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CAREER: Hierarchical Control for Large-Scale Cyber-Physical Systems

PI: Prof. Wei Zhang

Dept. of ECE

Ohio State University

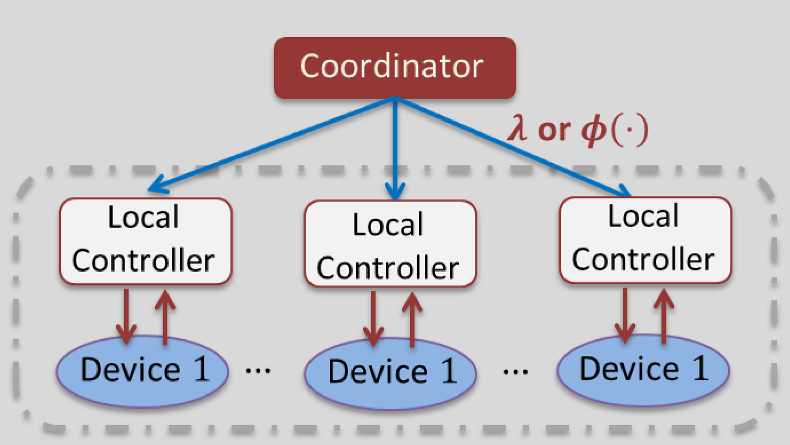
❑ Background

- Large population of agents
- Decoupled static or dynamic models
- Coupled decision due to shared environment/resources
- Often involve human decision makers

Fundamental Question

How to design control strategies to achieve a desired population objective while respecting local preferences and constraints for individual agents?

❑ Hierarchical Control Architecture



Research Challenges

- information structure
- rationality assumption
- agent dynamics
- population dynamics

Individual Agents

- Local objectives depend on coordinator control signal
- Local control law respect local preferences/constraints

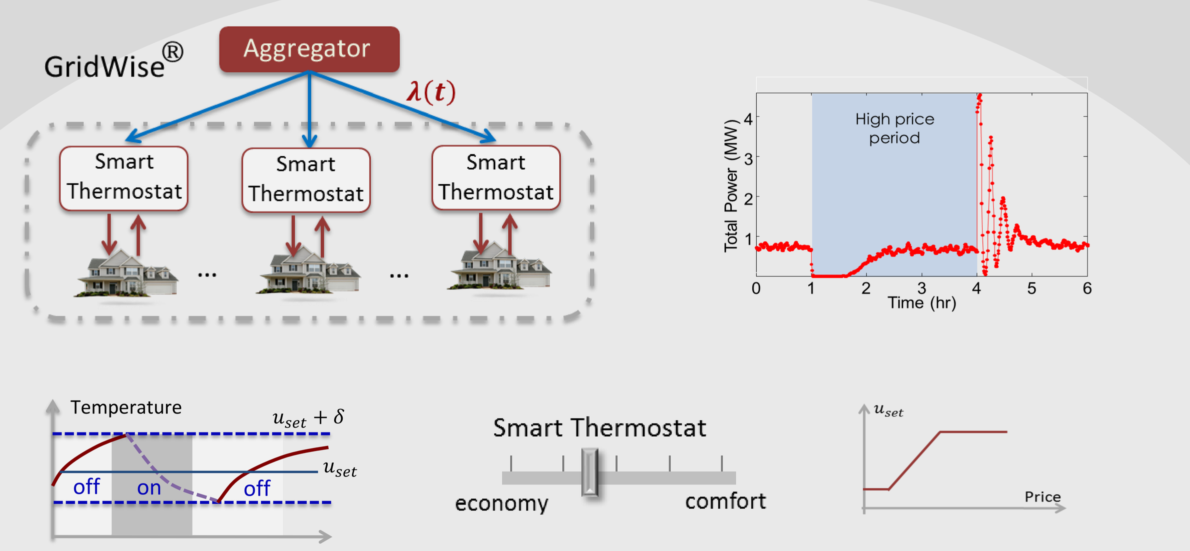
Coordinator's objective

- macroscopic control signal/rules
- steer aggregated population behavior

❑ Proposed Two Paradigms for Hierarchical Population Control

Paradigm I: Hierarchical population control with nonstrategic agents (HPCN)

