Downlink Performance of Coordinated Multipoint (CoMP) in Next Generation Heterogeneous Networks

Jamil Sultan[1,2]
[1]*Telecommunication Engineering Technology Deptartment*
[1]*Sana'a Community College*
[2]*Computer Network Eng. Dept*
[2]*University of Modern Sceinces*
Sana'a, Yemen
jameel730@gmail.com

Waheb A. Jabbar
College of Engineering
Faculty of Computing, Engineering and the Built Environment
Birmingham City University
Birmingham B4 7XG, UK
waheb.abdullah@bcu.ac.uk

Nashwan S. Al-Thobhani[1,2]
[1]*Computer Network Engineering Technology Deptartment*
[1]*Sana'a Community College*
[2]*Faculty of Engineering*
[2]*University of Modern Sciences*
Sana'a, Yemen
nashwansg@gmail.com

Abdulaziz Al-Hetar
School of Engineering
Lebanese International University (LIU)
Sana'a, Yemen
alhetar.aziz@ye.liu.edu.lb

***Abstract*— Next generation networks are envisaged to be heterogeneous networks (HetNets), primarily through the dense deployment of small cells in the coverage area of macro cells. HetNet leads to new cell edges with high-level inter-cell interferences (ICIs) that can be increased twice compared to the conventional cellular network design. Consequently, mitigating ICI plays a vital role in the next generation networks. Coordinated multipoint (CoMP) is an advanced communication technique that is able to mitigate the strongest ICI signals and turn them into useful signals. In CoMP, multiple macro and/or small transmission points (TPs) are involved in the transmission to cell edge users leading to further enhance performance of these users. In this paper, we investigate the downlink (DL) performance of 5G HetNet when CoMP technique is used for ICI mitigation. A system-level simulation is developed in order to evaluate and compare the DL performance of joint transmission (JT) CoMP scheme, dynamic point selection (DPS) CoMP scheme and Non-CoMP scheme. The effect of CoMP margin on the performance of CoMP technique is also investigated. Simulation results show that JT scheme outperforms DPS and Non-CoMP schemes in terms of the average DL signal-to-interference-plus-noise ratio (SINR), average DL spectral efficiency and outage probability. In addition, the percentage of users who use CoMP increases as CoMP margin is increased. Simulation results also show that the percentage of users whose CoMP TPs consists of one macro TP and one small TP is the highest and this percentage increases as CoMP margin is increased.**

Keywords*— *Coordinated Multipoint (CoMP); Joint Transmission (JT); 5G; Relay Node (RN); HetNets; Interference mitigation

I. INTRODUCTION

Mobile data traffic has significantly grown over the last decade, primarily because of the growing number of smart wireless devices and bandwidth-demanding applications. This trend is expected to be sustained, especially with the deployment of fifth generation (5G) and sixth generation (6G) networks [1]. It is forecast that by 2025 the number of cellular broadband subscribers will increase to 8.8 billion [2] and the network's data traffic is predicted to reach 351 Exabyte [3]. Heterogeneous network (HetNet) is among the most promising approaches to boost capacity and to enhance coverage with low-cost and power-efficient infrastructure in 5G and beyond networks [4]. In HetNet, small low transmission power base stations (BSs) are deployed by operators to overlay the macro cellular network and share its licensed spectrum [5]. These small cells may be femto cells, pico cells, micro cells, remote radio head (RRH), and relay nodes (RNs) [6].

In spite of the substantial advantages of enhancing the system performance of 5G networks, many challenges face the implementation of HetNets in practical cases [1]. Actually, typical problems face HetNets include severe inter-cell interferences (ICIs), high-energy consumption, high costs in deployment and management of small cells, increase number of handovers (HOs), spectrum reuse, backhaul, and limited infrastructure resources. In the HetNets environment, the simultaneous operations and the closeness of neighboring macro and small cells result in high-level interferences that limit the quality of experience for users and reduce the expectations of 5G [6]. It is observed that ICI in the HetNet can be increased twice compared to the conventional cellular network design. Consequently, managing, mitigating, and cancelling ICI play a vital role in the next generation cellular networks.

Many solutions have been proposed by 3rd Generation Partnership Project (3GPP) to address the interference problem. These techniques can be performed in cellular networks either with cooperation or without cooperation between network nodes. Inter-cell interference coordination (ICIC) concept was introduced in 3GPP Rel-8 to deal with interference issues at cell edges and mitigate interference on traffic channels only. However, this method fails to control ICI on control channels as well as in HetNets due to the power difference of transmission points (TPs) [7]. These limitations were bypassed with the 3GPP Rel. 10 specification wherein enhanced ICIC (eICIC) was developed to deal with interference issues in HetNets and to mitigate interference on both traffic and control channels. eICIC ensures orthogonal resource allocation through using absolute blank subframes (ABSs), where the macro TPs are muted to allow interference-free transmission for micro/femto TPs [8]. The proliferation of device density, combined with raised heterogeneity of wireless infrastructure compounded the ICI problem. This required more sophisticated and dynamic coordination approaches. Consequently, CoMP was introduced in the 3GPP Rel-11 as a dynamic mechanism which entails the coordination between multiple transmit or reception points. If full cooperation is assumed, the channel state information (CSI) and data for all users are shared by the CoMP cluster TPs that are linked with ideal backhaul to coordinate with each other [9].

