Performance Analysis of Coordinated Multi-Point with Scheduling and Precoding schemes in the Heterogeneous Network

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Abstract—**Coordinated Multi-Point (CoMP) is considered as a technology in the 3rd Generation Partnership Project (3GPP) Long Term Evolution-Advanced (LTE-A) system. In this paper, we design and analyze the performance of the Coordinated Scheduling/Beamforming (CS/CB) technique, which is one major category of CoMP. We perform Monte Carlo simulations with a Heterogeneous Network (HetNet) in LTE-A. Simulation results show that the proposed CoMP can improve Signal to Interference plus Noise Ratio (SINR), and the spectrum efficiency of macrocell and picocell users through a graph of the Cumulative Distribution Function (CDF). From these results, we also show significant performance gain when we apply various techniques of scheduling and precoding with the CoMP.**

Keywords- CoMP; HetNet; LTE-A; Precoding; Scheduling

I. INTRODUCTION

Mobile communication technology has been constantly evolving to satisfy the communication market, which requires high-speed support for high-capacity and high-quality. The next generation of wireless communication requires a data rate of 100Mbps class for dynamic user equipment (UE), and 1Gbps class for static UE. It aims to enable high-speed network access using information devices anytime, anywhere, through integration of wired and wireless communications and broadcasting [1-2].

Recently, through the prevalence of smart phones, the needs of users for quality anytime, anywhere data services have increased rapidly. Techniques that can support high data rates to users located within cell edges, as well as cell centers, came into demand. A cell center can increase data transmission speed, simply by using the support of additional antenna ports for each cell. But in the case of a cell edge, it is difficult to increase the data rate up to any limitations without cooperation, because this location receives too much interference from adjacent cells. Also frequency reuse techniques being deployed using small cells, such as femto cell or pico cell, within the macro cell area can provide high speed data services to dense user areas. Accordingly, the need for efficient methods to control the interference between transfer points is increasing [3].

Current standards and academic issues, such as how to control the interference from point-to-point transmission naming, identify Coordinated Multi-Point (CoMP), which was selected as a work item for Long Term Evolution-Advanced (LTE-A) Release 11.

In the paper, we will discuss the basic techniques of CoMP, and the effect of CoMP combined with several techniques, through simulation results. As an issue in fourth generation mobile communication, the CoMP environment in this paper is based on LTE-A systems.

The rest of the paper is organized as follows. Section II defines the CoMP basic system model. Section III briefly presents the various scheduling and precoding schemes. After evaluating the performance of the proposed schemes in Section IV, we conclude the paper in Section V.

II. SYSTEM MODEL

The Heterogeneous Network (HetNet) is one of the LTE-A system networks. HetNet complying with the LTE-A Release 11 Scenario 4 is discussed as follows [4].

As shown in Figure 1 (a), it is assumed that a macro cell is divided into three sectors. Three adjacent sectors consist of one cell site, and communication is coordinated. In Figure 1 (b), pico cells exist in a macro cell, and communication is coordinated with the macro cell. Users are uniformly and randomly distributed in each macro cell and pico cell [4-5].

In the conventional cellular system, users receive a signal from each anchor cell with interference signals from adjacent cells. We assume that user M_j is locates randomly in C_j and receives signals from three cells (denoted as C_1, C_2 and C_3) [6]. Assume H_{ij} is the channel gain from C_i to M_j. The received signal Y_1 at M_1 can be expressed as

$$Y_1 = H_{11}W_1X_1 + H_{21}W_2X_2 + H_{31}W_3X_3 + N \quad (1)$$

where X_i is the signal transmitted at C_i, W_i is the precoding matrix at C_i, and N is the additive white Gaussian noise at M_1.

As shown in the expression, Inter-Cell Interference (ICI) occurs, and the channel capacity is limited, according to the signal from an adjacent cell being considered as an interference signal. The following expression for C_1 is located within the user's Signal to Interference plus Noise Ratio (SINR).

