Joint Transmission for LTE-Advanced Systems with Non-Full Buffer Traffic

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***Abstract*—Joint Transmission (JT) as an example of downlink coordinated multi-point (CoMP) transmission can improve the overall system performance, particularly cell average and cell-edge throughput. Many studies are related to JT in homogeneous network and based on full buffer traffic which is not a practical scenario. We propose a JT method for LTE-Advanced systems with non-full buffer traffic in both homogeneous and heterogeneous networks. System-level simulations demonstrate that the proposed JT techniques clearly outperform single cell transmission scheme in terms of cell average and cell-edge performance.**

***Keywords*—coordinated multi-point (CoMP), joint transmission (JT), multiple-input multiple-output (MIMO)**

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) and multiple-input multiple-output (MIMO) can significantly improve frequency efficiency by exploiting the frequency diversity and spatial diversity respectively. They have been adopted in current and next generation wireless standards such as IEEE 802.16 and Long-Term Evolution (LTE). However the inter-cell interference, which is an essential issue naturally inherited from frequency reuse 1 deployment, still prevents these cellular systems to approach the theoretical performance.

Heterogeneous network deployment, where pico-cells are distributed in the coverage of a macro-cell, can improve the spatial reuse of the time-frequency resource. Compared with conventional homogeneous network (macro-cell-only deployment), heterogeneous network can provide fold peak capacity increase. This deployment has already been supported by LTE-Advanced Release 10. However the overlapping coverage of macro-cell and pico-cell, as well as their large power difference, makes the inter-cell interference much more serious compared with homogeneous network.

Downlink Coordinated Multi-Point (CoMP) transmission as a promising method can provide high spectral efficiency. The work item on downlink CoMP is now started by 3rd Generation Partnership Project (3GPP) in LTE-Advanced Release 11. Joint Transmission (JT) as a type of downlink CoMP can avoid and exploit the interference by allowing several geographically separated cells to transmit data to user equipments (UEs) [1]. Many studies related to JT in homogeneous network are proposed [2][3]. These related works are based on the full buffer traffic, which captures continuous traffic and non-varying interference. Obvious gain of JT can be observed in these literatures. However the full buffer traffic is not a practical scenario. In the reality, the traffic load is always time-varying. The system performance in a continuously changing environment with different traffic load can help us to get a full view of JT. It is critical for JT's commercial use and attracts many operators' attention [4]. In [5], Qualcomm proposes a non-coherent single-user (SU) and multi-user (MU) JT in LTE-Advanced. To support it, only a little modification on 3GPP LTE Release 8 is required. Under non-full buffer traffic, this technique improves the performance of cell-edge UEs but causes obvious loss at cell average throughput simultaneously compared with the single cell method.

In this paper, we propose a coherent MU-JT method for LTE-Advanced systems with non-full buffer traffic. Numerical results in both homogeneous and heterogeneous networks show that, compared to the single cell method in 3GPP LTE Release 10, very significant gains are available in terms of cell average as well as cell-edge performance by our proposed method.

II. SYSTEM MODEL

Consider an MIMO-OFDM cellular system with N sites where each site has three macro-cells, M pico-cells uniformly and randomly distributed in each macro-cell. Pico-cells are connected to the corresponding macro-cell via high capacity and low latency optical fiber. We further assume that via the backplane, three macro-cells associated to the same site can exchange information with zero latency and infinite capacity. Note that homogeneous network can be treated as a special case of heterogeneous network with M=0. Each cell (macro-cell/pico-cell) is equipped with N_t antennas and each UE has N_r antennas.

Several UEs are served by a cell-cluster $C^{(n)}$ which consists of L cells. In single cell transmission method, L is 1. The cell-cluster $C^{(n)}$ transmits R ($R \le \min(LN_t, KN_r)$, where K denotes the total number of UEs served by $C^{(n)}$ simultaneously) independent data streams. Data stream r is transmitted to the intended UE k by the power of P_r through the joint channel $H_{C^{(n)},k} \in \mathbb{C}^{N_r \times LN_t}$. $V_{C^{(n)},r}$ denotes the joint transmission precoder of data stream r. UE k receives the data stream r with the filter W_r.

