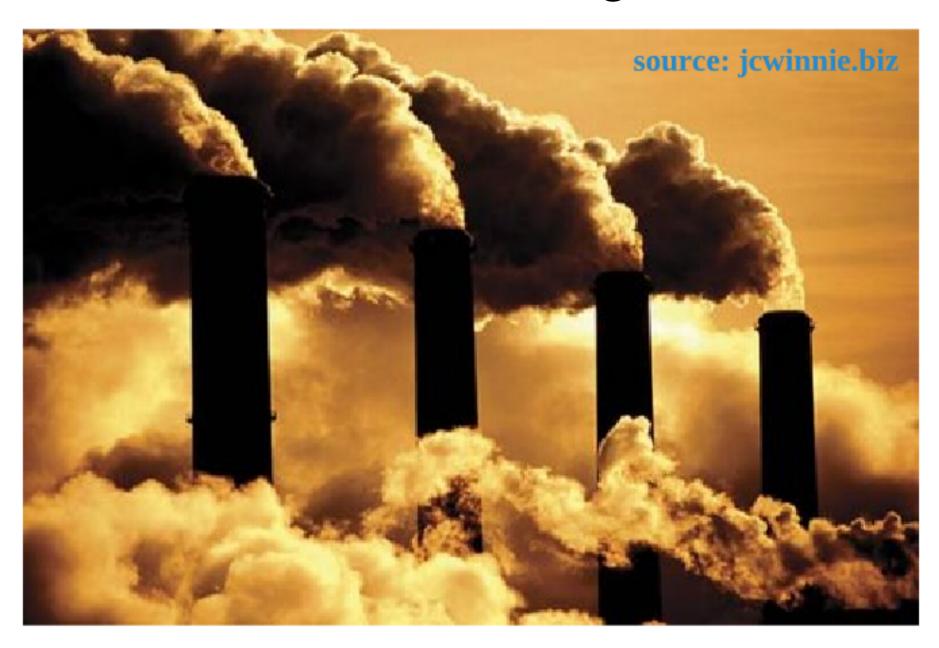
PACEM: The Colored Power Approach to Energy Demand Management