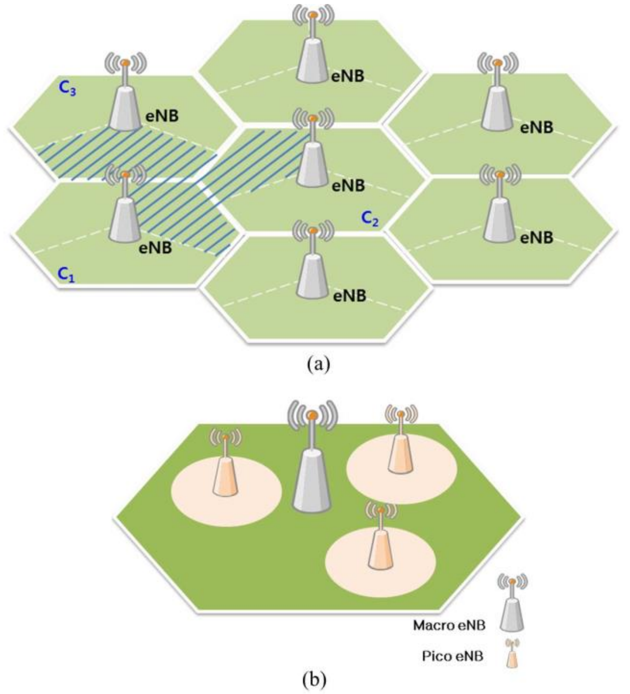

Figure 1. Structure of the HetNet complying with the LTE-A Release 11 Scenario 4: (a) Macro only, (b) Macro and Pico.

If one user receives a signal from its own serving cell, the signals from the other cells affect the user as interference, and then the SINR of M_1 can be expressed as

$$SINR = \frac{||H_{11}W_1||^2 P_1}{||H_{21}W_2||^2 P_2 + ||H_{31}W_3||^2 P_3 + N} \quad (2)$$

CoMP technology can control the interference among neighboring cells through cooperative communication technology, which is a promising 4G cellular standard being developed by the 3rd Generation Partnership Project (3GPP) standardization group. CoMP can improve the coverage, cell-edge capacity and/or system efficiency. For downlink CoMP, two different approaches are being considered, namely, Joint Processing (JP) and Coordinated Scheduling/Beamforming (CS/CB) in 3GPP LTE-A standard [4].

The SINR for a user that is located within C_1 in the CoMP JP scheme can be formulated as

$$SINR = \frac{||H_{11}W_1\sqrt{P_1} + H_{21}W_2\sqrt{P_2} + H_{31}W_3\sqrt{P_3}||^2}{N} \quad (3)$$

From the above expression, you can see that the interference signal from the neighboring cells also provides a useful signal through the cooperation among multiple cells, where only noise interferes with the signal.

The received signal at the user within each cell in the CoMP CS/CB scheme can be expressed as

$$Y_1 = H_{11}W_1X_1 + H_{21}W_2X_2 + H_{31}W_3X_3 + Z_1 \quad (4)$$

$$Y_2 = H_{12}W_1X_1 + H_{22}W_2X_2 + H_{32}W_3X_3 + Z_2 \quad (5)$$

$$Y_3 = H_{13}W_1X_1 + H_{23}W_2X_2 + H_{33}W_3X_3 + Z_3 \quad (6)$$

We measure the SINR for each cell by the above expressions, by the precoding matrix that has the highest SINR applied to each cell. As a result, the interference coming from the surrounding cell is minimized, and the received signal strength can be maximized. In this case, the precoding matrix is expressed as follows.

$$W_1{}' = \frac{||H_{11}W_1||^2 P_1}{||H_{21}W_2||^2 P_2 + ||H_{31}W_3||^2 P_3 + N} \quad (7)$$

$$W_2{}' = \frac{||H_{22}W_2||^2 P_2}{||H_{12}W_1||^2 P_1 + ||H_{32}W_3||^2 P_3 + N} \quad (8)$$

$$W_3{}' = \frac{||H_{33}W_3||^2 P_3}{||H_{13}W_1||^2 P_1 + ||H_{23}W_2||^2 P_2 + N} \quad (9)$$

We perform simulations using CoMP CS/CB, which shows a tradeoff between performance and complexity, and which is the best parameter, compared with other schemes.

III. SCHEDULING AND PRECODING TECHNIQUES

In this section, scheduling and precoding techniques are proposed as a way to improve the performance of CoMP. Each technique is described below.

A. *Scheduling*

We suggest a scheduling scheme to improve the CoMP performance through using scheduling, as Flexible Frequency Allocation Plan (FFAP) and Coordinated Scheduling (CS) schemes are used.

