2022 IEEE Wireless Communications and Networking Conference (WCNC) | 978-1-6654-4266-4/22/$31.00 ©2022 IEEE | DOI: 10.1109/WCNC51071.2022.9771927

Interactive CoMP Clustering for Load Balancing and Time Synchronization

Hanadi Salman*, Abuu B. Kihero *, and Hüseyin Arslan*†

*Department of Electrical and Electronics Engineering, Istanbul Medipol University, Istanbul, 34810 Turkey
†Department of Electrical Engineering, University of South Florida, Tampa, FL 33620 USA
Email: {hanadi.suleiman, abuu.kihero}@std.medipol.edu.tr, huseyinarslan@medipol.edu.tr

***Abstract*—This work aims to address the timing synchronization issue which limits the applicability of coordinated multipoint schemes, specifically joint transmission, in practical wireless networks. Following a brief description of the issue itself, and its repercussions on the network performance, the various conditions/solutions that mitigate this problem are recapped. Following this, we provide the background of the proposed approach to be used for mitigating the timing synchronization issues, namely, *common* cyclic prefix (CP) technique. Then, a clustering algorithm is proposed aimed at balancing the cell load with timing synchronization as a constraint. In load balancing stage, the first priority is given to users with higher received power and lower number of base stations in the candidate set. The results obtained via simulations indicate that heterogeneous network (HetNet) deployments suffer from timing synchronization when smaller CP duration is used, and this performance degradation can be resolved quite effectively using the *common* CP configuration.**

***Index Terms*—Coordinated multipoint (CoMP), clustering, cyclic prefix, load balancing, timing synchronization.**

I. Introduction

The demand for wireless connectivity has grown exponentially over the last few decades leading to higher interference in current cellular systems, a trend which is expected to continue in the next-generation wireless networks. This interference becomes a major limiting factor in terms of network capacity and performance. Base station (BS) cooperation, which is referred to in Third-Generation Partnership Project (3GPP) Rel-11 context [1] as coordinated multipoint (CoMP), is a key technology to mitigate this limitation. CoMP is considered as one of the core technologies of fourth generation (4G) systems and new feature for Wi-Fi 7 (i.e., IEEE 802.11be), and it is expected that it will continue as a promising candidate for the next generations [2].

CoMP transmission is generally applied within a group of BSs called a *cluster*. In the literature, three main clustering types are identified [3], [4]. Static clustering is the simplest clustering method with the smallest signaling overhead requirement. However, this method is irresponsive to the continuous changes within the network which limits its performance gains. In this sense, dynamic clustering is more flexible and practical which can mitigate inter-cluster interference dynamically based on network, user or hybrid decision [3]. Although it can achieve optimal performance, dynamic clustering requires exhaustive information interchange which increases the overhead. Considering the trade-off between performance and complexity, semi-dynamic clustering scheme aims at reducing the complexity without much loss of performance.

Along with the advantages of CoMP clustering [5] and the exponential growing of mobile data demand, better utilization of system capacity will be a key concept which need to be taken into account for cluster design. One way to do that is balancing the load of BSs in the coverage area by moving user equipments (UEs) from overloaded BSs to other BSs not fully utilized [6]. In general, spectral efficiency [7], [8], backhaul optimization [9], [10], energy efficiency [11], [12] and load balancing [13], [14] are studied in the literature as main objective functions for CoMP clustering.

In addition, synchronizing coordinating/cooperative BSs and served UEs in time and frequency is required; otherwise, CoMP usage is applicable to limited scenarios. Throughout this paper, only time synchronization has been studied. In conventional cellular systems, the UEs of a cell are synchronized only to the serving BS. The BS sends time advance control signals to these UEs to adjust their transmission time in order for their signals to be received at the BS at the expected time. The problem in CoMP, especially joint transmission (JT) scheme, is that the UEs now need to be synchronized to more than one BS. Since the BSs themselves are not synchronized to each other, a UE synchronizing itself to one of the BSs may lose synchronization with the others. This restricts the scenarios to the one that assures that the time difference between received signals is less than the cyclic prefix (CP) length of the orthogonal frequency division multiplexing (OFDM) symbol [15]; otherwise, inter-symbol interference (ISI) and inter-carrier interference (ICI) emerge which degrades the system performance. In the literature, most of the proposed clustering algorithms in CoMP systems do not take into consideration the time synchronization requirements of UEs' signals at coordinating BSs [16]–[18]. However, the work in [19] proposes a clustering scheme that can satisfy timing synchronization requirements. This work takes into consideration the difference in times of arrival of the UEs' signals at coordinating BSs and utilizes fixed clustering where the cluster is composed of the regions that ensure the time of arrivals lie within the CP duration so that there is no ISI.

