Adaptive Green Hosting

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"We are not going to solve the climate problem via efficiency – we must move to cleaner sources of energy."

Bill Weihl, March 2011
Facebook's Manager of
Energy Efficiency and Sustainability

The Carbon Footprint of Computing

- Greenhouse gas (GHG) emissions = climate change
- *Carbon footprint* measures the emissions of a population, system, or activity

The carbon footprint of IT is large and growing

- In 8 years, the annual carbon footprint of datacenters worldwide will exceed the footprint of entire countries [McKinsey, 2008]

- 9 of 14 large technology companies were graded "C" or below in GHG mitigation by Greenpeace [greenpeace.org,2012]

Web Hosting Centers

- Datacenters are buildings that house servers
- Earn money by leasing servers to Internet services
  - *Web hosting centers* lease servers primarily to e-commerce and static-content websites
  - (Popular media term, not necessarily technical)

Facebook datacenter

HostGator web host

- Compete for customers by providing high performance servers at low prices

Green Hosting Center

- Green hosting centers are a growing subculture
  - *Invest in reducing their carbon emissions*
  - *Use low carbon footprint to attract customers*
    - Provide competitive prices and equal performance
    - 83% of people prefer equal-priced green products
    - 71% of system managers say the same [rackspace, 2008]

Most hosts (today) profit *without* investing in clean energy

Some hosts profit despite investing in clean energy

Green hosts profit because they invest in clean energy

Examples of Real Green Hosts

- Green hosts are 8 of the 25 largest low-cost web hosts
  - Based on hosted domain names via DomainTools
  - Details in paper
- AISO.net, founded in 1997, recently saw large increases in customer base [vmware, 2008]
- HostGator is one of the largest web hosts worldwide (over 2 million sites hosted)

Green Hosting Challenges

- Green hosts invest in carbon offsets
- A *carbon offset* is a unit of clean energy that replaces a unit of dirty energy
  - Come from On-site solar panels or free markets
    - Example: A company spends $100 on solar panels in the Sahara Desert producing 100 Kwh of carbon offsets.
    - A third party (green host) can invest $10 in the company to receive 10 Kwh of carbon offsets
  - Clean energy costs more than dirty energy
- Only invest if it is likely to yield profit
    - *Investment—not charity*

