Cutting Electricity Cost For Service Provider Networks

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FDC

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Muhamad Fareed Zaffar

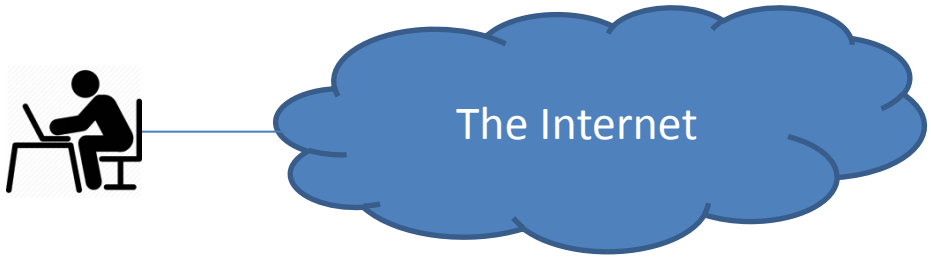
Aamir Qayyum

Agenda

- Background and motivation
- Opportunity and key idea
- Case studies:
  - Data centers
  - Cellular networks
- Conclusions and future work

Background

Background



Source: http://bit.ly/20pOBWJ

A YouTube data center

Source: http://bit.ly/1p07fEc

The Interne

Source: http://cnet.co/1Q9SkZ0

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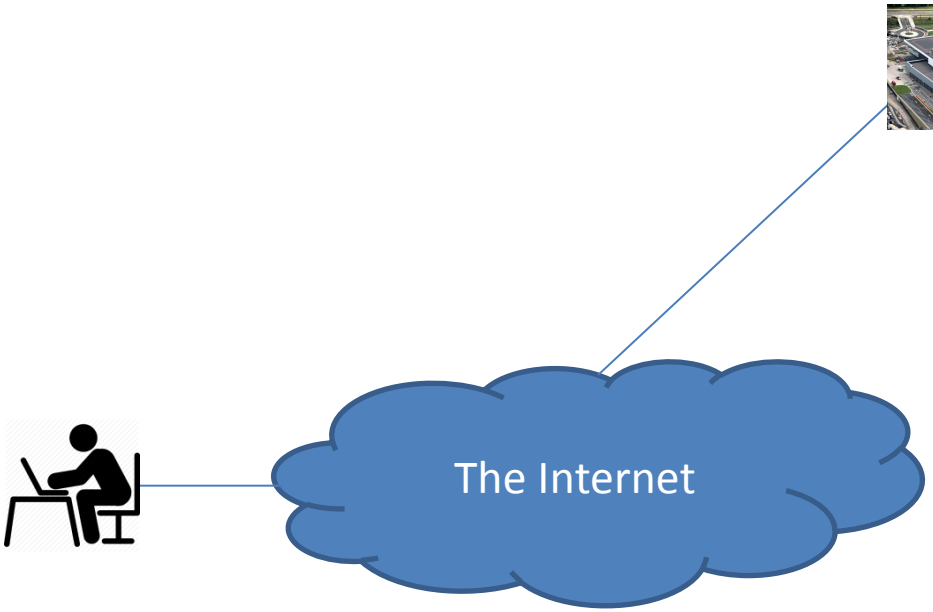

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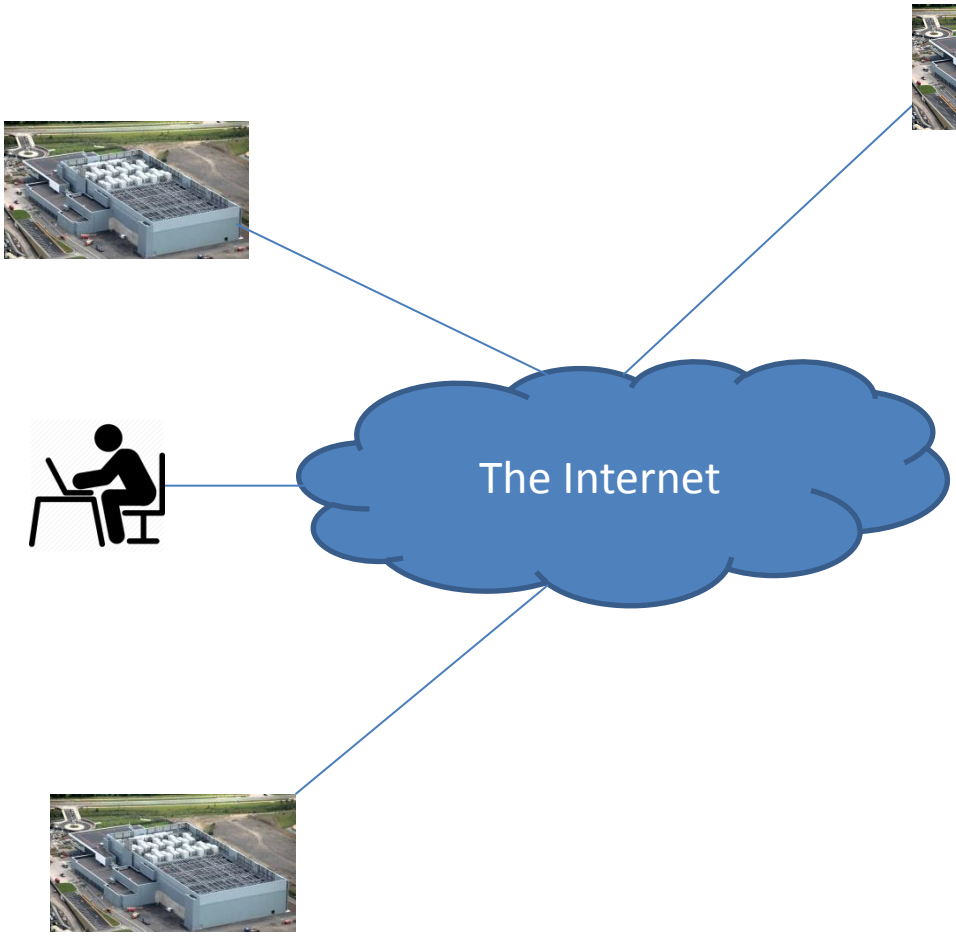

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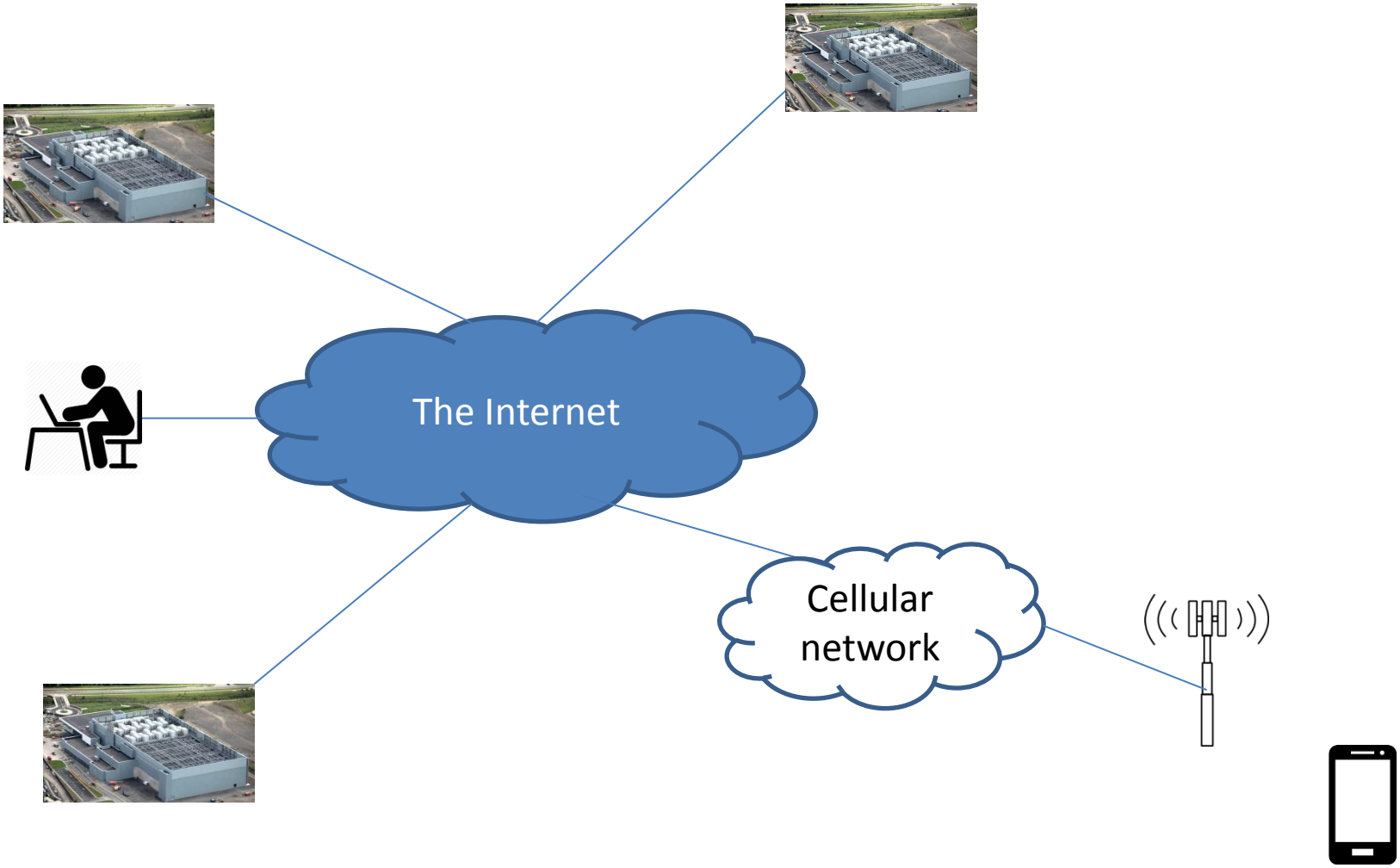

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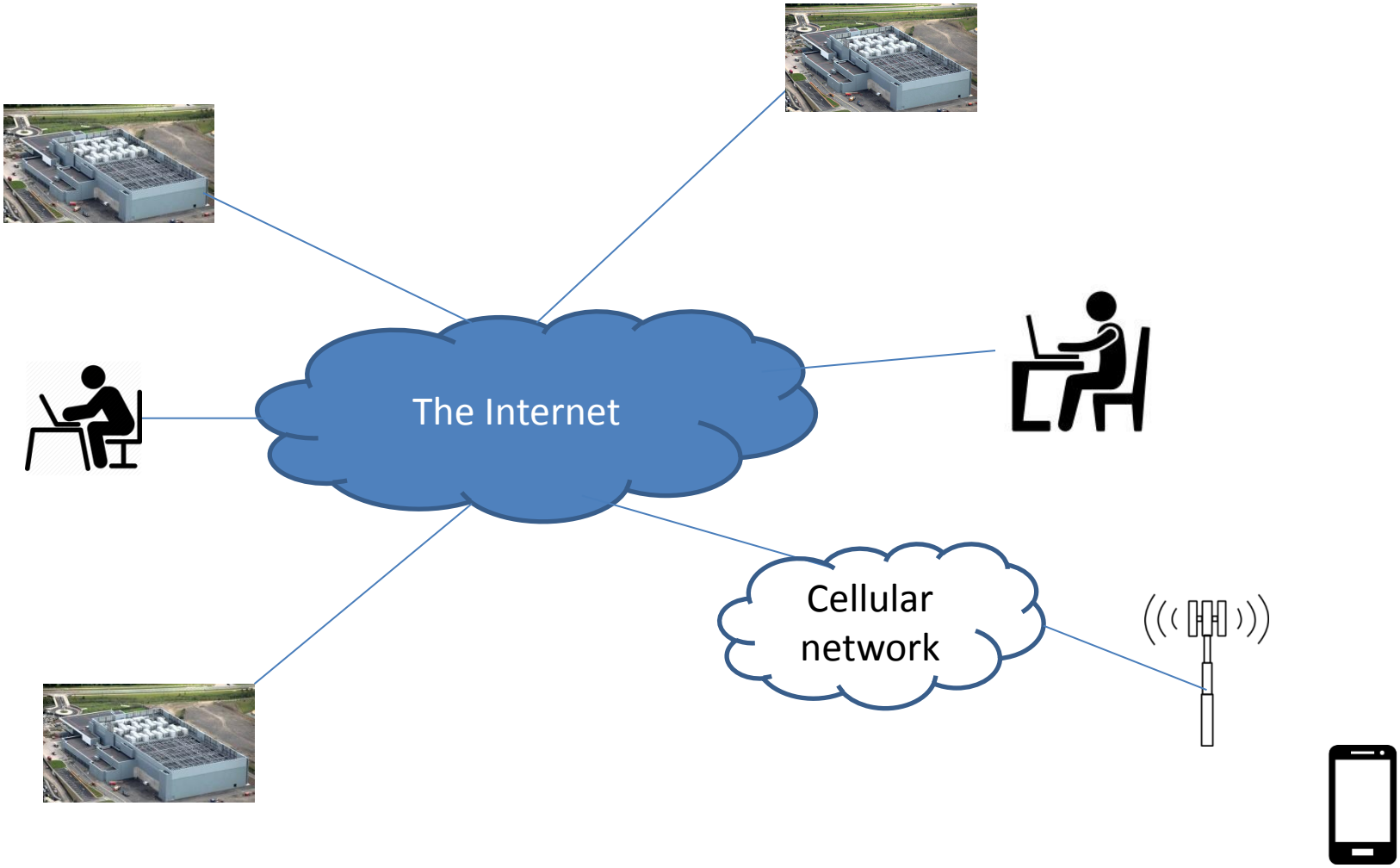

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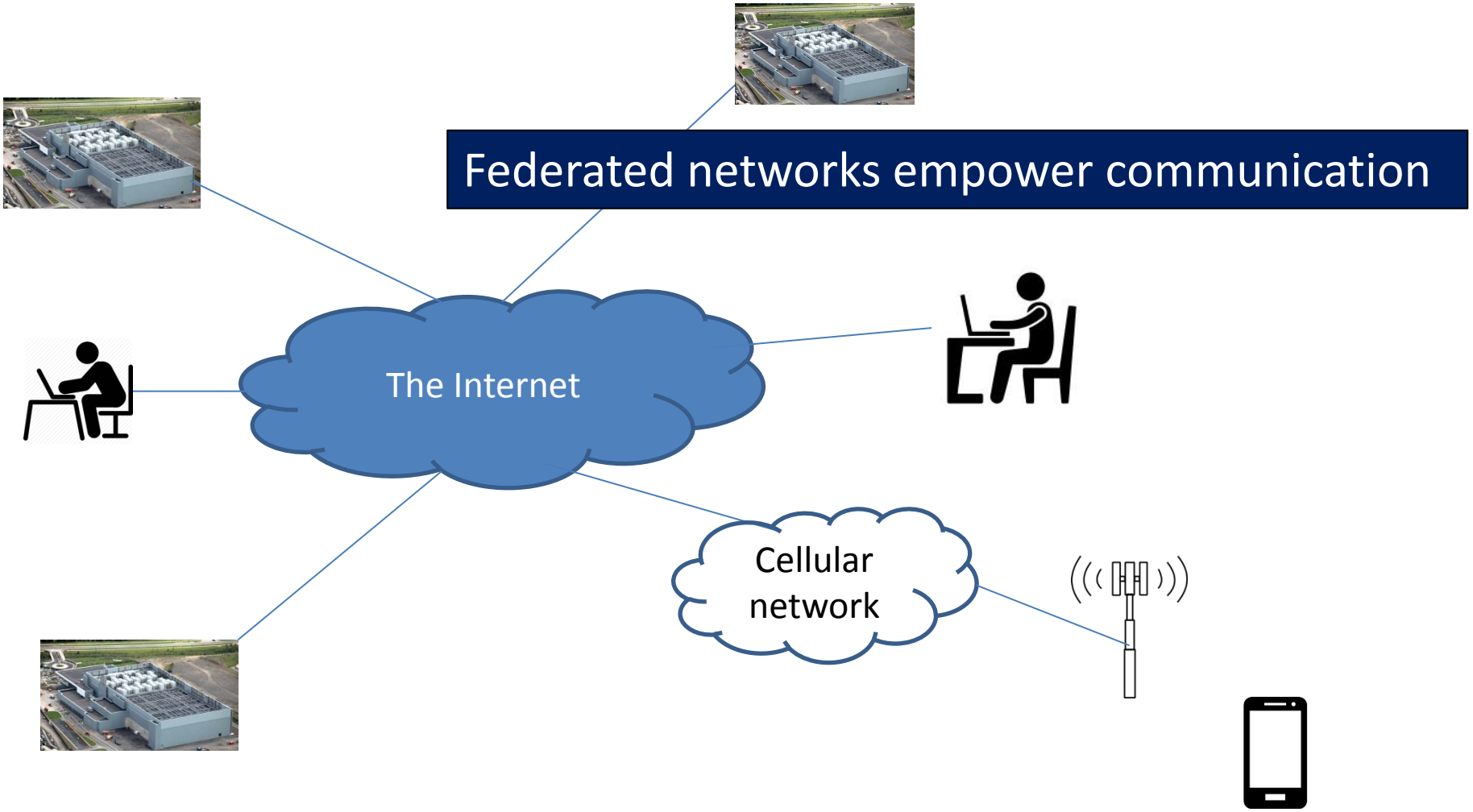
Federated networks empower communication
The Internet
Cellular network

Network Scale

Image source: http://bit.ly/1awWnLn

Network Scale

1 Data Center ~ 50,000 - 80,000 servers

Google's data center locations
http://bit.ly/1WbIvbe

Network Scale

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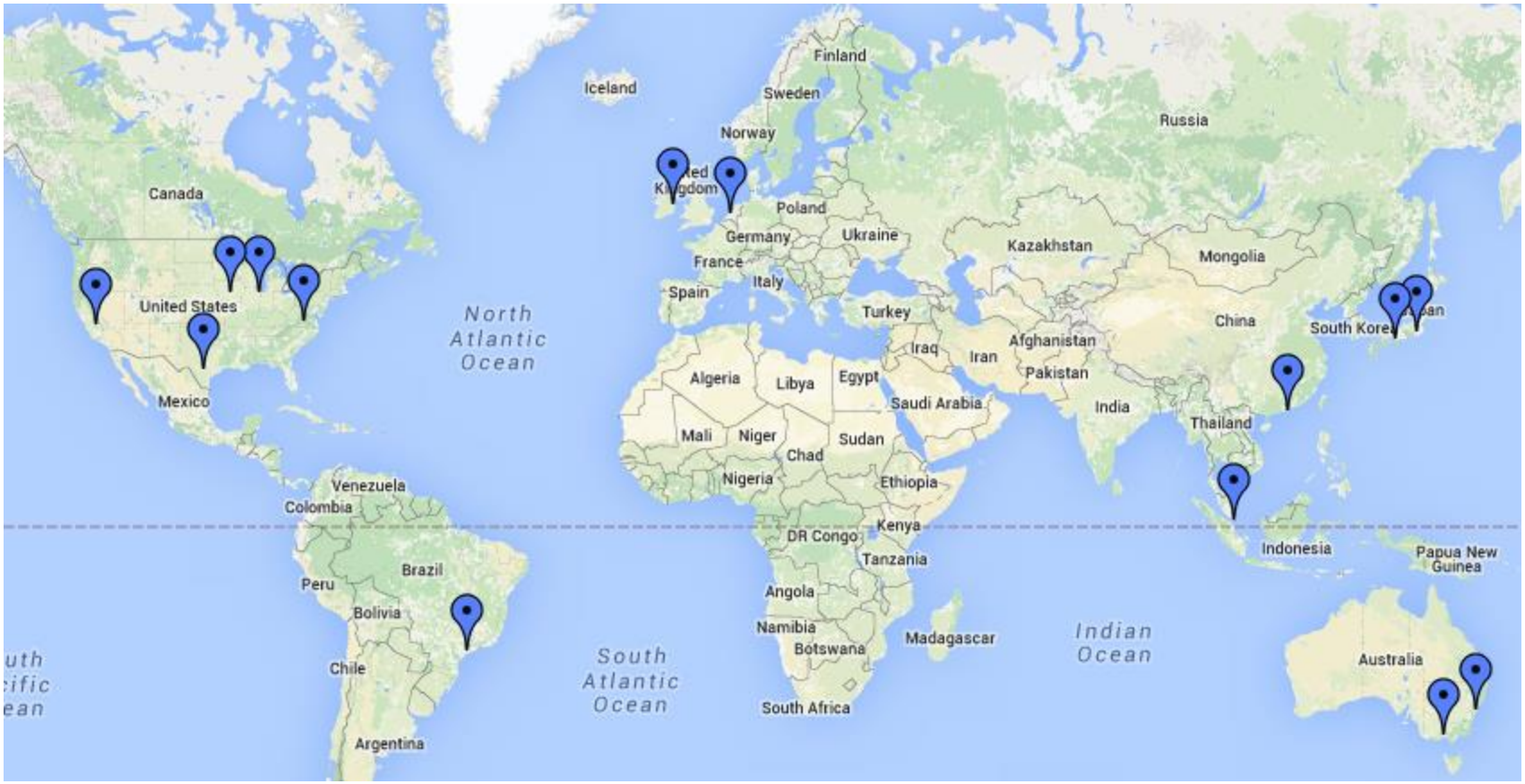
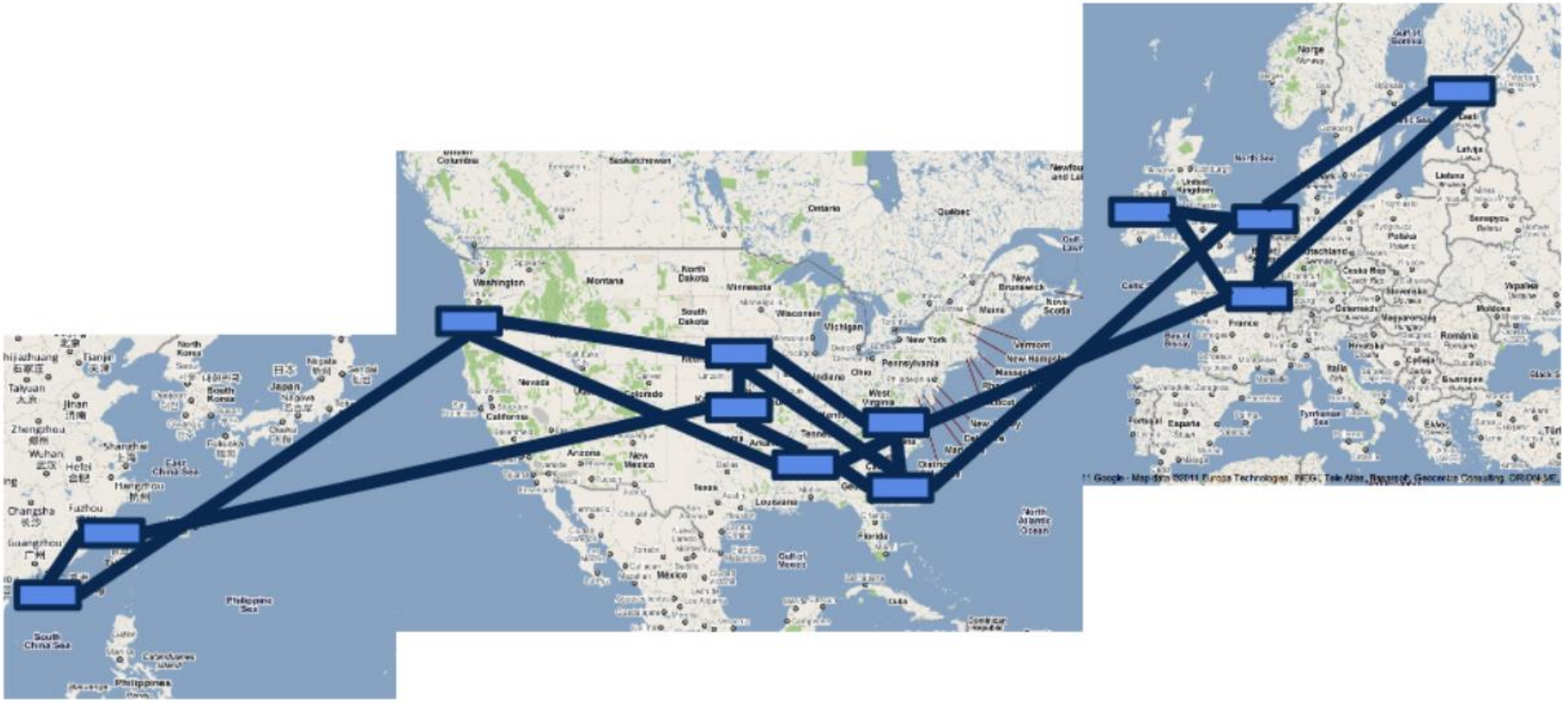


Microsoft Azure's data center locations
http://bit.ly/1mqvi26

Network Scale



Google's B4 SDN

Image Source: Jain et. al, "B4: Experience with a globally-deployed software defined WAN", SIGCOMM 2013

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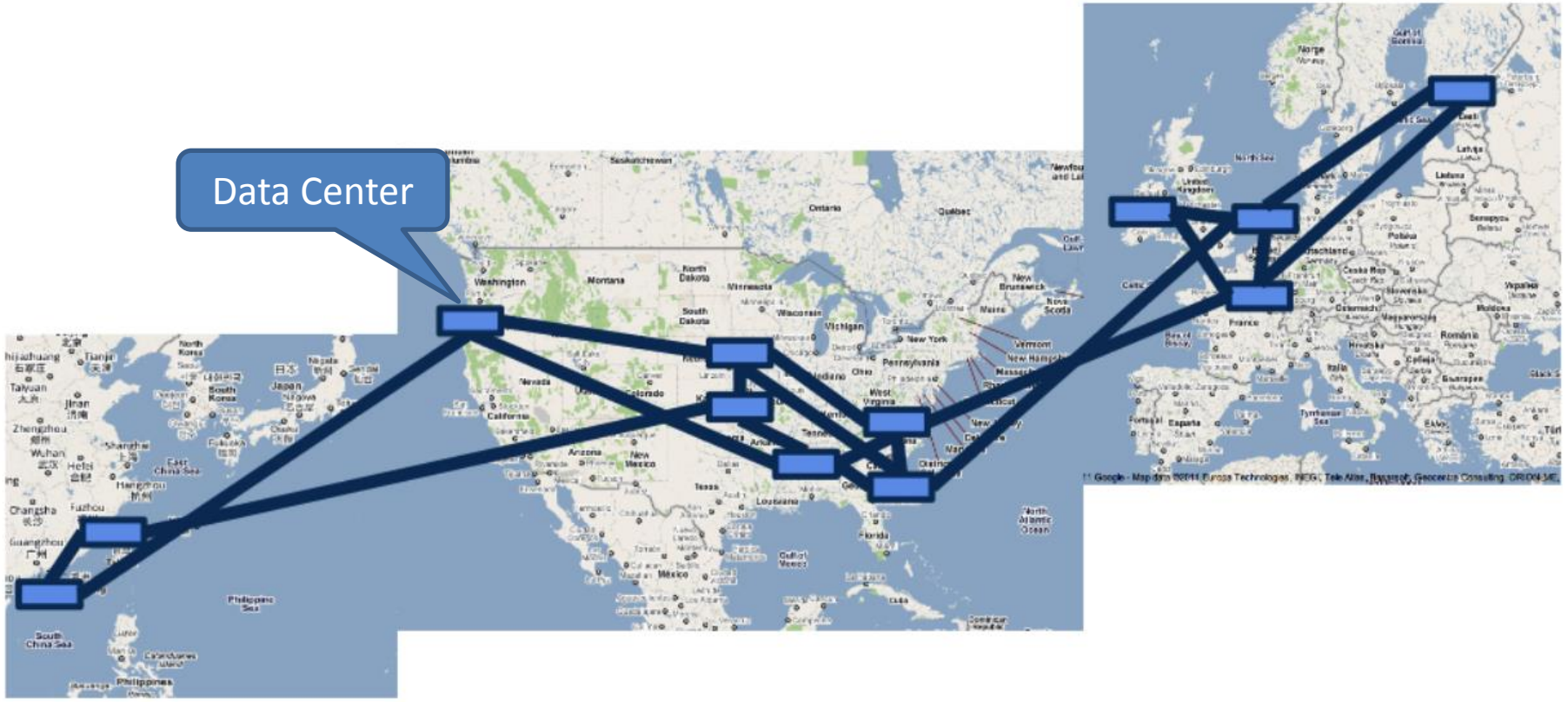

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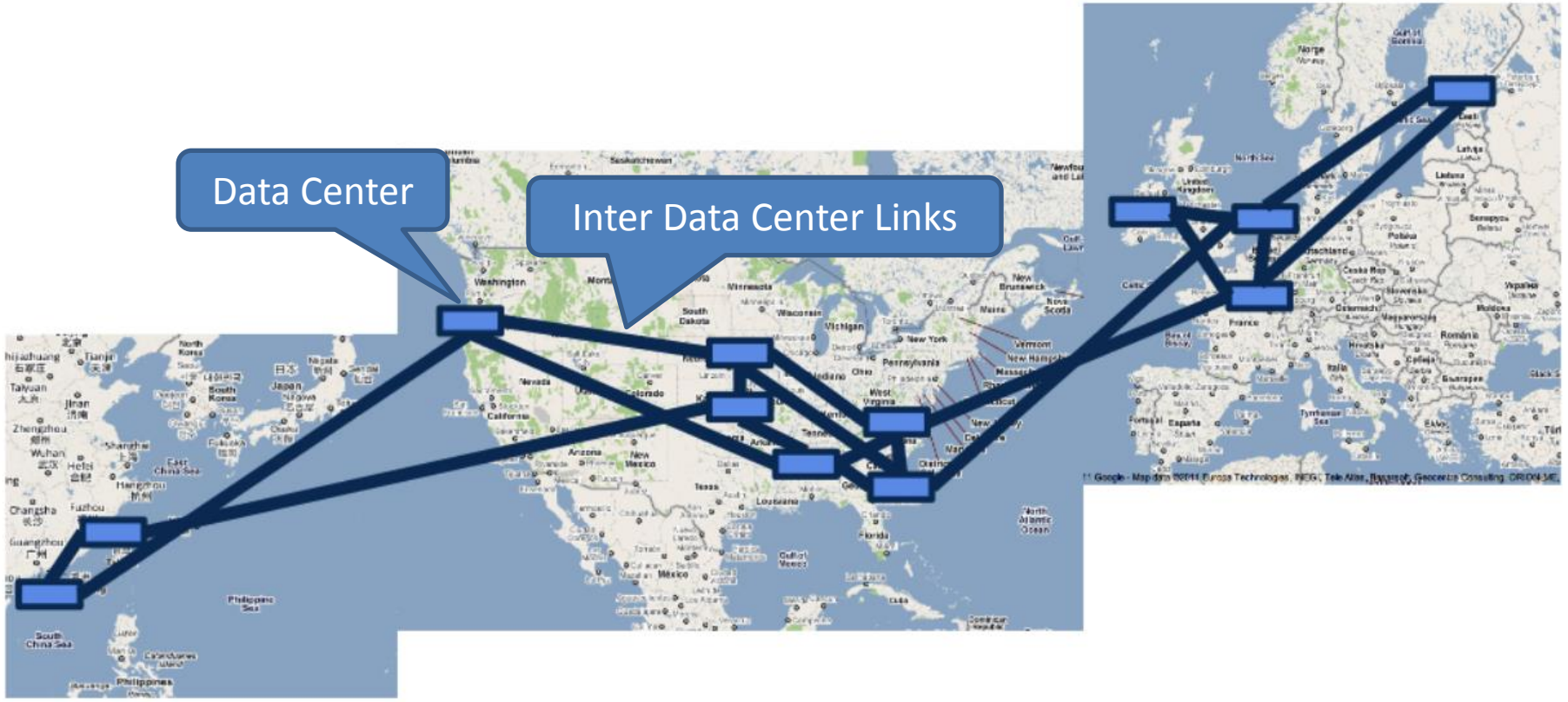

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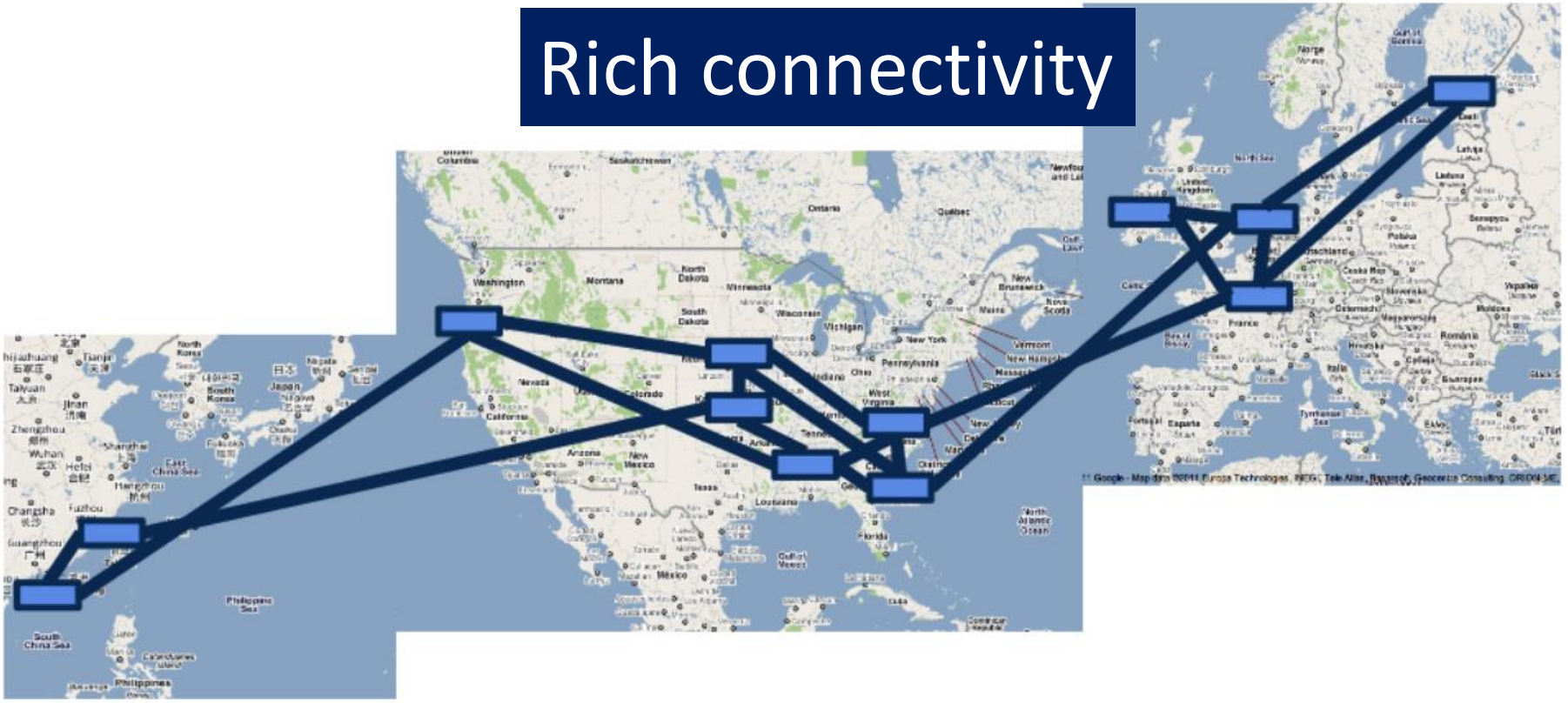

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Network Scale

- Amazon

Network Scale

- Amazon
  - 87 data centers
  - At least 2 M servers

Source: http://bit.ly/11erCWn

Network Scale

- Amazon
  - 87 data centers
  - At least 2 M servers
- Telenor Pakistan
  - 8000 cellular sites

