Pervasive Computing, IoT and Smart Buildings

Srinivasan Iyengar
srini@cs.umass.edu

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 Glasses
  - On-body monitoring
  - 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

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
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

Sensors

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

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
Data Center Energy Cost

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)
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 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 cost

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

- Newer cooling
  - Naturally cooled data centers
  - Underground bunkers

Build them in Iceland

- Free cooling-based data centers
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]

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
- Improved situational assessment, management, 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

Building Monitoring

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

- Wemo Smart Plug
- eGauge Meter with interface
- Smart meter
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

**A/C signatures**

**Meter data**

**A/C signature**

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**Use Renewables**

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

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

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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

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?
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

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