Distributed Pervasive Systems

- Distributed Pervasive Systems
- Sensor Networks
- Energy in Distributed Systems (Green Computing)
- Course wrapup

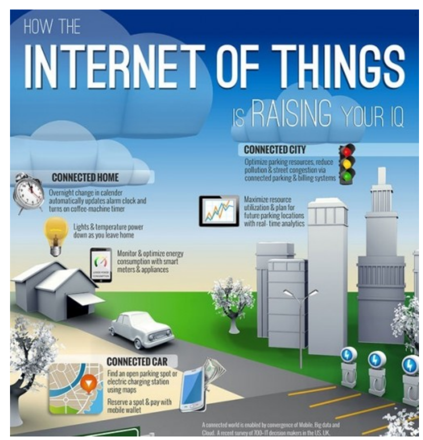
Pervasive Computing

- Computing become pervasive or ubiquitous

- Rise of “devices”
- Computing everywhere
  - smart cities, smart homes, smart highways, smart classroom, ...


Rise of Pervasive Computing

- Internet of things
  - ability to network devices and have them communicate
- Sensor networks
  - Large networks of sensors
- Driven by miniaturization of computing
  - Tiny sensors with computing and communication capability



Example Applications

- Smart home

Personal Health Monitoring

- Sensors to monitor fitness, diabetes, blood pressure, detect falls

Google tests prototype of diabetes-tracking 'smart' contact lens

Typical Smart Apps

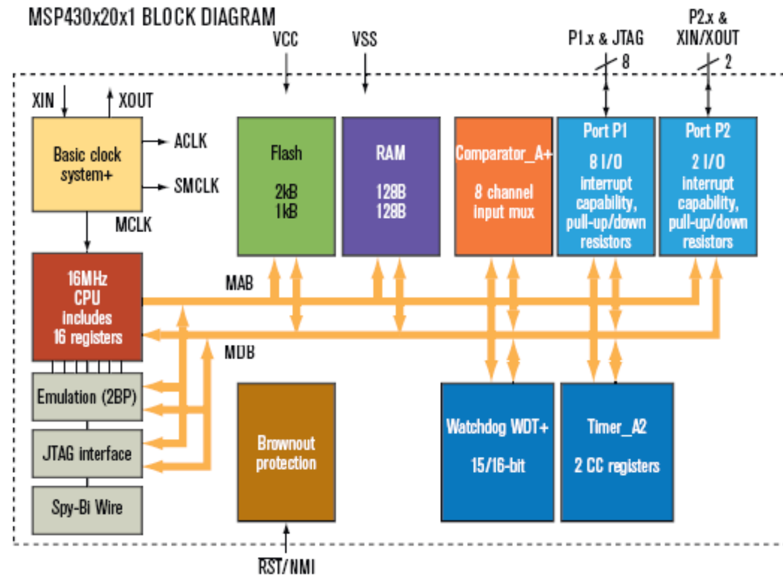
- Personal device to mobile phone to the cloud
  - Upload data to cloud via a mobile device (or directly)
  - Low-power communication to phone
  - Cloud provides analytics and provides feedback to phone
- Environmental sensors to internet to the cloud
  - Internet-enabled sensors
  - direct upload to servers / cloud
  - Cloud provides analytics and provides dashboard

Sensor Platform

- Smart devices are a sensor node
- Resource-constrained distributed system
- Typical Sensor platform
  - Low-power radios for communication
    - 10-200kbit/sec
  - Small CPUs
    - E.g. 8bit, 4k RAM.
  - Flash storage
  - Sensors
  - Battery driven or self-powered

Small CPUs

- Example: Atmel AVR
  - 8 bit
  - 4 KB RAM
  - 128 KB code flash
  - ~2 MIPS @ 8MHz
  - ~8 mA
- Example: TI MSP430
  - 16 bit (sort of)
  - 10 KB RAM
  - 48 KB code flash
  - 2 mA

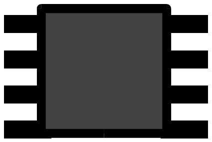


Higher-powered processors:
ARM7 (Yale XYZ platform)
32 bit, 50 MHz, >>1MB RAM
ARM9 (StarGate, others)
32 bit, 400 MHz, >>16MB RAM

