CPS: Small: Collaborative Research: Models and System-Level Coordination Algorithms for Power-in-the-Loop Autonomous Mobility-on-Demand Systems

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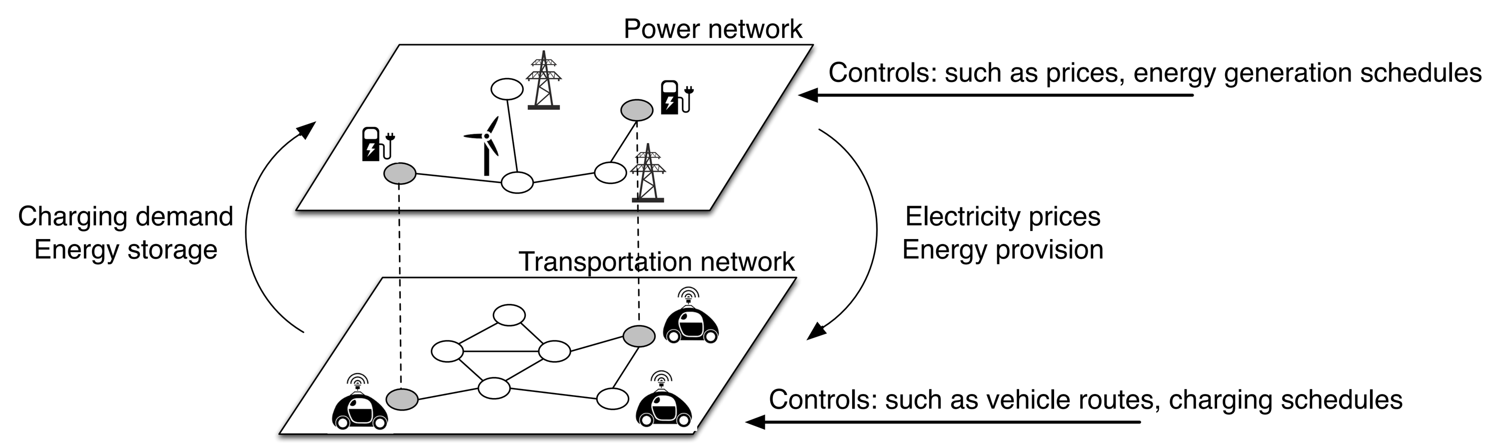
Project focus

Our goal is to devise computational methods for the optimal coordination of autonomous mobility-on-demand (AMoD) systems, with a central focus on accounting for the couplings between the power and transportation networks.

AMoD: similar to an "Uber" system, but with self-driving, electric vehicles

While providing mobility services, these electric vehicles could also act as mobile storage devices, providing a support mechanism for integration of intermittent renewable energy resources and relieving congestion in energy distribution networks



We plan to synergistically integrate and extend algorithmic techniques for vehicle routing, electricity demand management, power system optimization and market operation, and multi-agent system coordination in order to generate novel systematic tools for the modeling, analysis, and receding horizon control of power-in-the-loop AMoD systems.

Broader impact on society:

- AMoD has the potential to reduce the cost of travel and commute times, provide sustainability benefits such as increased overall vehicle utilization, reduce demand for urban parking infrastructure, and reduce pollution.
- Coupling AMoD with the energy infrastructure could yield additional sustainability and fuel cost reduction benefits.
- The results of this work can lead to insights on managing coupled infrastructure systems.
- Our results can also advance the knowledge base in the related fields of vehicle routing, game theory, and multi-agent system theory, which will have broad applicability to several other types of cyber-physical systems, from automated delivery and logistics with robotic vehicles, to human-robot teams for environmental monitoring and exploration.

