Enabling Coordinated Power Management in Multi-Tenant Data Centers

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Where the Internet lives

Google's data center in Mayes County, Oklahoma
Data centers are **power-hungry**

91 billion kWh; 34 power plants (ea. 500MW); 17 more by 2020

U.S. data centers in 2013

Power the entire state of Washington

> 10 billion USD

Source: Natural Resources Defense Council
Let’s make data centers energy-efficient...
Good news & bad news

**Good news first!**
(A snapshot of) **many** approaches

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**Power proportionality**

**Virtualization**

**Geographic load balancing**

**Workload scheduling**
Bad news

Most of the existing approaches cannot be (directly) applied in many large data centers...
What are data centers?
Multi-tenant colocation data center

• Multiple tenants house their own servers in one shared space and manage their equipment independently

• Data center operator is mainly responsible for facility support (e.g., power supply, cooling)
Who are using colocations?

• Almost all industry sectors
  – Including top-brand websites, e.g., Wikipedia, Twitter
Who are using colocations?

• Almost all industry sectors
  – Including top-brand websites, e.g., Wikipedia, Twitter
  
  Google  Apple  facebook  Microsoft

• Many clouds
  
  box  vmware

• Our Internet
  – According to Cisco, 55% Internet traffic will be processed through CDN providers, e.g., Akamai, by 2018 (up from 33% in 2013)
Why does colocation matter?

• There’re over 1,400 colocation data centers in the U.S.
• Projected to grow to US$ 43 billion by 2018*
  – Annual compound growth rate of 11%

* Source: http://www.marketsandmarkets.com/Market-Reports/colocation-market-1252.html
In fact...

“Most large data centers are built to host servers from multiple companies (often called colocation data centers, or ‘colos’).”

--- *The Datacenter as a Computer*, a study by *Google Research* in 2013
Estimated % of Electricity Usage by U.S. Data Center Segment in 2011

- Google-type data center: 37.3%
- Multi-tenant data center: 37.3%
- Enterprise data center (e.g., server room): 53.0%

Google v.s. Colocation

Diagram:
- Utility Substation
- AC/DC
- DC/AC
- Diesel Generator
- UPS
- PDU
- ATS

Server Racks

15
Google v.s. Colocation

- Utility Substation
- AC/DC
- DC/AC
- Diesel Generator
- UPS
- PDU
- Tenants

verizon terremark
Reality is worse...

- A commonly used pricing model
  - **Power Subscription** (i.e., reserved power capacity)
- **“Split incentive”**
  - Colocation operator desires energy saving
  - Tenants manage servers but have **no incentive** for energy saving

<table>
<thead>
<tr>
<th>CIRCUITS</th>
<th>KW</th>
<th>RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>20/120A</td>
<td>2.4</td>
<td>$350</td>
</tr>
<tr>
<td><strong>30/120A</strong></td>
<td><strong>3.6</strong></td>
<td><strong>$525</strong></td>
</tr>
<tr>
<td>20/208A</td>
<td>4.2</td>
<td>$610</td>
</tr>
<tr>
<td>30/208A</td>
<td>6.2</td>
<td>$910</td>
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Promotional pricing in Verizon Terremark’s Miami data center
Pricing tenants’ energy usage is **not good (enough)**

- **Uncoordinated** power management
  - High peak power demand charge
    - up to **40%** of total electricity bill
Pricing tenants’ energy usage is **not** good enough

**Coordinated**

- Uncoordinated power management
  - High peak power demand charge
    - up to 40% of total electricity bill
  - Fail to “follow the renewables”
Two stories coming next

**#1: Reducing colocation’s operating cost**

**#2: Enabling colocation demand response**
--- N. Chen, X. Ren, S. Ren, and A. Wierman “Greening Multi-Tenant Data Center Demand Response,” IFIP WG7.3 Performance 2015.
Cost, cost, and cost!

