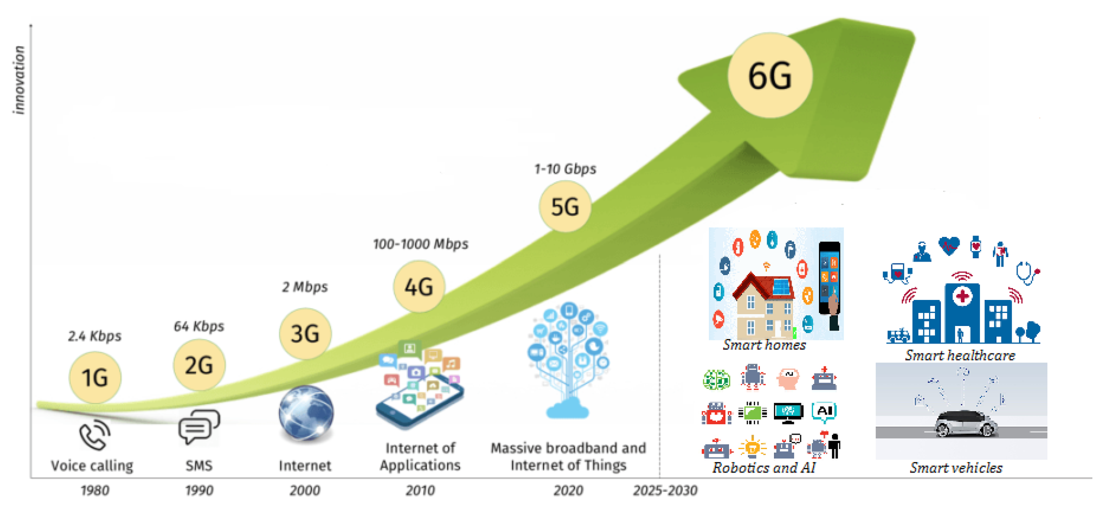
Resource Allocation Problems in Wireless Networks: A Survey

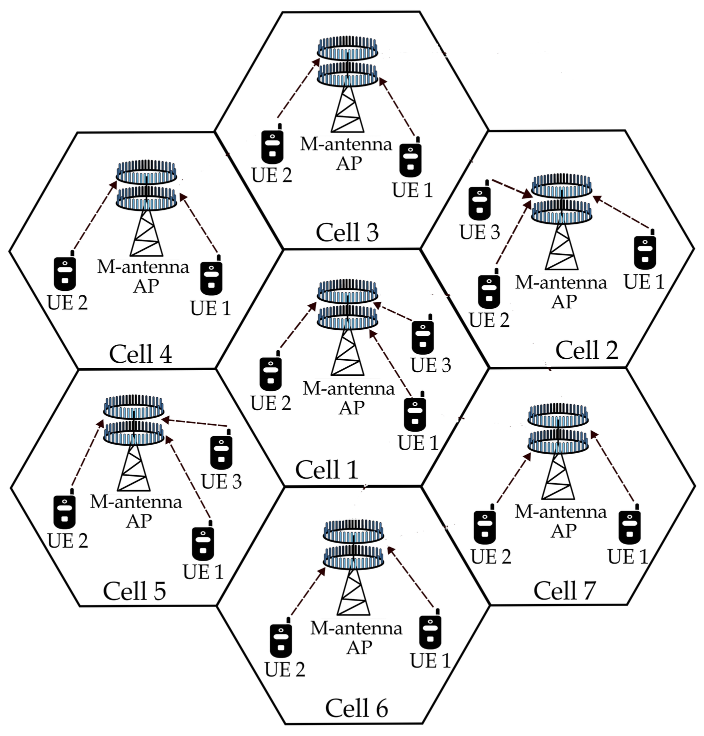
Peace Ayegba*, Sofiat Olaosebikan, and Shruthi Prusty. School of Computing Science, UofG

