Joint Transmission Coordinated Multipoint on Mobile Users in 5G Heterogeneous Network

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***Abstract*—To broaden user experience and support a wide range of bandwidth hungry devices cellular operators are adopting 5G network. However, the predominance of Inter-Cell Interference (ICI) in 5G stands as a hurdle for cell edge UEs. With increase in UE velocity, the effect of Doppler shift becomes more prominent, resulting in a significant drop in cell edge and mean data rates. A potential solution to improve the network service quality in the cell edge and reduce the impact of ICI for mobile users is to provide the UE with the best signal quality through coordination among multiple eNodeBs (eNB) located in different cell sites i.e., by virtually forming a massive antenna array with the coordinated eNB, a technique popularly known as Joint Transmission Coordinated Multipoint (JT CoMP). This paper investigates the performance of JT CoMP based heterogeneous network (HetNet) for UEs at different velocities while closed loop spatial multiplexing (CLSM) is active. With the inclusion of CLSM in JT CoMP, the obtained momentary channel state information can be utilized by coordinated eNBs for appropriate network gain enhancement. The simulation results demonstrate significant improvement in mean throughput and cell edge throughput for a CoMP based HetNet compared to a non-CoMP based HetNet with respect to UE velocity. The effectiveness of CLSM is found to degrade as UE velocity increases which is expected due to poor feedback capabilities of high velocity UEs. In contrast, simulation results show that the CLSM integrated inter-site based JT CoMP network provides improved reception for high velocity , while the intrasite-based CoMP network delivers better service at lower velocities.**

***Keywords*— JT CoMP, HetNet, ICI, CLSM, User velocity**

I. Introduction

Cellular communication is estimated to reach its apex with the widespread adoption of 5G. Forecasts on the recent influx of mobile data traffic estimate the high frequency and untapped broad spectrum of 5G to sustain the current surge of data traffic. On the other hand, high frequency limits the cellular coverage area, resulting in poor network service and risk of Inter-Cell Interference (ICI) for cell edge users.

Cellular deployment concepts such as heterogeneous networks (HetNet), ultra-densification of networks, among others, have been developed to ensure ubiquitous connectivity. Due to the proximity and varied power classes of macro and small cells, ICI is still prevalent in heterogeneous networks. The effect of ICI may cause the UE to be linked with an eNB, not providing the most substantial received power. [1]Transmission schemes such as Coordinated Multipoint (CoMP) are in the pipeline to tackle ICI and improve cell edge user throughput. CoMP is a cutting-edge technology that enables dynamic transmission and reception over multiple eNBs to enhance overall service quality for UEs as well as the system capacity and coverage. With CoMP, multiple coordinated eNBs serve a single UE in the best possible way for improving received signal quality. CoMP utilizes the signals from other cells as the desired signal to reduce ICI and improve cell edge throughput. [2]

Driven by the need to mitigate ICI and bridge the gap between cell edge and average throughput, in-depth research on CoMP is ongoing. Researchers in [2] investigated two different frequency spectrum allocation: shared and dedicated schemes for CoMP technology for HetNet and Remote Radio Head (RRH) scenarios and found improvement in cell throughput by increasing transmitted signal power over the shared spectrum. The study in [3] shows visible improvement in cell edge throughput and spectral efficiency by reducing average transmitted power with the help of support vector machine (SVM) for practical Joint Transmission (JT) downlink CoMP in LTE-A systems. Allocation of different frequency spectrums for macro and small cells for CoMP transmission in [4] reduces interference and boosts the network gain more than the existing CoMP scenarios. In [5], resource scheduler performance under highly mobile conditions in HetNet illustrates Round Robin (RR) scheduler to outperform Proportional Fair (PF) scheduler at high velocities in downlink (DL) performance. The impact of CoMP for HetNet using different frequency spectrums for macro cells and small cells under mobile conditions is still left to be studied. Simulation results of [6] indicate significant enhancement in cell edge throughput by implementing intersite and intrasite based JT CoMP in a macro cell network with UEs moving with the velocity of 30km/h but failed to achieve efficient channel prediction at the precoder and reduce feedback delay. The study in [7] discusses the effect of Centralized Coordinated Scheduling(C-CS) and Distributed Coordinated Scheduling(D-CS) for Coordinated Scheduling (CS) CoMP on UEs in high velocities. C-CS outperforms D-CS in all velocities in DL performance. But the paper presents no analysis on maintaining flexible networking behind Coordinated Multipoint and integration of CoMP in higher layers for CS. Work in [8] considers the effect of changing the bandwidth on the mean number RB occupancy, average user throughput, and spectral efficiency with changing the number of users per cell at different Transmission Time Interval (TTI) in DL performance of CoMP enabled homogenous network.

