A Contract Design Approach for Colocation Data Center Demand Response

Kishwar Ahmed, Mohammad A. Islam, Shaolei Ren

FIU School of Computing & Information Sciences

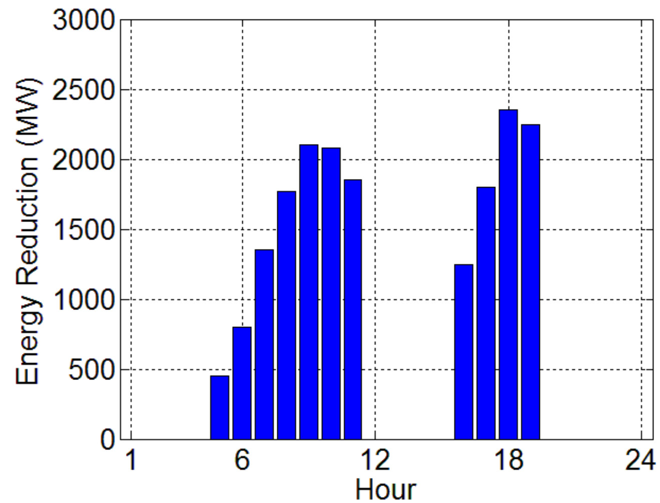
MOTIVATION

Demand Response (DR)

- Customers reduce power consumption
  - Peak electricity price period
  - Maintain power system stability
- 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
- Crucial to maintain transmission efficiency
- 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

Data centers as Controllable Load Resource

- Data centers are promising participants in DR
  - Presence of Energy Storage Device (ESD)
  - Server consolidation
    - Within short time
    - Without affecting normal operation
- A field study by LBNL
  - Data centers save significant energy in DR
  - No impact on data center operations or SLA

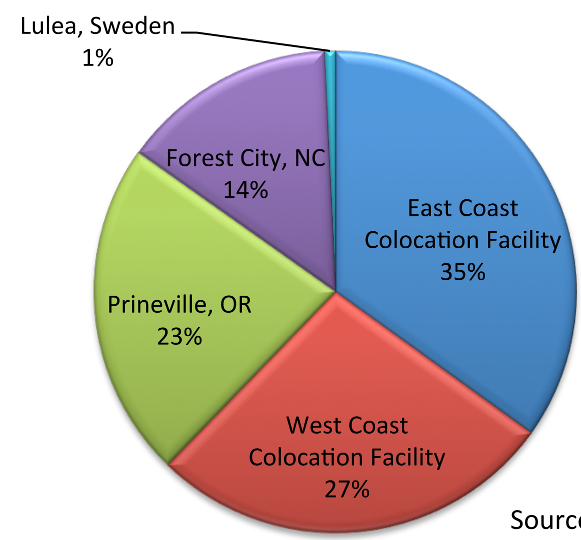
Colocation data center

- Multi-tenant data center
- Why Colocation?
  - Reduced building and maintenance cost
  - Enhanced security
- Colocation vs. owner-operated data center
  - Colocation
    - Tenants control servers
    - Facility manager with limited operational capability
  - Owner-operated
    - Data center operator controls both servers and supporting system

Colocation data center (Continued)

- A popular option to small and medium businesses (SMBs)
  - Universities, hospitals, enterprises
- Only popular to SMBs?
  - No!
- Many cloud providers
  - E.g., VMware
- Large-scale companies
  - E.g., Facebook

Facebook's energy usage: 2012



Source: Facebook

Some numbers

- 64% of organizations utilize data center colocation services
- More than 1500 colocation data centers in USA!
- Revenue of colocation increasing 9.4% every year
- Expected worldwide revenue in 2017: $30 billion
- Colocations in New York collectively consume 400MWs of power
  - Comparable to google's global data center power demand

