A Thesis for the Degree of Ph.D. in Engineering

AI-Powered Optimization Approaches for Antenna Beamforming in Multi-Cell HAPS Systems

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Thesis Abstract

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Thesis Title

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Thesis Summary

High altitude platform station (HAPS) systems have emerged as a key solution to address the increasing networking demands of the Internet of Things (IoT), providing wide-area coverage, low latency, enhanced network resilience, and cost-effective service delivery, particularly in remote regions. Given that the continuous movement of HAPS and the inherent mobility of user equipments (UEs) often lead to low and unevenly distributed UE throughput, it is crucial for HAPS systems to dynamically control the antenna using beamforming techniques. However, the current reactive approaches to dynamic control fail to effectively minimize the number of low throughput UEs and achieve low time complexity. To overcome these challenges, we propose a clustering-aided particle swarm optimization (PSO) algorithm to determine the antenna parameters, enabling HAPS to configure multiple cells and dynamically control beams based on UE distribution. This algorithm leverages UE clustering information to redefine the search space, reducing the complexity while enhancing the ability to find the global optimum. Specifically, we propose a novel regulated K-means algorithm that groups UEs into appropriately balanced clusters, precisely reducing the search space for global optimization. Simulations using real-world UE distributions demonstrate that our proposed method outperforms conventional approaches in reducing low throughput UEs and providing balanced throughput distribution, while maintaining low computational complexity.

To further address the limitations of iterative optimization in real-time scenarios, we extend this work by proposing a neural network-based beamforming optimization approach. Although the clustering-aided PSO algorithm has demonstrated the state-of-the-art performance in dynamically determining antenna parameters, it relies on iterative search, which introduces result instability and constrains real-time applicability. Meanwhile, an earlier attempt to use a multilayer perceptron (MLP) model for direct prediction offer shorter computation time but cannot achieve throughput quality comparable to that of the state-of-the-art method. In contrast, our proposed model directly predicts antenna parameters from UE distribution, replacing the iterative search process with a neural network. Evaluated using the real-world distribution data, the results demonstrate that our proposed method effectively enables stable real-time decision-making while maintaining throughput performance close to the best existing iterative optimization method.