In this paper, we use FTP model 2[6]. This imitation model captures the variable system load by adjusting the interval between the end of previous file download and the UE request for the next file, i.e. reading time D, which is satisfied with exponential distribution. The Probability Distribution Function (PDF) of D is:

$$f_D = \lambda e^{-\lambda D}, D \geq 0 \quad (1)$$

In this traffic model, the file size S and the total number of UEs are fixed. UEs can be separated into two types, i.e., idle UE which is during reading time and active UE which is during download procedure. In Fig.1, an example of traffic generation is shown with 3 UEs per cell.

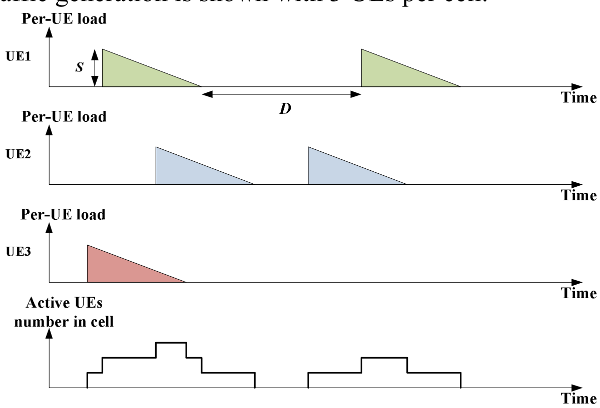

Fig. 1. Illustration of traffic generation of FTP model 2 in [6]

III. TWO DESIGN CRITERIA FOR MU-JT UNDER NON-FULL BUFFER TRAFFIC MODEL

In non-full buffer traffic, the number of active UEs is time-varying (see Fig.1). One cell may turn on/off with existing/non-existing active UEs. It makes the inter-cell interference in non-full buffer traffic more complex and unpredictable compared with that in the full buffer traffic. To eliminate it by the single cell method becomes very difficult. In this paper, the multi-cell coordination method, i.e., JT, is proposed to exploit the inter-cell interference in both homogeneous and heterogeneous networks with non-full buffer traffic. And a load centralization approach is proposed to mitigate the multi-user interference (or called as intra-cell interference) in heterogeneous network. In this section, after a careful analysis on the interference, two criteria for the selections of the measurement set and the transmission points are given respectively.

A. Measurement set selection

The signal to interference-plus-noise ratio (SINR) of stream r at UE k is given by

$$q_r = \frac{P_r \left| W_r H_{C^{(n)},k} V_{C^{(n)},r} \right|^2}{\underbrace{\sum_{i \neq r} P_i \left\| W_r H_{C^{(n)},k} V_{C^{(n)},i} \right\|_2^2}_{I_{intra}} + \underbrace{\sum_{c \notin C^{(n)},i} P_i \left\| W_r H_{c,k} V_{c,i} \right\|_2^2}_{I_{inter}} + N_0} \quad (2)$$

where N_0, and $\|\cdot\|_2$ denotes the power of received additive noise and the Eulidean norm respectively.

In (2), I_{Intra} and I_{Inter} denote multi-user and inter-cell interference respectively. When UE k is served by the single cell method, i.e., L=1, it can only receive the data from the serving cell. The signal from the other cells is treated as inter-cell interference I_{Inter} at UE k. If L>1, it means that UE k can be served several cells simultaneously, then the signal is enhanced and I_{Inter} is weakened. In one extreme example, if we perform JT among all cells in the cellular system, there is no inter-cell interference ideally. Hence JT can bring a SINR gain compared with single cell transmission definitely.

However JT among more cells requires a much higher speed backhaul to exchange data, synchronization and control signals among all transmission points [9]. As mentioned in Section II, there are high capacity and low latency links among macro-cells/pico-cells belonging to the same site. Therefore, intra-site JT is considered in this paper. Furthermore, one cell with very weak received power has little influence on the UE. We propose:

Criterion 1: Extend the measurement set within the same site as large as possible, only when the cells satisfy:

$$RSRP_{serv}\text{-}RSRP_{coop} \leqslant Thr1 \quad (3)$$

where $RSRP_{serv}$ and $RSRP_{coop}$ denote the reference signal received power (RSRP) from the serving cell and the cooperation cell respectively.