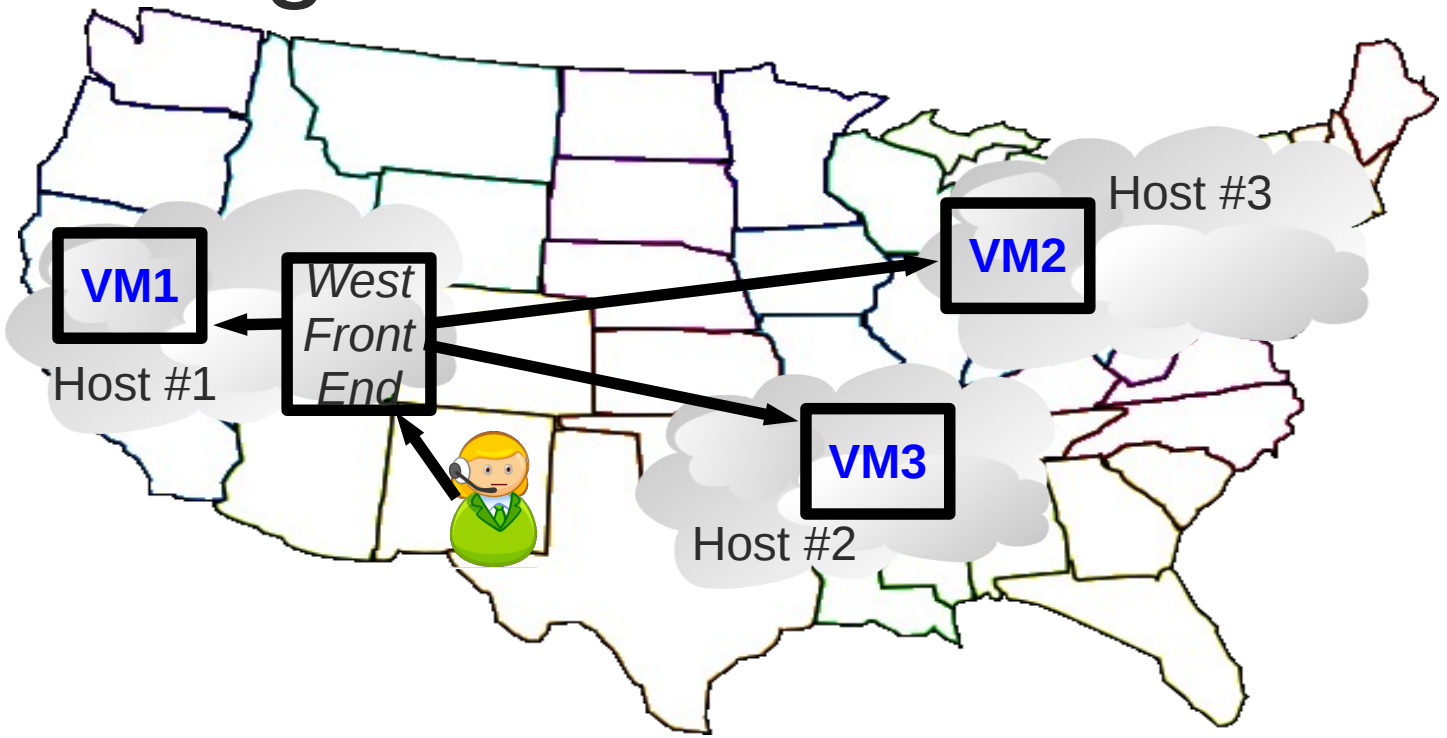
Our Contribution

- How many carbon offsets should a green host buy?
  - Too few offsets does not attract customers
  - Too many wastes money on offsets
- Adaptive Green Hosting
  - Understand how Internet services (i.e., hosting center customers) will respond to carbon offsets
  - Buy only enough carbon offsets to maximize profit
- Goal: Study adaptive green hosting and quantify its potential benefit
  - Basis of ongoing implementation work

Outline

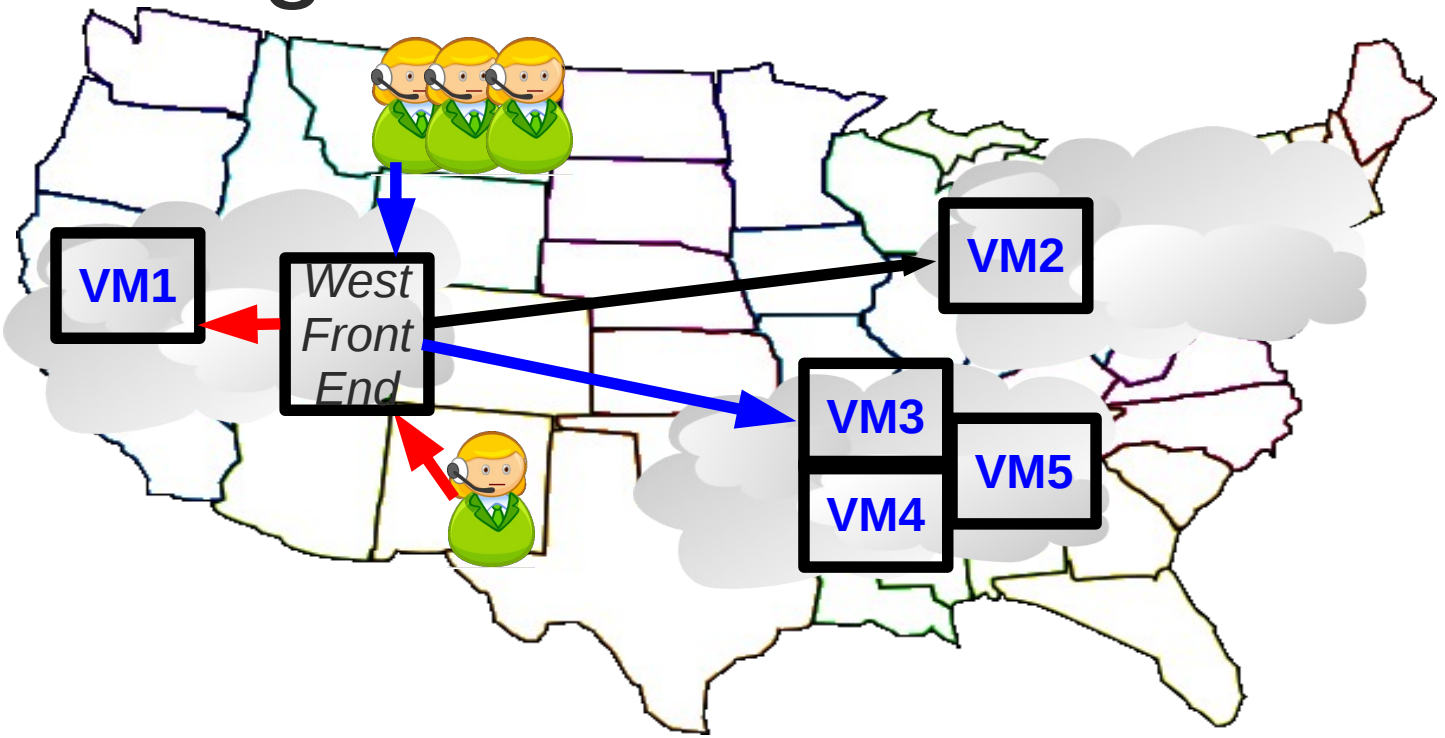
- Modeling Carbon-Aware Internet Services
- Adaptive Green Hosting
- Experiments
- Conclusion