This study aims to mitigate the effect of ICI in HetNet and improve network service quality for mobile users ranging from 0-120 kmph velocity by implementing JT CoMP in HetNet. Effective channel prediction at the precoder and appropriate information on Channel State Information (CSI) can be achieved by integrating closed loop spatial multiplexing in JT CoMP, which is essential for the seamless deployment of CoMP among the coordinating eNBs. The network architecture adopted in this paper is easy to implement and cost-effective. The solution offered in the paper can improve cell edge network service, reduce the number of handovers and increase spectral efficiency.

The remainder of the paper is divided into the following sections: Section II gives an overview of CoMP operation. Section.III presents the system model and performance metrics used to evaluate the performance of CoMP. Simulation results are presented and analyzed in Section IV, and Section V concludes the whole paper.

II. CoMP OPERATION

CoMP consists of two main parts: centralized coordination and decentralized/distributed coordination. Cooperation and coordination comprise between the eNBs. A central unit (CU) for centralized coordination is the brain where CSI and data are present. The CU pre-calculates all frequencies and delivers them to coordinated eNBs as remote radio heads (RRHs) through a star-like network system [9]. In CoMP, the available interferences amongst eNBs are reduced; on the other hand, the size of overhead increases the overall information for the user's data in the whole network. To compensate for the latency, a fast path needs to be applied, for example, optical fiber.

A specific number of eNBs can transmit their data to terminals in their specific cells in case of distributed CoMP. For the distributed coordination, the network follows mesh network system as shown in Fig 1. At least any of the two eNBs can work together and coordinate to support a UE. There is no presence of CU, and here the overhead size actually decreases, and so does the level of discipline. [9] [10].

The downlink CoMP is classified into joint processing (JP) and coordinated scheduling/beamforming (CS/CB). In the case of JP, the UE uses data from each eNB or each sector of an eNB, which are regarded as a CoMP cooperation unit. CoMP cooperation unit may consist of different eNB sites or it may use different sectors of a single eNB site as shown in Fig. 2.

The JP is further divided into joint transmission (JT) and dynamic cell selection. For JT, the UE receives simultaneous transmissions on the same resource blocks (RBs) from each eNodeB or each sector of the CoMP cooperation unit. Thus, the quality of the received signal improves and ICI is avoided.

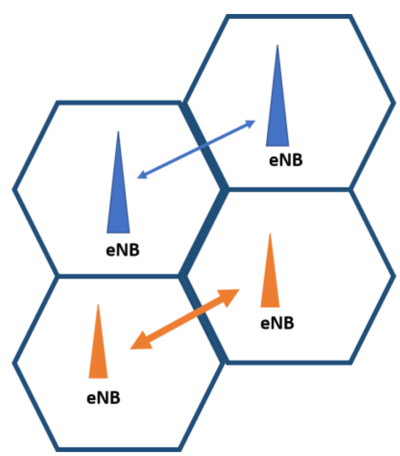

Fig.1. Distributed CoMP Network

For dynamic cell selection, the UE receives the transmission from one eNB or one sector of the CoMP cooperation unit at a time. The points that transmit data to the UE are dynamically selected.

In the case of CS/CB, the eNBs or sectors of the CoMP cooperation unit cooperatively perform beamforming for data transmission to a UE. The UE receives data from a single point and coordination within the CoMP cooperation unit determines this point.

JT-CoMP necessitates coordination among sympathetic units. This process often generates large SINR boost; nevertheless, it requires more bandwidth. Most JT-CoMP investigation is concerned with designing an ideal user-centric cluster size and distributing the relevant capabilities individually. The DL transmission allows for two or more simultaneous data broadcasts to a targeted client. [11]

A common spectrum is used by every adjacent cell in a JT-CoMP scheme. While centrally controlled JT-CoMP has flawless synchronization capacities, a central coordination station must broadcast the computed precoding weights and associated content to all cells, which might overload the backhaul capacity. At the selected point, signal superposition is accomplished in such a manner that the intended signal (constructive) is maximized while the destructive signal is minimized. [12]