B. Transmission points selection

From the above discussion, one JT UE is always occupying more time-frequency resources than the single cell UE. This is one big hidden cost of JT. In an MIMO-OFDM system, we can handle this problem by scheduling several UEs in the same time-frequency resource via some space division multiple access (SDMA) methods. The SDMA can improve the system performance by exploiting the available spatial degrees of freedom in a downlink multi-user MIMO channel. However SDMA will cause multi-user interference, i.e., I_{Intra} in (2). It can be eliminated ideally by Zero forcing (ZF) [8] with the complete CSI at the transmitter. In practice, only partial CSI can be available at the transmitter with the limited bandwidth of feedback links. Due to the inaccuracy of the transmission beam, the transmission power to the intended UE is leaked to the UEs scheduled on the same time-frequency resource. On the other hand, in heterogeneous network, the transmission power of macro-cell is always much higher than that of pico-cell. Hence at the same precision of transmission beam, macro-cell in the transmission points always causes stronger multi-user interference than pico-cell does.

To mitigate the multi-user interference in heterogeneous network, a straightforward approach is to turn off[1] the

1 Note that "turn off" means to mute the data channel of macro-cell in this paper.

macro-cells in the transmission points. In non-full buffer traffic, the number of simultaneously active UEs is always limited. Hence this approach is realizable by off-loading the active macro-cell UEs to pico-cells. However it may make the service unavailable at some UEs which are far from pico-cells. Our task is to distinguish when macro-cells in the candidate transmission points can be turned off during the scheduling.

To discuss clearly, we first divide the coverage of macro-cell into four parts, i.e. pico-cell center, pico-cell victim, macro-cell interim and macro-cell inherent area (see Fig.2).

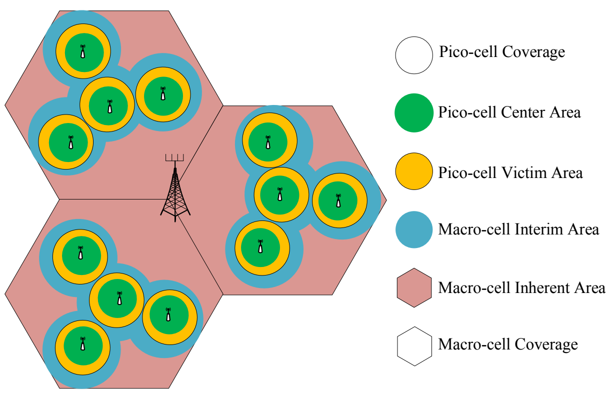

Fig. 2. Illustration diagrams of area separation.

These four parts can be distinguished according to the RSRP:

$$\begin{cases} RSRP_m - RSRP_p < Thr2 & Type\text{–}1: pico\ center\ area \\ Thr2 < RSRP_m - RSRP_p \le 0 & Type\text{–}2: pico\ victim\ area \\ 0 < RSRP_m - RSRP_p \le Thr3 & Type\text{–}3: macro\ interim\ area \\ RSRP_m - RSRP_p > Thr3 & Type\text{–}4: macro\ inherent\ area \end{cases} \quad (4)$$

where $RSRP_m$ and $RSRP_p$ denote RSRP from macro-cell and the highest RSRP from pico-cell respectively.

Type-1 and Type-2 UEs suffer obvious interference from macro-cell. The performance of the latter can be improved significantly when macro-cell is turned off. Type-4 UEs can work well under macro-cell and suffer very weak interference from pico-cells. The power of received signal by Type-3 UE from pico-cell is weaker than that from macro-cell. We can restrict the difference within a small range by adjusting *Thr*3. Moreover when we off-load Type-3 UEs from macro-cell to pico-cell and turn off macro-cell, they can receive no interference from the muted macro-cell. The received signal from pico-cell/pico-cells can be kept in an acceptable quality. To verify the above analysis, we plot the geometry (which is also referred to as wideband SINR) of Type-3 UE served by macro-cell (original serving cell based on RSRP) or by the strongest pico-cell (See Fig.3). Note that when Type-3 UEs can receive the signal from several pico-cells via JT, the performance can be improved further.