Background: Cloud Service



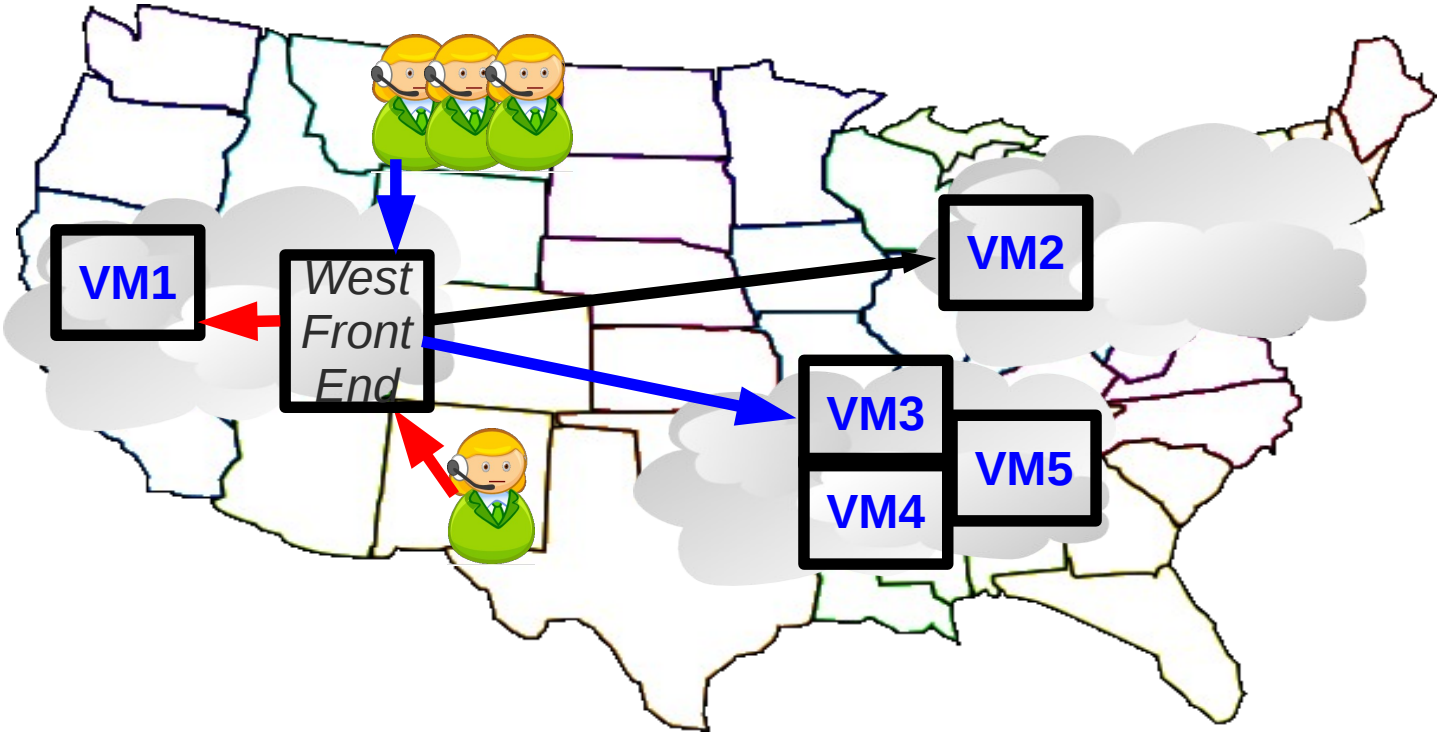
- Accepts requests from end users
- Routes them to virtual machines across multiple hosts
- Responds quickly

Background: Cloud Service



- Respond quickly --> Use host nearest to VM
- Cost efficiency --> Use host with high throughput per VM
- ***Scale out by leasing more resources (adding VMs)***

Carbon-Aware Services

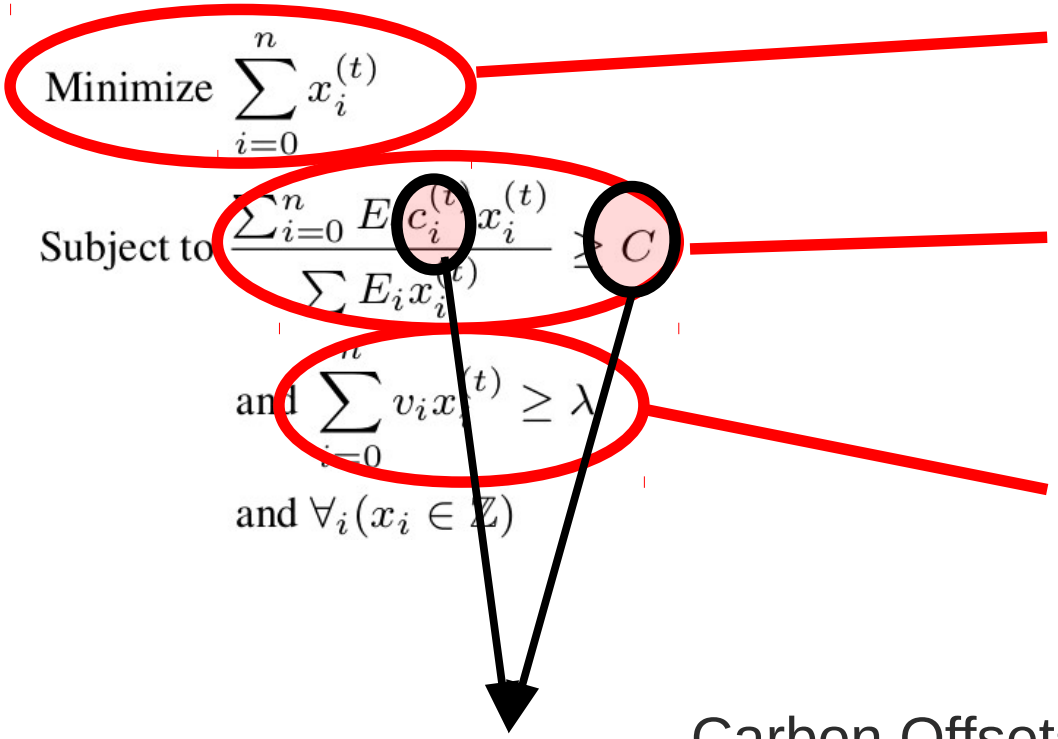


- Traditional model: Find the policy that maximizes cost efficiency within response time constraints

