Contract-based Emergency Demand Response Participation of Multi-tenant Colocation Data Center

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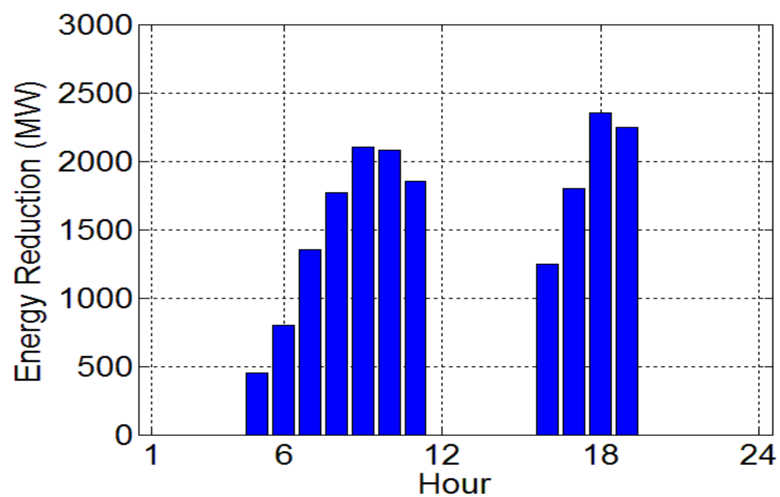
MOTIVATION AND BACKGROUND

Demand Response (DR)

- Customers reduce power consumption
- Demand response getting popular
  - Some reports
    - Current: **180%** increase in demand response from 2010 to 2012 in Baltimore Gas and Electric
    - Future: DR participation to **double** in 2020

Emergency Demand Response (EDR)

- Ensures reliability during emergency period
- A recent EDR example:
  - Extreme cold in beginning of Janurary 2014
  - Closure of electricity grid
  - EDR in PJM and ERCOT



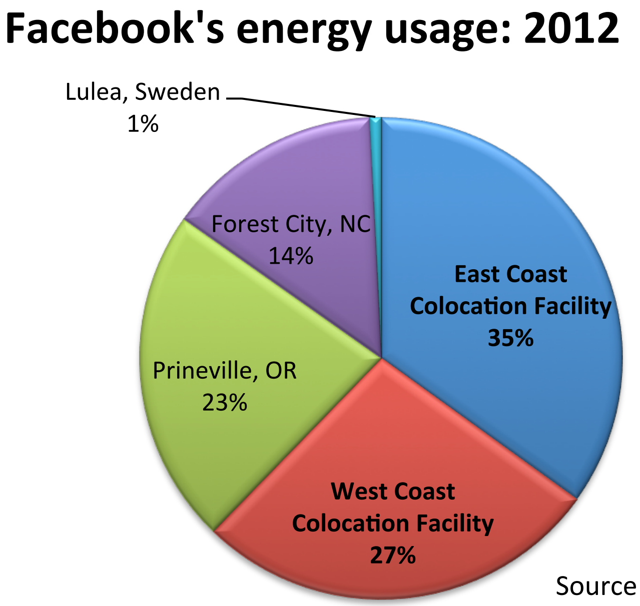
Energy reduction target at PJM

Colocation data center

- Multi-tenant data center
- Colocation vs. owner-operated data center
  - Colocation
    - **Tenants** control servers
  - Owner-operated
    - **Data center operator** controls both servers and supporting system

Colocation data center (Contd.)