The FFAP scheme suggests that the whole frequency band be divided into two parts: a CoMP frequency zone for the cell-edge user (CEU)'s transmission, and a single sector frequency band for the cell-center user (CCU)'s transmission, as shown in Figure 2.

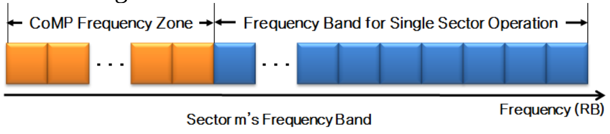

Figure 2. Structure of the CoMP FFAP scheme.

The differentiation between CEUs and CCUs can be made based on the received SINR at the UE.

$$SINR \leq \gamma \quad (10)$$

where γ is a predetermined threshold in dB.

The CS scheme is a way in which all users that exist in one cell can be distinguished into CCU or CEU and then, the sum of highest priority of CCU for each sector in one cell and the highest priority of CEU in one cell are compared. The priority is based on the received SINR.

If the CEU's priority is higher, the system will be calculated based on the CoMP mode. Otherwise, CCUs are calculated based on the Non-CoMP mode. In this mode, we send a signal to users using the common transmission

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method. The flow chart for the CS scheme is shown in Figure 3 [7].

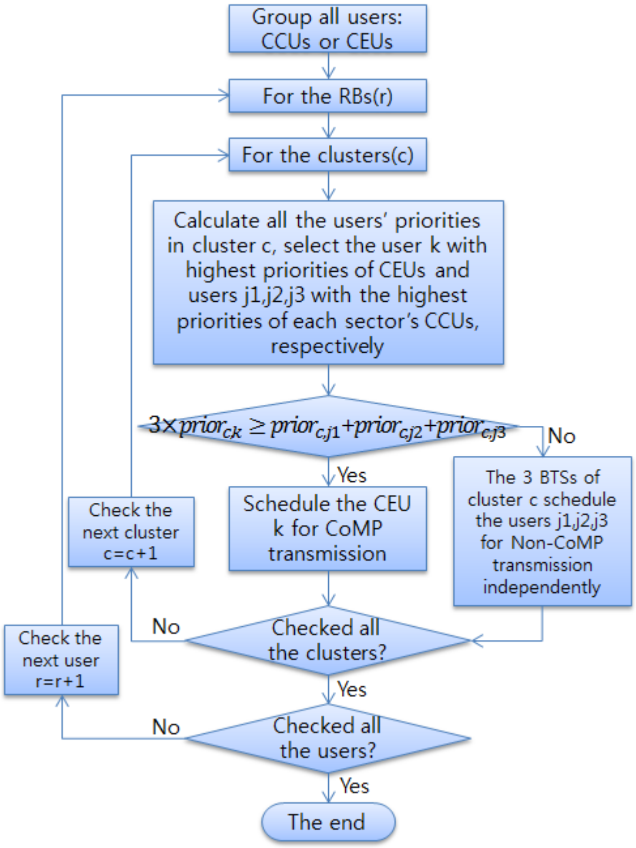

Figure 3. Flow Chart of the CoMP CS scheme.

B. *Precoding*

A precoding scheme is another way to improve the performance of CoMP. Precoding is a technique to increase the SINR and spectrum efficiency of a signal, by multiplying a specific matrix with the channel in the transmitter. Singular Value Decomposition (SVD), Polar Decomposition (PD), Tomlinson Harashima Precoding (THP) and QR Decomposition (QRD) schemes are used as precoding techniques.

Using the SVD scheme, the channel is separated in parallel, by multiplying an orthogonal matrix U and V. The basic equation for the channel matrix H and the precoding matrix W are expressed as

$$\begin{aligned} H &= U\Sigma V^H \\ W &= V \end{aligned} \tag{11}$$

Using the PD scheme, the channel is separated, based on the SVD scheme. The channel matrix H and the precoding matrix W are expressed as follows.

$$\begin{aligned} H &= QSP^H = AU^H \\ A &= QSQ^H \\ W &= U = PQ^H \end{aligned} \tag{12}$$

The THP scheme is a nonlinear precoding based on Costa's "writing on dirty paper result" information theory [8]. In other words, if the transmitter knows the interference signal beforehand, it can get the same channel capacity as the non-interference channel condition. THP precoding additionally uses modulo operation, which is symmetric nonlinear operation based on costa's precoding. The modulo operation is given as

$$mod_A(x) = x - A\left\lfloor \left(x - \frac{A}{2}\right)/A \right\rfloor \tag{13}$$

A block diagram of this technique is shown in Figure 4.