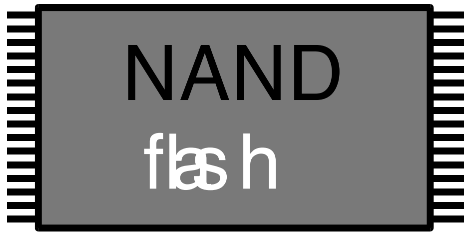
Low Power Radios

- ISM band – 430, 900, or 2400 MHz
- Varying modulation and protocol:
  - Custom (FSK?) – Mica2, 20 kbit/s
  - Bluetooth
  - Zigbee (802.15.4) - ~200kbit/sec
- Short range
  - Typically <100 meters
- Low power. E.g. Chipcon CC2420:
  - 9-17 mA transmit (depending on output level)
  - 19 mA receive
- Listening can take more energy than transmitting

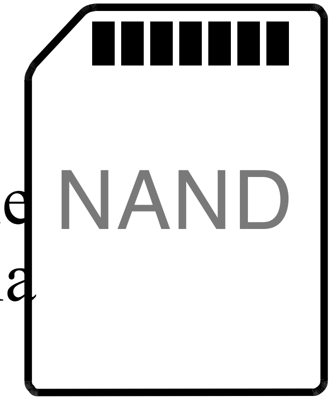
Flash Storage



Serial NOR flash



Removable flash media



- Raw flash
- Small (serial NOR), very low power (NAND)
- Page-at-a-time write
- No overwrite without erasing
- Divided into pages and erase blocks