- A popular option to small and medium businesses (SMBs)
  - Universities, hospitals, enterprises
- Large-scale companies
  - E.g., VMware, Facebook



Source: Facebook

Some numbers…

- 64% of organizations utilize data center colocation services
- Revenue of colocation increasing 9.4% every year
- Colocations in New York collectively consume 400MWs of power
  - Comparable to google's global data center power demand

LITERATURE REVIEW

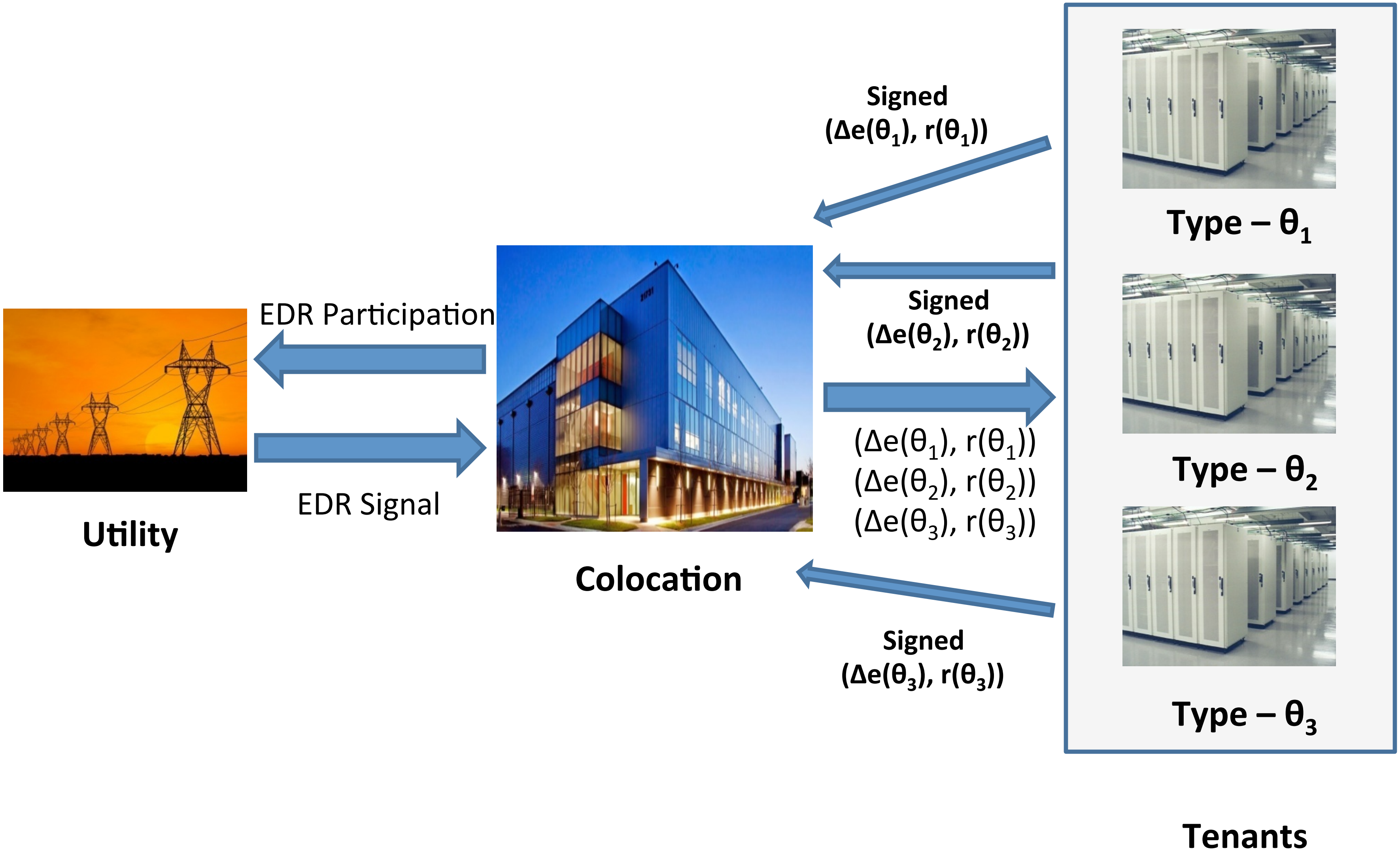
Related work

- Optimization of data center resources exploiting ancillary services by utility (e.g., [1])
  - **Owner-operated** data center
- Multi-tenant colocation demand response ([2, 3])
  - Requires **complex** bidding mechanism
  - Subject to tenants **cheating behavior**

