Achieving Energy Efficiency & Demand Response in Homes with Wireless Sensor Networks

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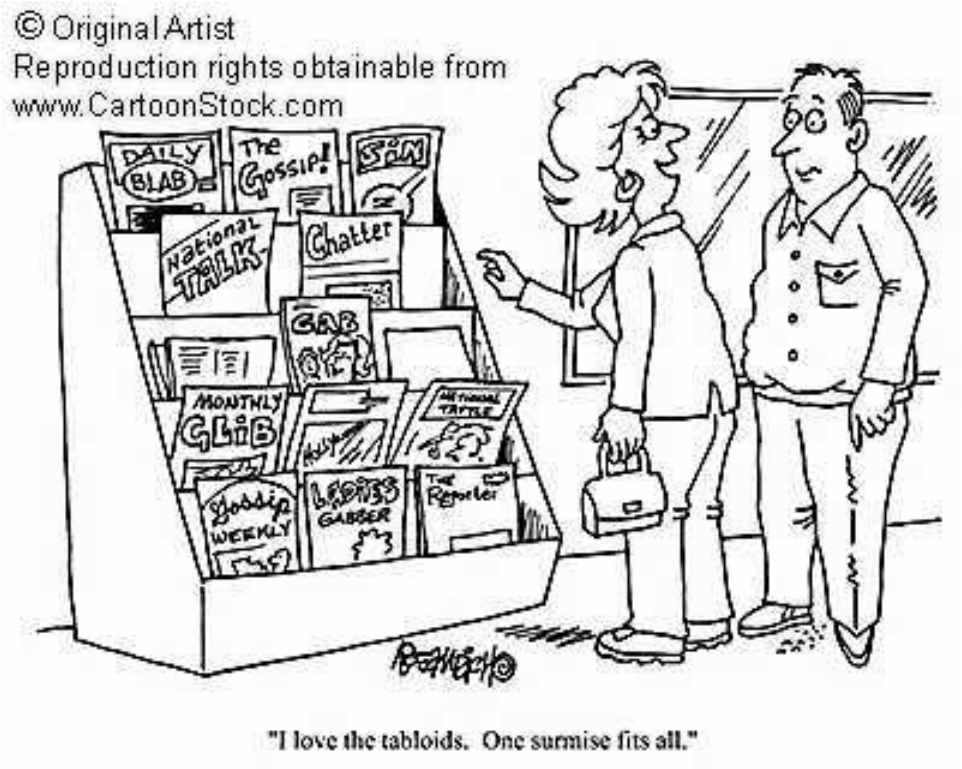
Presentation to DRETD TAC

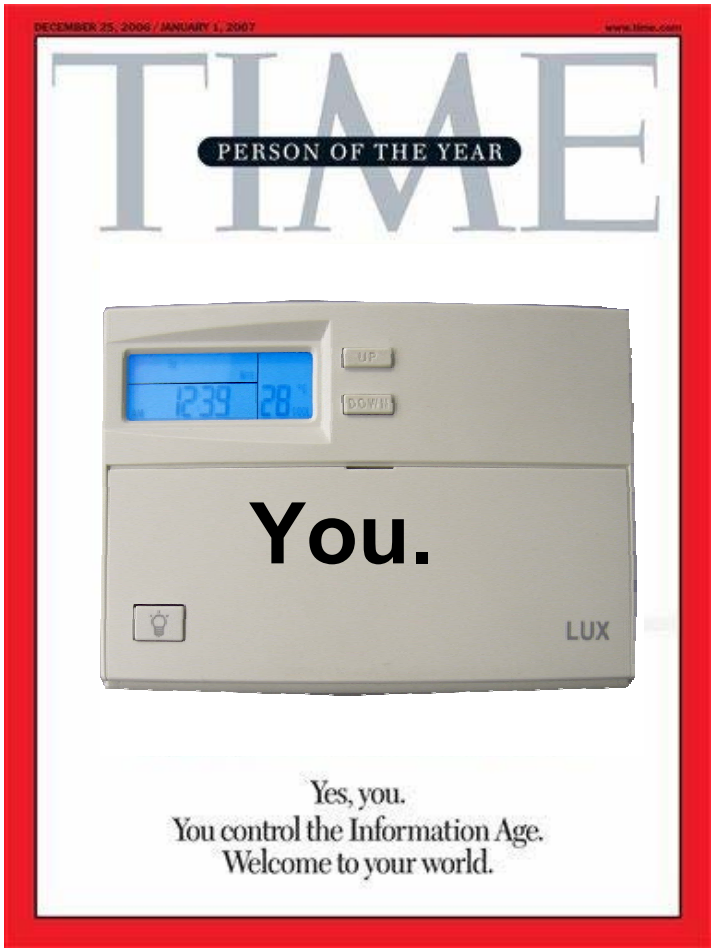
On behalf of DRETD Team

2/19/08

Motivation



"I love the tabloids. One surmise fits all."



