User-centric JT-CoMP clustering in a 5G cell-less architecture

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***Abstract*—This work investigates the performance of user-centric joint transmission coordinated multipoint (JT-CoMP) clustering in a control/data decoupled cell-less architecture taking radio resource assignment into account. In CoMP networks, a trade-off exists between signal to interference noise ratio (SINR) gain and loss of radio resources. To achieve a balance between SINR gain and loss of radio resources, it is essential to find an optimal power level difference (PLD) value that can identify the number of users that can operate under a CoMP mode. Also, CoMP requires a proper radio resource management approach that can support the resource assignment from multiple base stations (BSs). In this paper, we study the effect of choosing a PLD value on the per-user throughput of CoMP and non-CoMP users. Also, we provide a radio resource management scheme that can support a CoMP cell-less architecture. Simulation results demonstrated that a PLD value of 5 dB can provide a good balance between SINR gain and loss of radio resources. Also, efficient radio resource scheduling improves the throughput of 65% of non-CoMP users and 35% of CoMP users when the PLD value is 5 dB.**

***Index Terms*—5G, cell-less architecture, user-centric, CoMP, decoupled control/data.**

I. Introduction

The emerging wireless technologies such as coordinated multipoint transmission (CoMP) and decoupled control and data planes will enable future wireless architectures to become cell-less. CoMP was introduced by 3GPP Release 11 to mitigate inter-cell interference which will be a major concern in future wireless networks due to dense deployment of base stations (BSs).

JT-CoMP in the literature focuses on developing optimal user-centric clustering approaches where a user can form its own cooperative set of BSs. According to [1], the user-centric clustering approach is proposed in a single-tier dense environment to deal with the inter-cell interference. The clustering approach is achieved by measuring the average path loss of each user to determine its potential serving BSs. Based on a given objective function, it will then form its own set of cooperative BSs with the objective of maximizing the normalized goodput. It is proven that the proposed clustering approach outperforms the static clustering approach. In [2], the author proposes a user-centric clustering scheme in order to improve the user experience at the cell edge. Two algorithms are proposed which are respectively optimal and suboptimal clustering algorithms, and their performance is then compared with the conventional static clustering approach in terms of average user throughput and cell edge throughput. Based on the results obtained, the two algorithms outclass the static clustering approach. The work in [3] proposes a user-centric clustering approach to manage inter-cell interference in heterogeneous networks. In this approach, users can choose whether to operate under non-CoMP or CoMP modes. A user will operate in a non-CoMP mode if the second strongest BS power is not comparable with the power from the primary BSs. Likewise, if the powers are comparable, then the user will operate in CoMP mode. A user-centric clustering approach is also being proposed to maximise the energy efficiency in heterogeneous networks [4]. From the results, it is shown that the proposed algorithm performs better than static clustering in terms of energy efficiency.

Although most research that has been done shows that JT-CoMP will improve the SINR of the user significantly, however a CoMP user will require the same physical radio resources to be reserved in both cells, and cannot be reused by the cooperating BSs. This reduction in physical radio resources available will mean that the non-CoMP users might be affected. Therefore, it is important to balance the gain of SINR and the loss in the available resources.

Only a limited body of research has been carried out on joint user-centric JT-CoMP that takes into account the radio resource scheduling. For example in [5], the authors investigated the performance of user-centric JT-CoMP taking radio resource scheduling into account. However, the impact of choosing the right power level difference (PLD) value on the performance of both CoMP and non-CoMP users in terms of throughput was not studied.

Decoupling the control plane from the data plane is an emerging wireless architecture that has been proposed to satisfy the 5G requirements. In this architecture, macro BSs are responsible for providing coverage and supporting control signaling, whereas small cell BSs that are located within the coverage area of macro BSs handle data traffic.