Background

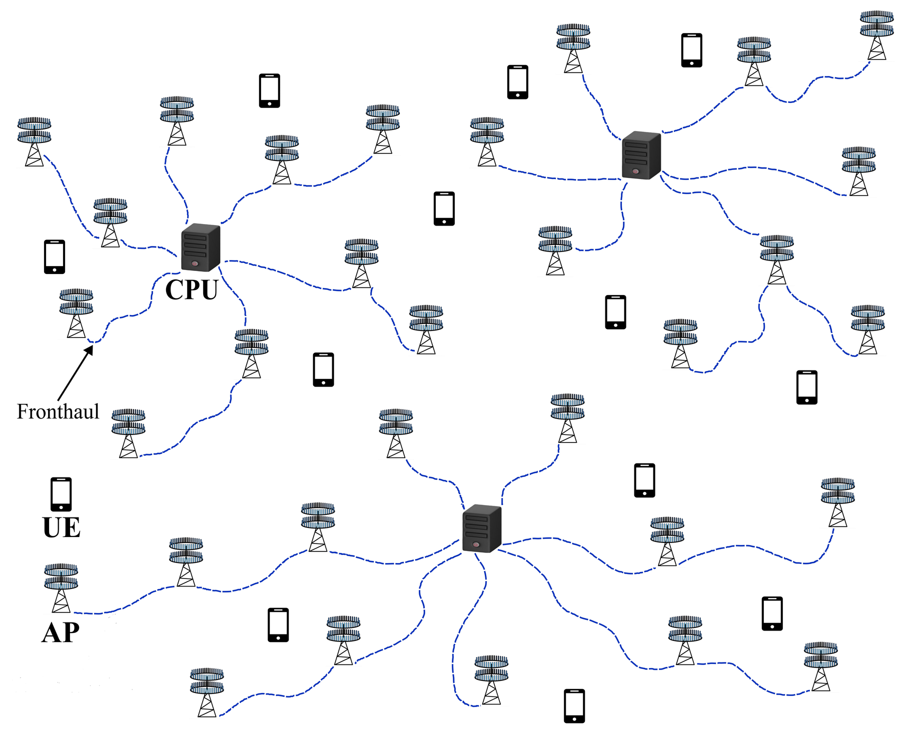
The importance of wireless networks cannot be stressed enough considering that it fosters information exchange among billions of people. Cellular networks is the technology that 1G - 5G relies on. However, as the number of devices that depend on wireless networks continues to grow (it is estimated that there will be over five billion internet users in 2023 [1]), this technology will no longer be suitable. For future wireless networks (e.g., 6G), the key technology that has the potential to enhance connectivity and provide uniform quality of service for users is referred to as *cell-free massive multiple-input multiple-output* (CF-mMIMO). This new technology offers a wide range of algorithmic problems that are generally NP-hard [2] including AP selection, pilot signal assignment, power allocation, all categorised under the umbrella of *resource allocation problems*.



(a) Evolution of wireless networks



(b) In cellular networks, each user (UE) is served by one access point (AP) within a defined boundary.



(c) A cell-free network with numerous APs jointly serving the UEs and with no notion of boundaries.

Access point selection

Problem description: The CF-mMIMO architecture allows each user to be served by multiple APs. However, it is not feasible to have all the APs in the network serving the UEs because this will blow up power consumption. As such, we are faced with the problem of selecting the best subset of APs to serve each user while maximising the user's performance (also known as special efficiency) and at the same time minimising power.