- Typical values: 512B pages, 32 pages in erase block
- Garbage collection needed to gather free pages for erasing

"Cooked" flash

Disk-like interface
512B re-writable blocks
Very convenient
Higher power consumption

Battery Power

- Example: Mica2 “mote”
- Total battery capacity: 2500mAH (2 AA cells)
- System consumption: 25 mA (CPU and radio on)
- Lifetime: 100 hours (4 days)
- Alternatives:
- Bigger batteries
- Solar/wind/… (“energy harvesting”)
- Duty cycling

Sensors

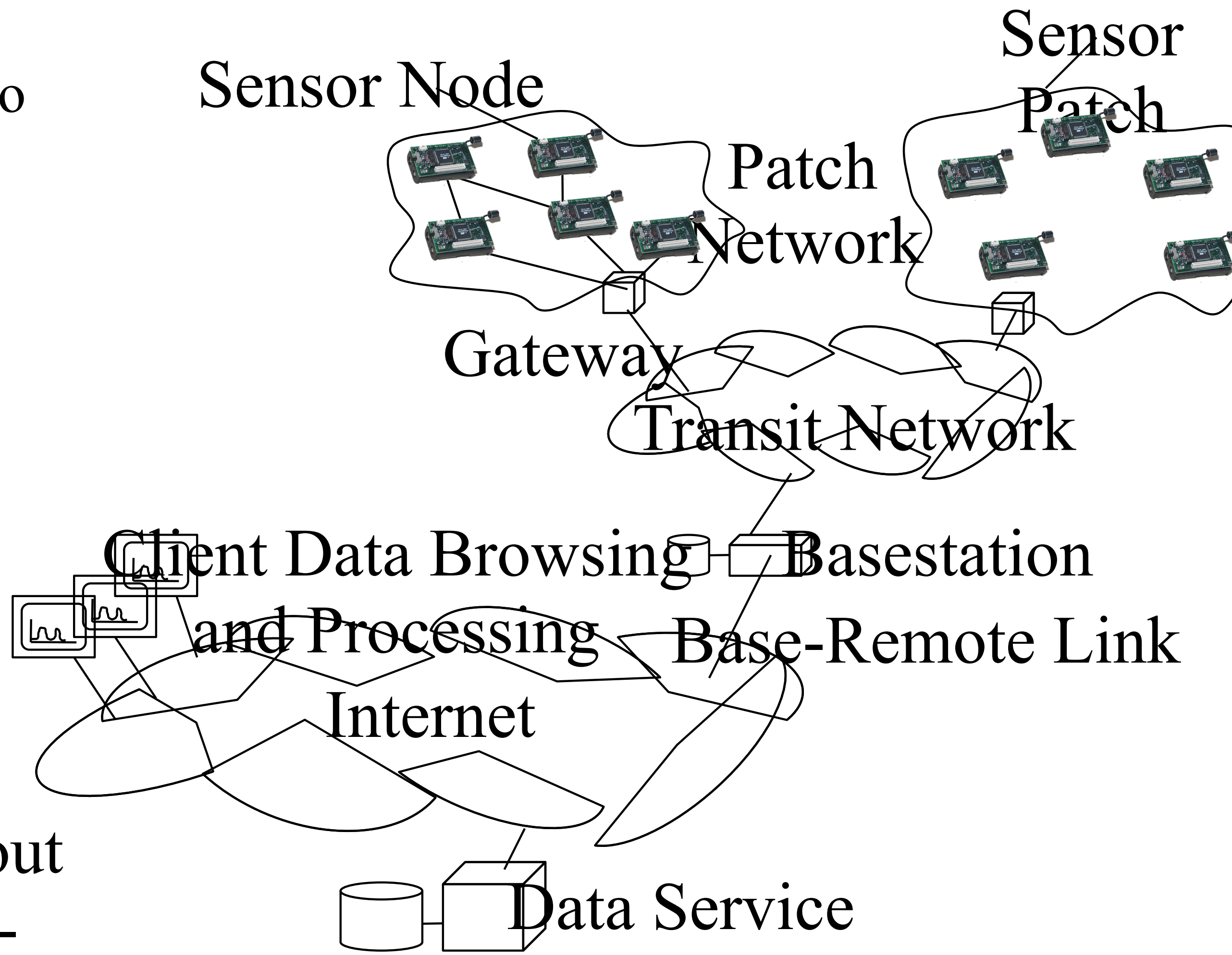
- Temperature
- Humidity
- Magnetometer
- Vibration
- Acoustic
- Light
- Motion (e.g. passive IR)
- Imaging (cameras)
- Ultrasonic ranging
- GPS
- Lots of others…