Our contribution: **We propose an easily-implementable contract-based mechanism for target energy reduction in emergency demand response program for colocation data center**

[1]. M. Ghamkhari and H. Mohsenian-Rad, "Data centers to offer ancillary services," in *Smart Grid Communications (SmartGridComm), 2012 IEEE Third International Conference on*. IEEE, 2012, pp.436–441.
[2]. L. Zhang, S. Ren, C. Wu, and Z. Li. *A Truthful Incentive Mechanism for Emergency Demand Response in Colocation Data Centers, in Infocom 2015*.
[3]. Chen, Niangjun, Xiaoqi Ren, Shaolei Ren, and Adam Wierman. "Greening Multi-Tenant Data Center Demand Response.", in IFIP Performance, 2015

Model overview



PROBLEM FORMULATION AND ALGORITHM

Objective and constraints

- Objective: Minimize total cost

$$\min_{(\Delta e(\theta_i), r(\theta_i))} \sum_{\theta_i \in \Theta} m_{\theta_i} \times r(\theta_i) + \alpha \times e_b$$

  - m_{θ_i} denotes number of tenants of type-θ_i

- Constraint 1: Colocation should achieve target energy reduction (Δe_{th})

$$\gamma \times \sum_{\theta_i \in \Theta} m_{\theta_i} \times \Delta e(\theta_i) + e_b = \Delta e_{th}$$

Objective and constraints (Contd.)

- Constraint 2: Individual Rationality (IR)
  - Participants achieve non-negative pay-off

$$r(\theta_i) - v(\theta_i, \Delta e(\theta_i)) \geq 0$$

- Constraint 3: Incentive Compatibility (IC)
  - Tenant chooses its own type to maximize utility

$$r(\theta_i) - v(\theta_i, \Delta e(\theta_i)) \geq r(\theta_i') - v(\theta_i, \Delta e(\theta_i'))$$

Two cases

- Contract design with **complete** information
  - Colocation operator has complete knowledge of type of each tenant

$$\min_{(\Delta e(\theta_i), r(\theta_i))} \sum_{\theta_i \in \Theta} m_{\theta_i} \times r(\theta_i) + \alpha \times e_b$$

s.t., IR, IC and energy reduction constraints

Two cases (Contd.)

- Contract design with **incomplete** information
  - Colocation operator lacks information of tenant's type distribution

$$\min_{(\Delta e(\theta_i), r(\theta_i))} \sum_{\theta_i \in \Theta} E[m_{\theta_i} \times r(\theta_i) + \alpha \times e_b \mid \{m_{\theta_i}\}_{\theta_i \in \Theta}]$$

s.t., IR, IC and energy reduction constraints

  - $\{m_{\theta_i}\}_{\theta_i \in \Theta}$ denotes distribution of tenants to different types