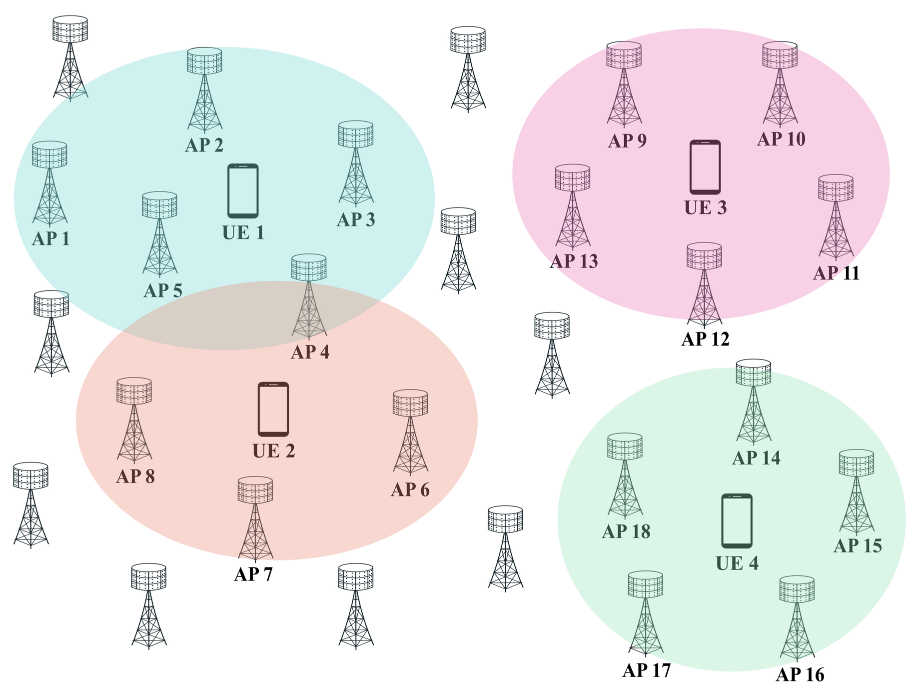


Figure 1: Overlapping clusters of APs (represented in different colours) can serve a single user. For instance, AP4 can serve UE1 and UE2 at the same time.

Goal: For each UE, find a subset of AP that will jointly serve it such that the total spectral efficiency of the network is maximised.

Existing results: To deal with the hardness of this problem, several methods based on Hungarian algorithm, Tabu search, and convex optimisation have been proposed. Following from empirical analysis in the literature, the best known heuristic algorithm for AP selection uses hierarchical clustering with time complexity $O(K^2 \log K)$ where K is the number of UEs, followed by a bisection method with complexity $O(|M_k|^2 K^4)$ where M_k is the subset of APs serving user k [3].

Pilot signal assignment

Problem description: In CF-mMIMO, APs need to acquire the Channel State Information (CSI) of the network before they can efficiently serve UEs. To obtain this information, the UEs will have to transmit pilot signals to the APs. The problem here is that the available pilot signals are limited in general, each of them have to be used concurrently by some UEs, and this causes pilot contamination. Unfortunately, this leads to inaccurate CSI, interference among UEs, and ultimately, reduced network performance.