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

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

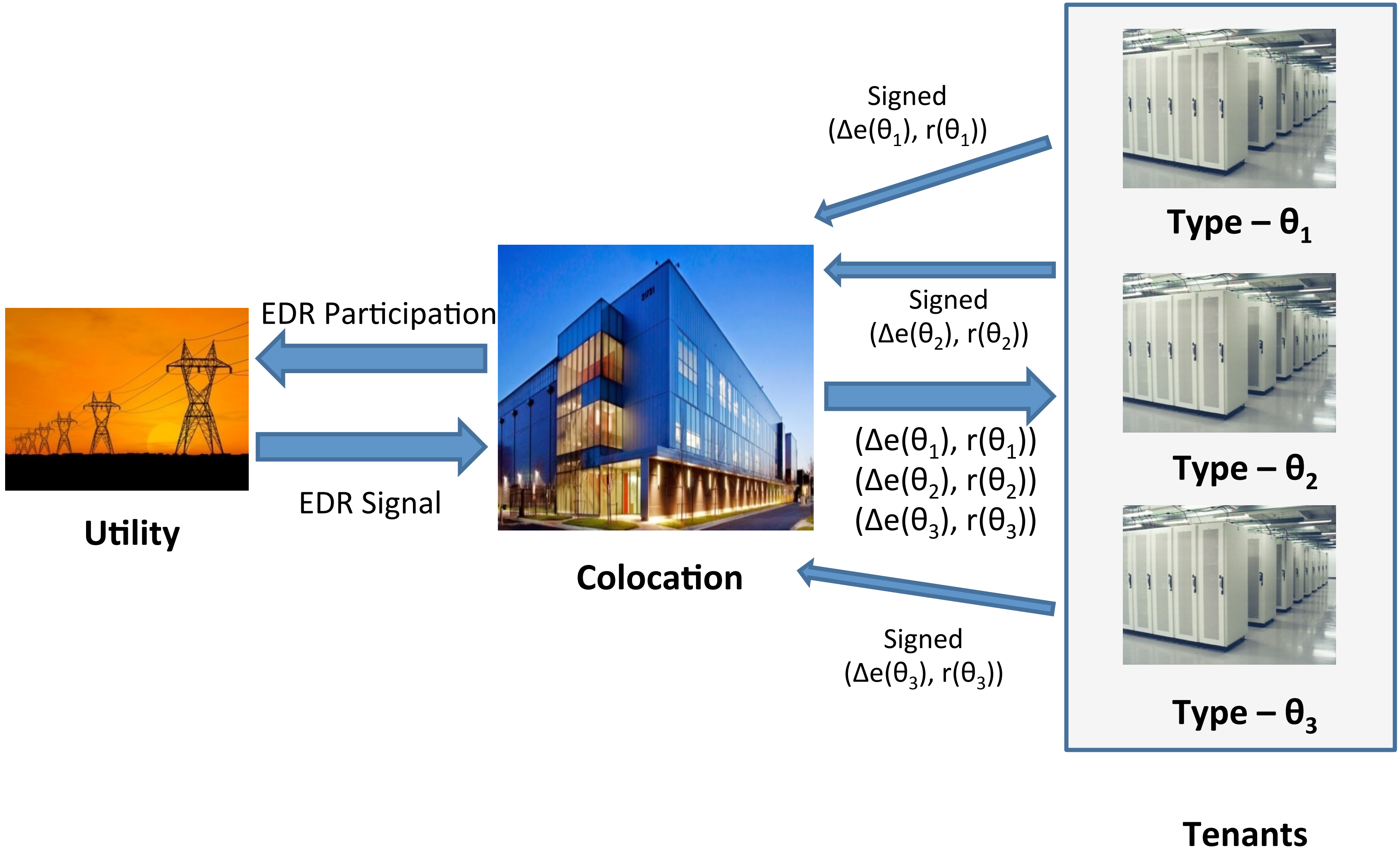
[1]. M. Ghamkhari and H. Mohsenian-Rad, "Data centers to offer ancillary services," in *Smart Grid Communications (SmartGridComm), 2012 IEEE Third International Conference on*. IEEE, 2012, pp.436–441.
[2]. L. Zhang, S. Ren, C. Wu, and Z. Li. *A Truthful Incentive Mechanism for Emergency Demand Response 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

Participants in model

- Utility
  - RTOs or electric power system controlled by RTOs
  - Signals DR requirement
    - Emergency situations
- Facility manager
  - Controls and coordinates colocation
  - Achieves target energy reduction
- Tenants
  - Own and control servers
  - Participate in energy reduction through consolidating workloads in fewer servers and turning off idle servers

Model overview



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

PROBLEM FORMULATION AND ALGORITHM

Objective and constraints

- 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
- Tenants' energy reduction needs to be equal to target energy reduction (Δe_{th})

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

  - γ denotes power usage effectiveness (PUE) of colocation

Objective and constraints (Continued)

- Individual Rationality (IR) constraint
  - Participants in contract mechanism achieve non-negative pay-off

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

- Incentive Compatibility (IC) constraint
  - 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

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

$$\text{s.t., IR, IC and energy reduction constraints}$$

Two cases (Continued)