In this paper, we mainly incorporate timing synchronization as one of the constraints for CoMP clustering performance and the main contributions of our work to the literature are summarized as follows:

- A *common* CP based approach for alleviating the timing synchronization issue is proposed.
- A user-centric dynamic CoMP clustering algorithm capable of balancing BSs' loads while considering timing synchronization requirements of UEs' signals at coordinating BSs is presented, and the *common* CP solution is included as a constituent step to improve the system performance.
- System-level simulation results of the proposed algorithm are provided for a heterogeneous network (HetNet) deployment. These results indicate that timing synchronization is especially critical when small CP duration is used, and how *common* CP addresses this problem and provides better system throughput while lowering the number of unconnected users in the system.

The rest of this paper is structured as follows. The system model and assumptions along with a brief description of *common* CP technique are illustrated in Section II. Next, the proposed clustering algorithm is presented in Section III. Section IV provides corresponding system-level simulations. Section V concludes this paper.

II. System Model and Assumptions

In this work, a system model similar to the one used in the recent literature [16] and [20] is considered. The scenario is assumed to consist of one macro-BS (MBS) with M small BSs (SBSs) and K UEs distributed within circular coverage area of MBS with radius r. All transceivers are equipped with single antenna. Locations of the SBSs are modeled as random process following Poisson point process (PPP) distribution with density λ_{BS}. The coverage area is assumed to have UEs with uneven PPP distribution where there are hotspot area with UE density λ_h within a radius of r_h ($r_h < r$) and non-hotspot area with UE density of λ_l within a radius of r_l ($r_h < r_l < r$). The SBSs are connected to the MBS through optical fiber backhaul links and share their respective channel state information (CSI) data with the MBS. In addition, Ideal backhaul and perfect CSI knowledge are assumed. Throughout this paper, JT is used as coordination scheme where UE data is available at all BSs within the cluster. Zero-forcing (ZF) precoding is employed where intra-cluster interference is completely cancelled. We assume that each transmitted signal block is modulated by the CP-OFDM scheme.

The samples of the transmitted baseband OFDM signal after CP insertion can be expressed as

$$x(n) = \frac{1}{\sqrt{N}} \sum_{v=0}^{N-1} X(v) e^{\frac{j2\pi vn}{N}}, \qquad -N_g \leq n \leq N-1 \quad (1)$$

where $x(n)$ denotes the nth sample in OFDM signal, $X(v)$ represents the data symbol modulated on the vth subcarrier. N and N_g are the size of inverse fast Fourier transform (IFFT) and the CP length, respectively.

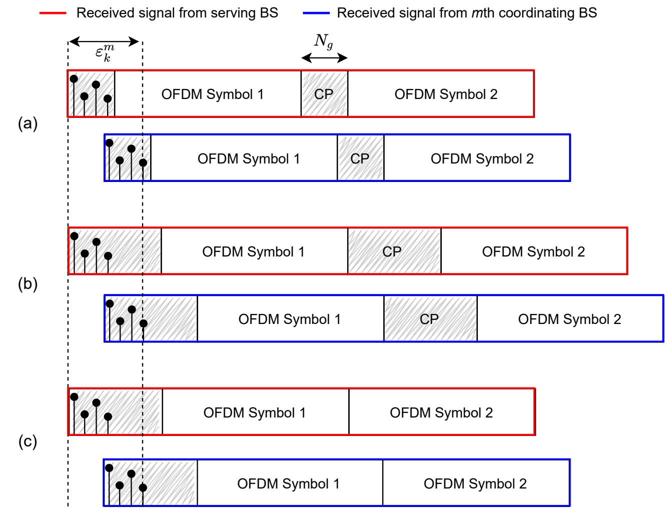

Fig. 1: Illustration of different CP configurations in CoMP network: (a) *normal* CP, (b) *extended* CP, and (c) *common* CP. ε_k^m denotes the timing delay of received signal at kth UE from mth coordinating BS.