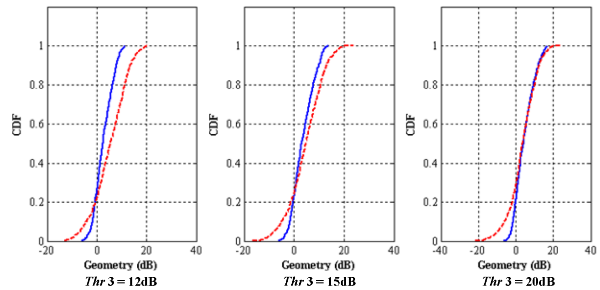

Fig.3. The geometry of Type-3 UEs served by macro-cell (the blue solid lines) or the strongest pico-cell (the red dashed lines)

From the above discussion, we can conclude that to turn off macro-cell has a little influence on UEs, except Type-4 UEs. In this paper[2], we propose:

Criterion 2: One macro-cell is involved in JT, only if in this macro-cell, there is at least one active UE satisfied:

$$RSRP_m\text{-}RSRP_p > Thr3 \quad (5)$$

Criterion 2 indicates that, to guarantee that Type-3 UE can receive data from pico-cell/pico-cells when macro-cell is turned off, the candidate transmission points should include, besides the serving cell (macro-cell), 1 pico-cell at least. To achieve this goal, *Thr*3 must be less than or equal to *Thr*1, i.e.

$$Thr1 \ge Thr3 \quad (6)$$

The transmission points selection based on *Criterion* 2 can be implemented by the following equivalent approach at the scheduler[3]. First the serving cell for each UE is re-selected with a range expansion (RE) bias, i.e., *Thr*3. Then turn off the macro-cell if there is no active UE selecting this macro-cell as its serving cell. At last, the transmission points are selected from the remaining macro-cells and pico-cells following *Criterion* 1. After the above steps, macro-cell, which has no active Type 4 UE, will be excluded from the transmission points of all active UEs and be turned off.

Note that *Criterion* 2 does work only in heterogeneous network, because there is no pico-cell in homogeneous network. In homogeneous network, we select the cells in measurement set as the transmission points directly for simplicity.

IV. MEASUREMENT AND SCHEDULING PROCESS

Based on two criteria given in Section III, we develop an MU-JT method for LTE-A systems with non-full buffer traffic in this section.

2 Note that *Criterion* 2 cannot be extended to the full buffer traffic model directly, because UEs, including Type-4 UEs, are always assumed to be active.

3 This transmission points selection cannot be implemented by UE, because the state of the other UEs is non-known to this UE.

A. Measurement and feedback

At the UE, the selection of measurement set follows *Criterion* 1. For Type-1, 2, 3 UEs, the real transmission points are unknown in the measure procedure. Therefore in heterogeneous network, UEs, except Type-4 UEs, are configured to measure and feed back two groups of rank indication (RI), channel state information (CSI) and channel quality indication (CQI) assuming three macro-cells belonging to the same site in their measurement sets turning on or off respectively[4].

More than one data streams (the number is represented by $\mathrm{RI} \le \min(LN_t, N_r)$) can be allocated to the same UE simultaneously in MU-JT. For description simplicity, we assume one data stream per UE in this section. It can be extended to rank adaptation directly by processing data streams one by one. Note that the simulation results in Section V are based on rank adaptation.

To support coherent JT, single cell precoder plus inter-cell phase difference information is required to be available at the scheduler. In our proposed method, the feedback of partial CSI[5] relies on a hierarchical feedback method [10]. This method extending single cell CSI feedback, which has already been supported by LTE, to multi-cell feedback has a good backward compatibility.

In CQI estimation, we assume that there is no multi-user interference in the same set of transmission points. The inter-cell interference is estimated based on the reference signals without precoding and assuming minimum mean square error (MMSE) receiver filter is used. The estimated SINR $\tilde{q}_r$ is

$$\tilde{q}_r = \frac{P_r \left| W_r H_{C_k,k} V_{C_k,r} \right|^2}{\sum_{C \ne C_k, i} P_i \left\| W_r H_{C,k} V_{C,i} \right\|_2^2 + N_0} \tag{7}$$

where C_k is the measurement set of UE k. The estimation results are quantized as CQI and fed back to the serving cell.

