Demand Side Management with a Human Behavior Model for Energy Cost Optimization in Smart Grid

M Ghorbaniparvar, X Li, and N Zhou

Dept of ECE, State Univ of New York, Binghamton

Introduction

- Demand Side Management (DSM) : schedule energy consumption of the customers to optimize the cost.

- Benefits of DSM:
- 1- Reduce the Peak to Average Ratio (PAR)
- 2- Balance energy consumption

- Smart meters and HEMS can be applied to develop a more effective DSM scheme.

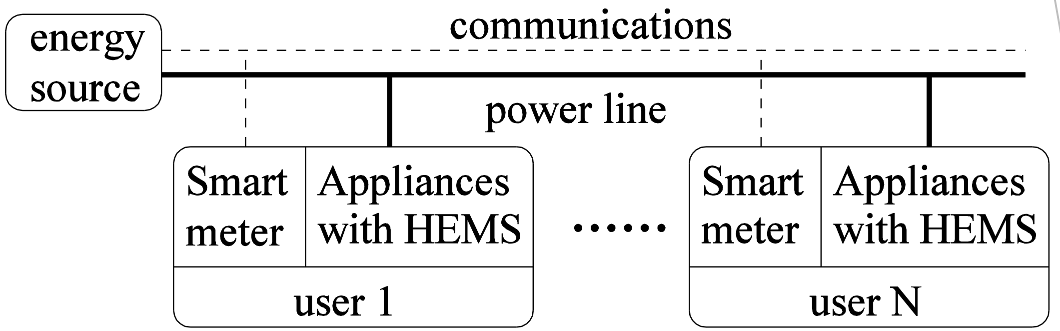
Problem

- A severe challenge to DSM is how to deal with complex human behavior.

- Example:
- 1- Customer may adopt the DSM scheme after a sustainability education.
- 2- Customer may leave the DSM scheme for convenience reasons rather than cost reasons

- We adapt a population dynamic model into DSM

DSM Model



- Consider:
- n = energy user
- N = total number of users
- a = appliance of an energy user, $a \in A_n$
- A_n = set of all appliance of user n
- Each appliance consumes energy $x_{n,a}(h)$
- where h is time, $h \in H$
- H = optimization time horizon

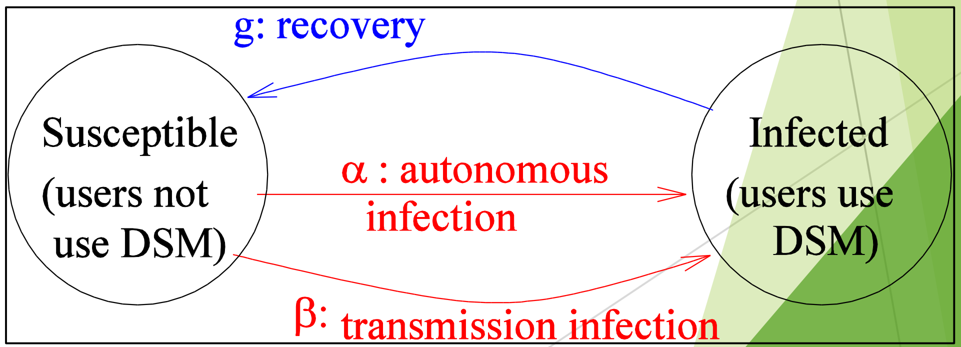
DSM Model

- Total energy usage is $\sum_{h\in H} L(h) = \sum_{h\in H}\sum_{n\in N}\sum_{a\in A_n} x_{n,a}(h)$
- Total cost of the system is $C(\mathbf{x}) = \sum_{h\in H} f_h(L(h)) = \sum_{h\in H} f_h\left(\sum_{n\in N}\sum_{a\in A_n} x_{n,a}(h)\right)$
- The DSM problem is to schedule and shift the energy usage profile ***X*** so as to minimize ***C(X)***.
- There are game theoretic algorithms for reaching the global minimum. But human behavior model has not been considered in these studies.