Rel-12 extended the CoMP concept to multiple eNBs connected with non-ideal backhaul [10]. Enabling this extension necessitated the standardization of signaling over X2 interface to allow exchange of CoMP hypothesis set and its related benefit metric, containing reference signal received power (RSRP) measurements, between cooperating eNBs. 3GPP Rel-13 proposed some improvements concerning CSI and enhanced relative narrowband transmission power (eRNTP), where the latter is mainly useful for power allocation in a CoMP setting [11]. Rel-14 explored alternatives to joint transmission (JT) CoMP scheme due to its stringent strict synchronization and CSI requirements, leading to development of non-coherent JT (NC-JT) [12]. Further enhancements were proposed in Rel-15 by monitoring X2 characteristics and the space-time variation to update or manage CoMP sets under the self-organizing network (SON) umbrella. However, later 3GPP releases introduced the multitude of technologies required to satisfy the requirements imposed by 5G and beyond networks [7].

Hence, CoMP is introduced in Rel-10 and known as one of the communication techniques that is able to provide benefits of ICI mitigation, and cell edge signal-to-interference-plus-noise ratio (SINR) enhancement and throughput/capacity improvement [13]. CoMP technique mitigates the dominant interfering signal(s) and turning them into useful signals. Therefore, CoMP allows cell edge users to be served by the strongest base stations in order to reduce the interference that it suffers from. However, expansion of the 5G use cases resulted in a renewed interest in CoMP. This is mainly because of a transformation of the advantages behind CoMP, where instead of limiting it to capacity/throughput enhancement, many works on CoMP are being developed to leverage diversity for reliability and other requirements [7]. In other words, extensive works on CoMP in literature aimed at addressing the various requirements of 5G and beyond networks; such as mobility managements [14], increasing reliability and reducing latency [15], reducing energy consumption [16] and enhancing security against eavesdropping [17]. The main aim of this paper is to investigate the downlink (DL) performance improvement of 5G HetNet when CoMP technique is used for mitigating ICI. In fact, the DL performance of two CoMP schemes; namely joint transmission (JT) scheme and dynamic point selection (DPS) scheme, are investigated and compared with Non-CoMP scheme.

The remainder of this paper is outlined as follows. Section II offers an overview of the related techniques of CoMP. The system model is introduced and described in Section III. Then, in Section IV, the simulation results are analyzed and discussed. Lastly, the paper is concluded in Section V.

II. Techniques Related to CoMP

In CoMP, several TPs coordinate dynamically, supporting joint scheduling and transmission of the signals along with the joint processing of received signals by the receiver. CoMP relies on the measurements of the RSRPs from the neighbor cells that are made at the user equipment (UE) and sent back to the serving cell in periodic measurement reports [18]. Using this report and by comparing the RSRPs of the candidate TP cell and that of the serving cell, the serving cell selects a candidate TP to be included in the CoMP cluster for this user. Hence, CoMP clusters are formed on a per-user basis, where the *b*-th TP is included in the *u*-th UE's CoMP cluster depending on the satisfaction of the following criteria [7]

$$RSRP_{b,u} \geq RSRP_{ser,u} - M \tag{1}$$

where $RSRP_{b,u}$ is the received RSRP of the link between the *b*-th TP and *u*-th UE, $RSRP_{ser,u}$ is the received RSRP between the current serving TP and *u*-th UE and M is the CoMP margin which represents the maximum difference between the received RSRPs from the serving TP and candidate TPs.

Three different CoMP scenarios were proposed by 3GPP for both homogeneous networks and HetNets [9]. The first scenario is intra-site CoMP which is implemented on homogeneous network, in which different sectors of the same TP are coordinated together. Owing to the colocation, there is no added load on the backhaul in this scenario. The second scenario is inter-site CoMP which is also applied on a homogeneous network wherein only macro-cell BSs and high power RRHs are considered to apply coordination with each other in a CoMP cluster. The third scenario is applied on HetNets wherein it is possible to implement CoMP between macro cell and low power small cell.

CoMP works in two ways: uplink (UL) and DL. DL CoMP calls for close coordination among TPs serving a UE. These TPs are located in different areas. Three main DL coordination categories are recognized by 3GPP for LTE-Advanced [19] according to the required backhaul capacity and scheduling complexity. These DL categories are JT, DPS and coordinated scheduling/coordinated beamforming (CS/CB). In this paper, we have investigated the DL CoMP of JT and DPS schemes only.