Source: http://bit.ly/1T9VBqd

Network Scale

Massive infrastructure

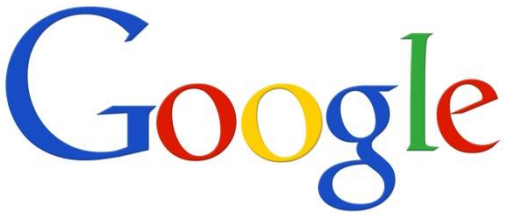
Network Scale

Massive infrastructure → Massive power draw

Network Scale

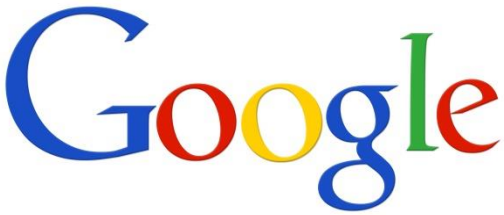
Network Scale

Motivation



Motivation

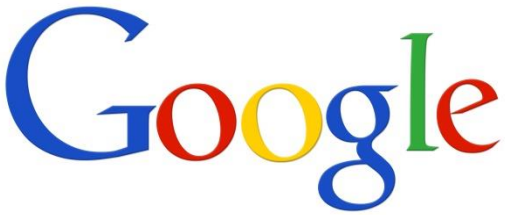
Annual DC Opex



$951 M

Source: datacenterknowledge.com

Motivation

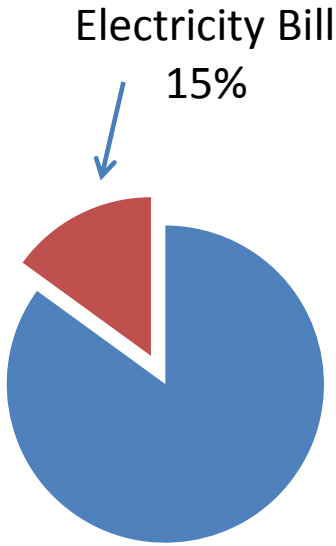


Annual DC Opex

$951 M

Electricity Cost

$143 M



Source: Greenberg et. al, "Cost of a cloud: Research Problems in Data Center Networks", CCR 2009

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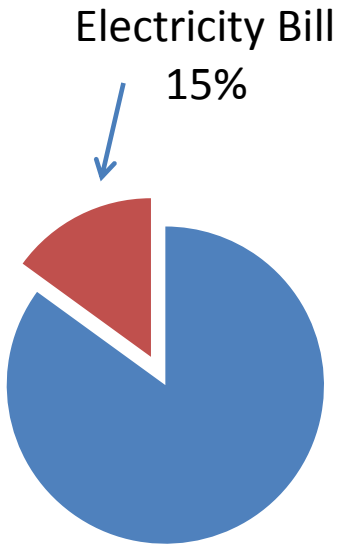

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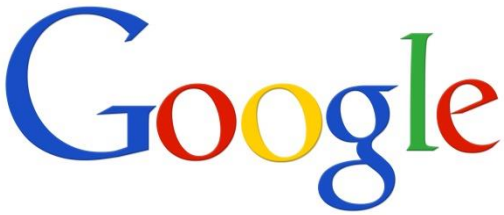

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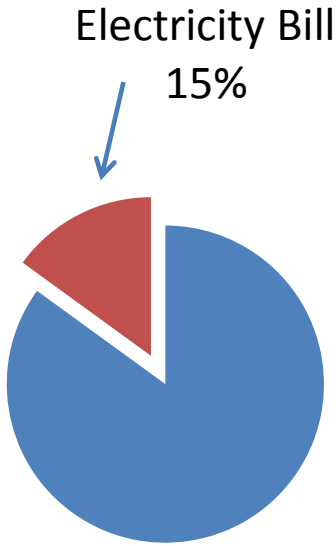

Electricity Cost 2012

$81 M

Motivation

Annual DC Opex

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Electricity Cost

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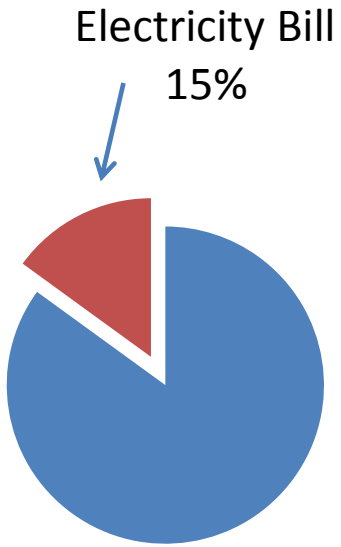

Electricity Cost 2012

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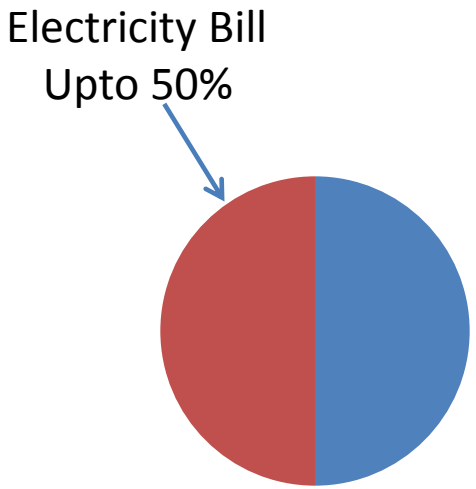
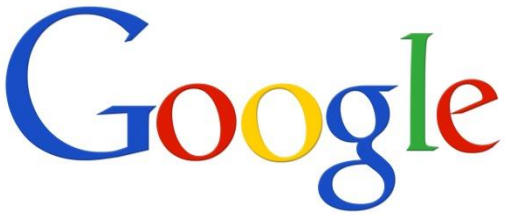


Source: GREENNETS

Motivation



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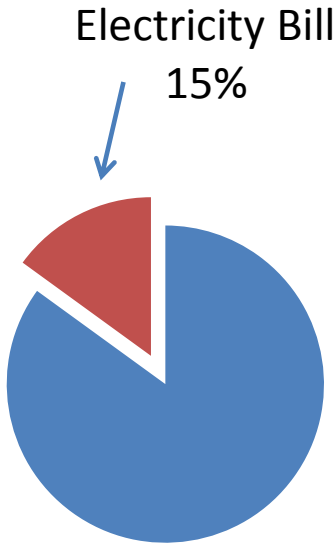

Significant electricity costs

Electricity Cost 2012

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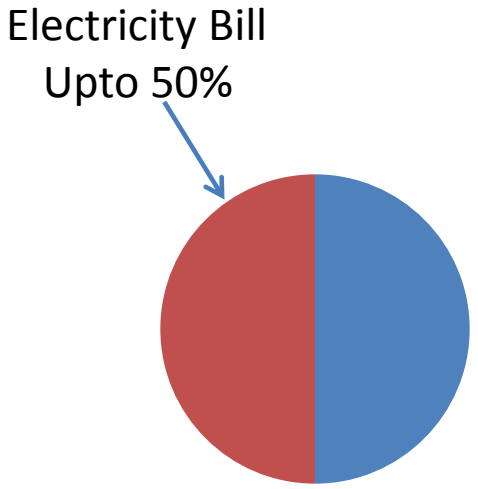

Agenda

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- **Opportunity and key idea**
- Case studies:
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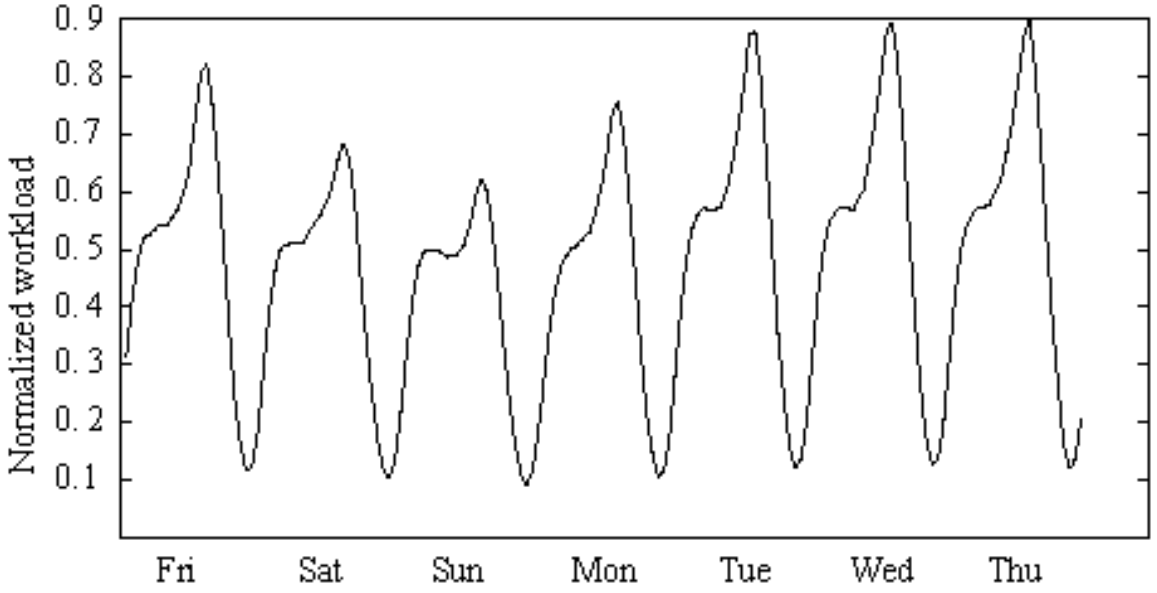
- Conclusions and future work

Opportunity

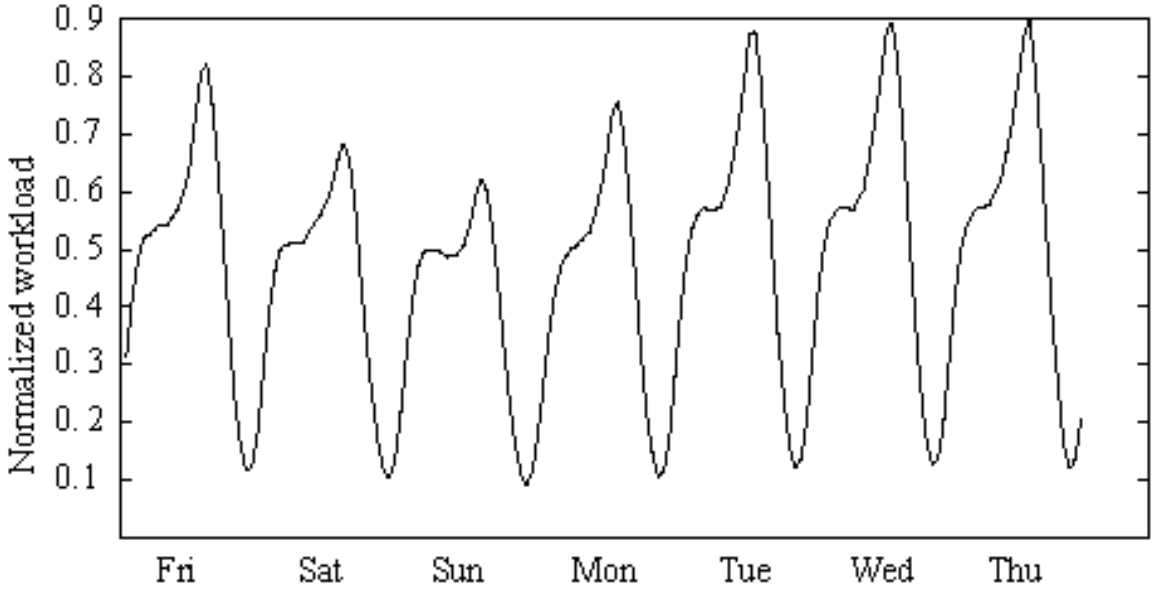
Network workload has systematic variations



A. Nazir et. al, "Unveiling Facebook: a Measurement Study of Social Network Based Applications"
Barroso et. al, "The Case for Energy Proportional Computing", IEEE Computer, 2007
Peng et. al, "Traffic-Driven Power Savings in Operational 3G Cellular Networks", MOBICOM 2011

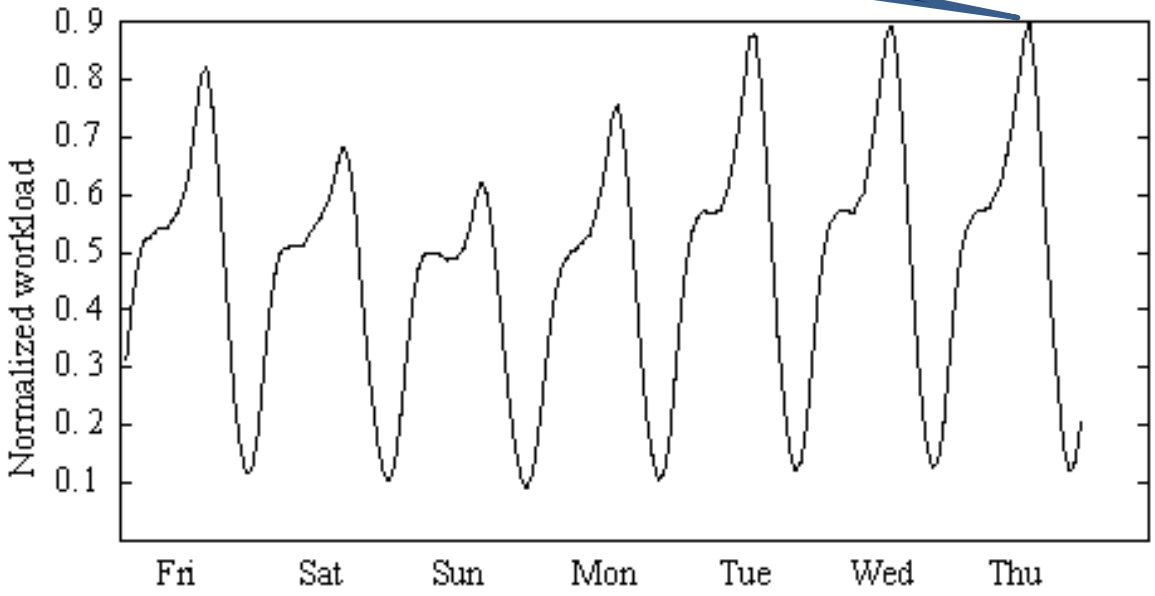
Opportunity

Peaks and troughs quite pronounced



Opportunity

Deploy sufficient resources to handle peak



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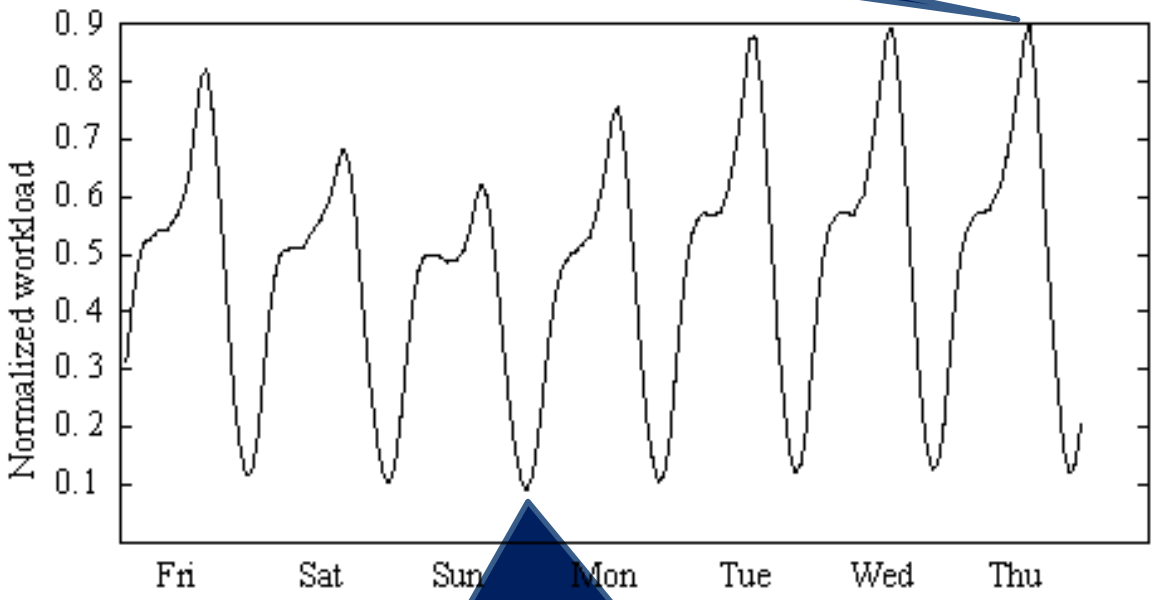
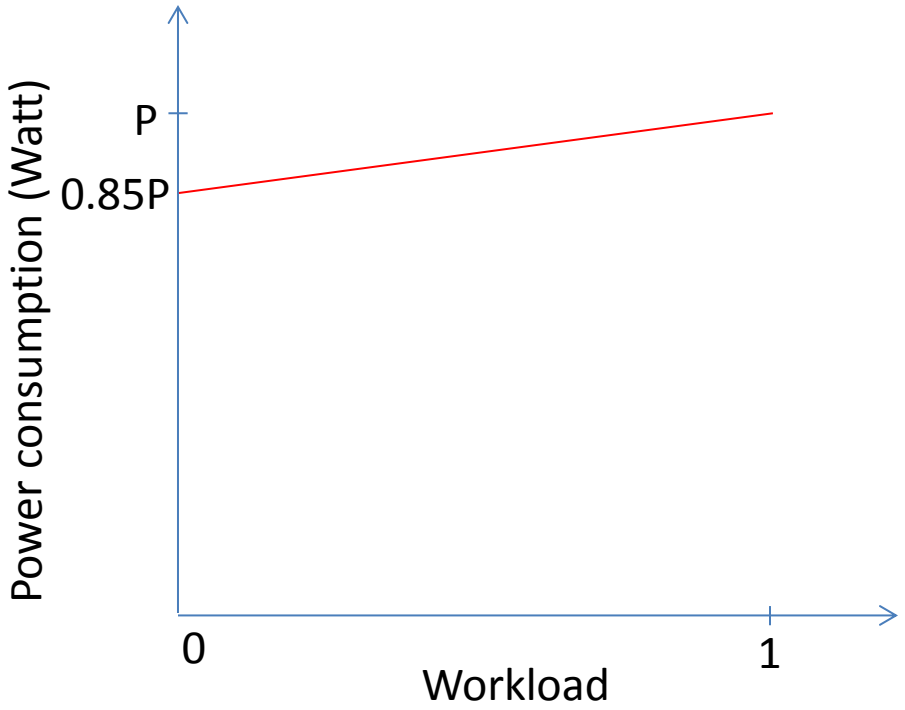


Most equipment (nearly) idle

Opportunity

DC Idle power
75%-85% of peak power



Source: Emerson, “Energy Logic: Reducing Data Center Power Consumption…”

Opportunity

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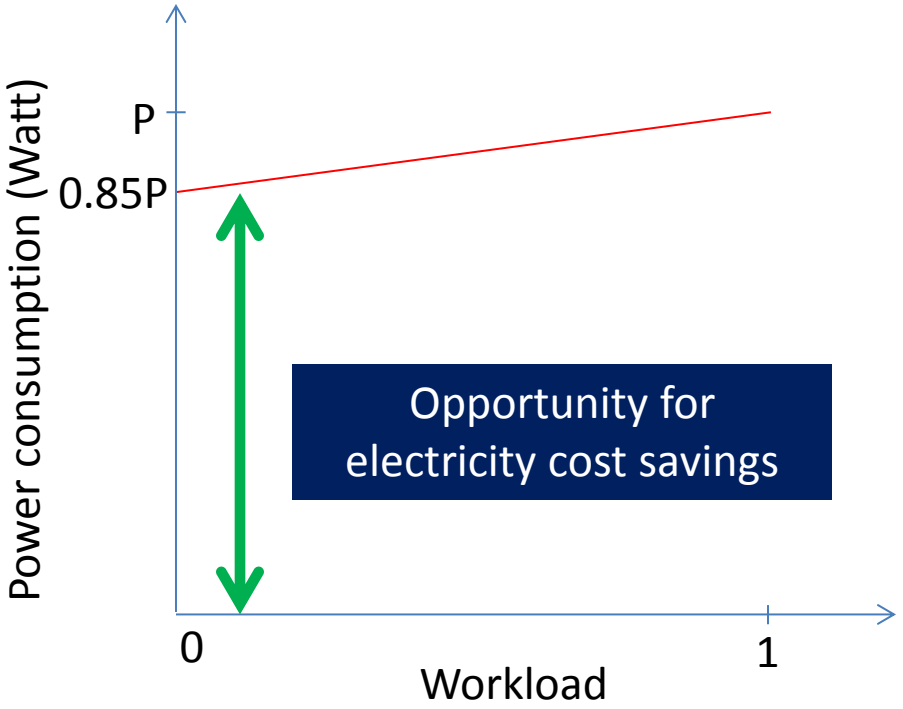
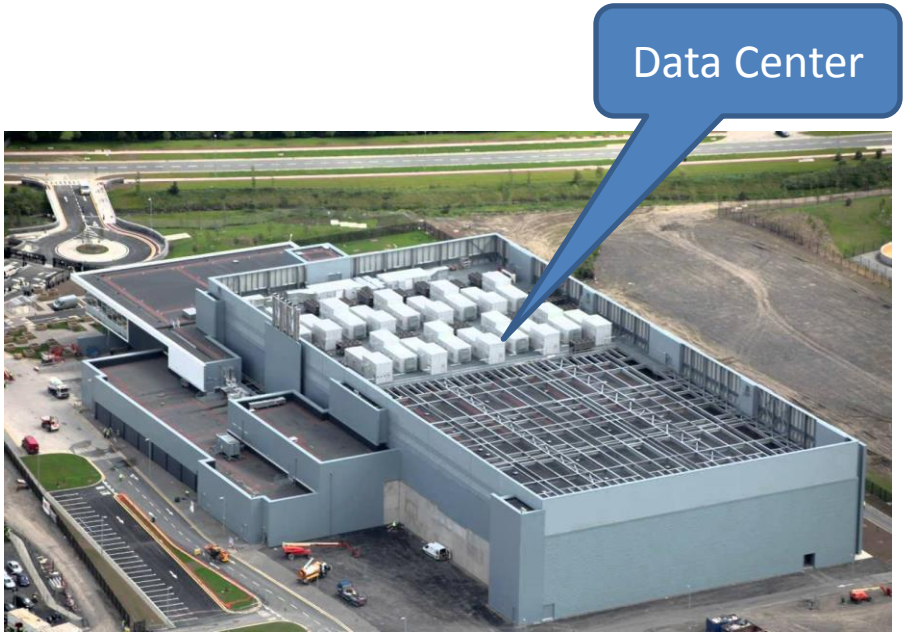


Source: Emerson, “Energy Logic: Reducing Data Center Power Consumption…”

Key Idea

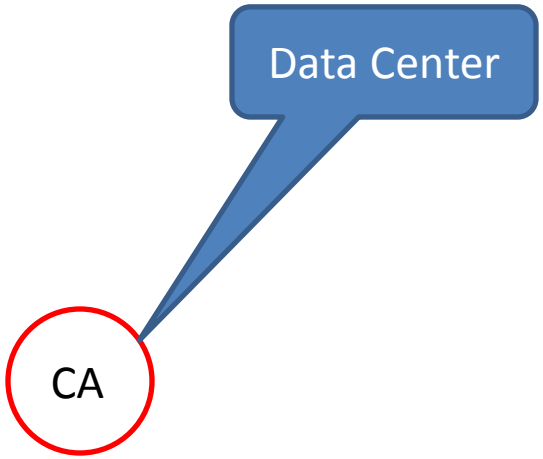
Deactivate idle equipment

Key Idea



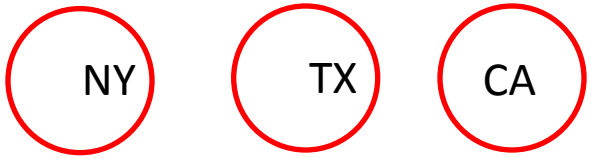
Key Idea

CA: California



Key Idea

CA: California
NY: New York
TX: Texas



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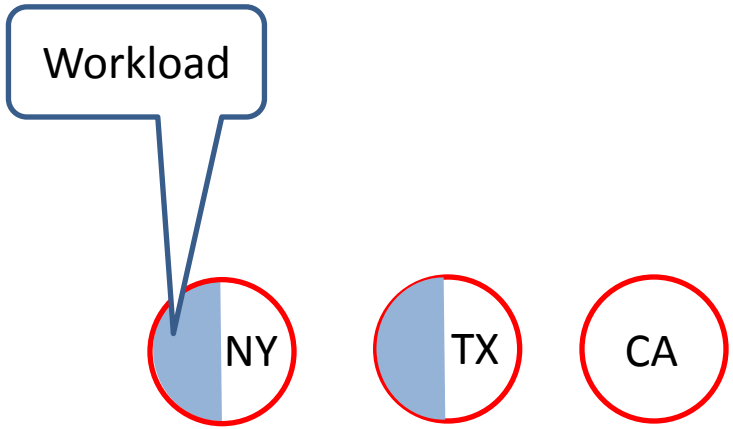

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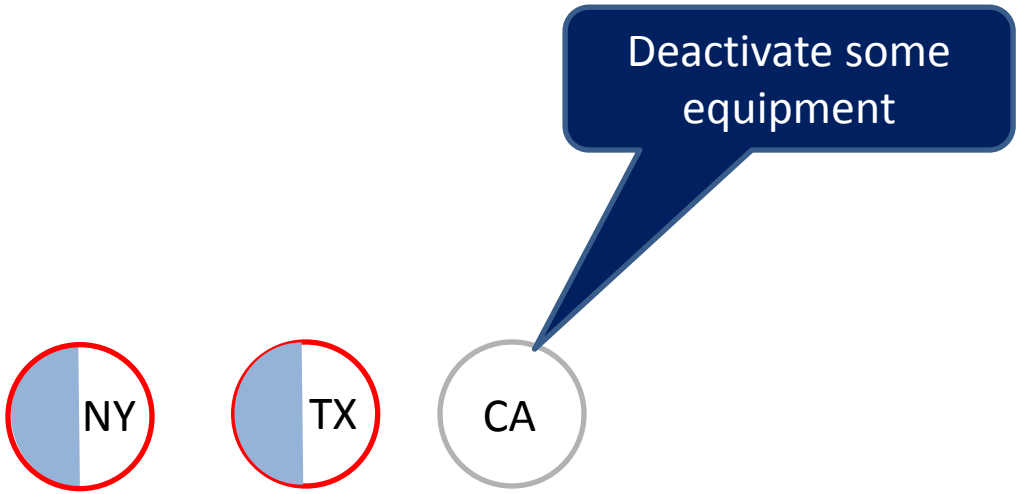

Key Idea

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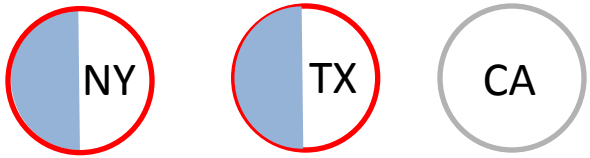
Resource pruning cuts electricity cost



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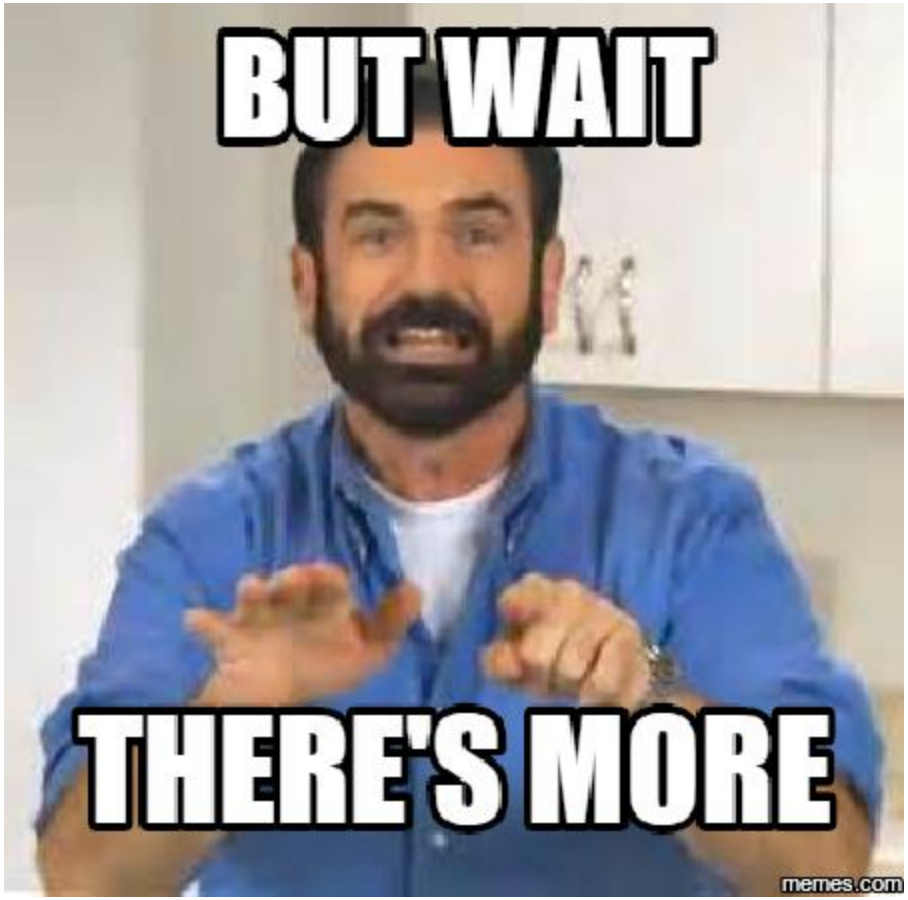
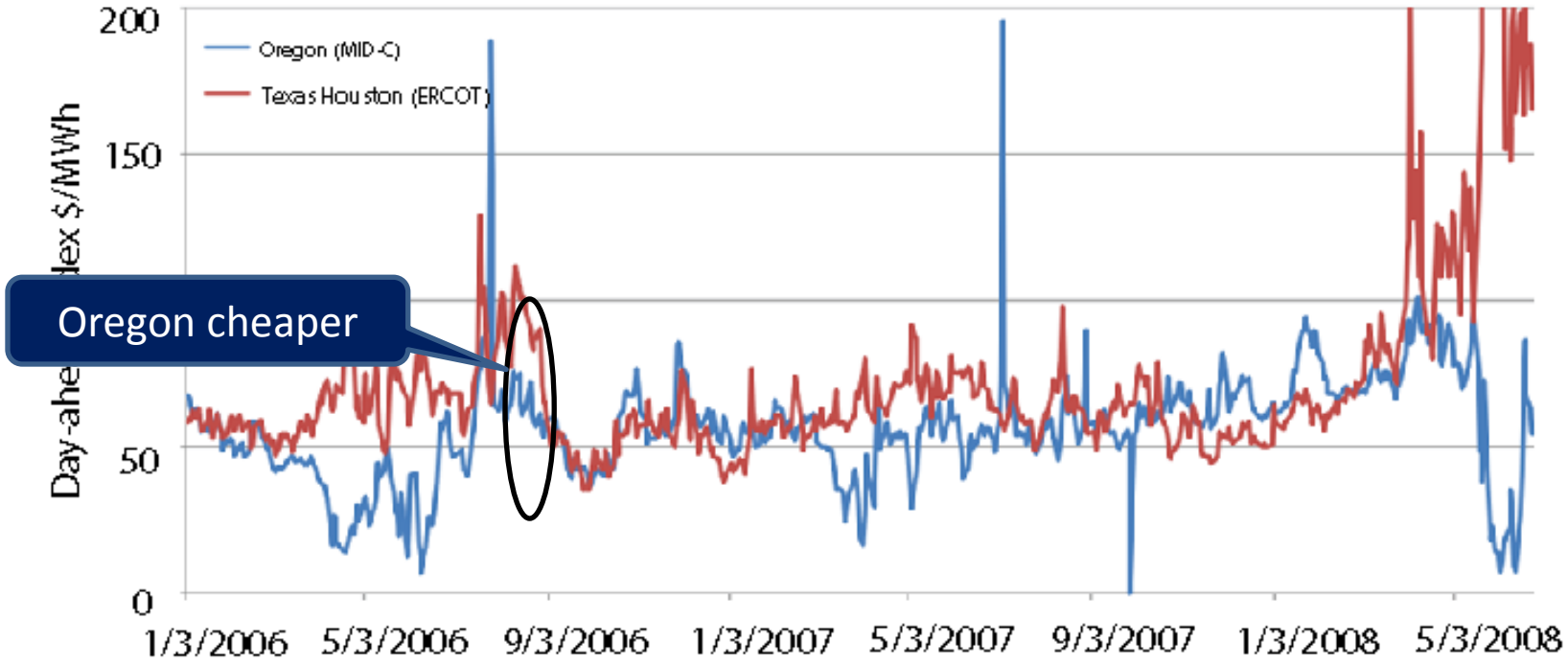


An Observation



A. Qureshi et. al, “Plugging into energy market diversity”, HOTNETS 2008

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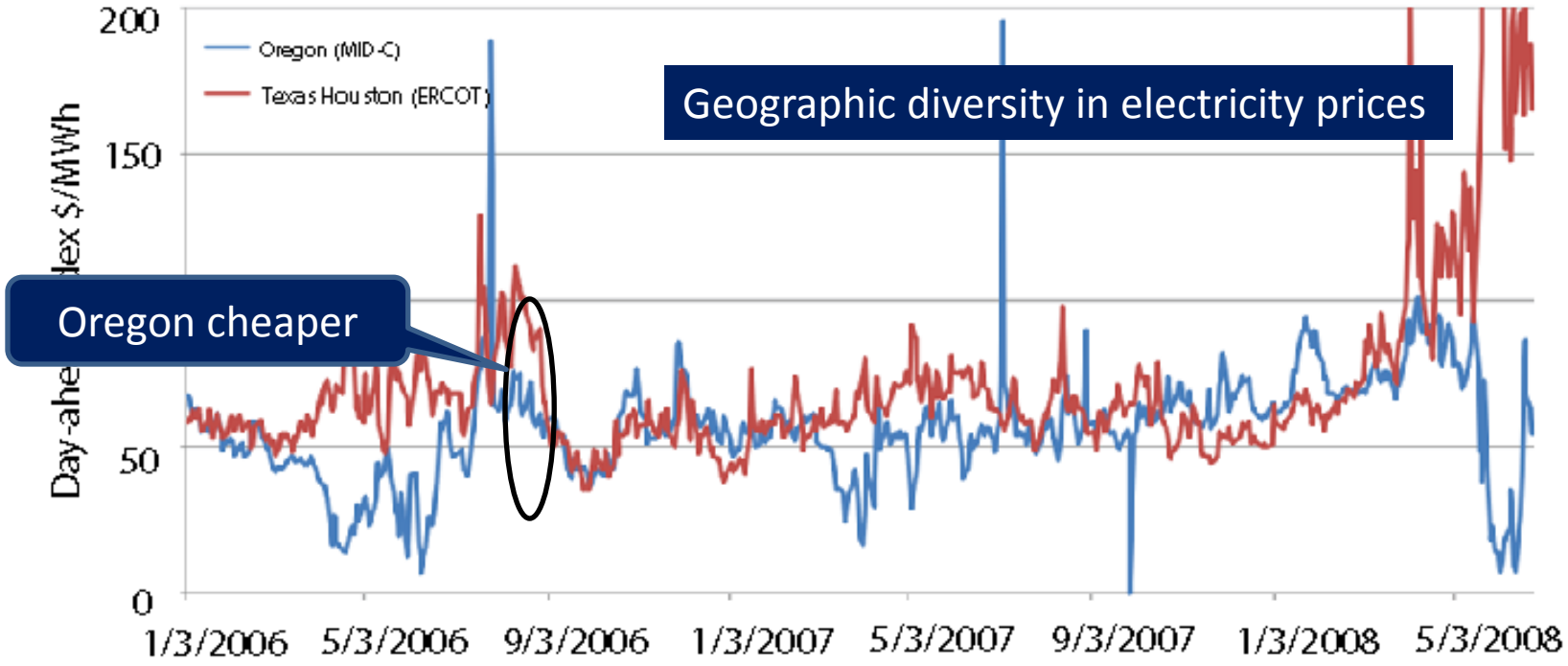