Let the sample indices of a perfectly synchronized OFDM symbol be $\{-N_g, \ldots, -1, 0, 1, \ldots, N-1\}$ and the timing delay of received signal from a coordinating BS due to time synchronization mismatch and channel's delay spread is ε where $-N_g \leq \varepsilon \leq 0$, then the orthogonality among subcarriers will not be destroyed and the timing delay will only introduce a phase rotation in every subcarrier symbol at the fast Fourier transform (FFT) output as [21]

$$Z(v) = X(v)H(v)e^{\frac{j2\pi v\varepsilon}{N}} + W(v), \qquad -N_g \leq \varepsilon < 0, \quad (2)$$

where v is the subcarrier index, Z and H indicate the received symbol and the channel's frequency response, respectively. W is a complex Gaussian noise term. For a coherent system, this phase rotation is compensated by the channel equalization scheme. In case the timing delay is outside the range in (2), the orthogonality among the subcarriers will be destroyed. Due to the insufficient duration of *normal* CP and the spectral inefficiency of *extended* CP, *common* CP technique is used throughout this paper as an efficient technique to maintain the timing synchronization in CoMP system. The main concept of the *common* CP is using a single CP for equalizing the entire block containing multiple OFDM symbols [22]. This technique is possible if the coherence time of the channel is large enough, i.e., the channel response does not change during the entire block. Fig. 1 illustrates different CP configurations in CoMP network.

In this study, user-centric clustering is employed where each UE is assigned to its own cluster within the group of SBSs and/or MBS. Precisely, the mth BS can be part of kth UE candidate set, $\mathcal{S}_k$, if the following two conditions are satisfied;

$$P_m^k > P_{min}, \quad (3)$$

$$P_{ser}^k - P_m^k \leqslant P_\circ, \quad (4)$$

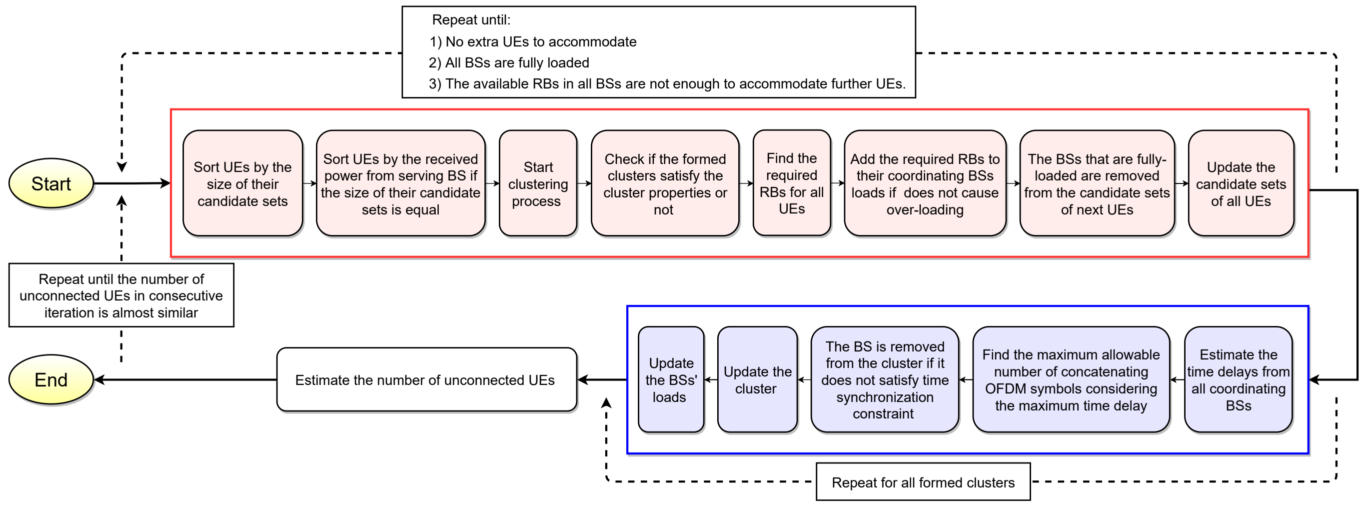

Fig. 2: Flowchart of the proposed clustering algorithm, red and blue boxes present load balancing and timing synchronization steps, respectively.