Dr. Jacob Beal, Prof. Hal Abelson, Vinayak Ranade, Tim Shepard, Nelson Elhage

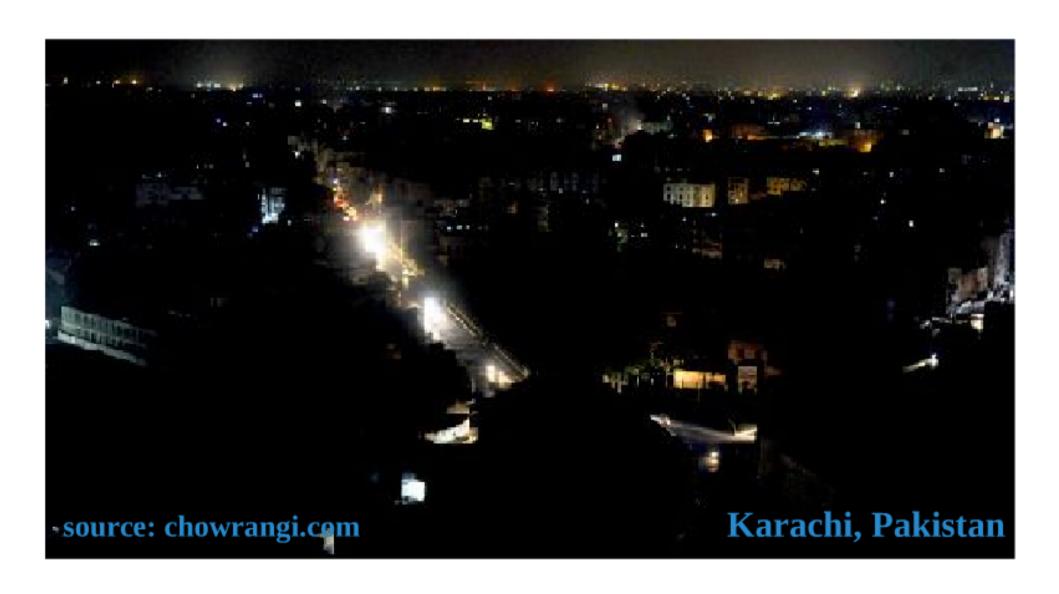




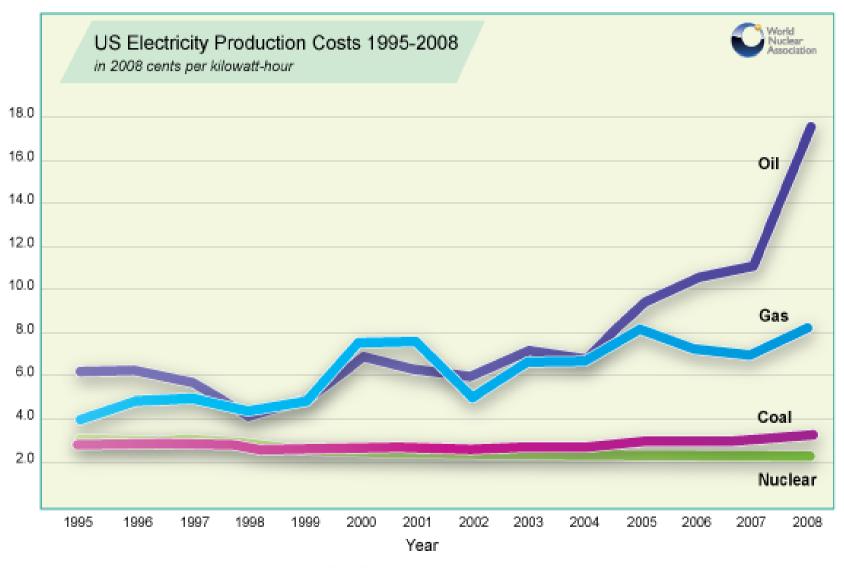
Motivation: Preventing Pollution



Motivation: Energy Security



Motivation: Market Inefficiency



Production Costs = Operations & Maintenance + Fuel. Production costs do not include indirect costs or capital.

Source: Ventyx Velocity Suite, via NEI

Inefficiency of Demand vs. Intention

- Demand peaks are extremely costly
 - \$ billions to utilities, local governments
- Consumers dramatically reduce demand when:
 - ... aware of actual appliance energy use
 - ... informed about neighbors' energy use
 - ... aware of stress on power grid

Goal: peak-shaving and demand management by automating volunteerism

Key Challenges

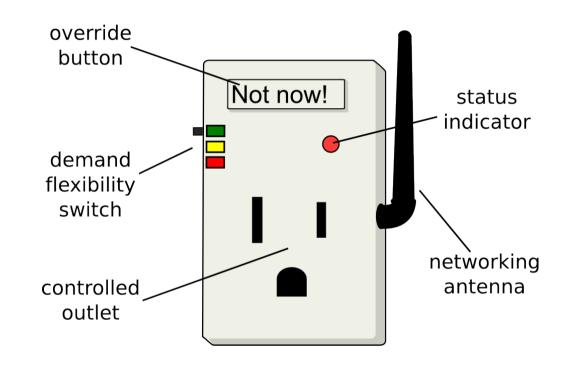
- Scalability:
 - Safe, reliable response from millions of devices in a few minutes
- Consumer interface:
 - High benefit, low "annoyance factor"
 - Eliciting useful information
 - Privacy concerns
- Deployability:
 - Technology alignment w. market structure
 - Low cost devices
 - Market fragmentation across grid & in home