Temperature differences of up to three degrees from room to room are not uncommon, *EnergyStar*

Application Achievements

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Thermostat UI

Peffer

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Layered Model

Peffer, Chen, Jiang

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Optimal Control

Chen

QuickTime™ and a
TIFF (LZW) decompressor
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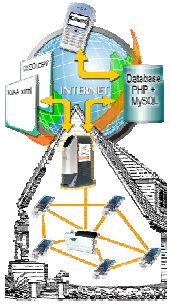
Thermal Modeling

Jiang



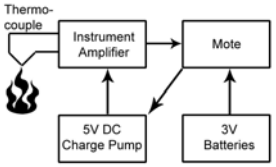
System Architecture

Ota

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Multi-Sensor Thermostat

Ota



Modular Monitoring

Ahrens, Hsu, Ota

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

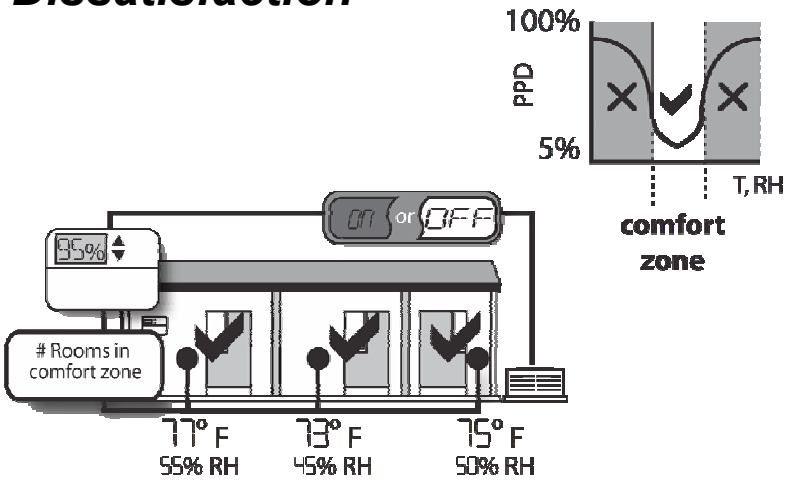
RF Performance

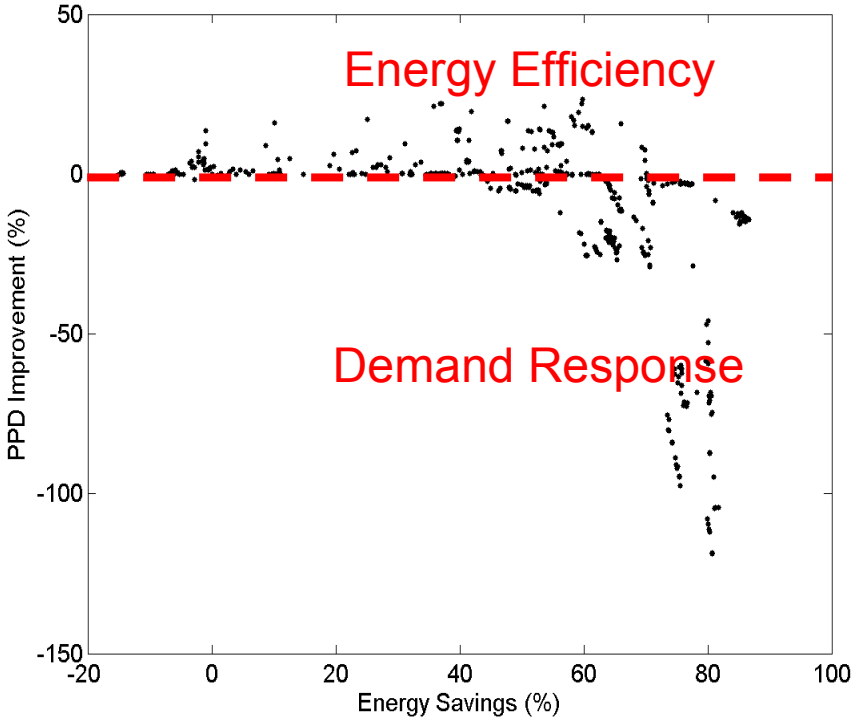
Ota

Multi-Sensor Thermostat

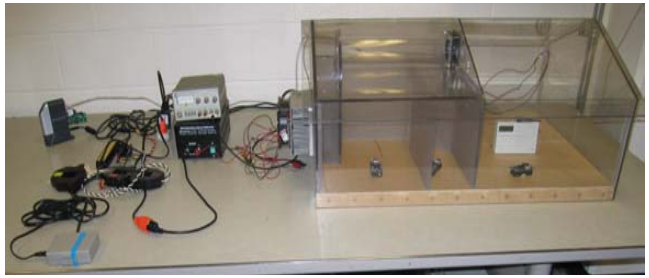
- Measure environment conditions in every room.
- 7 strategies, design for retrofit, no new actuators.
- Comfort control rather than temperature control.
- Energy efficient and DR opportunities.

Example Strategy:
Maximize the Number of Rooms Below a Threshold Comfort Dissatisfaction

