Secure Demand Shaping for Smart Grid

On constructing probabilistic demand response schemes with the tools of game and control theory

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The increasing usage of sensor-actuator networks by NCS/SCADA systems raises significant concerns about privacy. Developing novel schemes for *demand response in smart electric gird* is an increasingly active research area. These schemes aim to control/flatten demand curves and shift consumption times to the off-peak periods, which allows to to improve efficiency. Indeed, higher volatility of user demand results in higher average distributor's expenses on wholesale electricity which creates upward pressure on retail prices. In addition, high volatility of residential demand for electricity posits a considerable problem for stability and efficiency of electric grid. Altogether, these reasons have resulted in a long standing interest in the ways to reduce demand volatility (and thus to lower average costs). This interest is especially strong now, as it is driven by the new capabilities of advanced metering infrastructures (AMI) and Smart Utility Networks (SUN).

While theoretically AMI/SUN enable the design of real-time pricing mechanisms, in practice, several complications arise in terms of implementation. Firstly, various studies on risk preferences of users indicate that users prefer flat rate pricing, and are even willing to pay a premium to avoid being charged a non-flat price for energy usage. Moreover, residential users show low responsiveness to price signals. Secondly, the transmission of (disaggregated) user demand data to a distributer may causes substantial privacy concerns, and the two-sided real-time communication between the distributer and the users introduces numerous insecurities. For e.g., the information (demand data) from smart meters of individual households to central dispatch (distributor) could be falsified, corrupted or suppressed. Moreover, even when the actual demand data reaches the distributor uncorrupted, the pricing information could be altered maliciously. Such insecurities could even induce network instability. Yet, with increasing wholesale price(s), and predictions of further price escalation, distributors are experimenting with tiered pricing models. Thus NCS/SCADA for demand response in smart infrastructures face the following dilemma: On one hand, in order to increase the efficiency of electricity provision, user prices

should reflect the scarcity of electricity. On the other hand, fairness, privacy and security considerations limit the usability and attractiveness of real-time pricing for retail electricity.

To mitigate these considerations, we suggest a novel class of schemes of reducing the volatility of residential energy demand by building on the insights from economics of public goods [1], i.e., by viewing the user contributions to demand volatility as a public good. Our goal is to construct reward-based schemes that incentivizes users to shift their demand to off-pick times. The key feature such schemes is their relative simplicity (in comparison to other schemes which require the knowledge of how responsive the users are in shifting their demand from peak to off-peak times). Essentially, such schemes are based on a probabilistic reward structure for users who shift their demand to the off-peak times, and is robust to incomplete information about user demand and risk preferences. We demonstrate that such mechanisms can be implemented in a fully commercial setting via *lottery-like schemes*, which will require only a small outlay to design fully functional commercial prototype. In addition to its favorable privacy-preserving features, our approach is advantageous in the perspective of cyber-security. Lastly, such schemes could be used in conjunction with other existing demand response mechanisms (e.g., the time-of-day pricing).

References

[1] J. Morgan, Financing public goods by means of lotteries,Review of Economic Studies, vol. 67, no. 4, pp. 761-84, October 2000.