- Carbon-aware service: Find the policy that maximizes cost efficiency within response time
  AND carbon footprint constraints

Carbon-Aware Services

- **Prior work provides frameworks for carbon-aware optimizations**
  - Le et al. IGCC 2010 (best paper);
  - Liu et al. Greenmetrics 2011, SIGMETRICS 2011;
  - Zhang et al, Middleware 2011



Be efficient: Minimize number of instances used

Be carbon aware: Offset ratio should be greater than a certain number

Respond quickly: Queue length should not be too large

Carbon offset ratios C are $\frac{\text{Carbon Offsets}}{\text{Total Energy}}$

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Green Hosting Today

- Problem: How many carbon offsets should a green host buy?
  - Too few offsets does not attract customers
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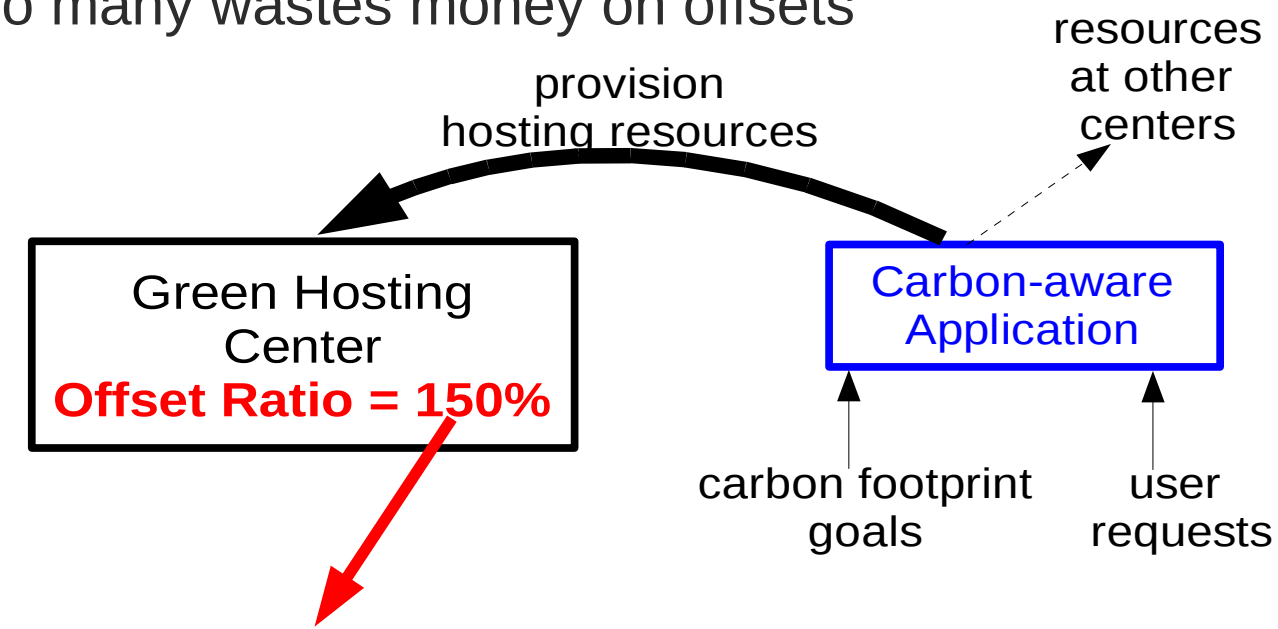
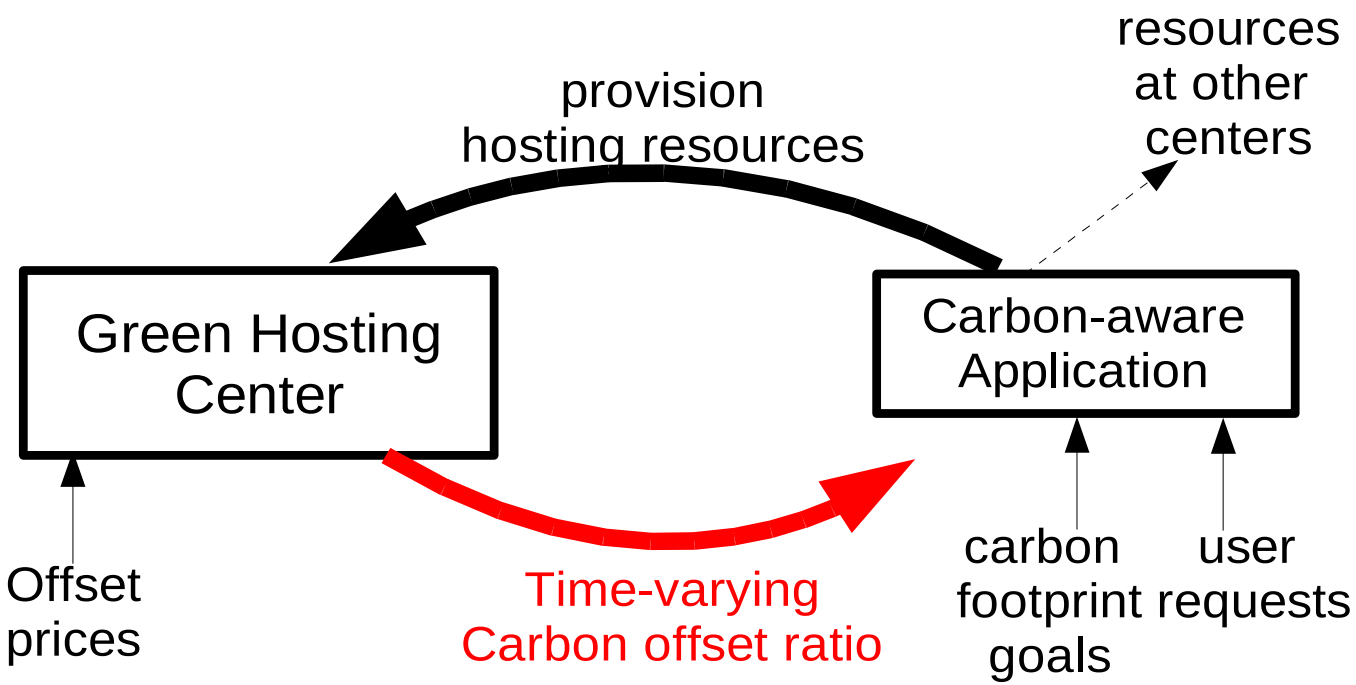