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

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

$$\text{s.t., IR, IC and energy reduction constraints}$$

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

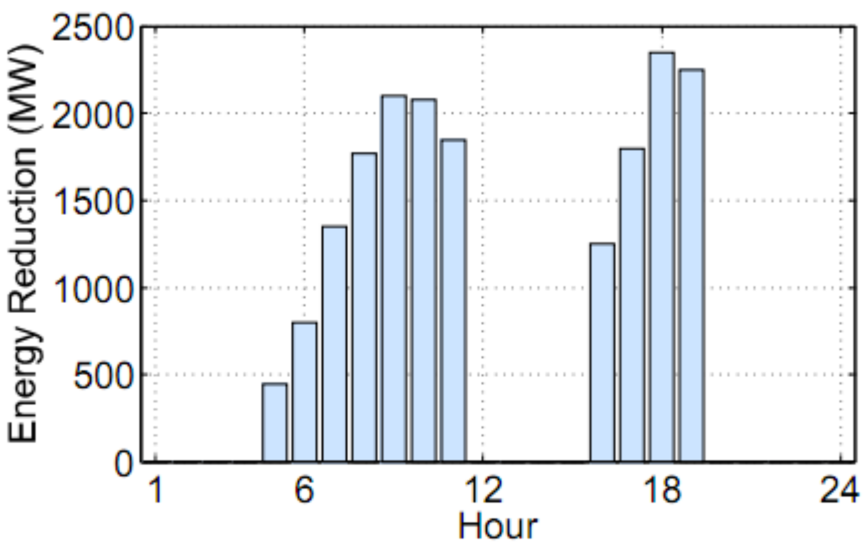
Algorithm and theorem

- **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 (i.e., feasibility of contracts)
  - The proof follows through mathematical induction

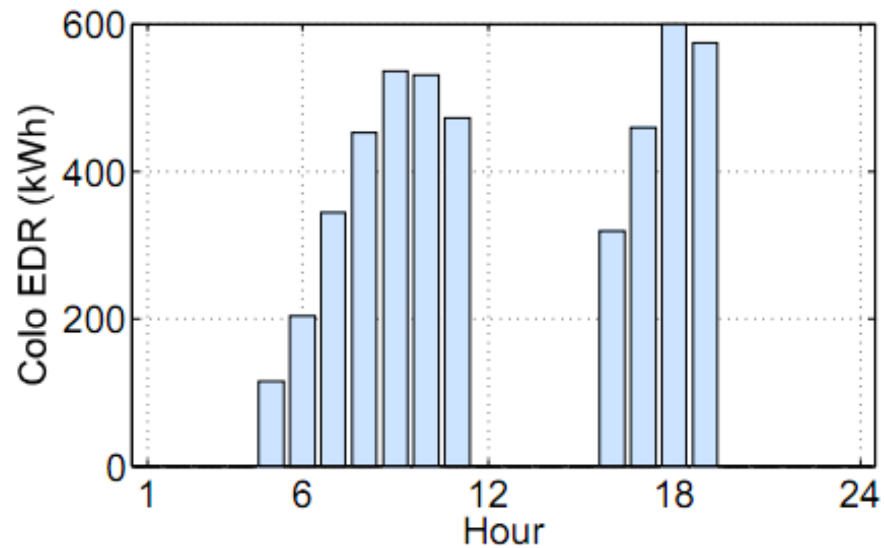
[4] Lingjie Duan; Lin Gao; Jianwei Huang, "Contract-based cooperative spectrum sharing," in *New Frontiers in Dynamic Spectrum Access Networks (DySPAN), 2011*