B. Scheduling for MU-JT method

At the base station, a centralized scheduling architecture is used in our JT method. In this architecture, one cell within each cell-cluster works as a central scheduler. We assume that RI/CSI/CQI and RSRP of the active UEs in the cell-cluster are available at the central scheduler, and the scheduling results (including UE pairing results, resource allocation and transmission weight) can be transferred to the corresponding transmission points without delay. Note that this assumption is reasonable due to the restriction of intra-site JT.

The scheduling includes three steps, i.e., the transmission points selection as the description in Section III, the transmission precoder computation and UEs pairing, and modulation and coding scheme (MCS) selection.

Before transmission precoder computation, we need reconstruct the joint CSI vector $V_{C^{(n)},r} \in \mathbb{C}^{LNt\times1}$ so as to provide the imitation of the joint channel matrix between UE k and $C^{(n)}$.

$$V_{C^{(n)},r}^H = [V_{C^{(n)}(1),r}; V_{C^{(n)}(2),r}; \ldots; V_{C^{(n)}(L),r}]^H \xrightarrow{Imitate} H_{C^{(n)},k} \tag{8}$$

where $(.)^H$ denotes Hermitian transpose and $V_{C^{(n)}(l),r}$ denotes the precoding vector of $C^{(n)}(l)$ in the reported joint CSI if $C^{(n)}(l)$ is the transmission point of UE k, or is zero vector. In this paper, we use zero-forcing (ZF) method in MU transmission precoder computation:

$$\hat{V} = V^H (V \cdot V^H)^{-1} \tag{9}$$

where $V = [V_{C^{(n)},1}^H; V_{C^{(n)},2}^H; \ldots; V_{C^{(n)},R}^H] \in \mathbb{C}^{R\times LN_t}$ is the composite CSI. The r^{th} column of $\hat{V}$, i.e. $\hat{V}_{C^{(n)},r} \in \mathbb{C}^{LN_t\times1}$, is the precoder vector after ZF and used as the transmission precoder of stream r. The candidate UEs are scheduled in a greedy manner to maximize the weighted sum rates of the data streams, i.e.

$$\text{To maximize} \quad \sum_{k,r} \lambda_k \log_2(1+\hat{q}_r) \tag{10}$$

where $\hat{q}_r$ is re-calculated SINR. After ZF, the real transmission precoder $\hat{V}_{C^{(n)},r}$ is different to the reported CSI $V_{C^{(n)},r}$. This leads to a mismatch between the real SINR and the reported one via CQI. Therefore we need to re-calculate SINR, which is given by:

$$\hat{q}_r = \tilde{q}_r \left| V_{C^{(n)},r}^H \hat{V}_{C^{(n)},r} \right|^2 \tag{11}$$

In non-full buffer traffic model, the downloading time related to user experience is an important parameter in performance evaluation. The scheduling priority weight related to waiting time for UE k related to data steam r is given by:

$$\lambda_k = \frac{t_{current} - t_{generate}}{u_k} \tag{12}$$

where $t_{current}$ and $t_{generate}$ denote the current time and the generation time of current packet, u_k denotes the size of current packet un-transmitted for UE k.

Finally, we choose the proper MCS for each data stream based on the re-calculated SINR.

V. Simulation Assumptions and Results

We perform system level simulation on MU-JT introduced in this paper. The numerical results in both homogeneous and heterogeneous networks are shown in this section.

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4 There are 3 macro-cells in one cell-cluster. It indicates that there are 8 macro-cells turning on/off state combinations. In our paper, in order to restrict the feedback overhead, we assume that 3 macro-cells in the same cell-cluster will turn on or off synchronously in both measurement and scheduling process.

5 Partial CSI in [10] is equivalent to the right unitary matrix in the singular value decomposition (SVD) of the joint channel matrix.