Recently, the authors in [6] applied CoMP in a decoupled control/data architecture with the objective of balancing the load and maximising the spectral efficiency. In the proposed approach, a user will form its own cluster of x BSs that provide the best received power as long as that x does not go beyond a maximum cluster size. The results proved that the proposed algorithm is effective in balancing the load especially in dense environments. However, the authors did not investigate the impact of choosing the PLD value on the performance of CoMP and non-CoMP users. Also, it focused only on user-centric clustering without focusing on radio resource management.

Separating the control plane from the data plane and serving users jointly from multiple BSs converts the current wireless network into a cell-less architecture. This paper focuses on a 5G cell-less architecture in which control and data planes are decoupled and cell-edge users are served jointly by multiple BSs. The aim is to investigate the performance of CoMP and non-CoMP users under the 5G cell-less architecture and also to find an optimal PLD value that can balance between SINR gain and loss of radio resources.

The organisation of this paper is as follows. Section II presents the system model which includes system layout, operation mode, performance metrics and radio resource assignment. Section III provides simulation results. The overall work is concluded in section IV.

II. System Model

A. System Layout

A downlink cell-less architecture network is considered in this work. The cell-less network consists of one macro base station and N pico BSs deployed in an area. The macro BS supports control signaling whereas the pico BSs handle the data traffic. Each tier of the network is assigned different frequency spectrum, thus no inter-cell interference is expected between macro and pico BSs. Users are randomly deployed in the same area. Two different cases are studied in this work. The first case is the traditional approach where CoMP is not applied while the second approach applies CoMP. All users in the first case operate as normal or non-CoMP users where each user receives data only from one BS. In the second case, users are divided into two groups: non-CoMP and CoMP users. Non-CoMP users receive data from the BS that provides the strongest received power whereas CoMP users are served jointly by the two strongest BSs.

B. Operation Mode

In a cell-less CoMP architecture, users can operate under a non-CoMP or CoMP mode. Non-CoMP users are typically users that are located at the center (non-cell-edge users) and they are served by a single BS. In the CoMP mode, a user (usually one located at the cell-edge) may be served by the two strongest BSs that provide the highest received power. To allow a user to operate under the CoMP mode, two pico BSs need to cooperate and jointly transmit the same data to the CoMP users.

The following steps explain how a user selects its own two cooperative BSs (the authors in [6] have implemented a similar approach)

1. Each user measures the average power that it receives from all neighboring pico BSs based on the following:
$$p_{in}^r = p_{in}^t |g_{in}|^2 \tag{1}$$
where p_{in}^r is the average power that is received by user i from the n^{th} pico BS, p_{in}^t is the power transmitted by the n^{th} pico BS and g_{in} is the channel gain that consist of the path loss and shadowing.

2. Each user sorts the average powers it receives from all surrounding BSs in a descending order as follows:
$$p_{in}^r = \arg\max p_{in}^r \quad , n \in N \tag{2}$$

where p_{i1}^r denotes the best serving pico BS for user i whereas p_{i2}^r denotes the second best serving pico BS and so on.

3. Each user compares the strongest power it receives with the second strongest power. This comparison is referred as the PLD. If the second strongest power is comparable with the strongest power, then the user operates under the CoMP mode. This allows the user to be served by the two strongest BSs which helps not only to eliminate the interference coming from the second strongest BS but also to convert the signal of the second strongest BS into a useful signal. In the case that the signal of the second strongest BS is not sufficiently strong compared with the strongest BS, a user operates under the non-CoMP mode. Mathematically, this comparison can be written as follows:

$$\text{User } i \text{ mode} = \begin{cases} \text{NonCoMP} & \text{if } \frac{p_{i1}^r}{p_{i2}^r} > \alpha \\ \text{CoMP} & \text{if } \frac{p_{i1}^r}{p_{i2}^r} \le \alpha \end{cases} \tag{3}$$

where α is the power level difference value that determines whether a user should operate in CoMP or non-CoMP mode. It is obvious that increasing the PLD value increases the number of CoMP users and vice versa. It is essential to carefully choose an effective PLD value because a small PLD value prevents some users that are located at cell-edge from operating under CoMP mode although they still receive a sufficiently high signal from the second strongest BS. As a result, those users will suffer from high interference. On the other hand, choosing a large PLD value includes users that may not benefit from CoMP in terms of SINR gain because the power that they receive from the second strongest BS is not sufficiently strong. In addition, serving users with a slight or no SINR gain as CoMP users consumes the available resources and as a result leaves non-CoMP users with fewer number of resources.