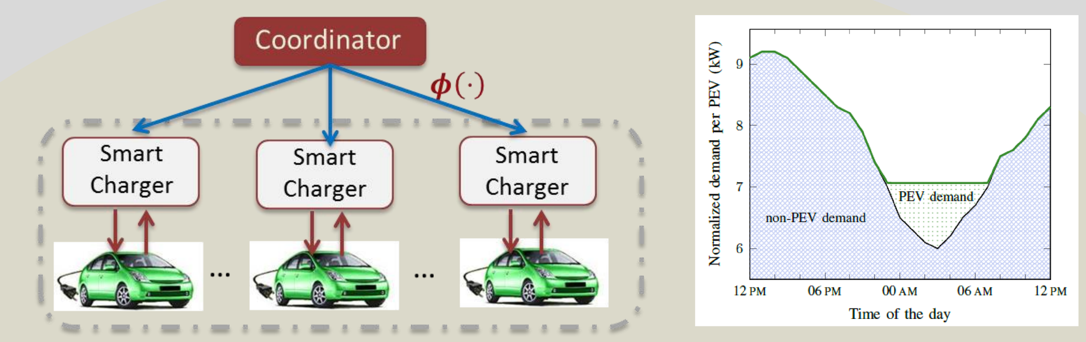
Predefined local control law with user specified parameters



- Simple agent dynamics and local response logics
- But complex population dynamics

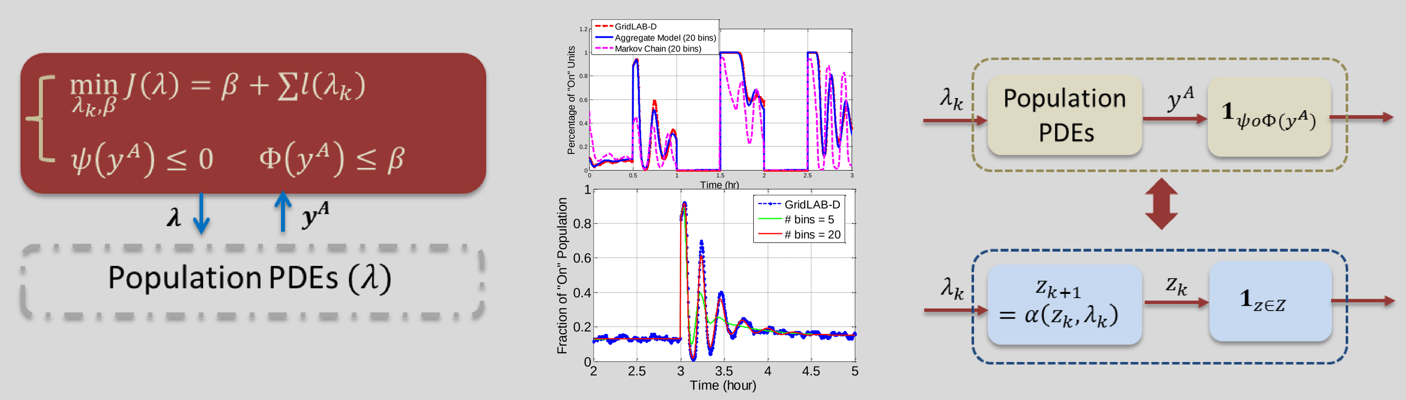
Paradigm II: Hierarchical population control with strategic agents (HPCS)

Agents strategically optimizes utility functions coupled through coordinator's rule



- Electricity price depends on total demand
- The coupling price induces a game among all strategic agents
- Most works focus on analysis of the mean field equilibrium for a given game without evaluating the equilibrium

❑ Preliminary Results and Proposed Research



- Developed a unified hybrid system model for individual agent dynamics under local response rules
- Developed a stochastic hybrid system model to capture population dynamics

- This project will further study general HPCN Problem: **Optimization problem with PDE Constraints**
  - Coupled PDEs & complex boundary conditions
  - Develop novel abstraction based framework

❑ Preliminary Results and Proposed Research

Our contribution: Identify an important class of mean-field games for which

- mean field equilibrium is socially optimal
- social optimal solution is ϵ-Nash
- Computing mean-field Nash is convex optimization

- This project will further study general HPCS Problem: **Uniform price mechanism design for large population**
- Develop uniform price mechanism framework for large population of dynamic agents via ϵ-Nash equilibrium
- Theoretically sound + numerically tractable

❑ Scientific Impact

- Advance scientific and engineering foundations for large scale CPS
  - Abstraction for hybrid systems, stochastic hybrid systems theory, mean-field game theory, mechanism design, Stackelberg games, bi-level optimization

❑ Broader Impact:

- Provide design principles and algorithms for real world CPS
  - Smart power grid: DER coordination for renewable integration (collaboration with Pacific Northwest National Laboratory)
  - Intelligent transportation (collaboration with the Smart City initiative at Columbus)