Pervasive Computing, IoT and Smart Buildings

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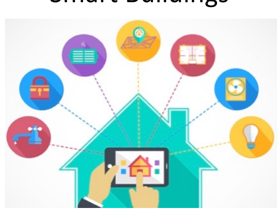
Pervasive Computing

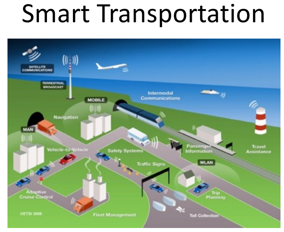
- Computing is becoming increasingly ubiquitous
- Sensing and computing "everywhere"
  - Increasingly part of physical environments
  - Enables many new application domains

Smart Health

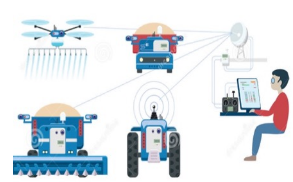
Smart Buildings



Smart Transportation



Smart Agriculture



Rise of Pervasive Computing

- Miniaturization of computing
  - Tiny sensors with computing and communication capability
  - MEMS: MicroElectroMechanical Systems
  - Expectation: Moore's law-like growth in MEMS
- Rise of internet of things
  - Network of Physical Devices
  - Ability to network devices and have them communicate
  - Large network of sensors

Smart Health

- Early Wearables devices
  - Fitness, exercise tracking
  - Sleep, heart rate, …
- New technologies emerging:

Smart Clothing

On-body monitoring

Smart Glasses

Gaze tracking, fatigue detection

Smart Buildings

- Proliferation of smart devices in homes

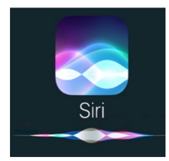
Thermostat

Smart Plug

Smart Appliances

Smart Lock

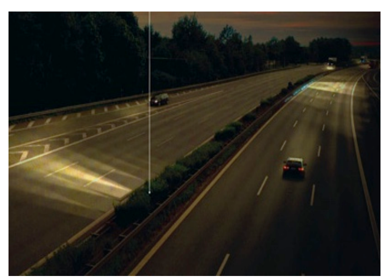
- Phone and voice interfaces:



Smart Transportation

- Smart Roadways
  - Reactive Lights/Dynamic Lanes
  - Road Condition Monitoring
  - Traffic Management

- Connected Cars
  - Accident avoidance
  - Fleet Management
  - Real time public transport alerts



Typical smart app

- 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

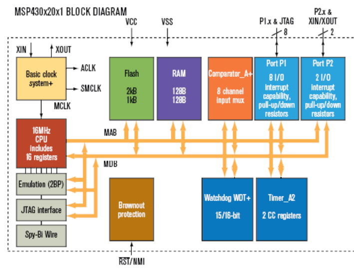
- Environmental sensors to internet to the cloud
  - Internet-enabled sensors
  - Upload to directly to servers / cloud through a router
  - Cloud provides analytics and provides dashboard

Sensor Platform

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

Small CPUs

- Example: Atmel AVR
  - 8 bit
  - 4 KB RAM
  - 128 KB flash on-chip
  - ~8 mA



- Example: TI MSP430
  - 16 bit
  - 10 KB RAM
  - 48 KB flash
  - 2 mA

Higher-powered processors:

- ARM7 - 32 bit, 50 MHz, >>1MB RAM
- ARM9 - 32 bit, 400 MHz, >>16MB RAM

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Low Power Radios

- Industrial, Scientific and Medical (ISM) Band
  - 900 MHz (33 cm), 2400 MHz (Bluetooth)
- Varying modulation and protocol
  - Zigbee (IEEE 802.15.4) – Modulating Phase
  - Bluetooth (IEEE 802.15.1) – Modulating Frequency
- Short range
  - Typically <100 m
- Low power. E.g. Chipcon CC2420:
  - 9-17 mA transmit (depending on output level)
  - 19 mA receive
- Listening can take more energy than transmitting

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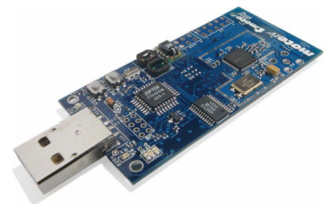
Battery power

- 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
  - Energy Harvesting (Solar/Wind/Motion)
  - Duty cycling

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Sensors

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

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Self-harvesting Sensors

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

Typical Design Issues

- Single node
  - Battery power/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
  - Derive insights
  - Make recommendations, send alerts
  - Provide active control

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

Historical Overview

- 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

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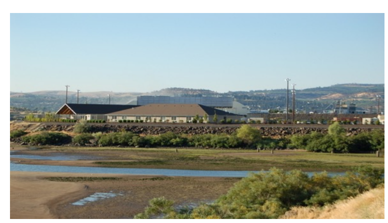
What is a data center?