A. Joint Transmission (JT)

In JT, user data and also CSI/scheduling information are shared among the coordinated TPs. This allows a UE to potentially receive a signal from many transmission points simultaneously. This type of coordination provides strong received signal strength, high spectral efficiency and throughput [19]. However, it requires high backhaul bandwidth with low latency due to exchange of user data among multiple TPs. Multiple TPs can serve to single user either coherently or non-coherently, changing interference signal to useful signal. Coherent transmission refers to joint precoding design and synchronized transmission to achieve coherent combining. On the other hand, joint precoding is not required in non-coherent JT; but user data is received from multiple TPs where data is separately precoded from each cell [7].

B. Dynamic Point Selection (DPS)

This is a special type of JT where user data is transmitted from one TP only and serving TP is changed dynamically in each sub-frame. The TP selection is based on resource availability and CSI [20]. Fading conditions are exploited to select the best serving cell at each sub-frame. This enables the network to serve the UE by the TP which momentarily provides the best channel condition to the UE, or to achieve load balancing between the TPs. Similar to JT, user data in DPS is also available at multiple TPs. It should be noted that in some literature the JT and DPS are referred to as joint processing (JP) [21].

C. Coordinated scheduling/beamforming (CS/CB)

In CS/CB, the data intended to a user is saved only in its serving TP and the resources scheduling and beamforming are dynamically coordinated by the cooperating TPs. Resource scheduling is dynamically coordinated between cells and beamforming vectors are designed and aligned to increase the desired user signal strength, hence decreasing the interference with neighboring UEs [19]. In addition, the transmission decisions are made by semi-static point selection (SSPS). The main advantage of this technique is reduced load at the backhaul as only one station serves a particular UE for a specific period. Therefore, UE data is directed to only that serving station.

III. SYSTEM MODEL

A. Network Model

In this paper, the DL performance of the CoMP technique in 5G HetNets is investigated using a system level simulation developed in MATLAB software. The simulated network consists of 7 hexagonal cells with a wrap-around structure. The simulated network has 7 macro gNBs and 84 small RNs. The RNs are assumed to be decode-and-forward (DF) layer 3 relays [22] in which the RNs decodes the received signals before forwarding the signal to the destination. It is also assumed that the RNs are in-band relays wherein the access and backhaul links are separated in time-domain to realize the in-band relay operation. UEs are uniformly distributed throughout the center cell and the first tier cells with 30 UEs per each cell. Each user moves randomly in each simulation iteration and its new direction of movement is randomly chosen by means of the modified random direction mobility model [23]. In the meantime, traffic model used is the full buffer model in which every UE has data to transmit or receive in the buffer all the time [24]. Each user is assigned one physical resource block (PRB), which consists of a group of 12 sub-carriers. Each sub-carrier has a bandwidth of 15kHz and hence the bandwidth of each PRB is 180 kHz. The CoMP algorithm described in [7,25] is considered. Table 1 presents the main simulation parameters [26,27]. In this simulation, the DL performance of three schemes is investigated and compared; namely JT scheme, DPS scheme and Non-CoMP scheme. The effect of the CoMP margin on the performance of CoMP technique is also investigated. The comparison metrics are the average DL SINR, average DL spectral efficiency and outage probability.

B. Propagation Model

In this simulation, we consider an urban area that contains both macro and small cells. It is assumed that the backhaul links between the gNBs and RNs are reliable and in line of sight (LOS). On the other hand, the access links between the gNB and UE and between RN and UE are in non LOS (NLOS). The considered model for calculating the access link path loss for both macro and small cell is the WINNER II (Type C2) [28, 29] as follows:

$$PL = \left[44.9 - 6.55\log_{10}(h_T)\right]\log_{10}(d) + 26.46 + 5.83\log_{10}(h_T) + 20\log_{10}\left(\frac{f}{2}\right) \tag{2}$$

where h_T is the height of gNB/RN transmit antenna, d is the distance (in meter) between gNB/RN and UE, and f is the carrier frequency in GHz.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Cell radius	500 m
Carrier frequency	3.5 GHz
Channel bandwidth	10 MHz
Number of macro gNBs	7 with wrap-around
Number of small RNs	84
FFT Size	1024
Number of data subcarriers	600
PRB bandwidth	180 kHz
UE distribution	Uniform random distribution
CoMP margin (M)	3 dB, 6 dB, 9 dB and 12 dB
Cluster size (Q)	2
Transmitted power	gNB: 46 dBm, RN: 33 dBm, UE: 23dBm
Noise power density	-174 dBm/Hz
Shadowing standard deviation	Access links: 10 dB, Backhaul links: 4 dB
Antenna heights	gNB: 30m, RN: 15m, UE: 1.5m
UE speed	30 km/hr
Traffic model	Full buffer
Noise figure	gNB/RN: 5 dB, UE: 9 dB

