Modeling and Managing Uncertainty in CPS Energy Systems

CPS energy systems show up in a large number of societal applications from smart energy grids, smart buildings to geographically distributed data centers. Each of these applications struggle with parametric uncertainty as its fundamental modeling and prediction challenge: supply and/or demand of energy, workload certainties across time or across geographic locations etc. Many algorithmic strategies have been devised to address such uncertainties from statistical models (or energy use, electricity pricing etc) to online algorithms workload deferral in case of data centers, and various sensing solutions (such as occupancy sensing) to reduce uncertainty in smart buildings, to policy mechanisms for managing integration of electric vehicles to the smart grid. As computation migrations across mobile and cloud platforms, unfortunately the challenge of workload modeling, energy availability, storage capacity is magnified especially in case of applications that have more diverse needs in latency and responsiveness. In this discussion, we will examine the nature of uncertainty in CPS energy systems, commonly deployed strategies, especially those that provide tight regret or competitive ratio bounds using sophisticated online algorithms. Until recently, uncertainty estimation has been a province of statistical analysis methods: methods that make a reasonable guess or a posteriori assessment of likelihood estimates to build elaborate mathematical structures and reasoning tools for predictive modeling of important system parameters. Such analysis inherently assumes mathematical niceties that are not readily justified in modern cyber-physical systems where transient behavior dominates ruling out steady state or even stationarity. Going forward, I see innovations in uncertainty reduction through augmented sensing, runtime model buildings and combinatorial analysis. For instance, our work has shown that, by incorporating physical models – such as nature of timing drifts in crystal oscillators – the quality of combinatorial bounding can be improved (from worst case competitive ratio scenarios). These results point to the exciting possibility of advancing and applying complexity theory to advance estimation quality in discrete event systems. Complexity theory provides a mathematical foundation for computer science as differential equations provide a mathematical foundation for the physical sciences. It goes beyond merely enumerative exploration of exact combinatorial solutions: it has been used to understand phenomena from disciplines such as biology and economics, both plagued by phenomenal uncertainties. All that is needed is the ability to model processes as computer simulations. Then, for instance, the complexity of equilibria determination provides a lower bound on the time to reach equilibria. Going forward, we can expect methodological possibilities to incorporate increasingly sophisticated models of cyber-physical interactions (temperature effects, drifts, variability) in a combinatorial reasoning framework. We hope to seed such a discussion as a potential fundamental advance in CP energy systems.

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