$$0 \leq \frac{\text{Carbon Offsets}}{\text{Total Energy}} < \infty$$

With markets, a host can buy more offsets than total energy

Adaptive Green Hosting

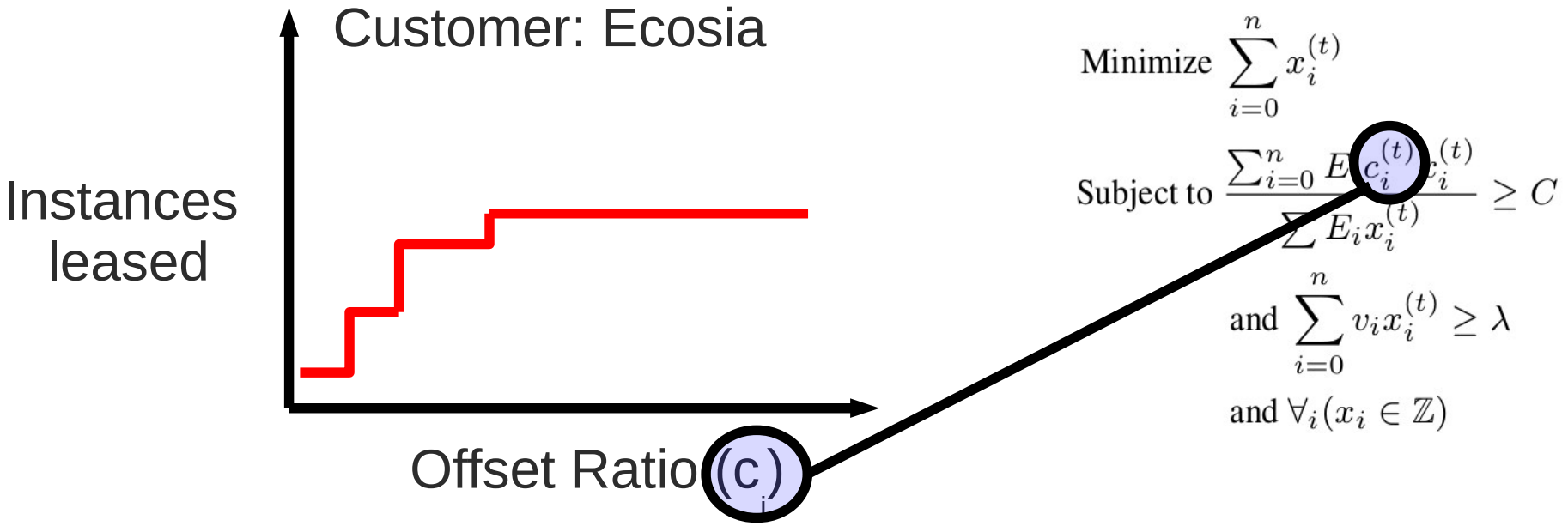
- Solution: Adapt to user demands



- At every provisioning interval, choose an offset ratio such that
  1. Maximum resources are leased
  2. Least money is spent on offsets

Carbon-Offset Elasticity

- In economics, *elasticity* measures the marginal effect of one parameter on a variable
- *Carbon-Offset Elasticity* measures the effect of offset ratio on the amount of resources leased
  - η(c), where c is the offset ratio.
  - It explains who cares about using clean energy? By how much?