The inter-site (inter-cluster) CoMP can be expressed by,

$$y_m = \sum_{l\in Bm} H_{l,m} d_{l,m} + \sum_{l\in Bm} H_{l,m} \sum_{i\in U_l \backslash m} d_{l,i} + x_m \quad (1)$$

$$x_m = \sum_{l\in B\backslash Bm} H_{l,m} \sum_{i\in U_l} d_{l,i} + n_m \quad (2)$$

The $d_{l,m}$ is transmitted signal and $H_{l,m}$ expresses the channel matrix, where l and m is used to signify the particular eNB and UE; the noise vector, which is additive in nature, is represented by n_m. The normalized complex data symbol is presented through x_m. [12]

A. Inter-site CoMP

The CoMP mechanism has synchronized cell activity occurs at several regions, and because of backhaul limits, its installation can be challenging at present. [13] Several self-sustaining modules or distant radio heads connected via fiber to a central baseband unit are possible options for a single site. Inter-site collaboration necessitates additional air interface and backhaul communication latency. As a result, only a limited number of

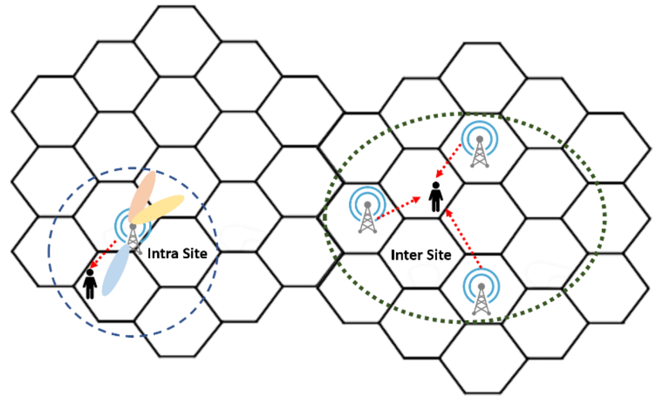

Fig. 2. Intra-site and Inter-site CoMP Network

eNBs may work together to maintain overhead to an acceptable level. [6]

B. Intra-site CoMP

This is the process where scheduling choices are made locally, so that there is no extra signaling overhead to deal with, making intra-site coordinating more accessible and more feasible. [13] Coordination here occurs at the eNB plane, with all eNB cells belonging to the same hub. The quantity of clusters for this is equivalent to the total amount of sites, and frequency reuse is simple to achieve. [14]

C. Closed Loop Spatial Multiplexing (CLSM)

CLSM allows various transmissions on multiple layers via precoding in order to accommodate the capabilities to multiplex the route in LTE. [14] Compared to some of the other transmission schemes, which are used to boost system bandwidth and the area of coverage, using the CLSM scheme allows a higher peak for DL data rate. UE sends the precoding matrix indicator (PMI), which ensures maximum efficiency for the highest SINR within the present channel circumstances. CLSM provides better performance under the low mobility of the users, as in this condition, UE can easily provide well-detailed feedbacks, which matches with existing channels. [15] There are many types of schedulers, but among them, Round Robin (RR) and Proportional Fair (PF) are the most well-known. For high mobility UE, RR has been discovered to ensure improved throughput and fairness index (FI). Since RR does not focus on the channel quality for a UE, it has one of the simplest scheduling algorithms. Priority function (P) is the controller for the resource allocation scheme in RR.

$$P = \frac{T^{\alpha}}{R^{\beta}} \quad (3)$$

Here α and β are parameters that are used to control the FI. For RR α=0 and β=1, whereas for PF α=1 and β=1. [5]

III. SYSTEM MODEL

The JT CoMP technology is considered for a HetNet in which the users are moving at different velocities. Assuming that there are constraints from low capacity at the backhaul, the use of CLSM is considered.

CSI denotes the network attributes, which define how a signal propagates from the sender to the recipient and provide a collection of network metrics representing the amplitudes and phases of each subcarrier. The channel is expressed as

$$H(f_k) = \|H(f_k)\| e^{j(\angle H)} \tag{4}$$

where, $H(f_k)$ is the CSI quality at the subcarrier with f_k as the central frequency, and H is the phase. In practice, the recipient examines and quantifies CSI before responding to the transmitter. [16]