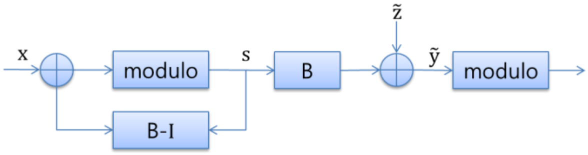

Figure 4. Block Diagram of THP precoding scheme.

QRD scheme creates the precoding matrix through QR decomposition, which factorizes the channel matrix. The basic equations for the channel matrix H and the precoding matrix W are given as

$$\begin{aligned} H &= RQ^H \\ W &= QF \end{aligned} \tag{14}$$

IV. SIMULATION PARAMETERS AND RESULTS

We confirm the performance gain according to the use of CoMP technique in heterogeneous network scenario in LTE-A system. In addition, the performance gain for the scheduling and precoding with CoMP techniques will be confirmed. We use Cumulative Distribution Function (CDF) to analyze the SINR and spectrum efficiency.

A. *Simulation Environments*

The simulation environment follows the 3GPP LTE-A standard. We perform system-level simulations using Matlab, based on the parameters of Table 1 [9]. We assume that three pico cells exist within one macro cell, and are located in the edge site of the macro cell.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Carrier Frequency	2 GHz
Bandwidth	20 MHz
Cellular Structure	Hexagonal grid, 2-tiers, 7 cell sites, 3 sectors per site, 3 pico cells per site
No. of MS per cell	100 MSs
Antenna Configuration	BS: 2, MS: 2
BS Max TX Power	49 dBm – 20 MHz Carrier
Cell Radius (R) = ISD/ROOT3	1732/ROOT3=~1000m → Macro cell
Path Loss Model	Macro cell: L = 128.1 + 37.6log10(R), R in km Pico cell: L = 140.7 + 37.6log10(R), R in km
Shadow Std. Deviation	8 dB
MS Noise Level	174 dBm/Hz
UE Noise Figure	9 dB
NodeB Noise Figure	5 dB
Correlation distance of Shadowing	50 m
Shadowing correlation between cells/sectors	0.5 / 1.0
Minimum distance	Macro-Pico: >75m, Pico-Pico: >40m, Macro-UE: >35m, Pico-UE: >10m
BS antenna gain plus cable loss	14 dBi for micro, macro cell case
Antenna Pattern	70 degree sectored beam =70 degree, Am=20dB
Scheduling scheme	FFAP, CS
Precoding scheme	SVD, PD, THP, QRD

B. *Simulation Results*

Using Non-CoMP scheme as a baseline for evaluating the performance of the proposed scheme, we send a signal to users.

1) *CoMP simulation with Scheduling*

The CDF graphs of the SINR are shown when we apply two kinds of scheduling techniques to CoMP in Figures 5 and 6, respectively. Figure 5 is for a Macro UE, which is for a macro cell when communication is coordinated among macro cells. Figure 6 is for a Pico UE, which if for a pico cell when communication is coordinated among macro cell and pico cell.

From these figures, we can find that using the scheduling (FFAP or CS) with CoMP brings a performance gain, compared with the non-CoMP. Especially the CS with CoMP can be seen to provide the highest contribution towards improving the performance.

The CDF graphs of spectrum efficiency are shown when we apply two kinds of scheduling techniques to CoMP as in Figures 7 and 8, respectively. Figure 7 is for Macro UE, when communication is coordinated among macro cells. Figure 8 is for Pico UE when communication is coordinated among macro cell and pico cell.

From these figures, we can find that using the scheduling with CoMP brings a performance gain, compared to with non-CoMP. CS with CoMP can be seen to offer the highest contribution to improve the performance.

Also, in the case of Pico UE, the overall performance is better than in the case of Macro UE, because the pico cell is located at the edge of the macro cell.