Computing the Carbon-Offset Elasticity

Major Contribution

Go from this

$$\text{Minimize} \sum_{i=0}^{n} x_i^{(t)}$$

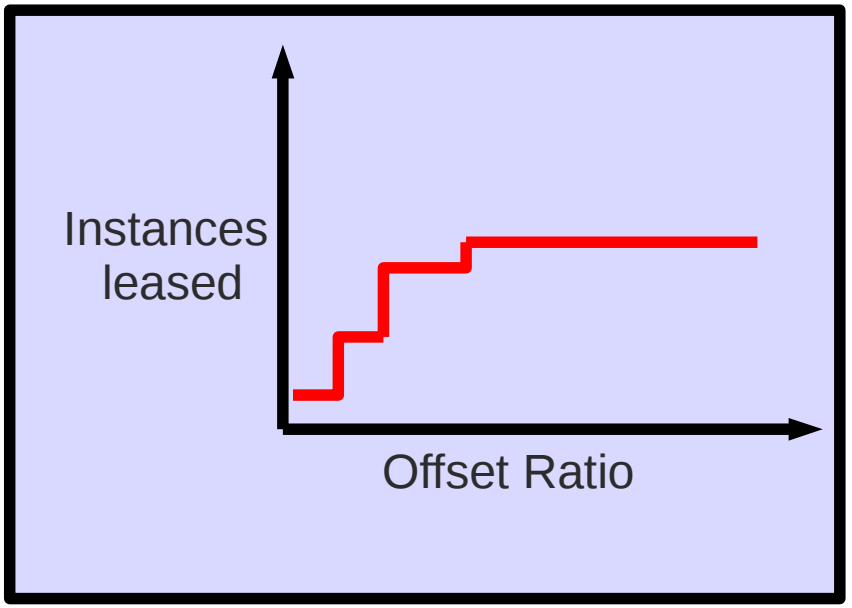
$$\text{Subject to} \frac{\sum_{i=0}^{n} E_i c_i^{(t)} x_i^{(t)}}{\sum E_i x_i^{(t)}} \geq C$$

$$\text{and} \sum_{i=0}^{n} v_i x_i^{(t)} \geq \lambda$$

$$\text{and } \forall_i (x_i \in \mathbb{Z})$$

C = 100%, λ = 10 rps, v = <..>

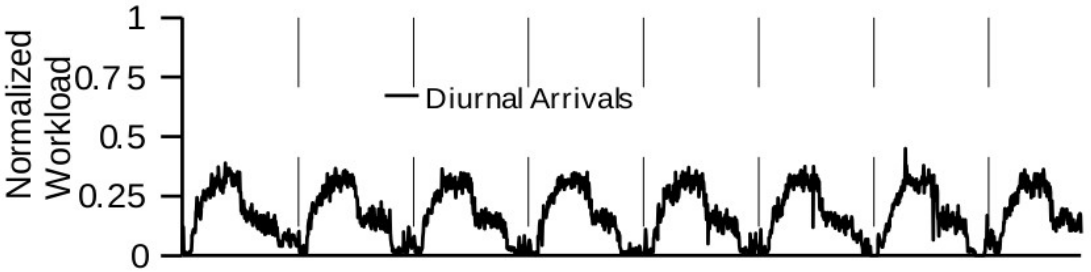
To this



- **For N discrete settings of c_i, we compute a host's carbon offset elasticity for by solving N integer programming problems.**

Interesting Observations

- Given the arrival rate, per-VM processing rate, and the service's footprint goals, we can compute the offset elasticity
  - F(Offset elasticity, price of carbon) = Profit
  - We call this the Oracle Adaptive Approach
- Good news: Average processing rates may be stable
- Good news: Carbon footprint goals (while diverse) likely stable
- Bad news: Request arrival rates and market prices vary



Adaptive Green Hosting

- Oracle adaptive
  - Sets the offset ratio to the value that maximizes profit for the upcoming interval.
  - Not realistic to know arrival rates and prices in advance
- We study a reactive approach
  - Internet services tell each host what their ideal offset ratio was for the previous hour.
  - Considers history of service's ideal offset ratio
    - If ideal ratios over last 2 hours match, we change the offset ratio to the matching value
    - Otherwise, assign ratio to the statistical mode