- Electricity cost

<table>
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<tr>
<th>Amortized Cost</th>
<th>Component</th>
<th>Sub-Components</th>
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<tr>
<td>~45%</td>
<td>Servers</td>
<td>CPU, memory, storage systems</td>
</tr>
<tr>
<td>~25%</td>
<td>Infrastructure</td>
<td>Power distribution and cooling</td>
</tr>
<tr>
<td>~15%</td>
<td>Power draw</td>
<td>Electrical utility costs</td>
</tr>
<tr>
<td>~15%</td>
<td>Network</td>
<td>Links, transit, equipment</td>
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Table: Guide to where costs go in an Google-type data center.

Cost, cost, and cost!

- Electricity cost $\approx 40\%$ of TCO

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Table: Guide to where costs go in an Google-type data center.

Let’s reduce the electricity cost ($\text{OpEx}$)!
Coordinated power management

RECO

Idea: dynamically pay tenants for **not** using energy
What is RECO?
What is RECO?

Market-Enabled DCIM System

Integrated Optimizer

Incentive

Power & cooling

CRAH

Operator

Tenant #1

Tenant #2

Operator
But, how to ... 

- Know tenants’ responses to rewards?

Cut energy by ....??
But, how to ...

- Know tenants’ responses to rewards?
- Set supply air temperature?

\[ T_{inlet} = T_{supply} + D \cdot P_{server}(r) \]
But, how to ... 

- Know tenants’ responses to rewards?
- Set supply air temperature?
- Reduce peak demand?
  - Peak demand charge is determined as the maximum power (e.g., over 15-min interval) over a billing cycle
  - Set higher rewards during peak demand periods, but when does the peak demand occur?
RECO

- Track the “peak” power demand online
  - Set a higher reward only when the expected upcoming power usage exceeds the tracked peak

Minimize “energy cost + reward” (plus peak demand charge)

Update “peak” power usage

![Graph showing normalized power over time](image)
Case study
How to evaluate RECO?

• Scaled-down prototype system
  – 5 Dell PowerEdge servers, each having 6 VMs
    • Tenant #1: Hadoop workloads (e.g., data analytics), with a maximum deadline of 15 minutes
    • Tenant #2: Web workloads based on key-value stores (e.g., Facebook), with a SLA of 95% delay not exceeding 500ms
• Power management
  – AutoScale, which is being used in Facebook’s production system

Our prototype system housed in FIU-SCIS data center
RECO saves operator’s OpEx

• Benchmarks
  – BASELINE: power-based pricing without rewards

10+% cost saving!
Tenants receive rewards for “free”

- Tenants 1 & 2 save 6.5% and 3.5%, respectively
  - Without violating SLA
- Results further confirmed by simulations

**RECO is “win-win”!**
Data center is energy hog

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Data center is an energy hog

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Power industry is changing

Supply                  Demand

13x

Random

Supply = Demand

Demand response

“Demand response provides an opportunity for consumers to play a significant role in the operation of the electric grid by reducing or shifting their electricity usage during peak periods in response to time-based rates or other forms of financial incentives.”

--- energy.gov
Demand *follows* supply

Demand \textit{follows} supply

- Data center demand response
  - Data center has large yet \textit{flexible} energy demand
  - Recognized by U.S. EPA and data center industry

Why colocation demand response?

• “Most large data centers” are colocations
• Many colocations are in metropolitan areas
  – Downtown Los Angeles, New York, Silicon Valley, etc.
  – This is where demand response is most wanted!

Example: On July 22, 2011, hundreds of colocation data centers participated in emergency demand response and contributed by cutting their electricity usage before a nation-wide blackout occurred in the U.S. and Canada.

–– A. Misra, “Responding Before Electric Emergencies.”
How do colocations participate in DR?

• Current practice
  – Turn on diesel generator upon utility’s request
    • Very expensive and high carbon emissions

In California, diesel generator produces 50 to 60 times the NOx pollution of a typical gas-fired power plant, and diesel particulate represents the state’s most significant toxic air pollution problem.
How do colocations participate in DR?

