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Living in a converged world - impossible without standards?

Distributed Demand-Side Management with Load Uncertainty

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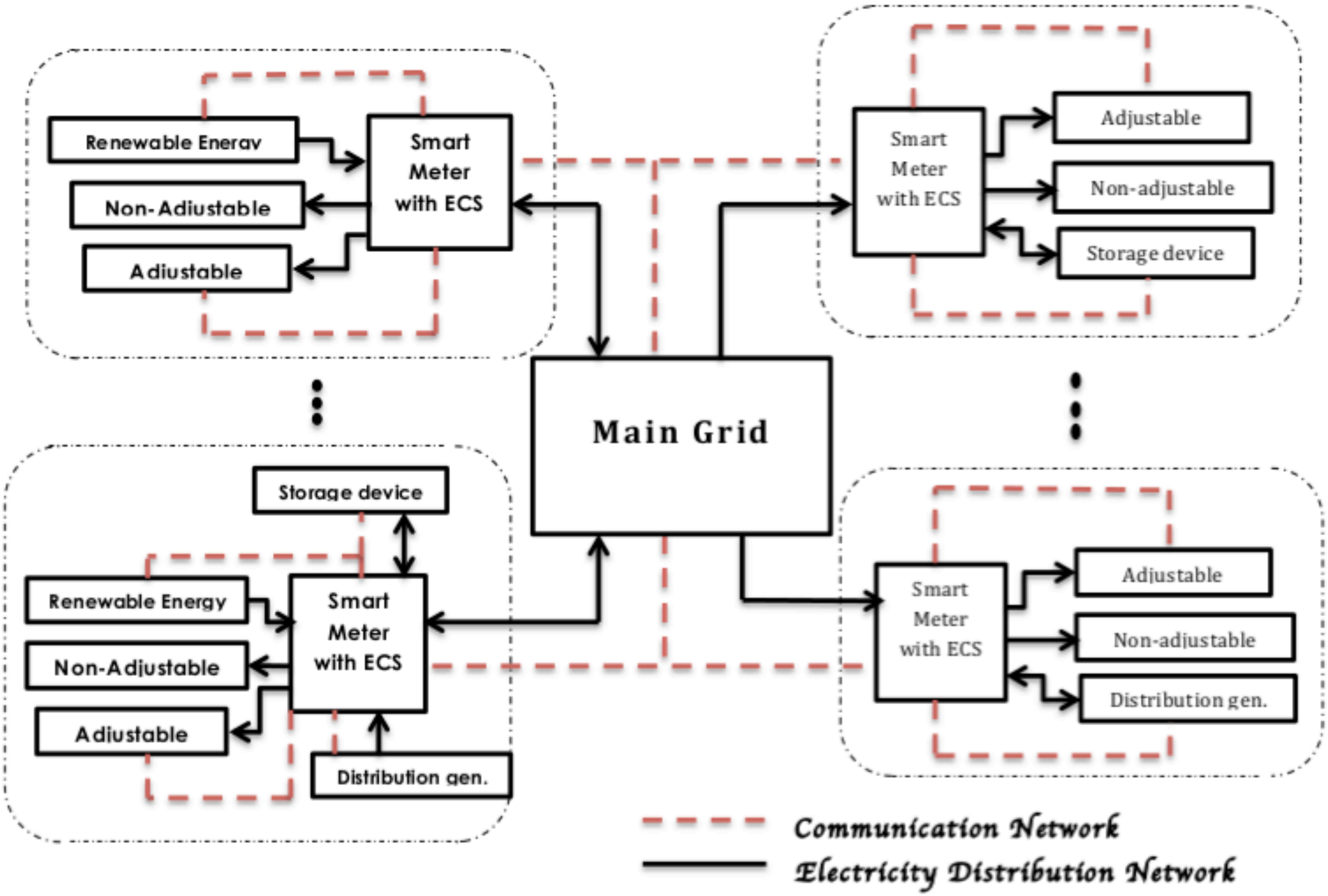
What is Smart Grid?

- A smart grid is a modernized electrical grid that uses *information and communications technology* to gather and act on information in an automated fashion to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity.

- Electric grid modernization involves,

    1. Improvement of infrastructure
    2. Addition of the digital layer
    3. Business process transformation

How is it different from the existing Electricity Grid ?



What is Demand side Management ?

