The Study and Field Trial of Coordinated Multi-point Techniques in Heterogeneous Network

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Abstract. With the development of mobile internet service, Long Term Evolution (LTE) system provides higher data rate and better user experience. One way to provide higher bitrates is to exploit or mitigate the interference by cooperation between sectors or different sites. Coordinated Multi-Point (CoMP) is one of the promising concepts to improve cell edge user data rate and spectral efficiency firstly introduced in LTE Release 11. In this paper, the principle and challenges of CoMP are introduced, and also the performance and results of CoMP based on field trial are given, especially the gain of cell edge user in heterogeneous network are analyzed. Finally, several proposals and suggestions of CoMP application are given in the end of this paper.

Keywords: Coordinated Multi-point · Joint reception · Coordinated scheduling

1 Introduction

LTE use MIMO-OFDM to achieve improved spectral efficiency within one cell [1–3]. With the evolution of LTE, new features are introduced in latest releases of the 3GPP specifications. One method coordination of eNBs to avoid interference and constructive exploitation of interference through coherent eNB cooperation is done. The cooperation techniques aim to avoid or exploit interference in order to improve the cell edge and average data rates. CoMP can be applied both in the uplink and downlink [4].

One of the fundamental differences between CoMP Multi-User (MU) MIMO systems and single-cell MU MIMO systems lies in the per base station power constraint [5]. By using CoMP, coherent transmission with coordinated base stations can significantly improve both the cell average throughput and the cell edge throughput. In CoMP a number of TX (transmit) points provide coordinated transmission in the DL, and a number of RX (receive) points provide coordinated reception in the UL. The set of TX/RX-points can either be at different locations, or co-sited but providing coverage in different sectors, they can also belong to the same or different eNBs [6].

CoMP is firstly introduced in 3GPP technical report 36.814 in February 2009, and officially compiled in Release 11 [7]. Rel.11 standardized uplink CoMP. The feature is transparent to UE, so it can also work in Rel.8 network. Rel.11 enhanced inter-cell

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DMRS on PUSCH, PUCCH and SRS. For downlink CoMP, Rel.11 introduced the VCI (virtual cell identity), different VCIs can be configured in one cell, and the resource are pseudo-orthogonal between different virtual cells. VCI reduces RS interference between different transmitting points to ensure the reliable demodulation of reference signal. The CoMP cooperating sets (macro cell, micro cell) can be configured according to the location of the UE. With UE feedback, Rel.11 introduced the concept of the channel state information of the process. UE periodic and non-periodic feedback are both based on the channel state information process. Interference measurement and channel quality indicator are newly defined to support the accurate measurement of the channel state information.

Rel.12 introduced inter-cell CoMP, namely the distributed CoMP with non-ideal backhaul. New signaling interaction between X2 are introduced, such as RSRP measurement reports, etc. Cooperative or mute transmission scheme is supported. The non-ideal backhaul scenes in R12 can be applied to the macro-micro scenario.

In this paper, the principle of different strategies of CoMP are presented, the challenge for backhaul transmission and delay is analyzed. The UL JR and DL CS algorithm and flow are discussed in Sect. 3. Followed by simulations and field trial in heterogeneous network. Finally, a conclusion is given in the end.

2 Principle and Challenge of COMP

CoMP involves several possible coordinating schemes among the access points. Firstly, CoMP can be applied both in downlink and uplink. Secondly, there are inter-site and intra-site CoMP according to the cooperating objects. Multiple sectors of one base station (eNB in 3GPP LTE terminology) can cooperate in intra-site COMP, whereas inter-site COMP involves multiple eNBs. Furthermore, downlink CoMP can be classified as Joint Processing, including Joint Transmitting (JT), Dynamic Point Selection or Blanking (DPS/DPB), and also Coordinated Scheduling or Beamforming (CS/CB). With JT, multiple cells transmit identical data by using the same Resource Block (RB), which improves the performance of reception, working as diversity gain from MIMO. With DPS, multiple points share the same data like JT, but the data is sent by one cell with best channel quality while other cells are muted. CS CoMP allocates different RB to cell-edge UEs to avoid interference, and CB CoMP utilized beamforming technology to transmit orthogonal resources. Similarly, Uplink CoMP has Joint Reception (JR) in the uplink scheduling and coordination beamforming. The following Fig. 1 details the principles of these CoMP techniques [8].

