Lecture 26: May 4

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26.1 Introduction

This lecture covers topics related to Pervasive Computing, Internet of Things, Smart Buildings and Green Computing.

26.2 Pervasive Computing

Computing is becoming increasingly ubiquitous (sensing and computing is 'Everywhere'). Some popular examples of this include Smartphones, Smart buildings, Smart transportation, etc. For example : PIR sensor is used to detect when a person has entered a room and switch on the lights.

26.2.1 Rise of Pervasive Computing

The rise of pervasive Computing has been possible due to the below 2 aspects :

- Miniaturization of Computing : Sensors have become tiny in terms of physical dimensions. This is particularly true with the growth of MEMS (Microelectromechanical systems). MEMS sensor can transform mechanical, thermal, biological, chemical, optical, and magnetic phenomena into electrical signals. In future it is likely that sensor sizes will reduce to nano-scale dimensions.
- Internet of Things(IoT) : This is nothing but a network of physical devices which are able to talk to each other and then transfer data to the cloud.

26.2.2 Applications

26.2.2.1 Smart Health

Early wearable devices were able to track heart rate, number of steps, etc for the purpose of fitness tracking and monitoring sleep. Fitbit is the most popular example of such a wearable device. Newer technology do much more than this. For example: Smart Clothing - Devices embedded in the clothing are able to do on-body monitoring for sweat detection. Smart glasses are able to track gaze in order to detect fatigue.

26.2.2.2 Smart Buildings

Some of the examples of devices that make building infrastructure smarter include Thermostat, Smart Plugs, Smart appliances, Smart Lock etc. A Smart appliance like a smart-fridge is potentially able to detect food spoilage. Nest Thermostats are examples of smart thermostats that can learn usage pattern and dynamically control temperature settings. These devices can be controlled through a phone or voice interface.

26.2.2.3 Smart Transportation

One of the major examples of Smart Transportation is *Connected Cars*. Potential applications include Accident avoidance (pedestrian detection etc.), fleet management (cars can start/stop at the same time) and real-time public transport alerts.

26.2.2.4 Smart Roadways

Sensors can be used to switch on street lighting only if an automobile is passing nearby or dynamically direct cars to different lanes. They can also be used to monitor road conditions and for the purposes of Traffic management. For Ex: Austin has a program where signals from Bluetooth-enabled cars are used to estimate traffic density On the streets.

26.2.3 Design of 'Smart Infrastructure'

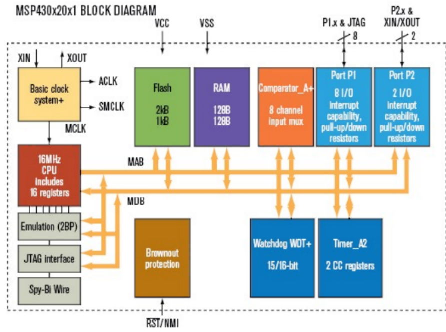
A typical application includes a personal device that is able to communicate with a mobile phone over a low-power network channel. The mobile phone then uploads the data to the cloud. In the cloud, the server performs analytics on the data and may provide feedback to the phone.

Another possible design is where the sensors in the environment upload data directly to the cloud. Ex: Smart Energy meters

Different elements of a distributed network of resource-constrained smart devices (also referred to as sensor nodes) are as follows -

26.2.3.1 CPU

The sensor nodes have very small CPU's. Popularly used CPU's are *Atmel AVR* (8-bit instruction set, 128 KB on-chip flash, 8 mA current draw) and *TI MSP430* (16-bit instruction set, 10 KB RAM, 48 KB flash, 2 mA current draw). As silicon technology evolves, the trend is for more compute to be available with lower energy consumption. Thus newer CPU's for these applications include *ARM 7* (32 bit, 50 MHz, 1 MB RAM), *ARM 9* etc



MSP430 board

26.2.3.2 Low-Power Radios

Communication is essential for a network of nodes to work together. The ISM Band (Industrial Scientific and Medical Band) is free for applications to communicate and is unlicensed. Some of the commonly used spectrum is 2400 MHz for Bluetooth and 900 MHz (33cm).
Different radio communication protocols work through different means. Zigbee (IEEE 802.15.4) works by modulating phase and Bluetooth (IEEE 802.15.1) works by modulating frequency of radio waves. These communication protocols typically have practical ranges of less than 100 meters. Chipcon CC2420 is a popular radio chipset.
An essential requirement of these radios is low power. Typically in these radios the energy consumption is higher while receiving than transmitting. This is because the radio needs to be 'ON' all the time, while it can transmit for a short time and go to sleep.

