=1,i\neq b}^{B} H_{i,k}^n P_i^n F_{i,k}^n X_i^n + G_{b,k}^n n_k^n \\ &= G_{b,k}^n M_{b,k}^n X_b^n + G_{b,k}^n \sum_{i=1,i\neq b}^{B} M_{i,k}^n X_i^n + G_{b,k}^n n_k^n \end{aligned} \tag{5.4}$$

Let N_0 denotes the noise and I_k^n denotes the co-channel interference including inter-cell and intra-cell interference respectively. In here, we assume that the received signal with precoding matrix matches CMI report and ignore the interference from other UEs. The signal from the cell b and cell c regarded as the desired signal in the case of CoMP coordinated beamforming, while signal from other cells is regarded as ICI interference. Thus, the SINR at k-th non-CoMP UE can be described as

$$\begin{aligned} SINR_k^n &= \frac{\left| g_{b,k}^n m_{b,k}^n x_b^n \right|^2}{I_k^n + N_0} \\ &= \frac{\left| g_{b,k}^n m_{b,k}^n x_b^n \right|^2}{\sum\limits_{i=1,i\neq b}^{B} \left| g_{i,k}^n m_{i,k}^n x_i^n \right|^2 + \sigma^2 \left| g_{b,k}^n \right|^2} \end{aligned} \tag{5.5}$$

Suppose that $\mathcal{B}$ denotes the cluster of CoMP transmission points consists of serving cell b and the other ordinated CoMP cell c, the SINR for CoMP UE can be described as

$$SINR_k^n = \frac{\left| g_{b,k}^n m_{b,k}^n x_b^n \right|^2 + \left| g_{c,k}^n m_{c,k}^n x_c^n \right|^2}{\sum\limits_{i=1,i\neq b,i\neq c}^{B} \left| g_{i,k}^n m_{i,k}^n x_i^n \right|^2 + \sigma^2 \left| g_{\mathcal{B},k}^n \right|^2} \tag{5.6}$$

To analyze the fairness performance of the overall system, we quantified the fairness performance by using Jain's fairness index:

$$J(T_1, T_2, \cdots, T_k) = \frac{\left(\sum_{k=1}^{K} T_k\right)^2}{K \cdot \sum_{k=1}^{K} {T_k}^2} \tag{5.7}$$

where T_k denotes the total throughput the k-th user can get in the whole simulation duration. The Jain's fairness index is equal to one when all users receive same total amount of data service and the system reaches the maximum fairness. On the contrary, the Jain's fairness index approaches zero if the scheduler tend to serve only certain UEs but ignore other UEs so the system has worse fairness performance. Table 5.1 shows other simulation parameters in our LTE simulation model, we mainly follow the CoMP system-level simulation assumptions in Table A.1-1 in 3GPP (2011a).

Table 5.1 Simulation Environment for LTE-Advanced in 3GPP

Parameter	**Value**
System layout	Hexagonal grid, 7 eNodeBs, 3 cells per eNodeB
System bandwidth	20 MHz
Inter-site distance	500 m
Number of UEs per cell	30 (uniform distribution)
Distance dependent path loss	128.1 + 37.6log10(r) dB, r in kilometers
Shadowing standard deviation	10 dB
Shadowing correlation	0.5 (inter-site)/1.0 (intra-site)
Penetration loss	20 dB
Channel model	Transmission Mode 3 & 4
Maximum Doppler frequency	fD = 5.55 Hz (3 km/h @ 2 GHz)
Exponential window	25 TTIs
eNodeB/UE Tx power	46 dBm/23 dBm
eNodeB/UE antenna gain	15 dBi/0 dBi
eNodeB/UE antenna height	20 m/1.5 m
Antenna configurations Downlink	2-by-2
Control Signal delay	0 sec
Modulation and coding schemes	QPSK (R = 1/8 - 5/6), 16-QAM (R = 1/2 - 5/6), 64-QAM (R = 3/5 - 4/5)
Joint transmission scheme	Zero-forcing precoding