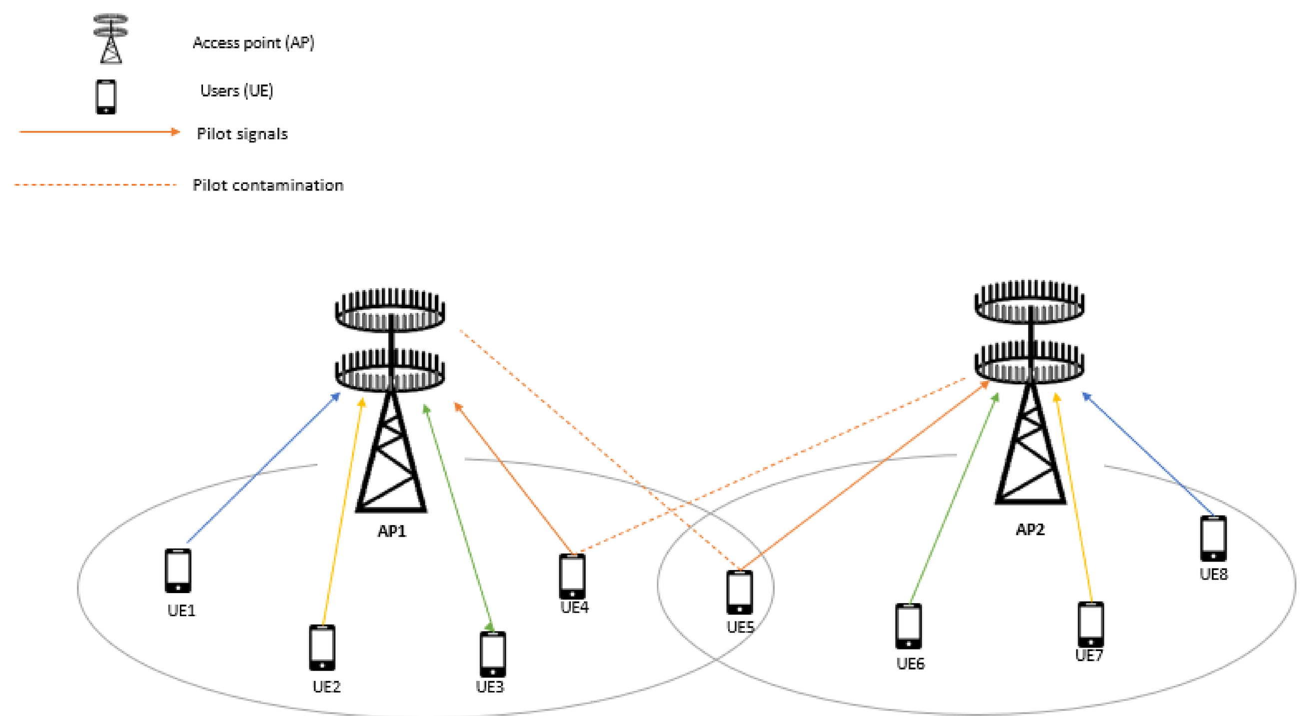


Figure 2: Pilot signals (represented by different coloured arrows) are sent from each UE to APs. UE4 and UE5 are close to one another and they are assigned to the same pilot, hence contamination occurs.

Goal: Find an assignment of pilot signals to UEs that minimises total pilot contamination and maximises network performance.

Existing results: Some existing pilot assignment heuristics are based on max k-cut, graph colouring, and Hungarian algorithm [4]. To the best of our knowledge, the max-k-cut heuristic performs better than other methods with time complexity of $O(K^2)$ and with an approximation ratio of $(1 - \frac{1}{K})$ [4].

Future directions

It is widely assumed that resource allocation problems in wireless networks are NP-hard. However, the hardness results for some of these problems are yet to be formally constructed, e.g., the pilot assignment problem. Our aim is to resolve the complexity of unknown cases as well provide polynomial-time algorithm for special cases of these problems. Further, we will explore fixed-parameter tractable algorithms, as well as graph clustering techniques that takes into account the dynamic nature and structural properties of the CF-mMIMO architecture. Finally, we will consider game theoretic approaches, which have been highlighted in recent literature as an unexplored yet natural choice to study distributed resource allocation.

References

[1] S. Odea. Global internet user growth 2018-2023. url=https://www.statista.com/statistics/1190263/internet-users-worldwide/,Statista, 2022.

[2] L.Zhi-Quam, and Z. Shuzhong. Dynamic Spectrum Management: Complexity and Duality. IEEE Journal of Selected Topics in Signal Processing, vol 2, pgs 57 – 73, 2008.

[3] R. Wang, M.Shen, Y.He and X.Liu. Performance of Cell-Free Massive MIMO With Joint User Clustering and Access Point Selection. IEEE Access, 9:40860–40870, 2021.

[4] Z. Wenbo, H. Yigang, L. Bing, and W. Shudong. Pilot assignment for cell free massive MIMO systems using a weighted graphic framework. IEEE Transactions on Vehicular Technology, vol 70, 6:6190-6194, 2021.

*Supported by a College of Science and Engineering Scholarship, University of Glasgow.

p.ayegba.1@research.gla.ac.uk | Sofiat.Olaosebikan@glasgow.ac.uk | 2829720p@student.gla.ac.uk