Power allocation analysis in cell-free networks

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***Abstract*— Power control has been used to deal with co-channel interference and energy efficiency in mobile communication systems. This work compares different uplink power control schemes implemented in a cell-free (CF) system simulation, namely stepwise removal algorithm (SRA), fractional power control (FPC) and max power (MP). Numerical results show advantages of using FPC against the others algorithms.**

***Keywords*— Power Control, Cell-free, Energy Efficiency, Co-channel Interference.**

I. Introduction

The fifth generation (5G) of mobile networks has been a paradigm change as it supports the so-called massive multiple-input and multiple-output (MIMO), allowing a more direct connection and upgrading the link capacity [7]. Typically, a single access point (AP) with a large antenna serves connected user equipments (UEs), forming a cellular system [4].

For the upcoming sixth generation (6G), it has been proposed a cell-free (CF) setup, in which UEs transmit and receive signals from various APs jointly and coherently within an area controlled by a central processing unit (CPU), which can perform the radio resource management (RRM). Furthermore, the system bandwidth is shared by all UEs in the system [3].

In both scenarios, co-channel interference is a recurrent problem since it reduces the link data rate [1, Chapter 1]. Particularly, the CF setup benefits from an interference processing at the CPU. However, it does not deal with the energy efficiency of the system; thus, it is necessary a power control function to manage the transmitted power.

In [1, Chapter 1], it is presented classical power control techniques for cellular networks. For instance, it addresses the stepwise removal algorithm (SRA), a centralized way of allocating power as it is made by a central node that knows all channel gains. Different techniques have been proposed, like fractional power control (FPC) [5], in which the path-loss (PL) is partially compensated by setting a transmitted power based on a compensation factor and a targeted received power.

In this context, this work presents the application of three power control algorithms in a CF system. It shows how signal-to-interference-plus-noise ratio (SINR) and link capacity behave when applied to the following power control models: max power (MP), SRA and FPC. It compares the efficiency of the three schemes in terms of SINR and the transmitted power.

In the results, the SINR values indicate advantages in the use of FPC instead of SRA and transmitted power values shows its advantages instead of MP due a better use of power resources.

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II. System Model

This work presents a CF network with M single-antenna APs distributed in a uniform grid, as in [3], within an $L \times L$ area, and controlled by a CPU via a fronthaul network. There are K single-antenna UEs, uniformly distributed, in uplink with each AP in the system using a transmit power p_k through one resource that uses a bandwidth B. Let $P_{\max}$ be the total available UE transmit power. Then, $p_k \leq P_{\max}$.

Let $h_{k,m}$ be the large-scale fading (LSF) component of the channel response between UE k and AP m given by [3]:

$$h_{k,m}(d) = 10^{-\frac{\sigma_s + 30.5 + 36.7 \log_{10}\left(d_{k,m}\right)}{20}}, \tag{1}$$

where $d_{k,m}$ is the distance between UE k and AP m, and σ_s is the shadowing effect, which is modeled as a random variable normally distributed with zero mean and standard deviation σ.

The key performance indicator (KPI) herein adopted to evaluate the system is the SINR, which is represented by γ_k. For simplicity, perfect channel state information (CSI) is assumed to be available at the CPU. Let P_{N} be the noise power, defined based on B. Also, let $\mathbf{h}_k \in \mathbb{R}^M$ denote the channel vector of the k-th UE towards the M APs. Given that, the SINR is obtained by assuming minimum mean-squared error (MMSE) processing of the received signals at the CPU, then obtaining the upper-bound SINR as follows [3]:

$$\gamma_k = p_k \mathbf{h}_k^{\mathrm{H}} \left(\sum_{i=1, i\neq k}^{K} p_i \mathbf{h}_i \mathbf{h}_i^{\mathrm{H}} + P_{\mathrm{N}} \mathbf{I}_M \right)^{-1} \mathbf{h}_k \,. \tag{2}$$

III. Power Control Algorithm

In this section, it will be presented the power allocation algorithms used in this work: MP, FPC and SRA.

A. Max Power

The MP approach is the simplest way to allocate power in a system and a good comparison metric as it sets full transmit power to every UE [6], i.e., $p_k = P_{\max}$, $\forall k \in \{1, \ldots, K\}$.