- DSM is the modification of consumer's demand of electricity through various methods such as financial incentives and consumer education

- A process by which electrical *utilities in collaboration with consumers,* achieve predictable and sustainable change in electricity demand

- Usually the goal of DSM is to encourage the consumers to use less energy during peak hours or to move the time of energy use to the off-peak hours

Energy Consumption Schedule (ECS)

- The ECS devices are built inside the smart meters

- Smart meters are connected to communication networks and power grid.

- The aim is to reduce the total energy cost as well as the peak-to average-ratio (PAR)

- Two approaches for energy consumption management in buildings:
  Reducing consumption and *Shifting Consumption*

- Deployment of storage and ECS devices for DSM

System Model I

- We consider N users served by one utility company.
- Each user has a smart meter with ECS, that communicates with his/her devices and the utility company through the advanced metering infrastructure (AMI)
- Each user $n \in N$, is considered to have non-adjustable loads, adjustable load and a storage device.
- $\mathcal{K}_n \rightarrow$ a set of adjustable load appliances: PHEVs, air conditioner, etc.
- For each device $k \in \mathcal{K}_n$, we define energy consumption Scheduling vector

$$x_{n,k} \triangleq [x_{n,k}^1, \ldots, x_{n,k}^T]$$

System Model II

- $x^t_{n,k}$ → one-hour energy consumption scheduled for device k from subscriber n
- Non-adjustable load at slot t is $x^t_{n,0}$
- User n is also having a storage device
- Let $p^t_n \geq 0$, $t = 1, \ldots, T$, be the energy available in the battery at the end of slot t, and p^{max}_n the capacity of the battery.
- The available energy at the beginning of the horizon is p^0_n
- The battery can be either charged or discharged during slot t

System Model III

- b_n^t → the energy drawn from or provided to the battery.
- $b_n^t < 0$ → discharging & $b_n^t > 0$ → charging.
- The energy stored in the battery is given by
$$p_n^t = p_n^{t-1} + b_n^t, \qquad t = 1, \ldots, T.$$
- b_n^t is constrained by the maximum charge/discharge $$b_n^{dis} < b_n^t < b_n^{ch}$$
- The battery-supply energy is no more than the consumption, $$b_n^t + \sum_k x_{n,k}^t + p_{n,0}^t \geq 0$$
- Battery has efficiency $\eta_n \in (0, 1)$, the discharge at slot is t limited by
$$b_n^t \geq -\eta_n p_n^{t-1}$$

System Model IV

- The total hourly energy consumption for $n \in N$ is

$$l_n^t \triangleq \sum_{k \in \mathcal{K}_n} x_{n,k}^t + x_{n,0}^t + b_n^t.$$

- For the adjustable loads, each user selects the time interval $[\alpha_{n,k}, \beta_{n,k}]$ that the energy consumption for device k is valid to be scheduled

- Total energy consumption for device k from user n is

$$E_{n,k} = \sum_{t=\alpha_{n,k}}^{\beta_{n,k}} x_{n,k}^t$$

$$x_{n,k}^t = 0, \forall t \notin \{\alpha_{n,k}, \ldots, \beta_{n,k}\})$$

Motivation

How to manage energy consumption of adjustable appliances in order to reduce PAR and minimize the cost.

Formulation of Optimization Problem

- Devices may have some maximum power levels $\gamma_{n,k}^{max}$, as well as the minimum power level $\gamma_{n,k}^{min}$
- The upper-bound and lower constraints on the ECS vector $\boldsymbol{x}_{n,k}$ for each device

$$\gamma_{n,k}^{min} \leq x_{n,k}^{t} \leq \gamma_{n,k}^{max}, \quad \forall t \in \{\alpha_{n,k}, \ldots \beta_{n,k}\}.$$

- The total load of N residential users at each hour of the day is $L_t = \sum_{n \in N} l_n^t$

Cost of Electricity

- $C^t(\cdot) \rightarrow$ the cost of electricity over a slot t
- The cost that the utility incurs to provide electricity to the end user
- The cost of the same load may be different at different time of the day
- The multi-residential load control task amounts to minimizing the total cost of electricity