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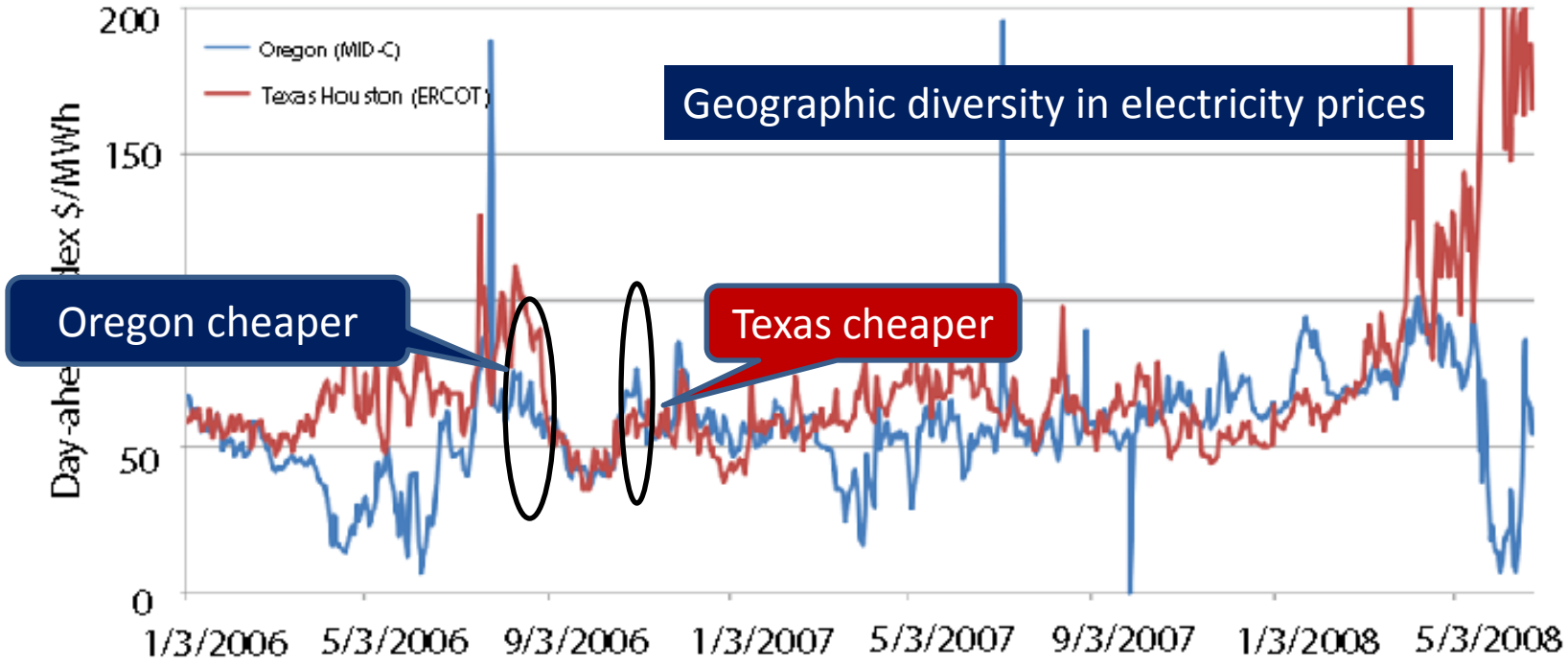

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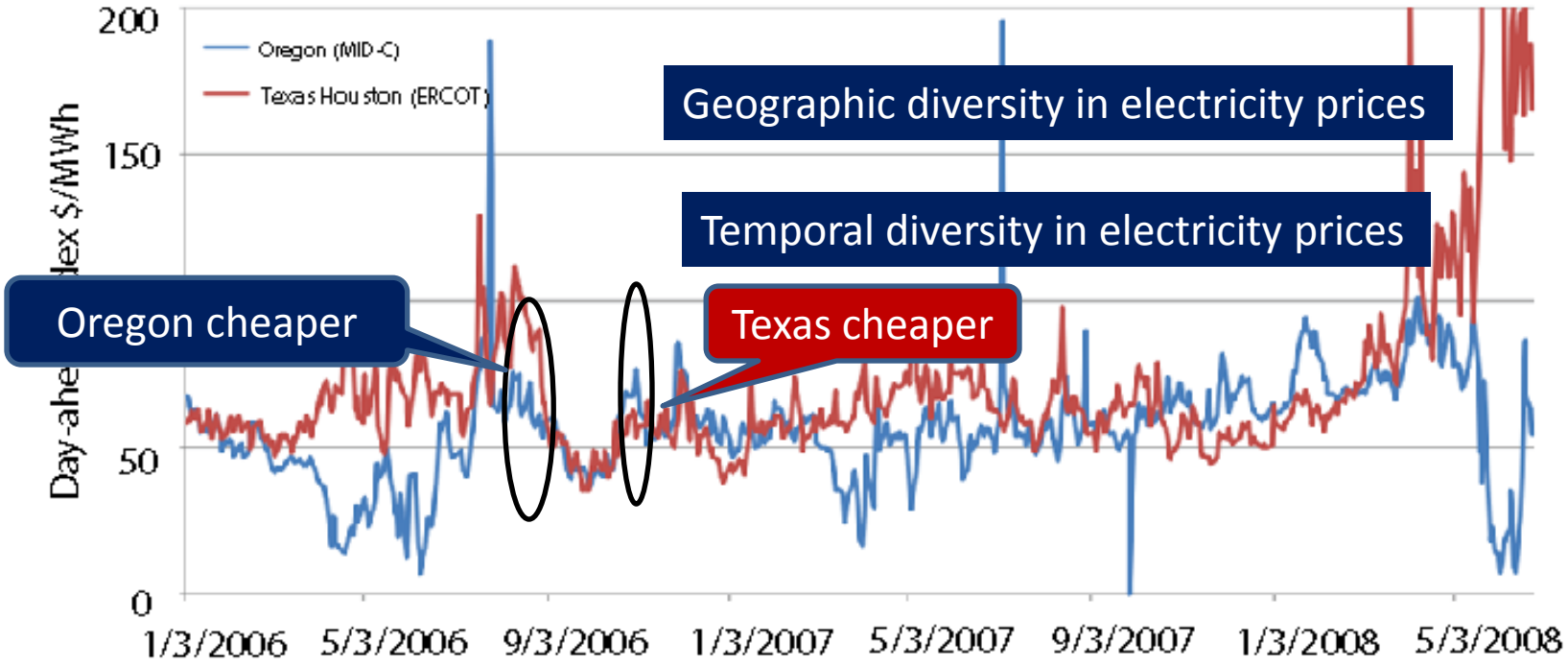

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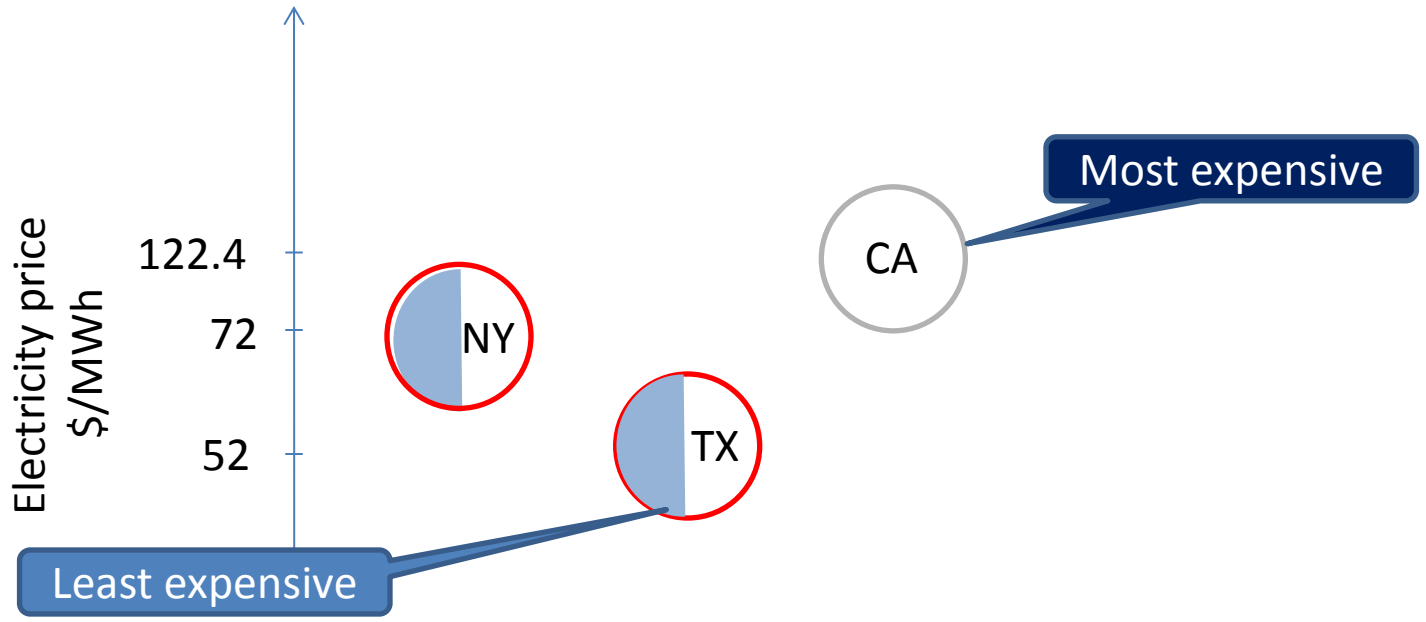

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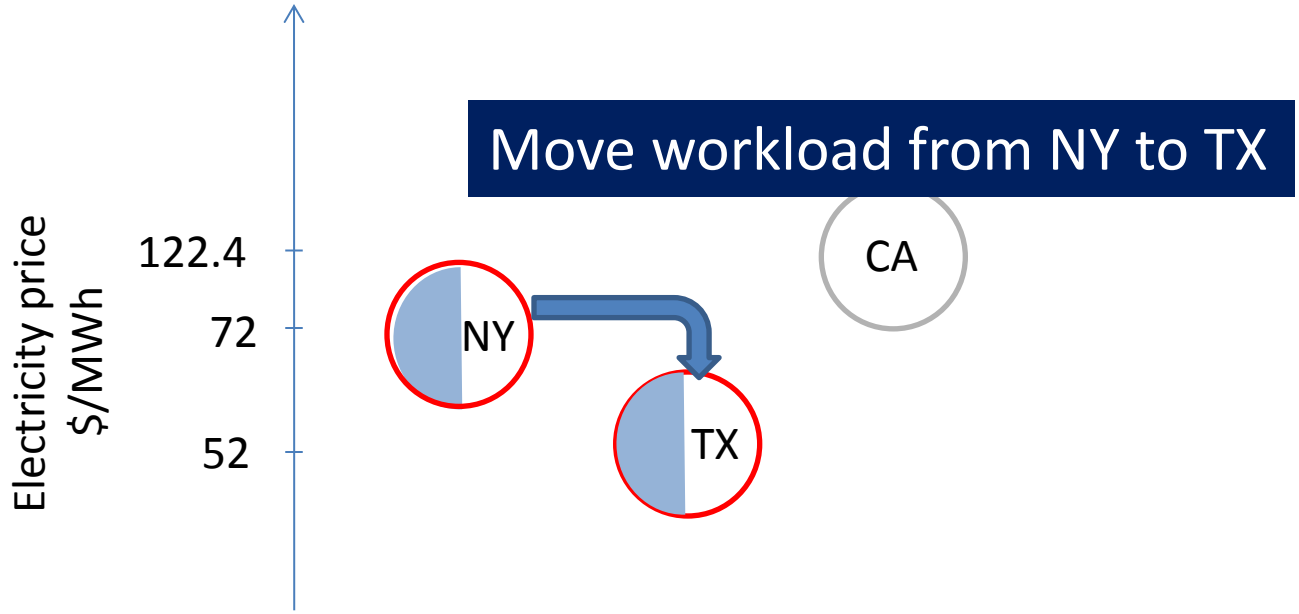

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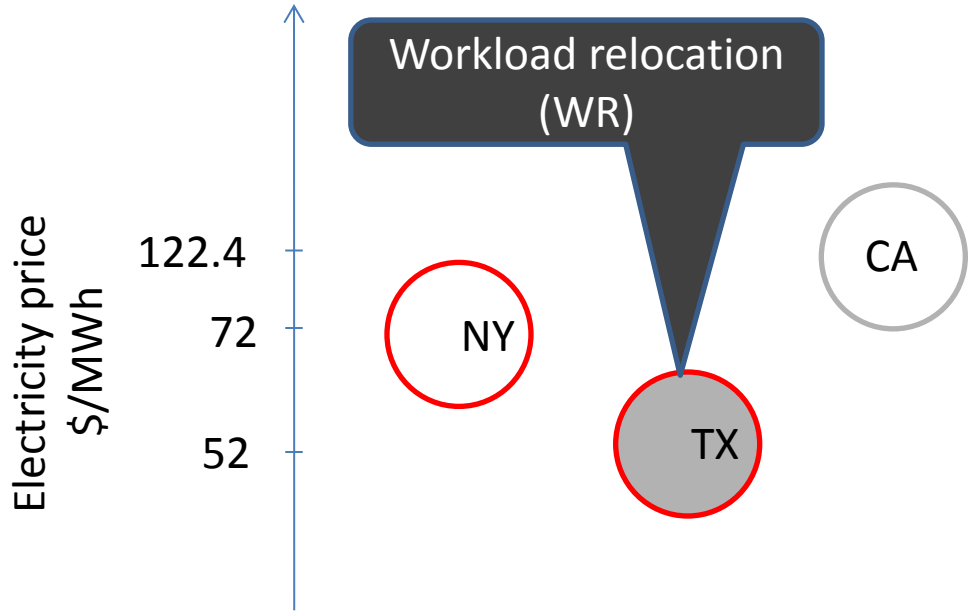

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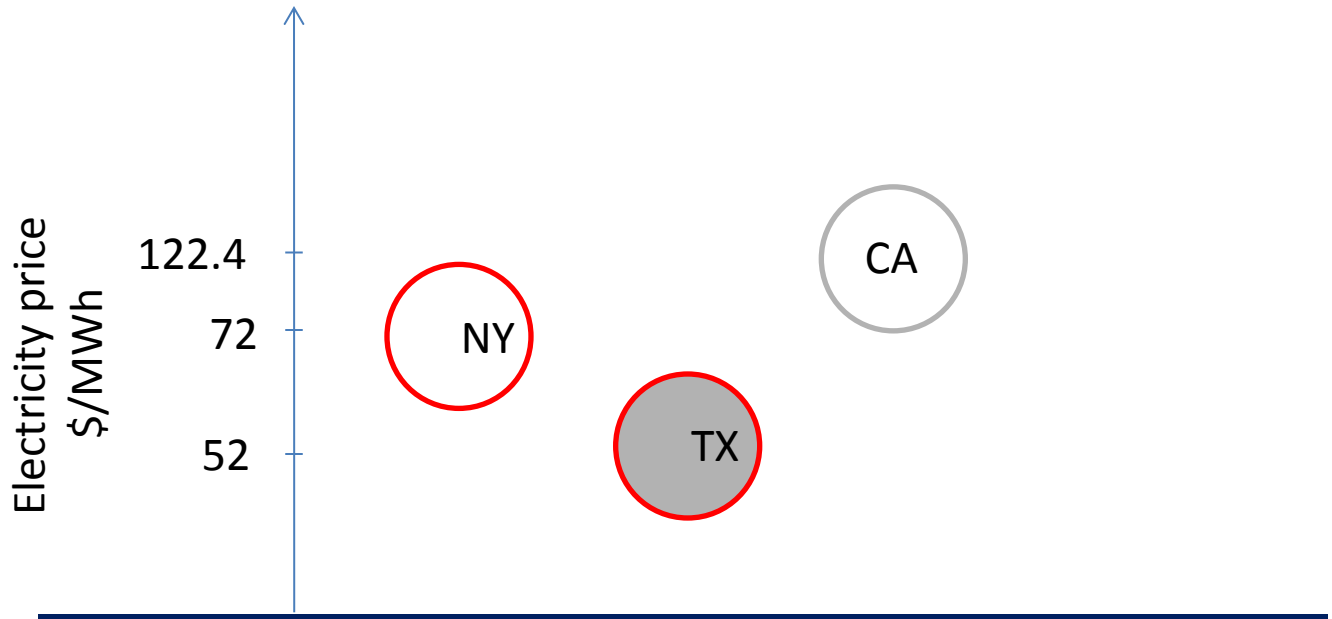

Workload relocation cuts electricity cost ***further***

Key Idea

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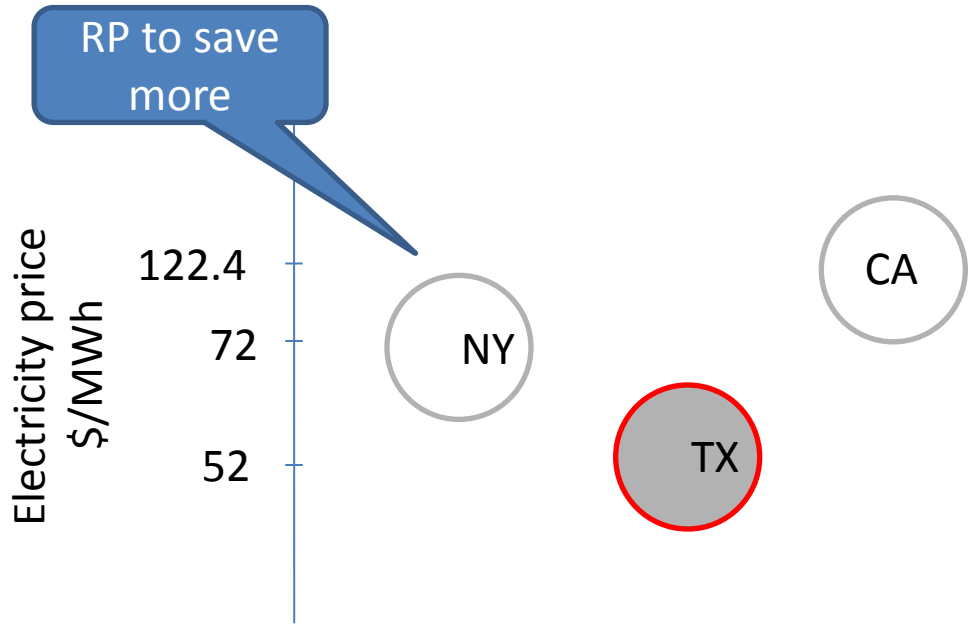

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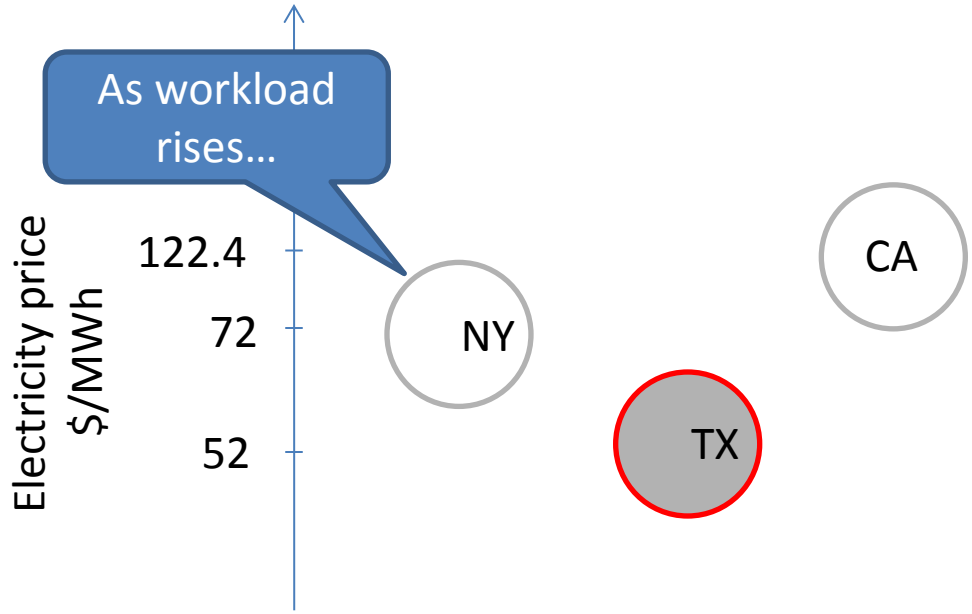

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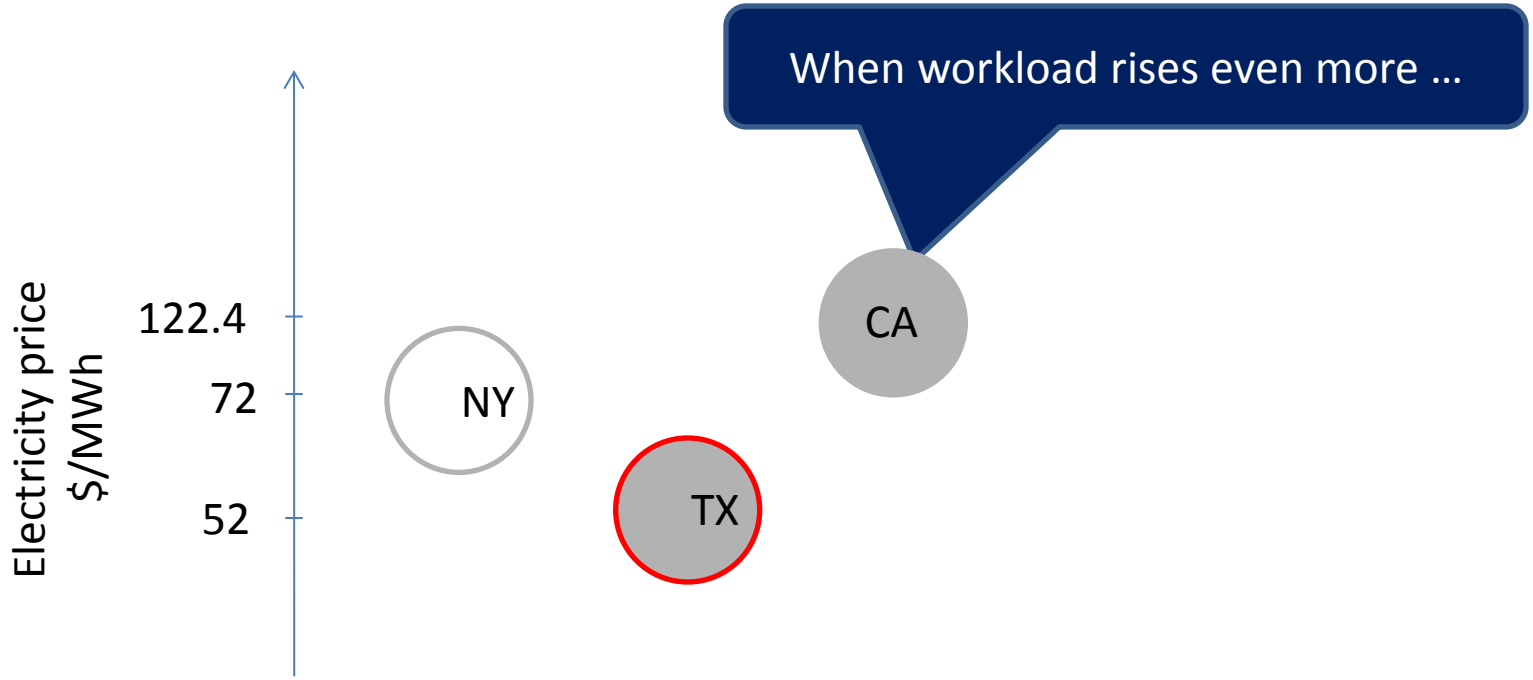


Key Idea

RP and WR can cut electricity costs

Key Idea

RP and WR can cut electricity costs

Ain’t no such thing as a free lunch

Transition Costs

- Transition costs may be present
  - Examples:
    - Expensive inter data-center traffic

Transition Costs

- Transition costs may be present
  - Examples:
    - Expensive inter data-center traffic
    - Energy spent while resuming and sleeping

Transition Costs

- Transition costs may be present
  - Examples:
    - Expensive inter data-center traffic
    - Energy spent while resuming and sleeping
- Relocate Energy Demand to Better Locations (RED-BL)

This Thesis

Towards systematic minimization of network electricity cost

using Workload Relocation (WR) and Resource Pruning (RP)

while considering transition costs

Contributions

Data centers

INFOCOM Mini-Conference 2012

- Optimization framework
- Simulation based evaluation

Computer Networks, 2014

- Finer granularity
- NP-Completeness

Cellular Networks

GLOBECOM 2013

- Adaptation of optimization framework
- Simulation based evaluation

Submitted

- NP-Hardness proof *
- Additional evaluations

* With the help of Dr. Mudassir Shabbir, ITU, Lahore

Agenda

- Background and motivation
- Opportunity and key idea
- Case studies:
  - **Data centers**
  - Cellular networks
- Conclusions and future work

Case Study – I : Background

Source: http://bit.ly/1mrIi7o

Case Study – I : Background

- Data center operator
  - Geographically distributed data centers

Case Study – I : Background

- Data center operator
  - Geographically distributed data centers
- Data center equipment

IT Load	Non-IT Load
Servers	Lighting
Storage	Cooling
Network	Power distribution

Case Study – I : Background

- Data center operator
  - Geographically distributed data centers
- Data center equipment

IT Load	Non-IT Load
Servers	Lighting
Storage	Cooling
Network	Power distribution

- Power consumed is affine function of workload

Case Study – I : Background

- Data center operator
  - Geographically distributed data centers
- Data center equipment

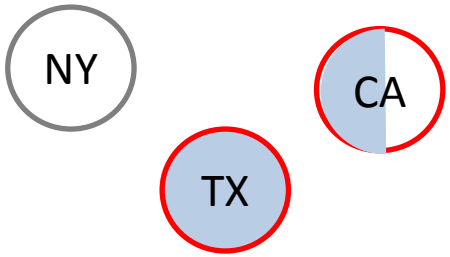
IT Load	Non-IT Load
Servers	Lighting
Storage	Cooling
Network	Power distribution

