User-centric Cell-Free versus Small Cells

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***Abstract*— Cellular networks have been improved since 2G and have achieved a good amount of data rate, but it lacks low variation of data rate in all coverage area. User-centric cell-free is an emerging architecture for mobile communications and can be part of 6G, such network works with a cluster with 2 or more APs. The basis to study cell-free is that the premise of it is to allow UEs in cell-edge have good amount of data rate, such as UEs in cell-center. The focus of this article is to show differences between cell-free and cellular networks and how cell-free can be much better than a cellular architecture in an uplink channel UE(user equipament)-AP(access point).**

***Keywords*— user-centric cell-free, 6G, SBrT 2024, article.**

I. Introduction

Cellular network is based on a limited cell, a single AP serving UEs in its coverage area. This architecture creates a problem that UEs in cell-edge have much lower data rate than UEs in cell-core [1]. Cell-free is a new deployment for mobile communications. It is the concept that an AP does not have a core or an edge, it consists on a set of preferred APs serving an UE. The fact that UEs can set the APs that provides better its needs, denotes a type of cell-free: *User-Centric Cell-Free.*

For this article, it makes necessary computer simulation because of random variables and large number of repetitions, so in the Results section it is available cumulative distributions about energy efficiency and link capacity comparing cell-free and small cells, and it is discussed what is a good number for clustering APs in a scenario with 64 APs in a square with 400m²

A. Problem with cellular networks

Cellular network was developed in the 1950s to serve voice calls. So if you have a SNR above a threshold that makes possible a stable connection, you have a stable voice call, and if you have much more SNR than threshold, it does not increase much quality from the service[2]. But nowadays mobile communication serves data transmission and data receiving. The SNR that makes possible voice calls does not serve enough data rate[1]. This is the problem with cellular networks, UEs close to AP have peaks of quality that UEs far from AP do not have. In a scenario of 1 UE, the data rate is lower far from AP because of the distance, according to [1], It's common (40dB) difference between cell-center and cell-edge . To improve quality for UEs in cell-edge was developed small cells, that is a high density of APs in certain coverage area. It decreases the distance between cells because of the high amount of cells, but the number of cells can not be that large. If there are many more cells than simultaneously active UEs, deploying another cell would cause higher inter-cell interference in the system.

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II. User-centric Cell-Free

In a cell-free design, there are L distributed APs jointly serving UEs in certain area. It is not the focus of this article to explain how APs are connected, but in summary, a central processing unit connected to the core network via backhaul link serves a set of APs via fronthaul link. This is commonly called as C-RAN and is the foundation of cell-free.

The game changer about cell-free in a scenario with 1 UE, which means no interference, is that signals received in each AP can be summed and jointly processed. In each receiver can be applied max ratio combining to maximize overall signal strength, it helps to decode better the signal. Imagine a cluster with 3 APS and 1 UE, the spatial domain between each AP and UE is different, which means that most likely to each AP receives the signal a little different, because of the unique channel UE-AP in spatial domain. Then each AP can collaborate to decode the signal with a different part of the signal with different errors. It is like a puzzle, each AP has different parts of the puzzle and can jointly solve it.

A. Benefits of cell-free

[1] shows in eq. 1.10 that a cellular network small cells SNR is:

$$SNR^{small-cell} = \frac{P_{tx}}{\sigma_{ul}^2} max_{l \in \{1,\dots,L\}} \beta(d_l) \tag{1}$$

In which P_{tx} is the power transmitted, σ^2 is the power noise and is equal to 96 dBm, and $\beta(d)$ is the power received at AP l. As in cellular networks each UE is assigned to one cell and only served by its AP, $\beta(d)$ is the highest number in in the path gain vector of all L APs. (OBS: não sei se devo chamar de path gain vector, mas se há um vetor com o modelo de propagação calculado para cada AP, $\beta(d)$ é o maior).

[1] shows in eq. 1.14 that a cell-free network SNR is:

$$SNR^{cell-free} = \frac{P_{tx}}{\sigma_{ul}^2} \sum_{l=1}^{L} \beta(d_l) \tag{2}$$

Now it is not the highest path gain, but a sum of all path gains at all L APs.

III. System Model

The total band in the system is 10 Mhz, the number of geographically distributed APs is equal to 64, the number of UE and channel is equal to 1. The area considered is a square with 400m²

$$\beta(d)[dB] = -30.5 - 36.7log_{10}(\frac{d}{1m}) \tag{3}$$

From [1] propagation model assumes the equation above. d is the distance between UE and AP. The equation shows that -30.5 dB of the power is lost at 1m distance and 36.7 dB of power is lost for every ten-fold increase in the propagation distance.