C. *DL Interference*

In this paper, only the co-channel interference and the first tier of co-channel interfering cells are taken into account. Furthermore, the worst case in calculating the interference is considered wherein it is presumed that all PRBs are allotted in every cell simultaneously. During the first time slot of all simulated schemes, the interference at a given PRB is due to the transmission of the gNBs only. During the second time slot of the JT scheme and for users in the CoMP region, the interference at a PRB is due to the simultaneous transmissions of two gNBs or simultaneous transmissions of one gNB and one RN. On the other hand, for the JT users that are not in the CoMP region, the interference is due to the transmission of gNB only or RN only. However, the interference in DPS scheme is similar to that of the JT scheme except that there are no simultaneous transmissions during the second time slot and the interference caused by either gNB or RN. It should be noted that for JT and DPS schemes, the cells in which the CoMP cluster TPs are located do not cause any interference to the desired users. For Non-CoMP scheme, the interference is due to the transmission of either gNB or RN.

D. *Average DL SINR Model*

For Non-CoMP user u , the received DL SINR from station s on PRB j measured at UE can be written as

$$\gamma^{j}_{Non-COMP,u} = \frac{P^{j}_{s} g^{j}_{s,u}}{\sum_{i \neq s, i \in N} P^{j}_{i} g^{j}_{i,u} + \sigma^2} \qquad (3)$$

where P^{j}_{s} is the transmit power allocated to the PRB j by gNB/RN s , $\sum_{i \neq s, i \in N} P^{j}_{i} g^{j}_{i,u}$ is the total interference on the PRB j that is caused by other gNBs/RNs, N is the set of all stations in the simulated network, σ^2 is the noise power and $g^{j}_{s,u}$ denotes the channel gain between gNB/RN s and user u on PRB j that is given by:

$$g^{j}_{s,u} = 10^{(-PL+G_T+G_R-\chi)} \qquad (4)$$

where PL is the path loss between gNB/RN and UE as defined in (2), G_T is the gain of the gNB/RN transmit antenna, G_R is the gain of the UE receive antenna and χ is the loss due to the large-scale shadow fading. χ is modelled as a lognormal random variable with zero mean and standard deviations of 4 dB and 10 dB for the backhaul links and access links, respectively. The shadowing's temporal correlation is considered in this simulation and the decorrelation distance is set to 25 m.

For JT and DPS CoMP schemes, we consider that all the coordinating TPs participating in the joint transmissions for users form CoMP cluster Q. Thus, the DL SINR of a JT-CoMP user u on PRB j from a CoMP cluster Q is given by:

$$\gamma_{JT,u}^{j} = \frac{\sum_{s \in Q} P_s^j g_{s,u}^j}{\sum_{i \notin Q, i \in N} P_i^j g_{i,u}^j + \sigma^2} \quad (5)$$

where $\sum_{s \in Q} P_s^j g_{s,u}^j$ is the received power from CoMP cluster Q and P_s^j, $\sum_{i \notin Q, i \in N} P_i^j g_{i,u}^j$, σ^2 and $g_{s,u}^j$ are as defined in (3).

However, the DL SINR of a DPS-CoMP user u on PRB j from a CoMP cluster Q is given by

$$\gamma_{DPS,u}^{j} = \arg\max_{s \in Q} \left[\frac{P_s^j g_{s,u}^j}{\sum_{i \notin Q, i \in N} P_i^j g_{i,u}^j + \sigma^2} \right] \quad (6)$$

E. *Modulation and Coding Rate*

After the measurements of DL SINR of each PRB made at the UE, the DL SINR is then quantized into a channel quality indicator (CQI) value which indicates the best modulation and coding rate that might be used by UE in order to achieve a packet error rate (PER) less than a target. These CQI values are then fed back by UE to the gNB/RN. Table 2 shows the CQI, required SINR and spectral efficiency of the different modulation and coding rates used in this simulation [30, 31].

TABLE II. SINR AND CQI MAPPING TO MODULATION AND CODING RATE

CQI	Modulation Scheme	Code Rate (x 1024)	Spectral Efficiency (bits/symbol)	Required SINR (dB)
1	QPSK	120	0.2344	-5.147
2	QPSK	193	0.3770	-3.18
3	QPSK	449	0.8770	0.761
4	16QAM	378	1.4766	4.694
5	16QAM	616	2.4063	8.573
6	64QAM	567	3.3223	12.289
7	64QAM	772	4.5234	15.888
8	64QAM	873	5.1152	17.814
9	64QAM	948	5.5547	19.829

F. *Outage Probability*

The outage probability can be defined as the probability that the DL SINR (γ_{DL}) is below the smallest SINR required for the UE to attain services (γ_0)

$$P_{out} = P[\gamma < \gamma_o] \quad (7)$$

In this simulation, the outage probability is calculated by way of the percentage of users for which the DL SINR (γ_{DL}) is lower than the minimum SINR (γ_0) that is required to support the minimum modulation and coding scheme (MCS) (MCS1 which relates to QPSK modulation scheme with code rate of 0.2344). In fact, the minimum SINR in this simulation is equal to $\gamma_0 = -5.147\,dB$ according to [30].