Unlike ICIC or eICIC, CoMP uses not only the frequency and time domain resources, but also the spatial domain, known as a fast interference coordination. Therefore, the fast-changing UE channel information must be reported during each scheduling took place. UEs measure their Channel State Information (CSI) and report to eNB, which includes Channel Quality Indicator (CQI), Rank indicator (RI) and Precoding Matrix Indicator (PMI). For this purpose, eNB gives UEs instruction on which cell's CSI are be measured by using particular RB, CSI-Reference Signal.

The delay requirements for transmitting CSI and data are strict, especially for JT and JR, the CQI and users' data must be shared between the transmission and

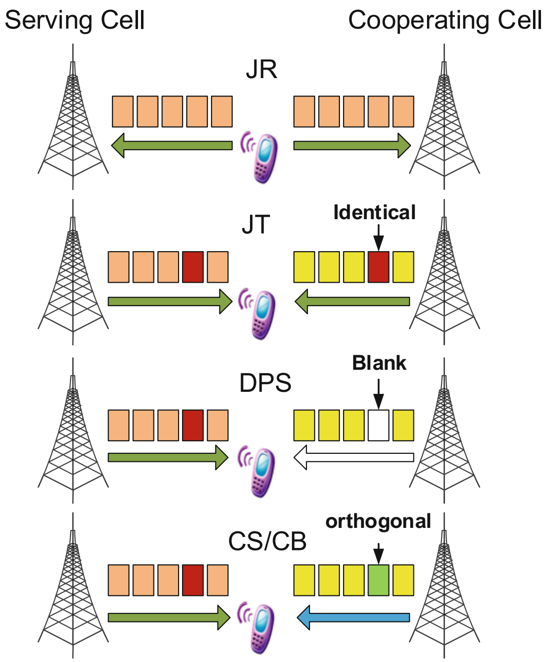

Fig. 1. The framework of PCI Self-Configuration

Table 1. Information and delay Requirement for CoMP

Type	Information requires	Magnitude of delay	Resource domain
JR	User data, JR scheduling, Reference signal configuration information, CSI	100 µs, Ideal backhaul	Frequency, Spatial
JT	User data, JT scheduling, Precoding information, CSI	100 µs, Ideal backhaul	Frequency, Spatial
DPS	Scheduling, Reference signal configuration information, Precoding information, CSI	Ms, Ideal backhaul	Frequency, Time, Spatial
CS/CB	Scheduling, CSI	Ms, Ideal backhaul	Frequency/Spatial

coordinating cells in TTI level, which brings the transmission network a challenge not only on delay but also in bandwidth. The requirement of different strategy are shown in Table 1. In this situation, the use of fiber link for Common Public Radio Interface (CPRI) is necessary in commercial cases.

3 Uplink JR and Downlink CS

In this section, the downlink CS and uplink JR are discussed since the JT and DPS have demanding requirement for backhaul and commercial prospects are uncertain.

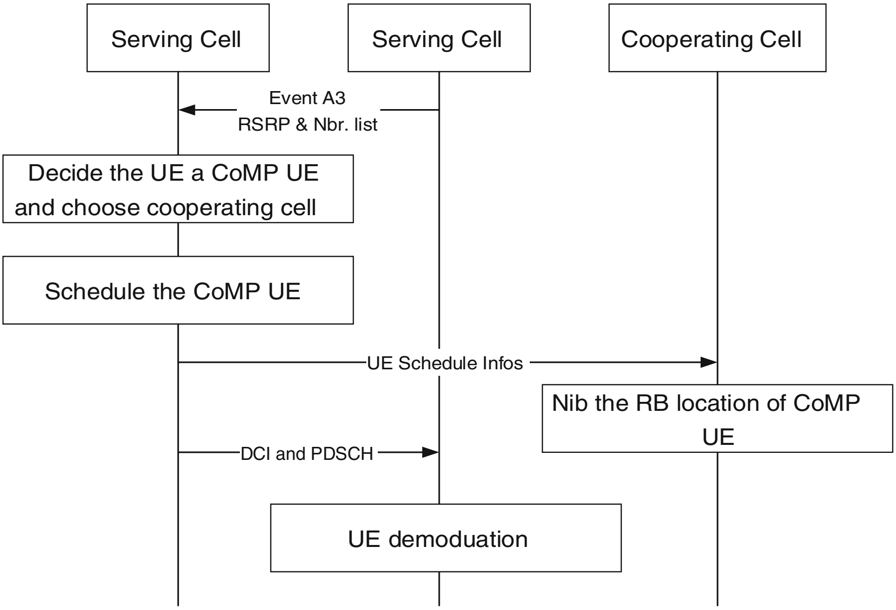

Fig. 2. The flow of downlink CS

Centralized and distributed algorithm both works for downlink CS according to the location where algorithm executes. For centralized CS, scheduling and channel state information of each cell are transmitted to a centralized control network element, from where the user downlink resource are uniformly managed. However, the scheduling decision are made by the serving cell in a distributed algorithm, the serving cell manages the downlink CS resource based on the scheduling and CSI information transmitted from cooperative cells. As shown in Fig. 2:

(1) UE measures RSRP according to A3 message, and then report the neighbor cell list and neighbor relations to the serving cell.
(2) UE serving cell determined whether trigger CoMP or not, and identify the coordinated neighbor cells.
(3) Serving cell schedule UE and sent the scheduling information to the coordinated cells.
(4) Coordination cells avoid scheduling the identical CoMP-used RB resource while scheduling their own UE.
(5) Serving cell transmits the scheduling information and data to the CoMP UE.
(6) UE perform demodulation.

One key parameter to trigger the algorithm is SINR of UE, particularly the UE at the cell edge receive strong interference. The situation can be formulized as:

$$SINR = \frac{P_s}{I_{MAX} + I_{others} + N}, \tag{1}$$

Where P_s is signal power of serving cell, I_{MAX} is the strongest signal power from neighbor cell, I_{others} is the interference power from other cells combine, and N is noise power. After CS executing, the $SINR$ is improved:

$$SINR' = \frac{P_s}{I_{others} + N}, \tag{2}$$

For cell edge UE, usually the rate is limited by the interference, and the I_{MAX} always much stronger than the other interference and noise, $I_{MAX} \gg I_{others} + N$. Therefore, after applying CS, $SINR'$ is improved significantly, $SINR' \gg SINR$.

On the other hand, uplink JR chooses two (or more) qualified joint cells to cooperate. For uplink UE, twice the antennas participate in joint receiving. The performance gain obtain from two aspects.

- Joint gain: the signal sent by the UE at the cell edge (overlapping the two cells) can be simultaneously received by different cell antennas. Enhance joint reception received higher signal quality.
- Interference restrain gain: UE in cooperative cell is selected for joint process who receives the interference from the UE at cell edge. The UL CoMP joint progress restrain the interference to obtain the interference restrain gain.

In a cellular network, the JR gains distributes in different regions. As shown in Fig. 3, different colors indicates different types of gain:

- Light blue: Joint gain obtain from intra-BBU
- Yellow and orange: Joint gain obtain from inter-BBU
- Dark blue: Interference restrain gain from intra-BBU

Data combining takes place after receiving from separate antennas. The position of combining affects the process complexity, inter-cell transmission, and the performance gain. Extra physical processes are needed to support uplink JR. The procedure is showed in Fig. 4.

Additional physical layer operation under CoMP:

(1) Channel estimation is not only required by source UE, but also by neighbor UE.
(2) Soft information of CoMP UE is obtain after two user equalization.
(3) CoMP UE performance gain by combining the soft information.

In general, transmitting the original time domain or frequency domain I/Q signal obtains higher performance gain at the expense of higher complexity and transmit bandwidth. On the other hand, transmitting the soft bit data after demodulation require lower resource but acquire lower gain.

4 Field Trial and Measurement Results

In this section, field trials are performed to further investigate the performance of typical strategies of CoMP. Some large-scale field trial has been carried out in urban area in Shang Hai. Table 2 shows the basic field trial parameters setting. There are 19 cells on 7 sites involved in CoMP JR. The average distant of every two sites are 350 M, and the antenna height are 20 m. The system bandwidth is 20 MHz and the UE is carried on a measurement vehicle with speed of 10 km/h and the data traffic transmitted from the beginning till the end [8].

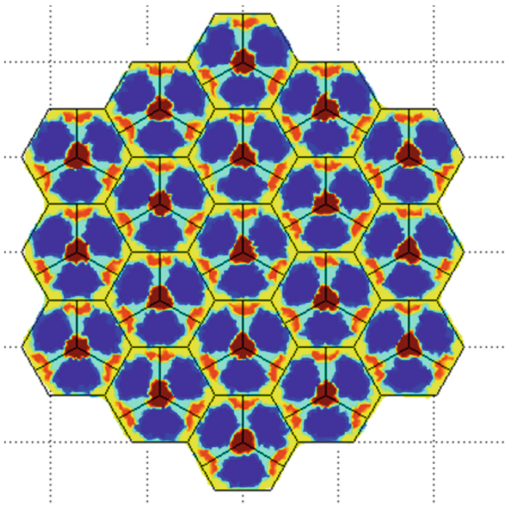

Fig. 3. The gain area of uplink JR (Color figure online)