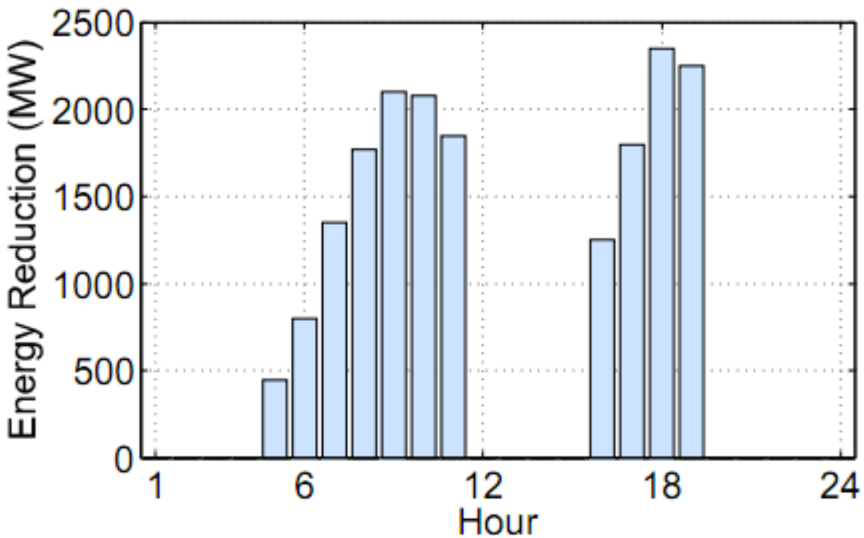
Algorithm and theorem

- **Algorithm:** We use exhaustive search algorithm to find optimal solution (also considered in [4])
- **Theorem:** The designed contracts minimize the colocation operator's cost while satisfying both IR and IC constraints
  - The proof follows through mathematical induction

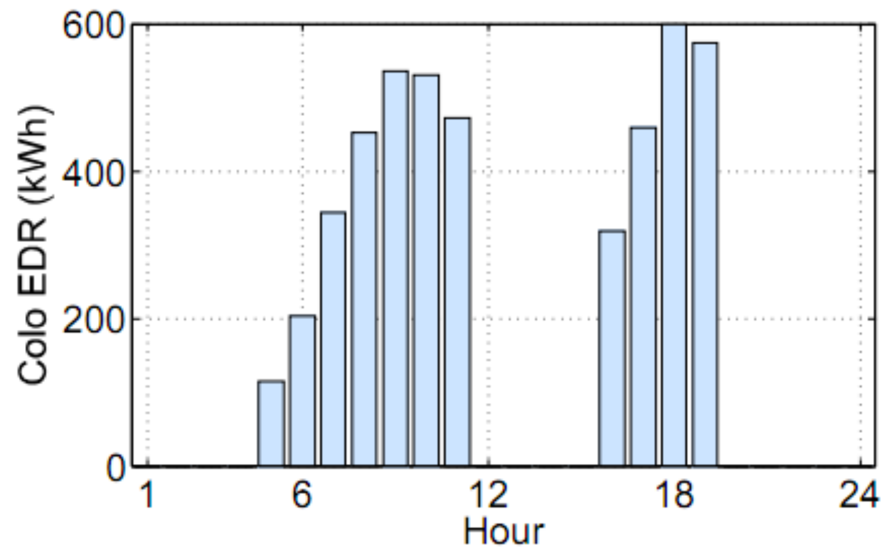
[4] Lingjie Duan; Lin Gao; Jianwei Huang, "Contract-based cooperative spectrum sharing," in *New Frontiers in Dynamic Spectrum Access Networks (DySPAN), 2011*