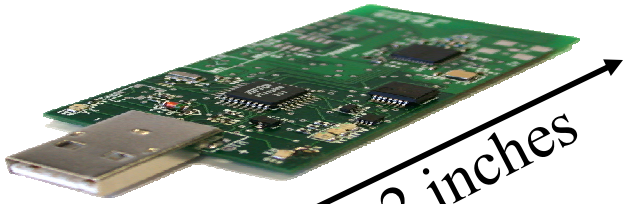




Hands-on Experience from Deployments of Wireless Sensors



2003

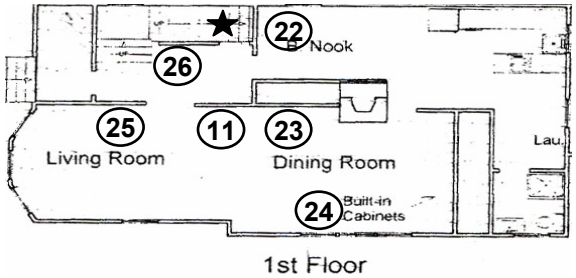


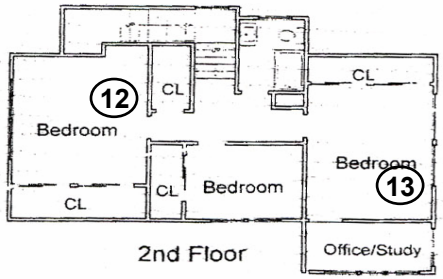
2004/2005

2006

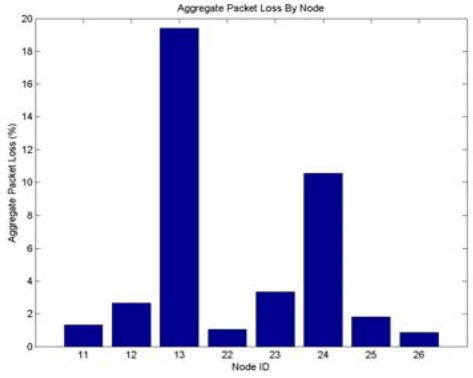
2.4 GHz RF Performance

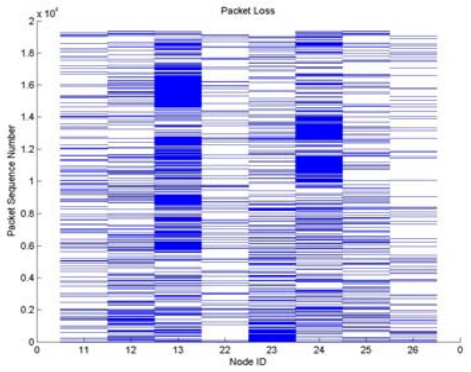
- Empirical testing in homes throughout Northern California.
- Conclusion: multi-hop networking necessary.
- Conclusion: control must handle data uncertainty.





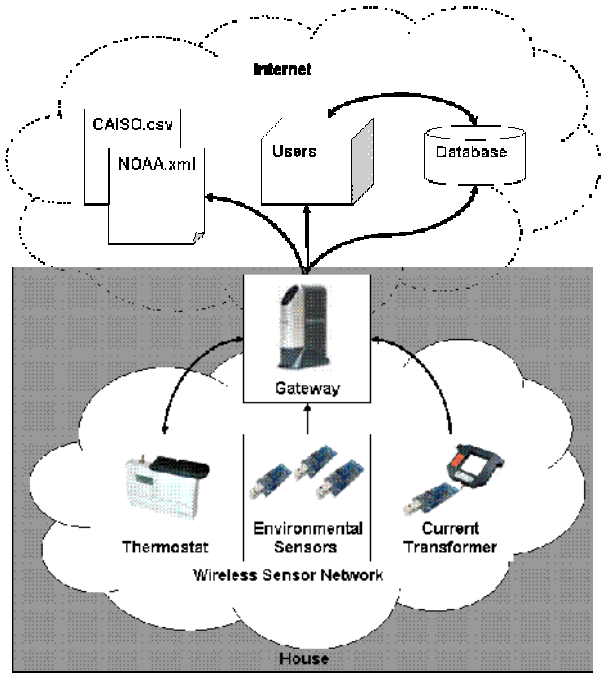
★ = base station ◯ = node

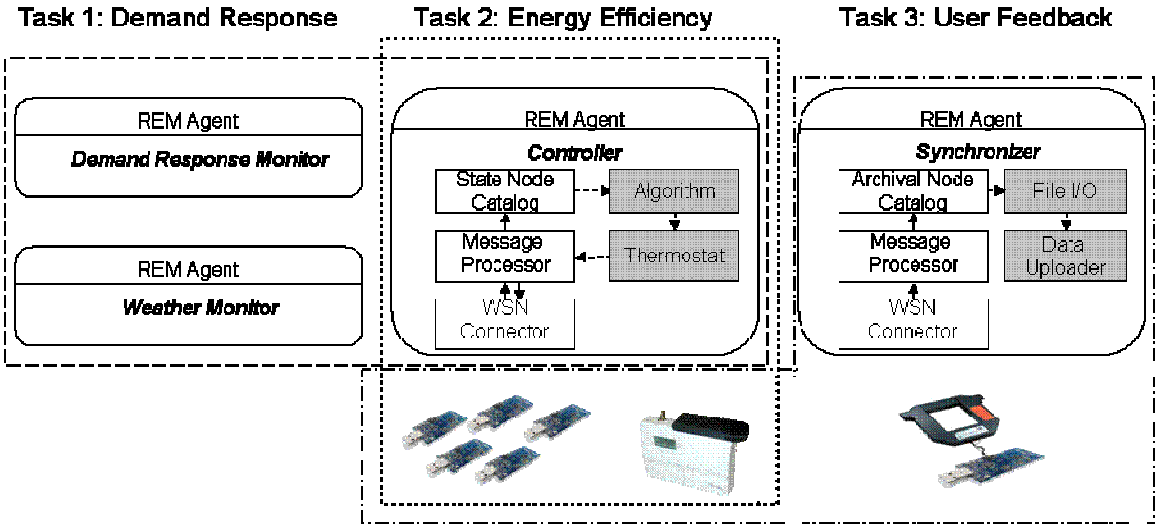




Systems Engineering

- Perception, actuation, communication, decision making.
- Agent-based architecture is scalable and extensible.
- Agent-based architecture leverages layered architecture.