where P_{min} and $P_{\circ}$ are minimum received power threshold and maximum received power offset from the serving BS. P^k_{ser} is the kth UE serving BS. P^k_m is the signal power received by kth UE from mth BS given in (5) where P^{Tx}_m is the transmitted power from mth BS. The distance between mth BS and kth UE in meter is denoted by d_{mk}. f_c and σ are carrier frequency in GHz and shadowing factor in dB, respectively.

$$P^k_m = P^{Tx}_m - (36.7\log_{10}(d_{mk}) + 26\log_{10}(f_c) + 22.7 + \sigma) \quad (5)$$

The condition given by (3) prevents increased signaling and wasted resources by ensuring that BSs which do not provide sufficient coverage to the kth UE are not added to $\mathcal{S}_k$. Besides, the condition in (4) ensures that only the BSs that deliver signal strength within a given range with respects to the kth UE's serving BS are included in $\mathcal{S}_k$. The kth UE's cluster, C_k, complies with the following properties:

- C_k is a subset of $\mathcal{S}_k$ including BSs with the highest received powers, i.e., $C_k \subseteq \mathcal{S}_k$,
- The maximum number of BSs in a cluster is bounded by maximum cluster size, S_{max}, i.e $|C_k| \leq S_{max}$, where $|.|$ presents the cardinality of a set.
- Timing synchronization is ensured among the BSs as in (6) where ε^m_k and ε^{ser}_k are the timing delays of the received signal from the mth BS in C_k and the serving BS of the kth UE, respectively. G_k is the maximum allowable number of concatenated OFDM symbols considering the minimum channel coherence time, $T_{c,min}$, between the coordinating BSs and kth UE. Mathematical expression of G_k is given in (7) where $T(= T_s\ N)$ and $T_g(= T_s\ N_g)$ are the time duration of single OFDM symbol and the CP duration, respectively. T_s is sampling duration, and $\lfloor . \rfloor$ is flooring operation.

$$0 \leq \varepsilon^m_k - \varepsilon^{ser}_k \leq G_k\ T_g \quad (6)$$

$$G_k = \left\lfloor \frac{T_{c,min}}{T + T_g} \right\rfloor \quad (7)$$

The impact of JT on the signal quality is given through the reduction of the interference power by the amount of power gained from coordination that the kth UE experiences, the corresponding signal-to-interference-and-noise ratio (SINR) is given as follows;

$$SINR_k = \frac{\sum_{i \in C_k} P^k_i}{\sum_{l \in \mathcal{M}, l \notin C_k} P^k_l + N_0 B_T} \quad (8)$$

where $\mathcal{M} = \{1, 2, \ldots, M+1\}$ is a set of the indices of all SBSs and MBS in the coverage area. P^k_i and P^k_l are the received powers at kth UE from ith coordinating BS and lth interfering BS, respectively. N_0 is noise power spectral density and B_T is total system bandwidth. The maximum achievable throughput, y_k, can be estimated as:

$$y_k = B_{RB}\log_2(1 + SINR_k) \quad (9)$$

where B_{RB} is the bandwidth of single resource block (RB). The dedicated RBs required for kth UE from all BSs in C_k can be defined as [16]

$$r_k = \frac{B_R}{y_k\ |C_k|}, \quad (10)$$

where B_R is the bit rate required for each UE. Additionally, we assume that any mth BS in the coverage area, either SBS or MBS, has RB_m allocated RBs. In addition, the mth BS load, ℓ_m, can be defined as

$$\ell_m = \frac{\sum_{k \in \mathcal{K}_m} r_k}{RB_m} \quad (11)$$

where $\mathcal{K}_m$ is a set of active UEs associated with mth BS. ℓ_m should be ≤ 1 to ensure that mth BS is not over-loaded.

III. Proposed Clustering Algorithm

In this section, utilization of the proposed user-centric dynamic clustering in CoMP system is expressed considering the loads across the BSs and the timing synchronization between UE and its coordinating BSs. The main goal of the proposed algorithm is to minimize the total number of unconnected UEs in the network. The algorithm is split into two stages; load balancing, inspired by the work in [16], and timing synchronization. These stages keep repeating until the number of unconnected UEs is almost same in consecutive iterations. Fig. 2 summarizes the proposed clustering algorithm steps for both stages.