Optimization Problem

$$\min_{\boldsymbol{x}_1,\ldots,\boldsymbol{x}_N} \quad \sum_{t=1}^{T} C^t \left(\sum_{n \in N} \left(b_n^t + \sum_{k \in \mathcal{K}} x_{n,k} + x_{n,0}^t \right) \right)$$

$$\text{subject to} \quad b_n^t + \sum_k x_{n,k}^t + x_{n,0}^t \geq 0,$$

$$\sum_{t=\alpha_{n,k}}^{\beta_{n,k}} x_{n,k}^t = E_{n,k},$$

$$\gamma_{n,k}^{min} \leq x_{n,k}^t \leq \gamma_{n,k}^{max}, \quad \forall t \in \{\alpha_{n,k}, \ldots, \beta_{n,k}\},$$

$$x_{n,k}^t = 0, \quad \forall t \notin \{\alpha_{n,k}, \ldots, \beta_{n,k}\},$$

$$b_n^{dis} < b_n^t < b_n^{ch}, \quad t = 1, \ldots, T,$$

$$p_n^t = p_n^{t-1} + b_n^t, \quad t = 1, \ldots, T$$

$$b_n^t \geq -\eta_n p_n^{t-1}.$$

Optimization Problem

- The centralized fashion can be used to solve the problem
- Central unit performs the optimization
- It requires each user to provide detailed information about his/her energy storage capabilities as well as the energy consumption of devices.

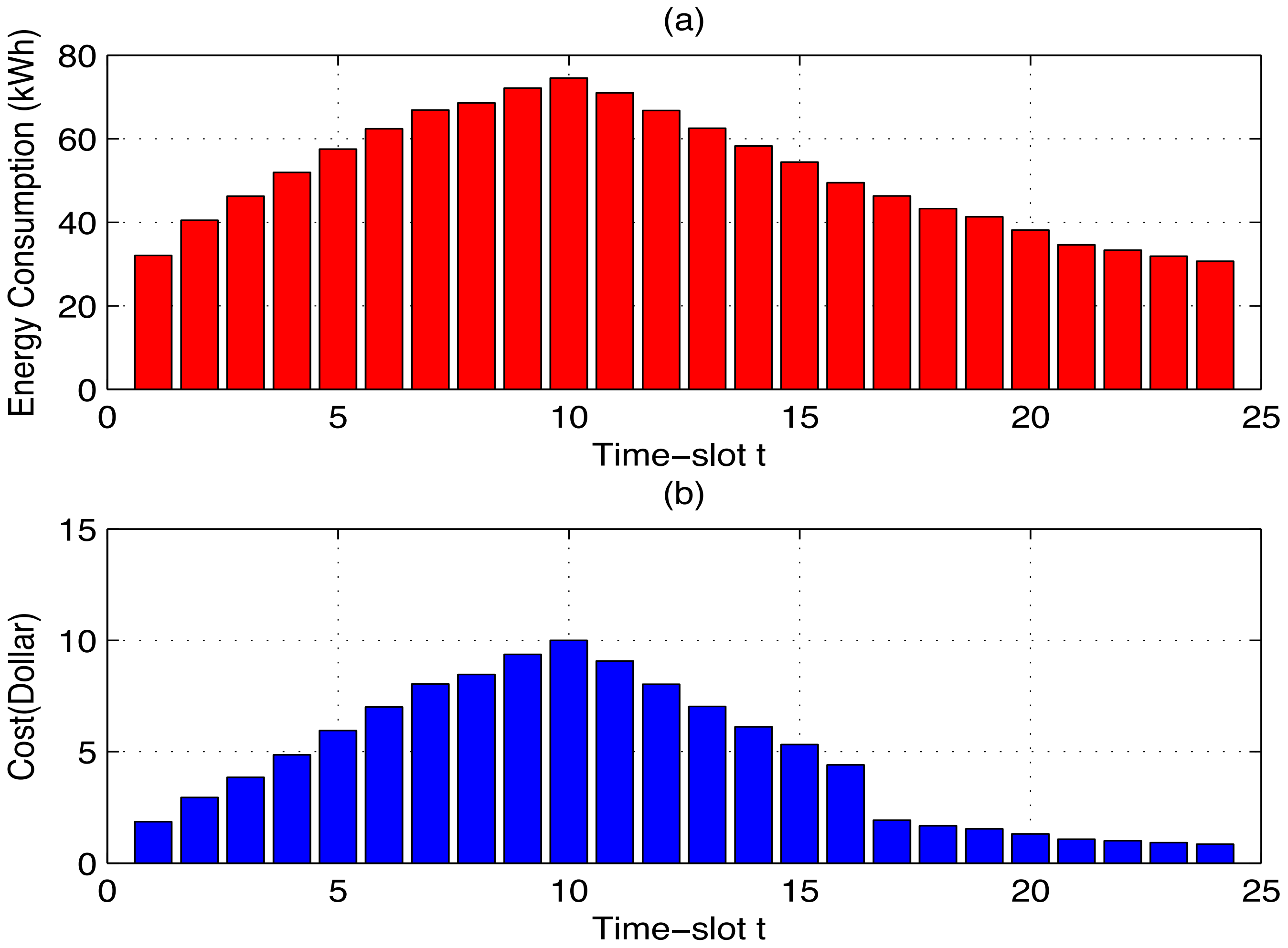
Private issues may discourage users to subscribe to the optimization process if Centralized fashion is adopted

- We proposed a distributed fashion.