VALIDATION

Energy reduction target

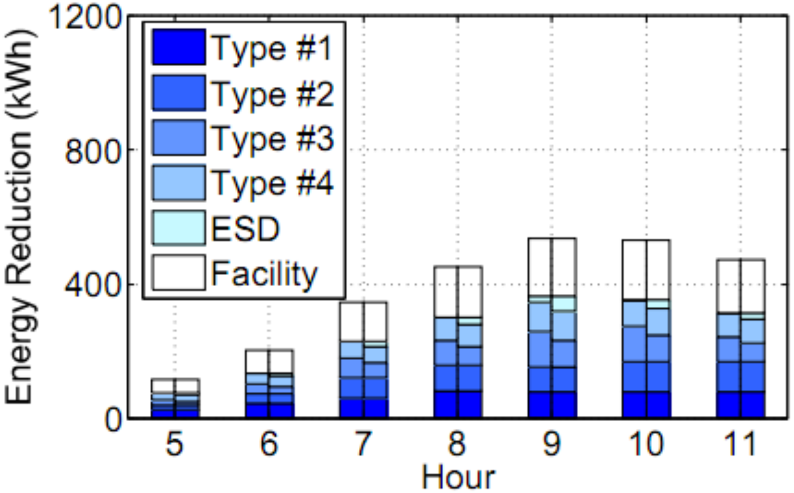


(a) Energy reduction target at PJM on January 7, 2014

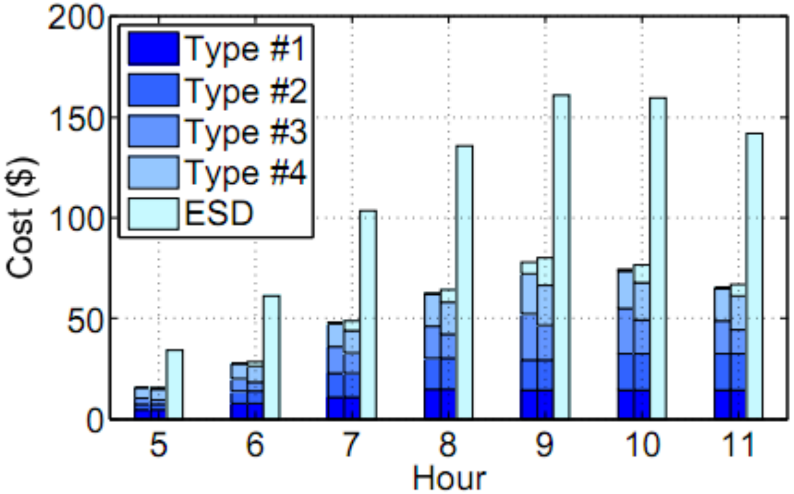


(b) Scaled energy reduction target at colocation

Results



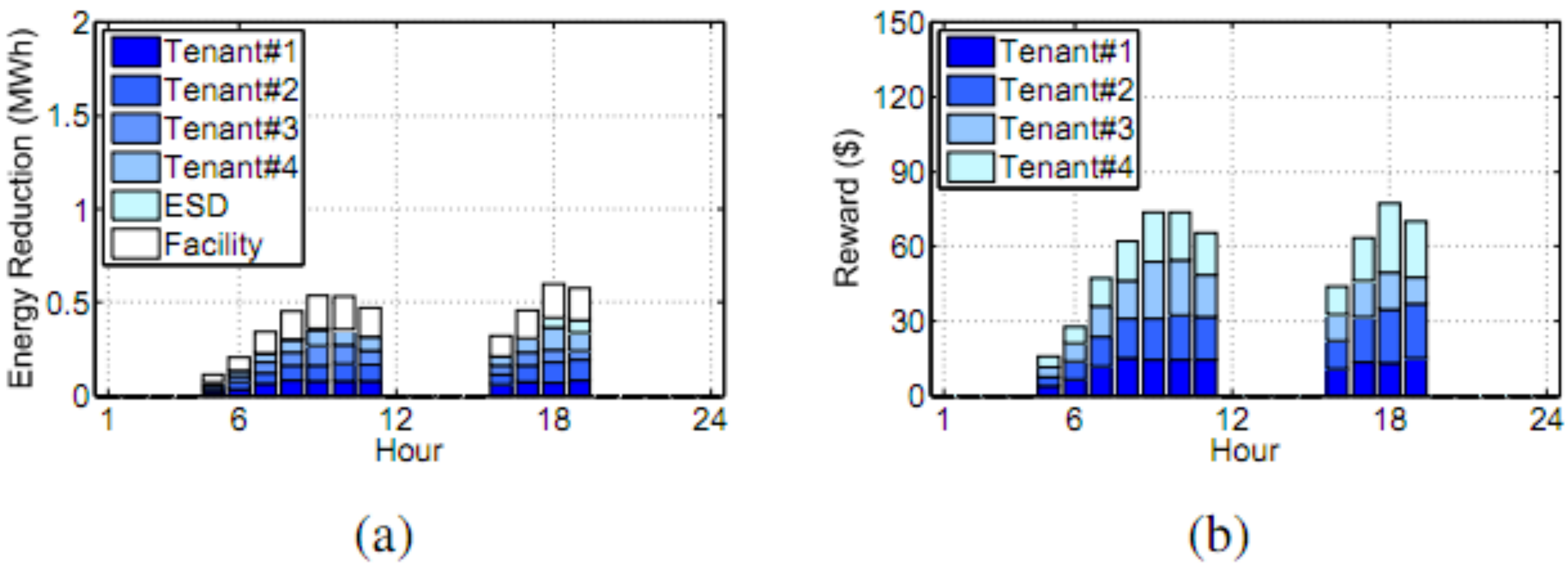
(a)