A. Load Balancing

When the network has been initialized, each UE selects the candidate set following conditions in (3) and (4). The UEs' clusters are formed considering the load status of BSs. The exact steps of this stage are as follows:

1) Sort the UEs by the size of their candidate sets, such that:

$$| \mathcal{S}_1 | \leq | \mathcal{S}_2 | \leq \cdots \leq | \mathcal{S}_k | \leq \cdots \leq | \mathcal{S}_K | . \quad (12)$$

2) If candidate sets of two or more UEs have the same size, sort the UE by their received power from the serving BS.
3) Start the clustering process with the UE that has the smallest candidate set size and receives the highest power from the serving BS. Then, move to next UEs.
4) The formed clusters for all UEs have to satisfy the cluster properties mentioned in Section II.
5) Find the required RBs for each UE from each BS in its cluster as in (10).
6) Add the RBs found in the previous step to all the BSs in the cluster as long as this does not cause over-loading to any of these BSs. Otherwise, the UE is denied the access to the network and the process moves on with the next UE.
7) Check the loads of all BSs in the system. BS which is fully-loaded (i.e. $\ell_m = 1$), is removed from the candidate set of next UEs.
8) Update the candidate sets of all UEs.
9) Above steps are repeated until:
   a) No extra UEs to accommodate.
   b) All BSs are fully-loaded, i.e. $\ell_m = 1$ for $\forall m \in \mathcal{M}$.
   c) The available RBs in all BSs are not enough to accommodate further UEs.

B. Timing Synchronization

In order to recover the transmitted signals from the corresponding coordinating BSs at specific UE, the time delays of the received signals must fulfil the condition in (6). To ensure the timing synchronization in UE's cluster, the steps are summarized as follows:

1) Estimate the time delays from all coordinating BSs.
2) Find the maximum allowable number of concatenating OFDM symbols as in (7) considering the maximum time delay.

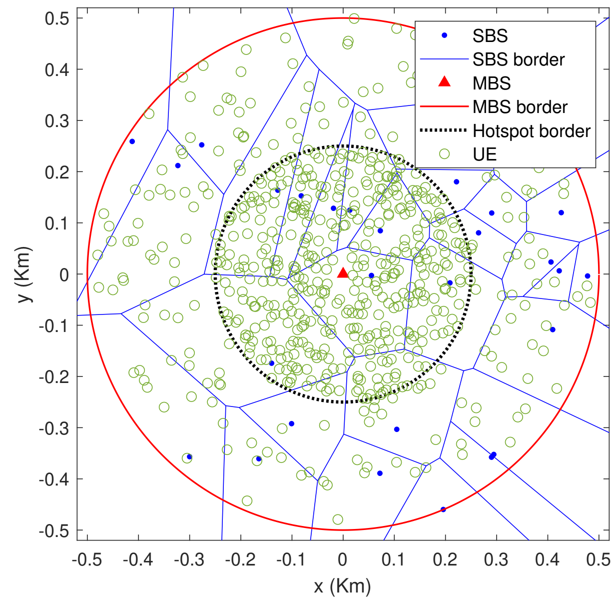

Fig. 3: An example of the generated network layout, SBS boundaries following Voronoi tessellation.

TABLE I: Simulation Parameters

Parameter Name	**Parameter Value**
Simulation Environment	Urban Microcell
Frequency Carrier (f_c)	5 GHz
Channel Bandwidth (B_T)	5 MHz
RB bandwidth (B_{RB})	180 KHz
Number of RBs/MBS	100
Number of RBs/SBS	25
Shadow fading standard deviation (σ)	4 dB
UE thermal noise density (N_0)	-174 dBm/Hz
MBS total transmit power	46 dBm
SBS total transmit power	41 dBm
Min received power to include in cluster (P_{min})	-110 dBm
Max received power offset from serving BS ($P_\circ$)	20 dB
Max cluster size (S_{max})	3
Guaranteed bit rate for UEs (B_R)	512 Kbps
SBS density (λ_{BS})	80 SBS/Km^2
UE density - Hotspot (λ_h)	1200 UE/Km^2
UE density - Non-Hotspot (λ_l)	800 UE/Km^2
Simulation area radius (r)	0.5 Km
Hotspot area radius (r_h)	0.25 Km

3) If any BS does not satisfy the condition in (6), The BS is removed from the cluster.
4) Update the clusters
5) Update the loads of the BSs.