**Buy energy reduction from tenants!**

- **Current practice**
  - Turn on **diesel generator** upon utility’s request
    - Very expensive and high carbon emissions
  - **Incentivize** and **coordinate** tenants’ energy reduction
    - Tenants typically have great flexibilities in reducing energy
How to enable efficient colocation DR?

• Problem at hand

\[
\begin{align*}
\min_{\alpha, y} & \quad \alpha \cdot y + \sum_{i} c_i(s_i) \\
\text{s.t.,} & \quad y + \sum_i s_i = \delta
\end{align*}
\]

#1: Pricing tenants’ energy reduction

--- But, tenants’ responses are unknown...

#2: VCG-type reverse auction

--- Tenants need to submit complex cost functions (revealing their private information), payment made to tenants may be unbounded, payment may be “unfair”, etc.
How to enable **efficient** colocation DR?

- **Problem at hand**

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#1: Pricing tenants’ energy reduction

---

**Our proposal**: Supply function bidding!

#2: VCG-type reverse auction

---

Tenants need to submit complex cost functions (revealing their private information), payment made to tenants may be unbounded, payment may be “unfair”, etc.
Market setup: supply function bidding

Diesel energy $y = \delta - \sum_i s_i$

Cut energy $\delta$

Utility

Supply bid $b_i$

Price $p$

Operator

Tenants

Cut energy by $s_i = \delta - \frac{b_i}{p}$

#1: Operator announces supply function $s(b, p) = \delta - \frac{b}{p}$

#2: Tenant $i$ submits bid $b_i$ to maximize its own profit

#3: Operator clears market price $p$ to minimize its own cost (payment to tenants plus diesel cost)

#4: DR is exercised
Efficiency analysis

• **Benchmark:** Social cost minimization

\[
\begin{align*}
\min & \quad \alpha \cdot y + \sum_i c_i(s_i) \\
\text{s.t.,} & \quad y + \sum_i s_i = \delta
\end{align*}
\]

• Tenants can be
  - **Price-taking:** Consider the price as is
  - **Price-anticipating:** Consider the impact of bidding decisions on the equilibrium price
Price-taking tenants

**Theorem:** When tenants are price-taking, the market equilibrium \((b, p, y)\) is unique and characterized by

\[
\min_{s, y} \sum_i c_i(s_i) + \frac{\alpha}{2N} \delta [y + (N - 1)\delta]^2
\]

s.t., \(\sum_i s_i + y = \delta\)

Further, the equilibrium satisfies \(\sum_i c_i(s_i) \leq \sum_i c_i(s^*_i) + \frac{\alpha \delta}{2N}\) and \(y \leq y^* + \frac{\delta}{2}\), where * denotes the socially optimal solution.

Similar results hold for price-anticipating tenants!
Case study

- DR signals issued by PJM on January 7, 2014, due to cold weather
- Reduces cost by over 50% compared to diesel-only solution (and very close to “social” optimum)
  - Diesel usage can be reduced by more than 60% or even completely eliminated
(Two + one) messages

#1: Multi-tenant colocation is very critical
--- approx. 40% of total data center energy

#2: Power management in colocations is uncoordinated

#3: From uncoordinated to coordinated
--- Reduce colocation’s operating cost
--- Transform energy hog to a social asset
Colocation Providers, Customers Trade Tips on Energy Savings

Why the majority of data centers are failing at energy efficiency

By Heather Clancy
Published August 26, 2014
Tags: Energy Conservation, Energy Efficiency

NRDC: Multi-Tenant Data Centers Need To Play Bigger Energy Efficiency Role

America’s Data Centers Consuming and Wasting Growing Amounts of Energy

Critical Action Needed to Save Money and Cut Pollution
RagingWire guarantees 100% uptime with CA at the center.

Today, every data center customer demands "always on." CA management software gives RagingWire the power to put it in writing. Guaranteed. CA.com/AtTheCenter