Resource allocation in Cell-Free Massive MIMO Systems via Hungarian Algorithm

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GTTI on-line workshop

Wireless Intelligence:
From Reconfigurable Surfaces to Edge/Cloud Communications

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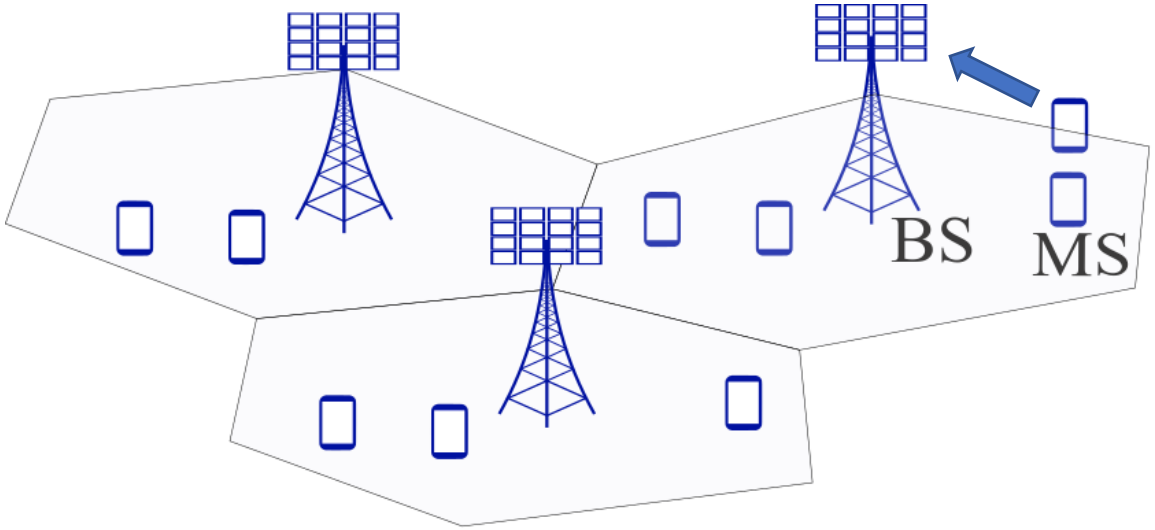
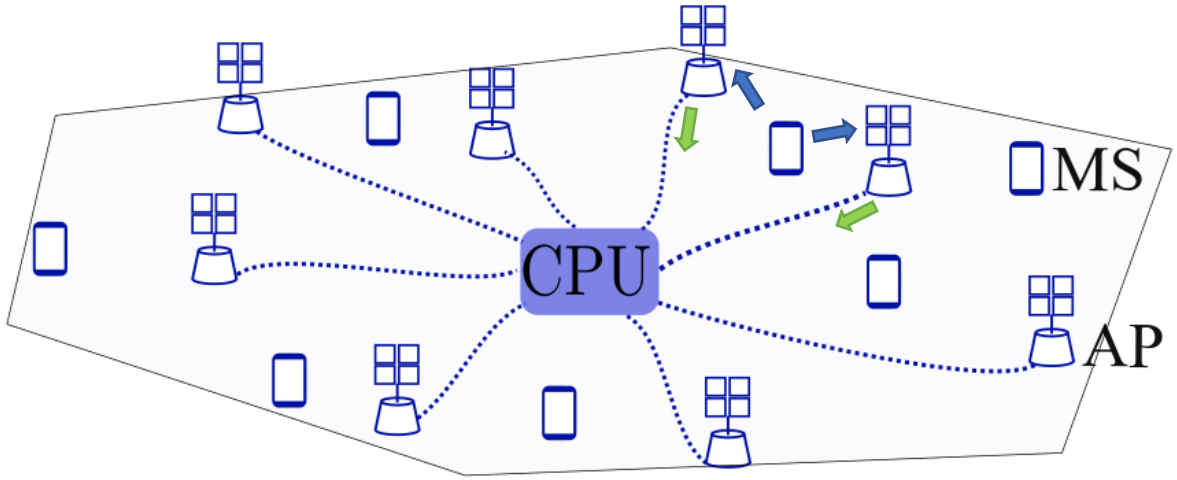
Cell-free Massive MIMO



(a) Massive MIMO cellular network



(b) Cell-free massive MIMO network

- H. Q. Ngo, A. Ashikhmin, H. Yang, E. G. Larsson, and T. L. Marzetta, “Cell-free massive MIMO versus small cells,” *IEEE Transactions on Wireless Communications*, vol. 16, no. 3, pp. 1834–1850, Mar. 2017.
- S. Buzzi and C. D’Andrea, "Cell-Free Massive MIMO: User-Centric Approach," in *IEEE Wireless Communications Letters*, vol. 6, no. 6, pp. 706-709, Dec. 2017.

