Collaborative Multi-CPU Approach for Interference Suppression in Distributed Cell-Free Massive MIMO System

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Abstract

Interference remains a significant challenge in Cell-free massive MIMO (CF-mMIMO) systems because of the wireless connection between CPUs, APs, and users. To mitigate this challenge, coordination between CPUs and APs is necessary. This study proposes coordination among APs, along with beam rescheduling based on interference levels, to address interference on the fronthaul. Additionally, CPU coordination is suggested to alleviate interference between APs associated with different CPUs on the backhaul. Simulation results show substantial improvements in Signal-to-Interference Ratio (SIR), particularly in densely populated urban areas. These findings demonstrate the effectiveness of the proposed approach in enhancing signal quality and system performance within densely deployed wireless networks.

Ⅰ. Introduction

Cell-free massive MIMO (CF-mMIMO) is an emerging technique envisioned for 6G wireless networks, where access points (APs) are dispersed over a large geographical area. APs are connected to users via fronthaul links and to central processing units (CPUs) via backhaul links[1].

On the fronthaul, user-centric AP clusters are dynamically formed, allowing multiple APs to collaborate in serving and scheduling beams towards individual users. While this distributed coordination can enhance spectral efficiency and coverage, it also introduces inter-site interference, especially when serving multiple users simultaneously.

Each AP is linked to a CPU through either wired or wireless backhaul connections. Wired connections may be impractical in remote areas, while wireless connections can lead to interference between nearby APs associated with different CPUs, known as inter-edge interference. This occurs because each CPU independently coordinates the beams of its APs without considering potential interference with other CPUs' AP clusters as shown in Figure 1.

One potential solution to mitigate inter-site interference is to facilitate coordination among APs. Similarly, coordination among CPUs can be explored for the backhaul. Various studies have proposed approaches to resolve the issue. However, effectively mitigating interference, both on the fronthaul and backhaul, remains a significant challenge.

In [2] the authors proposed an inter-site interference mitigation technique by sharing a list of APs whose interference exceeds a predetermined threshold, along with their pilot assignment information. However, the proposed scheme introduces an independent channel estimator processing function at each virtual CPU (vCPU), which computes the channel for affected APs.

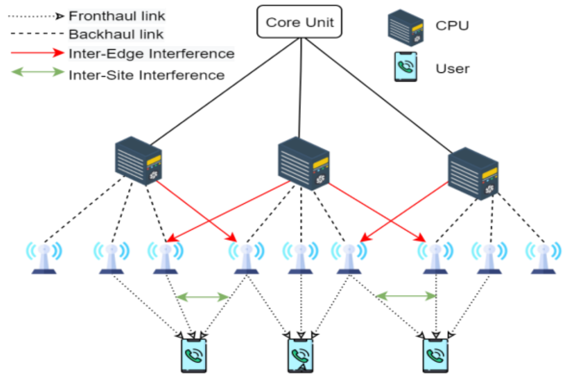

Figure 1: Interference in CF-mMIMO

This approach can increase the overall computational complexity and cost of the system. Another study [3] introduced a coordinated beamforming technique to mitigate interference, where the beams of affected APs are scheduled to avoid potential inter-site interference. However, this work addressed the inter-site interference problem assuming an optical fiber connection between APs and CPUs on the backhaul, leaving the issue of inter-edge interference unaddressed.

The authors in [4] termed users served by multiple CPUs on the backhaul as "intercoordinated users" and proposed a two-stage solution to address the interference problem. In their approach, the CPU connected to the master AP is designated as the primary CPU, while the remaining CPUs serving the user are termed non-primary CPUs. They advocate that sharing information on the backhaul and continuous coordination among CPUs can be costly. Therefore, if a CPU is not the primary CPU for a particular user, and the APs connected to that CPU are causing interference, those APs may drop the connection to the worst-affected intercoordinated user.

While various studies have put forward techniques to address interference on both the fronthaul and backhaul, managing interference remains a persistent challenge. Continuous coordination among CPUs and APs can be computationally intensive and may not always be practical. Thus, there's a demand for scalable and efficient solutions that can effectively tackle inter-cluster interference while preserving the advantages of distributed coordination inherent in the CF-mMIMO architecture.