- Power consumed is affine function of workload

Let's recap how we can use WR and RP

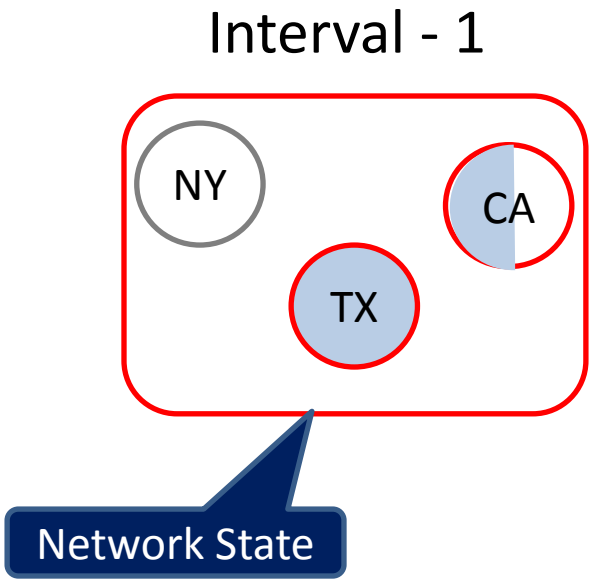
Problem Model

Interval - 1

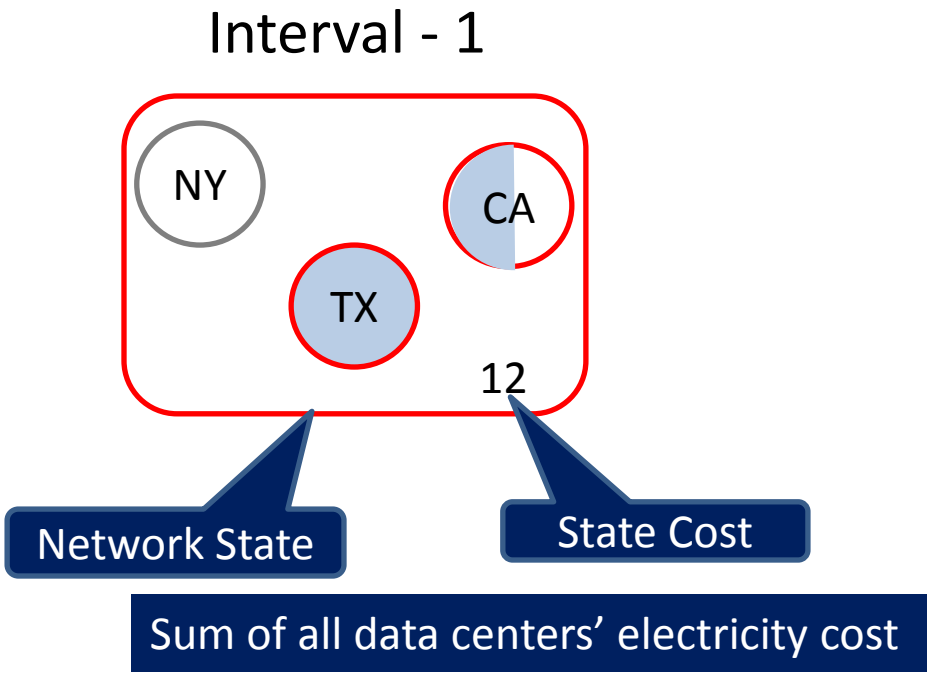


Electricity price driven workload assignment

Problem Model

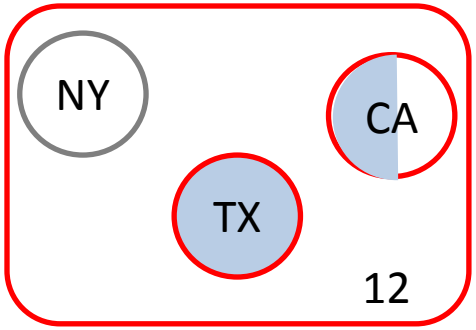


Problem Model

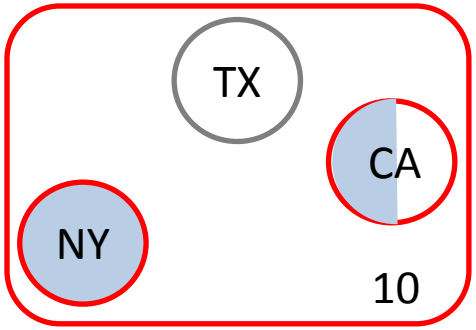


Problem Model

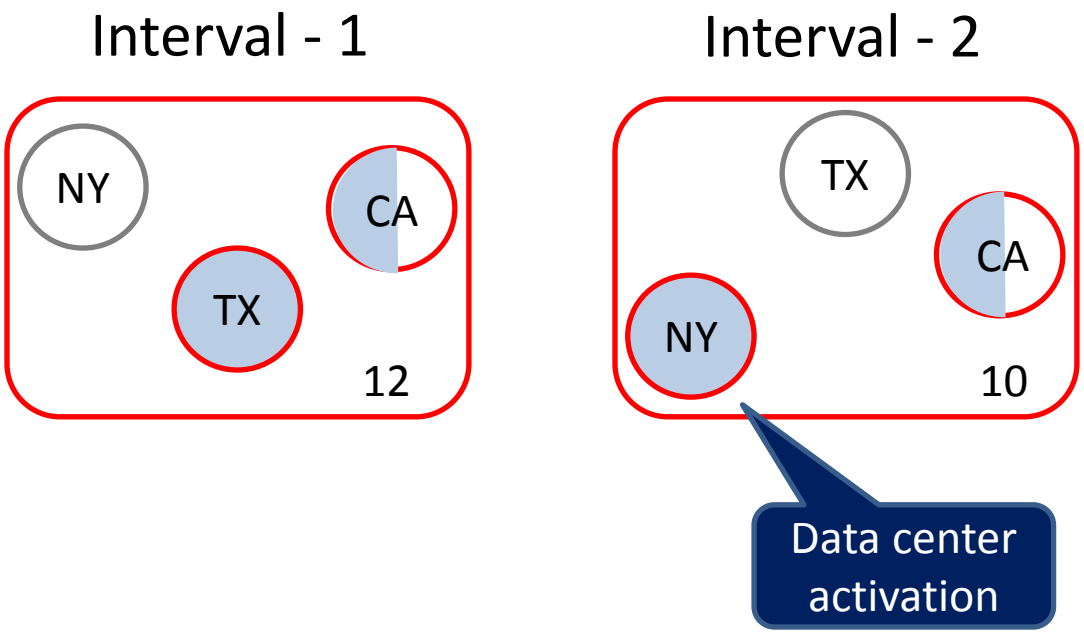
Interval - 1



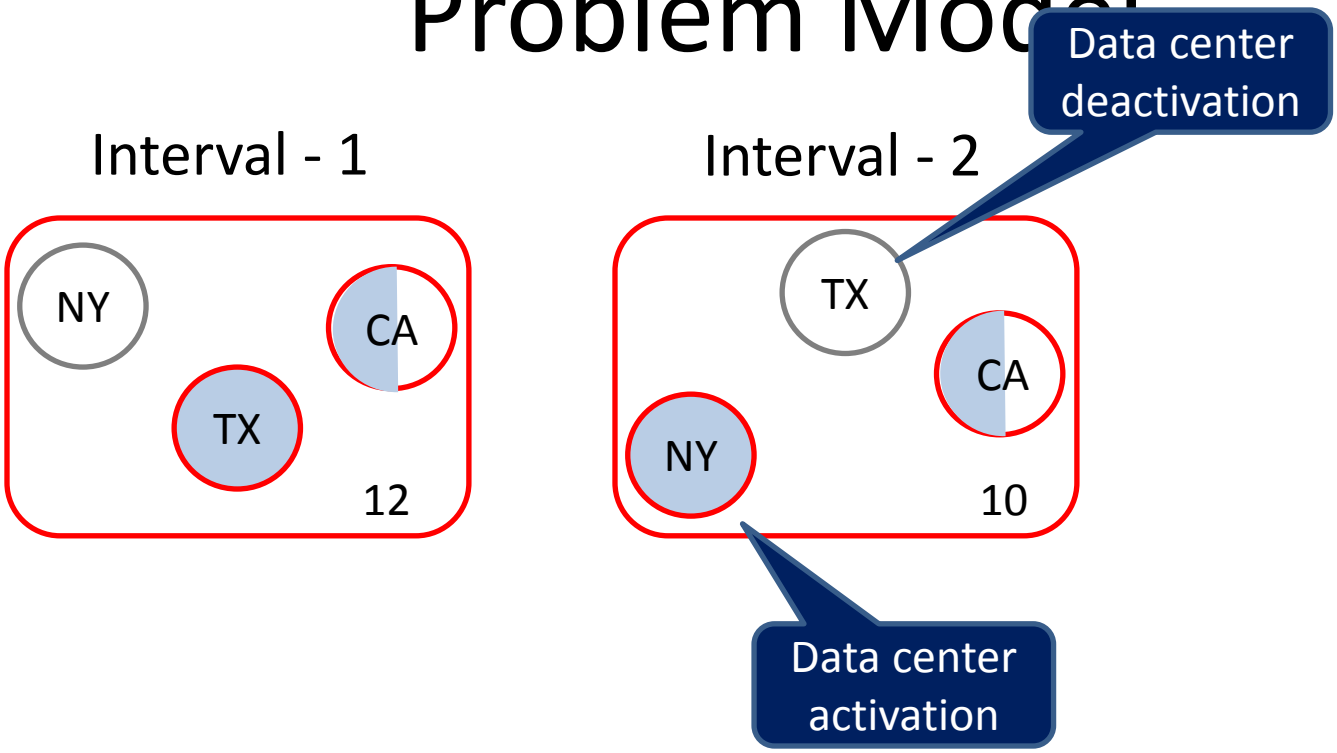
Interval - 2



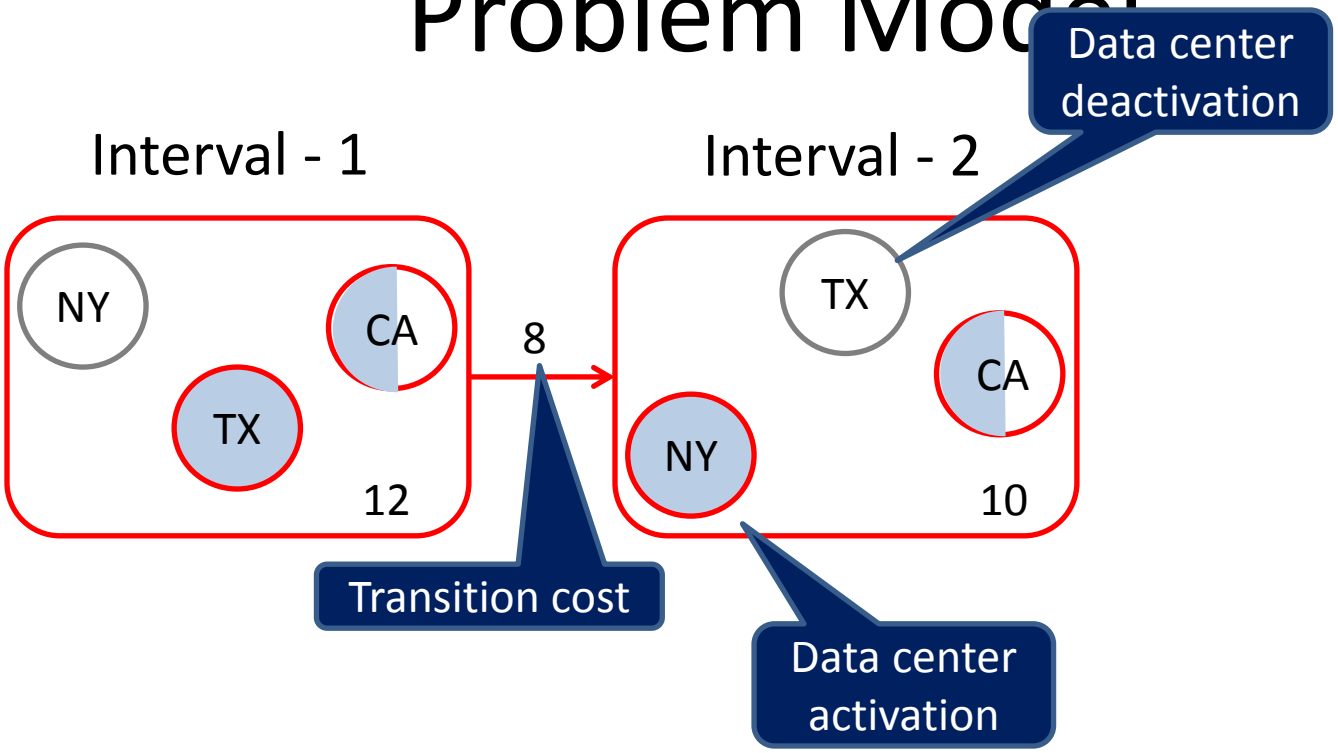
Problem Model



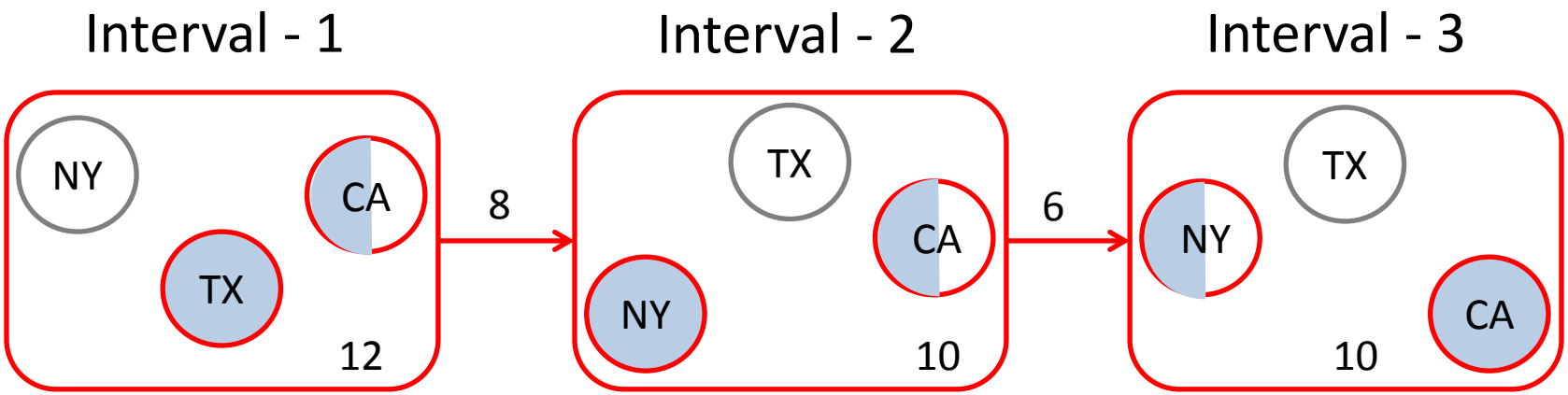
Problem Model



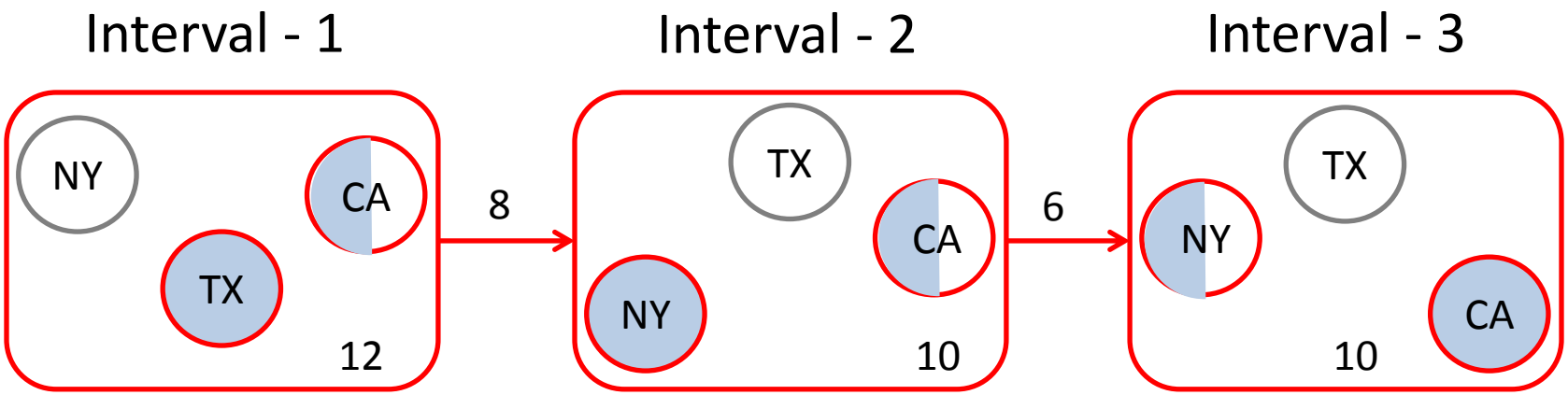
Problem Model



Problem Model

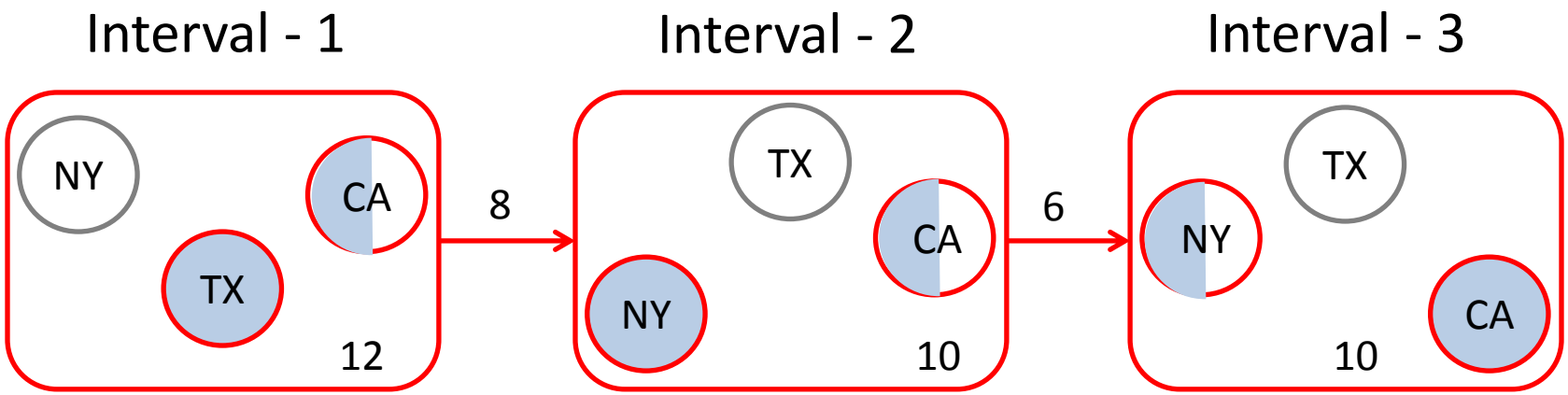


Problem Model



Locally optimal

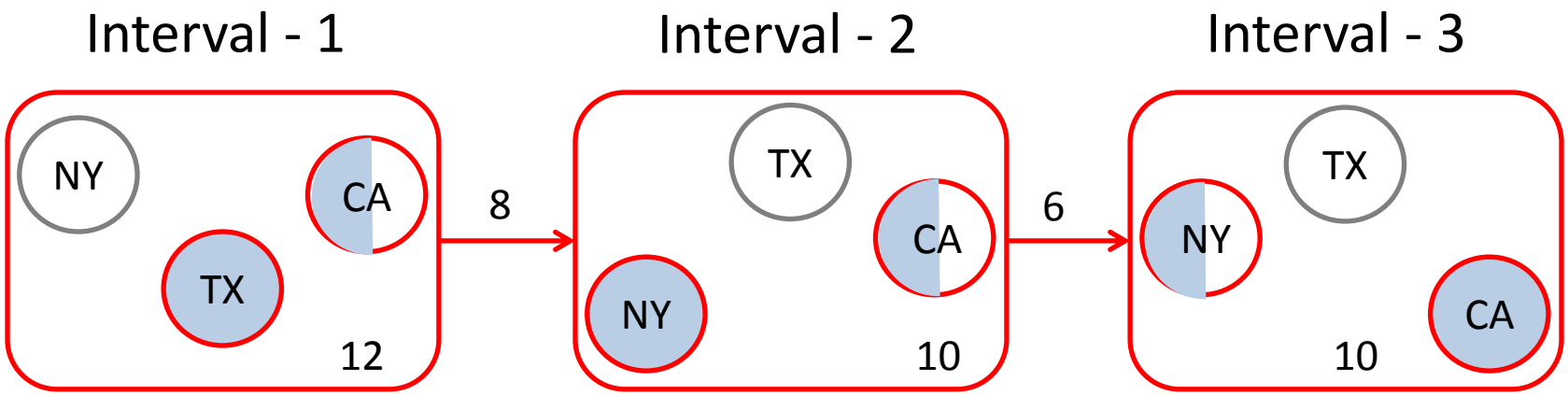
Problem Model



Locally optimal

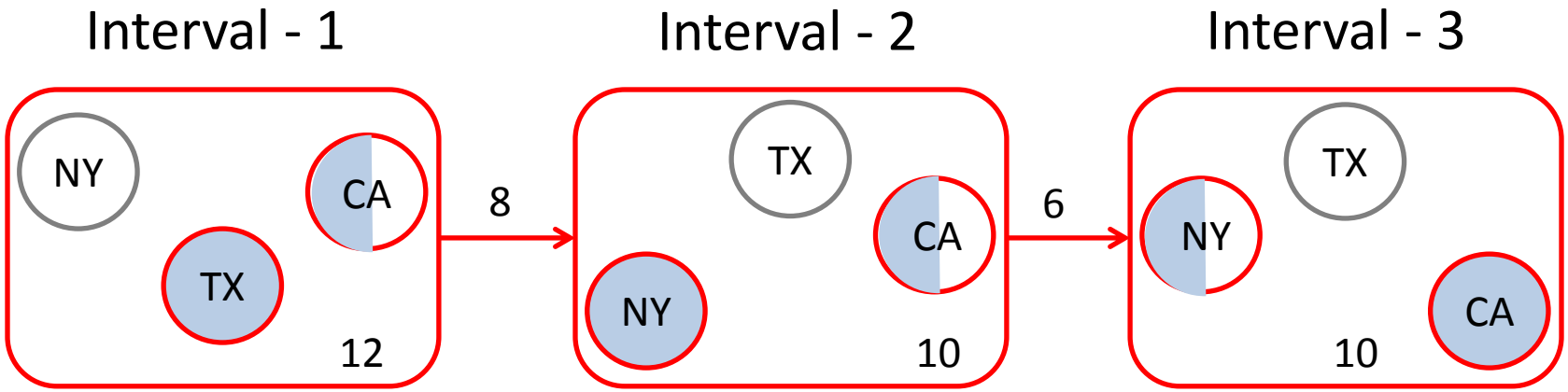
Might not be globally optimal

Problem Model

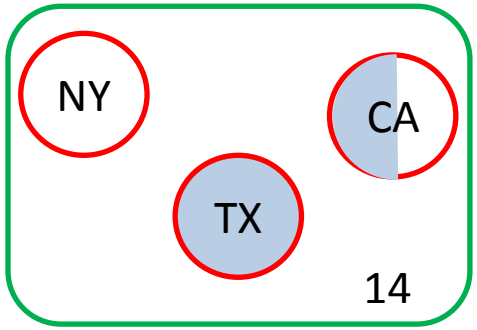


An alternative workload mapping

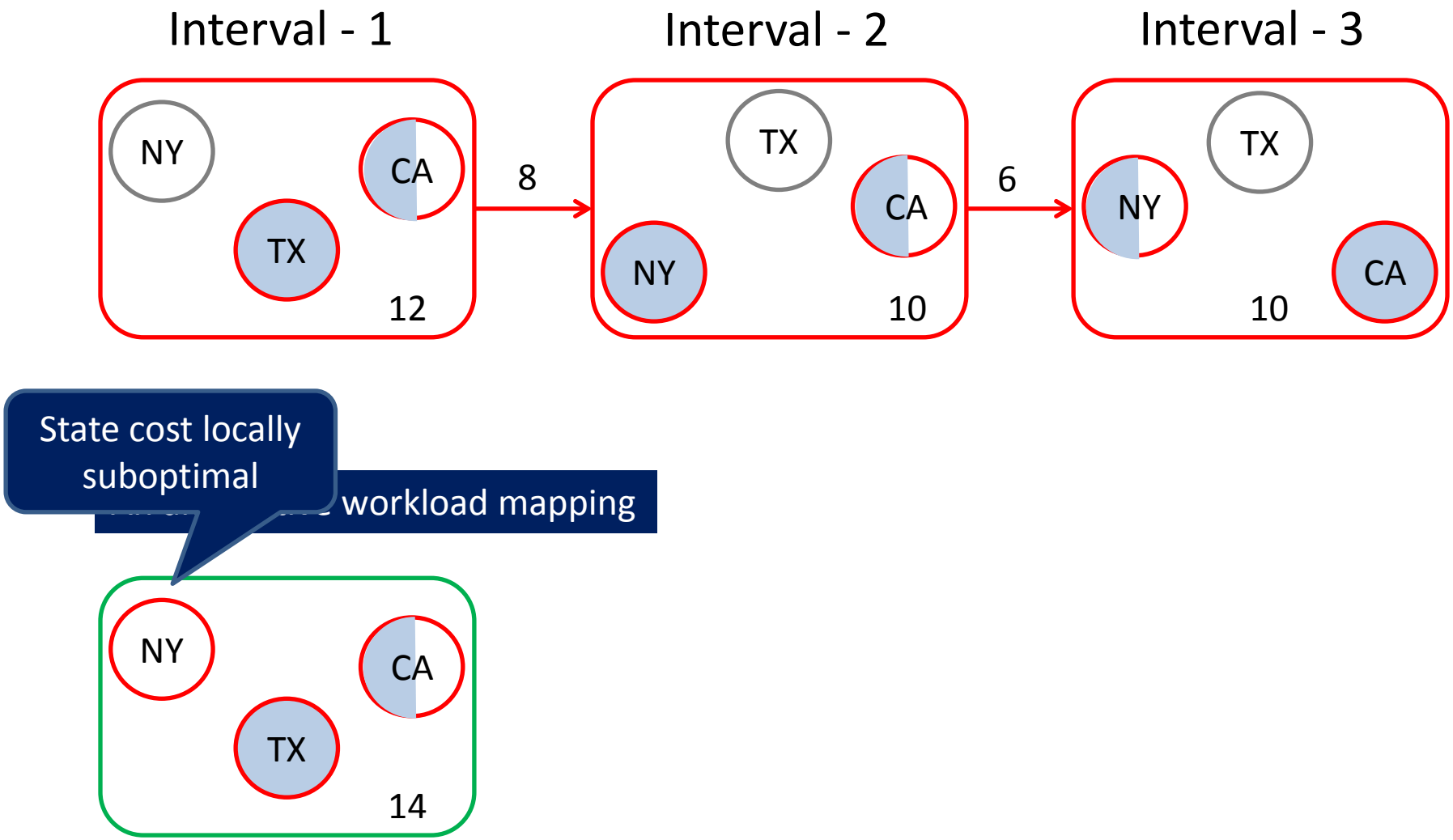
Problem Model



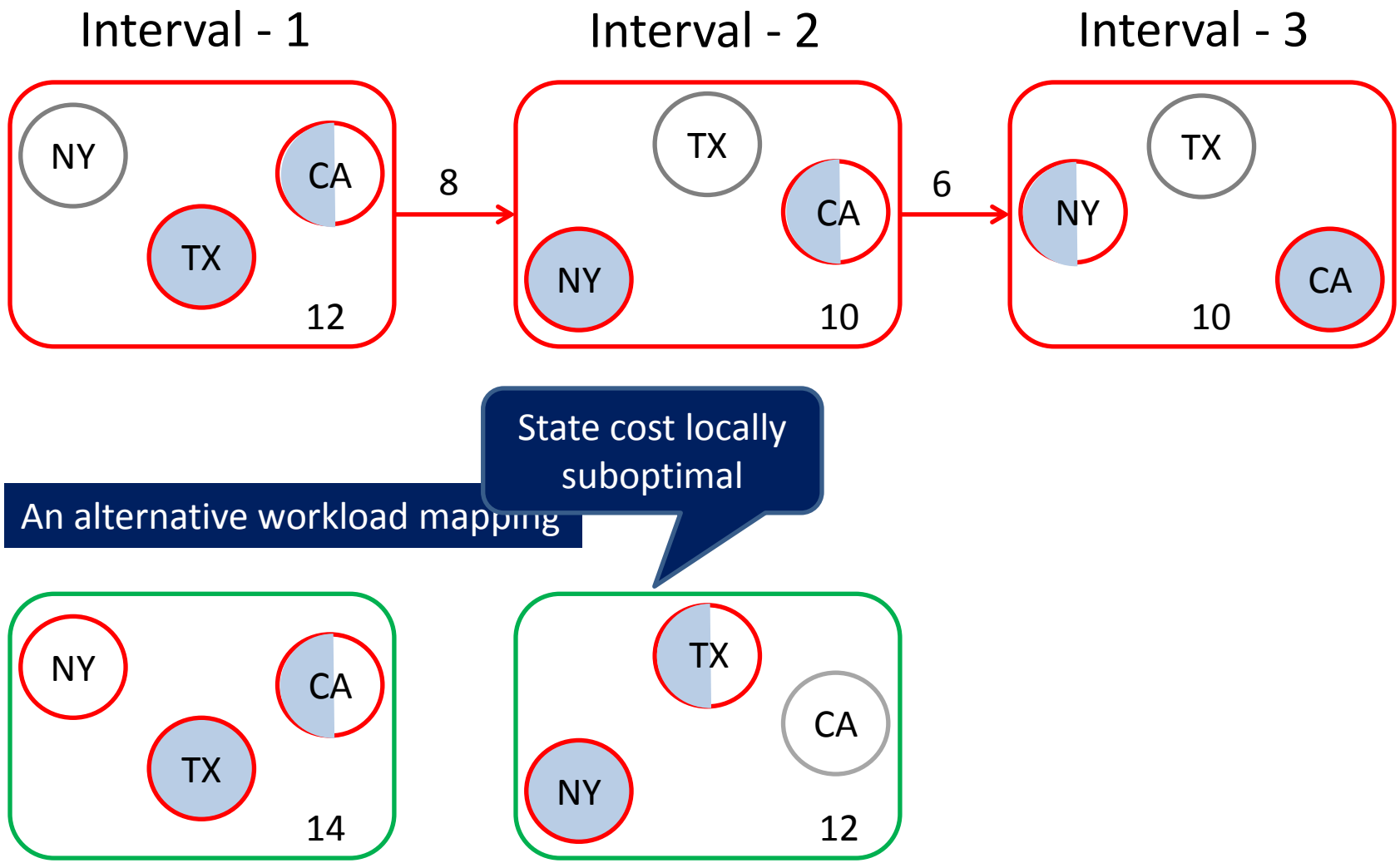
An alternative workload mapping



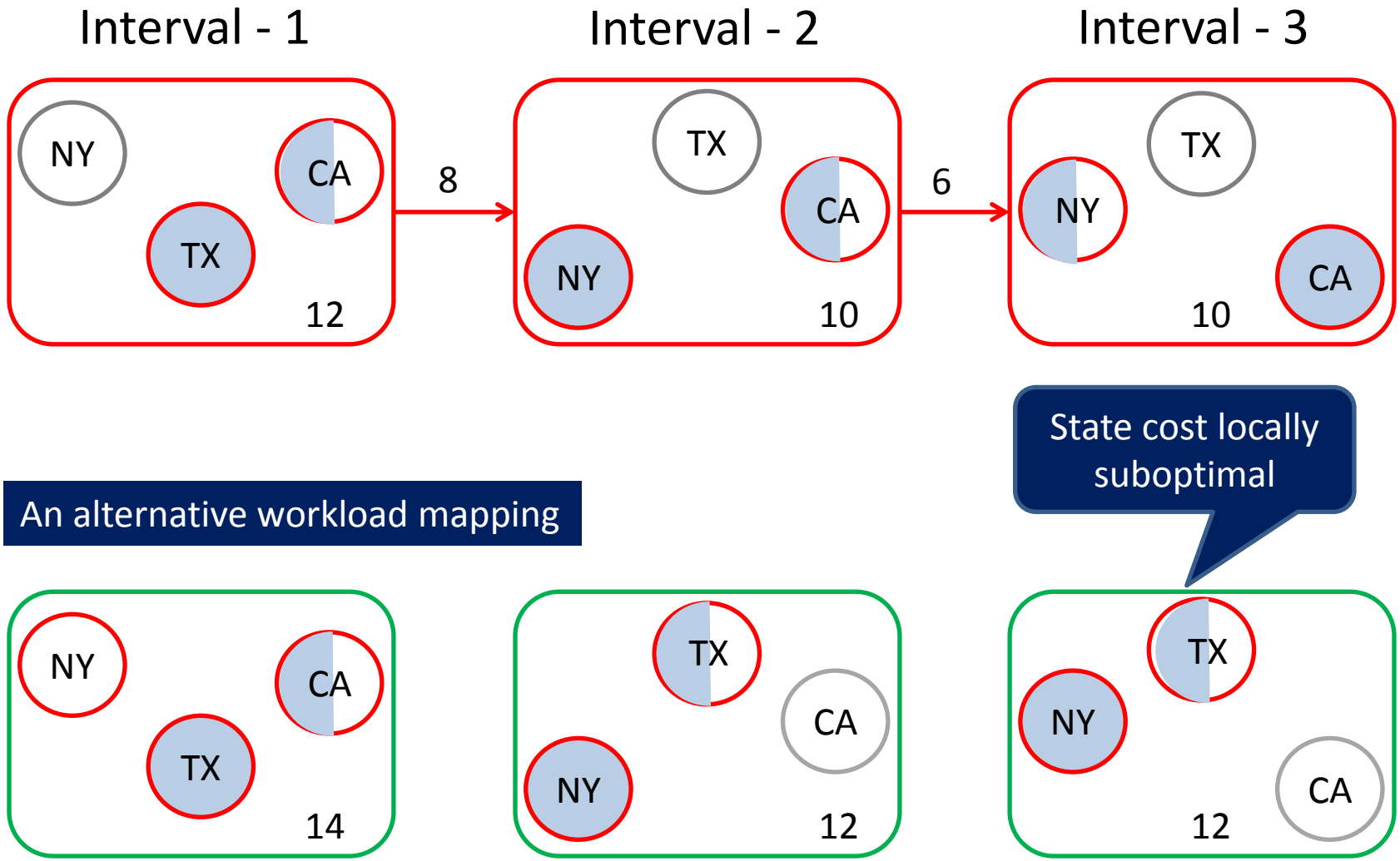
Problem Model



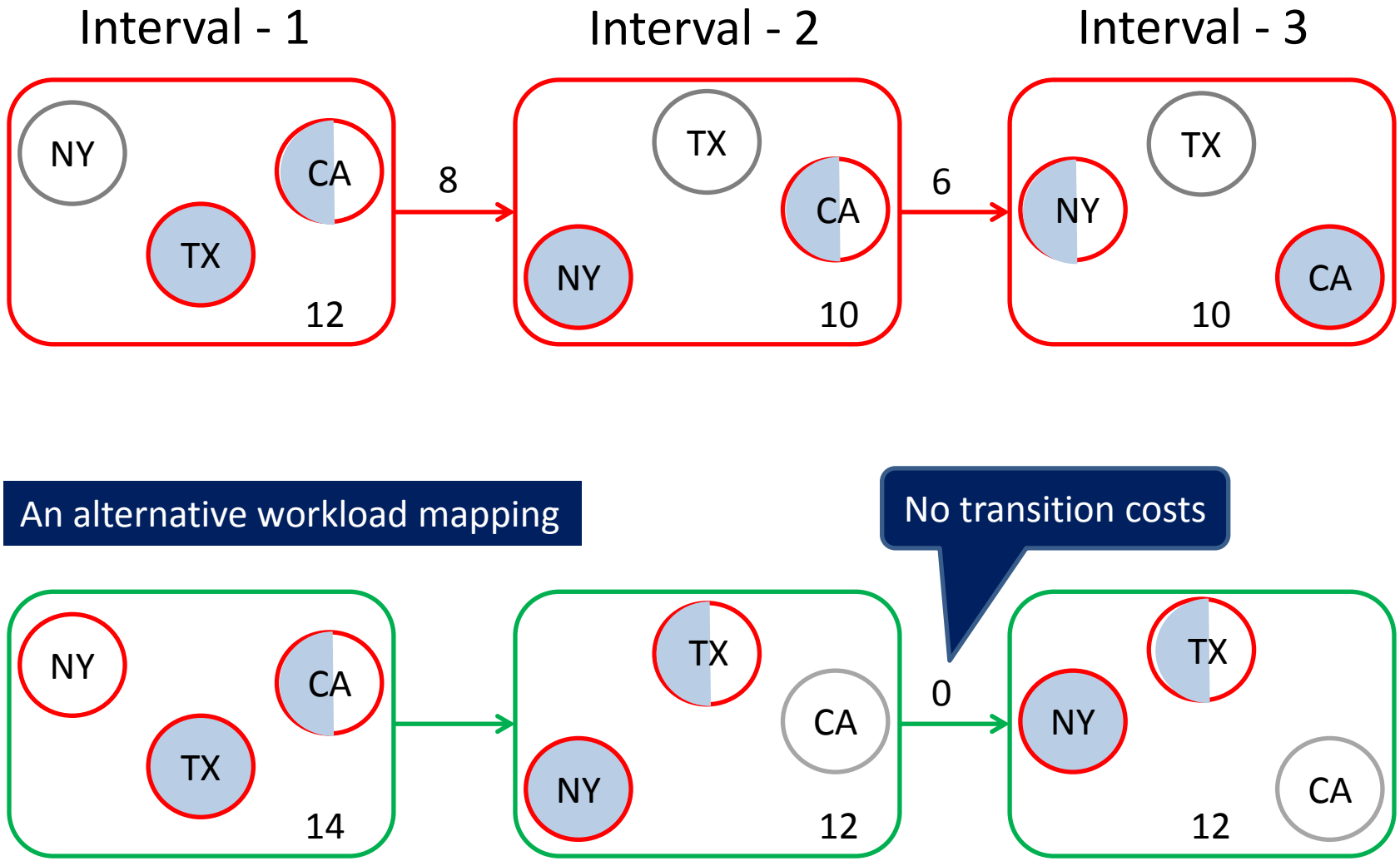
Problem Model



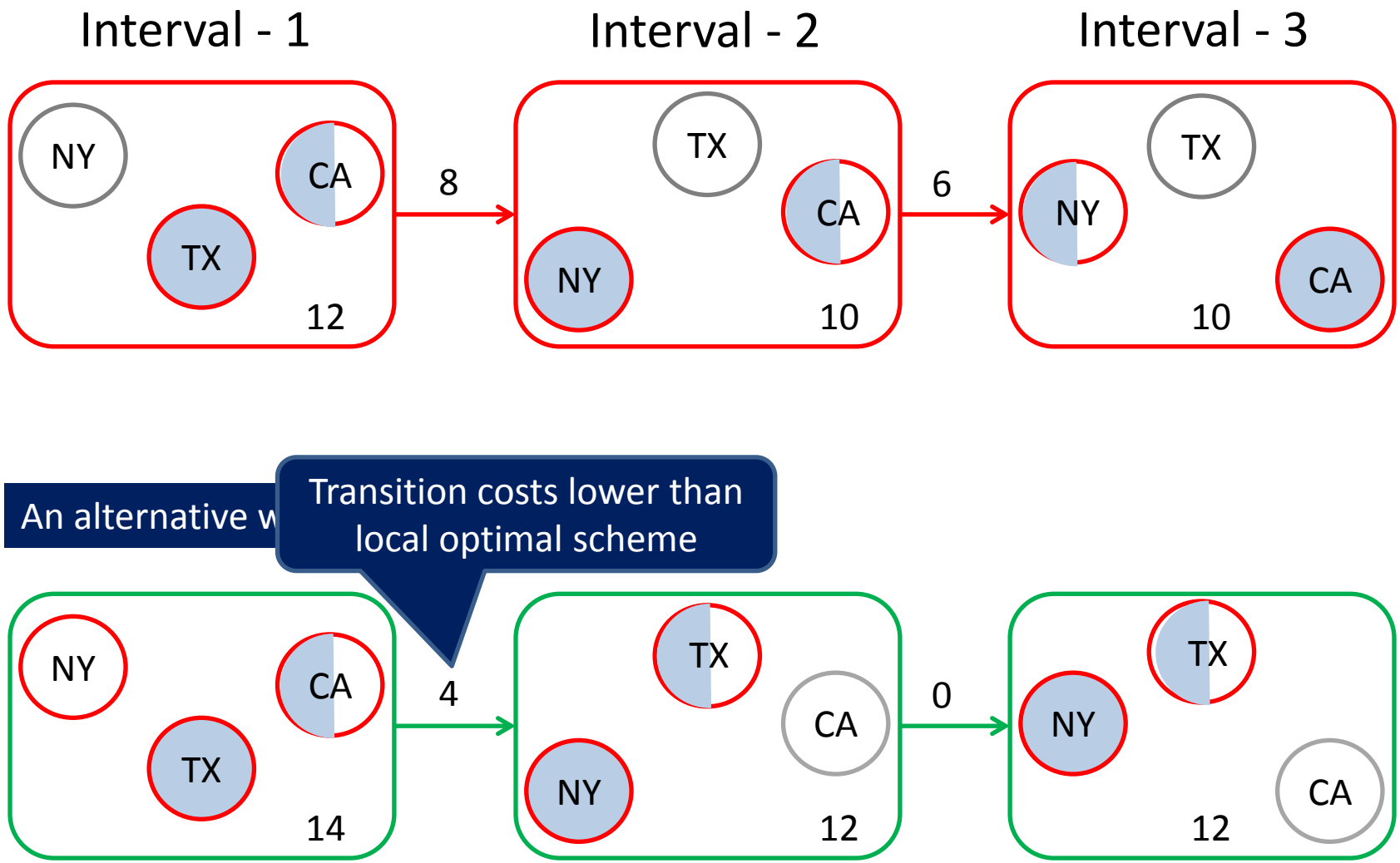
Problem Model



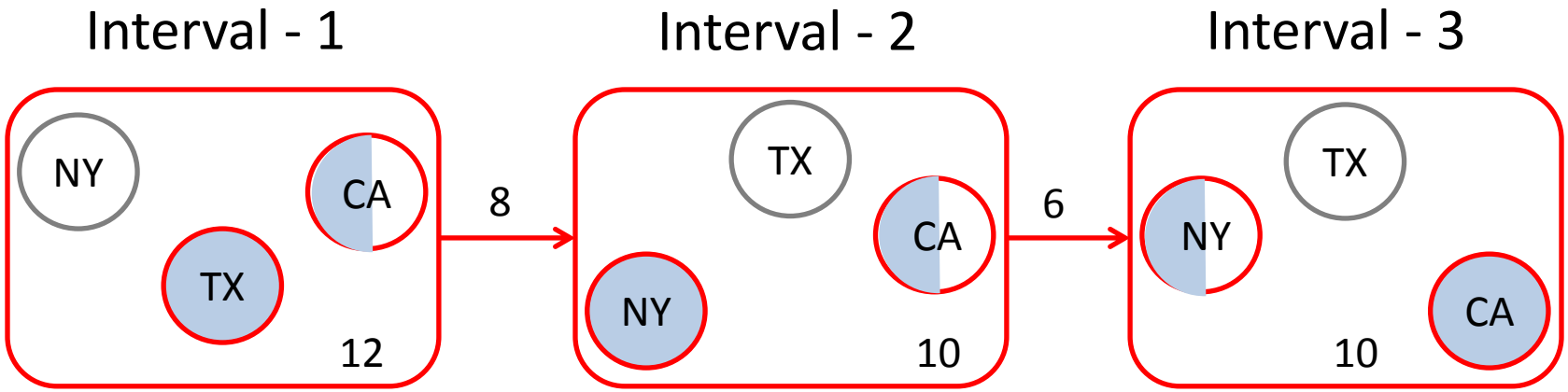
Problem Model



Problem Model

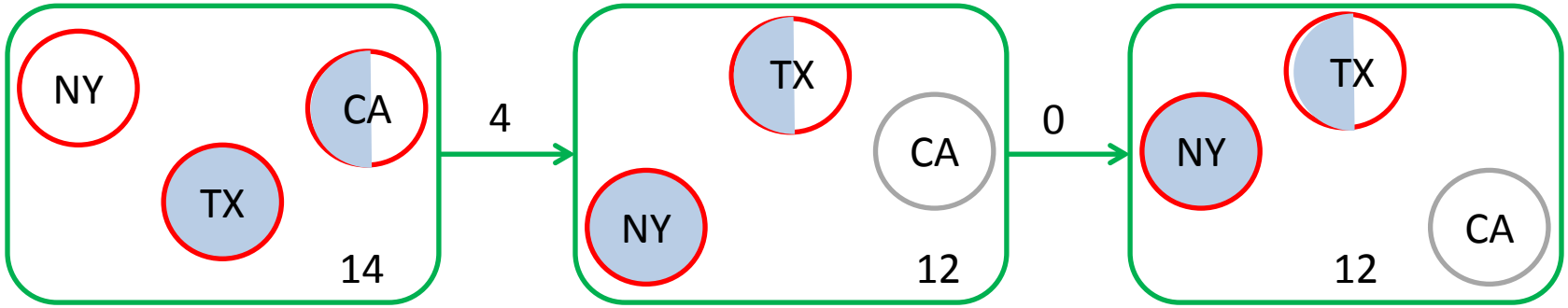


Problem Model

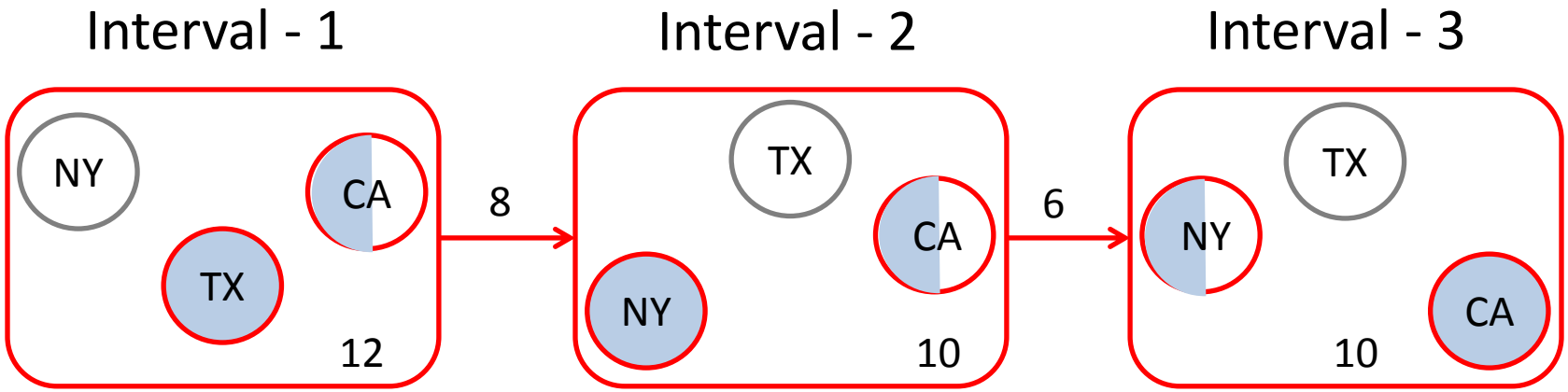


An alternative workload mapping

Total cost: 42



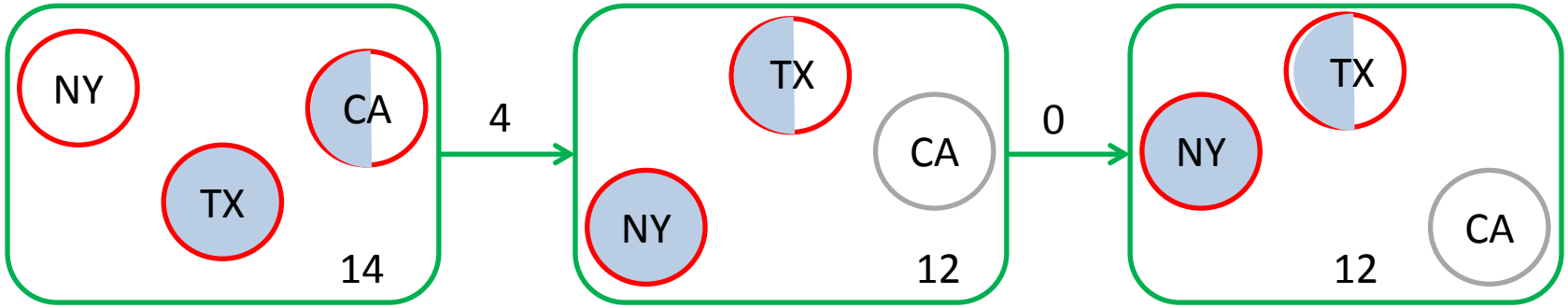
Problem Model



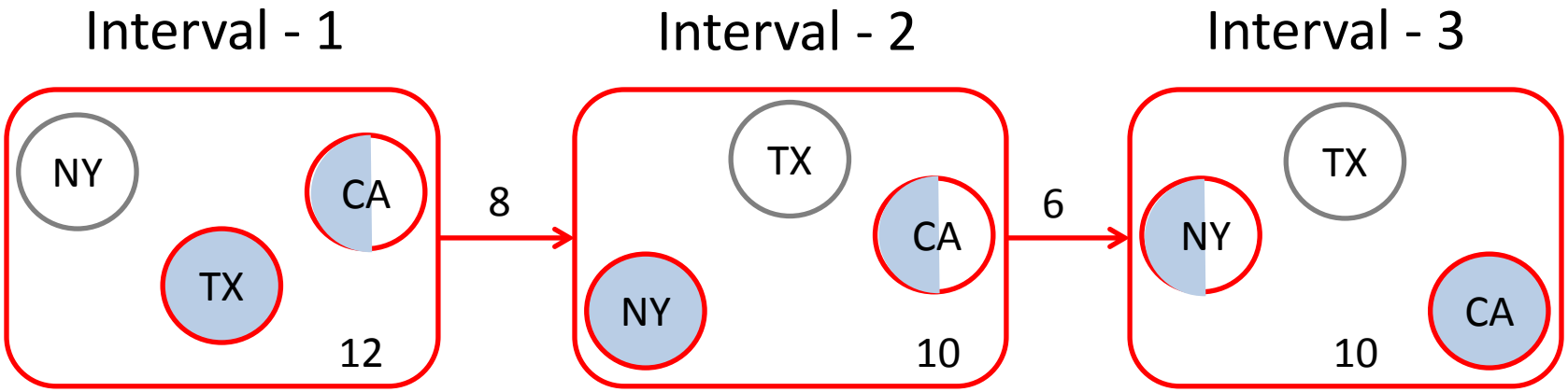
Total cost: 46

An alternative workload mapping

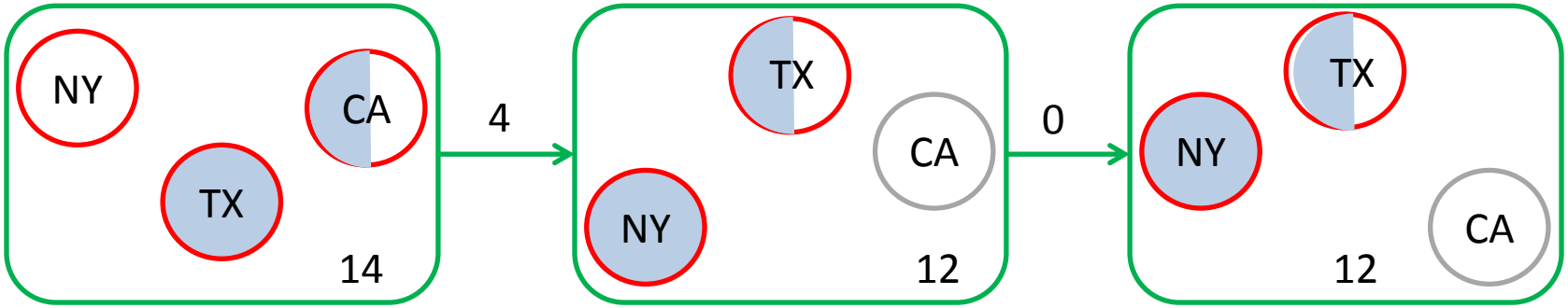
Total cost: 42



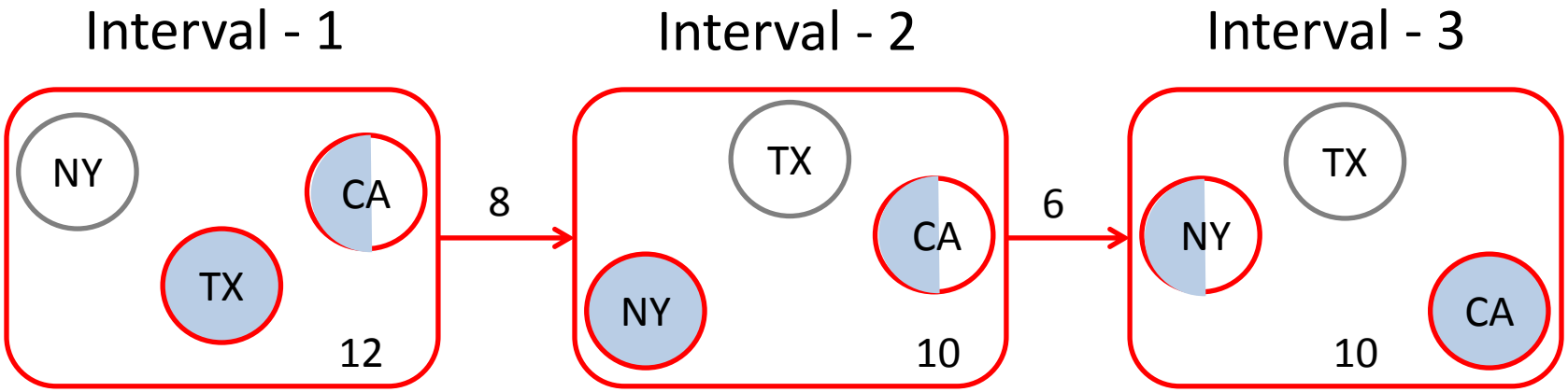
Problem Model



Optimal State Trajectory Problem

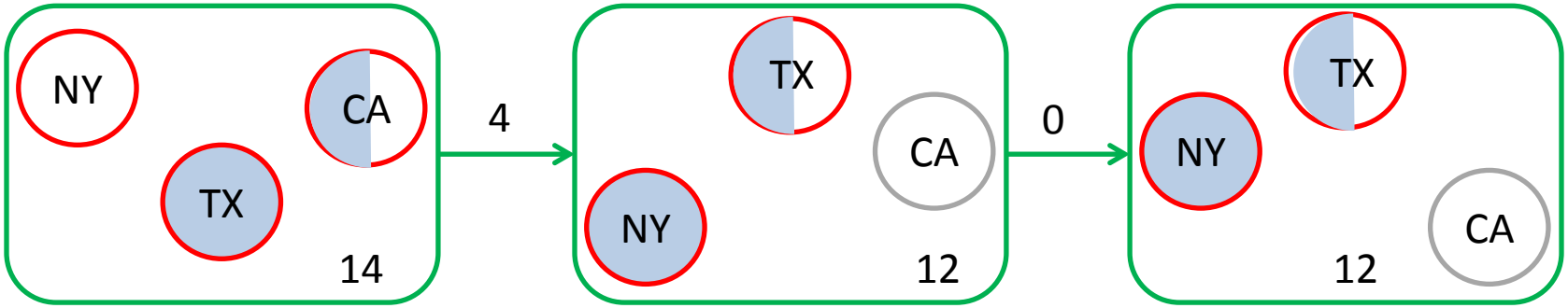


Problem Model



Optimal State Trajectory Problem

Relocate Energy Demand to ***Better*** Locations (RED-BL)



Optimization Formulation

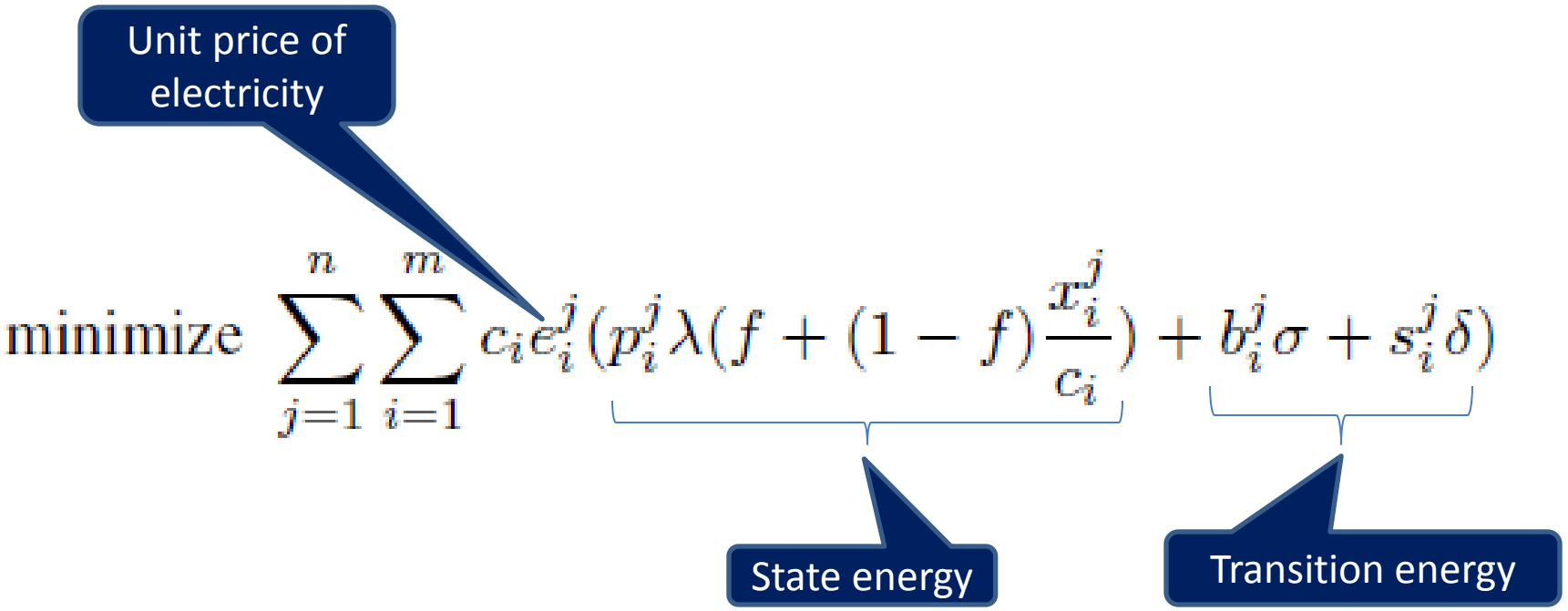
$$\text{minimize} \sum_{j=1}^{n}\sum_{i=1}^{m} c_i e_i^j \left(p_i^j \lambda\left(f + (1-f)\frac{x_i^j}{c_i}\right) + b_i^j \sigma + s_i^j \delta\right)$$

Transition energy

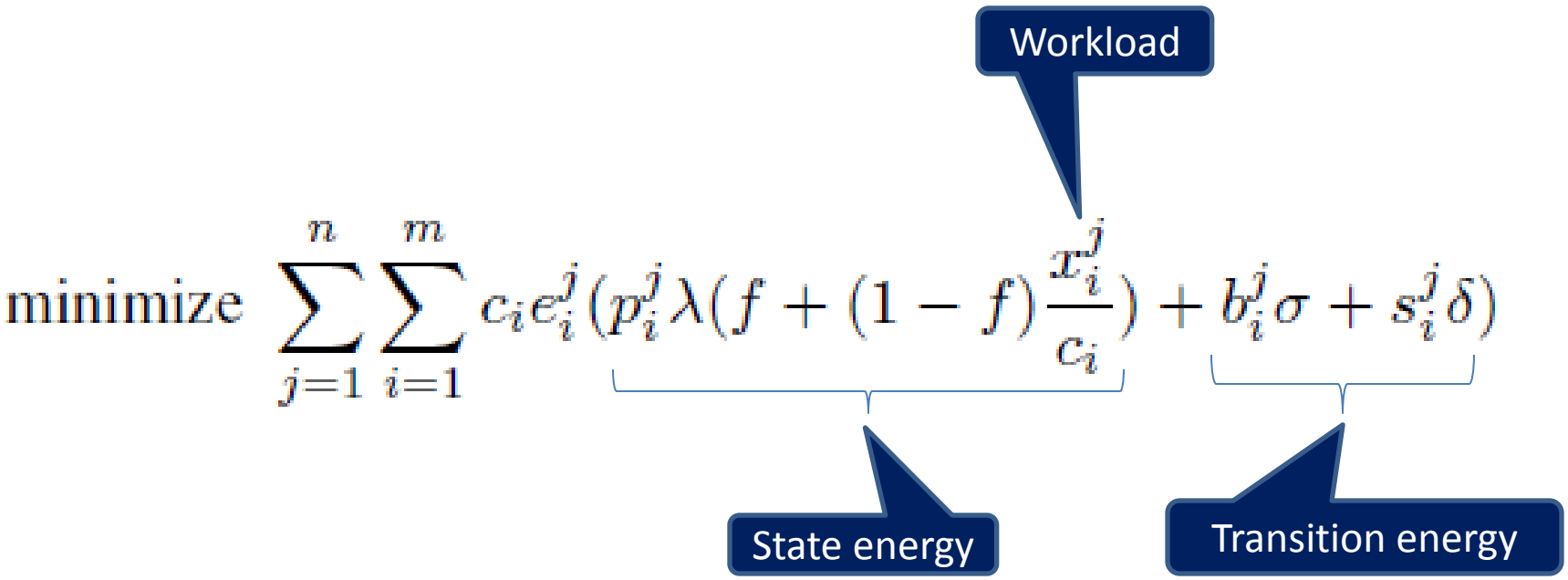
Optimization Formulation