IV. SIMULATION RESULTS AND DISCUSSIONS

Fig. 1 shows the average DL SINR as a function of the CoMP margin for JT, DPS and Non-CoMP schemes. As can be seen from Fig. 1, the average DL SINR for JT scheme is higher than that of the DPS and Non-CoMP schemes at the considered values of the CoMP margin. In addition, the average DL SINR for JT scheme slightly increases as CoMP margin is increased. The average DL SINR for Non-CoMP scheme is fixed at the different values of CoMP margin because CoMP is not implemented in this scheme and hence this scheme does not depend on the CoMP margin. At CoMP margin of 12 dB, JT scheme offers SINR gains of 9.4% compared to Non-CoMP scheme. These results may appear to hardly justify the use of CoMP. This is because of that the averaging process in the results of Fig. 1 is done over all users (in the CoMP and non-CoMP regions). The benefits of CoMP are for those users located at CoMP region (cell edge). However, a different picture in terms of higher gains will be obtained if we consider the average SINR for those users only who actively use CoMP (users located in CoMP regions only) as will be explained in next figure.

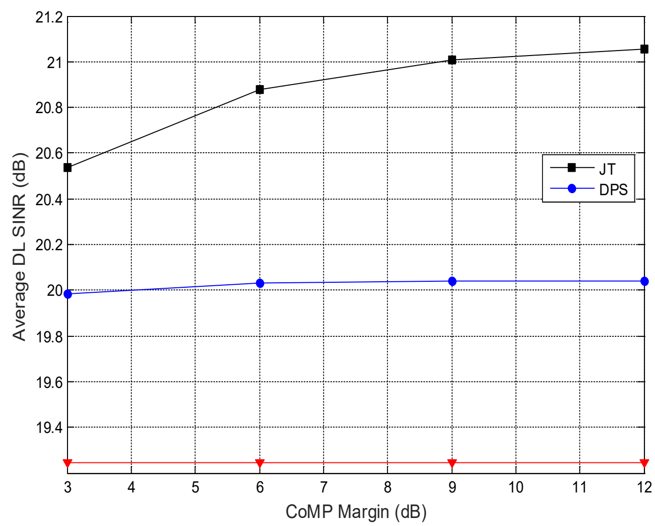

Fig. 1. Average DL SINR for all users at different values of CoMP margin

Fig. 2 illustrates the average DL SINR as a function of the CoMP margin for the JT, DPS and Non-CoMP schemes for UEs in the CoMP region only. As can be seen from Fig. 2, the average DL SINR for JT scheme is higher than that of other considered schemes. In addition, the average DL SINR increases as CoMP margin is increased. The difference in the average DL SINR between the JT scheme and DPS and Non-CoMP schemes decreases as CoMP margin is increased. In fact, at CoMP margin of 3 dB, the achieved DL SINR for JT scheme is 13.81 dB whereas the average DL SINR for DPS and Non-CoMP schemes are 11.97 dB and 9.39 dB, respectively. Hence, JT scheme outperforms DPS and Non-CoMP schemes by 15.4% and 47%, respectively. On the other hand, at CoMP margin of 12 dB, the JT scheme outperforms DPS and Non-CoMP schemes by 8.22% (15.56 dB to 17.05 dB) and 19.23% (14.3 dB to 17.05 dB), respectively. It should also be noted that even though both DPS and Non-CoMP schemes receive from single TP at each sub-frame, DPS outperforms Non-CoMP scheme at the different considered CoMP margins. In other words, DPS outperforms Non-CoMP scheme by 27.5% at CoMP margin of 3 dB whereas DPS outperforms Non-CoMP by 9% at CoMP margin of 12 dB. The reason behind this is that JT and DPS schemes benefit from the ICI mitigation achieved by CoMP technique while Non-CoMP scheme does not. Furthermore, for DPS scheme, the strongest TP is selected to transmit to the CoMP user which may change at each sub-frame which is not the case for Non-CoMP users. In fact, in Non-CoMP scheme, TP is changed whenever user moves from the current serving TP and performs handover to the target TP.

