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Cluster Handover Analysis for a Single-User Cell-Free MIMO Network

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Abstract— **This paper addresses the handover dynamics of a moving user equipment in a typical user-centric cell-free network, with access points connected to a central processing unit and spread over a coverage area. The analysis is based on three different access point cluster strategies. We analyze the signal-to-noise ratio experienced by the user equipment during its mobility, and also the number of handover events, i.e., when the user equipment changes its master access point. Simulation results indicate that a cluster with fewer access points performs almost as well as the extreme case of all access points serving user equipment.**

Keywords— **Cell-Free network, handover, user-centric cluster.**

I. INTRODUCTION

Currently, 5th Generation (5G) mobile communication systems support the so-called massive multiple-input multiple-output (MIMO) technology, which is typically deployed in cellular networks by equipping base stations (BSs) with very-large antenna arrays to cover angular sectors of cells [1].

However, as this system is based on a cellular layout, its performance is impaired due to inter-cell interference [2]. With this issue presented, a new technology called cell-free (CF) has been proposed for better management of the inter-cell interference [2]. The CF model guarantees better network coverage and data rate for the access point (AP)-user equipment (UE) relationship compared to the cellular system. The application of this model has been widely discussed for use in 6th Generation (6G), as it combines the advantages of already known systems [2]. The resulting network topology relies on a central processing unit (CPU) that controls several APs distributed in a given physical geographical space.

In CF networks, all APs can serve a given UE, consequently minimizing the amount of possible handovers. However, as discussed in [5], in such a CF setup the complexity of signal processing is too high as it increases with the user load. Thus, scalable CF setups define user-centric clusters with only a subset of APs serving a UE [5]. In this case, the UE connects to a master AP and possibly a few other APs to improve e.g. the signal quality. The handover in user-centric CF networks occurs when the UE changes its current master AP to a new one [3].

As in cellular systems, the handover to a new master AP has a high signaling cost, so it is important to understand how the cluster size impacts the handover dynamics, which is the contribution of this work. As analysis parameters we will use the signal-to-noise ratio (SNR) to determine the signal quality that the UE has and the ratio of how many times the master AP is exchanged per second, to determine whether a scenario is doing too much or too little handover.

II. SYSTEM MODEL

In this work, we study a scenario in which there are M APs placed in a regular grid, as in [2], and a single UE moving in a square total coverage area. APs and the UE are equipped with a single antenna. Furthermore, the UE moves using the concept of a random walk, i.e., it chooses its moving direction at random, as explained in [4].

Let h_m be the channel coefficient between the UE and the m-th AP, defined as:

$$h_m = \sqrt{10^{-\frac{\beta(d_m)+X_m(\sigma_s)}{10}}}, \tag{1}$$

where $d_m > 1\,\mathrm{m}$ stands for the distance between the UE and the m-th AP, $\beta(d_m) = 30.5 + 36.7\ \log_{10}(d_m)$ is the path loss coefficient [2], and $X_m(\sigma_s) \sim \mathcal{N}(0, \sigma_s^2)$ is the shadowing effect [6] modeled as a random variable normally distributed with variance σ_s^2 and sampled every $10\,\mathrm{m}$ along the UE trajectory.

The handover process is based on the uplink SNR experienced by the UE while it moves in the network. We adopt the definition of uplink SNR γ presented in [2, chapter 1]:

$$\gamma = \frac{p}{\sigma_{ul}^2} \sum_{m \in \mathcal{C}} |h_m|^2, \tag{2}$$

where p represents the UE transmit power, while σ_{ul}^2 is the thermal noise power, and $\mathcal{C}$ denotes the subset of APs the UE is connected to, with cardinality $c = |\mathcal{C}|$, which forms the user-centric cluster.

III. CLUSTERING

In this work, the initial assignment of the master AP is given as the AP that provides the best path gain at the time UE requests access to the network [2]. To investigate the impact of cluster strategy on handover dynamics, two cluster strategies are considered. The first defines a fixed cluster size, while the second adopts a dynamic AP cluster allocation.

The handover process is based on path gain analysis. When we have a cluster with a fixed value of APs, the APs that will be connected will be those with the highest path gain within this pre-determined value.