Intuition: Arrival rates and prices change gradually over time

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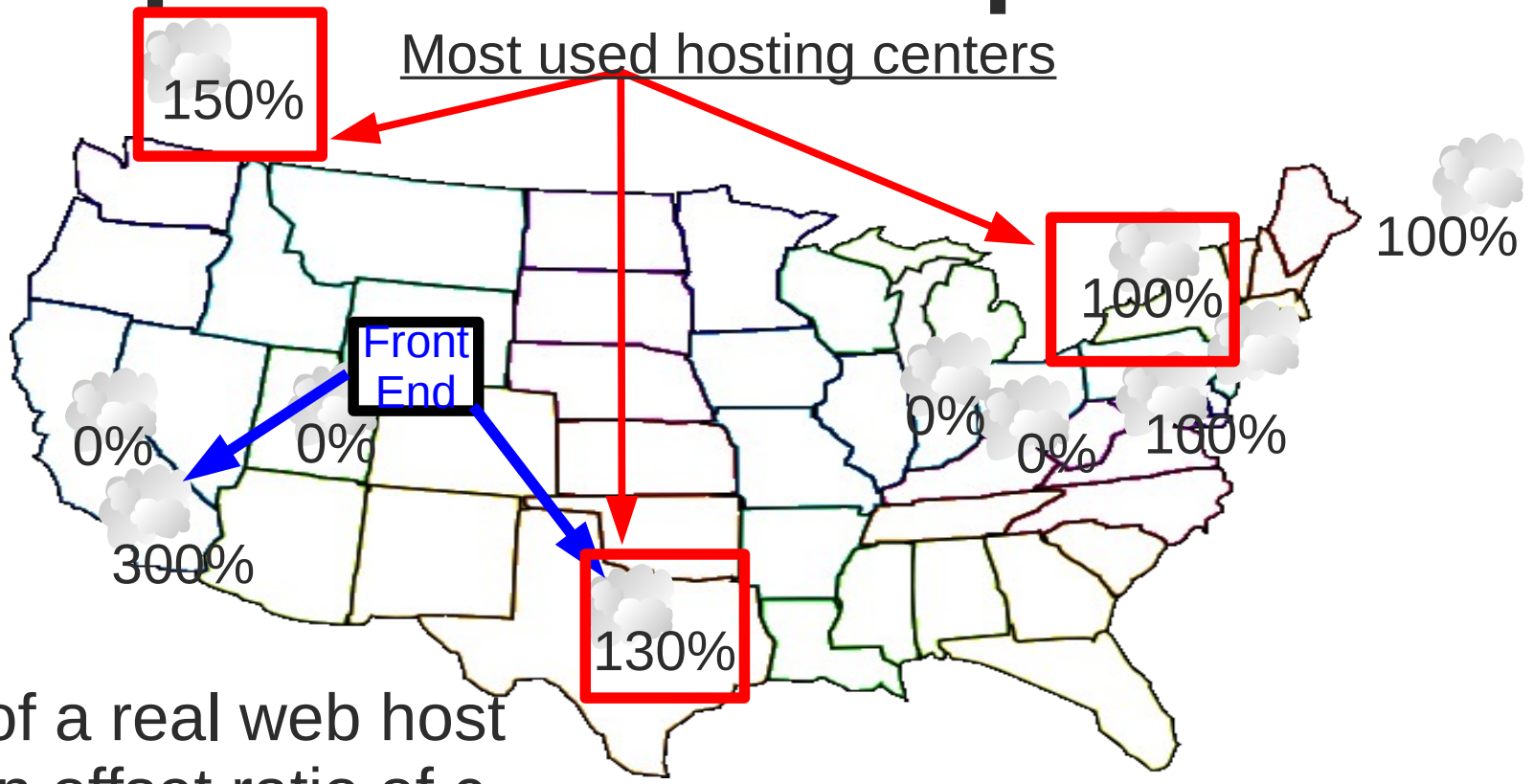
Experimental Setup



c% Location of a real web host with carbon offset ratio of c

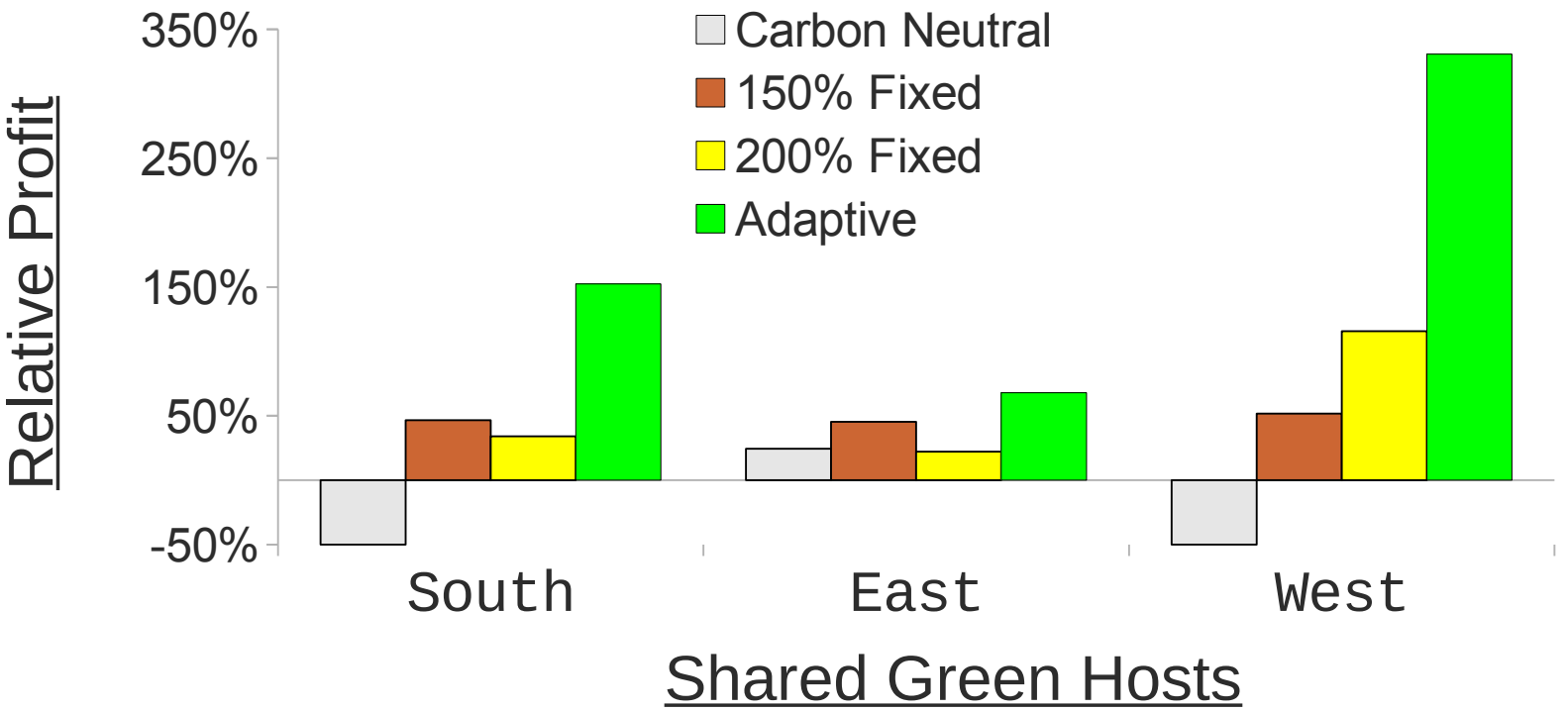
Front End At each host, there is a front end with target ratio C = 100%.
It routes requests either: 1) locally
2) nearest host with ci > 100,
3) a host with even more ci

