PACEM: The Colored Power Approach to Energy Demand Management

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Motivation: Preventing Pollution

source: jcwinnie.biz
Motivation: Energy Security

source: chowrangi.com

Karachi, Pakistan
Motivation: Market Inefficiency

US Electricity Production Costs 1995-2008
in 2008 cents per kilowatt-hour

Year

Oil
Gas
Coal
Nuclear

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

Kill-a-Watt
Watt Minder
ResEnv plug node

A small upgrade to existing smart plugs...

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

override button

status indicator

demand flexibility switch

controlled outlet

networking antenna
Distributed Creation of Aggregate Model
Control Signal Implemented Locally

Target: 382 MW
Current: 493 MW (reduce 22.5%)
ColoredPower Algorithm

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

[Ranade & Beal, IEEE SASO 2010]
ColoredPower Algorithm

![Algorithm Diagram](image)

[Ranade & Beal, IEEE SASO 2010]
ColoredPower Experiments

Simulation on 100 device network:

[Ranade & Beal, IEEE SASO 2010]
Economic Mechanism Design

- $k$ color, $n$ player game:
  - Buyer (utility) purchases demand reduction
  - Sellers select color range to bid
  - Cost of truthfulness:
    \[
    (p(c_{i+1}) - c_i) \frac{1 + q - \sum_{j \leq i} s_j}{1 + s_{i+1}}
    \]

[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

http://zomenet.com
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