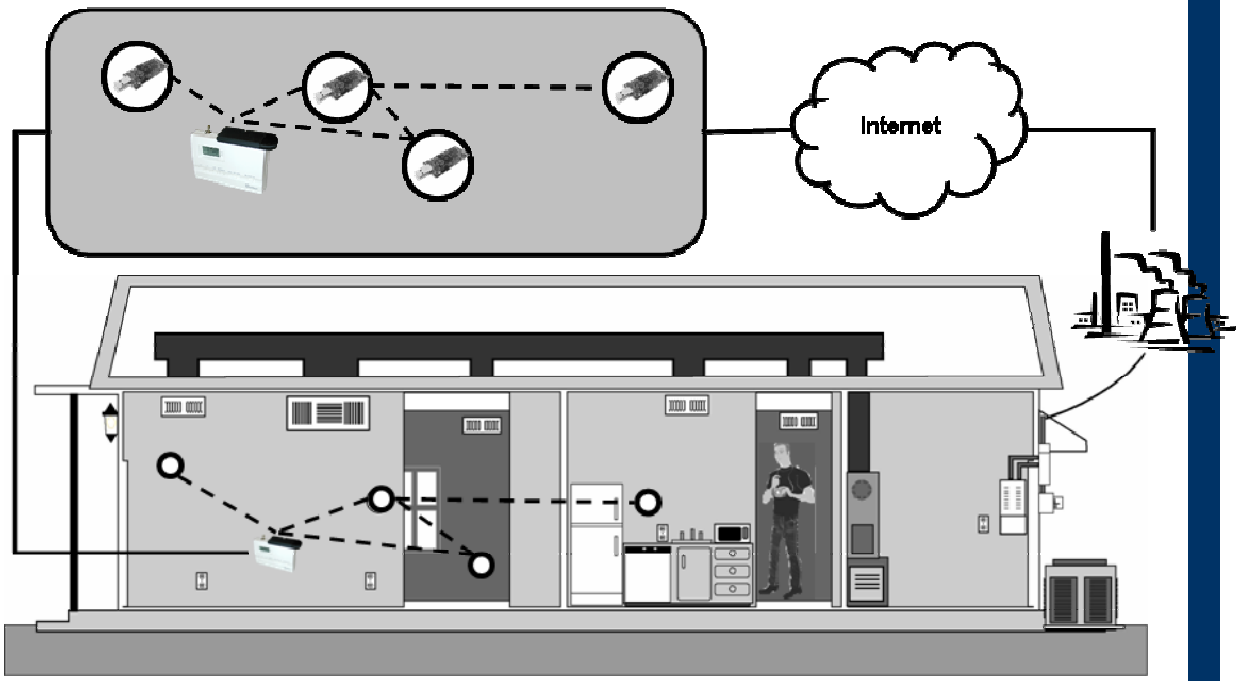




The "Disaggregated" Thermostat

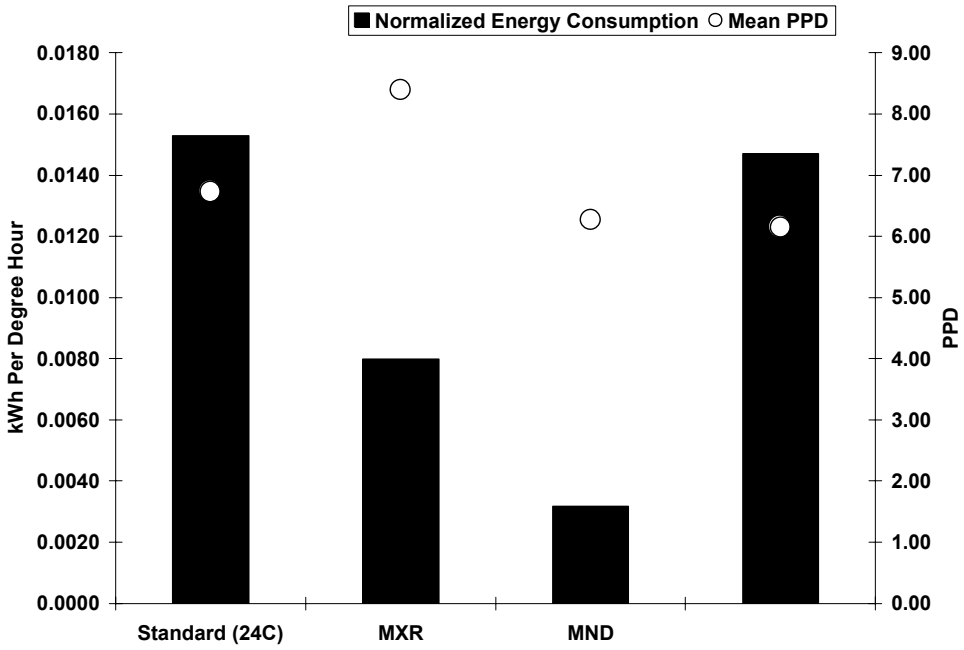
- **Communication-based functional separation.**
- **Spatial-temporal sensing with WSN's.**
- **Grid-aware to support Demand Response.**

	Old Way	*New Way*
Actuates	On/Off	On/Off
Uses	Single sensor	Multiple sensors
Measures	°F	°F, RH
Controls	°F	Comfort, cost
Aware	n/a	energy prices, weather



