Artificial Intelligence Aided Physical and MAC Layer Optimization Schemes for Three Dimensional NOMA Networks

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（3 次元 NOMA 無線網のための AI を活用した物理層と MAC 層の最適化法）

区　　分　：甲

論 文 内 容 の 要 旨

Non-orthogonal multiple access (NOMA) allows multiple user equipment (UE) to simultaneously share the same resource blocks using varying levels of transmit power at the base station (BS) side. This powerful feature of NOMA makes it a suitable candidate for future 6G mobile networks multiple access in order to meet the high connection density and data rates expectations set forth for 6G applications that require stringent operational demands such as haptic internet, 16K real-time video streaming, and bandwidth-hungry holographic AR/VR applications. In this thesis, we designed novel artificial intelligence (AI)-based frameworks to solve challenging PHY and MAC layers problems for three-dimensional NOMA (3D-NOMA) networks utilizing both terrestrial and non-terrestrial based communications. To optimize the PHY layer operation of 3D-NOMA networks, neural network (NN)-based orthogonal frequency division multiplexing (OFDM) signal processing is considered, whereas MAC layer operation optimization is accomplished via reinforcement learning (RL)-based resource management operation for both terrestrial and non-terrestrial NOMA downlink communications.

For OFDM signaling, high peak-to-average power ratio (PAPR) is a typical characteristic inherent in the multiplexed signals and has been a long-standing critical issue for mobile networks PHY layer optimization. The ever-increasing demand for low-latency operation calls for the development of low-complexity novel solutions to the PAPR problem. To address this issue while providing an enhanced PAPR reduction performance, in this thesis we propose a synchronous NN-based solution to achieve PAPR reduction performance exceeding the limits of conventional clipping and filtering (CF)-based schemes with lower computational complexity. The proposed scheme trains a neural network module using hybrid collections of samples from multiple OFDM symbols to arrive at a signal mapping with desirable characteristics.

On the other hand, to unlock the full potential of NOMA and reap its benefits, MAC layer-level resource management operation optimization is crucial. Specifically, proper allocation of transmission power and selection of candidate users for pairing over the same resource block are critical for an efficient utilization of the available resources. Reinforcement learning deploying double deep-Q networks (DDQN) is a promising framework that can be adopted for tackling the problem. In this thesis, an RL-based DDQN scheme is proposed for

opportunistic user pairing to access downlink NOMA systems with capacity-limited backhaul link connections. The proposed algorithm relies on proactive data caching to alleviate the throttling caused by backhaul bottlenecks, and optimized UE selection and power allocation are accomplished through the continuous interaction between an RL agent and the NOMA environment to increase the overall system throughput.

Moreover, for non-terrestrial 3D-NOMA operation, this thesis proposes two energy-efficient RL-based algorithms for millimeter wave (mmWave)-enabled unmanned aerial vehicle (UAV) communications toward 6G. This can be especially useful in ad-hoc communication scenarios within a neighborhood with main-network connectivity problems such as in areas affected by natural disasters. This is important since 6G mobile network design must accommodate use cases for mission-critical communications during emergencies. Dynamic selection of suitable hovering spots within the target zone where the battery-constrained UAV needs to be positioned as well as calibrated NOMA power control with proper device pairing are critical for optimized performance. We propose cost-subsidized multiarmed bandit (CS-MAB) and DDQN-based solutions to address these problems jointly.

For 3D-NOMA PHY layer, the proposed AI-aided OFDM PAPR reduction scheme operates at 16.7% faster signal processing speed along with about 12% improvement in the cubic metric measure of the OFDM signal compared to conventional clipping and filtering (SCF) for a 256-subcarrier OFDM PHY layer with QPSK modulation. On the other hand, at the MAC layer level, an 18.4% faster data transfer rates can be accommodated by the proposed DDQN RL agent for cache-enabled NOMA downlink resource management over a capacity-limited backhaul link when operating with 38-GHz mmWaves and 500 MHz system bandwidth. Moreover, significant UAV battery energy savings exceeding 90% can be accomplished for mission-critical, non-terrestrial NOMA downlink transmissions.