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Reinforcement Learning-based Optimization of Radio Resource Management and Trajectory Planning for Smart UAV Wireless Networks

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Thesis outline

This thesis develops a UAV-based wireless network to support new applications for future smart cities. Precisely speaking, our work here focuses on deploying UAVs to build an emergency wireless communications network for post-disaster surveillance and rescue operations. This system should be deployed as fast as possible to collect information from the post-disaster area in order to save precious human lives. Taking into consideration the paralysis of the cellular wireless network besides the energy supplies in the post-disaster area, UAVs have to accomplish two essential tasks. Firstly, it should collect pivotal information for the victims and the infrastructure in the post-disaster area using attached high-definition cameras. The collected data can be further analyzed by the disaster management center to identify victims' exact location, number, age, gender, and injury status. Also, it can estimate the infrastructure damage caused by this natural disaster. Secondly, with respect to the paralysis of the cellular wireless network, UAVs should design and optimize their flying trajectory to maximize the number of served victims in the post-disaster area. The collected data from those victims is considered vital in facilitating rescue operations.

However, there are a bunch of issues that need to be figured out to realize these kinds of UAV wireless communication networks. Firstly, due to the persistent increase in demand for mobile services, spectrum resources are becoming more and more scarce. Therefore, it is expected that future mobile networks will host modern communications technology that supports unsurpassed networking architecture and energy-efficient devices. To realize these novel concepts, new fundamental challenges have appeared on the surface. Unlike wired communications systems, due to national spectrum regulations and hardware limitations, the wireless world has limited links to distribute. Consequently, it will be mandatory for the traditional regulation of the spectrum to have a fundamental reform so that it can allow more efficient use of spectrum resources. Spectrum inefficiency has become a major concern; hence it is imperative to search for an effective solution to deal with the resource allocation problems from the spectrum point of view. Secondly, keep in mind that the cellular wireless infrastructure in the disaster area might not be functional or even might be ravaged after the disaster. Also, what makes the situation even more complicated is the paralysis of the power supply transmission lines after the disaster occurrence. Hence, with respect to the spectrum scarcity problem, our UAV emergency wireless communication system is deployed as a cognitive radio system that shares spectrum resources with another network. In other words, our system deployed as a dynamic spectrum access system which is considered a promising solution for the spectrum scarcity problem. Then, aiming to maximize the collected data by maximizing the number of the served victims in the post-disaster area under this extreme lack of energy resources, UAVs should carefully plan for their trajectory in accordance with these limited resources. To this end, this thesis introduces novel techniques to tackle these kinds of optimization problems which are constrained by the limited resources due to the post-disaster environment. The following parts of this thesis can be summarized as follows:

Chapter 2: *Reinforcement learning Applications for Smart UAV Wireless Networks*

- Surveys different machine learning techniques and highlight reinforcement learning algorithms.
- Introduces general problems that face implementing UAV wireless communications networks.
- Shows related works that included reinforcement learning algorithms to tackle different optimization problems related to wireless communication networks.

Chapter 3: *Reinforcement Learning-based Dynamic Spectrum Access System in Smart UAV Wireless Networks*

- Studies the implementation of UAV emergency wireless communication network as a cognitive radio network. This idea is introduced as an unconventional solution for the spectrum scarcity problem.
- Two MAB-based algorithms are implemented to study how to select the most suitable power to signal transmission. On the other hand, it should keep an eye on the interference threshold to the primary network.

* The results of Chapter 3 are published in:

1. **A. Amrallah**, E. M. Mohamed, G. K. Tran, and K. Sakaguchi, "Resource Allocation Based on Multi-Armed Bandits for Dynamic Spectrum Access System," *IEICE Technical Report; IEICE Tech. Rep.*, vol. 119, no. 449, pp. 87–92, 2020.
2. **A. Amrallah**, E. M. Mohamed, G. K. Tran, and K. Sakaguchi, "Radio Resource Management Aided Multi-Armed Bandits for Disaster Surveillance System," *in Proc. 2020 International Conference on Emerging Technologies for Communications (ICETC2020), Virtual*, K1-4, 2020.
3. **A. Amrallah**, E. M. Mohamed, G. K. Tran, and K. Sakaguchi, "Enhanced Dynamic Spectrum Access in UAV Wireless Networks for Post-Disaster Area Surveillance System: A Multi-Player Multi-Armed Bandit Approach," *Sensors*, vol. 21, no. 23, p. 7855, 2021.

Chapter 4: *Reinforcement Learning-based Trajectory Optimization in Smart UAV Wireless Networks*

- Studies the trajectory optimization for the UAV that supports emergency wireless communication networks in a post-disaster area.
- Implements a MAB trajectory optimization algorithm to maximize the offloaded data from trapped victims in the post-disaster area via maximizing the number of the served users. The whole optimization problem is constrained by the limited available energy for both the UAV and the victims.

* The results of Chapter 4 are published in:

1. **A. Amrallah**, E. M. Mohamed, G. K. Tran, and K. Sakaguchi, "Dual Energy-Aware Based Trajectory Optimization for UAV Emergency Wireless Communication Network: A Multi-Armed Bandit Approach," in *2022 Thirteenth International Conference on Ubiquitous and Future Networks (ICUFN)*, pp. 43–48, IEEE, 2022.
2. **A. Amrallah**, E. M. Mohamed, G. K. Tran, and K. Sakaguchi, "UAV Trajectory Optimization in a Post-Disaster Area Using Dual-Cost-Aware Bandits," *Sensors*, vol. 23, no. 3, p. 1402, 2023.
3. **A. Amrallah**, E. M. Mohamed, G. K. Tran, and K. Sakaguchi, "Optimization of UAV 3D Trajectory in a Post-disaster Area Using Dual Energy-Aware Bandits," Submitted to *IEICE Communications Express (ComEX)*.

Chapter 5: *Final Remarks and Future Work*

This Chapter concludes the thesis and shows the future directions to extend the presented work.