Adopting SISa Model for DSM User Behavior

- To model human behavior, we apply Susceptible-Infected-Susceptible with autonomous infection (SISa) model
  - Two groups of users: $S, I,$ where $S \subseteq N, I \subseteq N, S \cap I = \phi, S \cup I = N.$
  - User in S autonomously switches to ***I*** with probability ***a***
  - User in I infects user in S with probability ***β***
  - User in I switches back to S with probability ***g***
- At time ***t***, population size evolve as

$$\begin{cases} \frac{dS(t)}{dt} = -\beta S(t)I(t) + gI(t) - \alpha S(t) \\ \frac{dI(t)}{dt} = \beta S(t)I(t) - gI(t) + \alpha S(t) \end{cases}$$



Integrating SISa Model with DSM

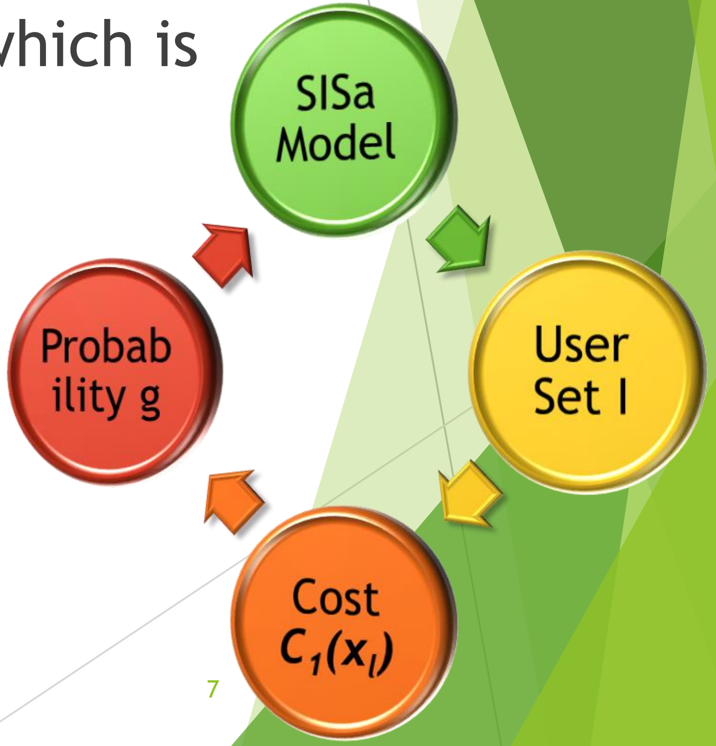
- SISa model changes DSM cost via user sets I and S
  - The larger the set I , and lower the cost

$$C_1(\mathbf{x}_I) = \min_{\mathbf{x}_I} \sum_{h \in H} f_h \left(\sum_{n \in I} \sum_{a \in A_n} x_{n,a}(h) + E_S(h) \right)$$

- DSM affects SISa model via recovery probability g which is a function of DSM cost, e.g.,

$$g(C_1(\mathbf{x}_I)) = \lambda C_1(\mathbf{x}_I) + \eta, \quad \text{or} \quad g(C_1(\mathbf{x}_I)) = \eta(1 - e^{-\lambda C_1(\mathbf{x}_I)})$$