After each iteration, the number of free-RBs is evaluated to check the availability to accommodate more UEs in next iterations. The number of unconnected UEs is estimated after each iteration, when the number of unconnected UEs in

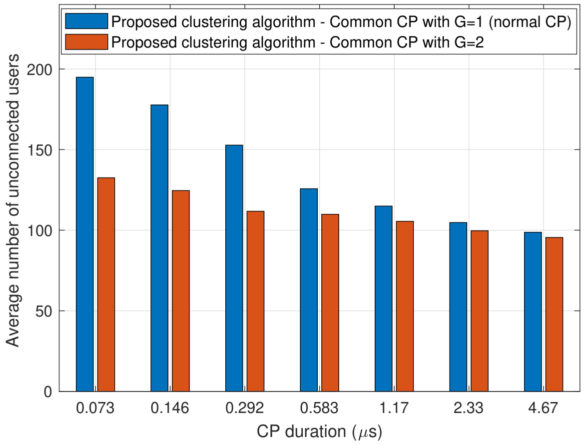

Fig. 4: The average number of unconnected UEs performance for different CP durations.

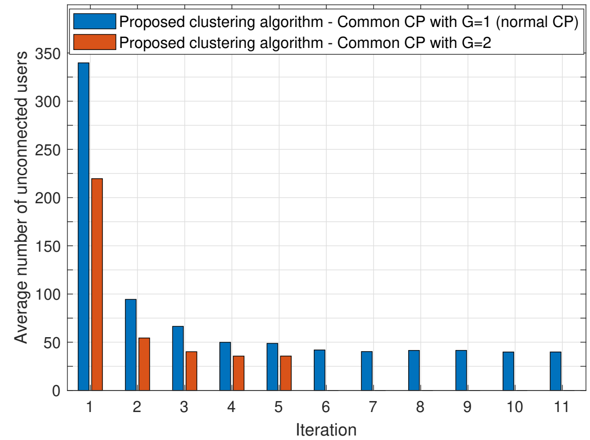

Fig. 5: Performance of proposed clustering algorithm using *common* CP with $G = 1, 2$ in terms of iteration.

consecutive iterations is almost similar, the clustering process is finished and UEs send clustering requests to get access to the network.

IV. Simulation Results and Discussion

In this section, the proposed clustering algorithm is examined in CoMP network illustrated in Section II. The simulations are carried out in MATLAB® environment and the simulation parameters are given in Table I. In line with the results observed in [16], we have selected a maximum cluster size of 3, since the coordination benefit diminishes with a higher cluster size. An example snapshot of the generated network layout is shown in Fig. 3. The simulation results are averaged over 1000 network realizations.

The average number of unconnected UEs for different CP duration is shown in Fig. 4. The proposed clustering algorithm is examined for two cases: 1) *common* CP with $G = 1$, alternatively called *normal* CP, and 2) *common* CP with $G = 2$. As we can see in Fig. 4, there is a significant difference between the two aforementioned cases at short CP durations which is diminishes at long CP durations. This is because timing synchronization is not an issue with long CP durations in HetNet scenario where the timing delay is normally less than the CP duration due to the short distance between SBSs. In other words, the condition in (6) is satisfied with long CP durations and short distances among SBSs.

The average number of unconnected UEs at different iterations is shown in Fig. 5 for $T_g = 1.17\mu s$. It is observed that the average number of unconnected UEs is reduced along the iterations due to timing synchronization constraint where some BSs will have available RBs which can be used to get access to unconnected UEs in next iterations. In addition, *common* CP with $G = 2$ provides less number of unconnected UEs compared to *common* CP with $G = 1$, this is because UEs can be served with smaller cluster sizes which leads to have more available RBs for unconnected UEs. Due to the early stopping