CHAPTER 6. SIMULATION RESULTS

The simulation is setup to be a 21 CoMP sectors 2x2 SU-MIMO OFDMA environment based on 3GPP specification. In our simulation, all sectors are assumed to operate on same frequency 2.1 GHz. The transmission mode 3 with large delay CDD is modeled for non-coherent CoMP-JT while transmission mode 4 with close-loop spatial multiplexing scheme is modeled for coherent CoMP-JT 3GPP (2012b). For the purpose to reduce the impact of data transmission delay and loading on X2 interface, the simulation is implemented in an environment of two neighbor eNodeBs both equipped with LTE-Advanced specification. We assume that 3-sector CoMP cooperating set and 2 CoMP transmission points are deployed in the environment, which implies there will be at most 2 sectors transmitting burst files to a single UE on certain allocated RBs simultaneously.

6.1 Impact of CoMP UE Selection

To find out the best threshold and operating region for CoMP user selection, we use hybrid scheduler PF+RF scheduler to observe the trend of throughput and fairness by varying the threshold of $RS_{k,0}$ and $RS_{k,1}$ in this section. Fig.6.1 shows that the $(\lambda, \theta) = (-1, -1)$ combination achieves the best balance between throughput and fairness performance compared to other combinations of higher λ and lower θ. When $\gamma = 0.9$, the throughput of $(\lambda, \theta) = (-1, -1)$ combination is improved 1 Mbits/sec compared to $(\lambda, \theta) = (-1, -3)$, and the fairness performance is still fixed at same level around 0.722. Higher λ and lower θ both result in larger operating region for CoMP UE selection; in other words, more UEs will be selected as CoMP UEs in a system when UEs' position is randomly distributed. The user throughput cumulative distribution function (CDF) for three different threshold of $RS_{k,0}$ and $RS_{k,1}$ combination is

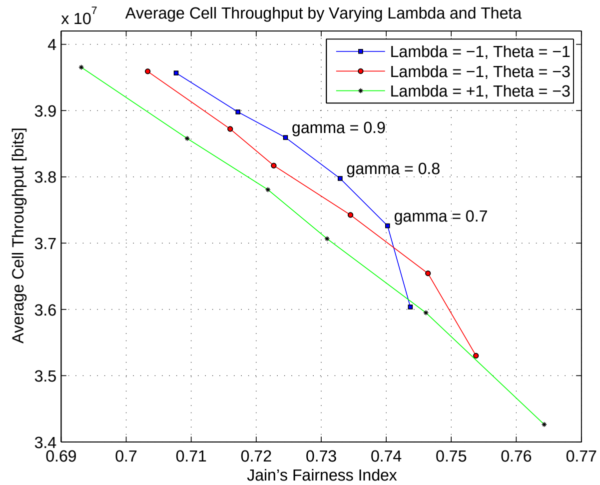

Figure 6.1 Average Cell Throughput and Fairness Performance with Different (λ, θ) Pair, PF+RF Scheduler, Transmission Mode 4

showed in fig.6.3. When the hybrid scheduler PF+RF scheduler is used, a better choice of CoMP operating area can uniformly increase average user throughput. With $(\lambda, \theta) = (-1, -3)$, 15% of users are allowed to served at 400 Kbits/sec or higher, while with $(\lambda, \theta) = (-1, -1)$ the proportion is increased from 15 % to 25 %.

In fig.6.2, λ and θ are analyzed separately by fixing each other's value. The results provide a stronger evidence to support the above results. In the left side of X-axis in both figures, more UEs are selected for CoMP transmission due to lower θ and higher λ so the system throughput is relative lower; while in right side of X-axis, much less UEs are selected for CoMP transmission so the system throughput decreases tremendously. However, the best operating point for CoMP user selection can be found at the peak in both figures. Our results show that the best thresholds for $RS_{k,0}$ and $RS_{k,1}$ are both -1 dB, and the results just match the criteria of handover report. For a handover mechanism in a LTE system, the hysteresis and TTT are generally set around 5-7 dB and 300 ms respectively to achieve lower call dropping ratio of handover failure ratio Jansen et al. (2010). Hence, to assign $(\lambda, \theta) = (-1, -1)$ allows the system to exactly select CoMP UEs in cell edge area during a period of time before handover start. The observation proves that the CoMP-JT mode should be operated in a limit size of cell edge area, and CoMP UEs have to be selected carefully. Low requirement for CoMP user selection will bring too many CoMP UEs and the system have to be bias towards users