Capturing User Requirements





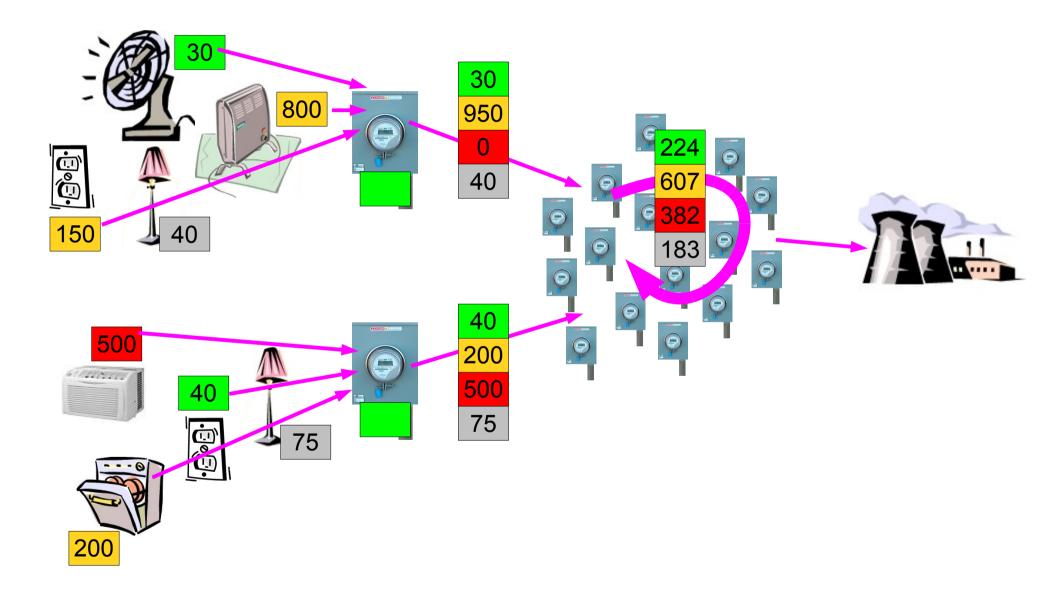
ResEnv plug node



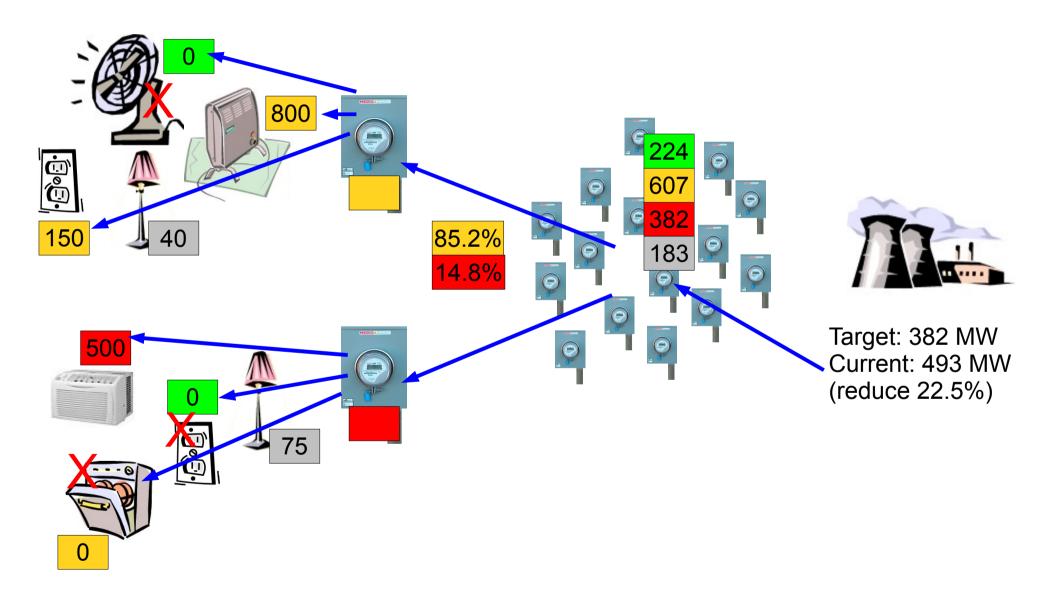
A small upgrade to existing smart plugs...

Qualitative Energy Flexibility: Green: anytime Yellow: peak power Red: emergencies only Black: uncontrolled

