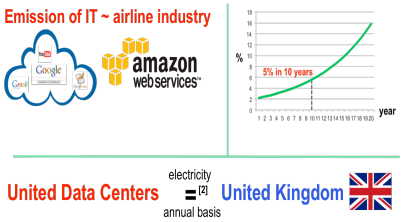
Enabling Demand Response from Cloud Data Centers -- from Sustainable IT to IT for Sustainability

Zhenhua Liu, Stony Brook University

Motivation

Emission of IT ~ airline industry



Research agenda

Sustainable IT

Geographical Load Balancing
[Sigmetrics11, ToN14] Pick of the Month
[GreenMetrics11] Best student paper award
[IGCC12] Best paper award

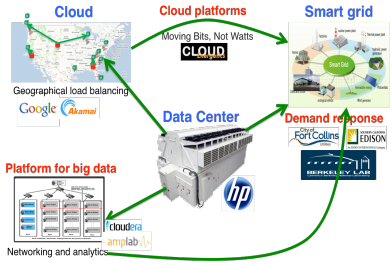
Design & Implementation
[Sigmetrics12 & 3 patents]
HP Net-Zero Energy Data Center
Computerworld Honors Laureate 2013

Data Center Demand Response
[Sigmetrics13, Performance Evaluation 2013]
Most downloaded list

Market Design [Sigmetrics14]

IT for Sustainability

Big picture



Geographical load balancing

Geographical Load Balancing Problem

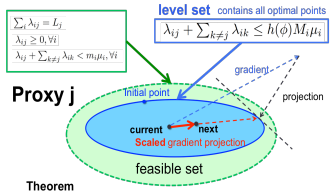
$$\min_{m_i,\lambda_{ij}} \sum_i \left(g_i(m_i; p_i, r_i, e_i) + \sum_j \lambda_{ij} r(f_i(m_i,\lambda_i) + d_{ij}) \right)$$

$$\text{s.t.} \quad \sum_{i\in N} \lambda_{ij} = L_j, \quad \forall j \in J$$
$$\lambda_{ij} \geq 0, \quad \forall i \in N, \forall j \in J$$
$$0 \leq m_i \leq M_i, \quad \forall i \in N$$
$$\lambda_i \leq m_i \mu_i, \quad \forall i \in N$$

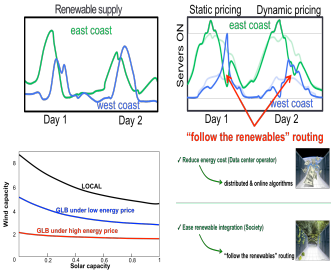
Observation: this is a convex optimization problem → centralized algorithm

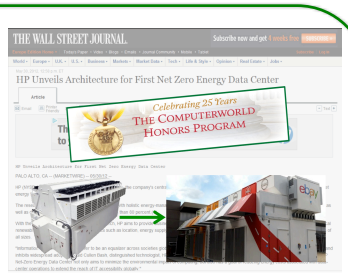
Challenge: how to distribute it

Key idea: conservative move



Theorem
Let $(\mathbf{m}(t),\boldsymbol{\lambda}(t))$ be the sequence generated by the distributed gradient projection algorithm, if the **step size** is small enough, then every limit point is optimal.





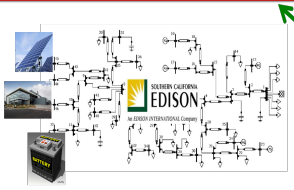
Model → Algorithm → Impact → System

Rigor + Relevance

Data center demand response

Great potential

World DC: 30GW → 4GWh storage ~ $20Billions



voltage violation rate
20MW DC = **3MWh storage**
with 20% flexibility — optimal location & fast charge rate

Big challenges

Time of use (ToU) pricing
Wholesale market
Ancillary service market
Coincident peak pricing (CPP)
} DCs rarely participate!

Challenges

Engineering Algorithm design for DC participation
[Sigmetrics13, Performance Evaluation 2013]
Most downloaded list

+

Economics Market design for utility companies
[Sigmetrics14]

$\min_d f(\mathbf{d}; t)$

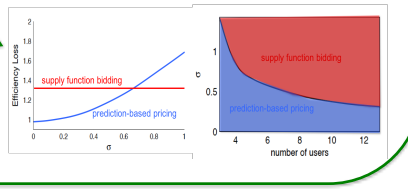
algorithm design for CPP

expected cost optimization
$\min_d E_t[f(\mathbf{d}; t)]$
→ data mining for patterns
less accurate with renewables

robust optimization
$\min_d \max_t [f(\mathbf{d}; t)]$
→ online algorithm
optimal competitive ratio

prediction-based pricing

supply function bidding VS **prediction-based pricing**



Ongoing work

Quantify the potential economic and environmental benefits of demand response from cloud data

Tackle the interdisciplinary challenges of both local control algorithm design and global market design

Study the data center ecosystem with attached renewable generation, electric vehicle charging stations, energy storage, etc.