C. Performance Metrics

The SINR that a user i receives is calculated is follows [6]:

$$SINR_i = \frac{P^t \sum_{k \in C_N^i} |g_{ik}|^2}{P^t \sum_{m \in N/C_N^i} |g_{im}|^2 + \sigma^2} \quad (4)$$

where P^t is the transmission power of a pico BS, N is the set of all the pico BSs in the network, C_N^i is the cluster size (one for a non-CoMP user and two for a CoMP user) and σ^2 is the noise power.

It is obvious that the SINR in (4) is related to equation 3. If a user chooses, based on (3), to be served by CoMP, then its SINR is improved since the interference that comes from the second strongest BS is eliminated and converted into a useful signal.

The Truncated Shannon Bound (TSB) [7] is used to model the transmission rate as follows:

$$Th = \begin{cases} 0; & for\ SINR < 1.8\ dB \\ \gamma log_2(1 + SINR); & for\ 1.8\ dB < SINR < 22\ dB \\ Th_{max}; & for\ SINR > 22\ dB \end{cases} \quad (5)$$

where γ is the attenuation factor and Th_{max} is the maximum transmission rate per bandwidth. According to [7], γ is set to be 0.65 and Th_{max} is 4.5 bps/Hz

To investigate the impact of CoMP on the per-user throughput of CoMP and non-CoMP users with and without CoMP, a measure termed throughput difference is used. The objective of throughput difference is to evaluate whether a user gains, loses or is not affected in terms of achievable throughput when CoMP is implemented. Throughput difference can be mathematically written as follows:

$$TD = Th_{Comp} - Th_{non-CoMP} \quad (6)$$

where Th_{Comp} is the throughput that a user gets when CoMP is used and $Th_{non-CoMP}$ is the throughput that the same user achieves when CoMP is not used. Equation 5 is used to calculate Th_{Comp} and $Th_{non-CoMP}$.

D. Radio resource assignment

Radio resource management in CoMP systems has a direct effect on the per-user throughput of CoMP and non-CoMP users. Assigning a large amount of radio resource to CoMP users improves their throughput; nevertheless, the throughput of non-CoMP users decrease since they will be left with fewer radio resources. Also, allocating a large amount of resources for non-CoMP users enhances their throughput but as a result the throughput of CoMP users decreases. To balance this trade-off, it is crucial to provide a CoMP radio resource management scheme that ensures fairness among CoMP and non-CoMP users. One way to achieve this balance and ensure that the performance of non-CoMP users is not degraded is to assign each CoMP user fewer physical radio resource blocks compared with non-CoMP users. For example, if a non-CoMP user gets 4 resources blocks, a CoMP user would get less than 4 resource blocks. It can be assigned half the bandwidth (2 resources blocks), quarter bandwidth (1 resource block) or in general a fraction b of the bandwidth. The reason for this is because it is expected that their SINR is significantly improved. Another reason is that a CoMP user requires two BSs to cooperate and reserve the identical radio resource block to serve this user. In other words, a resource block used by the strongest BS cannot be reused by the second strongest BS thus reducing the reuse from 1 to 2. This assignment where a CoMP user gets fewer radio resources is considered to be fair since the SINR of CoMP user is improved and CoMP users are served jointly by two BSs.

In this work, when CoMP is applied, each BS has two types of users: non-CoMP and CoMP users. CoMP users are the users that are located in the cell-edge and they are identified based on (3) whereas non-CoMP users are the users that are located nearer the cell centre. Also, each BS can have a number of overlapping regions. For instance, BS 1 can have an overlapping region with BS 3, 5 and 7.