Technical challenges

Objective 1: To generate methods for the analysis of P-AMoD systems. We will generate models and methods to analyze {P-AMoD} systems at a variety of spatio-temporal scales (i.e., from operational control to long-term strategic planning) and for a variety of possible infrastructures, e.g., multiple transportation service operators (TSOs), cooperative versus competitive interactions among TSOs, etc. Our tasks will devise:

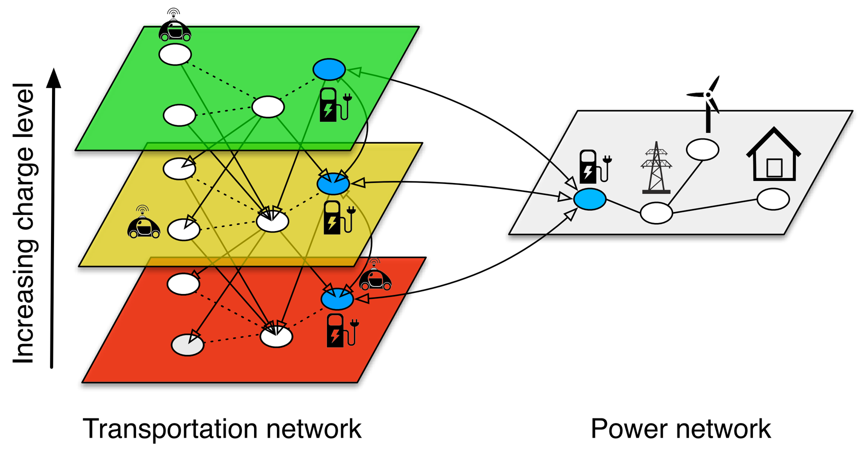
- Appropriate traffic and power system models
- Data-driven model learning and predictions

Objective 2: To generate methods for the system-level control of P-AMoD systems. By relying on receding horizon control and appropriate coordination and pricing mechanisms, we will devise system-level algorithms for the control of P-AMoD systems. The algorithms will account for the potentially conflicting objectives of the service operators involved, as well as the stochasticity and price elasticity of passengers' demand and energy provisions. We plan to study:

- Centralized model-predictive control of P-AMoD systems
- Controlling decentralized P-AMoD systems via pricing and taxation
- Controlling de-centralized P-AMoD systems via regulation
- Placement of charging stations and infrastructure upgrades

Objective 3: To validate models and algorithms, and assess the economic and societal impact of P-AMoD systems. Through case studies based on operational data, we will characterize the performance of the models and algorithms from Objectives 1 and 2, and assess the economic and societal impact of P-AMoD systems. Also, we will develop a routing and charging management tool for large-scale P-AMoD systems. We will validate our results through:

- A realistic case study of San Francisco Bay Area
- Integration of P-AMoD with renewable energy generation at a microscopic scale
- Routing and charging management tool for P-AMoD systems to effectively support the control of a large-scale ($>50,000$ vehicles) P-AMoD system

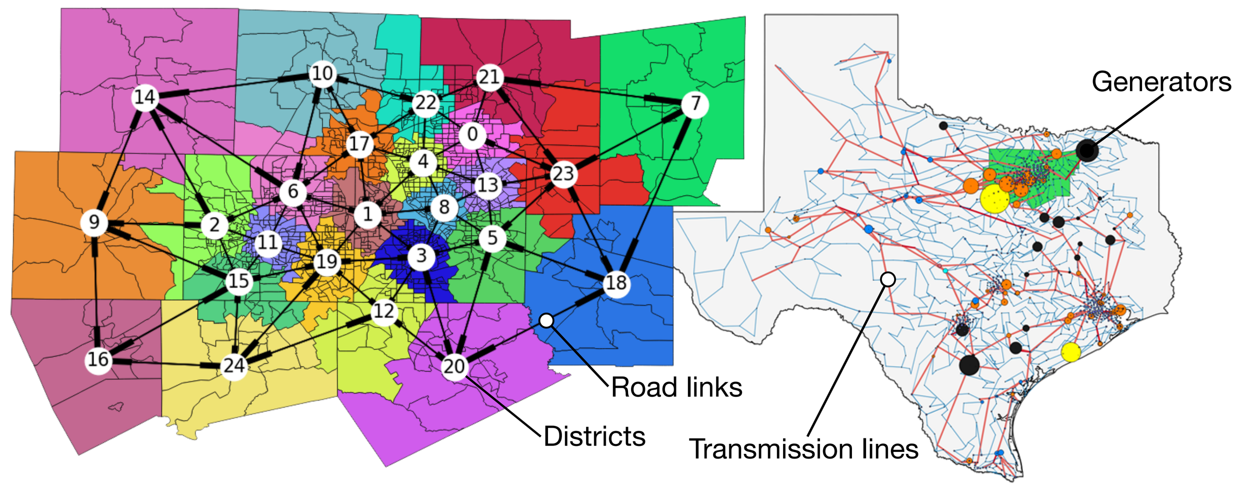


Broader impact (education and outreach):