Energy Efficiency with Disaggregated Thermostat

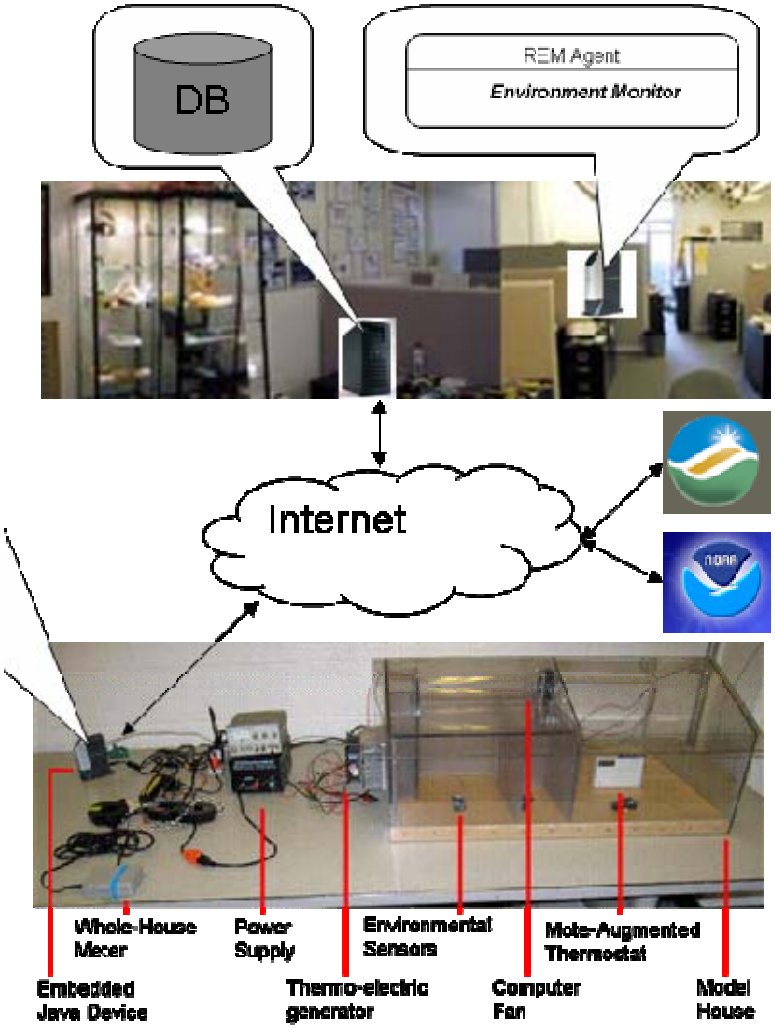
- Field testing multi-sensor control strategies.
- 7 sensors, 1 meter, 1 thermostat, 1 router.
- Energy savings in “live” deployments.

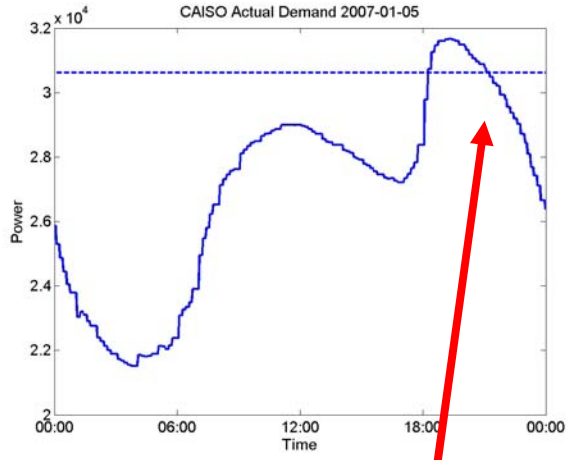


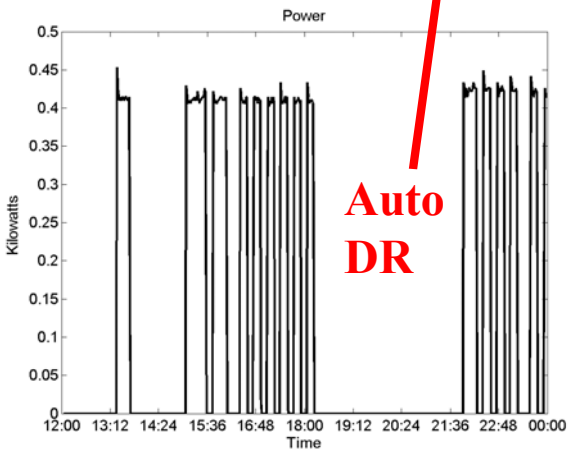
Auto Demand Response with Disaggregated Thermostat