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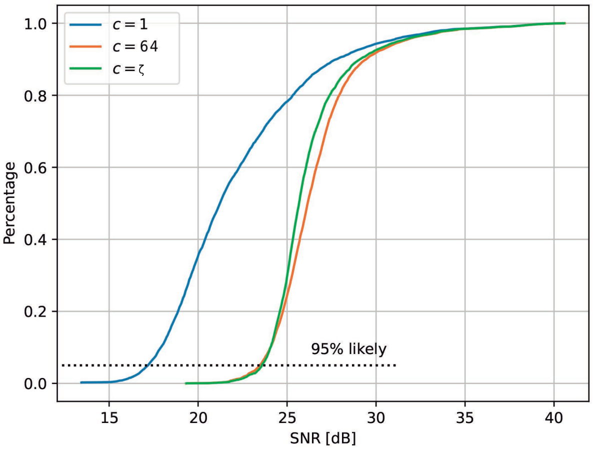

Fig. 1. CDF of SNR for different cluster sizes.

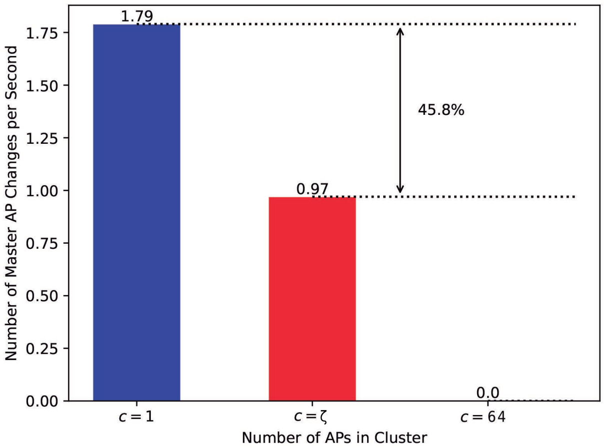

Fig. 2. Exchange ratio of AP per second for different cluster sizes.

A. Fixed-size cluster

To keep a fixed cluster size, we allocate a fixed number of APs to perform network services for the given UE, and when it moves beyond the coverage of the master AP that belongs to the cluster, the network generates a new service cluster for the UE with the same number of APs as the previous cluster.

B. Dynamic cluster

The dynamic allocation method of APs for clustering is a simplified form of the initial pilot assignment and cluster formation (IPACF) algorithm exposed in [3], where we define by inspection a limiting factor δ to determine the number of APs allocated for clustering.

IV. NUMERICAL RESULTS

In this work we simulate a CF network with a coverage area of $400 \text{ m} \times 400 \text{ m}$, $M = 64$ APs distributed evenly over this area, and a single UE. The UE performs a random walk process with a speed of 10 m/s, in which a new position is randomly defined every 10 m, until the UE trajectory reaches 4 km. The shadowing standard deviation is $\sigma_s = 2\,\text{dB}$ and the average number of dynamically allocated APs is ζ, that most often the cluster size is 3, while its average is approximately 4, the limiting factor $\delta = 10^{-12}$ W was verified by inspecting the magnitude of the path gain.

In Fig. 1, we have the cumulative distribution function (CDF) of the SNR. To analyze the impact of cluster size on it, we set the cluster size c to 1, ζ and 64, which represent the minimum, the variable and maximum number of APs in the cluster, respectively. It is possible to observe that to achieve the maximum SNR obtained with $c = 64$, it is not necessary to allocate all the APs to serve the UE. In other words, a cluster with few APs, where all of them have a high path gain in a given UE position, is sufficient to obtain a value approximate to the cluster that contains all the AP. The curves of $c = \zeta$ and $c = 64$ show basically the same SNR performance at various moments on the curve, while, with $c = \zeta$, there is an SNR gain of 0.55dB over the curve with $c = 64$ at the 5-th percentile.

Fig. 2 shows the number of handover processes executed per second, with $c = 1$ obtaining 1.79 master AP changes per second, and $c = 64$ with no handover occurrence. The scenario with $c = \zeta$ APs in a cluster has 45.8% fewer master APs changes per second than the $c = 1$ case, so, in addition to guaranteeing a higher SNR than the $c = 1$ case, there are also fewer handovers per second than the same case, reducing the complexity of the network [3].

Given the results herein presented, one can realize that, on one hand, small cluster size makes the CF network scalable in terms of signal processing complexity, but from a system perspective the number of handover occurrences increases, which cannot be neglected.

V. CONCLUSIONS

A performance analysis was made in a user-centric CF network for different APs clustering techniques and cluster sizes. The computational results show that to obtain a SNR relatively close to that provided by the total network, it is not necessary to allocate all APs, thus reducing the complexity of the network signal processing, due to the smaller number of AP master exchanges per second compared to the case of the maximum number of APs, still making it possible to solve any network scalability problems, as shown in [5].

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