Resource allocation problems

Two resource allocation problems are solved via Hungarian Algorithm:

- User-AP association
- Pilot assignment

Each of these problems is formulated as a **binary matching problem** with suitably defined *rewards* and the optimization variables correspond to the considered association.

A generic matching problem

$$\max_{z_{k,j}} \sum_{k=1}^{K} \sum_{j=1}^{J} z_{k,j} R_k^{(j)} \tag{1a}$$

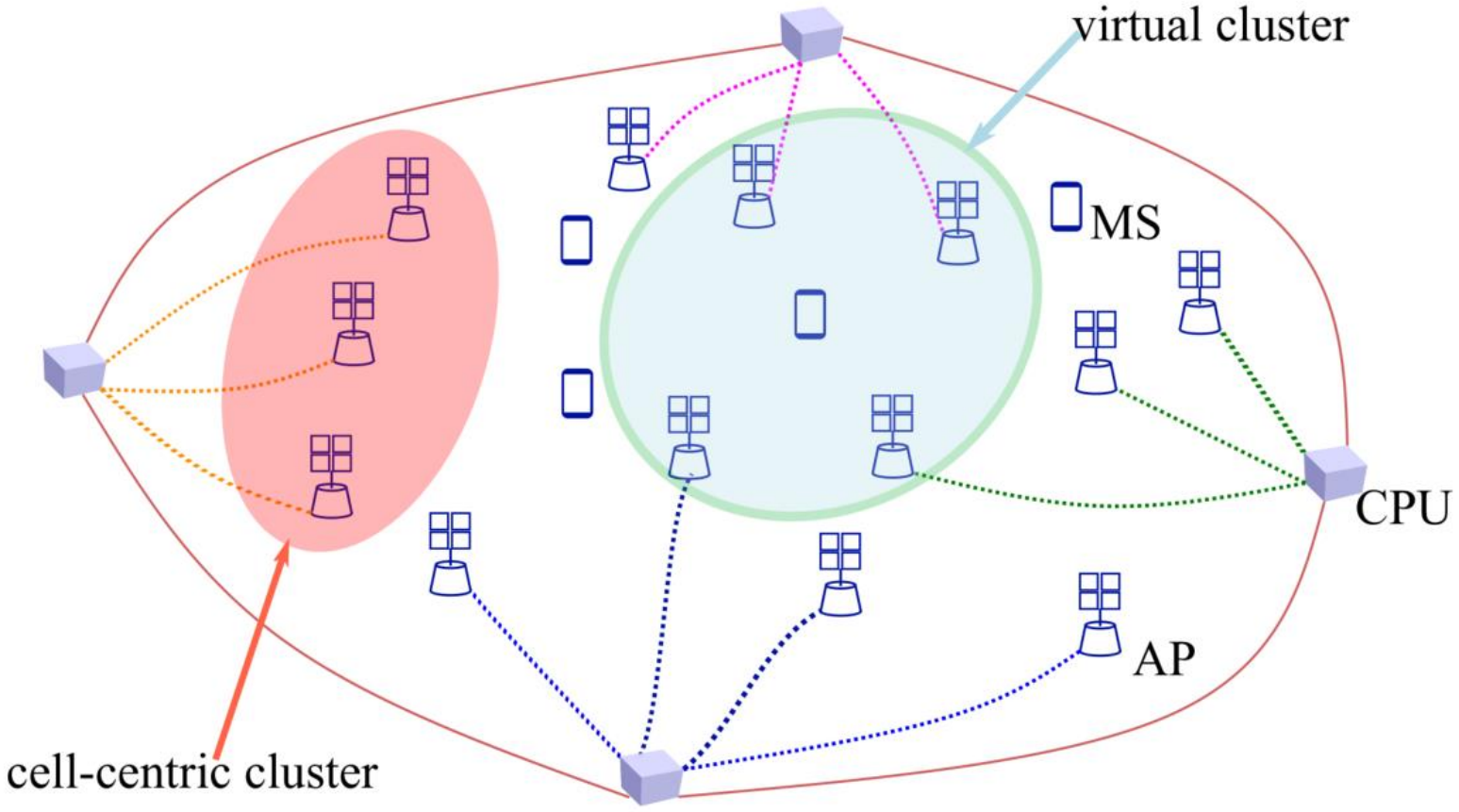
$$\text{s.t.} \sum_{k=1}^{K} z_{k,j} = 1 \; \forall \, j = 1, \ldots, J \tag{1b}$$

$$z_{k,j} \in \{0, 1\} \; \forall \, k, j \tag{1c}$$

This matching problem can be solved optimally in polynomial time by applying the **Hungarian algorithm**.

