Background

- The world’s energy crisis can be mitigated by saving wasted energy and managing demand
- Machine-to-machine and machine-to-human-to-machine information exchange will help
  - Ad hoc wireless sensor (& actuator) networks
  - MEMS current & voltage sensors (Prof. Dick White)
  - MEMS energy scavenging/storage for remote sensors
  - Standard information & object models for all devices
Electricity Energy & Demand

- **Electricity energy units kWh (MWh)**
  - Typical home: 500-1000 kWh/month
  - Typical refrigerator: <100 kWh/month

- **Electricity demand units kW (MW)**
  - 100 W (0.1 kW) incandescent ~ 23 W CFL
  - Typical air-conditioner: 3-5 kW
  - Large power plant 500 MW
  - Loads = Demand = Capacity = Power

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California – Electricity Overview

- Population: >34 M, 1.1% /year growth
- 2004 Electricity Use: 262,000 GWH
- 2004 Peak Demand: 54,500 MW
- Annual growth:
  - Consumption - 1.4%
  - Peak - 1.65%
- 2008-2012 facility loads:
  - ~11 M meters for <200 kW
  - ~33 k meters for >200 kW
Annual Per Capita Electricity Use
California vs. US

Per Capita Electricity Sales (not including self-generation) (kWh/person)

- California
- United States

Cal ISO Daily Peak Loads
January 1, 2000 - December 31, 2000

Peak Day August 16 - 43.5 GW

Commercial AC
Residential AC
California Daily Peak Loads -- 2006

Residential Air Conditioning
Commercial Air Conditioning

California’s Electricity Demand is Dynamic

CAISO Load Curve July 24, 2006

Actual Load  1st Forecast  1 in 10 Forecast
California’s Highest Peak Loads Occur Less Than 60 Hours Per Year

California’s Highest Peak Loads Can Result in High Energy Prices
The Future

- Price and reliability signals are coming to California in 2010
- Smart* devices can help users manage peak demand & everyday energy during periods of high prices & grid emergencies
- In particular communicating thermostats that receive signals can help avoid rolling blackouts and grid collapse

*communicating

Important Acronyms

- AMI: advanced metering infrastructure including interval meters, communications, back-office software, …, utility owned
- HAN: home area network of communicating devices including thermostats, pool pumps, appliances, gateways, routers, TV monitors, health monitors, …, consumer owned
Utility-Owned AMI

* Advanced Metering Infrastructure
  * **Interval meters** that can record usage on an hourly basis
  * **Communication infrastructure** that retrieve the hourly usage and send price and emergency signals to the home
  * **Back-office software** that processes hourly usage and bills the customer accordingly
Consumer-Owned Electric Loads
(e.g., appliances) in a HAN/controls

- Air conditioning/wall thermostats
- Space heating/wall thermostats
- Appliances/built-in dials
- Lighting/wall switches
- Pool pumps/built-in timers
- Water heaters/built-in thermostats

Example
Communicating Thermostat

- PCT = programmable communicating thermostat
  - A standard thermostat with added capabilities for managing price and reliability signals
  - A consumer-owned product
  - Smart (communicating) technology to save money 24/7/365 & 50 (<1%) high-priced peak hours/year while improving comfort
  - A more easily programmed thermostat
A Proposed PCT Reference Design

- A traditional programmable thermostat (PT) that has 4 added interfaces
  - One-way information broadcast receiver
  - An expansion slot for additional functionality and services
  - A simple manual override
  - Standard connectors for easier installation

One-way broadcast receiver

- Similar to the one-way reception systems being installed in new cars to display the name of the song you are listening to and/or the location of traffic congestion, the PCT will have a one-way receiver that can display information about prices and grid status
An expansion slot

* Similar to the expansion slots in a cell phone, an MP3 player and cameras that support memory cards, the PCT has a slot that can accept utility and third-party communications cards that allow participation in incentive programs at the user’s discretion and choice.

A simple manual override

* There going to be times when a consumer will not want the PCT (programmed by the consumer or their service provider) to act automatically as their proxy.
* Therefore, a simple manual override feature is built into every PCT.
Standard screw terminal connections

- Installing a new thermostat is often confusing because the multi-colored wires to air conditioning and/or heating units do not connect in a standard way.
- New screw terminal standards have been created with an eye toward future standards that will make it even easier for a homeowner to install a thermostat.