The throughput of DL transmission very much depends on the interferences. The interferences again are dependent on several factors, where the two major ones are the quality of the radio network design and the network load. The quality of the radio network measurements focus on selecting the site, choice of antenna, tilting of antenna, optimizing RF activities and so on. On the other hand, network load can be determined from the percentage of traffic present in the network.
A mobile UE, in contrast with their eNB, faces various qualities of the channel depending on their position in the cell. [7] This diversity (Average throughput) is expressed as

$$\mathrm{T_{avg}} = \frac{\sum_{\mathrm{k=1}}^{\mathrm{n}} \mathrm{T_k}}{\mathrm{n}} \tag{5}$$

where T_k is the total throughput for k^{th} UE and n is the total number of UEs. The UEs at the edge of the cell face two problems: the higher presence of ICI, and secondly, the received signal from eNB becomes weaker. So, UEs at the edge of the cell show a much-degraded performance with a very penurious data rate. The spectral efficiency depends on the bandwidth and data rate and it is given as

$$\mathrm{S} = \frac{\sum_{\mathrm{k=1}}^{\mathrm{n}} \mathrm{T_k}}{\mathrm{BW}} \tag{6}$$

T_k in equation (7) is the total throughput for k^{th} UE and BW is the network system bandwidth. [7]

IV. SIMULATION AND RESULTS ANALYSIS

The simulation has been conducted to ascertain the effectiveness of inter-site and intra-site JT CoMP schemes in the mitigation of ICI and enhancement of cell edge throughput for mobile users in a HetNet compared to a HetNet without CoMP implementation. Vienna link level simulator was used for this purpose. [17] The simulation considers the use of CLSM in the HetNet to analyze the impact of JT CoMP technology for user velocities. The simulation was conducted for a heterogeneous network and every eNB consists of a tri-sector antenna. All simulations used Round Robin (RR) scheduler. The simulation assumptions are shown in Table1. The simulation compares the performance of HetNet with and without CoMP implementation. The CoMP implementation was considered for both intersite and intrasite CoMP schemes. The comparison was made in terms of average UE throughput, cell edge throughput, and spectral efficiency, with variation of the UE velocity.

In Fig. 3 it can be seen that for all three schemes, the average UE throughput decreases with increase in UE velocity. Utilization of CLSM in the simulation allows approximations of UE CSI that is shared between eNBs to enhance performance. At higher UE speeds, CLSM is found to degrade its throughput. This is because the feedback is less detailed and lacks accuracy with respect to existing channels due to fast change of multipath environment when the UE velocity is high. Moreover, the Doppler spread increases at higher user velocities. The Doppler spread results from both the effects of Doppler shifts in the transmitted signal as well as the Doppler shifts in the ICI, scattering, reflection and multipath fading further degrading the system throughput. Thus, causing signal distortions and packet losses leading to decline in throughput.

DL transmission in HetNet without CoMP is heavily affected by ICI and therefore, as shown in Fig. 3, it exhibits the poorest

TABLE I. SIMULATION ASSUMPTIONS

No. of macro eNBs per cluster	7
No. of femto eNBs per cluster	21
MIMO Configuration	4x4
Transmission Mode	CoMP
Velocity	0-120 kmph
Resource Scheduling	Round Robin (RR)
Transmission Bandwidth	20 MHz
Distance between eNBs	1730 m
No. of UEs	210
Simulation Time	30 TTI

performance. In this case, there are fluctuations in throughput at higher UE velocities whereas in CoMP schemes, there is an overall decreasing trend. This phenomenon is due to the random nature of ICI causing inconsistent DL performance and it is not present in CoMP schemes due to their effectiveness in the reduction of ICI. For both CoMP schemes, it is noted that the average throughput is much higher than HetNet without CoMP implementation with intrasite CoMP scheme giving superior performance at lower velocities and intersite CoMP showing better results at higher velocities. This higher throughput for CoMP schemes can be attributed to the intense ICI management capabilities. Use of CLSM is also generally expected to give poor results at higher velocities. Contrary to that, implementation of CoMP along with CLSM in this simulation has yielded better DL performance as illustrated in Fig. 3, Fig. 4 and Fig. 5.

UE velocity and the multipath environment differ with UE position with respect to different eNBs. In the case of intersite CoMP, there is coordination between eNBs of multiple cells and the UE can be handed over to an eNB from a different cell where the network gain is higher and therefore, can provide better service. For intrasite CoMP scheme, communication between multiple eNBs is necessary for the creation of antenna array for better performance. This communication creates backhaul thereby causing it poorer than Intersite CoMP scheme at higher velocities but showing superior performance at lower velocities.