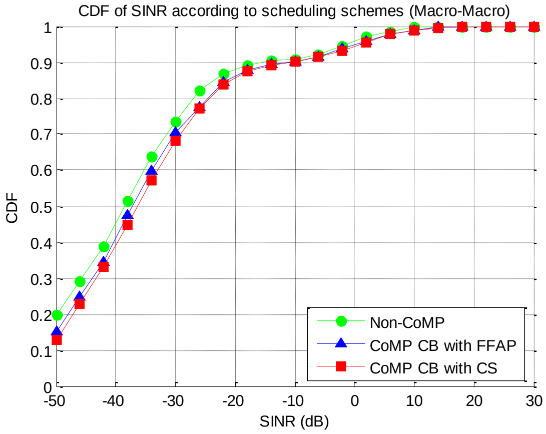

Figure 5. CDF of Macro UE SINR according to scheduling schemes.

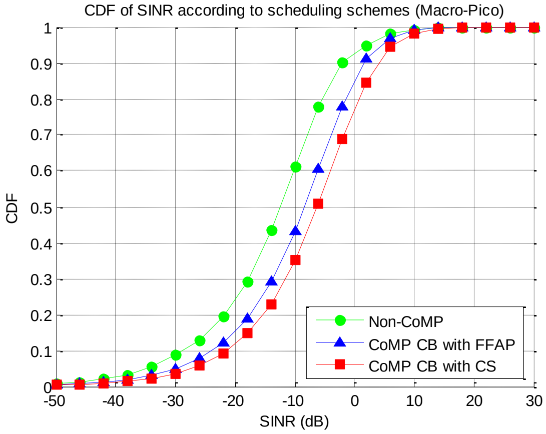

Figure 6. CDF of Pico UE SINR according to scheduling schemes.

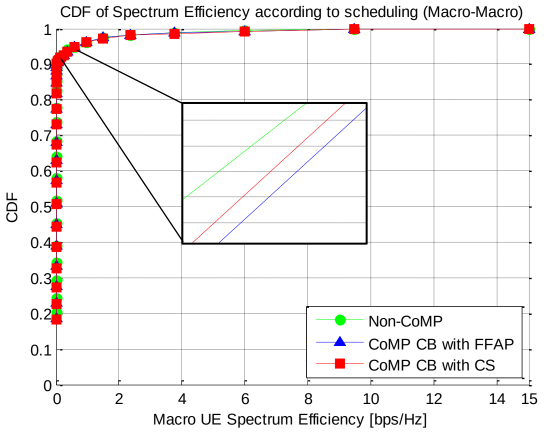

Figure 7. CDF of Macro UE Spectrum Efficiency according to scheduling schemes.

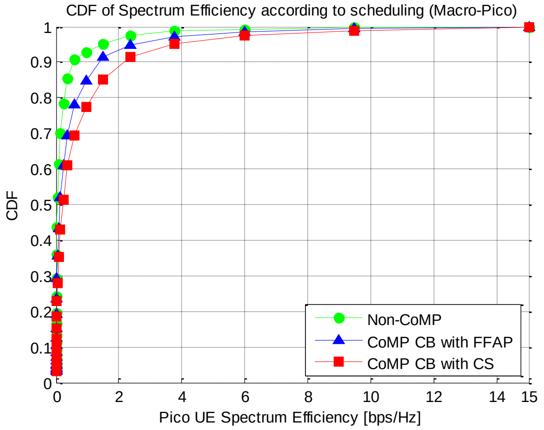

Figure 8. CDF of Pico UE Spectrum Efficiency according to scheduling schemes.

2) *CoMP simulation with Precoding*

Here, the CDF graphs of SINR are shown when we apply various precoding techniques to CoMP, in Figures 9 and 10, respectively. Figure 9 is for Macro UE, when communication is coordinated among macro cells. Figure 10 is for Pico UE, when communication is coordinated among macro cell and pico cell.

From these figures, we can find that using SVD precoding with CoMP brings a performance gain, compared to PD, THP and QRD schemes.

The CDF graphs of spectrum efficiency are shown when we apply various precoding techniques to CoMP, in Figures 11 and 12, respectively. Figure 11 is for Macro UE, when communication is coordinated among macro cells. Figure 12 is for Pico UE when communication is coordinated among macro cell and pico cell.

From these figures, we can find that using SVD precoding with CoMP brings a performance gain, compared to PD, THP and QRD schemes.