To identity the CoMP and non-CoMP users that belong to each BS, each BS considers all users that are located in its overlapping regions as its CoMP users irrespective of whether this BS is the strongest or second strongest BS. The remaining users that are located outside the overlapping regions are assumed to be non-CoMP users. In this work, the total bandwidth is divided into non-CoMP and CoMP bandwidth. We allocate the bandwidth of BS i for non-CoMP and CoMP users, respectively, based on the following:

$$BW_{i,non-CoMP} = \left(\frac{Available\ resources}{(NC + (b \times Co))}\right) \times NC \quad (7)$$

$$BW_{i,CoMP} = BW_{i,total} - BW_{i,non-CoMP} \quad (8)$$

where NC, Co denotes that number of non-CoMP and CoMP users, respectively, that belong to BS i, and b is the fraction of radio resources allocated to a CoMP user compared to its allocation when CoMP is not applied. We set b to be 0.25 so that each CoMP user gets a quarter of the CoMP radio resources. For instance, if a cell-edge user (CoMP user) gets 12 physical radio resource blocks when CoMP is not applied, it gets 3 physical radio resource blocks when CoMP is implemented. The reason for this setting is to provide a balance between SINR gain and loss of radio resources. Also, this setting ensures that CoMP does not excessively consume the available radio resources.

III. SIMULATION RESULTS

The performance of user-centric JT-CoMP clustering in a decoupled control/data cell-less architecture taking radio resource scheduling into account is evaluated using MATLAB. One macro BS whose coverage area is approximated by a radius of 0.5km is considered. A number of pico BSs are randomly distributed over the coverage area of the macro BS. The density of pico BSs is 20BS/km^2. Users are randomly distributed in the area with a density of 120 users/km^2. We consider two cases: the first case is when CoMP is not implemented while the second case is when CoMP is implemented. The performance of the users is evaluated with no CoMP and the performance of the same users is also evaluated but with CoMP. The reason to do this is to clearly study how CoMP affect the performance of users. The simulation parameters are summarised in Table I.

Table 1: Simulation parameters

Parameter	Value
Bandwidth	20MHz
PRBs/BS	100
Tx Power	30dBm
Pico path loss [8]	$140.7 + 36.7\log_{10}(R)$, R in km
Shadowing std. dev.	10dB
Noise power level	-174 dBm/Hz
Density of users	120 users//km^2
Density of pico BSs	20BS/km^2
Maximum cluster size	2
Traffic model	Full buffer

The percentage of CoMP and non-CoMP users for different PLD values ranging from 0 dB to 15 dB is shown in Figure 1. For the case when the PLD value is 0 dB, it is clear that all users operate as non-CoMP users. In this case, it is totally a non CoMP system. Increasing the PLD value decreases the number of non-CoMP users while the number of CoMP users increases. The reason that the number of CoMP users increases is because more users are able satisfy the requirement $\frac{p_{i1}^{r}}{p_{i2}^{r}} \leq \alpha$ if the PLD value α is set to be high.