26.2.3.3 Battery Power

Battery Power is a big concern in IoT. For example: A Mica2 "mote" has a battery capacity of 2500 mAH. The mote consumption is around 25 mA which gives it a lifetime of 100 hours. In order to extend the life of the node, following are the possible alternatives :

- Bigger Battery : More capacity
- Energy Harvesting : Charge the battery in the node or use energy directly from the environment through sources like Solar, Wind or Motion
- Duty Cycling : Switch on and off the mote at a particular frequency based on the application

26.2.3.4 Sensors

The sensors in the system are responsible for measuring external phenomena. They can be used to measure temperature, humidity, light, acoustics, location etc. For example : the phone screen brightness is adjusted based on ambient light.
Sensor fusion is the technique of deriving insights by fusing data from multiple sensors. Another challenge is sensor placement. The multiple sensors need to be placed such that they can cover the entire area that needs to be monitored and provide redundancies in case of failure. Apart from the use of batteries, it is possible for sensors to harvest energy from the environment to power themselves.

26.2.4 Typical Design Issues

The typical concerns while building a pervasive computing systems are :

- Node : Maximize the lifetime of the node by increasing the battery power through various techniques.
- Network of Sensors : The data from various kinds of sensors need to be aggregated together. Localization and synchronization among the nodes in the network based on signal strength, direction, etc is also important. Another concern is the protocol for routing the communication from one node to another.
- Server Side Processing : On the server, we can employ big-data analytics in order to derive insights from the data and provide recommendations and alerts.

26.3 Green Computing

There are two major aspects of Green Computing

- Greening of Computing : Here the attempt is to design energy-efficient hardware, software and systems.
- Computing for Greening : It is the use of computers to make physical infrastructure more efficient.

26.3.1 Historical Overview

Historically the necessity for better energy efficiency has been driven by the need for energy-efficient mobile devices where the motivation has been longer battery life, and growth of data center where the motivation has been to lower the electricity costs. Green computing is also important in order to lower the carbon footprint and to improve efficiency of other systems. The typical *compute* energy consumption is 20% in an office building, 50-80% at a large university. It is 3% of the total energy consumption today and is growing rapidly.

26.3.2 Data Centers

A data center is a facility for housing a large number of servers and data. For example: A Google data center can be many football fields big, housing more than 100000 servers and consuming 100 MW of electricity. The energy cost of running a data center is very high. PUE or Power Usage Effectiveness is the ratio of total energy consumed by a data center to the energy delivered for compute. Typical PUE is between 1.5 - 2. A PUE of 2 indicates that the energy cost to run the data center is twice that of delivering power to the servers. Google achieves a PUE of 1.1 which is an indication of high efficiency of Google data center infrastructure.

Data Center

26.3.3 Greening of Computing

Following are the considerations while designing computing systems that are more energy efficient.

- Reduce Server Cost : This is done by purchasing more energy-efficient hardware including servers, power supplies etc. In certain cases it is more efficient to run the data center through DC rather than AC.
- Server Management : The power cost can be reduced by intelligent power management of servers by turning them off while not in use; use of virtualization by moving applications to a concentrated number of physical machines running virtual instances.
- Cooling Cost : This would involve design of better air-conditioning, thermal engineering and innovative methods of cooling like moving data-centers to cold places like Iceland etc.
- Desktop management : In large companies with thousands of desktops, IT tasks like update, virus scan are generally scheduled during the nighttime. Automatic sleep and wake up policies enable better desktop power management and reduce overall power consumption.

26.3.4 IT for Greening

Modern buildings have a distributed system of nodes. They are used to perform the following actions

- Monitoring by Sensors : Energy consumption in the building can be monitored at the outlet-level or meter-level.
- Analyzing the data : Real-time usage data is provided by the energy monitors/sensors to the Building Management System (BMS). This data can be used for modeling, analytics and prediction using statistical techniques and ML. In a residential setting, smart thermostats like *Nest* can learn household patterns by collecting energy usage and temperature data over a period of time.
- Use of Renewables : There has been a significant growth of renewable energy adoption including Rooftop wind turbines, solar PV installation and solar thermal power. One of the challenges in the usage of renewable energy is that it is intermittent in nature and is influenced by rapidly changing external environmental conditions like cloud cover, temperature etc.
- Forecasting of renewable energy : The challenge is to design predictive analytics in order to model and forecast energy generation. One of the use case of forecasting is in EV charging stations. Solar panels are installed in parking lots, rest areas and garages. Intelligence is required to design charging schedules to address questions like *when to charge ? Which EV to charge ? and by How much ?*

The data can also be used to motivate consumers to be more energy efficient as well as reveal insights into usage patterns, cause of wastage and improve efficiency.