Ⅲ. Method

To mitigate both inter-site and inter-edge interference in CF-mMIMO systems, we propose a coordinated beam rescheduling approach coupled with communication among CPUs and APs.In a distributed CF-mMIMO setup, each AP computes channel state information (CSI) for all users within its coverage area and allocates beam vectors and other resources accordingly. However, interference may arise when the beam vectors of different users intersect during downlink data transmission.

To address this issue, we introduce AP-to-AP communication. After allocating the beam vector to a particular user and initiating data transmission, the user measures the interference level and reports it back to the serving APs. If the interference exceeds a predetermined threshold, the affected APs share their beam vector information. Based on this shared information, the APs can reschedule the phase, amplitude, and timing of their beams to mitigate the interference. To determine which AP should reschedule its beam for a particular user, we propose a decision criterion based on the reference signal received power (RSRP) value. Specifically, the AP with the lowest RSRP value relative to the user should reschedule its beam.

To mitigate inter-edge interference caused by interference between APs associated with different CPUs, CPU-to-CPU communication is necessary. We propose a CPU-CPU communication strategy. In this approach, CPUs and APs are strategically placed at predetermined locations, and beamforming is employed for wireless backhaul communication between CPUs and APs. Only APs located at the edge of a CPU's cluster may experience interference from nearby CPUs' signals.

To address inter-edge interference, CPUs communicate with neighboring CPUs and share scheduling information for the APs experiencing interference. Based on this shared information, interfering CPUs can adjust the beams directed toward the affected edge APs, thereby mitigating interference. Simulations were performed to assess the effectiveness of coordinated beam rescheduling in mitigating interference in CF-mMIMO systems in various interference levels, including urban, suburban, and dense urban areas. Our findings showed that there is a significant improvement in the Signal-to-Interference Ratio (SIR) for users who were experiencing strong interference from distant APs, particularly in densely populated urban areas. This suggests that beam rescheduling is a valuable technique for maintaining high signal quality and system performance in networks that are densely deployed, and have a high potential for interference.

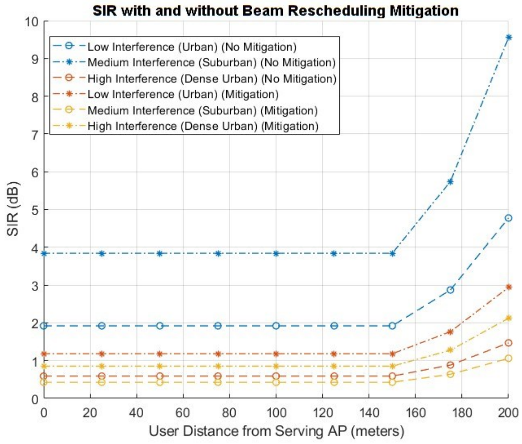

Figure 2: Simulation Results

Ⅲ. Conclusion

We propose a coordinated beam rescheduling approach to mitigate interference in CF-mMIMO systems. The solution along with beam rescheduling introduces AP-to-AP communication for inter-site interference mitigation and CPU-to-CPU communication for addressing inter-edge interference. By rescheduling beams and leveraging coordination among APs and CPUs, the proposed approach improves SIR and reduces interference levels while preserving the distributed coordination advantages of CF-mMIMO.

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REFERENCES

[1] Ajmal, M., Siddiqa, A., Jeong, B., Seo, J. and Kim, D., 2023. Cell-free massive multiple-input multiple-output challenges and opportunities: A survey. ICT Express.

[2] Ikami, A., Aihara, N., Tsukamoto, Y., Murakami, T. and Shinbo, H., 2023. Cooperation Method between CPUs in Large-Scale Cell-Free massive MIMO for User-centric RAN. IEEE Access.

[3] Ikami, A., Tsukamoto, Y., Aihara, N., Murakami, T. and Shinbo, H., 2022, September. Interference suppression for distributed CPU deployments in Cell-Free massive MIMO. In 2022 IEEE 96th Vehicular Technology Conference (VTC2022-Fall) (pp. 1-6). IEEE.

[4] Freitas, M.M., Souza, D.D., da Costa, D.B., Cavalcante, A.M., Valcarenghi, L., Borges, G.S., Rodrigues, R. and Costa, J.C., 2023. Reducing inter-CPU coordination in user-centric distributed massive MIMO networks. IEEE Wireless Communications Letters.