$$\text{minimize} \sum_{j=1}^{n}\sum_{i=1}^{m} c_i e_i^j \left(\underbrace{p_i^j \lambda \left(f + (1-f)\frac{x_i^j}{c_i}\right)}_{\text{State energy}} + \underbrace{b_i^j \sigma + s_i^j \delta}_{\text{Transition energy}}\right)$$

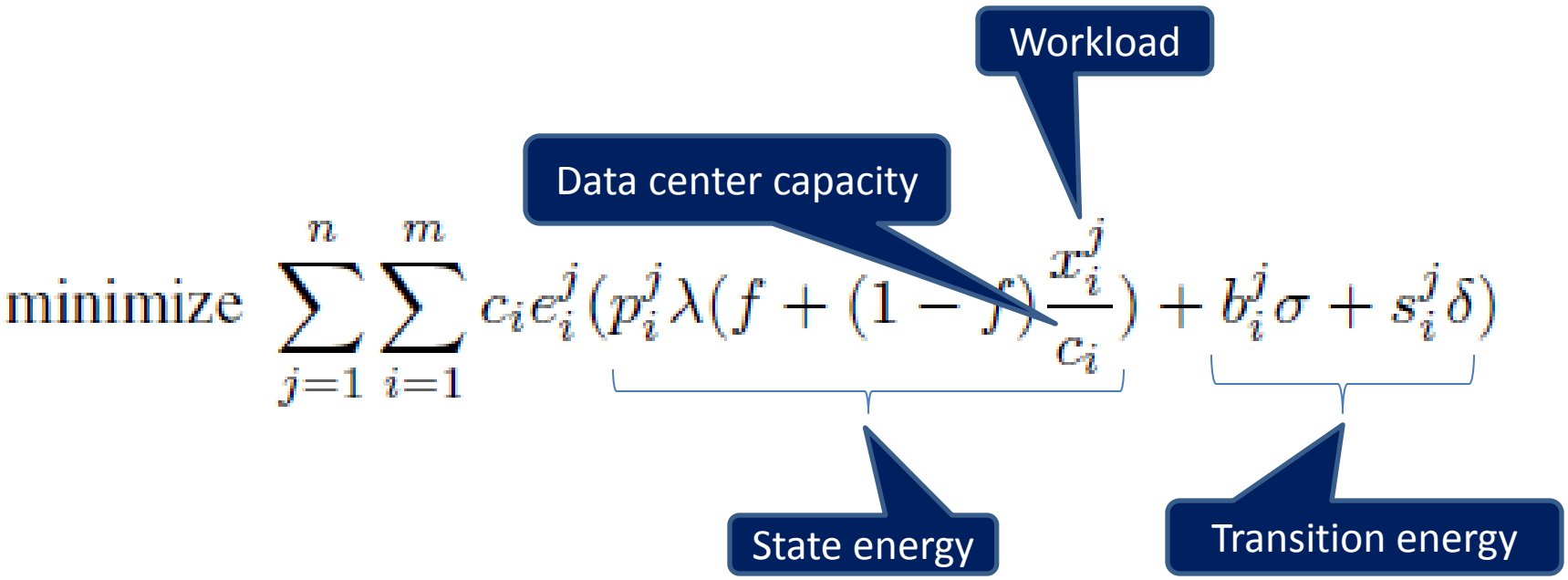
Optimization Formulation



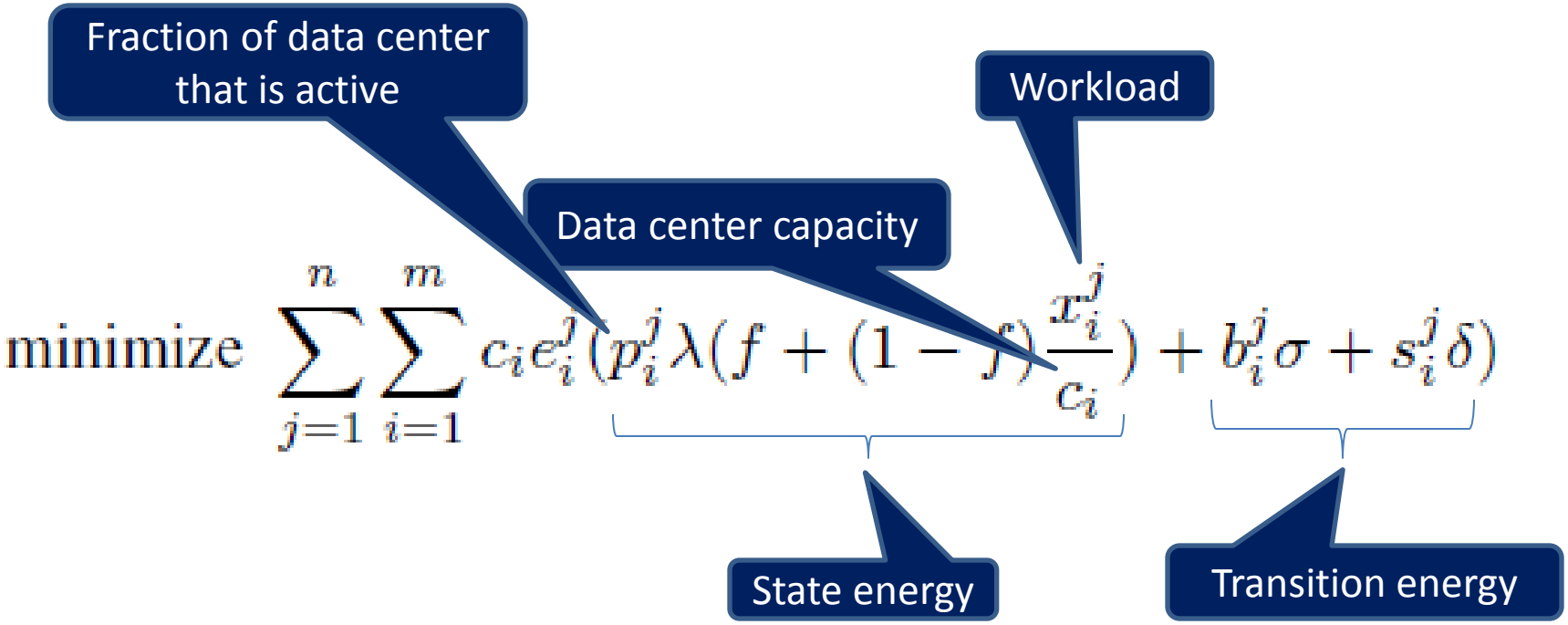
Optimization Formulation



Optimization Formulation



Optimization Formulation



Optimization Formulation

$$\text{minimize} \sum_{j=1}^{n}\sum_{i=1}^{m} c_i e_i^j \left(\underbrace{p_i^j \lambda \left(f + (1-f)\frac{x_i^j}{c_i}\right)}_{\text{State energy}} + \underbrace{b_i^j \sigma + s_i^j \delta}_{\text{Transition energy}}\right)$$

Optimization Formulation

$$\text{minimize} \sum_{j=1}^{n} \sum_{i=1}^{m} c_i e_i^j \left(p_i^j \lambda \left(f + (1-f) \frac{x_i^j}{c_i} \right) + b_i^j \sigma + s_i^j \delta \right)$$

Sum over all data centers

State energy

Transition energy

Optimization Formulation

$$\text{minimize} \sum_{j=1}^{n} \sum_{i=1}^{m} c_i e_i^j \left(p_i^j \lambda \left(f + (1-f) \frac{x_i^j}{c_i} \right) + b_i^j \sigma + s_i^j \delta \right)$$

Sum over all intervals

Sum over all data centers

State energy

Transition energy

Subject to several constraints (please see the thesis)

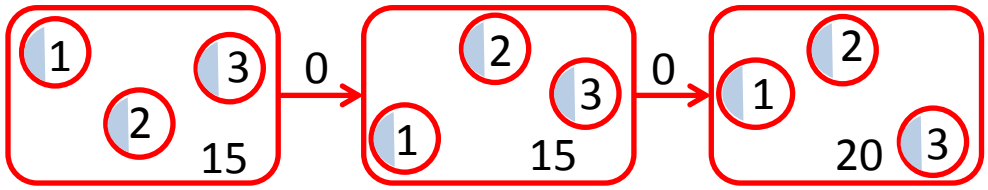
Experimental Setup

- Workload from 3 popular Facebook apps
- Electricity prices from 33 US locations
- Simulated a week-long deployment plan
- Compared RED-BL against various schemes

Comparison Benchmarks

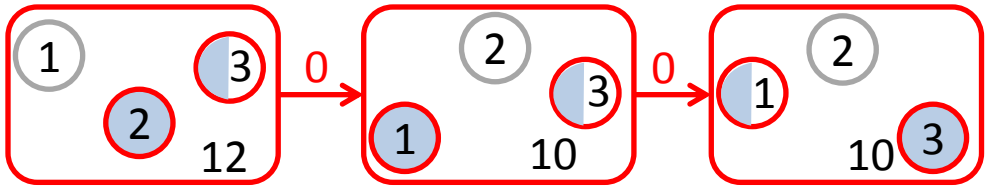
Comparison Benchmarks

UNIFORM: Equally distribute workload



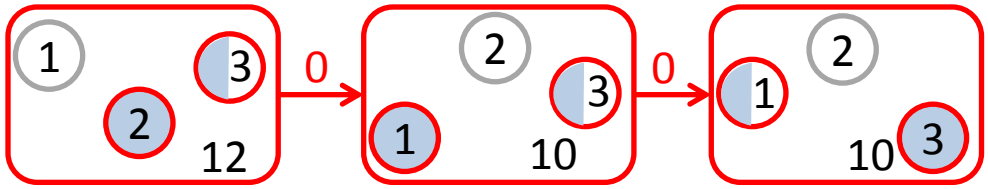
Comparison Benchmarks

LO: Local Optimal Ignoring Transition Costs

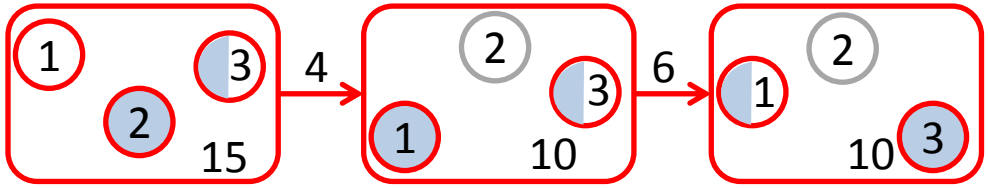


Comparison Benchmarks

LO: Local Optimal Ignoring Transition Costs



LS: Local Optimal with Selection



Comparison Benchmarks

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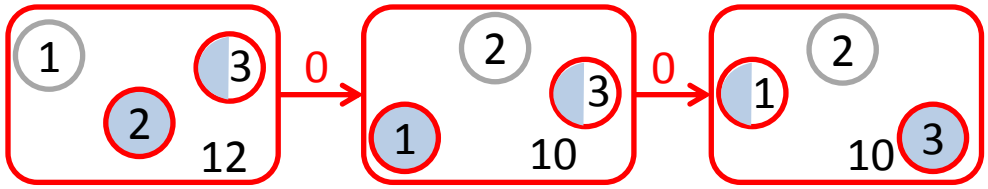
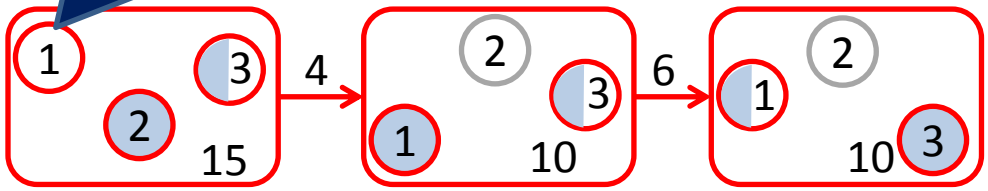


Sometimes idling is better

LS: Local Optimal with Selection



Comparison Benchmarks

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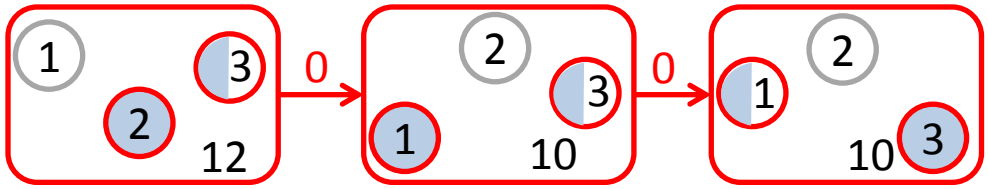

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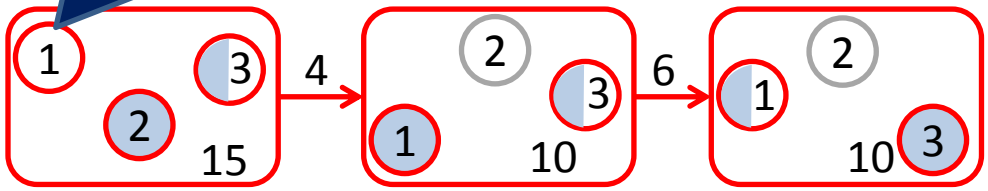
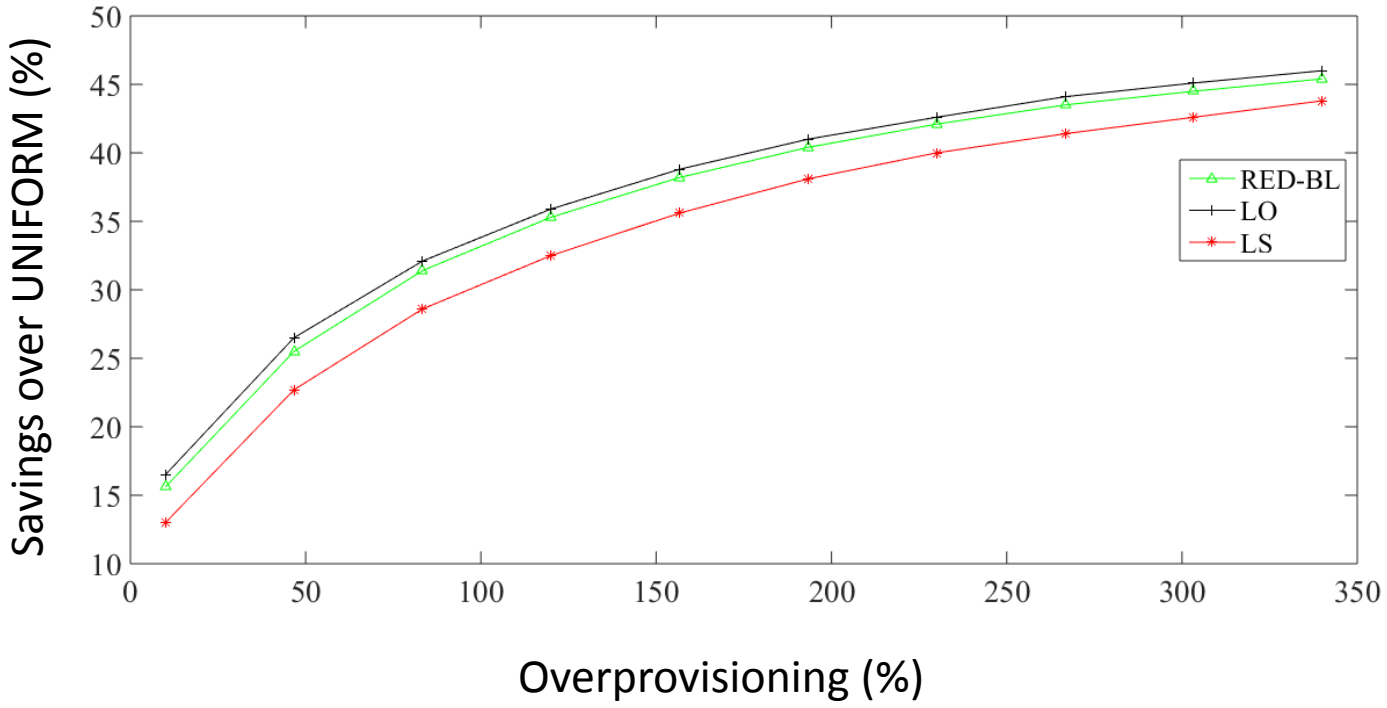
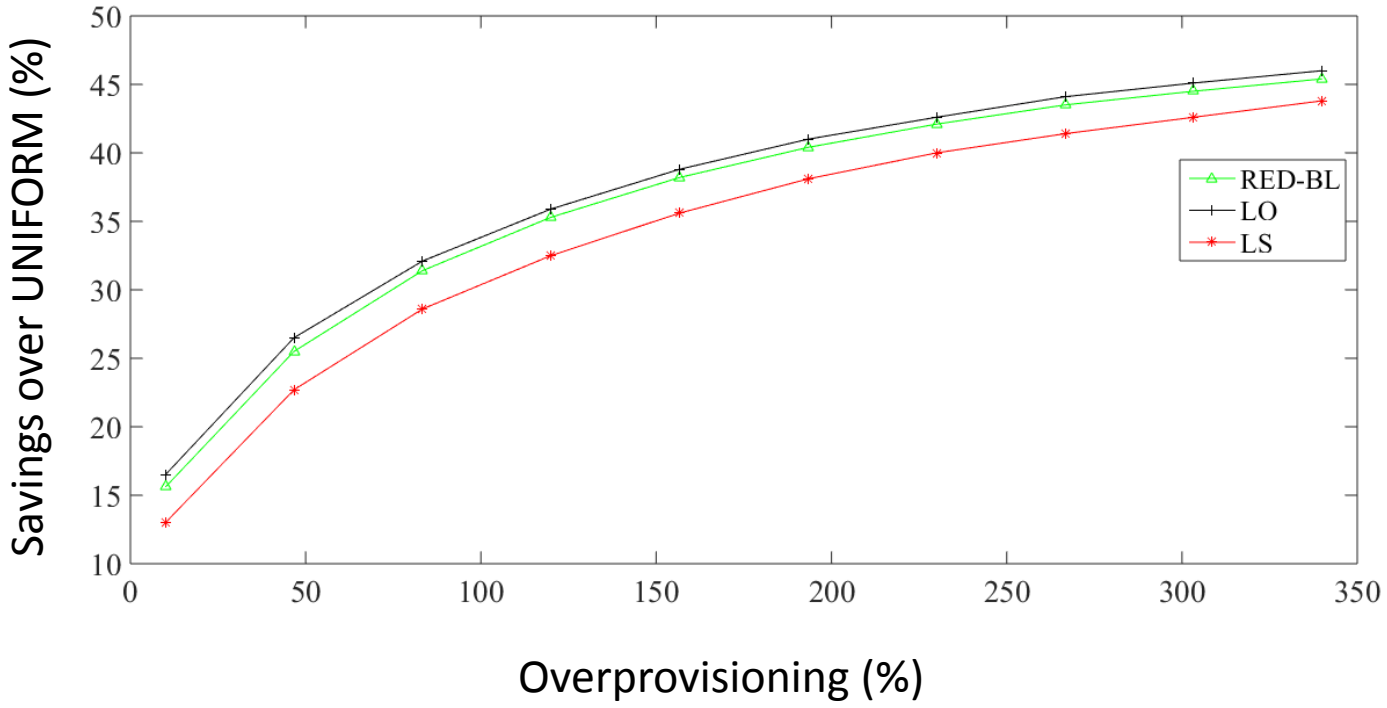