Our efforts include:

- Integration of research in courses: The PI will integrate results and insights from this project into her graduate course on network resource allocation as well as her undergraduate class on the principles of optimization
- Partnership with the EUREKA program at UCSB, which is focused on introducing underrepresented freshman students to the broader science community on campus and providing exposure to research through academic year internships.
- The PIs will organize workshops at premier controls and robotics conferences to disseminate the results about P-AMoD systems and promote a discussion about the related research challenges and societal benefits.

Quantifying the Potential Societal Impact of P-AMoD:



F. Rossi, R. Iglesias, M. Alizadeh, and M. Pavone, "On the interaction between Autonomous Mobility-on-Demand systems and the power network: models and coordination algorithms", under review.

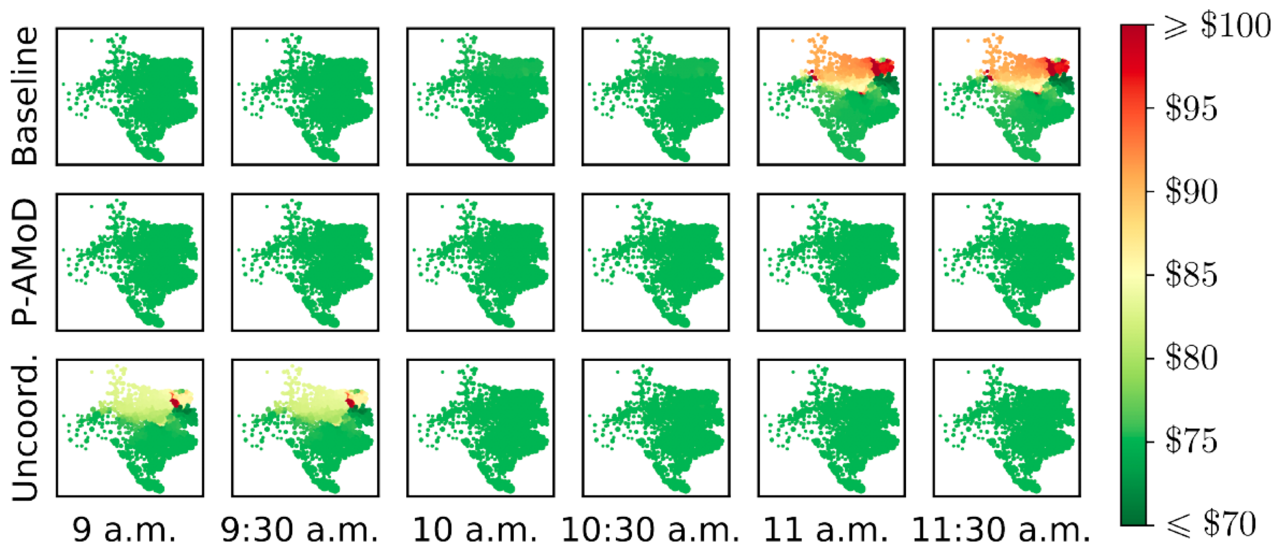


Figure 4. LMPs in Texas between 9 a.m. and 11:30 a.m. The presence of the AMoD fleet can reduce locational marginal prices; coordination between the TSO and the ISO can yield a further reduction. A battery replacement cost of $1 573 is considered.

- The average price of electricity in the P-AMoD case is 2.37% lower than in the uncoordinated case in the Dallas-Fort Worth area (corresponding to an annual savings of $147M for electricity customers, excluding the TSO).
- The energy expenditure of the TSO in the P-AMoD case is 44% lower than in the uncoordinated case (a saving of $180k per commuting cycle, corresponding to close to $90M/year).

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