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学位論文内容の要旨

Drones, with their flexible configuration, cost-effectiveness, and high mobility, have become increasingly feasible as aerial base stations in emergency communication scenarios due to decreasing costs and the miniaturization of communication and computing equipment. Particularly in cases of natural disasters and unexpected events, drones can rapidly enter affected areas to provide communication coverage, ensuring smooth communication between those in distress and rescue teams, significantly enhancing the efficiency of emergency responses. Compared to traditional base stations, drone-based aerial base stations offer greater deployment flexibility and coverage capabilities. Traditional base stations are often constrained by fixed locations and the integrity of infrastructure, which may be damaged or entirely nonfunctional in emergency situations. In contrast, drones can autonomously fly without ground support, quickly respond, and adjust their altitude and position as needed to ensure signal coverage in complex terrains or communication blind spots. Current research on drone base stations primarily focuses on the joint optimization of deployment locations and resource allocation to improve network service performance. However, challenges remain in accurately simulating real post-disaster scenarios, as simulations often fail to reflect the complexities of such environments, thereby hindering realistic optimization of drone trajectories. Moreover, traditional optimization methods can only optimize drone trajectories for specific scenarios and are inadequate for addressing trajectory optimization in dynamic environments.

In response to the aforementioned issues, this paper establishes a dynamic post-disaster scenario to improve network coverage and energy efficiency of drones by investigating the trajectory and resource allocation strategies of drone base stations. Additionally, within the context of vehicular networks, the paper designs an embedded multi-agent proximal policy optimization algorithm aimed at maximizing V2I link capacity and V2V link capacity while minimizing latency.

The main research content and innovations of this paper are as follows:

To address the trajectory optimization problem of drone base stations in dynamic scenarios, a mobile trajectory strategy for drone base stations is proposed to ensure coverage of ground mobile users, while also considering the issue of service fairness among users. The goal is to enhance the quality of service (QoS) for users. A scenario is designed where a fleet of drone base stations provides uplink services to multiple randomly moving ground users in an emergency communication setting, simulating a realistic post-disaster environment. In this scenario, a problem is formulated to maximize the coverage and service fairness for all ground users, jointly optimizing the 3D trajectories of the drone base stations and system fairness. However, the formulated optimization problem is non-convex, and to solve it, this paper proposes a deep reinforcement learning algorithm based on artificial intelligence techniques. Extensive training and testing were conducted, with results demonstrating that the algorithm converges effectively across different drone scenarios. The generalization tests further indicate that the trained network can effectively guide drone movements

under varying objective functions and scenarios with different levels of randomness.

To address the issue of limited energy in drones, this paper proposes an energy-efficient trajectoryand resource allocation strategy for a fleet of drone base stations, aiming to enhance energy efficiency and extend service duration. This study builds on the previous research, first defining an energy consumption model for drones, which includes three components: communication energy consumption, flight energy consumption, and hovering energy consumption. An optimization problem is formulated to maximize communication coverage while minimizing energy consumption, with the objective of optimizing drone trajectories to achieve these goals while ensuring coverage for ground users. The formulated optimization problem remains non-convex, and to solve it, this paper introduces a deep reinforcement learning (DRL) algorithm based on artificial intelligence techniques. Extensive simulations show that the proposed DRL algorithm outperforms three baseline methods. Additionally, experiments with different objective functions validate the effectiveness of the energy consumption minimization objective.

To address the uncertainty in communication resource allocation caused by the dynamic nature of vehicular networks, this paper proposes a deep reinforcement learning approach that utilizes shared resource blocks (RBs) between V2V and vehicle-to-infrastructure (V2I) communications. The objective is to minimize interference with V2I links while ensuring optimal vehicle-to-vehicle (V2V) performance. The study investigates a 5G cellular base station servicing multiple vehicles in a highway V2V unicast communication scenario. To select the optimal frequency bands and transmission power levels for each V2V link, the goal is to minimize interference with all V2I and other V2V links while preserving sufficient resources to meet latency constraints. This leads to the formulation of an optimization problem that seeks to maximize V2I link capacity, V2V link capacity, and minimize latency simultaneously. To solve this non-convex optimization problem, we propose a multi-agent proximal policy optimization (MAPPO) algorithm based on deep reinforcement learning. To accelerate the training of the deep reinforcement learning network, we integrate an embedding module to simplify and compress the input dimensions. By employing our embedded-MAPPO (E-MAPPO) algorithm, agents collaboratively optimize their transmission strategies to efficiently share the spectrum with V2I links. Simulation results demonstrate that our approach significantly reduces interference to V2I links while meeting the strict latency and reliability requirements of V2V communication, outperforming baseline methods.

審査結果の要旨

本研究では、災害時における UAV（Unmanned Aerial Vehicle）を用いた通信性の確保やモビリティネットワークの最適化において、強化学習の一つである PPO（Proximal Policy Optimization)をマルチエージェント化した MAPPO を用いてその効率を高めることを目的とする。災害時の避難経路誘導や外界との通信には携帯電話の接続性確保が重要である。しかし、電波塔の倒壊や局所的な利用者の集中等で、意図しない通信性能の低下や通信不可の環境に利用者が陥る可能性がある。そこで、UAV を電波中継基地とし、MAPPO を用いて利用者の分布に従って UAV の配置を最適化した。従来の研究では UAV の電波カバー範囲のみが議論されてきたが、本研究では UAV が消費するエネルギーにも着目し、カバー範囲、均等性、エネルギー消費を目的関数とすることでより現実に即した最適化を可能とした。さらにこの MAPPO を発展させ、高速道路や多くの自動車の行き交う都市部において自動車のモバイル通信環境最適化へ適用した。この際、マルチエージェントでの行動評価（Critic）を集中評価にするとともに、Actor-Critic のネットワーク間に次元数を削減して処理を高速化する "Embedded Layer"を挿入することで、大規模計算の高速化を可能とした。

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