A. Simulation assumptions

We consider a cellular system with 19 sites and each site has 3 macro-cells. In heterogeneous network, 4 pico-cells are distributed randomly in the macro-cell coverage area. SU-MIMO in LTE Release 10 is used as the baseline. To make the comparison fair, the number of UEs which can be scheduled simultaneously in MU-JT is restricted to be equal to the total number of cells in the cell cluster. UEs are dropped uniformly and randomly in homogeneous network. In heterogeneous network, the distribution of UEs follows Configure 4b in [6]. First 2/3 UEs are randomly and uniformly dropped within a 40 m radius of each pico-cell. Then the remaining UEs are dropped randomly and uniformly to the entire geographical area of the given macro cell. Note that the pico-cell UE dropping area is included in the second dropping area. Further assumptions are listed in Table 1, and more details are provided in [6].

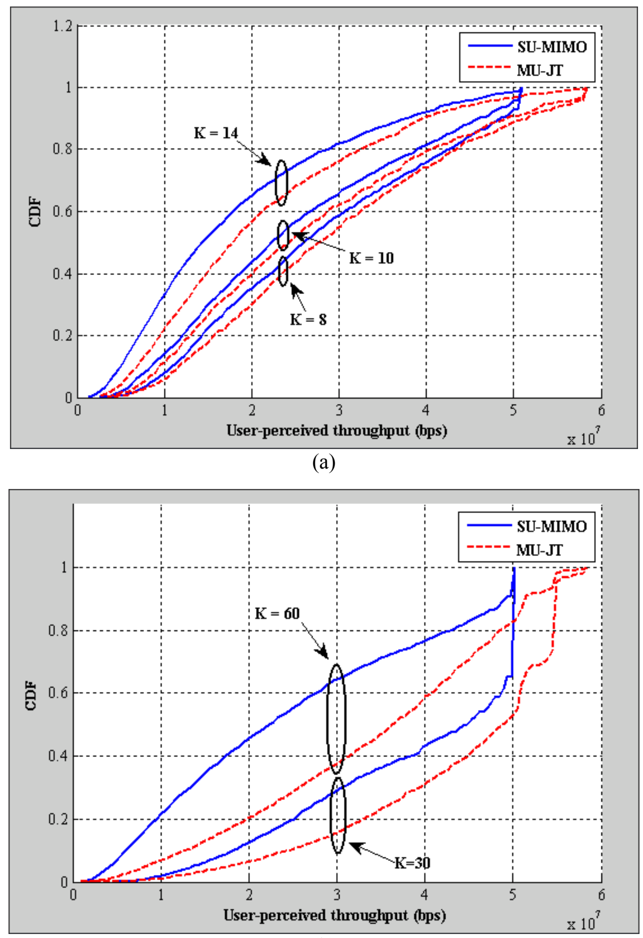
In this paper, we evaluate the system performance by user-perceived throughput (UPT) as 3GPP requirement [6]. The UPT is defined as the size of a burst divided by the time between the arrival of the first packet of a burst and the reception of the last packet of the burst. In the simulation, $Thr1=Thr3=20$dB.

TABLE 1: SIMULATION ASSUMPTIONS

Network	
Carrier frequency	2 GHz
Test Scenarios	Homogeneous network: 3GPP-Case1 Heterogeneous network: - Macro-cell: ITU UMa - Pico-cell: ITU UMi -100% UE dropped outdoors, no outdoor to indoor penetration loss UE speed: 3 km/hr
Duplex mode	FDD
System bandwidth	10 MHz
Transmit power	Macro-cell: 46dBm Pico-cell: 30dBm
Network synchronization	Synchronized
Antenna configuration	Macro-cell&pico-cell: - 4 antennas, 2 columns, cross-polarized closely-spaced XX - 2 antennas, 1 columns, cross-polarized, X UE: 2 antennas, 1 column, cross-polarized X
Traffic model	
Traffic model	Follow [6] FTP Model 2 λ: 0.2 File size: 0.5Mbytes
UE number	Homogeneous network: K = 8, 10, 14 UEs/macro-cell Heterogeneous network: K = 30, 60 UEs/macro-cell
Placing of UEs	Homogeneous network: Uniform and random distribution Heterogeneous network: Clustering distribution following Configuration 4b in [6]
Feedback	
Feedback content	- RI: adaptive rank assuming MU-JT -Single cell CSI: first r (rank) eigen vector(s) without quantization for multiple transmission points; - Inter-point phase/magnitude: un-quantized - CQI: JT SU-CQI
CSI feedback delay	4ms
CSI feedback period	5ms
Scheduler	
Criteria for CoMP	Homogeneous network: $Thr\ 1$ = 20dB Heterogeneous network: $Thr\ 1$=$Thr\ 3$ = 20dB
Scheduler	Greedy + Proportional Fair
Number of simultaneous UEs	Single-cell SU-MIMO: 1UE/cell MU-JT: Adaptive, at most 1UE/cell
UE receiver	Interference unaware MMSE
Precoding Scheme	Zero Forcing for MU-JT
Backhaul assumptions	Point-to-point fiber, zero latency and infinite capacity
HARQ	CC, Maximum 3 transmission