B. Stepwise Removal Algorithm

The SRA does a centralized power control by assuming all $h_{k,m}$ are known at the CPU, as defined by [1, Ch. 1]. For this technique, it is defined the matrix $\mathbf{Z} \in \mathbb{R}^{K \times K}$ in which each entry is defined as the ratio between interfering gain sum and desired gain sum for each UE as following:

$$z_{i,j} = \frac{\sum_{m=1}^{M} h_{j,m}}{\sum_{m=1}^{M} h_{i,m}} \,. \tag{3}$$

Let γ^* be the maximum feasible signal-to-interference ratio (SIR) in the system, defined using the maximum eigenvalue

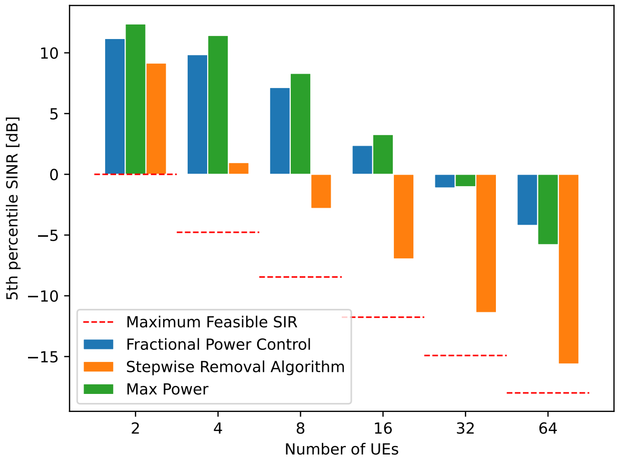

Fig. 1. Bar graph comparing the 5th percentile SINR for each power control algorithm and the maximum feasible SIR for each number of UEs.

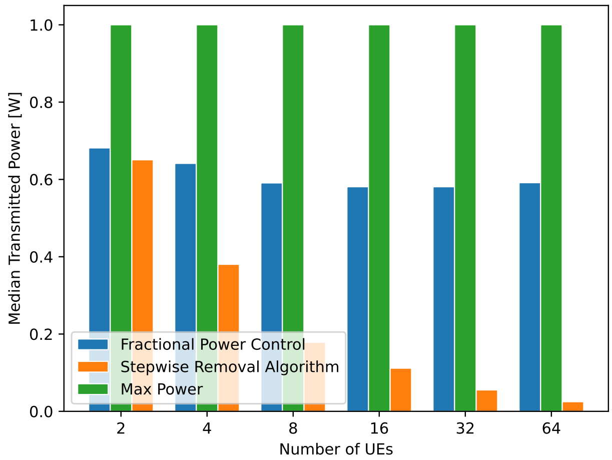

Fig. 2. Bar graph comparing the median transmitted power sum for each power control algorithm normalized by the max power according to the number of UEs.

λ^* of $\mathbf{Z}$ as $\gamma^* = \frac{1}{\lambda^*-1}$, as in [2]. To guarantee that SRA will not remove any link, it is fixed a maximum value of γ^* for every K. That means that UEs power vector is set as the eigenvector related to λ^*.

C. Fractional Power Control

In FPC algorithm, the LSF is partially compensated by considering a compensation factor α for a minimum received power p_0. Thus, $p_k = \min(P_{\max}, p_0\zeta_k^{-\alpha})$, in which ζ_k considers the $h_{k,m}$ related to each user and is given by [5]:

$$\zeta_k = \sqrt{\sum_{j=1}^{M} \mathrm{tr}\left(\mathbf{h}_{k,j}\mathbf{h}_{k,j}^H\right)},$$

where $\mathrm{tr}(\cdot)$ is the trace operator. Here, p_0 is set based on γ^* to guarantee a good comparison with SRA.

IV. Results and Discussions

To compare the algorithms it was run Monte Carlo simulations with 100 seeds. The used parameters are the following: $M = 64$, with $L = 400$ meters. $P_{\max} = 30$ dBm, $P_{\mathrm{N}} = -96$ dBm and the shadowing was calculated with $\sigma = 2$. The value of K, is variable and it is presented results for $K \in \{2, 4, 8, 16, 32, 64\}$. In FPC, $\alpha = 0.8$.

Figure 1 shows a bar graph of how the 5-th percentile SINR and the maximum feasible SIR behave for each algorithm when the number of UEs K varies. As shown, the bars decrease with the increase of K. For $K = 2$, SRA and FPC show a small difference and FPC is better in all cases. It is also better than MP for $K = 64$, when occurs a network overload. In all cases, the values reached by SRA are greater than γ^*, which means that results accomplish the algorithm parameter.

Figure 2 shows a graph bar with the normalized median transmitted power of each algorithm in function of the MP according to the number of UEs. The FPC bar decreases smoothly and the values keep between 70% and 60% of MP value. SRA decreases sharply until it represents almost 0% in $K = 64$, always smaller than FPC. For $K = 2$, SRA and FPC values are almost the same, which represents a similar behavior of both algorithms when the interference effect is small due to a low network load.

V. Conclusions

A power control analysis was carried out in a CF network for different UE loads. Simulation results indicate that MP and FPC provide better interference treatment than SRA in every case analyzed. SRA works well for a system with few UEs and has a lower energy expenditure than other algorithms, however does not deal well with interference when the network load rises. Thus, the use of this algorithm for the first cases is a good ecological alternative. When compared to MP, FPC deals with interference in a similar way and has a lower energy expenditure for all scenarios, including better behavior for high network load. Thus, FPC shows to be the best algorithm for those cases and the most efficient of them in general.

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