Fig. 3 depicts the SINR gains of the JT scheme over the DPS and Non-CoMP schemes. It is clear from this figure that the SINR gains of JT CoMP scheme decrease as the CoMP margin is increased. In fact, at CoMP margin of 3 dB, the SINR gains of JT CoMP scheme are 4.416 dB and 1.84 dB over the DPS and Non-CoMP schemes, respectively. However, compared to the DPS and Non-CoMP schemes, the SINR gains of JT scheme are 2.74 dB and 1.49 dB, respectively, at CoMP margin of 12 dB. The reason behind this is that at low value of CoMP margin the SINR difference between the CoMP cluster TPs is small and hence whenever SINRs of both TPs are added together, the total SINR is high compared to that of DPS or Non-CoMP schemes. On the other hand, at high value of CoMP margin the SINR difference between the CoMP cluster TPs is large and hence when SINRs of both TPs are added together, the total SINR is slightly higher than the SINR of DPS or Non-CoMP schemes.

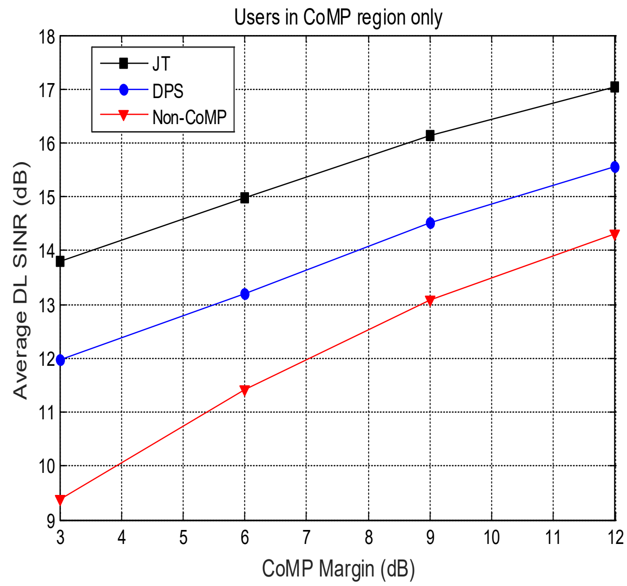

Fig. 2. Average DL SINR for users in CoMP region only at different values of CoMP margin

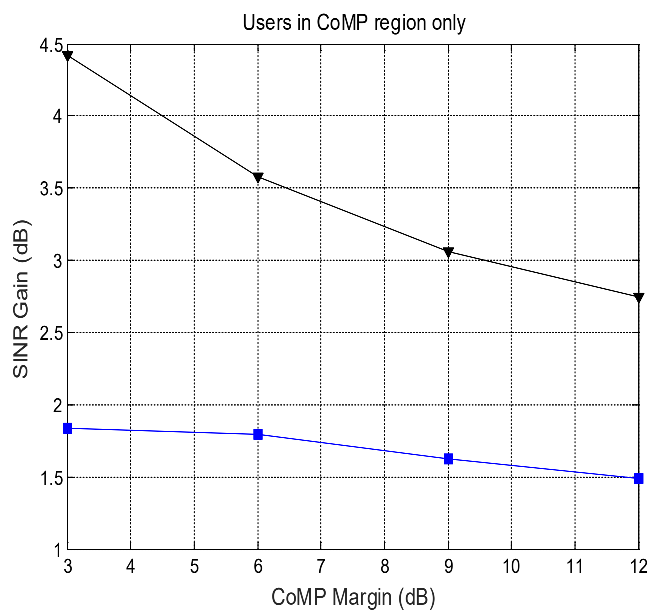

Fig. 3. SINR gains of JT scheme over DPS and Non-CoMP schemes at different values of CoMP margin

Fig. 4 depicts the percentage of users whose CoMP cluster TPs are either gNB and RN, two RNs or two gNBs from the total number of users in CoMP region at different CoMP margins. It is obvious from Fig. 4 that the percentage of CoMP users whose CoMP cluster TPs consists of gNB and RN is higher than the percentage of other CoMP users whose cluster TPs are either two gNBs or two RNs. In addition, as the CoMP margin increases, the percentage of users whose CoMP cluster TPs being gNB and RN is increased whereas the percentage of users whose cluster TPs being either two gNBs or two RNs are decreased. This is due to the higher transmitted power of gNB (46 dBm) compared to that of RNs (33 dBm) which allows it to be included in the CoMP cluster. On the other hand, the lowest percentages of cluster TPs being two gNBs is because of the larger distance between gNBs compared to the distance between gNB and RNs and the distance between RNs.