Distributed Creation of Aggregate Model



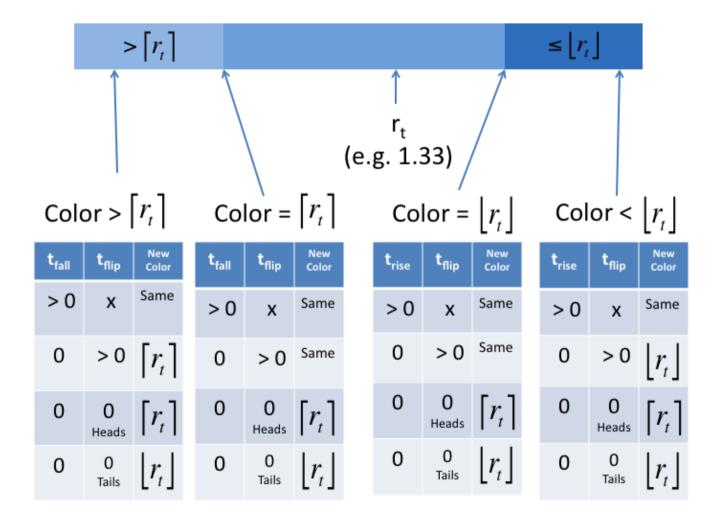
Control Signal Implemented Locally



ColoredPower Algorithm

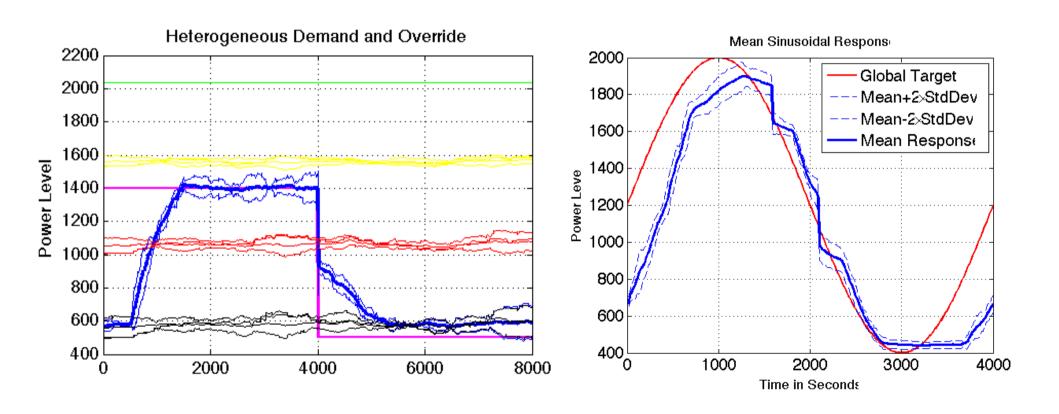
- Challenge: fast, private, robust, non-intrusive
- Approach: randomized distributed control
 - Aggregate flexibilility information to shared model
 - Disseminate control signals via gossip
 - Local decision; coin-flip for fractional color
 - Weight for availability, overdamped control

ColoredPower Algorithm



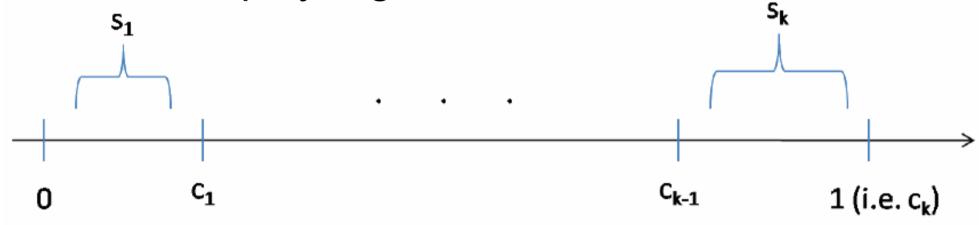
ColoredPower Experiments

Simulation on 100 device network:



Economic Mechanism Design

k color, n player game:



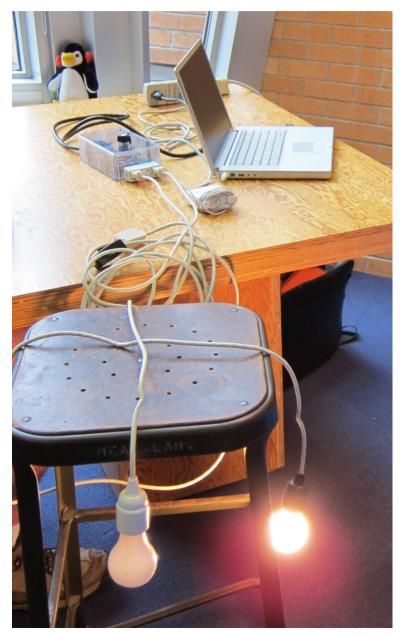
- Buyer (utility) purchases demand reduction
- Sellers select color range to bid
- Cost of truthfulness:

$$(p(c_{i+1}) - c_i)^{\frac{1+q-\sum_{j \le i} s_j}{1+s_{i+1}}}$$

[Ranade, MIT MEng 2010]

Prototype Devices

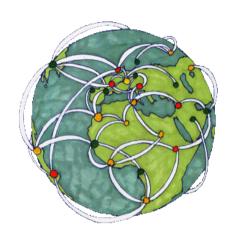
- Atmel AVR Raven
 - 8-bit processor
 - 802.15.4 wireless
- Current sensor
- Power control w. relay
- Button, rotary knob
- BOM: < \$100



Contributions

- PACEM system design
- ColoredPower distributed control algorithm
- Economic feasibility study
- Working prototype devices

Next step...



Zome Energy Networks

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