  - The smaller the cost, the smaller the probability ***g***



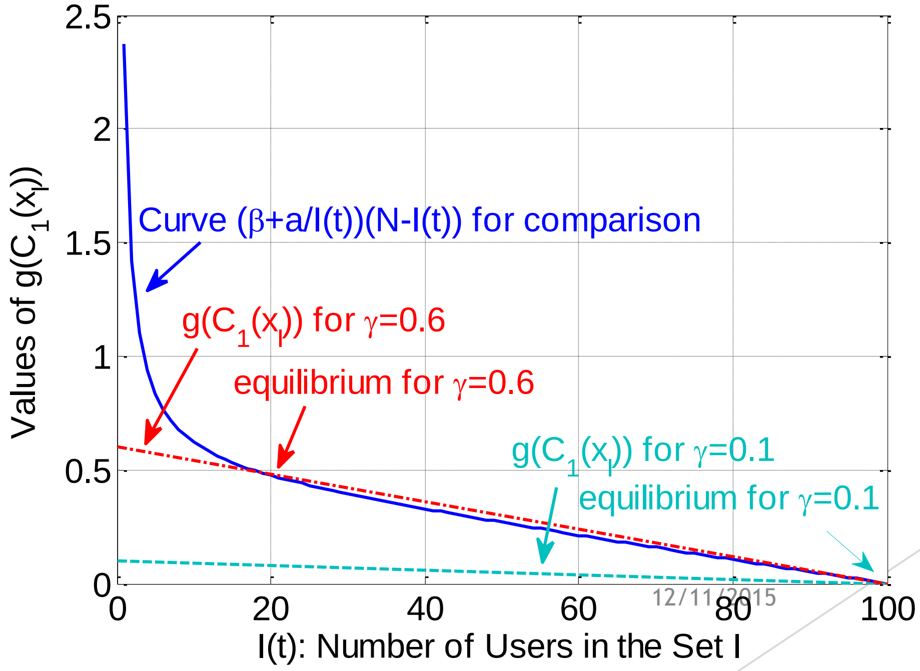
Convergence and Equilibrium

Analysis results: $g(C_1(\mathbf{x}_I)) \lessgtr (\beta+\alpha/I(t))(N-I(t))$ determines convergence

i) Desirable DSM: $I \to N$ if $g(C_1(\mathbf{x}_I)) < (\beta+\alpha/I(t))(N-I(t))$ for all I

ii) Undesirable DSM: $I \to \phi$ if $g(C_1(\mathbf{x}_I)) > (\beta+\alpha/I(t))(N-I(t))$ for all I

iii) Practical DSM: Equilibrium with $I+S=N, I \neq \phi, S \neq \phi,$ if else



Integrating SISa Model with Decentralized DSM

- Formulate game $\langle N, (x_n)_{n\in I}, (u_n)_{n\in I} \rangle$ with pay off function

$$u_n(\mathbf{x}_n, \mathbf{x}_{-n}) = -\sum_{h\in H} f_h\left(\sum_{a\in A_n} x_{n,a}(h) + \sum_{m\in N, m\neq n} L_m(h)\right)$$

- Best response strategy: $$\min_{\mathbf{x}_n} \sum_{h\in H} f_h\left(\sum_{a\in A_n} x_{n,a}(h) + \sum_{m\in I, m\neq n} L_m(h) + E_S(h)\right)$$
- This best response strategy can guarantee the convergence of the game to its Nash equilibrium that equals to the global optimum.