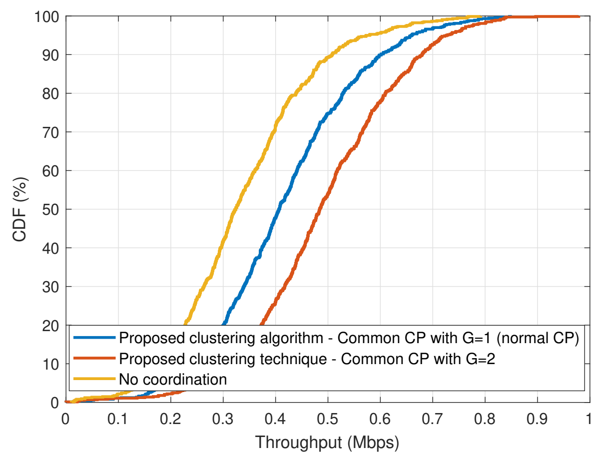

Fig. 6: Distribution of UEs' throughput in the network.

mechanism used on the proposed clustering algorithm to terminate the clustering process when the number of unconnected UEs does not change significantly in consecutive iterations, we can see that using *common* CP with $G = 2$ terminates the process in 6 iterations and almost 36 UEs remain unconnected while using *common* CP with $G = 1$ requires 11 iterations and results in 40 unconnected UEs.

The distribution of UEs' throughput in the network is illustrated in Fig. 6 for $T_g = 1.17\mu s$. Using *common* CP with $G = 2$ achieves better throughput distribution compared to *common* CP with $G = 1$, i.e., *normal* CP, and 'no coordination' scenario. This can be justified because far BSs can be part of UE cluster in case *common* CP with $G = 1$ is used, due to not having enough RBs in close BSs which leads to lower SINR and less throughput accordingly. While, *common* CP with $G = 2$ gives the UEs chance to get access to closest BSs which reduces the interference from neighbor BSs and leads to higher throughput. In addition to that it is not surprised that 'no coordination' scenario provides the worst throughput performance where the UEs suffer from high interference from the neighboring BSs since the UEs are connected only to their serving BSs.

V. Conclusion and Future Directions

This work focuses on the clustering problem in a CoMP network while taking into consideration the timing synchronization issue which is a major hurdle in its realization. First of all, an overview of the problem is provided, followed by an explanation of the *common* CP technique which is then used in the clustering algorithm to address the timing synchronization issue. The proposed clustering algorithm targets load balancing with timing synchronization as a constraint. In load balancing stage, the first priority is given to UEs with higher received power and lower number of BSs in the candidate set. In terms of timing synchronization and from the simulated results, we can conclude that HetNet deployment will suffer from timing synchronization only with smaller CP duration and we can improve the performance using *common* CP technique. An alternate approach that can be looked at in the future is channel shortening [23] that can be used either independently or in conjunction with *common* CP to address this issue.

Acknowledgment

The authors thank Muhammad Sohaib J. Solaija for his helpful suggestions regarding this manuscript. This work is supported by the Scientific and Technological Research Council of Turkey (TUBITAK) under Grant No. 3171084.

References

[1] 3rd Generation Partnership Project (3GPP), "Coordinated Multi-point Operation for LTE Physical Layer Aspects (Rel-11) ," Technical Report 36.819, ver 11.2.0, Sept. 2013.

[2] M. S. J. Solaija, H. Salman, A. B. Kihero, M. İ. Sağlam, and H. Arslan, "Generalized coordinated multipoint framework for 5G and beyond," *IEEE Access*, vol. 9, pp. 72 499–72 515, 2021.

[3] S. Bassoy, H. Farooq, M. A. Imran, and A. Imran, "Coordinated Multi-point Clustering Schemes: A Survey," *IEEE Commun. Surv. Tut.*, vol. 19, no. 2, pp. 743–764, 2017.

[4] F. Qamar, K. B. Dimyati, M. N. Hindia, K. A. B. Noordin, and A. M. Al-Samman, "A Comprehensive Review on Coordinated Multi-point Operation for LTE-A," *Computer Netw.*, vol. 123, pp. 19–37, 2017.

[5] V. Jungnickel, K. Manolakis, W. Zirwas, B. Panzner, V. Braun, M. Lossow, M. Sternad, R. Apelfröjd, and T. Svensson, "The role of small cells, coordinated multipoint, and massive MIMO in 5G," *IEEE comm. Mag.*, vol. 52, no. 5, pp. 44–51, 2014.

[6] I. Viering, M. Dottling, and A. Lobinger, "A Mathematical Perspective of Self-Optimizing Wireless Networks," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Dresden, Germany, 2009, pp. 1–6.