Remote Data Storage & Supervisory Control

Disaggregated Thermostat





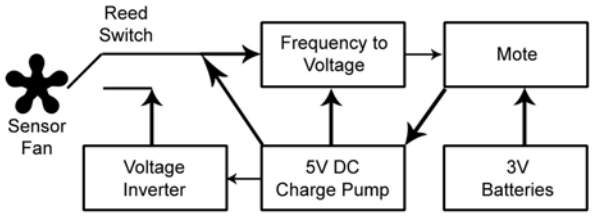


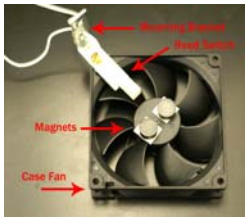
Auto DR

"Plug-able" Designs with Disaggregated Thermostat

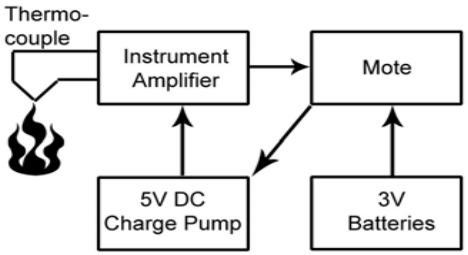
Predictive Maintenance Monitoring

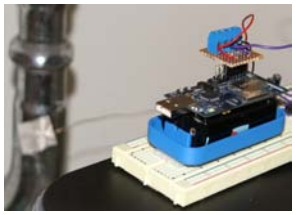
Anemometer





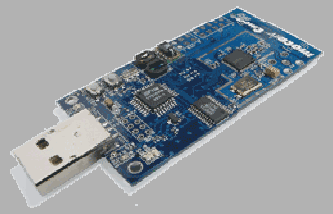
Surface Temperature





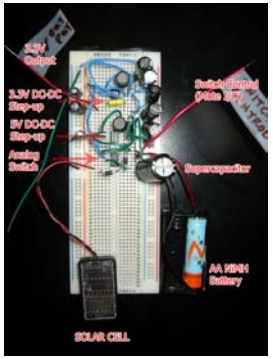
Mote Platform

- Temperature
- Humidity
- Solar



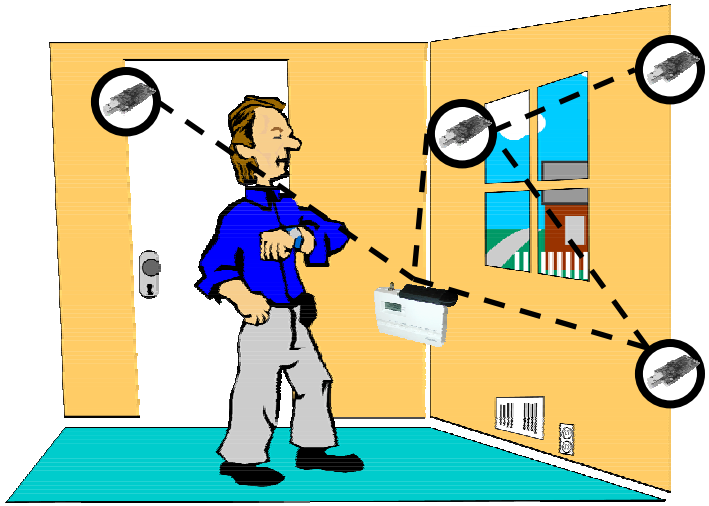