Self-harvesting Sensors

- Harvest energy from environment to power themselves
  - tiny solar panels, use vibration, airflow, or wireless energy

Typical Design Issues

- Single node
  - Battery power or how to harvest energy to maximize lifetime
- Inside a network of sensors
  - Data aggregation
  - Duty cycling
  - Localization, Synchronization
  - Routing
- Once data is brought out of the network (server-side processing)
  - "Big data" analytics



Green Computing

- Greening of computing
  - Sustainable IT
  - How to design energy-efficient hardware, software and systems?
- Computing for Greening
  - Use of IT to make physical infrastructure efficient?
    - Homes, offices, buildings, transportation

Some History

- Energy-efficient mobile devices a long standing problem
  – Motivation: better battery life, not green

- Recent growth of data centers
  – More energy-efficient server design
  – Motivation: lower electricity bills
    - Green systems, lower carbon footprint
- Apply "Greening" to other systems
  – IT for Greening

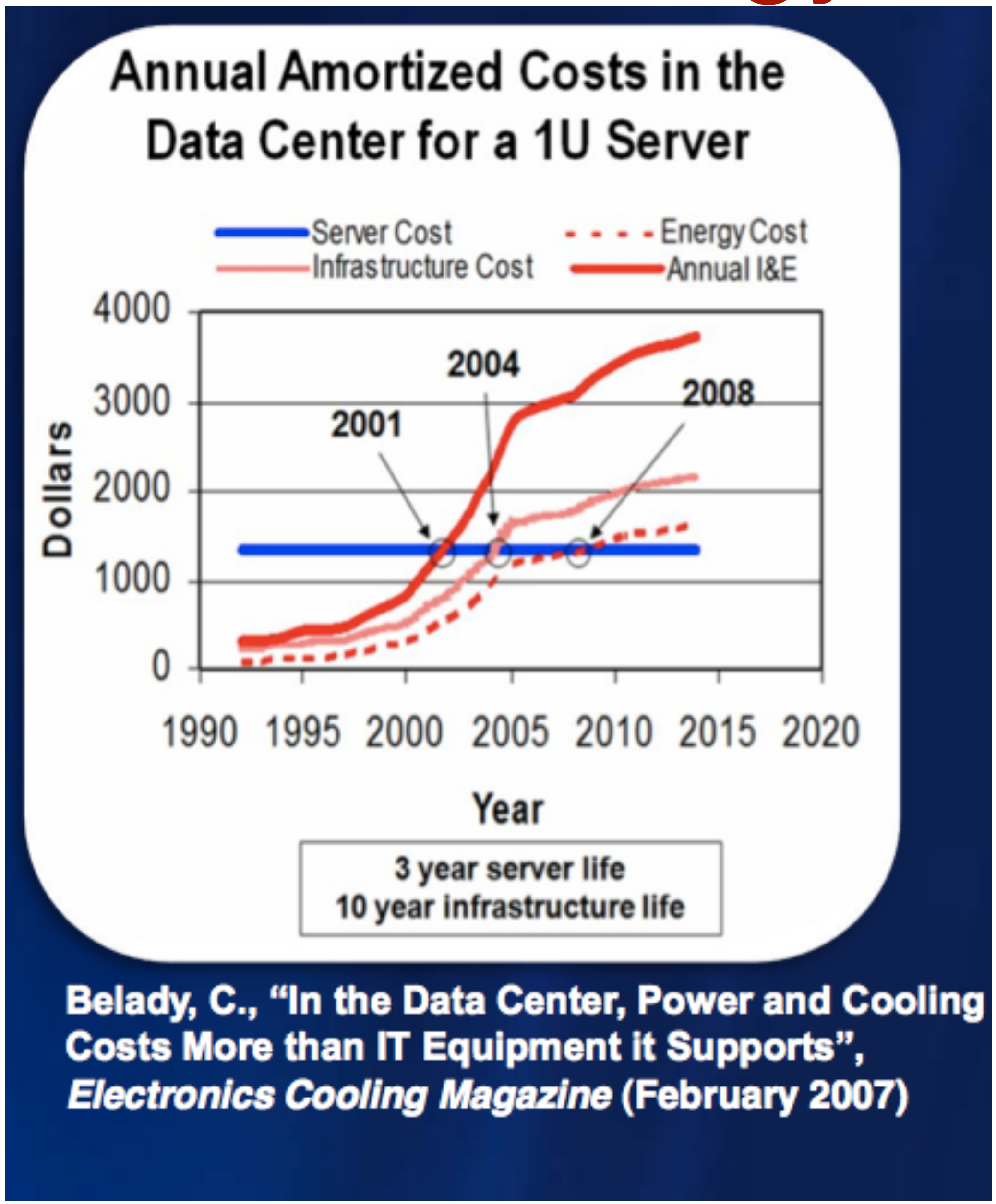
Computing and Power Consumption

- Energy to Compute
  - 20% power usage in office buildings
  - 50%-80% at a large college
  - 3% of our carbon footprint and growing
- Data centers are a large fraction of the IT carbon footprint
  - PCs, mobile devices also a significant part

What is a data center?

- Facility for housing a large number of servers and data storage
- Google data center (Dalles, OR)
  - 12 football fields in size
    - Compare to box stores!
  - 100 MW of power
    - Enough for a small city
  - ~ 100K servers

Data Center Energy Costs



Energy Bill of a Google Data center

- Assume 100,000 servers
- Monthly cost of 1 server
  - 500W server
  - Cost=(Watts X Hours / 1000) * cost per KWH
  - Always-on server monthly cost = $50
- Monthly bill for 100K servers = $5M
- What about cost of cooling?
  - Use PUE (power usage efficiency)
  - PUE =2 => cost doubles
  - Google PUE of 1.2 => 20% extra on 5M (~ $6M)

Class exercises

- Calculate the energy cost and carbon footprint of
  - A phone
  - A laptop
  - Always-on machine
  - A machine that is switched off in the night

How to design green data centers?