Best practical variant of local optimal

Cost Savings vs Over-provisioning

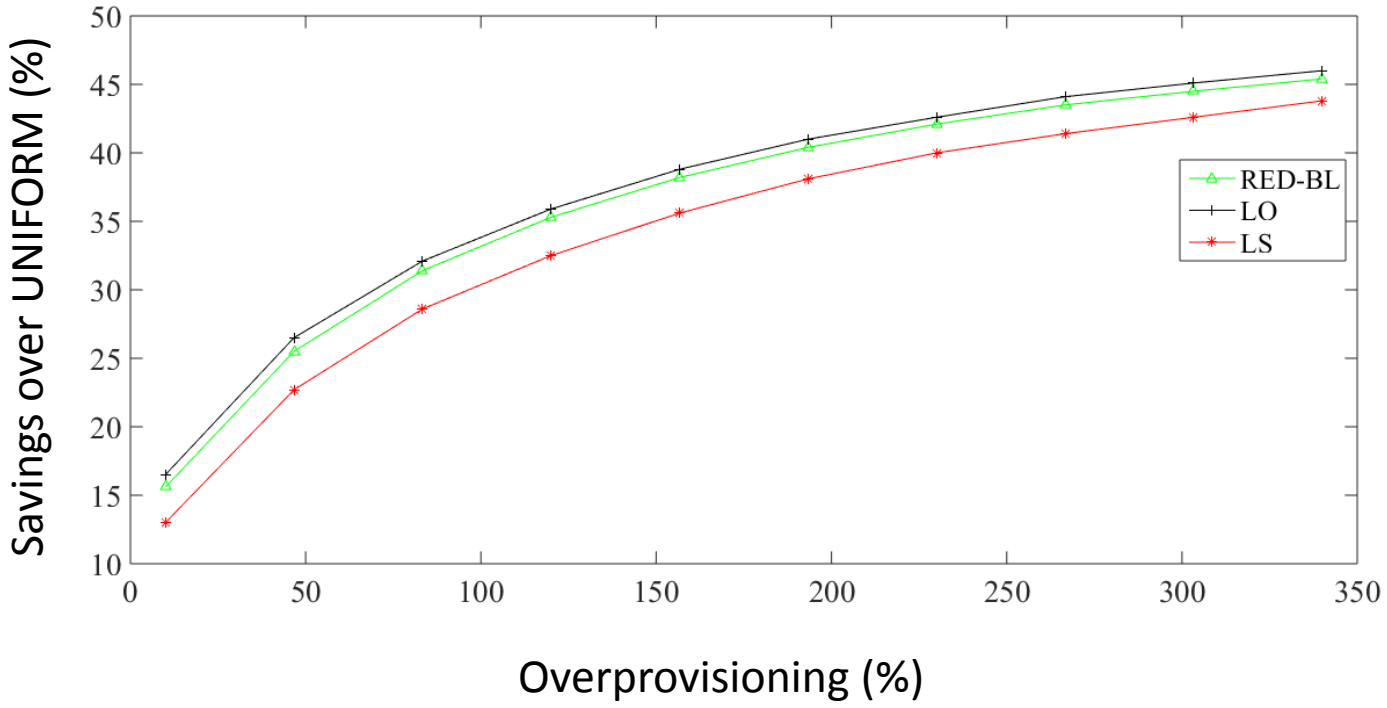


Cost Savings vs Over-provisioning



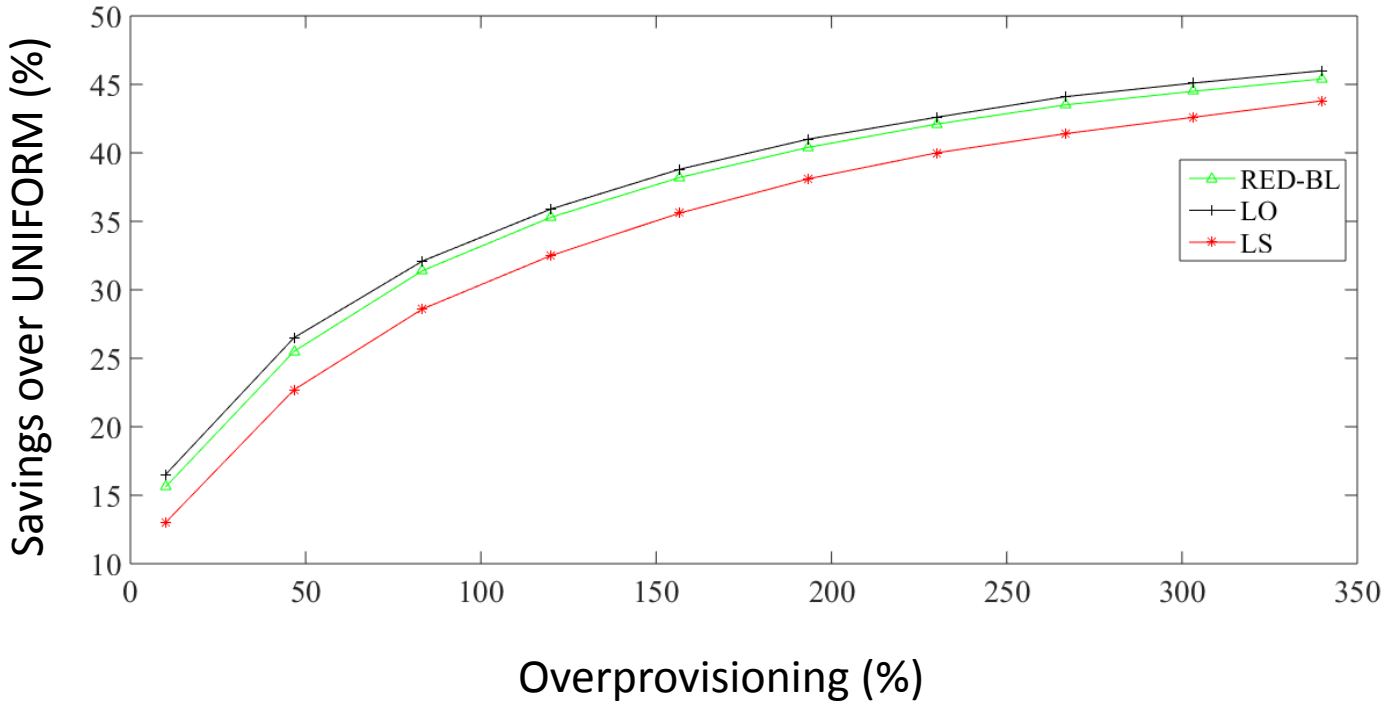
Increased over provisioning

Cost Savings vs Over-provisioning



Increased over provisioning → More capacity at cheaper locations

Cost Savings vs Over-provisioning

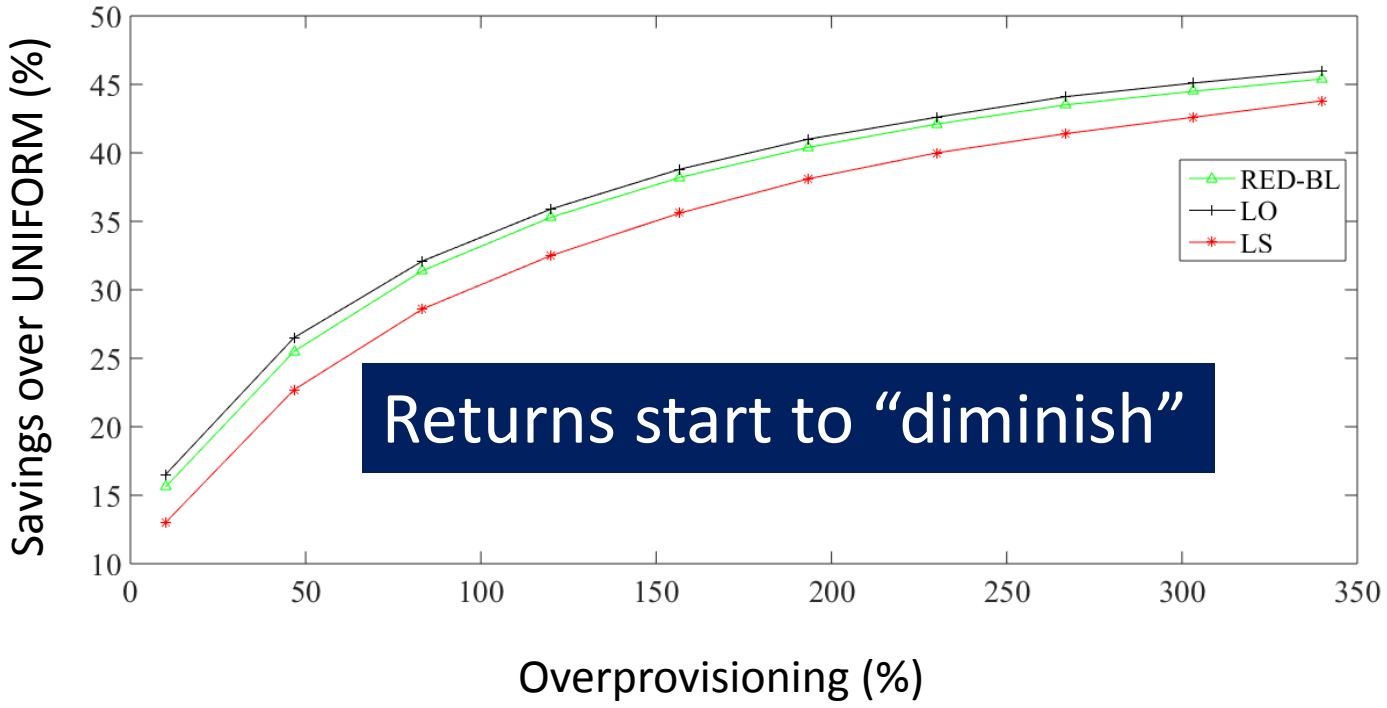


Increased over provisioning → More capacity at cheaper locations

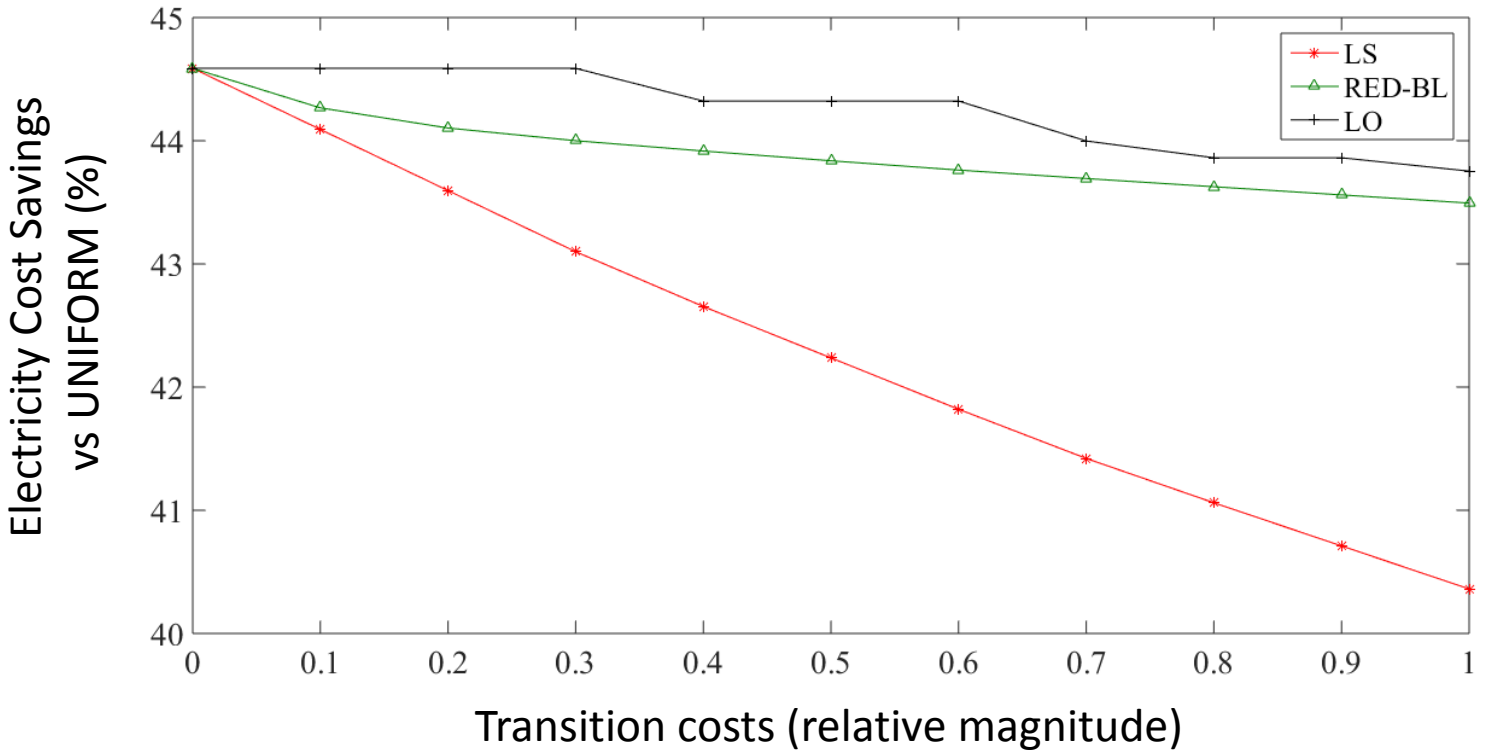
↓

Greater savings

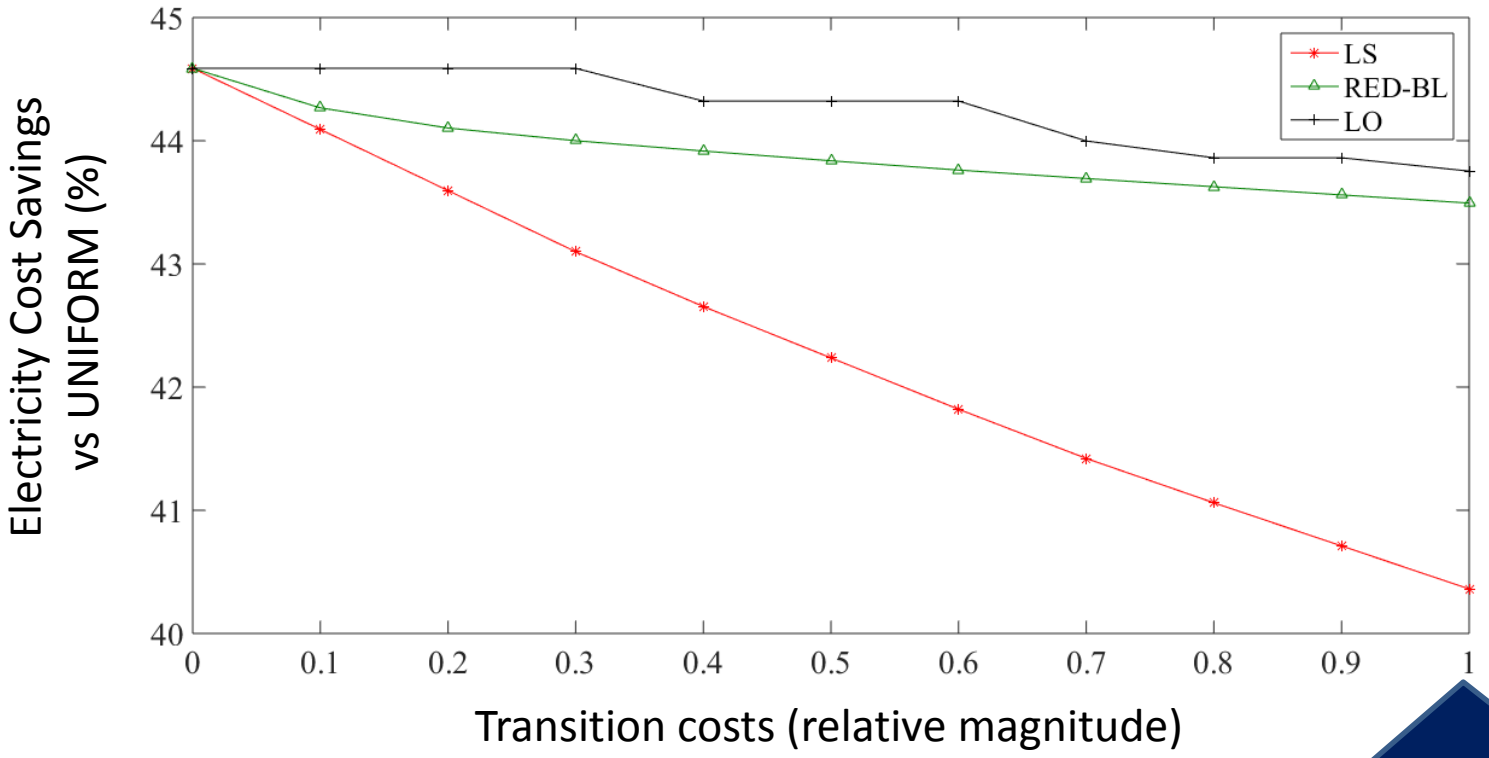
Cost Savings vs Over-provisioning



Electricity Cost vs Transition Cost

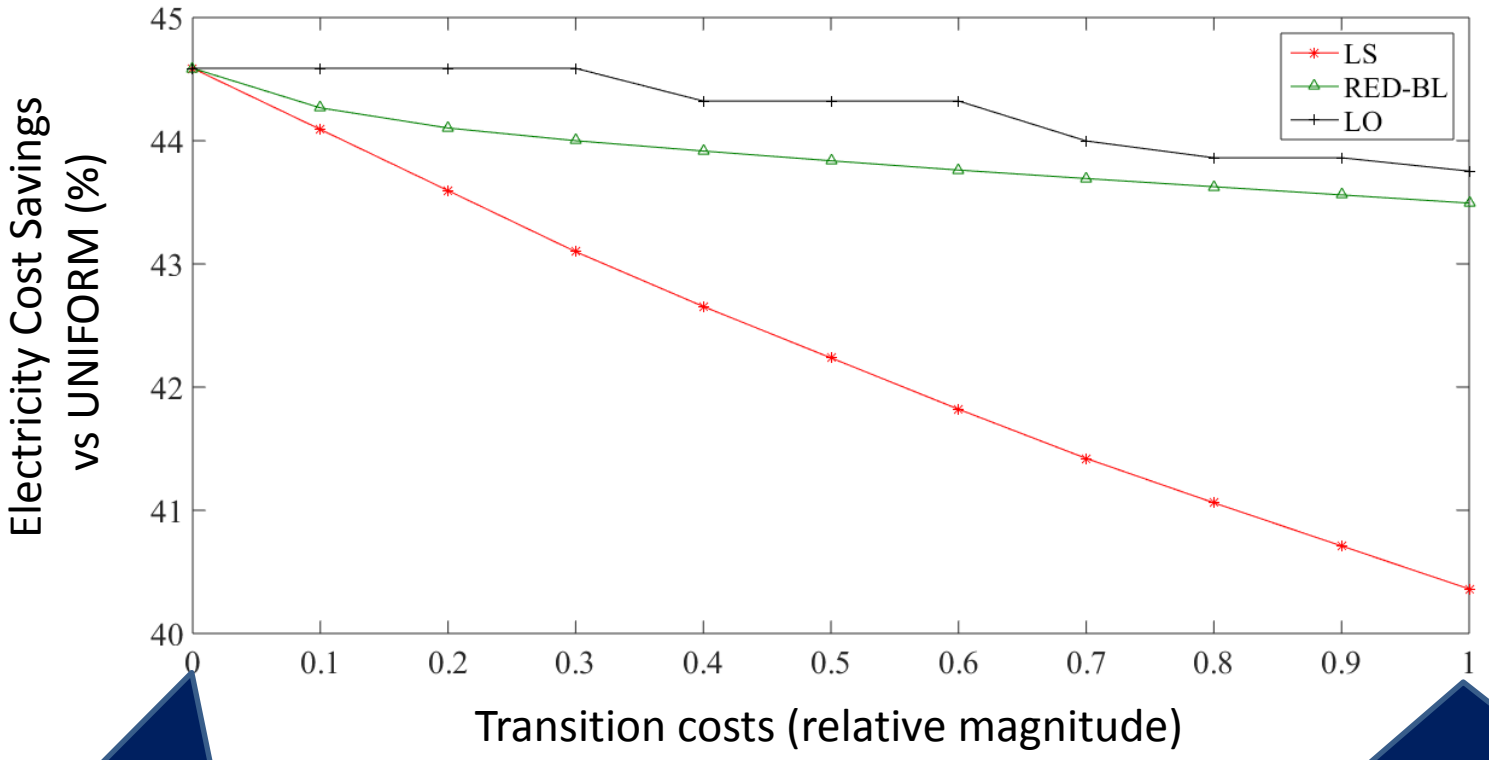


Electricity Cost vs Transition Cost



(De)activation overhead = energy cost

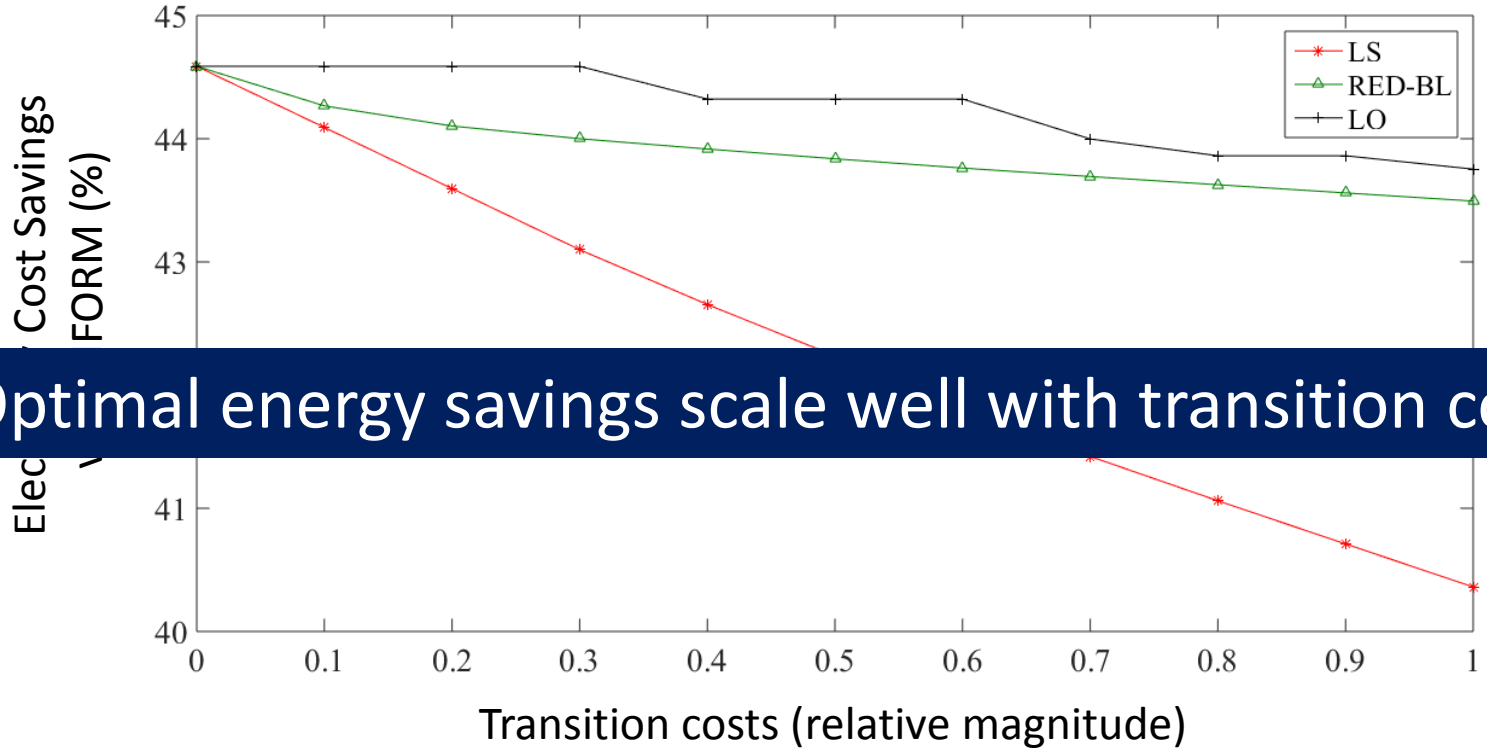
Electricity Cost vs Transition Cost



No transition costs

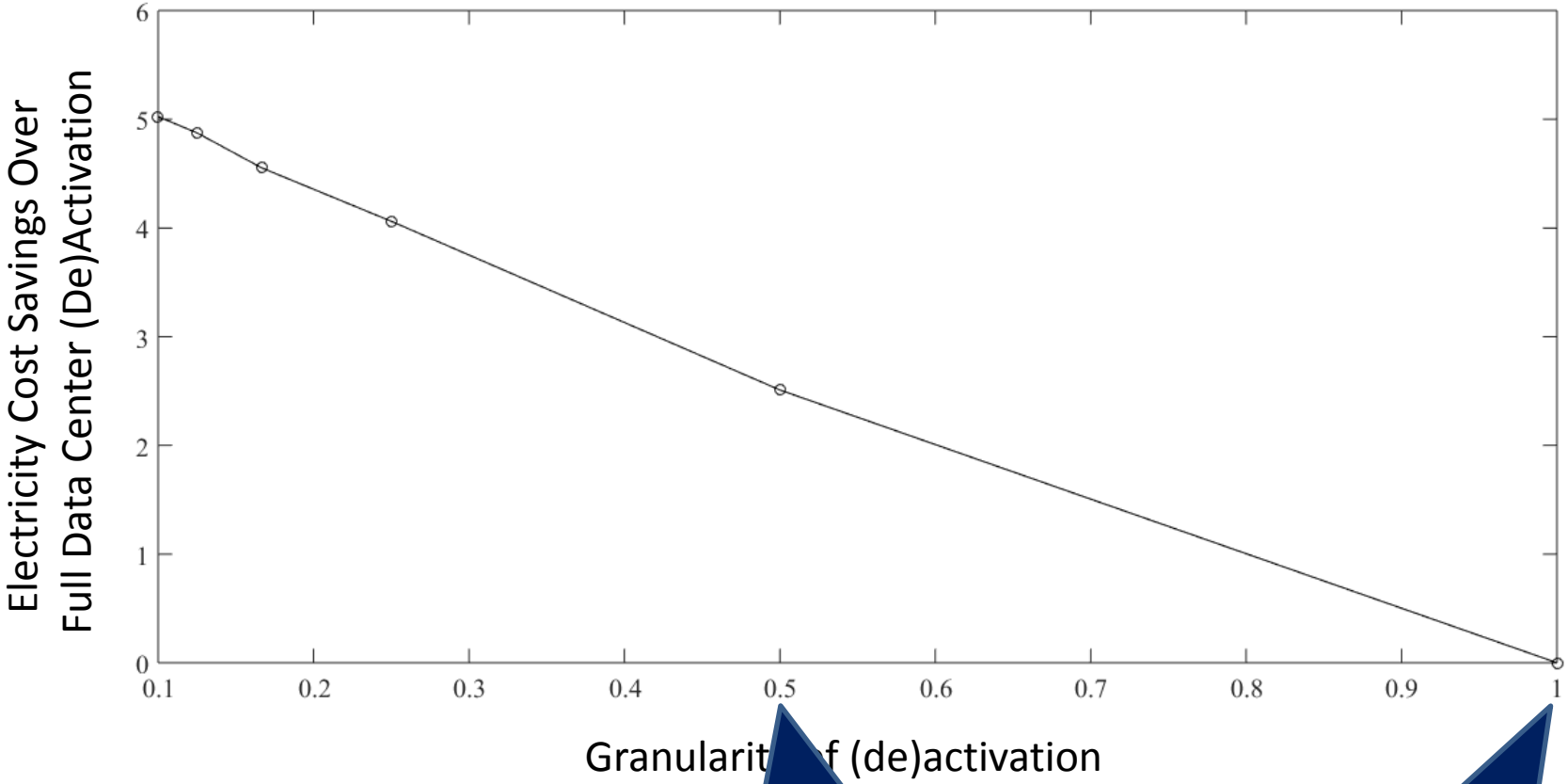
(De)activation overhead = energy cost

Electricity Cost vs Transition Cost



Optimal energy savings scale well with transition costs

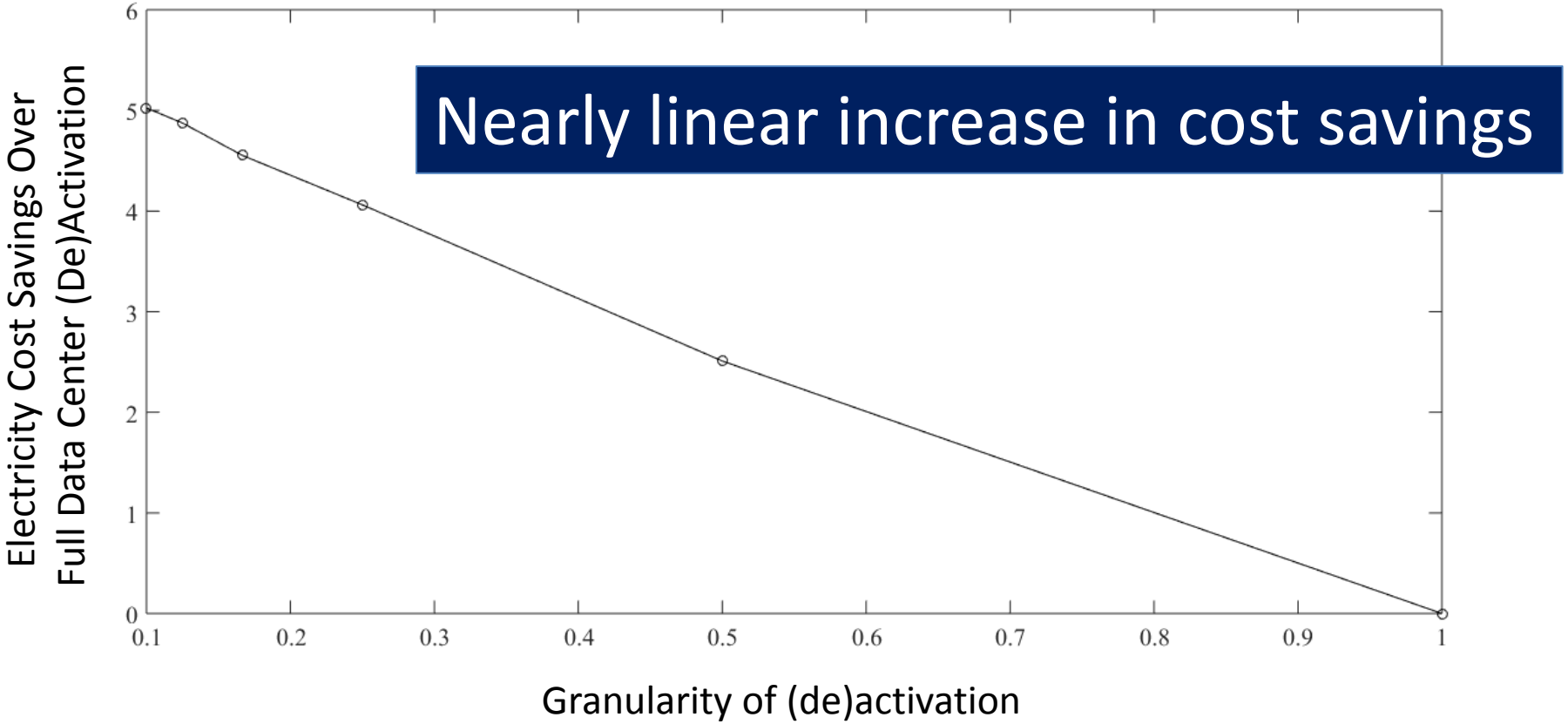
Granular (De)activation



Can (de)activate half a data center

Can only (de)activate entire data center

Granular (De)activation



Summary – Case Study I

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- Electricity cost savings can be achieved
  - Overprovisioning
  - Diversity

Summary – Case Study I

- Electricity cost savings can be achieved
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  - Diversity
- It is important to consider transition costs

Summary – Case Study I

- Electricity cost savings can be achieved
  - Overprovisioning
  - Diversity
- It is important to consider transition costs
- RED-BL has wider applicability

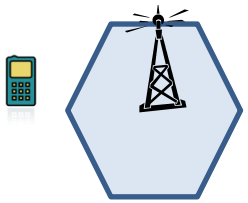
Agenda

- Background and motivation
- Opportunity and key idea
- Case studies:
  - Data centers
  - **Cellular networks**
- Conclusions and future work

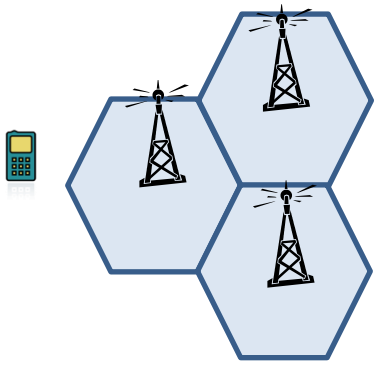
Case Study II
Cellular Networks

Case Study II
Cellular Networks

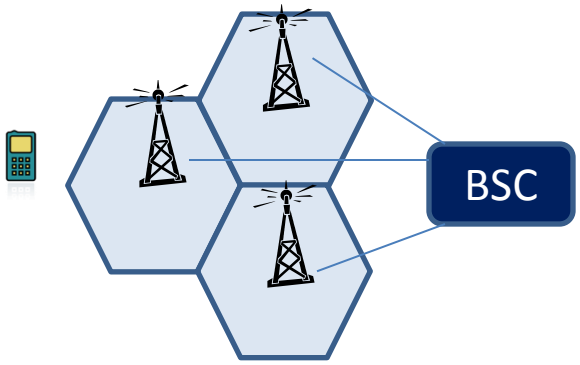
Case Study II
Cellular Networks



Case Study II
Cellular Networks



Case Study II
Cellular Networks



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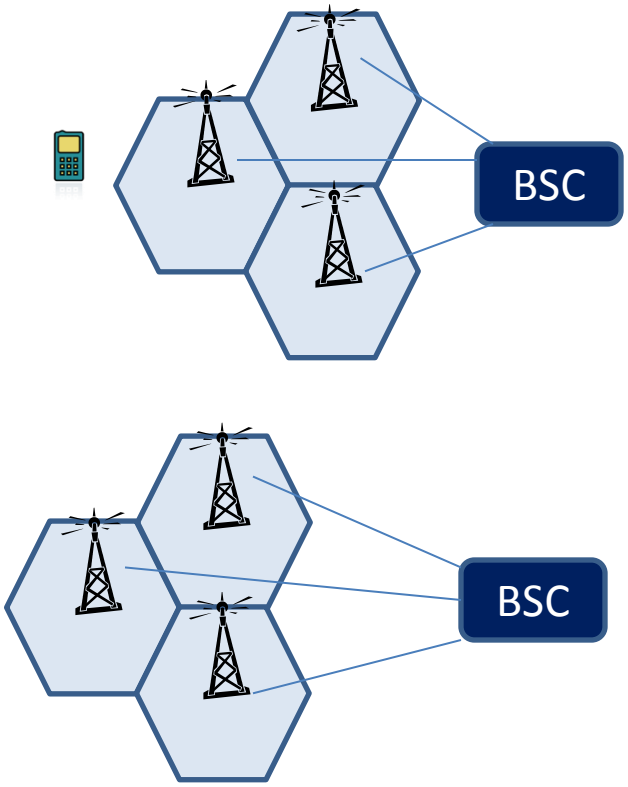
Cellular Networks



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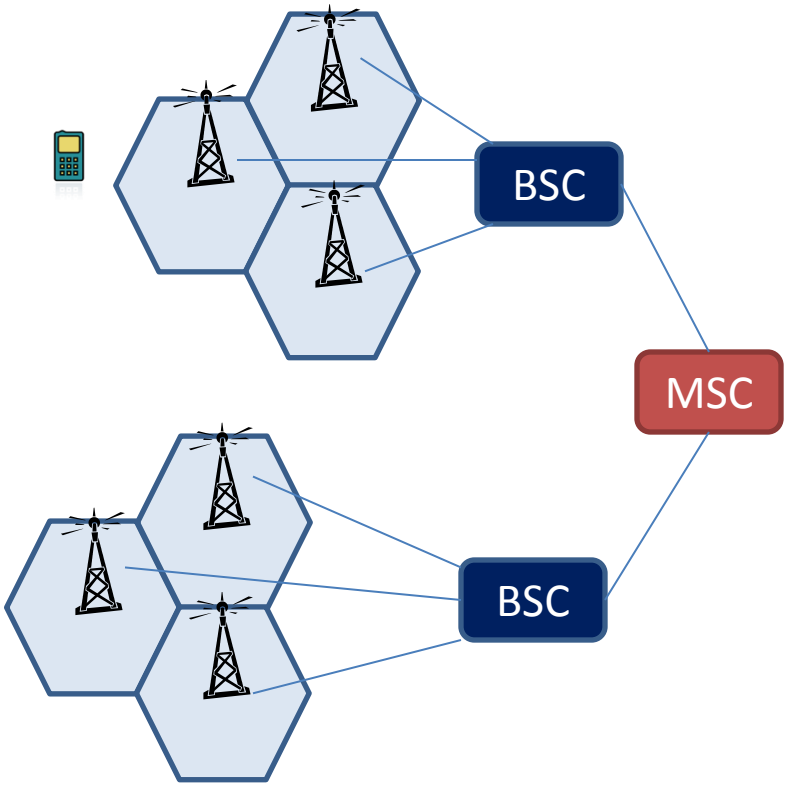