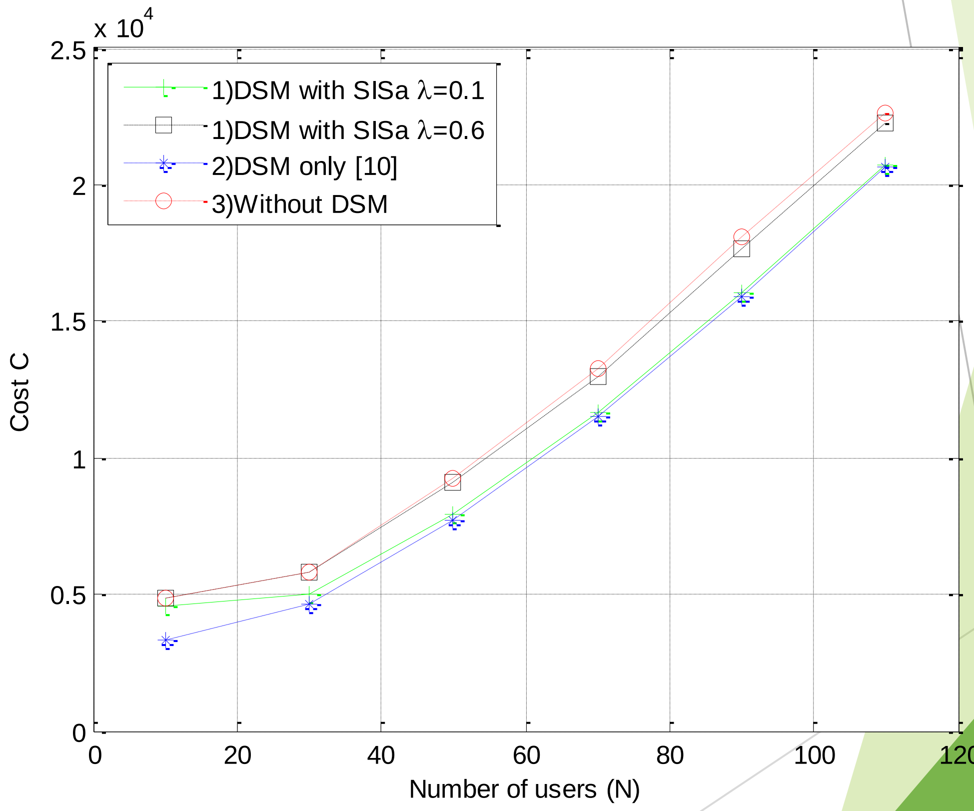
Simulation

- Parameters

- $f_h(t) = 0.3\ t^2$ day-time
- $f_h(t) = 0.2\ t^2$ night-time
- *$\beta = 0.005$, $\alpha = 0.019$ and $g(x) = \lambda x / C_{max}$*
- *Where C_{max} is highest cost*

Simulation

- Performance of centralized DSM schemes



- Initial condition:
- for our algorithm, I = Ø
- For algorithm in [10], I = N
- N = 10 to 110 users

[10] A.-H. Mohsenian-Rad, etc, “Autonomous demand side management based on game-theoretic energy consumption scheduling for the future smart grid,” *IEEE Trans. on Smart Grid*, Dec. 2010.

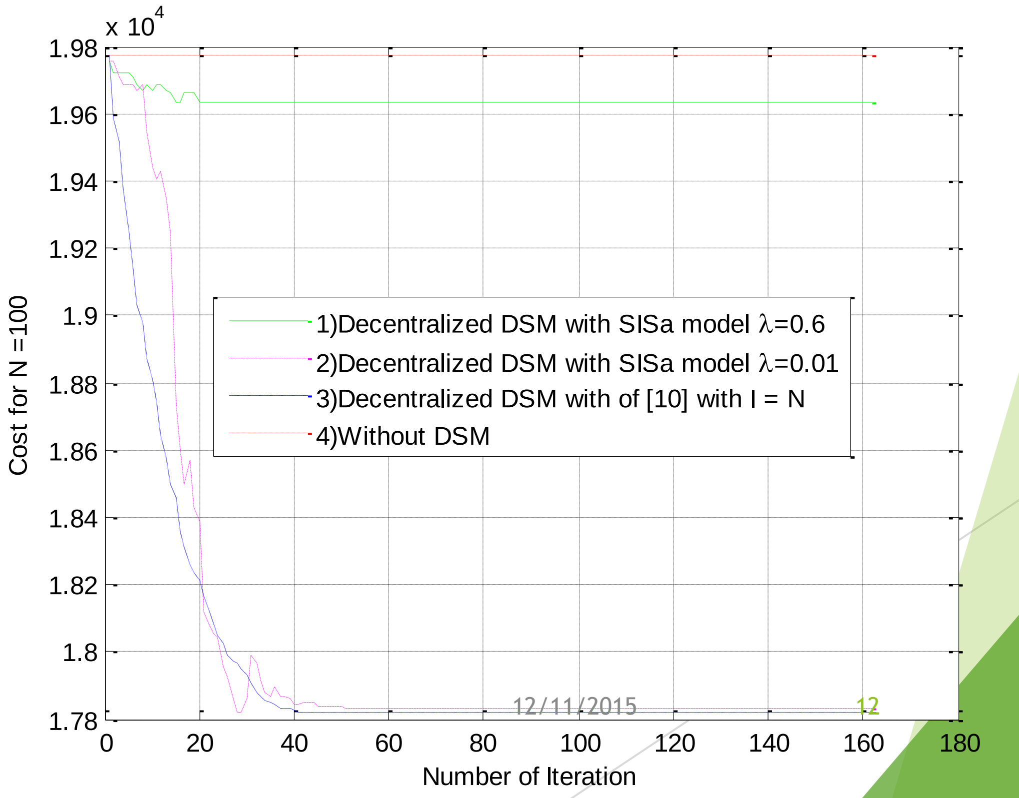
Simulation

- Convergence of decentralized DSM scheme.
- N = 100 users.
- Converge to global minimum

where N = I

- We can clearly see the

Impact of human behavior.



Conclusion

- To study the impact of human behavior to DSM, we adapt the SISa model into both centralized DSM schemes and decentralized game-theoretic DSM schemes.
- Convergence of model studied, which demonstrates the importance of addressing human behavior in DSM development.