PCT summary

- A PCT is a programmable thermostat that can receive information and respond according to user preference.
- It is capable of responding to price and other signals based homeowner choice.
- It has a manual override.
- It is easy to install.
Guiding principles

- Give consumers more information and control over their comfort energy usage whether or not they choose to join a utility or third-party incentive program
- Give consumers more choices with respect to service providers
- Make the thermostat a more useful tool
Conclusion

• 99% of all facilities are already built
• Wireless retrofit can be low cost
• Wireless communications provides flexibility for placement of
  • Remote sensors (MEMS current & voltage)
  • Information displays (Velcro LCD, appliance LCD, TV & PC monitors, cell phones, etc.)
Four PCT Interfaces

Human-Machine Interface  HVAC

Core Controller

Communication  Expansion

Home Depot Advertisement

Rule of thumb:
Selling price to cost of goods sold between 3:1 or 4:1
$12.70 x 3 - 4 = $38.10 - $50.80

Equivalent Programmable Thermostat cost from our bill of materials:
$12.70
## Summary of Minimum PCT Costs

<table>
<thead>
<tr>
<th>Added Interfaces</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalent Programmable Thermostat</td>
<td>$12.70</td>
</tr>
<tr>
<td>Communication Interface</td>
<td>$3.45</td>
</tr>
<tr>
<td>Human-Machine Interface</td>
<td>$0.15</td>
</tr>
<tr>
<td>HVAC Interface</td>
<td>$2.15</td>
</tr>
<tr>
<td>Expansion Interface</td>
<td>$1.75</td>
</tr>
<tr>
<td><strong>Total Bill of Materials</strong></td>
<td><strong>$20.20</strong></td>
</tr>
</tbody>
</table>

### Communication Interface - $3.45

- **Commercial FM Radio Station**
  - **Antenna & Support Electronics $0.20**
  - **Single-chip FM Receiver/ RDS Decoder $3.25**
**Human-Machine Interface - $0.15**

- Alert LED $0.05
- Alert Sounder $0.10
- Up/Down buttons for changing temperature and overriding economic event

**HVAC Interface - $2.15**

- Mounting Plate $1.00
- Female DB-9 $0.25
- Screw Terminals $0.40
- 24 VAC HVAC Systems
- Digitally Controlled HVAC
- DB-9 Connector $0.50
Californian Energy Commission

Expansion Interface - $1.75

SDIO Connector $1.00

Memory $0.75

Serial Data

Peripheral Devices

Audit

2-way WAN

2-way LAN

$10 Memory Card

$50 WiFi Card

$70 Bluetooth Card

Benefits of the interface:
• No additional interface chips or circuitry; SDIO interfaces directly with the microprocessor
• Low-voltage, low-power

Also supported:
• FM Radio Receiver
• 56K Modem
• GPS Receiver
• TV Tuner

Californian Energy Commission

Reasons for SI I/F Specs

• One PCT SI I/F for all of CA (US)
  • Retail purchased at Home Depot, etc.
  • Consumer owned, installed, maintained

• Common signaling throughout CA (US)

• Works with any minimum AMI system
  • Signals synched with AMI resolution

• Compatible with legacy technologies
  • Preserve richness of thermostat options
Cost/Price Targets

- Limit the total cost of all systems integration (SI) interfaces (I/Fs) component hardware to <$10
- Limit the total price of a minimum (reference design) version of a DR/EE thermostat to <$100

OSI 7-layer Networking Model

- Application
- Presentation
- Session
- Transport
- Networking
- Data Link
- Physical

Often Presentation and Session layers are omitted.
No Gateway

- No Gateway
- utility meter data
- meter or collector

No Gateway with remote message device

- utility meter data
- meter or collector
- T24 PCT
- HAN access using expansion port

Meter, Collector or PCT Gateway

- utility meter data
- meter or collector
- home meter data
- T24 PCT
- HAN access using expansion port

Separate Gateway

- utility meter data
- meter or collector
- home meter data
- gateway
- T24 PCT
- HAN access using expansion port