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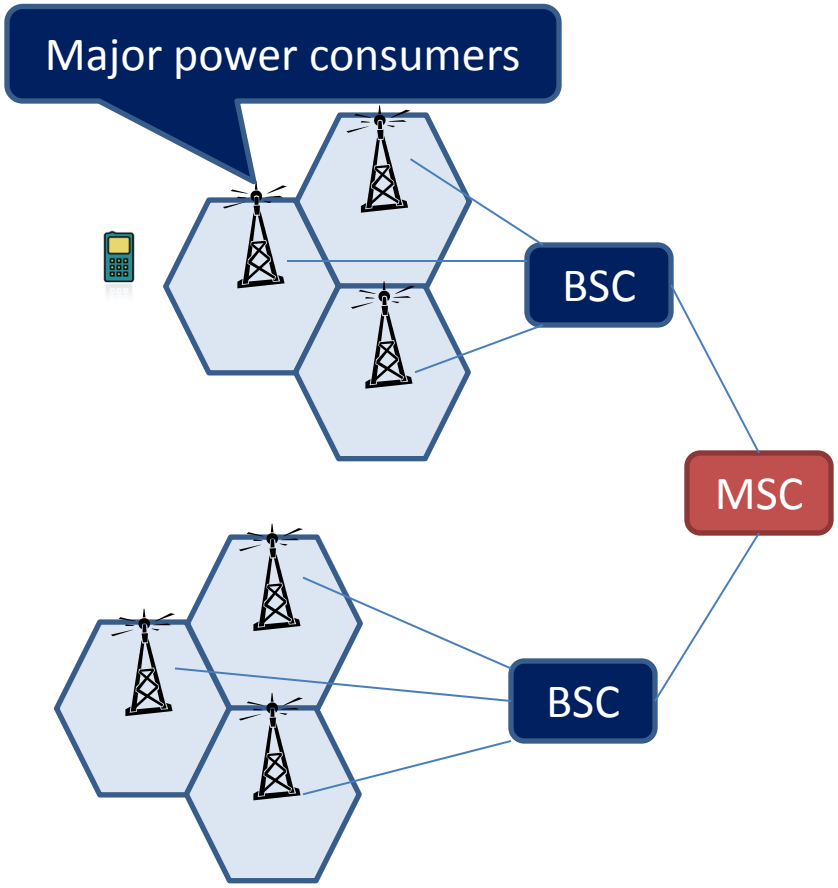

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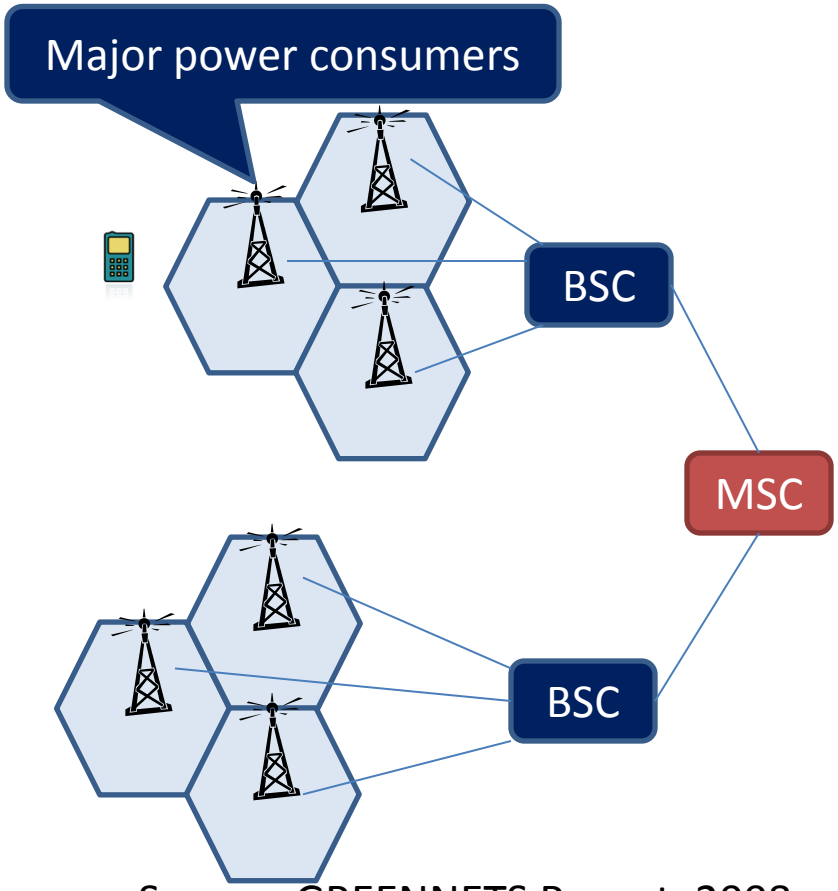
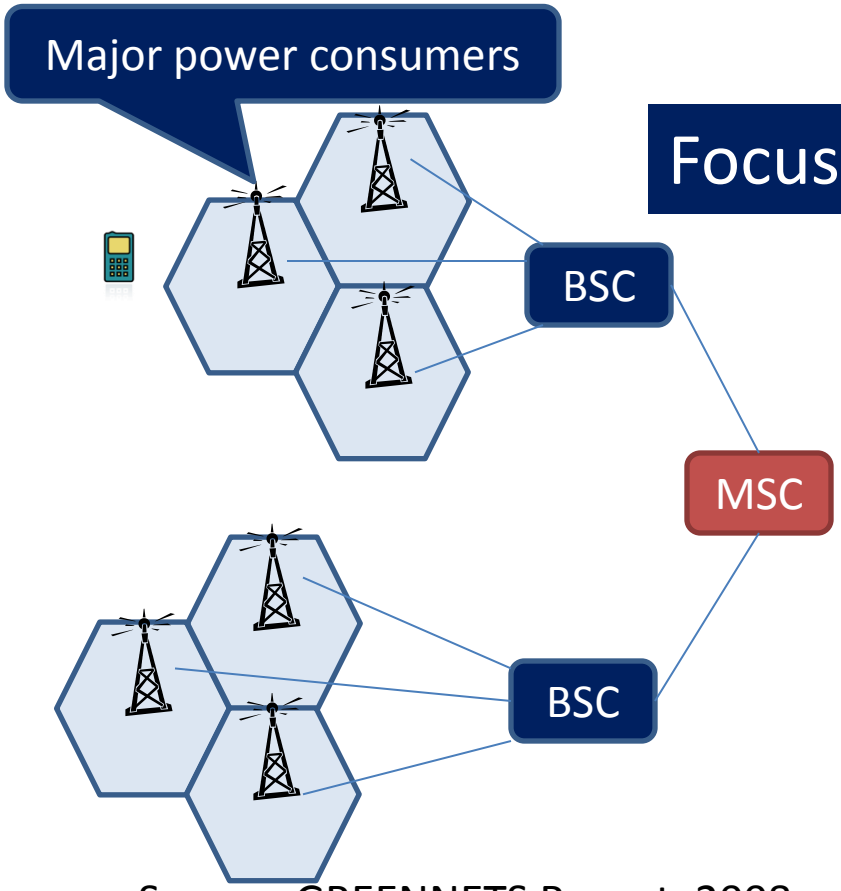


Source: GREENNETS Report, 2008

Marsan et. al, “Optimal Energy Savings in Cellular Access Networks”, ICC 2009

Case Study II
Cellular Networks

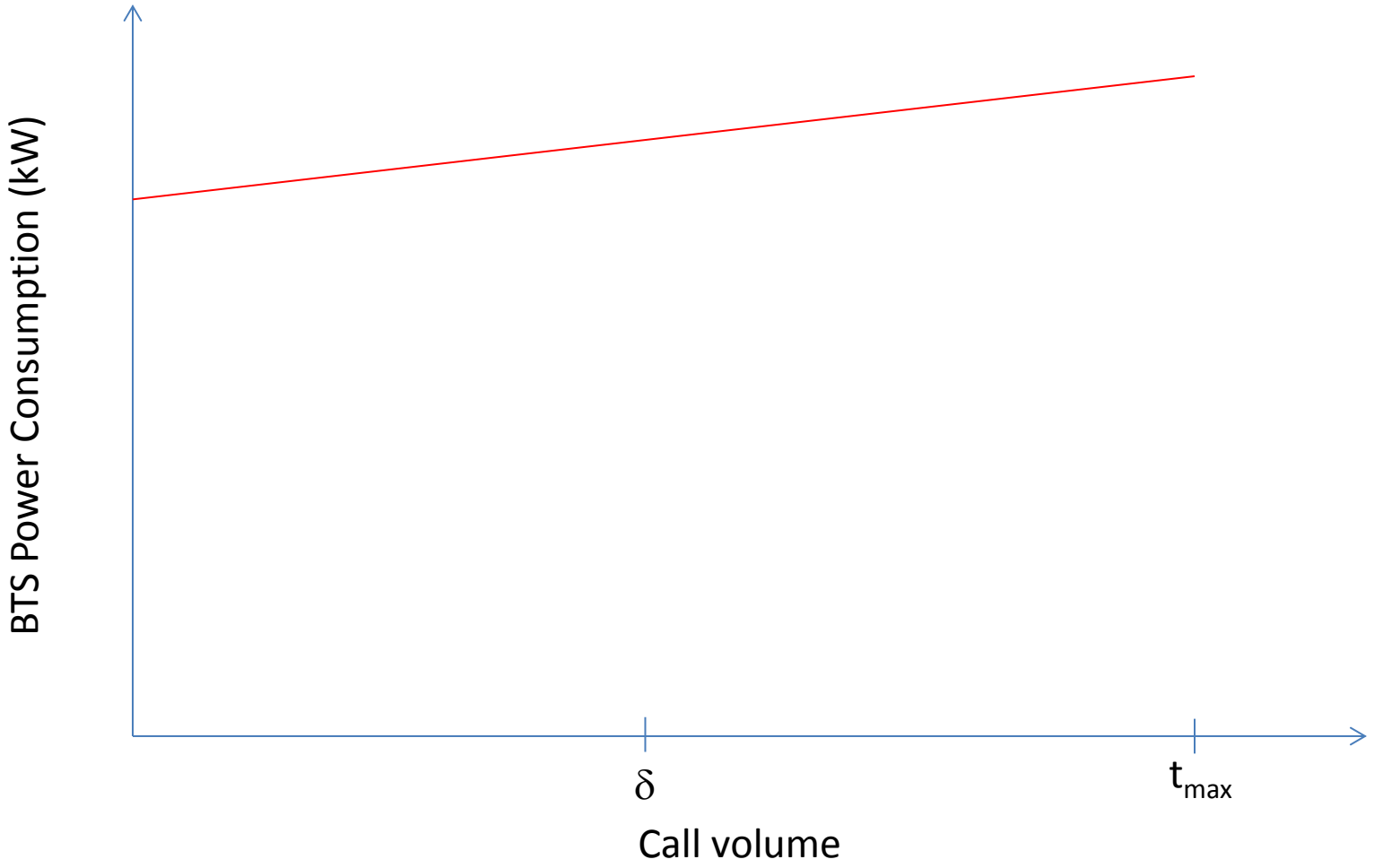


Focus on BTSs to cut electricity cost

Source: GREENNETS Report, 2008

Marsan et. al, “Optimal Energy Savings in Cellular Access Networks”, ICC 2009

Resource Pruning



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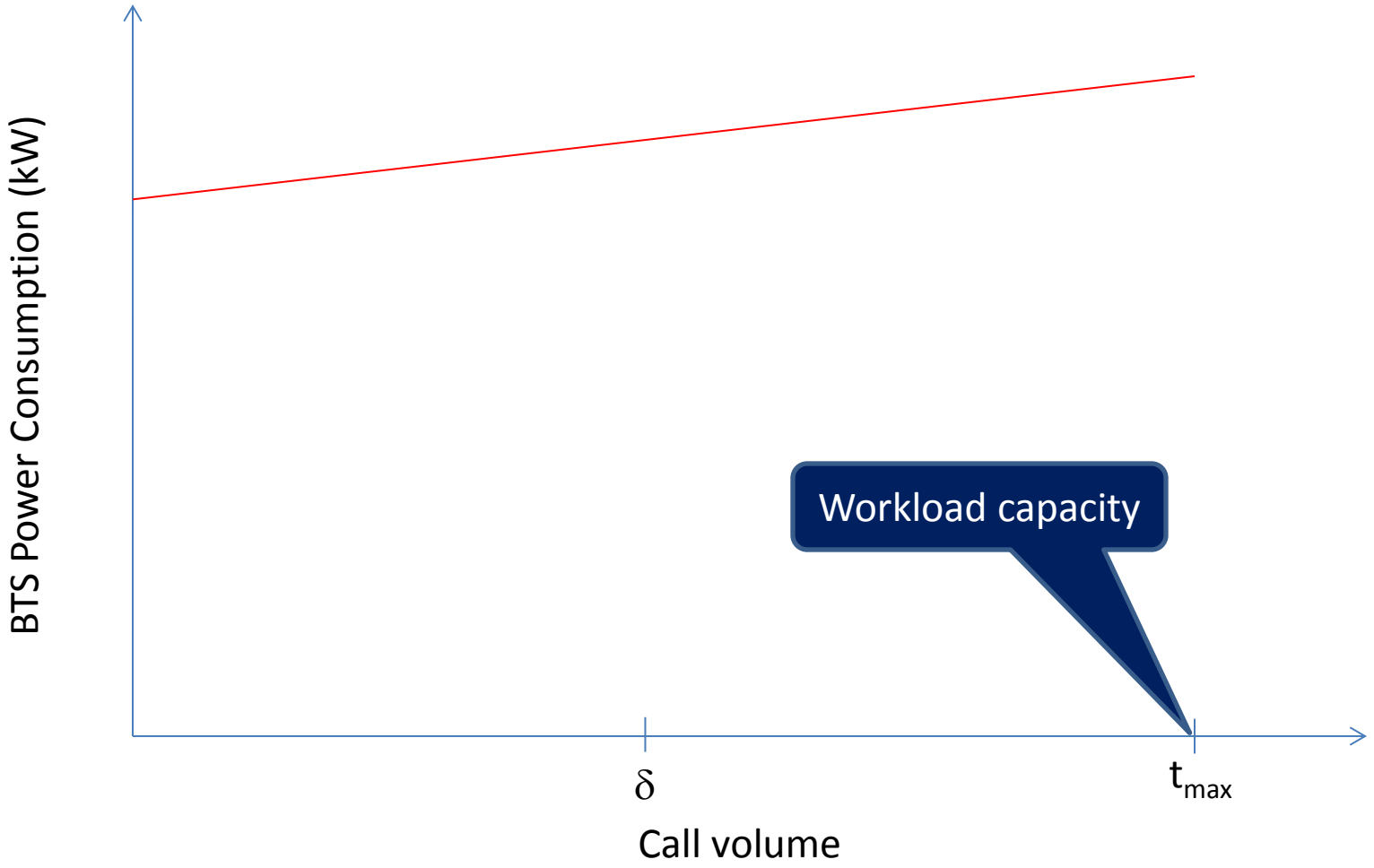

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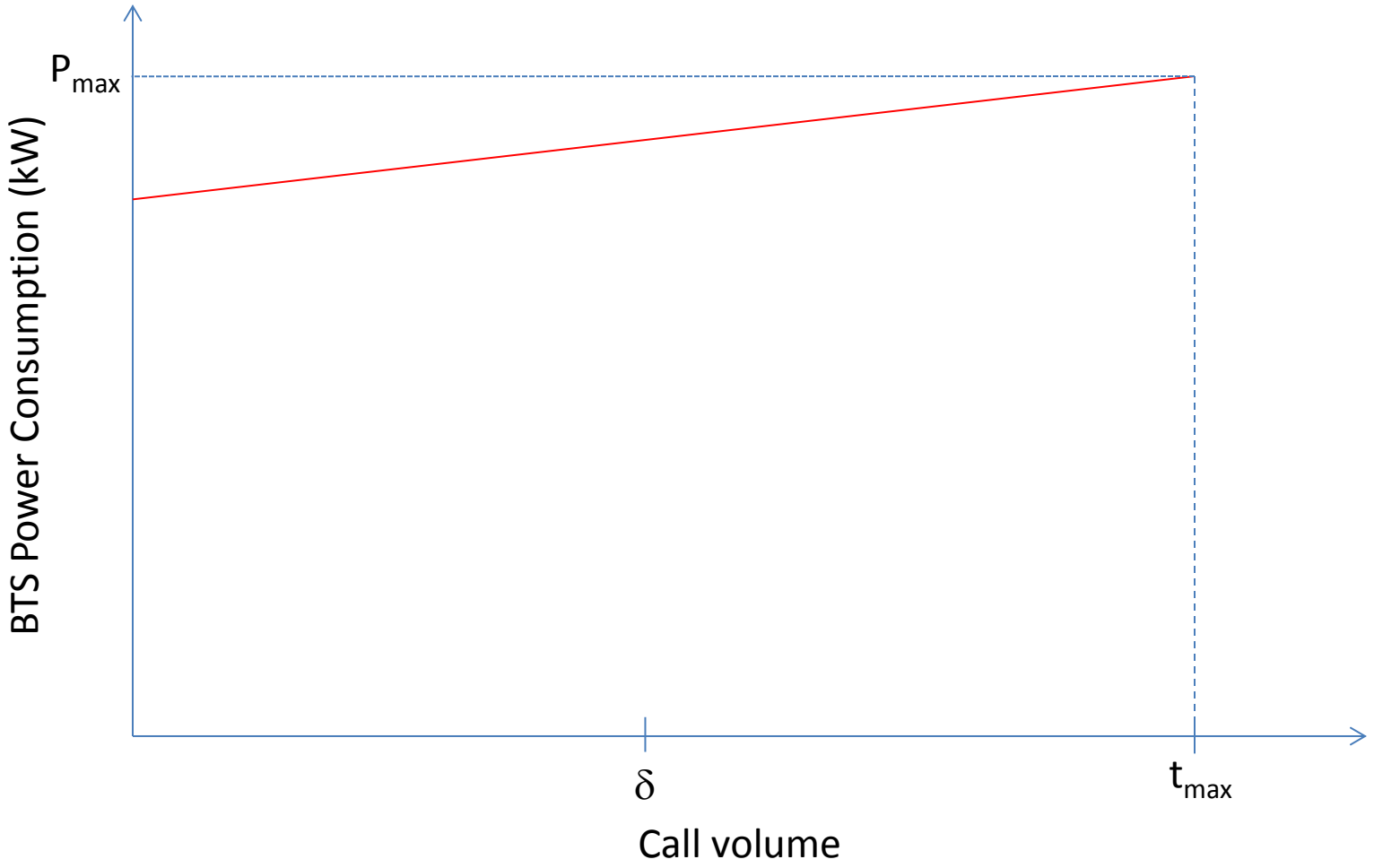

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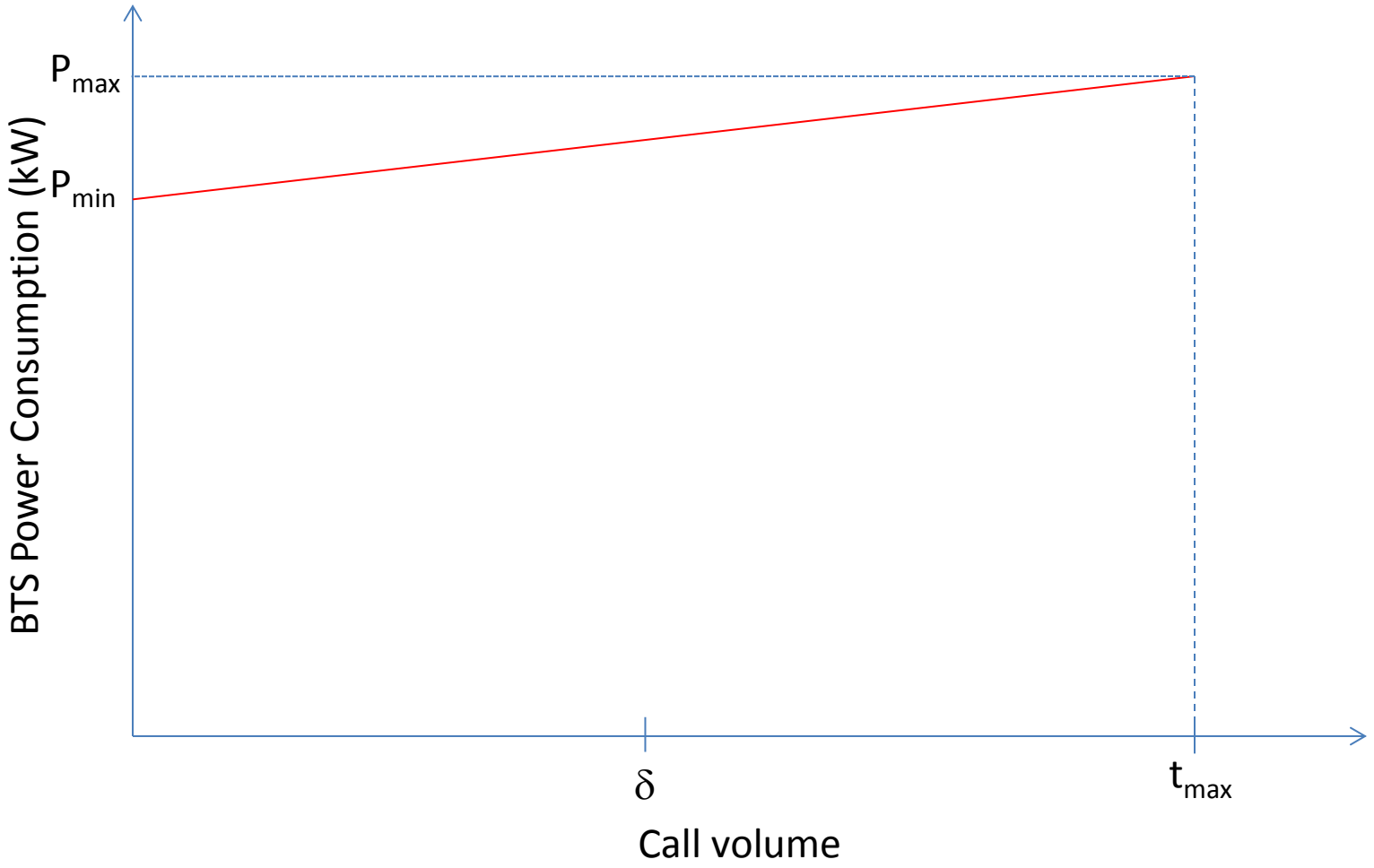

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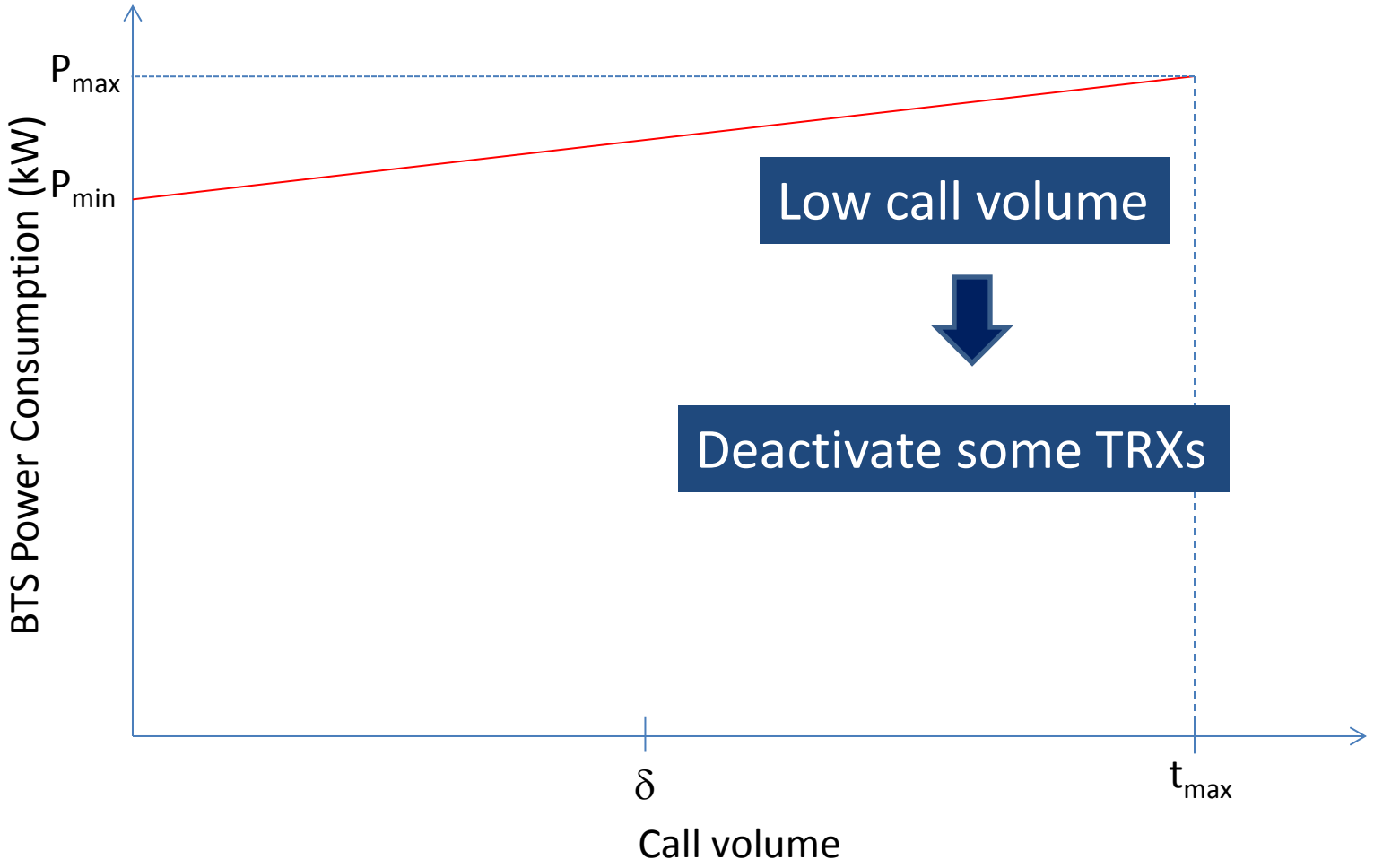

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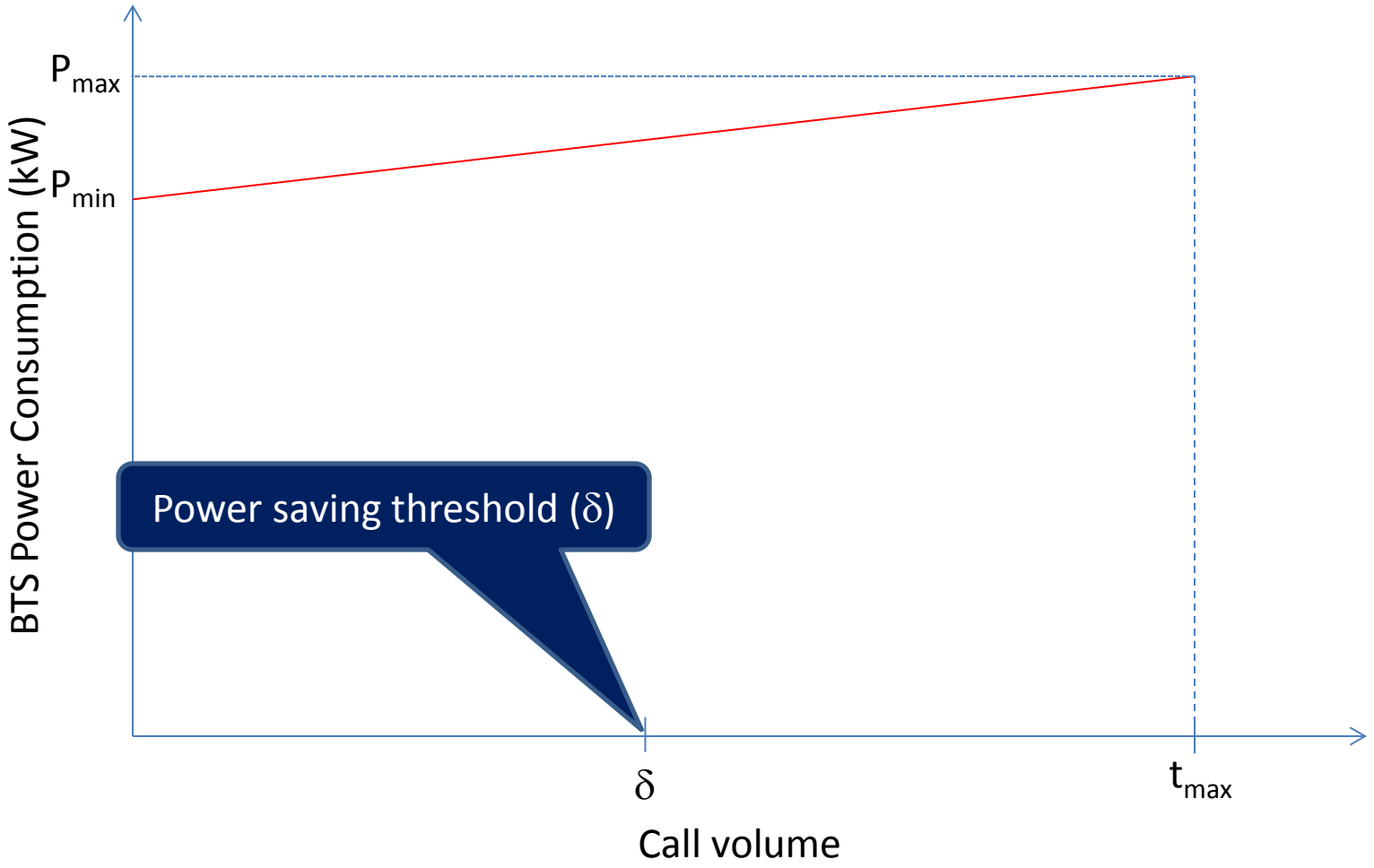

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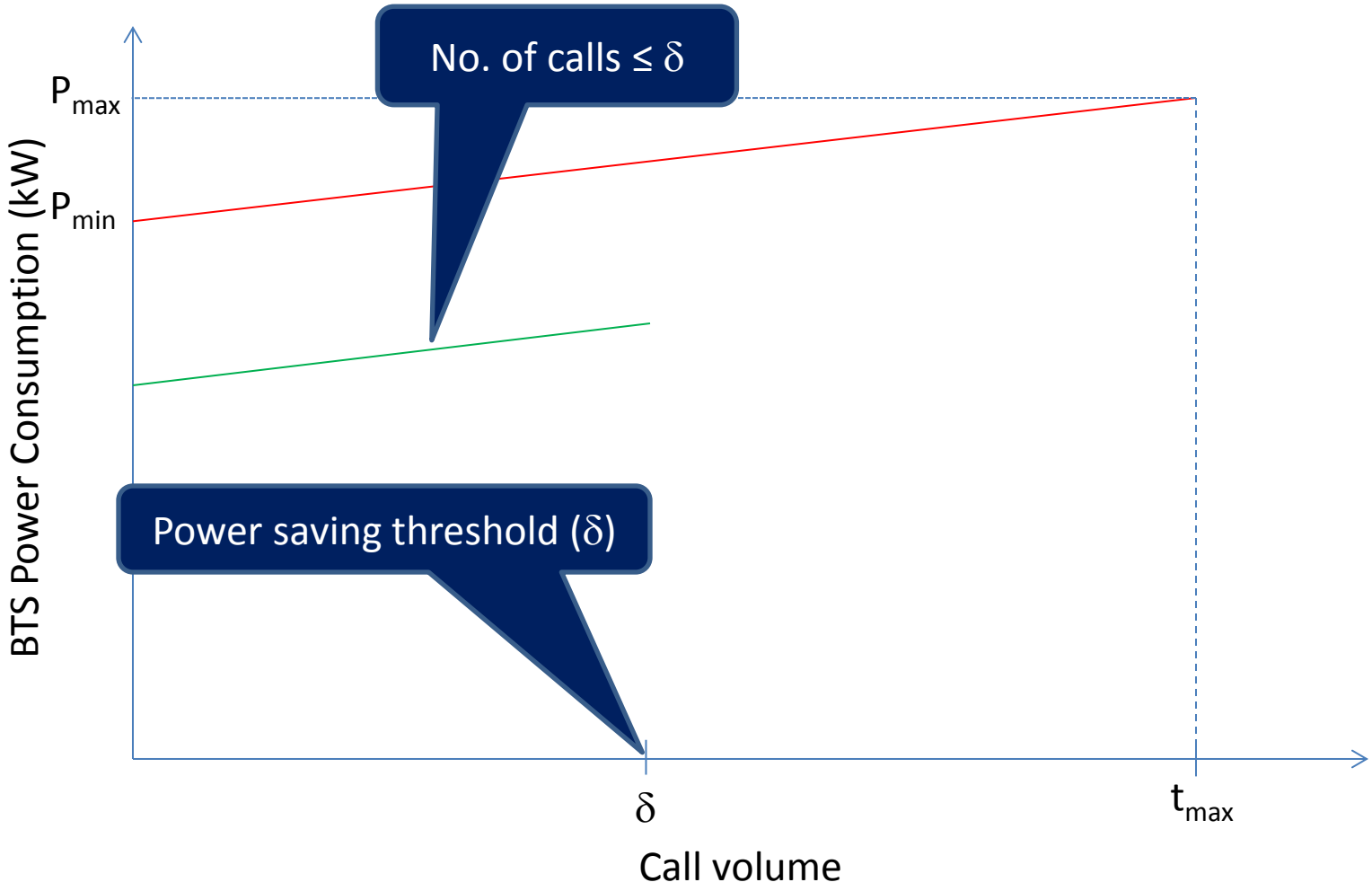

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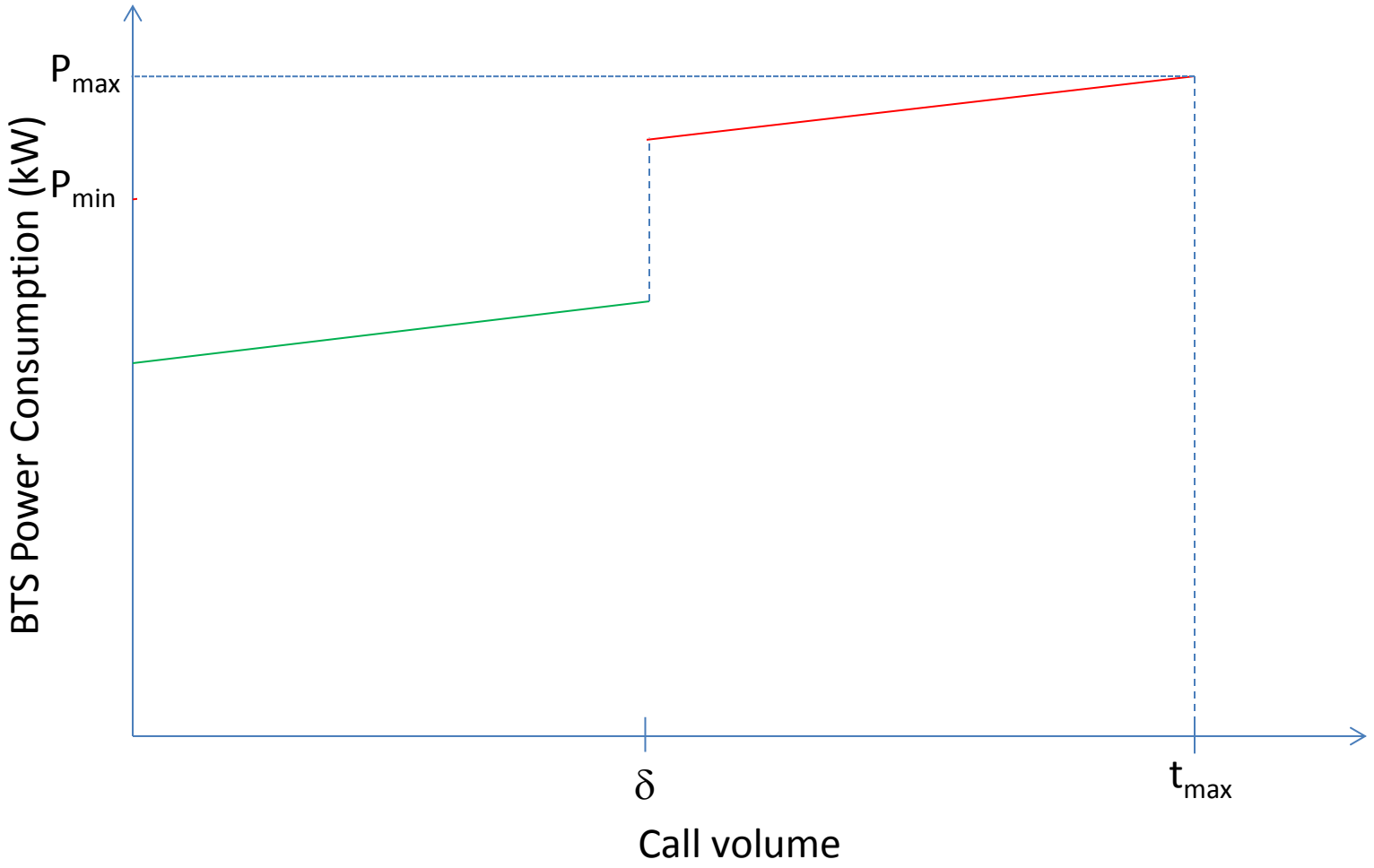