B. Simulation results

First we take an overview on the performance comparison between MU-JT and SU-MIMO in LTE Release 10. Fig. 4 shows the cumulative distribution function (CDF) curves of UPT in homogeneous and heterogeneous networks with N_t=4 respectively. It is seen that MU-JT can obviously improve the coverage of high UPT and cell-edge UEs' performance simultaneously. In particular, the gain of JT in heterogeneous network is much larger than that in homogeneous network for the more serious inter-cell interference in the former scenario.



(b)

Fig. 4. Performance comparison in homogeneous network (Fig.(a)) and heterogeneous network (Fig.(b))

We also simulate the MU-JT and SU-MIMO in LTE Release 10 with different parameters. In Fig. 5 and Fig. 6, the relative gains are given for mean UPT and UPT quantiles of 5% (cell-edge), 50% and 95%.

Fig. 5 shows the relative gains with different system loads in both homogeneous and heterogeneous networks with N_t=4. In LTE, the usage of time and frequency resource is chosen as a measure of the system load [11]. We can see that the relationship is very similar in homogeneous networks and heterogeneous networks. The relative gain, except at the 95% quantile, increases with increased system load. It is reasonable that more multi-user diversity gain can be obtained in proposed MU-JT method with higher system load.

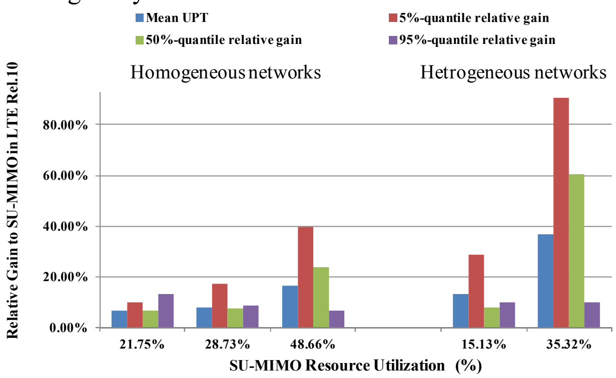


Fig. 5. The relative gains to SU-MIMO versus the system load

Fig. 6 shows the relative gain for different transmission antennas number in heterogeneous network. As expected, the relative gain increases with decreased transmission antennas per cell. This is due to the fact that the more spatial multiplexing gain can be obtained with more antennas at the transmitter and hence the less relative gain can be provided by MU-JT over the single cell method.

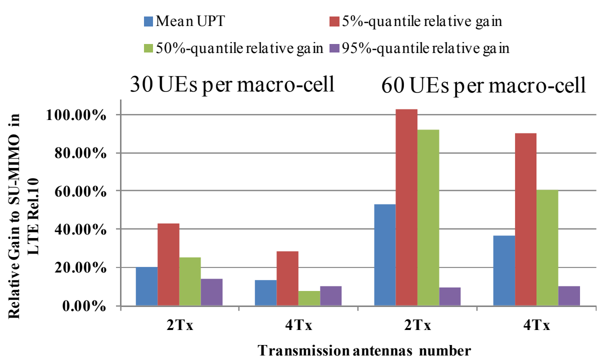


Fig.6. The relative gains to SU-MIMO versus transmission antennas number

VI. CONCLUSIONS

In this paper, we present an MU-JT method for LTE-A systems with non-full buffer traffic. After careful analysis on the intra/inter-cell interference, two basic criteria are proposed. Experimental results in homogeneous and heterogeneous networks demonstrate that a huge performance gain can be achieved at cell-average and cell-edge by MU-JT, compared with SU-MIMO in LTE Release 10.

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