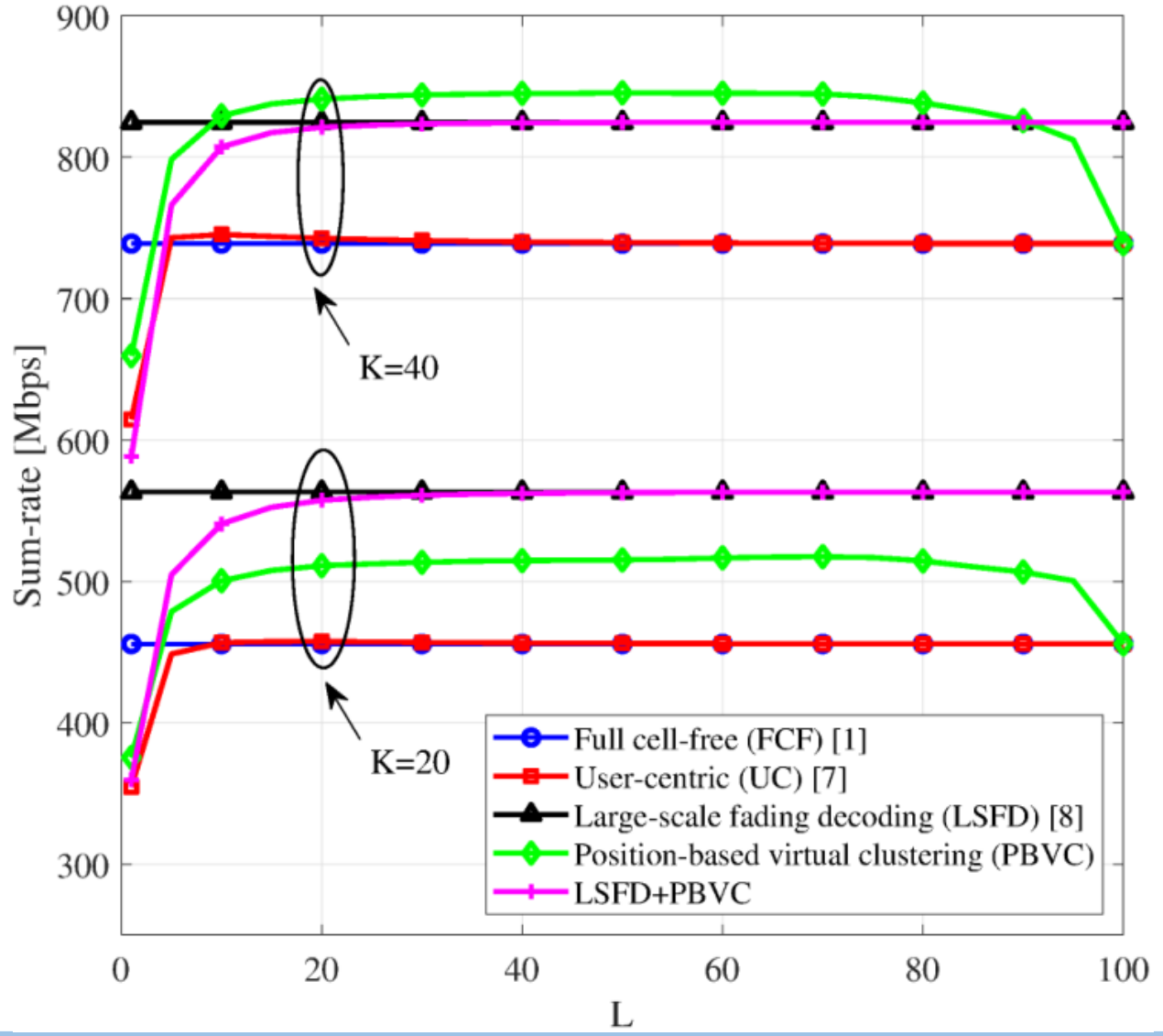
- H. W. Kuhn, "The hungarian method for the assignment problem," Naval research logistics quarterly, vol. 2, no. 1-2, pp. 83–97, 1955.
- D. Jungnickel, Graphs, networks and algorithms. Springer Science & Business Media, 2007, vol. 5.
- J. Munkres, "Algorithms for the assignment and transportation problems," Journal of the society for industrial and applied mathematics, vol. 5, no. 1, pp. 32–38, 1957.