CASE STUDY

Energy reduction target

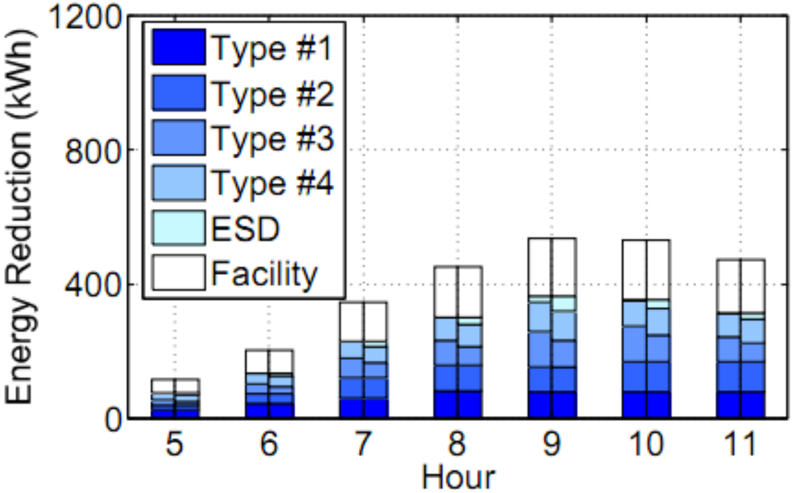


(a) Energy reduction target at PJM on January 7, 2014

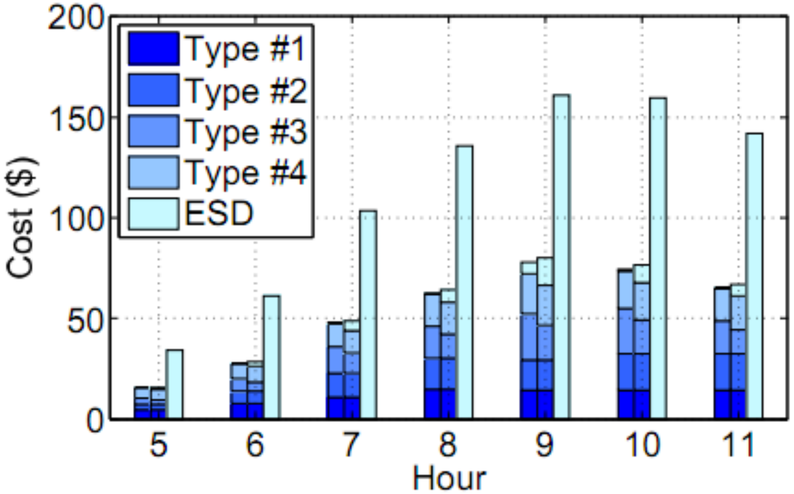


(b) Scaled energy reduction target at colocation

Simulation



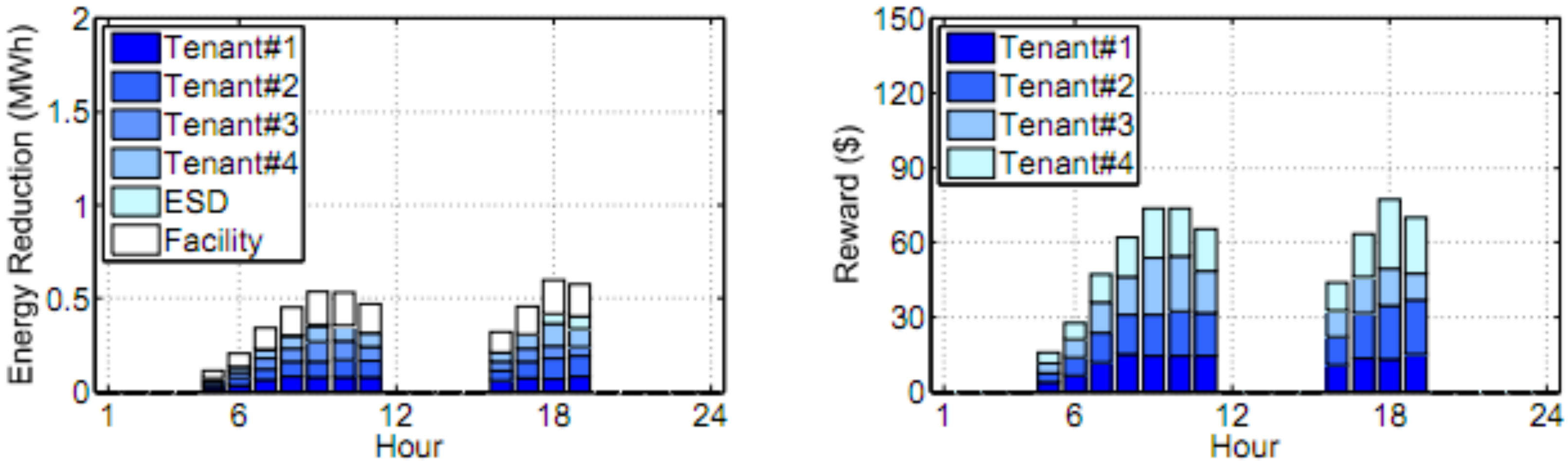
(a)



(b)

Achieve target energy reduction at much lower cost!

