Mechanism Design for Strategic Multi-Agent CPS

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Motivation

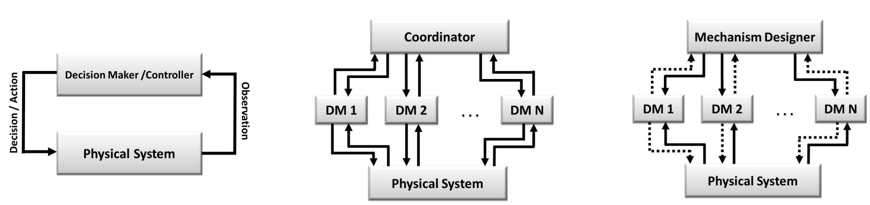
The originally developed CPS framework aims to address systems with the familiar diagram as in figure (1a), where the overall system consists of many components of different nature (*e.g.* discrete, and continuous) and captures the interaction of a physical system and a controller/decision maker(DM).

However, figure (1a) does not present a generic model of many emerging CPSs where the information and actions are decentralized and distributed among different DMs/controllers across the whole system. Such decentralized systems are now widespread in transportation, communication, and energy applications. In these systems each DM has its own observations and takes its own actions. The key feature of such systems, depicted in figure (1b), is that there is no central entity that has all information and takes all actions across the whole system. For such systems, the challenge is to determine a communication language and decision rules/control laws for agents so as to optimize some performance metric associated with the physical system's operation.

Even though the model in figure (1b) is more general than that of figure (1a), it still does not capture all modern CPSs. The model in figure (1b) assumes that all agents share the same goal, behave as a team and cooperate with one another. In many present day multi-agent CPSs each agent has its own private information and its own individual interest/objective. Electricity grid with revenue maximizing energy providers, computer networks with strategic servers, and transportation systems with selfish drivers are examples of such systems. In such systems, as in figure (1c), agents are strategic and do not have to follow the rules for communication and decision making/control proposed by the system designer. Instead, they have to be incentivized to follow the system designer's rules (dashed arrows). CPSs with strategic agents possessing asymmetric information motivate the research proposed in this position statement.

Proposed Research

In this position statement we present an approach to address systems as in figure (1c). We use game theory and theory of incentives along with decentralized stochastic control to address CPSs with strategic agents. We study different classes of models, design the optimal incentives/decision rules for these models and determine when it is possible to



(a) (b) (c)

Figure 1: Schematic diagrams of CPS

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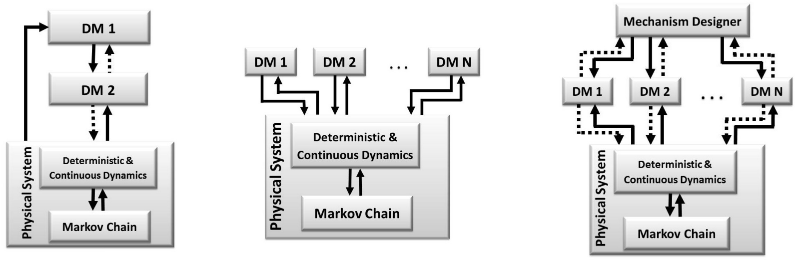

(a) (b) (c)

Figure 2: Proposed models

achieve the same optimal performance as in the corresponding models with cooperative agents. In all of the following models we assume that the physical system consists of two components: a discrete Markov chain that determines the mode in which the physical system operates, and a component with continuous dynamics that captures the evolution of the physical system in that mode. We propose to investigate models that are motivated by applications discussed in the section on potential impact, and capture fundamental conceptual issues associated with the operation and performance of CPS with strategic agents possessing asymmetric information. These models are:

- (*i*) A 2-agent system, where each agent has private information and observations as in figure (2a), and agent 1 seeks to induce agent 2 to behave in a desired way (a design problem for one agent).
- (*ii*) An N-agent system as in figure (2b), where the objective is to compare the system performance achieved when the agents are strategic to the system performance attained when the agents are cooperative (an analysis problem with N agents).
- (*iii*) An N-agent system as in figure (2c), where the goal is to design a mechanism to achieve the best possible performance when the agents are strategic (a design problem for N agents that incorporates ideas from (*i*) and (*ii*)).

Potential Impact

Within the context of CPS, the proposed research will reveal connections between the theory of decentralized stochastic control on one hand and the theory of incentives and game theory on the other hand. Furthermore, the proposed models for CPSs with strategic agents capture key fundamental problems/issues associated with the operation and performance of these systems. The solutions to these models along with the connections between stochastic control and theory of incentives will provide guidelines on how to achieve efficient designs in real world CPSs with many strategic DMs. The results will have broad applications; some of the immediate applications are: (a) By using model (*i*), we will be able to formulate and solve the problem of policy design for the electric grid's independent system operator who wants to induce the optimal usage of renewable energy resources by a generator. (b) By using model (*ii*), we will be able to assess the performance of dynamic pricing in electricity markets where individual demand and/or generator on the grid respond to a price signal, the state of the network and transmission lines are captured by a Markov chain, and electricity flow equations (*Kirchhoff*'s laws) are captured by a continuous component. (c) By using model (*iii*), we can capture the problem of optimal navigation for traffic control where each car on the road is operated by a strategic driver with its own utility, the roads' *phase* (*e.g. congestion* or *free flow*) is captured by a Markov chain and *traffic flow* is captured by differential equations (continuous component).