User-AP Association formulation



C. D'Andrea and E. G. Larsson, "User association in scalable cell-free massive MIMO systems," in *2020 54th Asilomar Conference on Signals, Systems, and Computers*, Nov. 2020, pp. 1–5. Online: *https://arxiv.org/abs/2103.05321*

User-AP Association: Numerical Results



Sum-rate versus L, i.e., number of APs in each VC, comparison of the proposed PBVC with the FCF, the UC, the LSFD and with the LSFD applied only to the subset of users in the system selected with the PBVC (LSFD+PBVC). Parameters: $M = 100$, $N_{\mathrm{AP}} = 4$ and $\tau_p = 16$.

[1] H. Q. Ngo, A. Ashikhmin, H. Yang, E. G. Larsson, and T. L. Marzetta, "Cell-free massive MIMO versus small cells," *IEEE Transactions on Wireless Communications*, vol. 16, no. 3, pp. 1834–1850, Mar. 2017.

[7] S. Buzzi and C. D'Andrea, "Cell-free massive MIMO: User-centric approach," IEEE Wireless Communications Letters, vol. 6, no. 6, pp. 706–709, Dec. 2017.

[8] E. Nayebi, A. Ashikhmin, T. L. Marzetta, and B. D. Rao, "Performance of cell-free massive MIMO systems with MMSE and LSFD receivers," in Proc. of 2016 50th Asilomar Conference on Signals, Systems and Computers, Nov. 2016, pp. 203–207.