Energy Scavenger

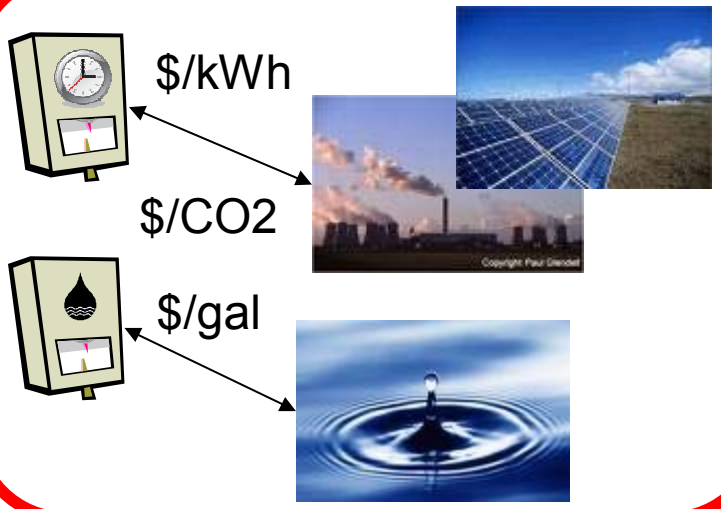
Solar



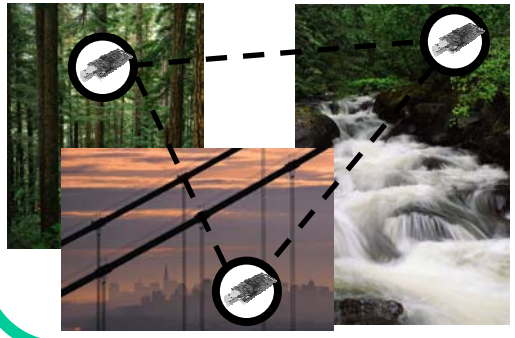
Vibrational

Vision: From Demand Response to Sustainable Choice

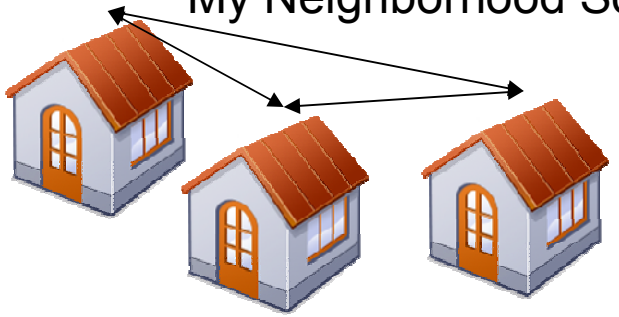




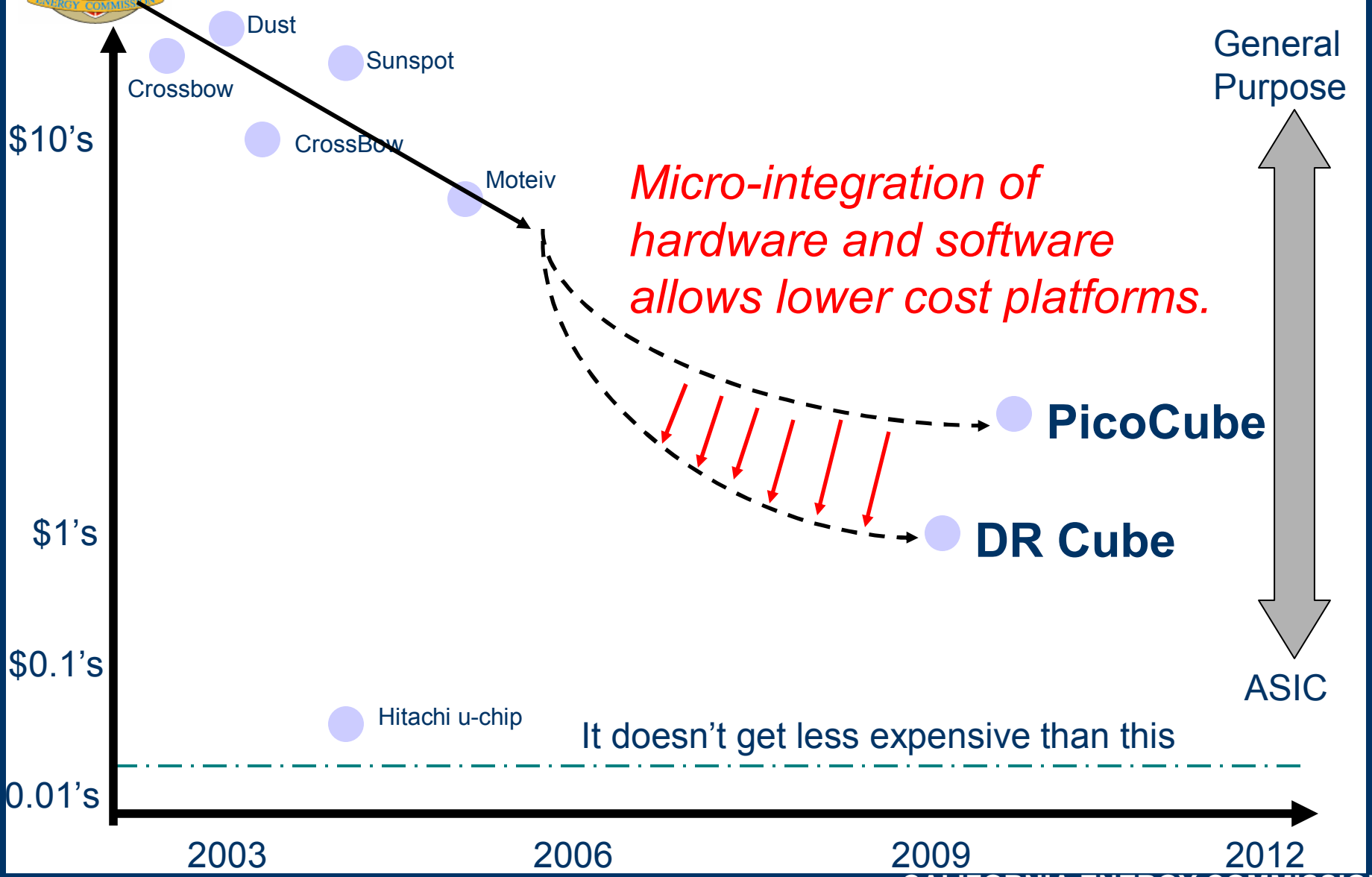
River water quality
City air quality



CO2/town
My Neighborhood Score



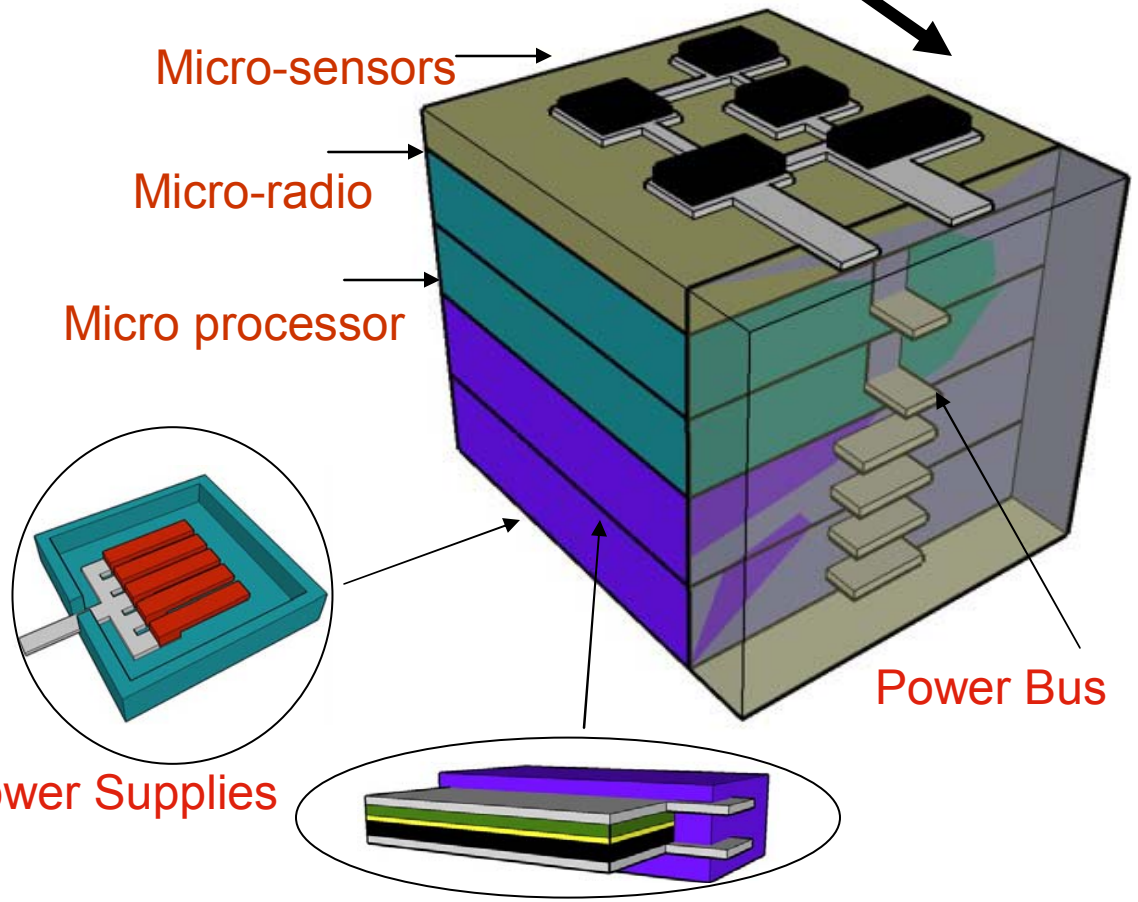
Towards the "DR cube" in 2009



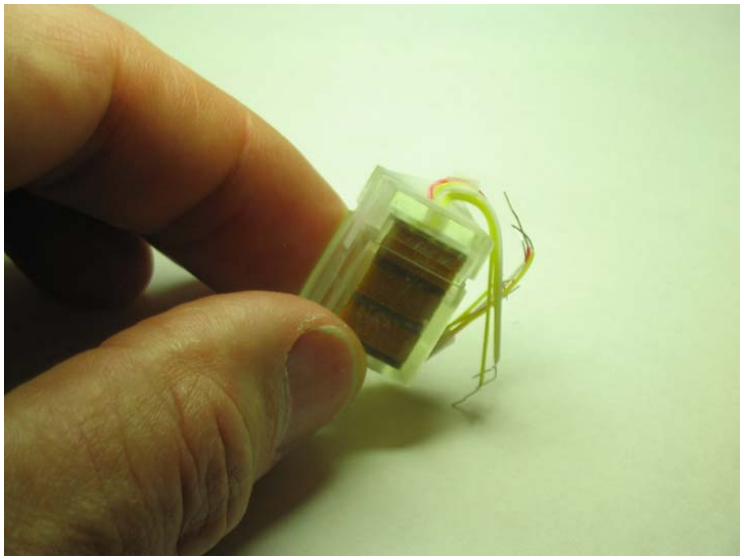
Micro-integration by the millions

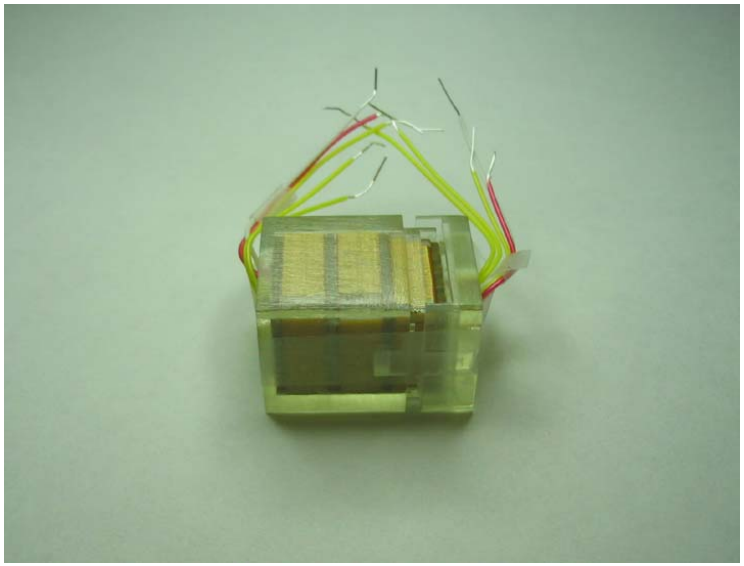
Software applications **run on the** **Hardware platforms**