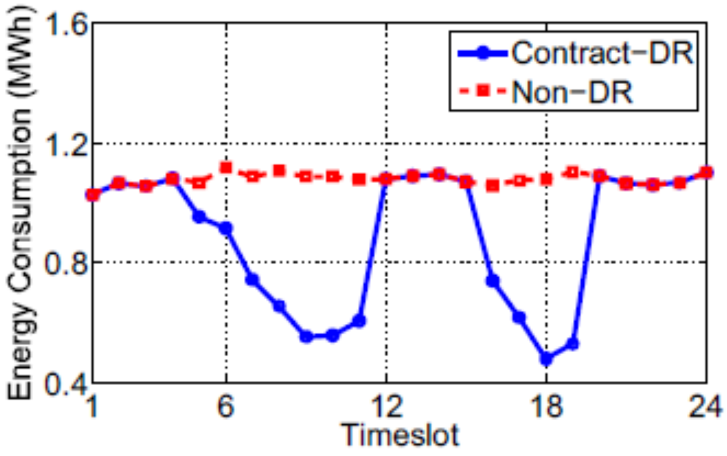
Simulation (Continued)



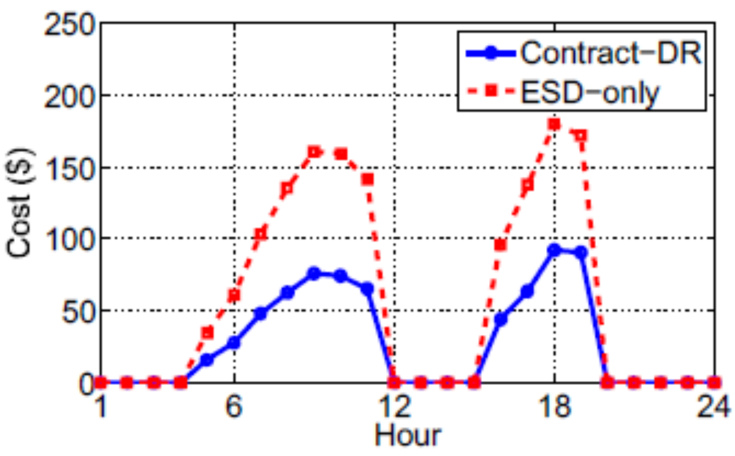
(a) (b)

Tenants also receive reward for EDR participation!

Comparison



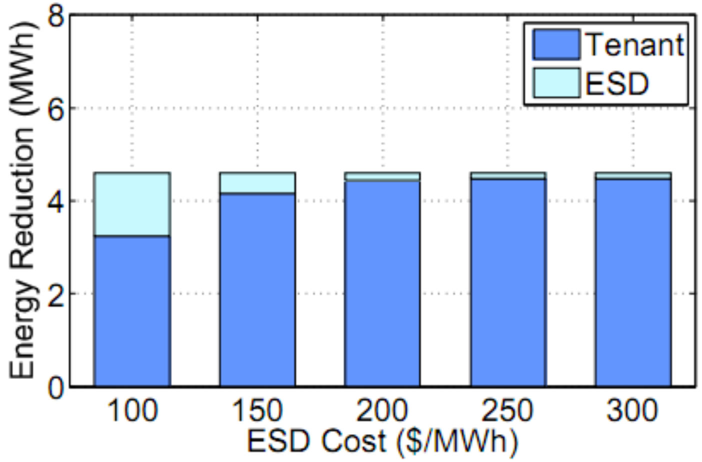
(c)



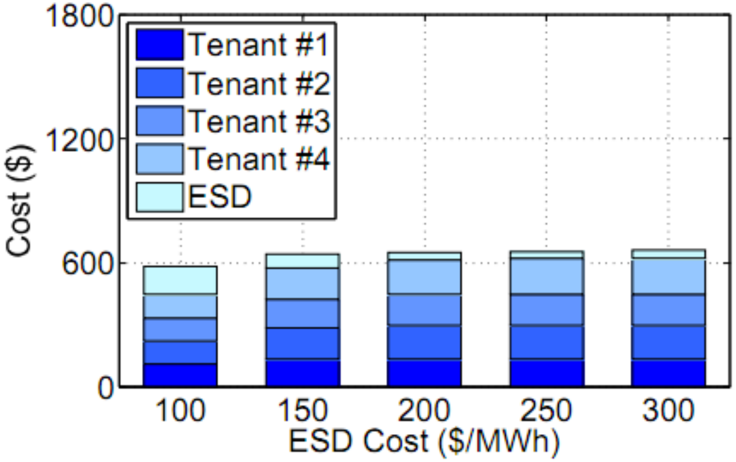
(d)

Comparison with non-demand response approach

Impact of ESD cost



(a)



(b)

Higher ESD cost => Increased tenant EDR participation

Conclusions

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

Thank you!