UEs at the cell edges are subject to heavy interference from neighboring cells. As seen in Fig 4, while HetNet without CoMP implementation had the greatest cell edge performance for static UE but showed a massive decline in cell edge throughput with UE starts moving due to delays due to limited frequency resource. One way to overcome the effects of ICI would be to increase transmission power which will in turn increase transmission cost. Therefore, it is not an economically efficient solution and not feasible compared to implementation of CoMP schemes. Once again, intersite CoMP offers the best results at higher velocities used in this simulation as the rate of decrease of cell edge throughput is the lowest out of the two CoMP schemes. In case of intersite CoMP, interference at the cell edge due to neighboring cells is easily identified through the sharing of UE CSI between eNBs of different cells and so, easily mitigated. Intrasite CoMP has comparatively poorer performance at the cell edge as the coordination is between eNBs of different sectors of same cell; it is less adept at reduction of interference from neighbouring cells.

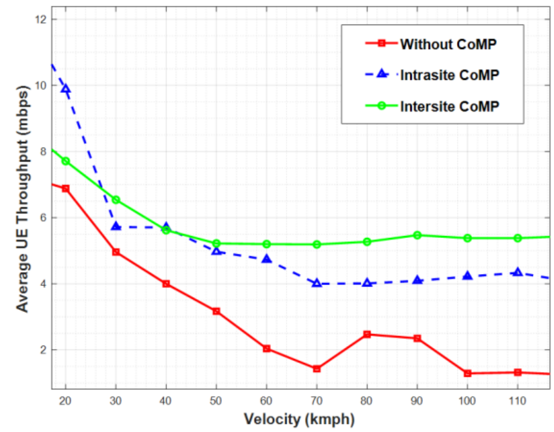

Fig. 3. Average UE throughput vs. UE velocity

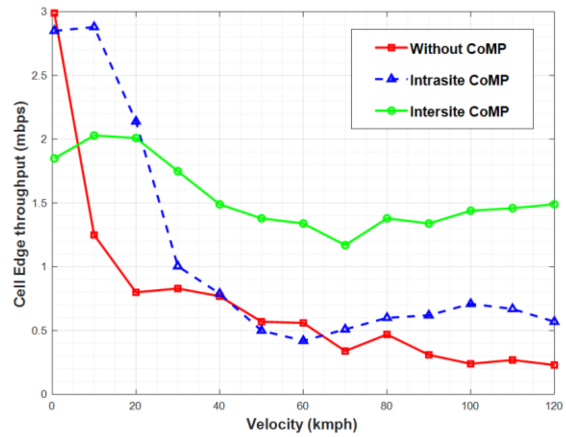

Fig. 4. Cell edge throughput vs. UE velocity

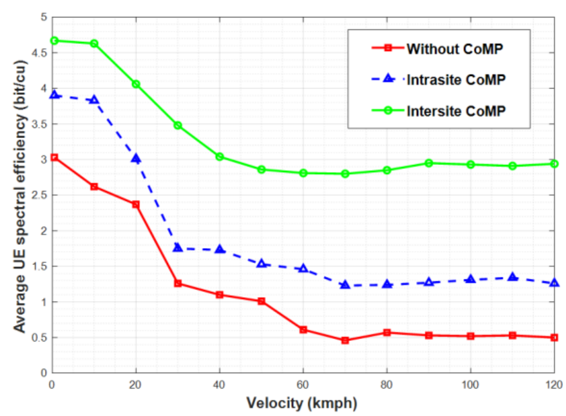

Fig. 5. Average UE spectral Efficiency vs. UE velocity

Coordination between eNBs in CoMP schemes results in choice of best eNB for DL transmission such that maximum signal power is achieved and ICI is minimized allowing for notably high spectral efficiency as illustrated in Fig. 5. It has been observed that implementation of CoMP boosts signal strength and upgrades coverage with Intersite CoMP having the most successful results.

V. CONCLUSION

In 5G communication technology, UEs with higher speeds are more susceptible to the effects of ICI and thus, have poorer DL performance. In this study, the ICI mitigation capabilities of JT-CoMP to improve DL throughput of mobile UEs at the cell edge in a HetNet have been thoroughly examined. From the results of average UE throughput, cell edge throughput and spectral efficiency obtained, it is evident that HetNet with CoMP implementation provides better performance than HetNet without CoMP due to communication between the eNBs. Moreover, it can be concluded that Intrasite CoMP works better for UEs in terms of average UE throughput, cell edge throughput and spectral efficiency. On the other hand, Intersite CoMP yields better results for UEs with higher speeds used in the simulation in regards to the same parameters and thus, more preferable for use at high speeds.

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