NSF CPS Career: Robust Optimization and Reinforcement Learning for Multi-agent EV Charging Systems under High Uncertainties

1 Project Summary

1.1 Overview

Electric vehicles (EVs) are increasingly recognized and adopted as a clean and effective transportation solution. However, developing a reliable charging network faces significant real-world challenges including both physical and cyber layers: 1) complex uncertainties: uncertainties arise from multiple interdependent networks, some of which are decision-dependent (DDU), and it is hard to obtain true probability distribution functions (PDF); 2) operational safety concerns: power grid operational constraints and EV charging and task completion constraints are hardly included in current reinforcement learning models; 3) computation scalability: the increasing number of EVs leads to an increased problem size and makes it hard to solve in real-time. The continuously evolving conditions as well as safety constraints further complicate the issue. **The overarching goal of this project** is to provide the theoretical and computational foundation that will allow scalable, robust and safe planning and management of EVs. This is an essential part of the PI's long-term career goal of realizing 100% transportation electrification. The PI's **educational goal** is to become an outstanding educator who can engage junior students to develop interdisciplinary expertise, and promote general understanding of optimization and machine learning in cyber-physical systems.

1.2 Intellectual Merit

The proposed project will advance research in EV charging infrastructure management and more broadly, multi time-scale decision-making in highly uncertain and interdependent systems by developing robust and dynamic optimization and reinforcement learning models and algorithms. To address the DDU and unknown PDF in the planning problem, we propose to develop two-stage distributionally robust optimization algorithms that incorporate complex uncertainties and detailed modeling of decision-dependent electricity and traffic demand. To tackle the challenges of operational safety issue, we propose to leverage the gradient information of all the operational constraints and add a backtracking mechanism added into the policy learning framework to perform a final verification of feasibility. To address the computation issue, we propose to develop multi-agent reinforcement learning algorithms which are distributed trained and executed, provide computationally efficient solutions that protect the privacy of each agent.

1.3 Broader Impacts

The theoretical models and operational tools proposed in this project will generate new value streams for large uncertain integrated networks collaborated planning and operation and encourage the transportation electrification. The experience gained through optimization and reinforcement learning algorithm development will provide valuable guidance to policy makers, electric utilities and fleet operators in managing large number of EVs. The proposed tools can be directly utilized by the university (UA) for the electric bus fleet management, by the vehicle manufactures (MBUSI) to understand long-term charging infrastructure scope, and local government and utilities (Alabama Power) to advance EV adoption. The PI plans to develop one new interdisciplinary course "Introduction to Planning and Management of Transportation Electrification" based on this project for both undergraduates and graduates major in engineering and related areas. The PI will work with the DEI Division at UA to bring more women engineers and underrepresented populations to STEM education. The PI will also utilize the resources of the local summer camp program in UA to engage high school students through dynamic hands-on activities, open-lab day, and developed educational platform, enhancing their enthusiasm for STEM subjects.