Simulation Parameters

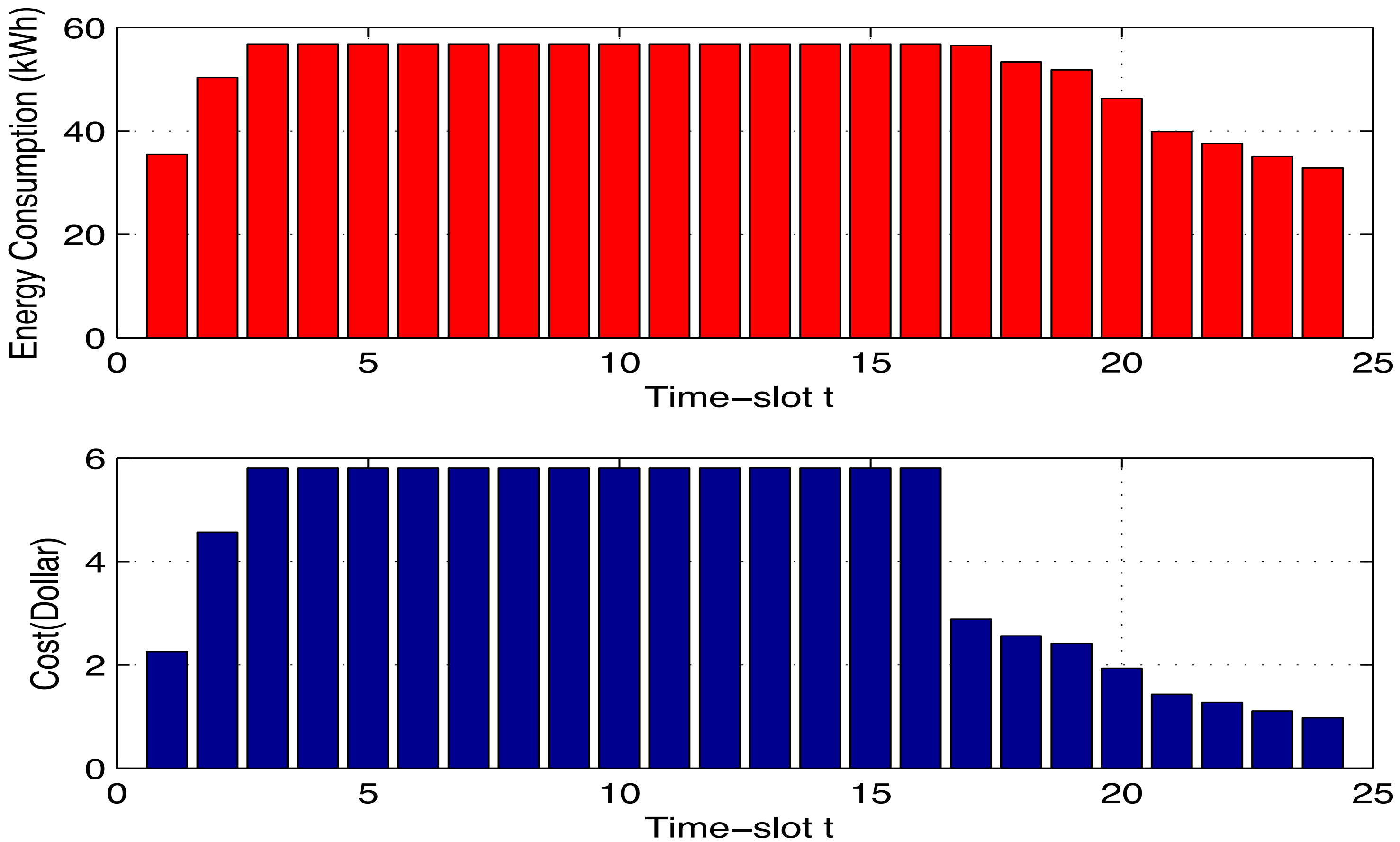
- *N = 20*, each having random adjustable and non-adjustable devices between *10 to 20*
- Non-adjustable load appliances include *electric bulbs, TVs, refrigerators etc*.
- These are loads whose *instantaneous power or starting time cannot be adjusted*.
- Adjustable load refers to the loads whose *instantaneous power, starting time or both can be adjusted*.
- Adjustable load appliances includes *PHEVs, dish washers, washing machines etc*.
- Users with and without storage devices are considered.