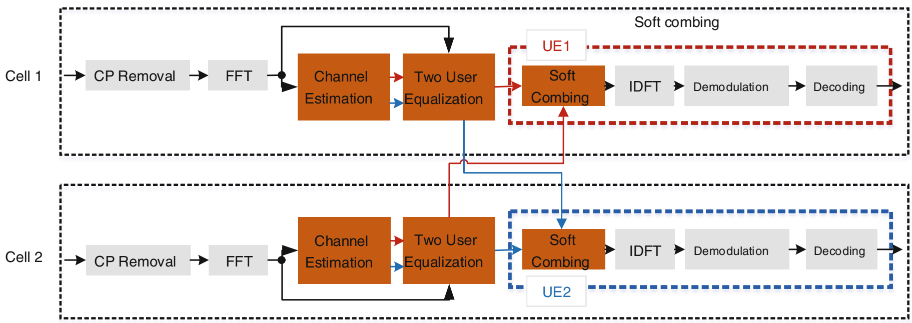

Fig. 4. The physical procedure of uplink JR

When the signal quality is poor, the uplink transmission between different shared TPs is launched. TPs measured the UE's channel quality conditions; According to the measurement results, the network selects strong signal node joint data reception, in this

Table 2. Parameters setting

PARAMETERS	ASSUMPTION
Cellular layout	19 cells of 7 eNBs
User layout	Circling, 1 users
Cell radius	350 m
BS Transmit Power	46 dBm
Carrier frequency	2 GHz
Band Width	20 MHz

case, the threshold is set to 6 dB. As shown in Fig. 5, non-cooperative area is compared to the cooperative area. Because of cooperation, the average through put gains about 20%–30%. In certain areas, even higher gains over 50% were observed.

Under HetNet scene, the main difference between HetNet CoMP and homogeneous Network is the power difference [9, 10]. The strategy can be the same in HetNet except the RSRP or other parameters should meet the threshold to activate CoMP.

In addition, the downlink CS feature is tested in a heterogeneous network scene. In this scenario, the UE moves from the center to the edge of the interfered cell (micro cell), which is under the signal coverage of the macro cell completely. The results in Fig. 6 shows that RSRP and the through puts are reducing gradually since the UE moves outward. The throughput decreases and finally approaches zero (shown as blue part); However, when the DL CS is on, the UE throughput raised in different degree (shown as red part), because of the coordination between the macro and micro cells. The user information is transmitted to the macro cell, macro cell schedule different RBs to avoid the interference. When the user moves to the cell edge, the avoidance of interference has become more evident, the cell spectral efficiency is further improved, and gain significantly compared to the downlink CS off.

Fig. 5. The uplink JR gains in Shang Hai

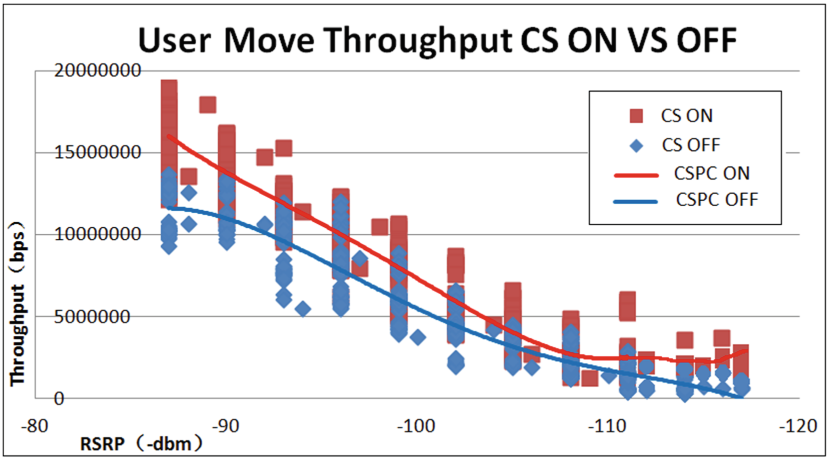

Fig. 6. The throughput of downlink CS on vs. off (Color figure online)

5 Conclusions

In this article, the overview of CoMP technology is given, the difference of five types of CoMP, both in uplink and downlink, are analyzed. Challenges and requirement for backhaul and delay are presented. As JT and DPS are regarded as the uneconomic methods for network operator, the UL JR and DL CS are more likely be applied in the future network. Therefore, flow and strategies of UL JR and DL CS are discussed in detail. Field trial has been taken both in homogeneous and heterogeneous network to support the conclusion. The trial results shows that under a certain condition, CoMP can provide higher bitrates and improve cell edge user rate significantly, and system spectral efficiency is improved as well.

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