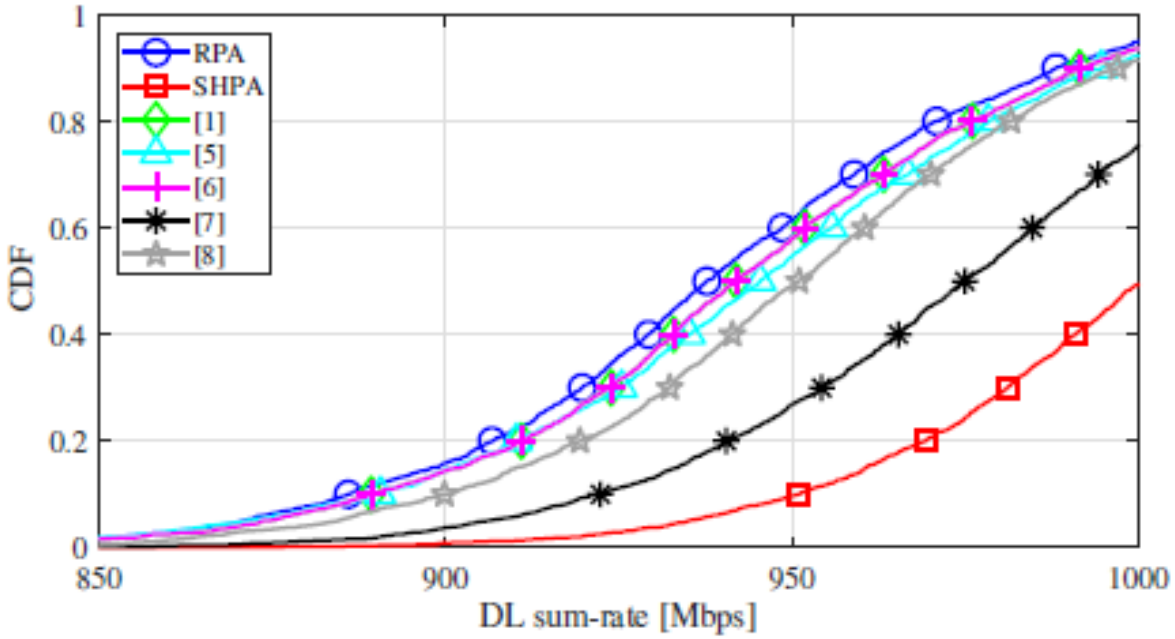
Pilot Assignment formulation

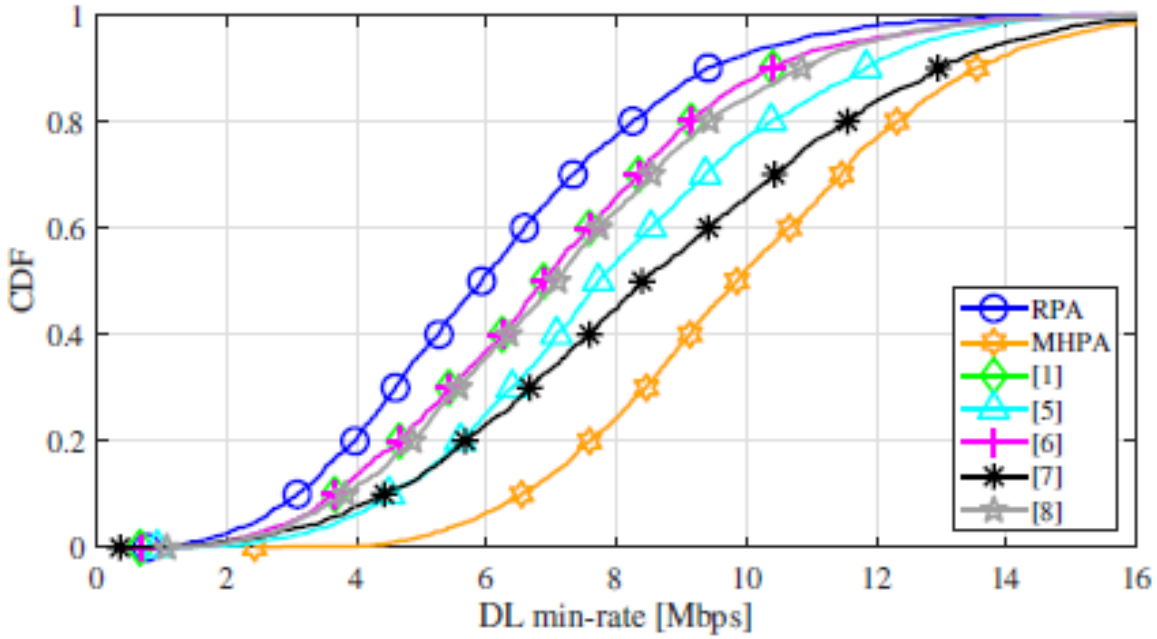
Two performance measures are considered for the pilot assignment:

- Sum-rate maximizing Hungarian PA (SHPA), which aims at the maximization of the system throughput, where the rewards of the Hungarian Algorithm are evaluated as the product between UL and DL rate for each user-pilot assignment.
- Minimum-rate maximizing Hungarian PA (MHPA), which aims at the maximization of the fairness across the users, where each reward is the smallest product between the DL and UL rates computed among all the users in the system that are using the same pilot.

S. Buzzi, C. D'Andrea, M. Fresia, Y. P. Zhang, and S. Feng, "Pilot assignment in cell-free massive MIMO based on the Hungarian algorithm," *IEEE Wireless Communications Letters*, vol. 10, no. 1, pp. 34–37, Jan. 2021.

Pilot Assignment: Numerical Results





CDFs of DL sum-rate and min-rate. Parameters: $M = 100$, $N_{\mathrm{AP}} = 4$, $K = 40$, $\tau_p = 8$.

[1] H. Q. Ngo, A. Ashikhmin, H. Yang, E. G. Larsson, and T. L. Marzetta, "Cell-free massive MIMO versus small cells," *IEEE Transactions on Wireless Communications*, vol. 16, no. 3, pp. 1834–1850, Mar. 2017.

[5] Y. Zhang, H. Cao, P. Zhong, C. Qi, and L. Yang, "Location-based greedy pilot assignment for cell-free massive MIMO systems," in *2018 IEEE 4th International Conference on Computer and Communications (ICCC)*, Dec. 2018, pp. 392–396..

[6] A. Ashikhmin, H. Q. Ngo, T. L. Marzetta, and H. Yang, "Pilot assignment in cell free massive MIMO wireless systems," Apr. 2017, US Patent 9,615,384.

[7] M. Attarifar, A. Abbasfar, and A. Lozano, "Random vs structured pilot assignment in cell-free massive MIMO wireless networks," in *2018 IEEE International Conference on Communications Workshops (ICC Workshops)*. IEEE, 2018, pp. 1–6.

[8] G. Femenias and F. Riera-Palou, "Cell-free millimeter-wave massive MIMO systems with limited fronthaul capacity," *IEEE Access*, vol. 7, pp. 44 596–44 612, Apr. 2019.

Conclusions

- A user-AP association in a scalable cell-free massive MIMO system where we formulate a matching problem between users and virtual clusters and solve it using the Hungarian algorithm.

- An iterative procedure based on the Hungarian algorithm for the pilot assignment has been described. The algorithm parameters can be tuned so as to maximize either the throughput or the fairness across users, and can be implemented based on the knowledge of the LSF coefficients.

- Both the procedures are effective and offer good performance with respect to the recent literature on these topics.

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