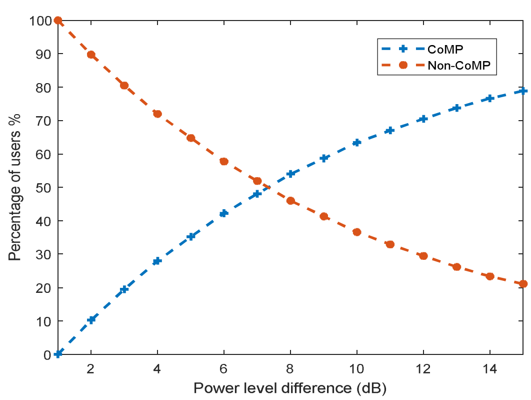

Fig.1: Percentage of non-CoMP and CoMP users for different PLD values

Figure 2 shows the outage probability for users with and without CoMP. In the case when CoMP is implemented, the outage probability is compared when the PLD value is 5dB, 10dB, and 15dB. From Figure2 , it can be seen that 39% of users get less than 1.8 dB with no CoMP. By applying JT-CoMP, it is expected that the users gain a significant improvement to the SINR since the interference that comes from the second strongest BS is not only eliminated but also converted into a useful signal. As can be observed from Figure 2, the percentage of users that achieve less than 1.8 dB when CoMP is implemented for PLD values of 5dB, 10 dB, and 15 dB, is 16%, 9%, 9%, respectively. It is clear that JT-CoMP can provide significant SINR gain. The figure also shows that a PLD value of 10 dB outperforms a PLD of 5 dB in terms of SINR gain since a 10 dB PLD value can attract more users to operate under CoMP. Figure 1 shows that there are 28% more users operate under CoMP when the PLD value is 10 dB compared to a PLD value of 5dB. Comparing a PLD value of 10 dB and 15 dB, the outage probability for both values is almost the same. The reason is because some users (15% users as shown in Figure 1) decide to operate as CoMP users when the PLD value is 15 dB, but do not significantly improve their SINR because the signal that they receive from the second strongest BS is not sufficiently strong.

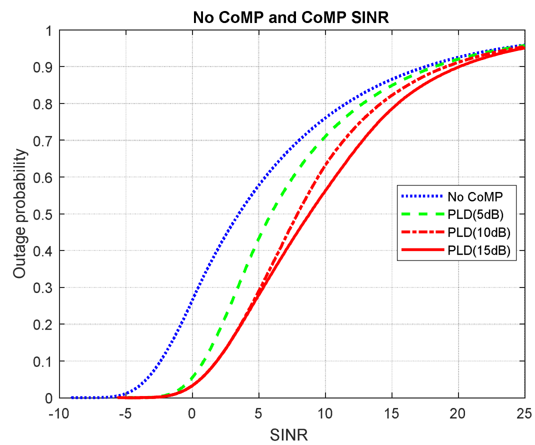

Fig.2 : Outage probability for no coMP and CoMP

Figure 3 illustrates a cumulative distribution function (CDF) plot of throughput difference for non-CoMP users when CoMP is applied. In this plot, a positive, negative or zero value of the x axis indicates that non-CoMP users gain, lose or are not affected in terms of throughput, respectively. Figure 3 shows that 65% of non-CoMP users gain throughput when CoMP is implemented and the PLD value is 5 dB. It also shows that 40% of non-CoMP users improve their throughput significantly where their throughput improvement is greater than 1 Mbps. However, about 16% of non-CoMP users lose some throughput. The reason that non-CoMP users significantly improve their throughput when CoMP is implemented is because each CoMP user is assigned only 0.25 of radio resources when it operates under CoMP, which leaves a larger amount of radio resources available for non-CoMP users. For the cases when the PLD value is 10 dB, and 15 dB, many non-CoMP users achieve significant throughput gain; however, some users significantly loss throughput.

Figure 4 shows a CDF plot of throughput difference for CoMP users. Based on the Figure, 35%, 28%, and 23% of CoMP users are able to improve their throughput when the PLD value is 5 dB, 10 dB, and 15 dB, respectively. The figure also illustrates that only 13% of CoMP users who lose throughput when the PLD value is 5 dB. However, when the PLD value increases more CoMP users loss throughput. It is obvious that a PLD value of 5 dB outperforms PLD values of 10 dB and 15 dB. The reason that a 5 dB PLD value performs better than 10 dB and 15 dB is because most of the 5 dB CoMP users gain significant SINR improvement thus achieve higher throughput although they are assigned less amount of radio resources. In other words, the SINR gain compensates for the reduction in the amount of radio resources. For 10 dB and 15 dB PLD values, the SINR gain of some CoMP users does not compensate the reduction of resources.