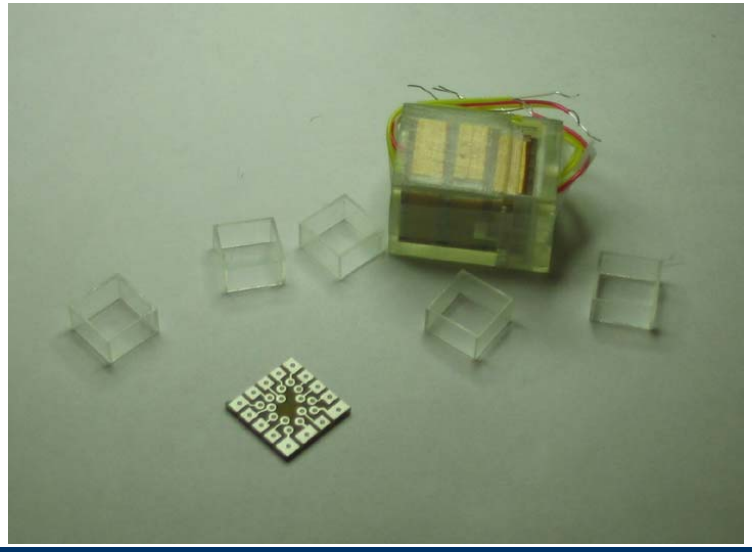
- **Control logic**
- **Learning algorithms**
- **Automation**
- **Distributed throughout all computers in the system**

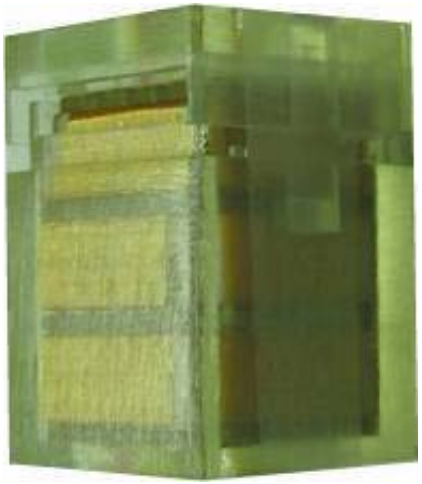


Beginning Micro-integration:
PicoCube January 2007



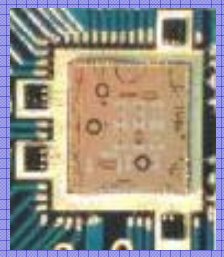






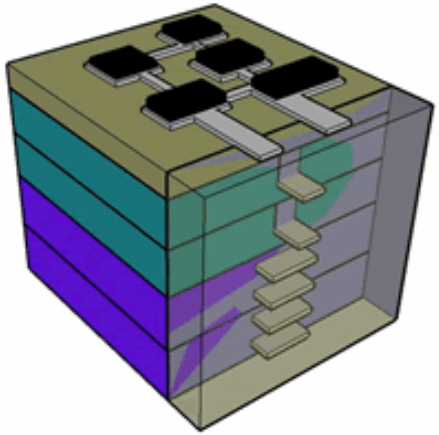
Micro-integration of Wireless Sensor Networks

Low Power Radio



"Disappearing Computer"

B. Gates, *Economist* (2003)



"Picocube"

Power Storage

Sensor

Renewable Power

Supply