The SNR assumes the equation 2 already discussed in the past section and it is assumed phase-synchronization among signals. The equation to calculate link capacity follows the form below and is known as Shannon equation:

$$C = \frac{band}{N} log_2(1 + SNR) \tag{4}$$

C is given in bits per second and the SNR is the channel condition. Energy efficiency calculates how much data rate the system provides for each joule and follows the eq. 21 and eq. 18 from [4]:

$$EE = \frac{C}{P(K)} \tag{5}$$

$$P(K) = \frac{P_{tx}}{\nu}\eta + \sum_{l}^{L} KP_{tc} + \sum_{l}^{L} P_{fix} + BRP_{ft} \tag{6}$$

EE is given in bit/joule and $P(K)$ is the total power consumed in the system. [4] says that η is the power amplifier and is equal to 0.4, ν is the power control coefficient and is equal to 1, K is the cluster width, P_{tc} is the consumption of all APs circuits and is equal to 0.2W, P_{fix} depends on the disce between AP and CPU and is equal to 0.825W, B is the system bandwidth, R is the UE data rate, and P_{ft} depends on the fronthaul data traffic. As the third term that consider the fronthaul traffic is out of scope in this article, it can be removed from the equation. It can happen because there is just one UE in the system and each AP is single-antenna, then it does not contributes a lot in terms of power consumption when compared to fixed power consumptions. So the new equation is:

$$P(K) = \frac{P_{tx}}{\nu}\eta + K(P_{tc} + P_{fix}) \tag{7}$$

IV. Numerical Results

In this section, we will analyze the results from simulation explained in section above.

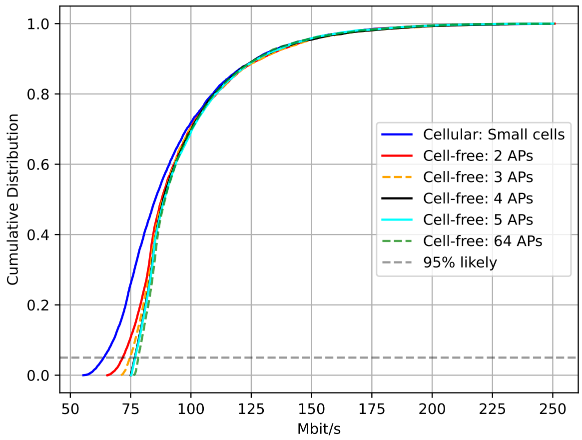

Fig. 1. This figure is the link capacity CDF in an uplink channel UE-AP

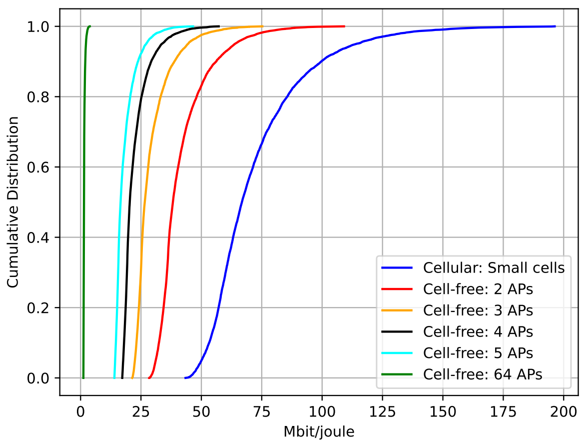

Fig. 2. This figure is the energy efficiency CDF in an uplink channel UE-AP

In Figure 1, we can see that because of the sum of all SNRs in connected APs, there is an improvement in link capacity at the 95% likely, which shows that in extreme scenarios, in cell-edge for example, cell-free is better.

In Figure 2, we can see that there is a high cost of energy using all APs for useful data receiving. Figure 1 shows that there is not a high improvement to use a cluster with all APs, so it is correct to affirm that it is worse use all APs for useful data receiving considering the cost to have a negligible improvement. It happens because far APs provide very low SNR values. So considering a scenario with 64 APs, a cluster between 2 and 5 satisfies energy efficiency and link capacity QoS.

V. Conclusions

Considering this study about an uplink channel UE-AP with 64 APs and 1 UE, cell-free networks can handle much better with high distances than cellular networks. Also it is clear that in terms of energy efficiency, a cluster with 64 APs is inefficient and it is not a game changer for data rate. A number between 3-5 of APs connected can provide higher link capacity than cellular network and also do not consume energy as much as a cluster with 64 APs

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