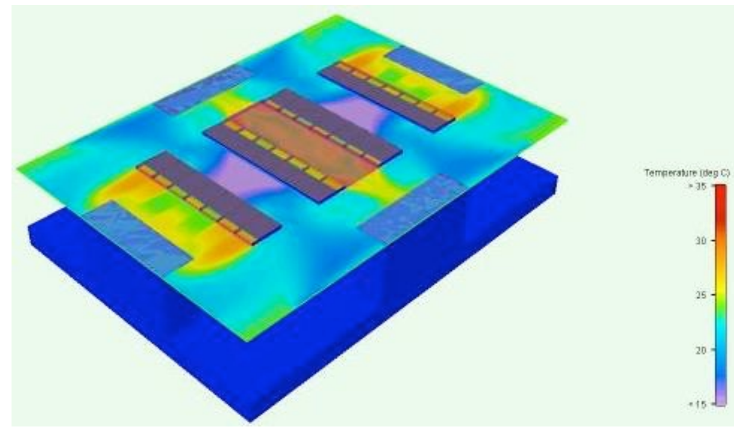
- A green data center will
  - Reduce the cost of running servers
  - Cut cooling costs
  - Employ green best practices for infrastructure

Reducing server energy cost

- Buy / design energy-efficient servers
  - Better hardware, better power supplies
  - DC is more energy-efficient than AC
- Manage your servers better!
  - Intelligent power management
  - Turn off servers when not in use
  - Virtualization => can move apps around

Reducing cooling costs

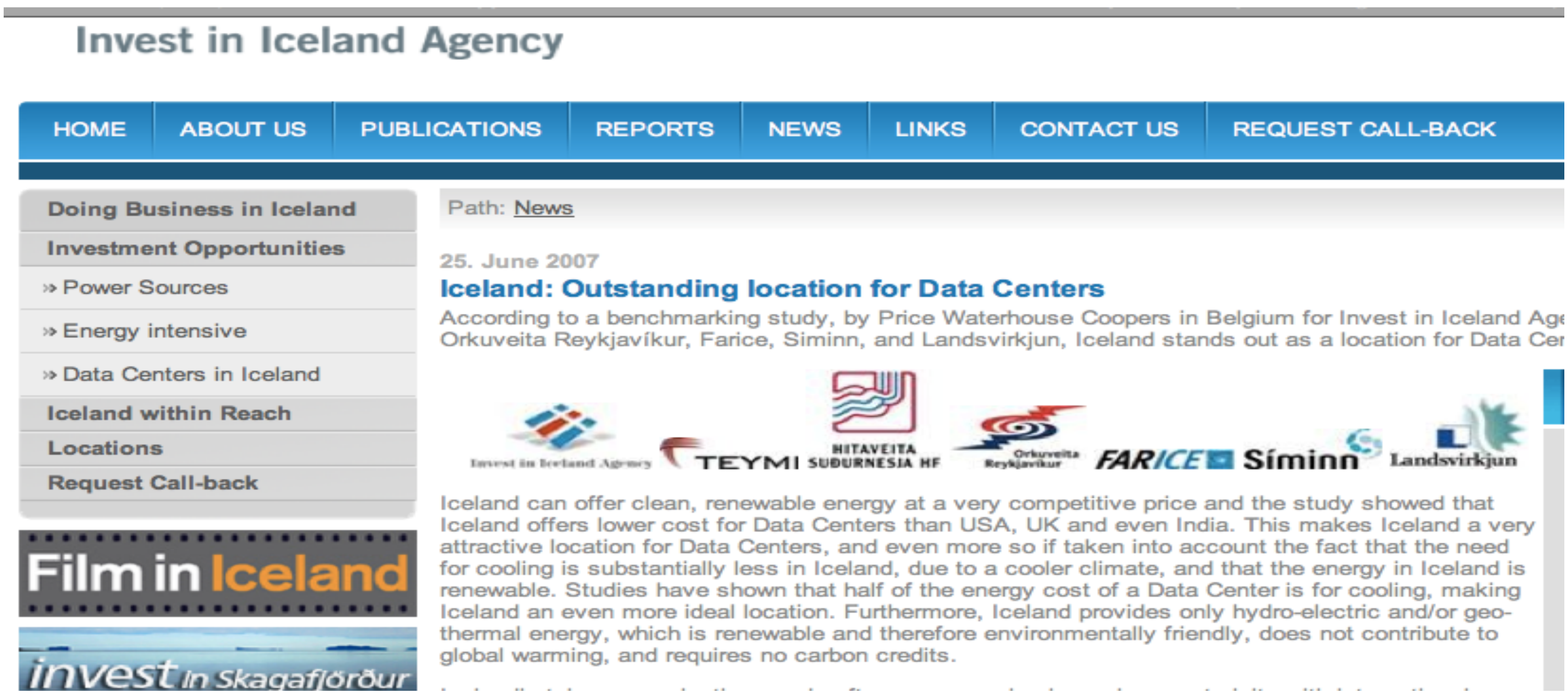
- Better air conditioning
  - Thermal engineering / better airflow
  - Move work to cooler regions