Also, the performance of the Pico UE is better than the Macro UE case.

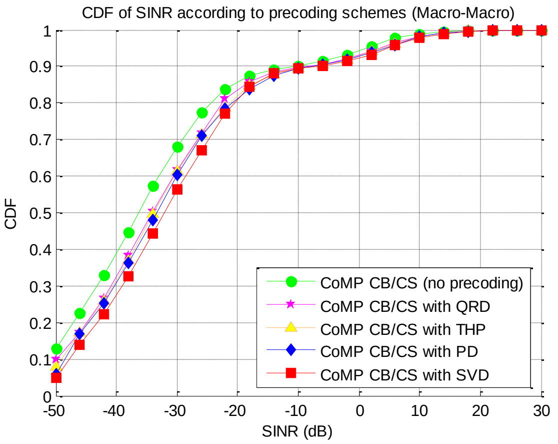

Figure 9. CDF of Macro UE SINR according to precoding schemes.

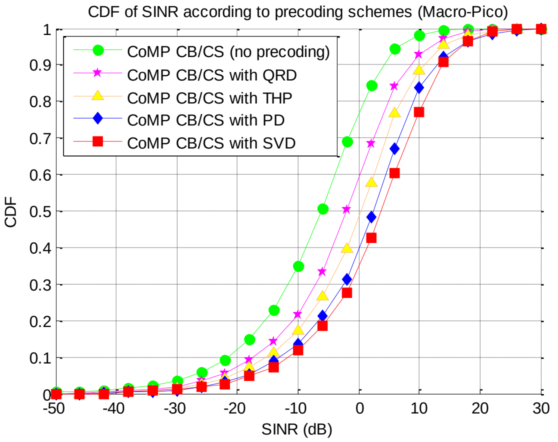

Figure 10. CDF of Pico UE SINR according to precoding schemes.

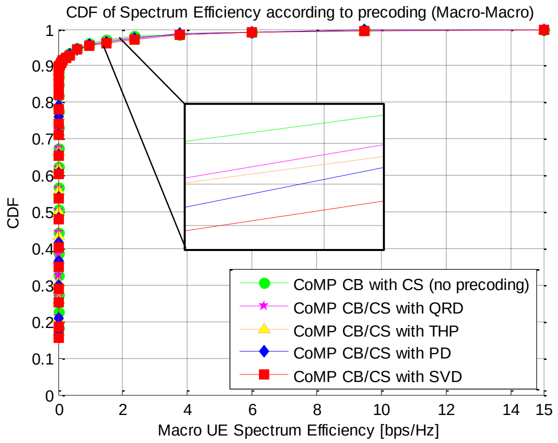

Figure 11. CDF of Macro UE Spectrum Efficiency according to precoding schemes.

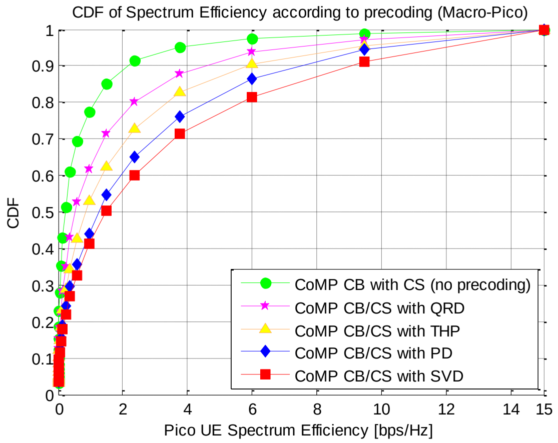

Figure 12. CDF of Pico UE Spectrum Efficiency according to precoding schemes.

V. CONCLUSIONS

We demonstrate a performance analysis of CoMP technique, for multi-point cooperation among users for next-generation cellular systems. System-level simulation results are based on HetNet in the LTE-A system.

We compare and analyze the performance according to the CoMP technique applied, in two cases; one is among only macro cells, the other is among macro cell and pico cell. In both cases, we can get an improved performance when using CoMP technique. It is also shown that CoMP techniques combined with scheduling and precoding achieved further improvement of performance.

As a result, we confirm that CoMP technology can be applied to HetNet, which has pico cells within a macro cell in the LTE-A system.

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