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

- 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

Each data center is 11.5 times the size of a football field.
Data Center Energy Costs

Annual Amortized Costs in the Data Center for a 1U Server

Belady, C., “In the Data Center, Power and Cooling Costs More than IT Equipment it Supports”, Electronics Cooling Magazine (February 2007)
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

Measure and monitor

Machine learning,
Data analytics

Deep analytics and prediction

Operational requirements

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 radio
  - 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

TED 5000-G

Gateway

Real-Time Use

$ 0.13 per Hour
1.206 kilowatts
October 01, 11:53 AM
Analyzing the data

- Energy monitors / sensors provide real-time usage data:
  - Smart meters:
  - 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?
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