- Newer cooling
  - Naturally cooled data ctrs
  - Underground bunkers

Build them in Iceland

- Free cooling-based Data Centers



Desktop Power management

- Large companies => 50K desktops or more
  - Always on: no one switches them off at night
  - Night IT tasks: backups, patches etc
- Better desktop power management
  - Automatic sleep policies
  - Automatic / easy wakeups [see Usenix 2010]

IT for Greening

- How can we use IT to make buildings green?
  - Use sensors, smart software, smart appliances, smart meters …..
- Building as an example of a distributed system
  - Sensors monitor energy, occupancy, temperature etc
  - Analyze data
  - Exercise control
    - switch of lights or turn down heat in unoccupied zones
  - Use renewables to reduce carbon footprint

Approach

Home AMI
PMU, in-network devices

Machine learning,
Data analytics

Operational
requirements

Measure and monitor — Deep analytics and prediction — Control, operations

Improved situational
Assessment, managements,
response

Improved forecasting
for energy generation,
demand, transmission

More efficient use
of renewables,
Cost decreases and improved
demand response

Potential Solution

- Monitor and profile usage
  - Power supply/demand profile
- Increase Efficiency
  - Turn on/off systems automatically
  - Consolidate computers
  - Tune various subsystems
- Use Alternative Energy Sources
  - Tune systems to variable energy supplies

Outlet level Building Monitoring

- Designed sensors for power outlet monitoring
  - Based on the Kill-A-Watt design
- Modified sensor with low-power wireless radi
  - Transmits data to strategically placed receivers
  - Use plug computers for receivers

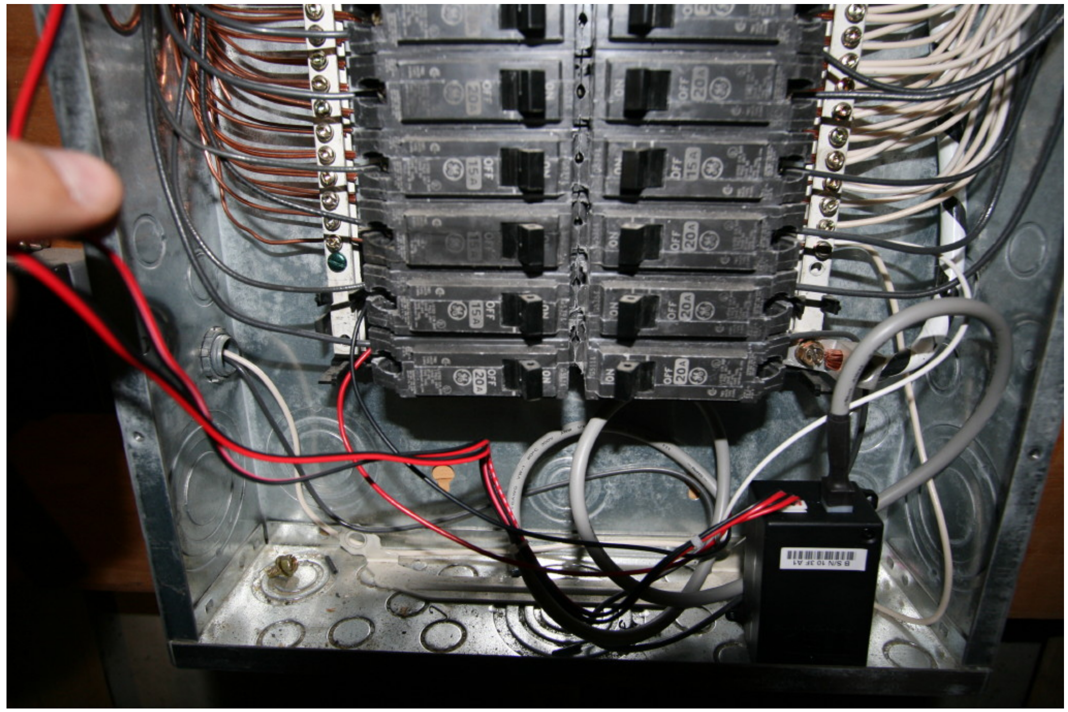
Fine-grained Building Monitoring

- Advantages
  - Accurate, fine-grain data
  - Cheap money-wise to build
  - Able to put them everywhere
  - Good experience for undergraduates