[7] C. Li, J. Zhang, M. Haenggi, and K. B. Letaief, "User-centric intercell interference nulling for downlink small cell networks," *IEEE Trans. Commun.*, vol. 63, no. 4, pp. 1419–1431, 2015.

[8] S. Feng, W. Feng, H. Mao, and J. Lu, "Overlapped Clustering for CoMP Transmissions in Massively Dense Wireless Networks," in *Proc. IEEE Int. Conf. Commun. Syst.*, Macau, China, 2014, pp. 308–312.

[9] A. Liu and V. K. Lau, "Exploiting base station caching in MIMO cellular networks: Opportunistic cooperation for video streaming," *IEEE Trans. Signal Process.*, vol. 63, no. 1, pp. 57–69, 2014.

[10] M. Deghel, E. Baştuğ, M. Assaad, and M. Debbah, "On the benefits of edge caching for MIMO interference alignment," in *Proc. IEEE Int. Workshop Signal Process. Advances Wireless Comm. (SPAWC)*, Stockholm, Sweden, 2015, pp. 655–659.

[11] G. Cili, H. Yanikomeroglu, and F. R. Yu, "Cell switch off technique combined with coordinated multi-point (CoMP) transmission for energy efficiency in beyond-LTE cellular networks," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Ottawa, ON, Canada, 2012, pp. 5931–5935.

[12] Z. Niu, S. Zhou, Y. Hua, Q. Zhang, and D. Cao, "Energy-aware network planning for wireless cellular system with inter-cell cooperation," *IEEE Trans. Wireless Commun.*, vol. 11, no. 4, pp. 1412–1423, 2012.

[13] H. Kim, G. de Veciana, X. Yang, and M. Venkatachalam, "Alpha-optimal user association and cell load balancing in wireless networks," in *Proc. IEEE Int. Conf. Comput. Commun. (INFOCOM)*, San Diego, CA, USA, 2010, pp. 1–5.

[14] Q. Ye, B. Rong, Y. Chen, M. Al-Shalash, C. Caramanis, and J. G. Andrews, "User association for load balancing in heterogeneous cellular networks," *IEEE Trans. Wireless Commun.*, vol. 12, no. 6, pp. 2706–2716, 2013.

[15] T. Koivisto and V. Koivunen, "Impact of time and frequency offsets on cooperative multi-user MIMO-OFDM systems," in *Proc. IEEE 20th Int. Symp. Pers. Indoor Mobile Radio Commun.*, Tokyo, Japan, 2009, pp. 3119–3123.

[16] 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.

[17] J. Zuo, J. Zhang, C. Yuen, W. Jiang, and W. Luo, "Energy Efficient User Association for Cloud Radio Access Networks," *IEEE Access*, vol. 4, pp. 2429–2438, 2016.

[18] D. Liu, S. Han, C. Yang, and Q. Zhang, "Semi-Dynamic User-Specific Clustering for Downlink Cloud Radio Access Network," *IEEE Trans. Veh. Technol.*, vol. 65, no. 4, pp. 2063–2077, 2015.

[19] A. M. Hamza and J. W. Mark, "A clustering scheme based on timing requirements in coordinated base-stations cooperative communications," in *Proc. IEEE Wireless Commun. Netw. Conf. (WCNC)*, Shanghai, China, 2013, pp. 3764–3769.

[20] S. Bassoy, M. A. Imran, S. Yang, and R. Tafazolli, "A Load-aware Clustering Model for Coordinated Transmission in Future Wireless Networks," *IEEE Access*, vol. 7, pp. 92 693–92 708, 2019.

[21] M.-j. Wang, L. Chen, W.-x. Zhu, K. Hua *et al.*, "A novel timing and frequency offset estimation algorithm for filtered OFDM system," *EURASIP J. Advances Signal Process.*, vol. 2020, no. 1, pp. 1–20, 2020.

[22] X. Wang, Y. Wu, and J.-Y. Chouinard, "On the comparison between conventional OFDM and MSE-OFDM systems," in *Proc. IEEE Global Telecommun. Conf. (GLOBECOM)*, vol. 1, San Francisco, CA, USA, 2003, pp. 35–39.

[23] P. J. Melsa, R. C. Younce, and C. E. Rohrs, "Impulse response shortening for discrete multitone transceivers," *IEEE Trans. Commun.*, vol. 44, no. 12, pp. 1662–1672, 1996.