Experimental Details

- Why three hosts per application? Why are they selected this way?
  - See paper for proof.
  - Intuition: 3 constraints (carbon, response time, efficiency) --> Rank of 3 (Fundamental Theory of Linear Programming)
- *How do you calculate processing rate?*
  - Profile an Apache workload & Estimate latency using geographic distance
- What are the factors in analysis? We compare...
  - 2 real request traces from a global enterprise app (one has heavier tail).
  - Effect of market pricing changes
  - 2 proposed reactive approaches

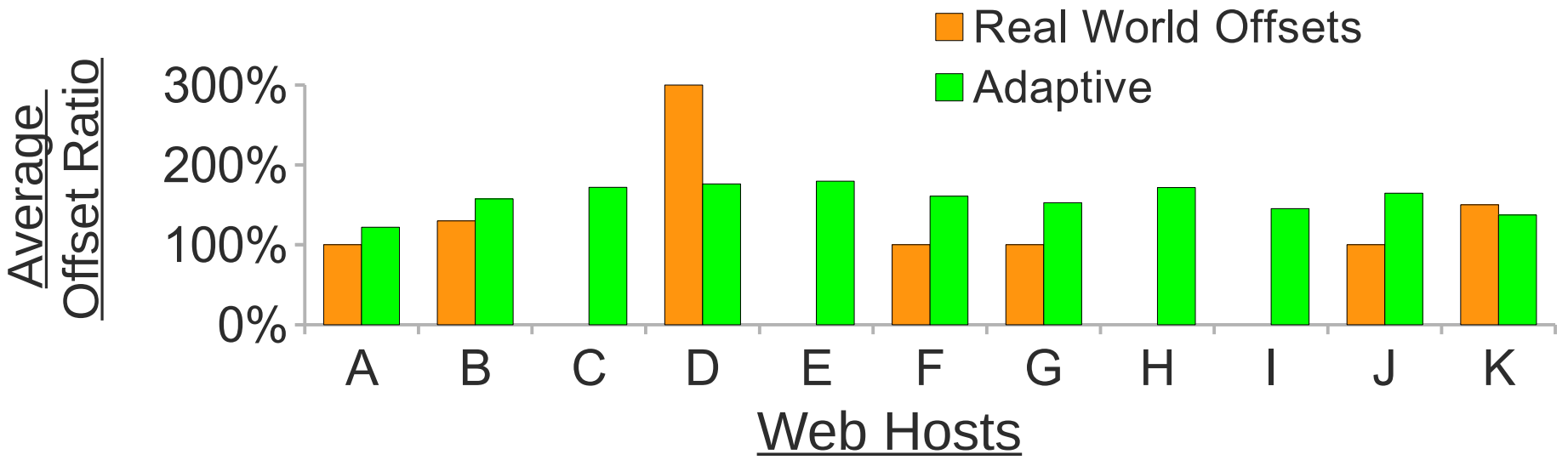
(see paper for full results and details)

Experimental Results



- Adaptive consistently outperformed static offsetting, increasing profit by at least 68% in each case
- Adaptive increased profit for the west host by more than 50%, compared to its aggressive real-world offsetting of 150%
- These results held even when services bought offsets directly (skipping the hosts). Recall, green hosting provides value without raising prices

Is Adaptive Green?



- The average offset ratio increased for 10 of the 11 hosts.
- Adaptive green hosting helps hosts increase their profit by investing in clean energy.
  - For traditional non-green hosts: Adaptive green hosting helps them buy carbon offsets with low risk, allowing them to make bold investments to bring in customers.
  - For green hosts: Adaptive green hosting helps green hosts avoid wasting money on too many offsets.

Conclusion

- Green hosts profit because they invest in carbon offsets

- Adaptive Green Hosting
  - Model carbon-aware applications to get offset-ratio elasticity
  - Use the elasticity to create reactive offsetting approaches

- Our adaptive approach can significantly increase the profit compared to a fixed approach used in practice.
- Improves profit for existing green hosts
- Tends to urge hosts to increase their investments in clean energy.