- Disadvantage
  - Expensive time-wise to build

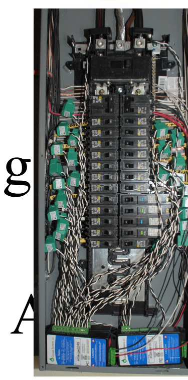
Meter level Monitoring

- Install on main panel



Analyzing the data

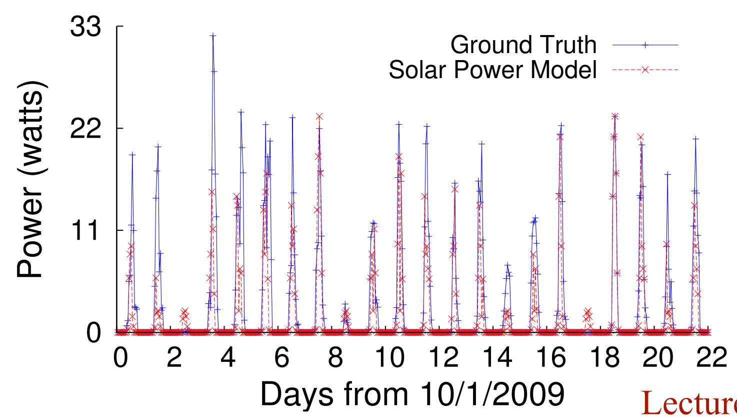
- Energy monitors / sensors provide real-time usage
  - Smart meters:
  - Building monitoring systems (BMS) data from office / co buildings
- Modeling, Analytics and Prediction
  - Use statistical techniques, machine learning and modeling to g p insights
    - Which homes have inefficient furnaces, heaters, dryers? A wasting energy in your home?
    - Is an office building's AC schedule aligned with occupancy patterns?
    - When will the aggregate load or transmission load peak?



Deployments in Western MA

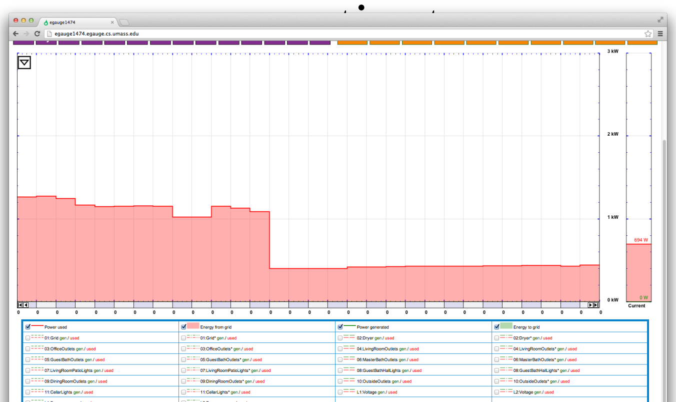
Use Renewables

- Rooftop Solar, Solar Thermal (to heat water)
- Design predictive analytics to model and forecast energy generation from renewables
  - Use machine learning and NWS weather forecasts to predict solar and wind generation
- Benefits: Better forecasts of near-term generation; "Sunny load" scheduling



People: Feedback and Incentives

- How to exploit big data to motivate consumers to be more energy efficient?
  - What incentives work across different demographics?
  - Deployments + user studies
- Big data methods can reveal insights into usage patterns, waste, efficiency opportunities
  - Smart phone as an engagement tool to deliver big data insights to end-users
    - Provide highly personalized recommendations, solicit user inputs,



Summary

- Greening of computing
  - Design of energy-efficient hardware & software
- Computing for greening
  - Use of IT for monitoring
  - Use of intelligent software for power management
  - Forecasting for renewable energy harvesting

Course Topics

- Processes and Threads
- Distributed Scheduling, Virtualization, Migration
- Distributed Communication
- Naming
- Canonical Problems
- Consistency & Replication
- Fault tolerance
- File Systems
- Middleware
- Security
- Special topics: Data centers, Clouds, Green computing, Pervasive systems