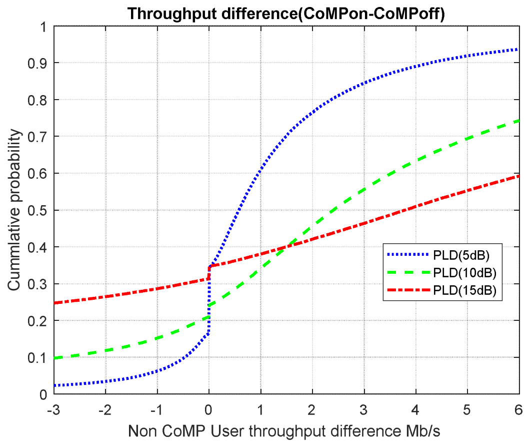

Fig. 3: Throughput difference for non-CoMP users

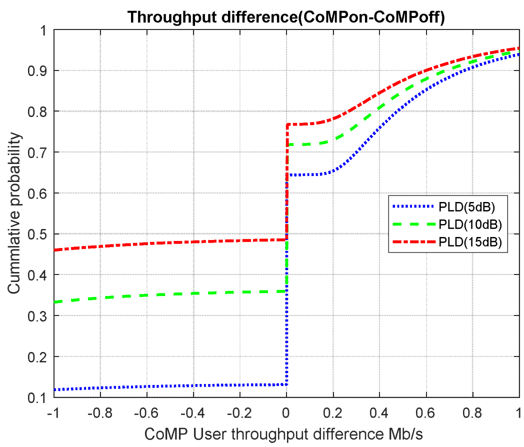

Fig. 4: Throughput difference for CoMP users

IV. Conclusion

This work investigated the performance of user-centric CoMP in 5G cell-less architecture where control and data planes are separated and users can be jointly served by more than one BS. While taking radio resource scheduling into account, this work studied the impact of choosing a PLD value on the performance of CoMP and non-CoMP users. Also, this work presented a radio resource assignment scheme that can support CoMP cell-less architecture. The results showed that a PLD value of 5 dB can provide a good balance between SINR gain and loss of radio resources. Also, the results demonstrated that by choosing a proper PLD value and allocating radio resources efficiently, JT-CoMP can improve the per-user throughput of 65% and 35% of non-CoMP and CoMP users, respectively.

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References

[1] V. Garcia, Y. Zhou, and J. Shi, "Coordinated multipoint transmission in dense cellular networks with user-centric adaptive clustering," *IEEE Transactions on Wireless Communications,* vol. 13, no. 8, pp. 4297-4308, 2014.

[2] H. S. Kang and D. K. Kim, "User-Centric Overlapped Clustering Based on Anchor-Based Precoding in Cellular Networks," *IEEE Communications Letters,* vol. 20, no. 3, pp. 542-545, 2016.

[3] A. H. Sakr and E. Hossain, "Location-aware cross-tier coordinated multipoint transmission in two-tier cellular networks," IEEE Transactions on Wireless Communications, vol. 13, no. 11, pp. 6311-6325, 2014.

[4] W. Nie, F.-C. Zheng, X. Wang, W. Zhang, and S. Jin, "User-centric cross-tier base station clustering and cooperation in heterogeneous networks: Rate improvement and energy saving," IEEE Journal on Selected Areas in Communications, vol. 34, no. 5, pp. 1192-1206, 2016.

[5] Liu, L., Zhou, Y., Garcia, V., Tian, L., and Shi, J. (2018). Load aware joint CoMP clustering and inter-cell resource scheduling in heterogeneous ultra dense cellular networks. *IEEE Transactions on Vehicular Technology, 67*(3), 2741-2755.

[6] S. Bassoy, M. Jaber, M. A. Imran, and P. Xiao, "Load aware self-organising user-centric dynamic CoMP clustering for 5G networks," IEEE Access, vol. 4, pp. 2895-2906, 2016.

[7] T. Jiang, A. Papadogiannis, D. Grace, and A. Burr, "Bungee deliverable: D4. 1.1 interim simulation," Deliverable, 2011.

[8] 3GPP Organizational Partners, 3rd Generation Partnership Project; technical specification group radio access network; evolved universal terrestrial radio access (E-UTRA); further advancements for E-UTRA physical layer aspects (release 9). 3GPP TR 36.814 Release 9 V9.0.0 (2010-03) (2010).