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



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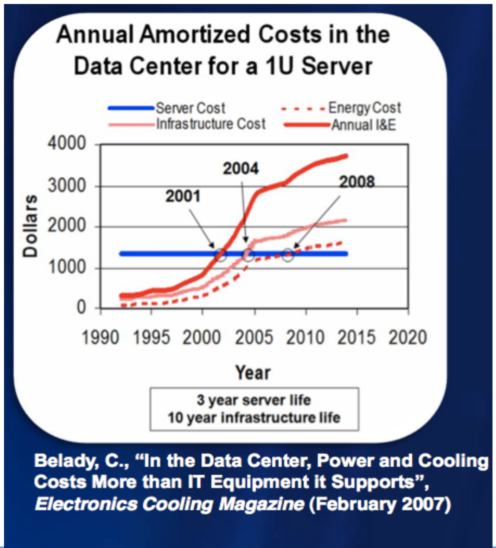
Data Center Energy Cost



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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)

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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

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Reducing server 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

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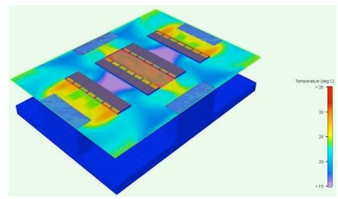
Reducing cooling cost

- Better air conditioning
  - Thermal engineering / better airflow
  - Move work to cooler regions
- Newer cooling
  - Naturally cooled data centers
  - Underground bunkers



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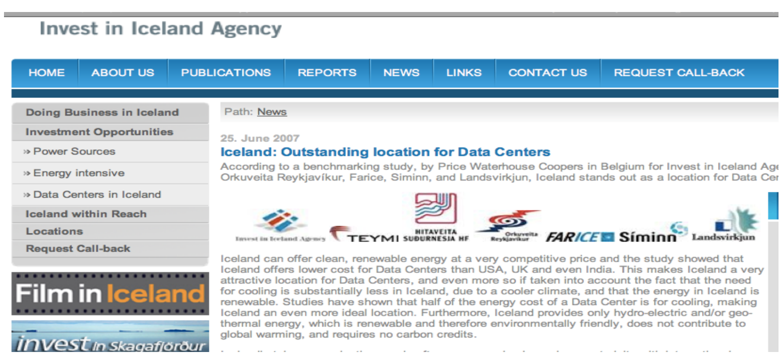
Build them in Iceland

- Free cooling-based data centers



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Desktop 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]

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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

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Approach

Home AMI
PMU, in-network devices

Measure and monitor

Improved situational Assessment, managements, response

Machine learning, Data analytics

Deep analytics and prediction

Improved forecasting for energy generation, demand, transmission

Operational requirements

Control, operations

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

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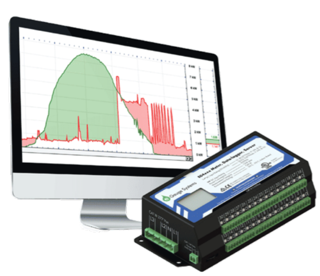
Building Monitoring

- Power monitoring at different levels -
  - Outlet-level monitoring
  - Meter-level monitoring