(b)

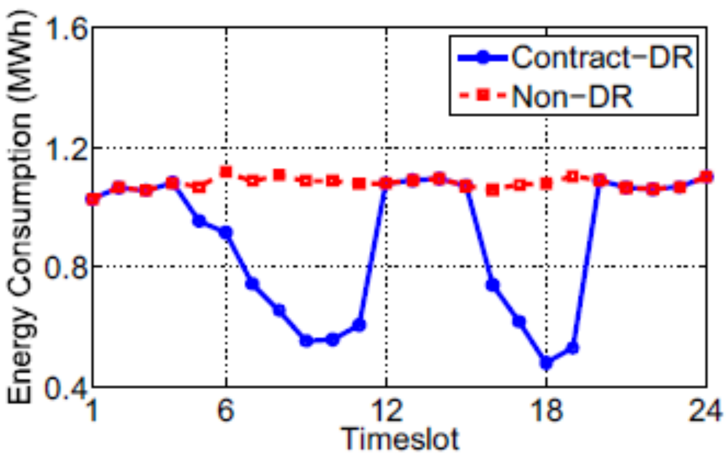
Achieve target energy reduction at much lower cost!

Results (Contd.)

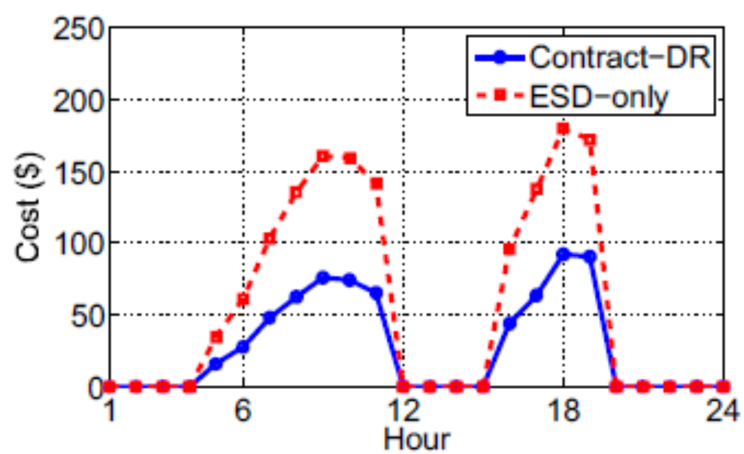


Tenants also receive reward for EDR participation!

Results (Contd.)



(c)



(d)

Comparison with non-demand response approach

Conclusions

- Studied
  - Colocation emergency demand response
- Proposed
  - Contract-based incentive mechanism
    - Achieves target energy reduction
    - Rewards tenants
- Trace-based simulation study
  - To validate Contract-DR

Questions?

BACKUP SLIDES

Colocation model

- Energy reduction by tenant of type-θ_i

$$\Delta e(\theta_i) = n_{\theta_i} \times e_{0,\theta_i} \times T$$

  - n_{θ_i} denotes number of servers turned-off
- Energy Storage Device (ESD)
  - To assist tenants in achieving energy reduction
  - Discharge amount: e_b
  - ESD discharge cost: α per kWh

Tenant utility

- Tenant's inconvenience cost

$$v(\theta_i, \Delta e(\theta_i)) = \xi_{\theta_i} \times c(\Delta e(\theta_i))$$

  - ξ_{θ_i} denotes cost of energy reduction
  - $c(\Delta e(\theta_i))$ denotes a general cost function of energy reduction

- Tenant's utility

$$u(\theta_i, \Delta e(\theta_i)) = r(\theta_i) - v(\theta_i, \Delta e(\theta_i))$$

  - $r(\theta_i)$ denotes reward awarded to tenant of type-θ_i