No Energy consumption Schedule ECS

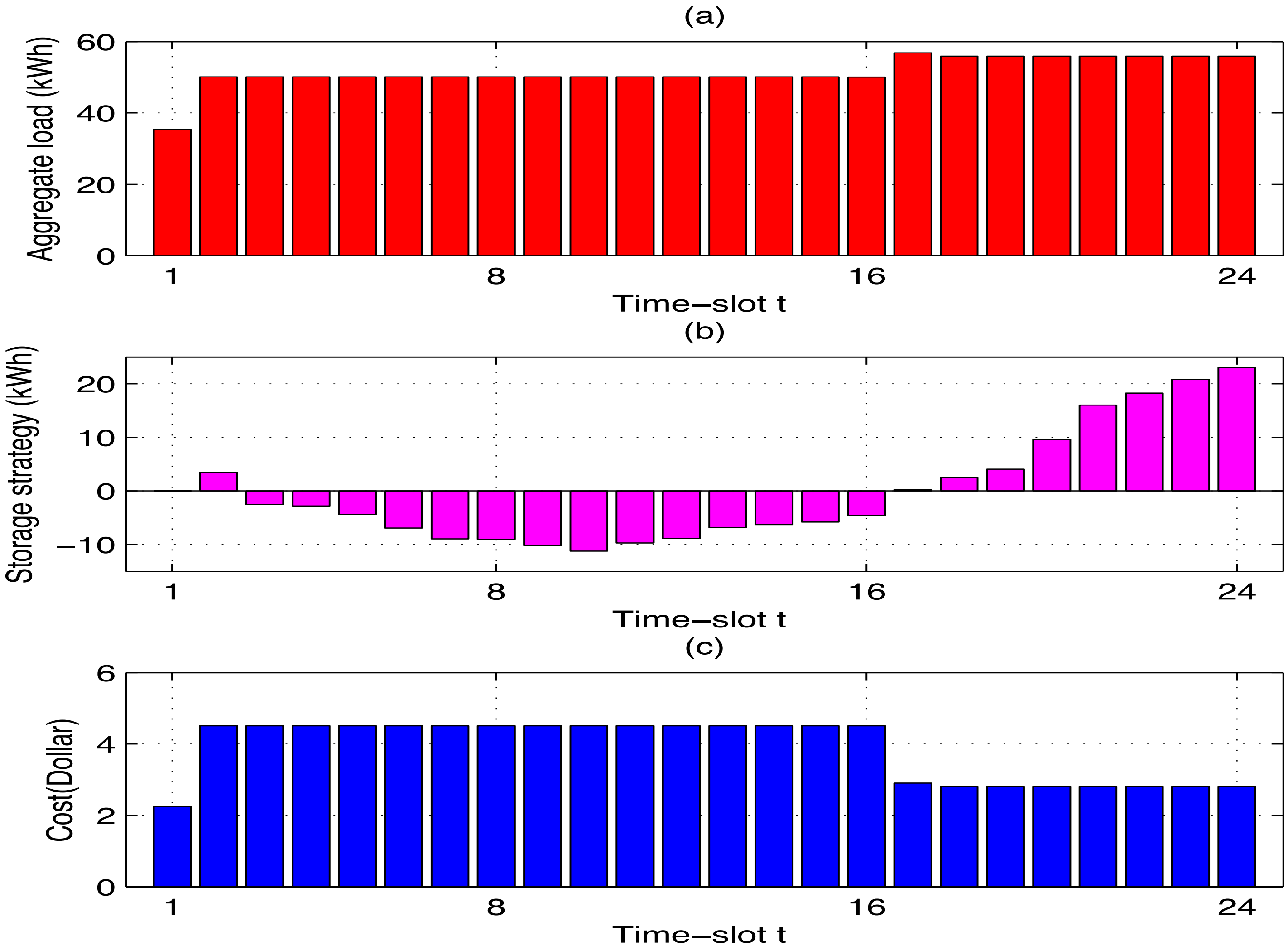


Users without ECS, total cost *$112.62*

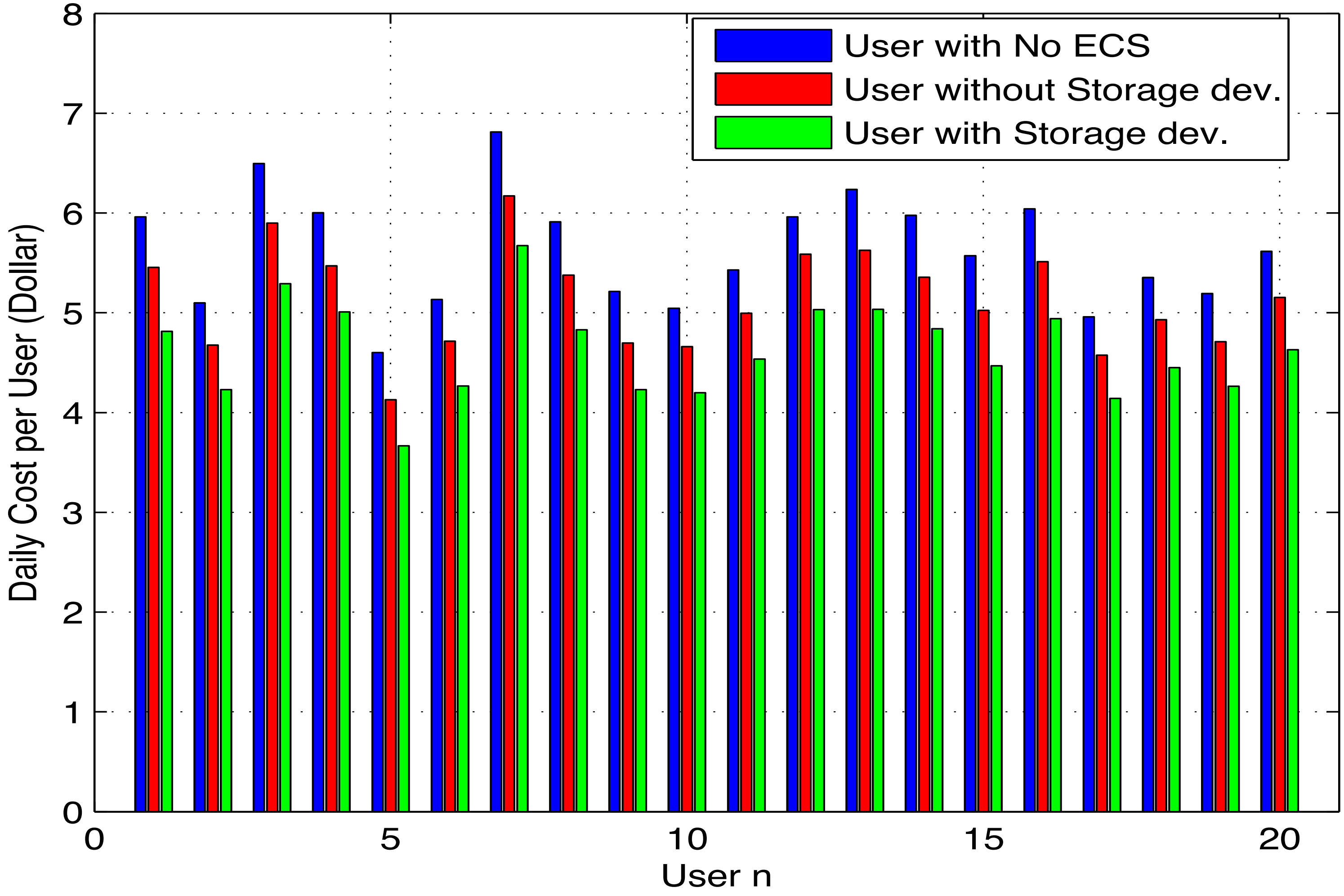
Energy consumption Schedule ECS



The ECS for users without storage devices, total cost *$102.72*



Users deploying ECS and storage devices, total cost *$92.54*



Comparison of cost paid by each user with/without storage devices

Conclusion

- We considered deployment of ECS devices in smart meters for DSM
- Difference in pricing mechanisms employed by utility companies gives incentive for users to trade the energy.
- Simulation results show significant reduction in cost for the ECS scheme over the system without ECS
- Energy Storage devices play an important role in reducing the cost paid by the consumers.

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