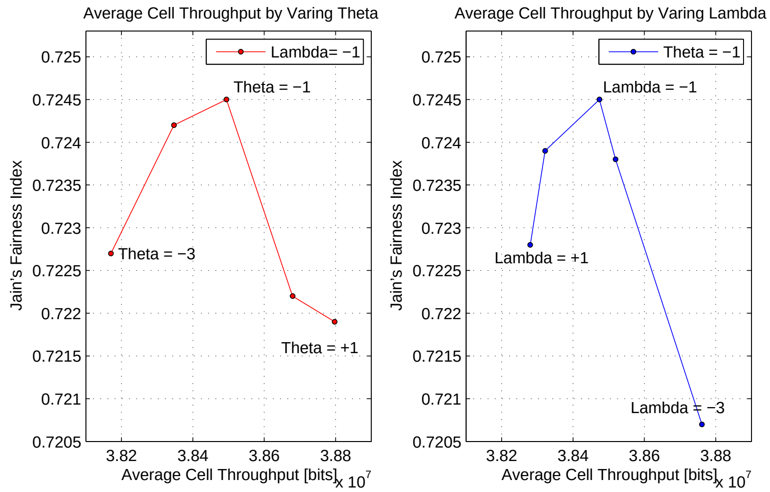

Figure 6.2 Average Cell Throughput and Fairness Performance by Varying λ and θ separately, Transmission Mode 4

which have poor channel conditions, so the overall system throughput will be undoubtedly reduced. In contrast to the oversized cell edge area, systems with high requirement may fail to perform CoMP transmission and/or overlap the operating region of handover mechanism. Furthermore, the control signals and CSI of CoMP transmission sharing between transmission points will somehow waste backhaul bandwidth due to failure of CoMP transmission.

Fig.6.1 also provide a suggestion for the tradeoff between system throughput and fairness performance. The results show that the RB allocation ratio γ has to be set around 0.8 to 0.9 to achieve the best balance between throughput and fairness. The lower γ implies the more resource allocated for CoMP UEs and the less resource allocated for non-CoMP UEs. Hence, oversize resource for CoMP transmission results in severe lack of resource for non-CoMP UEs which have better channel condition in cell center area, and such operation will significantly reduce overall system throughput and even fairness performance. It is not difficult to find the throughput dramatically decrease when γ is less than 0.7 due to too many RBs allocated for CoMP UEs. While in the case of $\gamma > 1.1$, the system tends to allocate most of available RBs for non-CoMP UEs in cell center area, so that the throughput will undoubtedly increase but the fairness decreases. The issue of extreme γ value will be discussed later in next subsection. For a general operation in realistic cellular systems, it is recommended that the ratio γ should be set around 0.8 - 0.9 to achieve the greatest overall performance.