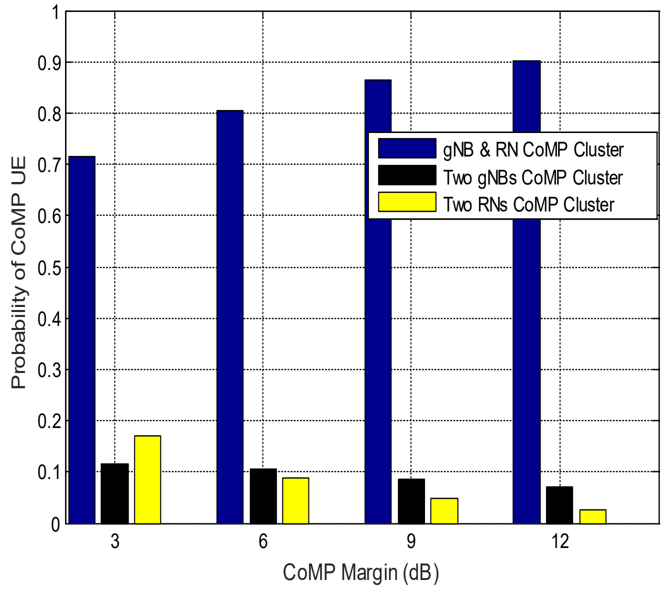

Fig. 4. Percentage of CoMP UEs whose cluster TPs are gNB & RN, two gNBs or two RNs as a function of CoMP margin

Fig. 5 presents the percentage of users who use CoMP from the total number of users at different values of CoMP margin. It is clear from the results of Fig. 5 that the percentage of users in CoMP region (the total CoMP probability) increases as the CoMP margin is increased. The reason behind this is that at small values of CoMP margin, the difference in RSRPs between the candidate TPs and serving TP is small and the CoMP criteria is hardly satisfied. As a result, the CoMP region is shrunk which decreases the number of TPs to be included in the CoMP cluster and reduces the CoMP probability. On the other hand, as the CoMP margin increases, the difference in RSRPs between the candidate TPs and serving TP is increased and the CoMP criteria is easily met. As a results the CoMP region is expanded and more TPs are included in the CoMP cluster which increases the CoMP probability.

The effect of CoMP margin on the average DL spectral efficiency for the users in the CoMP region only is illustrated in the results of Fig. 6. From the results of this figure it is obvious that the JT scheme provides the highest spectral efficiency at the considered CoMP margins. Furthermore, the average DL spectral efficiency of all considered schemes increase as the CoMP margin is increased. By increasing the CoMP margin from 3 dB to 12 dB, the average DL spectral efficiency for JT scheme and DPS scheme is improved by 21% (3.44 to 4.159 bps/Hz) and by 25.85% (3.056 to 3.846 bps/Hz), respectively. However, over CoMP region only and at CoMP margin value of 3 dB, the JT scheme offers spectral efficiency gains of as much as 12.6% (3.056 to 3.44 bps/Hz) and 38.8% (2.479 to 3.44 bps/Hz) compared to DPS scheme and Non-CoMP scheme, respectively. On the other hand, at CoMP margin of 12 dB, the JT scheme provides spectral efficiency gains of 8% (3.846 to 4.159 bps/Hz) and 16% (3.585 to 4.159 bps/Hz) compared to DPS scheme and Non-CoMP scheme, respectively. It should be noted that the spectral efficiency of Non-CoMP scheme increases as CoMP margin is increased even though the Non-CoMP scheme is not affected by changing the value of the CoMP margin. This is due to the fact that for all considered schemes, the spectral efficiency is averaged over users in CoMP region only. In addition, for each value of CoMP margin, the users in CoMP region is different and the averaged spectral efficiency for those users is also different as opposite to the case wherein the averaging process is done over all users which results in fixed average SINR and hence fixed average spectral efficiency for Non-CoMP users. In addition, as the CoMP margin increases, the CoMP region is extended to include users near to gNB/RNs whose obtained spectral efficiency are high and results in higher average spectral efficiency for Non-CoMP scheme.