Wemo Smart Plug



eGauge Meter with interface

Smart meter

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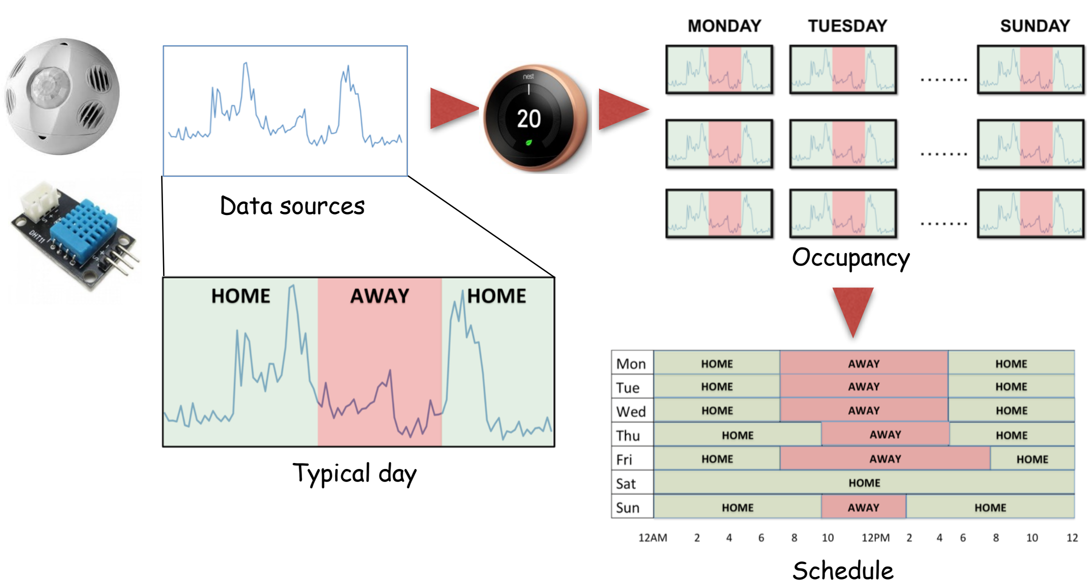
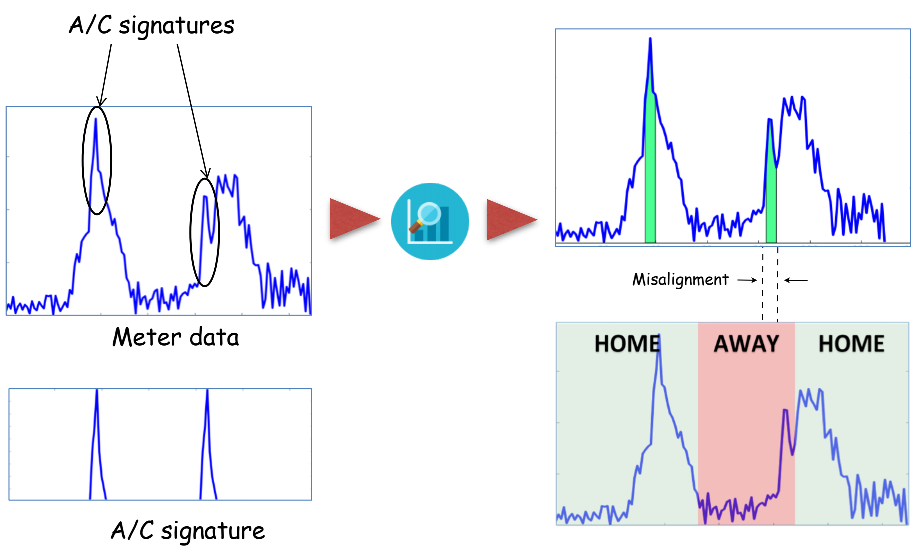
Analyzing the data

- Energy monitors / sensors provide real-time usage data
  - Building monitoring systems (BMS) data from office / commercial buildings
- Modeling, Analytics and Prediction
  - Use statistical techniques, machine learning and modeling to gain deep insights
    - Which homes have inefficient furnaces, heaters, dryers?
    - Are you 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?

Learning Thermostats



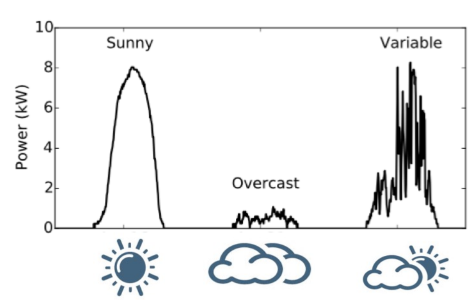
Does Your Thermostat need help



Use Renewables

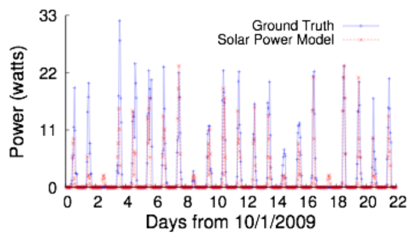
- Significant growth in renewable energy adoption
  - Rooftop Wind Turbines
  - Solar PV installation
  - Solar Thermal (to heat water)

- Highly Intermittent
  - Cloud cover, temperature, ……..



Forecasting renewable energy

- Design predictive analytics to model and forecast energy generation from renewables
  - Use machine learning and NWS weather forecasts to predict solar and wind generation



- Better forecasts of near-term generation; "Sunny load" scheduling

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Use case – EV Charging Station

- Solar panels installed in parking lots, rest areas, paid garages
  - Possible use case in offices and car rental services
- Assumptions
  - Arrival/departure times for EVs
  - Accurate Solar predictions
- Need intelligence in charging schedules
  - When to charge?
  - Which EV to charge?
  - How much?

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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, motivate users

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Summary

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

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