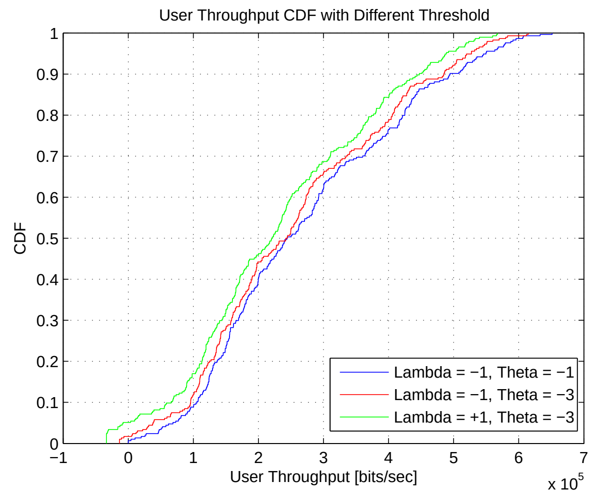

Figure 6.3 User Throughput CDF with Different (λ, θ), Transmission Mode 4

6.2 Hybrid Schedulers

In this section, the performance of different hybrid scheduling schemes is compared by varying the ratio of RB allocation γ from 0.7 to 1.3. From the system's point of view, UEs which are selected as CoMP UEs have to be scheduled in CoMP transmission once the user selection process is done per TTI. As per the discussion in previous subsection, higher γ results in more RBs allocated for non-CoMP UEs but less RBs for CoMP UEs. Thus, non-CoMP UEs can get more transport blocks to enhance the system throughput significantly but reduce fairness performance. Also, the schedulers have its essential goals for resource allocation. Obviously the MC scheduler is to maximize the throughput but totally ignore fairness performance, while PF scheduler tends to uniformly assign resource to object UEs but ignore the absolute value of throughput. Due to this reason, we claim that the PF scheduler should be applied on non-CoMP UEs which have better channel conditions to improve the poorer fairness. On the contrary, the key to improve resource allocation for CoMP transmission is to adopt throughput-based schedulers. Following the discussion in previous subsection, we apply $RS_{k,0}$ and $RS_{k,1}$ the threshold $(\lambda, \theta) = (-1, -1)$ on each user k for user selection and analyze several schedulers for CoMP transmission in our simulation.

Fig.6.4 shows the average cell throughput by using different hybrid scheduling schemes in transmission mode 3. The results show the combination of PF scheduler and RF scheduler

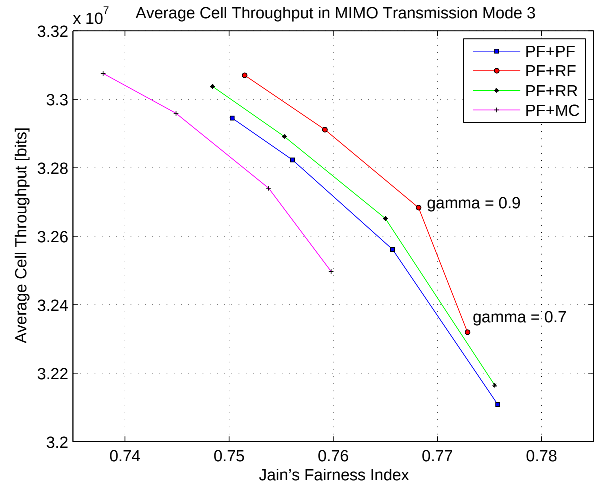

Figure 6.4 Average Cell Throughput and Fairness Performance in MIMO Transmission Mode 3, $(\lambda, \theta) = (-1, -1)$

has the most excellent performance for CoMP transmission, and the ratio γ should be set at 0.9 to achieve the best balance between throughput and fairness performance. Notice that the throughput and fairness performance both decrease considerably when γ is less than 0.7. Consider a CoMP cooperating set with average 30 users and 10 users are selected as CoMP UE in each cell, this is to say, 40 non-CoMP UEs and 20 CoMP UEs are involved in certain 2 CoMP transmission points. Thus, the ratio of CoMP UE is $\frac{K_b^C}{K_b} = \frac{1}{3}$ and the number of resource blocks for CoMP transmission is $N_b^C = 100 \cdot (\frac{1}{3})^{0.6} \cong 52$ if $\gamma = 0.6$ is applied. The ratio of RBs allocation is relatively bias to CoMP UEs too much. This will result in severe throughput decrease and also reduce fairness due to inefficient utilization of bandwidth, especially when the number of UEs increases.