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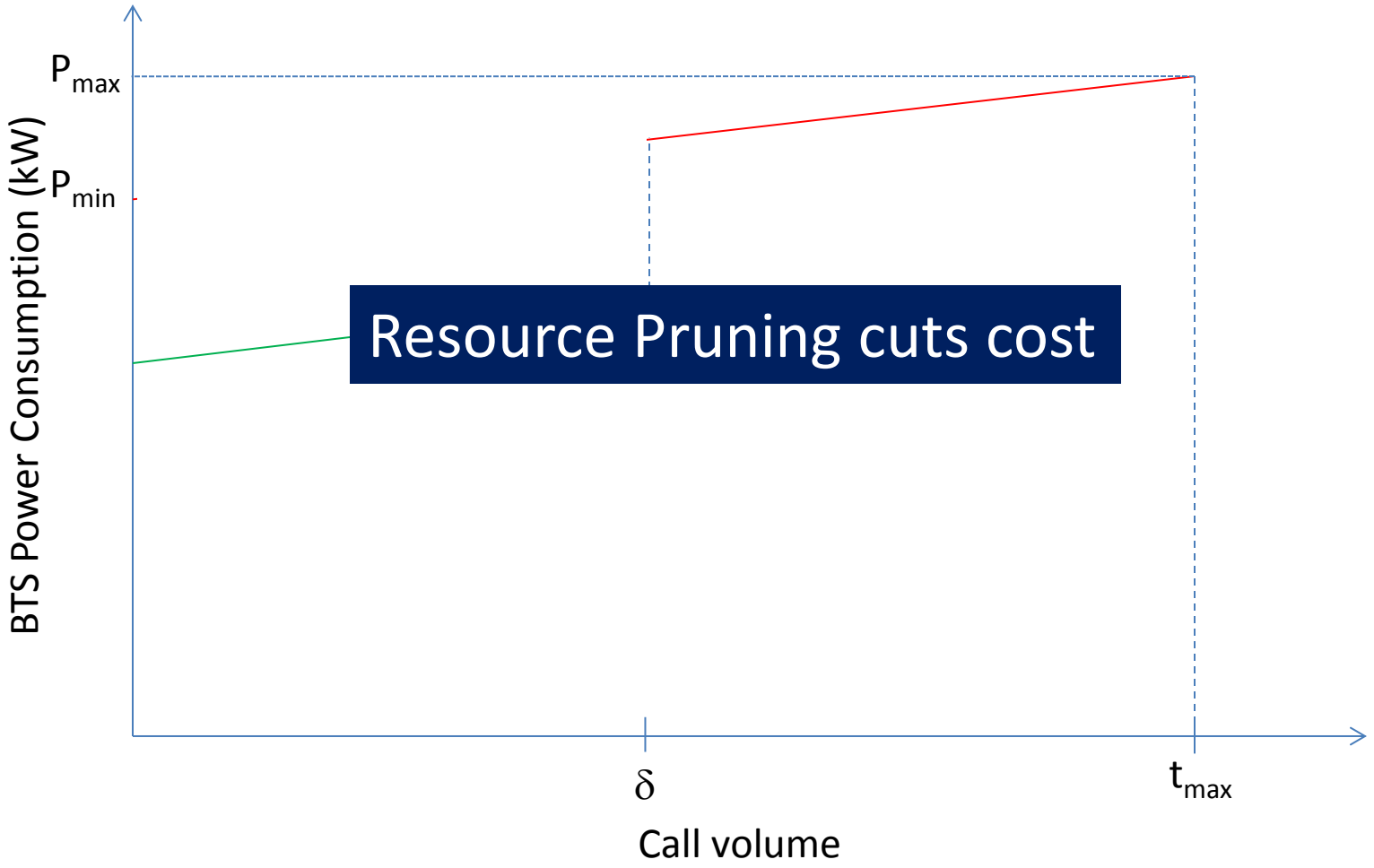
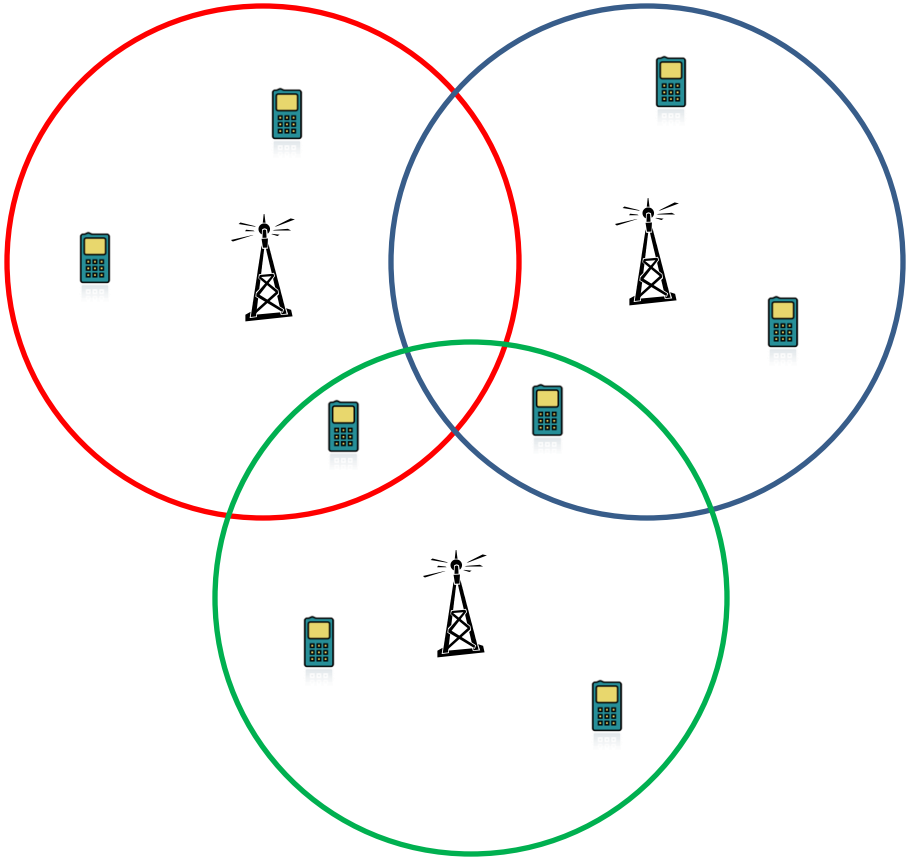


Does workload relocation help?



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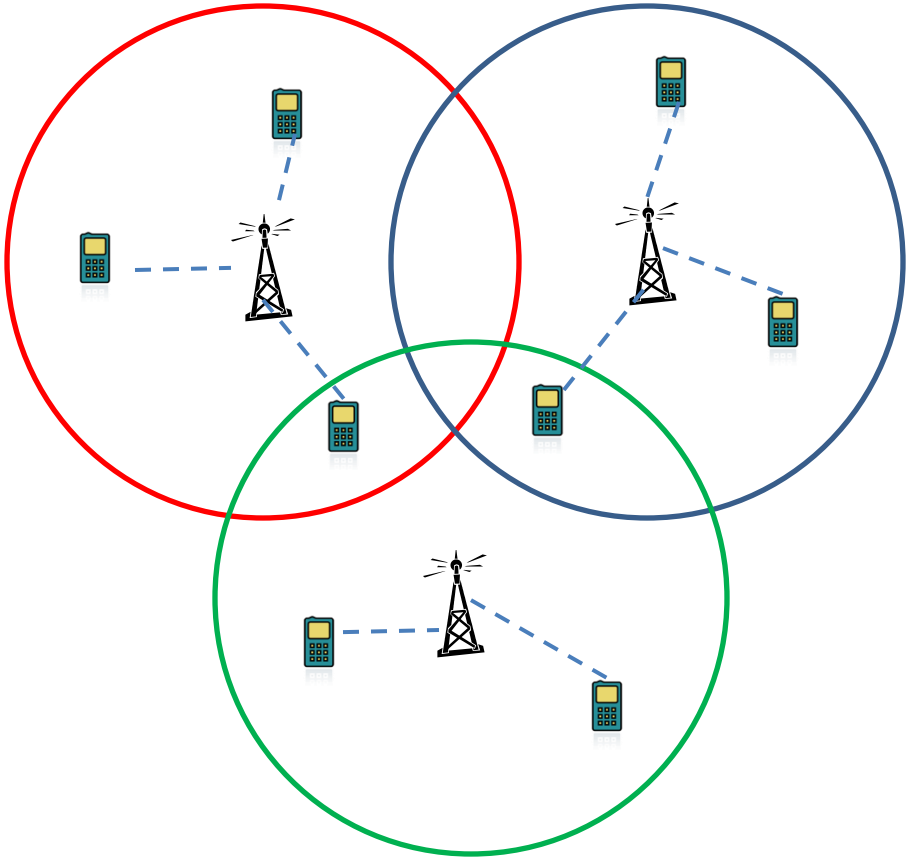

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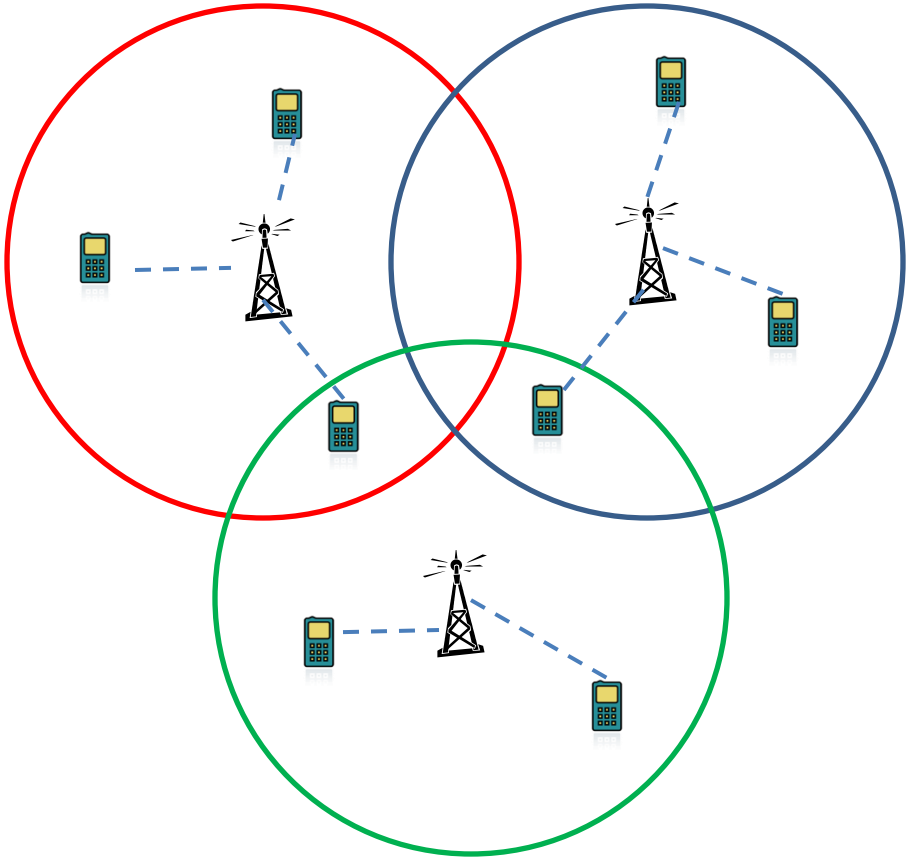

Assume that power saving is enabled if upto two calls are being served

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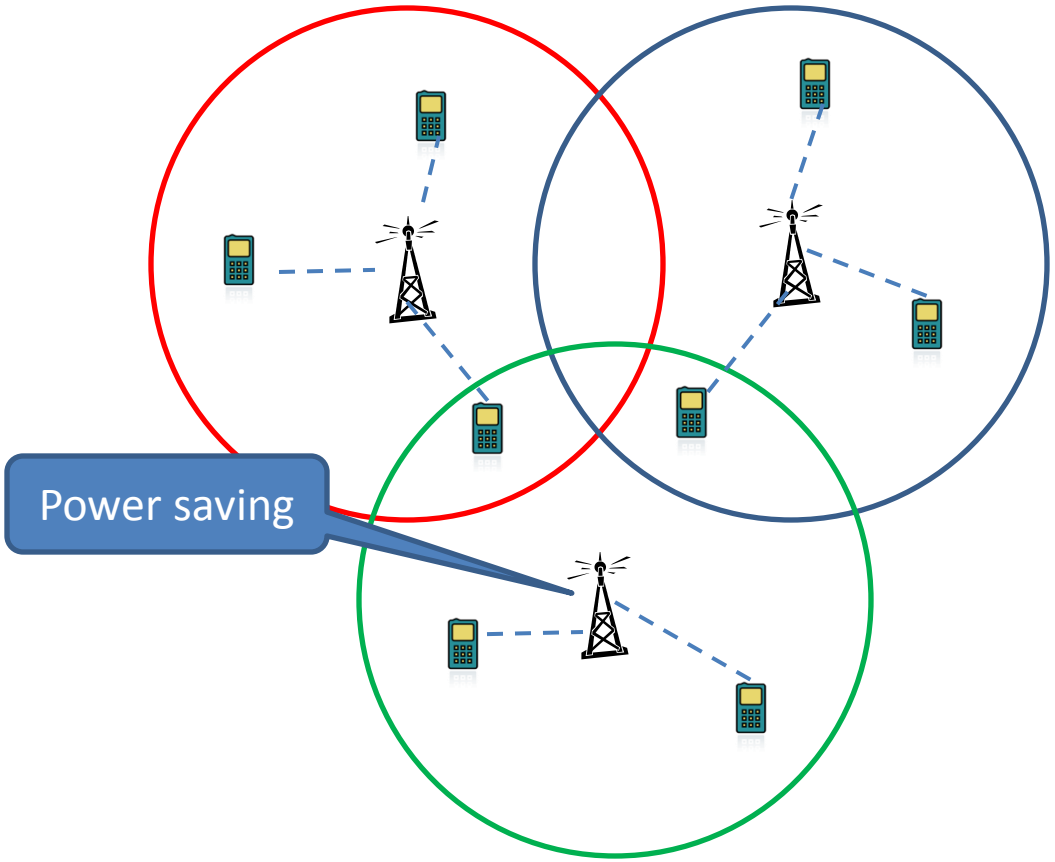

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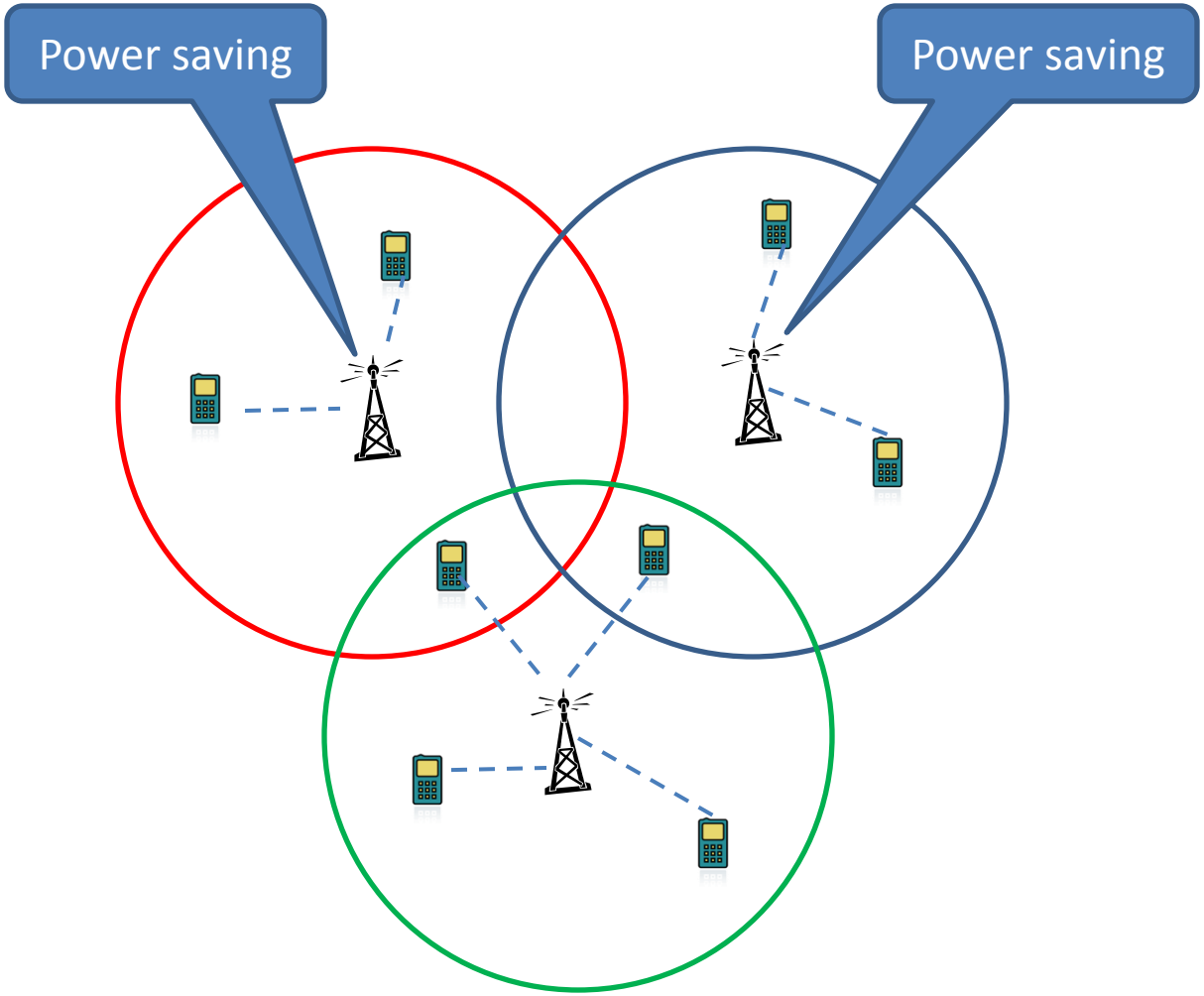

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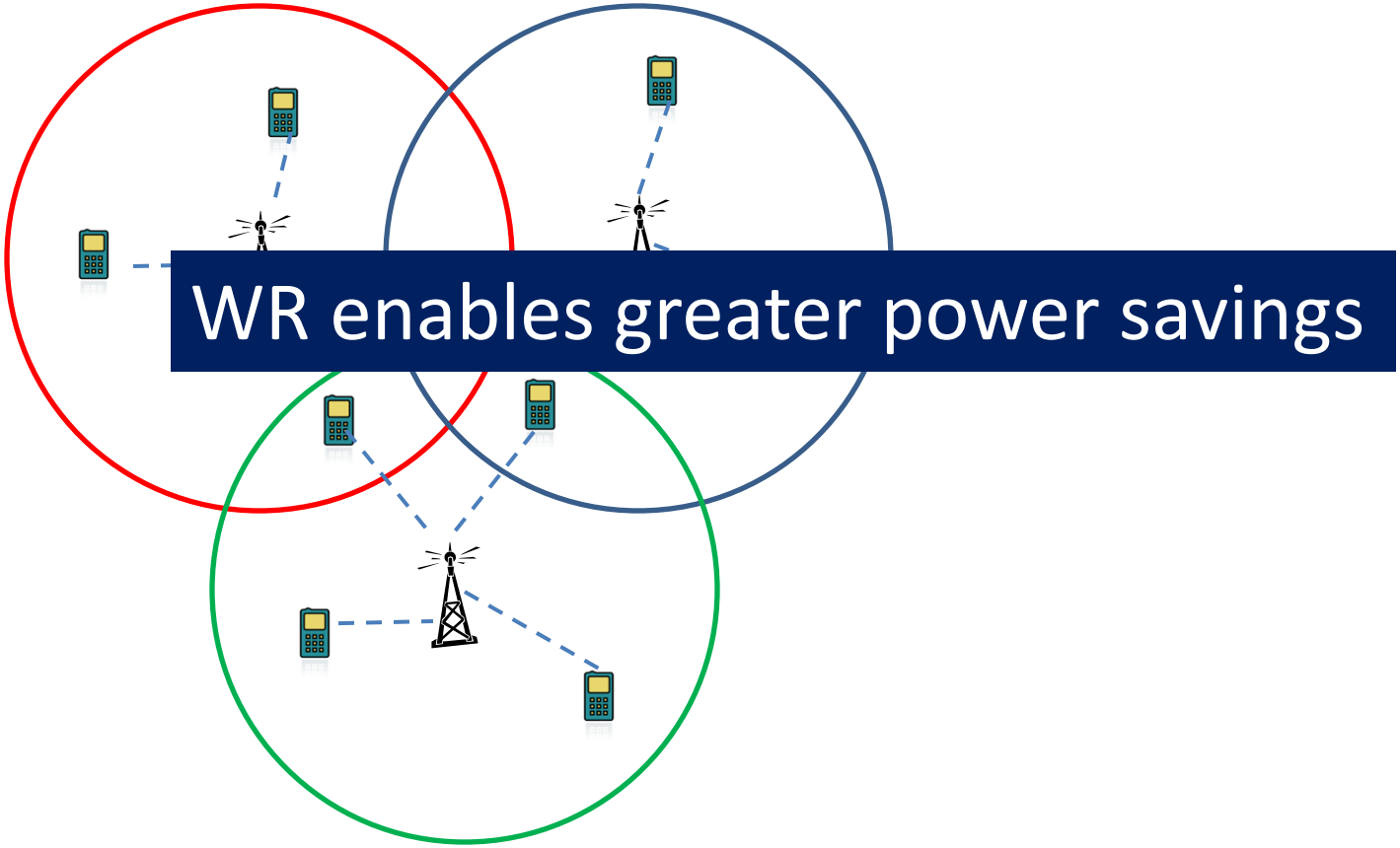

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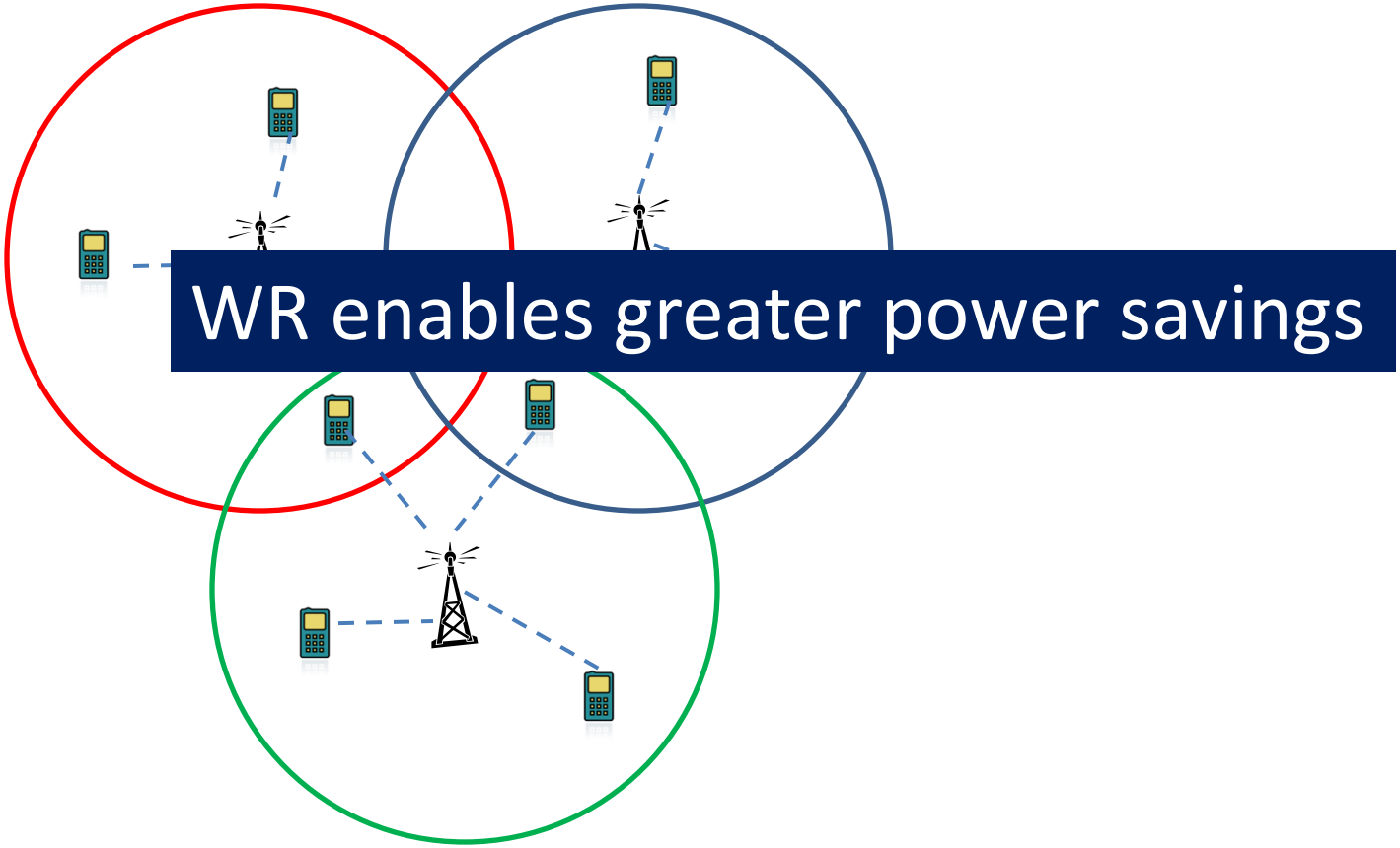
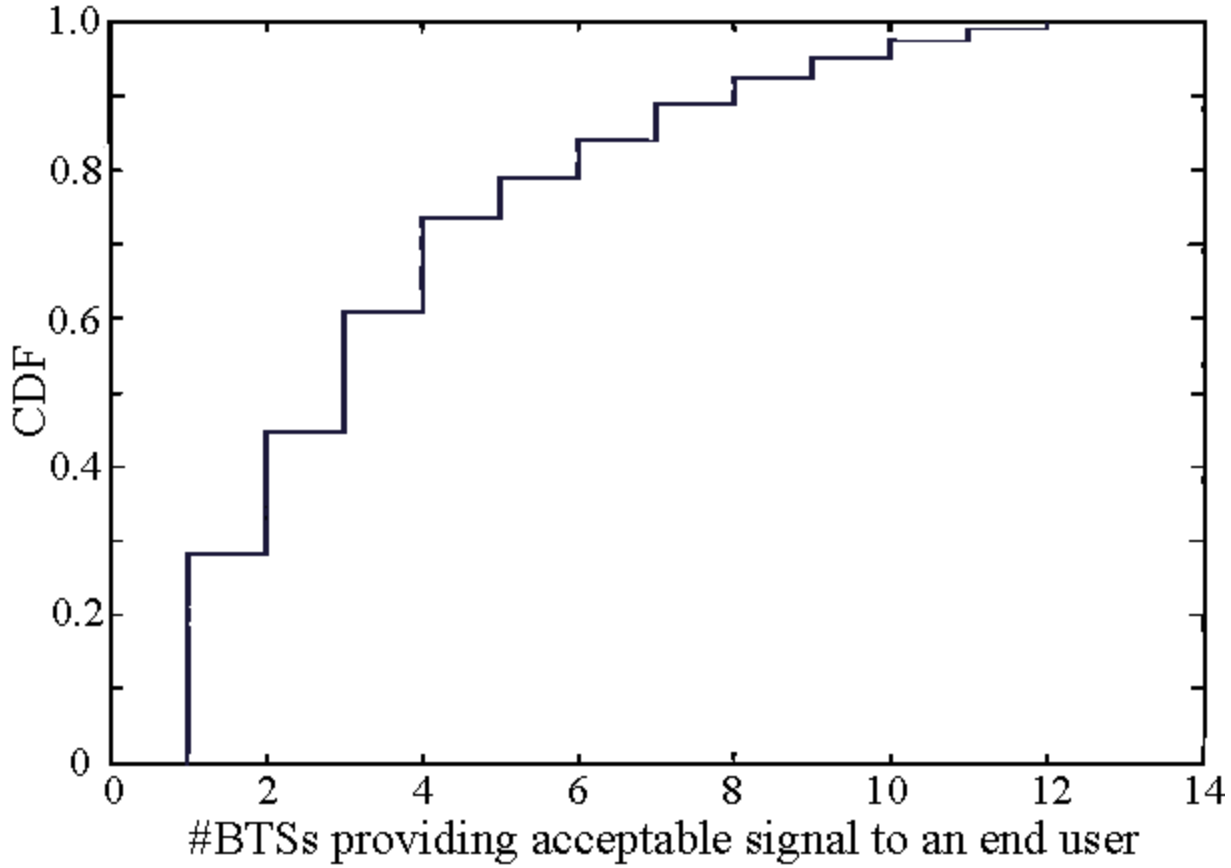


Is Workload Relocation Possible?



40% users receive signal from more than three BTSs

Optimization Formulation

$$\text{minimize} \sum_{j=1}^{n} \sum_{i=1}^{m} c_i e_i^j (p_i^j \lambda (f + (1-f)\frac{x_i^j}{c_i}) + b_i^j \sigma + s_i^j \delta)$$

Optimization Formulation

$$\text{minimize} \sum_{j=1}^{n} \sum_{i=1}^{m} c_i e_i^j (p_i^j \lambda [illegible] 1 - f) \frac{x_i^j}{c_i}) + b_i^j \sigma + s_i^j \delta)$$

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$$minimize \sum_{j=1}^{m} p_i^j$$

For every interval, minimize # TRXs

Optimization Formulation

$$\text{minimize} \sum_{j=1}^{n} \sum_{i=1}^{m} c_i e_i^j (p_i^j \lambda (1 - f) \frac{x_i^j}{c_i}) + b_i^j \sigma + s_i^j \delta)$$

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$$minimize \sum_{j=1}^{m} p_i^j$$

Experimental Setup

Experimental Setup

- Call volume traces for 2 days at 26 urban BTSs

Experimental Setup

- Call volume traces for 2 days at 26 urban BTSs
- Trace driven simulation:
  - Periodically obtain optimal call placement
  - Place BTSs with low-traffic in power-saving mode

BTS Power Consumption Models

Parameter	Value		
	Model 1	Model 2	Model 3
Idle Power (W)	1425	2401.8	2341.5
Peak Power (W)	1500	3887.5	2973.9
Power Saving per TRX (W)	20	50	100

Results: Power-Saving Feature Only

Energy savings	Model 1	Model 2	Model 3
Percentage	4.73%	5.43%	12.89%
Daily energy savings (kWh)	43.28	109.68	217.12
Country-wide daily savings - 31000 sites (MWh)	51.6	130.77	258.87

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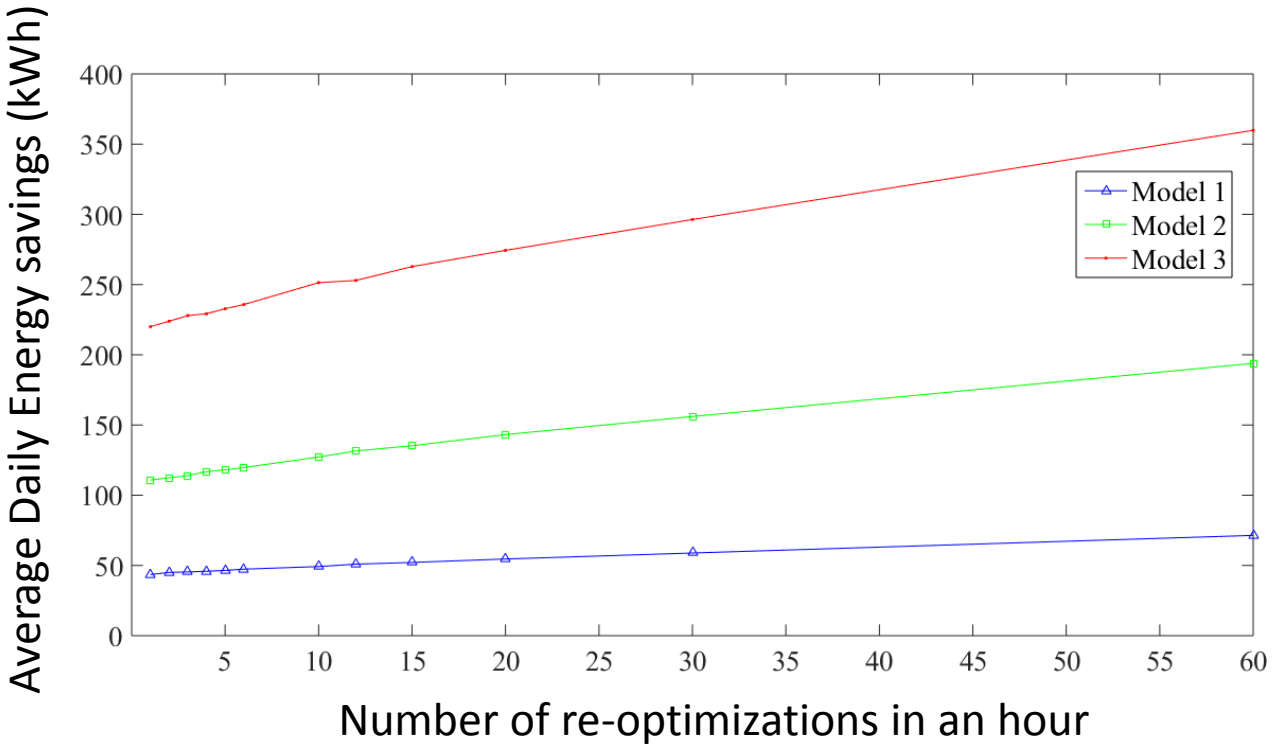
Energy Savings (kWh)
RP + WR



At least 9.8% lower power consumption

Effect of Granular Deactivation

Granularity	Model 1	Model 2	Model 3
2-state	5.38%	6.29%	14.94%
3-state	6.81%	7.73%	18.62%
6-state	8.70%	9.65%	23.37%

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Savings increase with finer granularity

Case Study II - Summary

- Overlaps in signal coverage
  - Some geo-flexibility in workload
- Built-in power saving feature
- Significant cost reduction through WR + RP

Drawing Parallels With Case Study I

Parameter	Cellular network	Data centers

Drawing Parallels With Case Study I

Parameter	Cellular network	Data centers
Network resource		

Drawing Parallels With Case Study I

Parameter	Cellular network	Data centers
Network resource		Servers

Drawing Parallels With Case Study I

Parameter	Cellular network	Data centers
Network resource	TRX	Servers

Drawing Parallels With Case Study I

Parameter	Cellular network	Data centers
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Workload relocation		

Drawing Parallels With Case Study I

Parameter	Cellular network	Data centers
Network resource	TRX	Servers
Workload relocation		Client redirect

Drawing Parallels With Case Study I

Parameter	Cellular network	Data centers
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Workload relocation	Call hand off	Client redirect

Drawing Parallels With Case Study I

Parameter	Cellular network	Data centers
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Resource pruning		

Drawing Parallels With Case Study I

Parameter	Cellular network	Data centers
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Transition costs		

Drawing Parallels With Case Study I

Parameter	Cellular network	Data centers
Network resource	TRX	Servers
Workload relocation	Call hand off	Client redirect
Resource pruning	BTS Power Saving	Server shutdown / idle / hibernate
Transition costs		(De)activation overheads

Drawing Parallels With Case Study I

Parameter	Cellular network	Data centers
Network resource	TRX	Servers
Workload relocation	Call hand off	Client redirect
Resource pruning	BTS Power Saving	Server shutdown / idle / hibernate
Transition costs	Negligible	(De)activation overheads

Agenda

- Background and motivation
- Opportunity and key idea
- Case studies:
  - Data centers
  - Cellular networks
- **Conclusions and future work**

Future Work

- Adaptation and application to 3G, 4G, 5G and beyond
- Factor in other forms of transition costs:
  - Cost of change in latency
  - Cost of increase in call blocking probability
- Experimentation on a real testbed
- Incorporation into an OA&M framework
- Interplay with energy markets

Conclusions

- RED-BL: an electricity cost reduction framework
  - Systematic application of WR and RP
- Can significantly reduce electricity costs
  - Data centers
  - Cellular networks
- Reduction in power consumption
  - Positive ecological impact