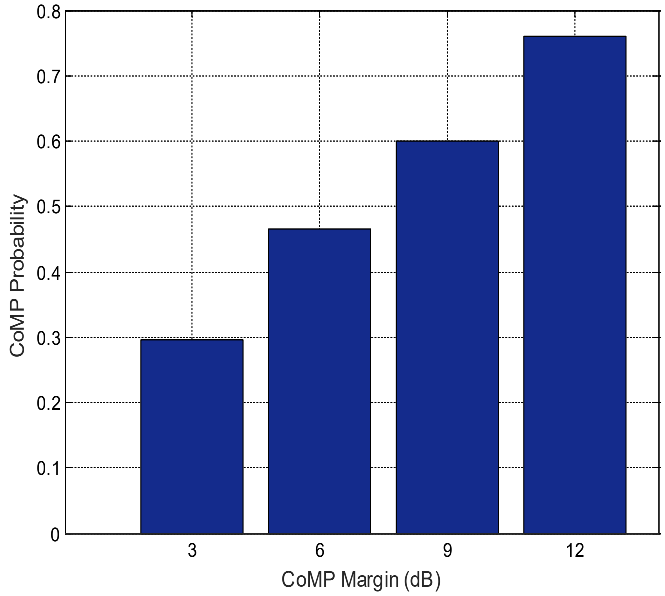

Fig. 5. Total CoMP probability versus CoMP margin

Fig. 7 depicts the outage probability versus CoMP margin for all considered schemes. It can be seen from Fig. 7 that the JT scheme outperforms DPS and Non-CoMP schemes and achieves the lowest outage probability at different values of CoMP margin whereas the Non-CoMP scheme has the highest outage probability. Furthermore, the outage probabilities for both JT and DPS schemes decrease when the value of CoMP margin is increased. In other words, when CoMP margin increases from 3 dB to 12 dB, the outage probability is decreased from 0.62% to 0.32% in JT scheme while the outage probability is decreased from 0.74% to 0.47% in DPS scheme. However, the outage probability of Non-CoMP schemes is fixed at 1.16% for the different considered CoMP margins.

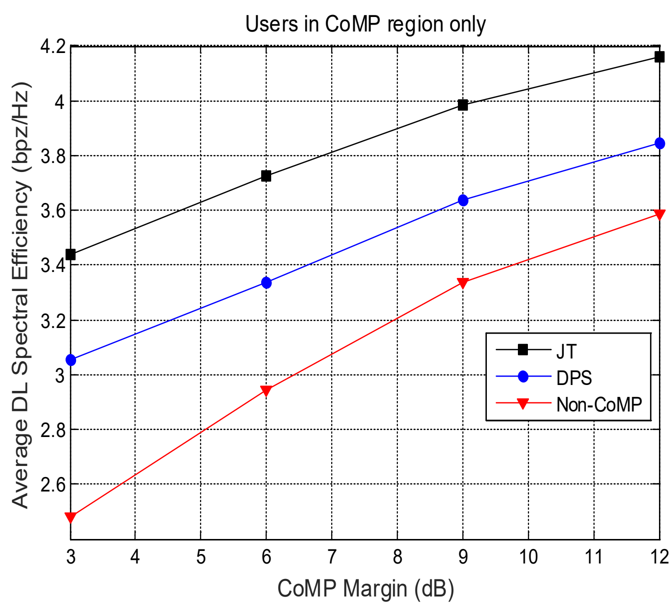

Fig. 6. Average DL spectral efficiency for users in CoMP regions only at different CoMP margin values

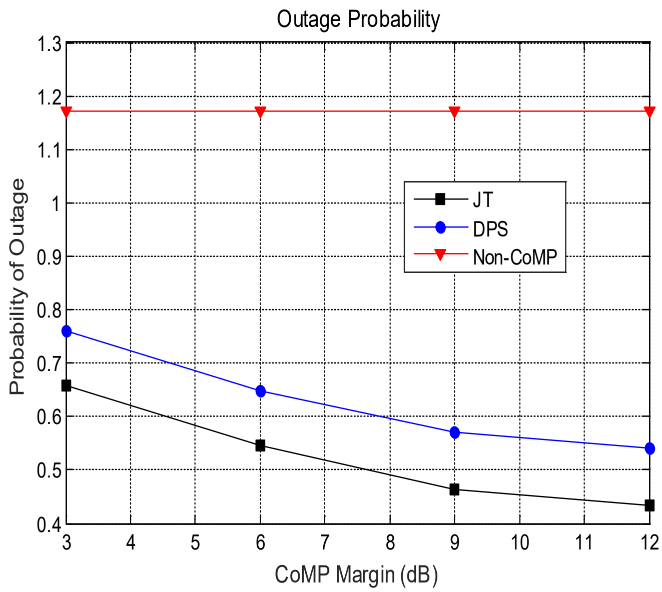

Fig. 7. Outage probability versus CoMP margin

V. Conclusion

This paper investigates the DL performance enhancement of 5G HetNet when CoMP is utilized for mitigating ICI. The effect of CoMP margin parameter on the performance of CoMP technique is also evaluated. Three schemes are considered and compared; namely JT, DPS and Non-CoMP schemes. Simulations results show that JT and DPS CoMP schemes significantly outperform Non-CoMP scheme in terms of average DL SINR and average DL spectral efficiency and outage probability. The reason behind this performance enhancement of CoMP schemes is due to the fact that CoMP technique eliminates the severe strongest ICI signals and turn them into useful signals. In addition, JT CoMP scheme obtains higher DL SINR, higher DL spectral efficiency and lower outage probability compared to DPS and Non-CoMP schemes at the different values of CoMP margins. In fact, compared to DPS and Non-CoMP schemes, the JT scheme achieves SINR gains of 15.4% and 47%, respectively whereas it offers spectral efficiency gains of as much as 12.6% and 38.8%, respectively. However, these gains decrease as CoMP margin is increased. Moreover, as CoMP margin increases, the CoMP region is expanded and hence the percentage of users who use CoMP is also increased. Furthermore, for CoMP users the highest probability is obtained for those users whose CoMP cluster TPs consists of one gNB and one RN.

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