In fig.6.5, we analyze the performance of transmission mode 4 with same simulation setup. The figure shows similar results as transmission mode 3 including the trend of hybrid schedulers and recommended ratio $\gamma = 0.9$. However, the difference between each hybrid scheduler is smaller than the difference in transmission mode 3. This is because the session handling equipment has relatively accurate channel estimation fedback from UEs in transmission mode 4 which is operated with closed-loop spatial multiplexing technique. The mechanism is accomplished by utilizing PMI pre-defined in the codebook and the table of precoding matrices are already known to both eNodeBs and UEs. It reduces the CQI gap between non-CoMP UEs

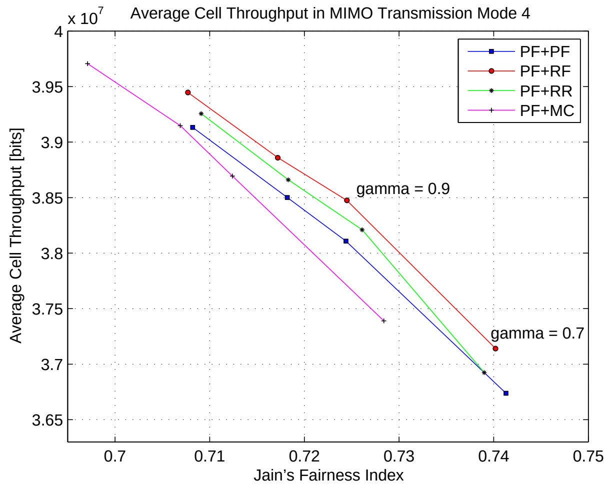

Figure 6.5 Average Cell Throughput and Fairness Performance in MIMO Transmission Mode 4, $(\lambda, \theta) = (-1, -1)$

and CoMP UEs, and higher MCS can be assigned to both of them in coherent transmission. Hence, the throughput performance of each hybrid scheduler increases to a higher level and closer to each other.

6.3 Number of UE

Fig.6.6 shows the average cell throughput versus number of UE in transmission mode 4. All of the throughput performance is getting higher when the number of UE increases, however, the curve flattens out when the average number of UE is more than 30 per cell. Although PF+MC hybrid scheduler has highest throughput, it has much lower fairness performance compared to other three hybrid schedulers. Nevertheless, the PF+RF scheduler has second highest throughput and it also has highest fairness performance.

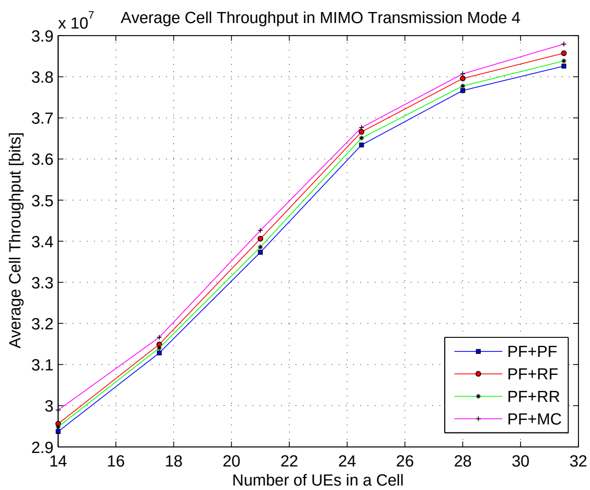

Figure 6.6 Average Cell Throughput versus number of UE in MIMO Transmission Mode 4, $(\lambda, \theta) = (-1, -1)$, $\gamma = 0.9$

CHAPTER 7. CONCLUSION

In this paper we analyze the system performance with CoMP operation by using three hybrid schedulers. The results show that the threshold of reference signal strength for CoMP selection should be set at $\lambda = -1$ dB for the upper bound of serving cell, and $\theta = -1$ dB for lower bound of potential coordinating neighbor cell. In order to take both cell center UEs and cell edge UEs into consideration , the ratio of RBs allocation γ should be set around 0.8 - 0.9 to achieve the balance of tradeoff between throughput and fairness performance. Also, the schedulers for CoMP transmission and non-CoMP transmission should be dedicated for the characteristics. PF+RF schedulers is the robust hybrid scheduling strategy for CoMP transmission in a 2x2 SU-MIMO OFDMA LTE-Advanced systems.

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