CMPSCI 677 Operating Systems **Spring 2018**

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22.1 Introduction

Jeremy Gummeson is a Senior Research Fellow at UMass, and a former research scientist at Hewlett Packard Labs and Disney Research. He works in the UMass Sensors and Laboratory for Advanced System Software labs.

22.2 Pervasive Computing

Pervasive or ubiquitous computing refers to the fact that computers and connected technology is becoming incorporated transparently around us, from places like our own wrist to the buildings we're in. Smartphones are nearly ubiquitous, and contain significant numbers of sensors. Computing is also increasingly becoming a part of physical environments, e.g. with smart homes and IoT devices.

Four major subsections of

22.2.1 Rise of Pervasive Computing

- Miniturization (Moore's Law); for example, Microelectromechanical systems (MEMS) are microscopic devices at a very small scale.
- Sensors have become more powerful and efficient. For example, look at how powerful smartphones have become.

22.2.2 Applications

22.2.2.1 Smart Health

Early wearable devices can track aspects relating to fitness, such as heart rate and serve as a step counter, as well as perform sleep tracking. Newer devices, some commercially available and some still in research, include smart clothing (devices embedded into clothing which can do on-body detection of, e.g., sweat detection) and smart glasses (which can track your eye pupil movements to detect fatigue).

22.2.2.2 Smart Buildings

Smart buildings includes connected thermostats (allowing you to adjust the temperature and view it remotely), smart plugs (being able to turn on and off devices remotely), smart appliances (e.g., a fridge or washing machine), and smart locks.

Smart buildings also encompasses devices like the Amazon Echo and Google Home, which serve as voice assistant devices, and also can be configured in mesh layouts where no matter where you are located in your home, a device can still hear you. This can help create a cohesive smart home ecosystem; for example, the Nest Thermostat can be controlled via phone or voice using a smart assistant.

22.2.2.3 Smart Transportation

Smart transportation involves both infrastructure and device improvements. With smart roadways, roads can have dynamically-adjusting lanes, speed limits, and reactive lights (which conserves energy).

With connected cars, an ongoing research topic involves fleet management, wherein cars would create a local area network using a Bluetooth-like protocol to be able to inform each other about their positions and prevent crashes.

22.2.3 Infrastructure Design

A typical example of the way in which smart devices work involves communication from the personal device to a wearer's smartphone, which is then connected to the internet and can communicate with servers in the cloud to sync data. The device to phone communication likely occurs via Bluetooth LE or a similar low-power technology. For devices that are more stationary, an environmental sensor can connect directly to the internet via a home network (e.g., with your home WiFi network), and then communicate with the cloud.

A dashboard interface can then likely serve as the way in which a user views the output of these devices, and that dashboard interface could either be a website which reads database data that was synced from the devices or reads from the devices directly over the network.

22.2.4 Sensor Platforms

22.2.4.1 CPU

Low-powered sensor nodes can be thought of as a resource-constrained distributed system. They typically use a small CPU (8-bit addressable bus, 4KB of RAM), a low powered radio transmitter (with rates of between 10 and 200 Kbit/sec), whichever sensors are needed for the application, a small amount of flash storage to store the OS and application components, and either a battery and/or a mechanism which allows the sensor to be self-powered (like a solar panel, for instance).

For example: an Atmel AVR (8-bit data path, 4KB RAM, 128KB flash-on-chip, around 8 mA of power consumption), a TI MSP430 (16-bit data path, 10KB RAM, 48KB flash), or a Raspberry Pi (ARM v6/v7, much closer to a smartphone in terms of processing ability).

22.2.4.2 Low-Power Radios

The ISM Band (Industrial, Scientific and Medical Radio Band) is often used for low-power communication between nodes, especially the 900MHz and 2.4GHz ranges. These band ranges are available for general use by communication equipment without registration via the FCC or other bodies.

Varying levels of modulation and different protocols are used, such as Zigbee which modulates the phase of radio waves and Bluetooth which modules the frequency. These methods are used for short-range, less than 100m communication.

There are some emerging methods and protocols currently under testing and development. The Chipcon CC2420 is an extremely low-power radio, requiring only 9-17mA of power to transmit and 19mA to receive. As is generally true across radio communication methods, listening for signals requires slightly more energy than transmitting.

22.2.4.3 Battery Power

The Mica2 Mote, a common mid-2000s sensor node, required 2 AA batteries and used 25mA of power. This provided around 100hrs of lifetime.

Some alternatives to provide for longer battery life include:

- Bigger batteries (duh.)
- Energy harvesting, which are methods which allow for the system itself to generate the power that it needs to operate. This might include motion, wind, or solar. In some cases, the thing being observed via the sensor can actually provide some energy which can then be used to power the sensor. Self-harvesting allows nodes to harvest energy from the environment to power themselves. This includes solar panels, vibration, thermal, airflow, and wireless energy transfer.
- Duty cycling, which involves waking up periodically and then sleeping a fixed amount. Methods can be used which allow for duty cycling without missing messages, if nodes' wakeup times are synchronized.
- Use of higher-order sensors, which require less energy. When a higher-order sensor is activated, then the lower-level sensor which requires more energy is activated. That way the lower-level sensor is only activated when it is predicated that the thing being observed is actually present or some change has occurred.

22.2.5 Types of Sensors

An incomplete list:

1. Temperature
2. Humidity
3. Magnetometer
4. Vibration
5. Acoustic
6. Light
7. Motion/IR
8. Imaging
9. Accelerometer
10. Location/GPS

Most of these sensors are now included in modern smartphones.

22.2.6 Typical Design Issues

For a single node:

- Battery power
- How to harvest energy to maximize lifetime

For a network of sensors:

- Data aggregation
- Duty cycling
- Localization/synchronization
- Routing

Outside of the network (server-side processing)

- Big data analytics
- Deriving insights from the data
- Sending alerts
- Providing active control of the nodes by an operator

22.3 Green Computing

How do you design energy efficient hardware/software/systems? Nowadays, IT is used to make infrastructure efficient.

Greening of Computing is an attempt to design energy-efficient hardware/software/systems, while computing for greening refers to the use of computers to make physical infrastructure more efficient.

22.3.1 Historical Overview

Energy efficient mobile devices are a long-standing problem. The recent growth of datacenters has resulted in a large focus on energy efficiency in server farms, because it lowers the operating cost.

22.3.2 Datacenter Power Consumption

Computers often require 20% of the power usage in office buildings, 50-80% of the power usage at a large college and, globally, >3% of our carbon footprint.

Datacenters encompass servers, network gear, and storage infrastructure. Google's Dallas DC requires 100MW of power to operate, and the server cost per KwH is $50/month.

22.3.3 Green Datacenters

Green datacenters reduce the cost of running servers and cooling, and use green infrastructure practices. They use more energy-efficient servers and manage their servers better collectively.

In order to reduce cooling costs, some innovative approaches for HVAC/air conditioning systems have been employed by thermal engineers. Naturally cooled datacenters are one option: build datacenters in Iceland!

22.4 Personal Research Projects

22.4.1 Battery-Free IoT (Disney Research)

Because RFID tags don't require battery power to operate (a capacitor is charged by the 900MHz signal emitted by a receiver), research has been done on ways to operate IoT systems using RFID. They have a read rate of around 50 samples/sec.

Challenges with ubiquitous RFID:

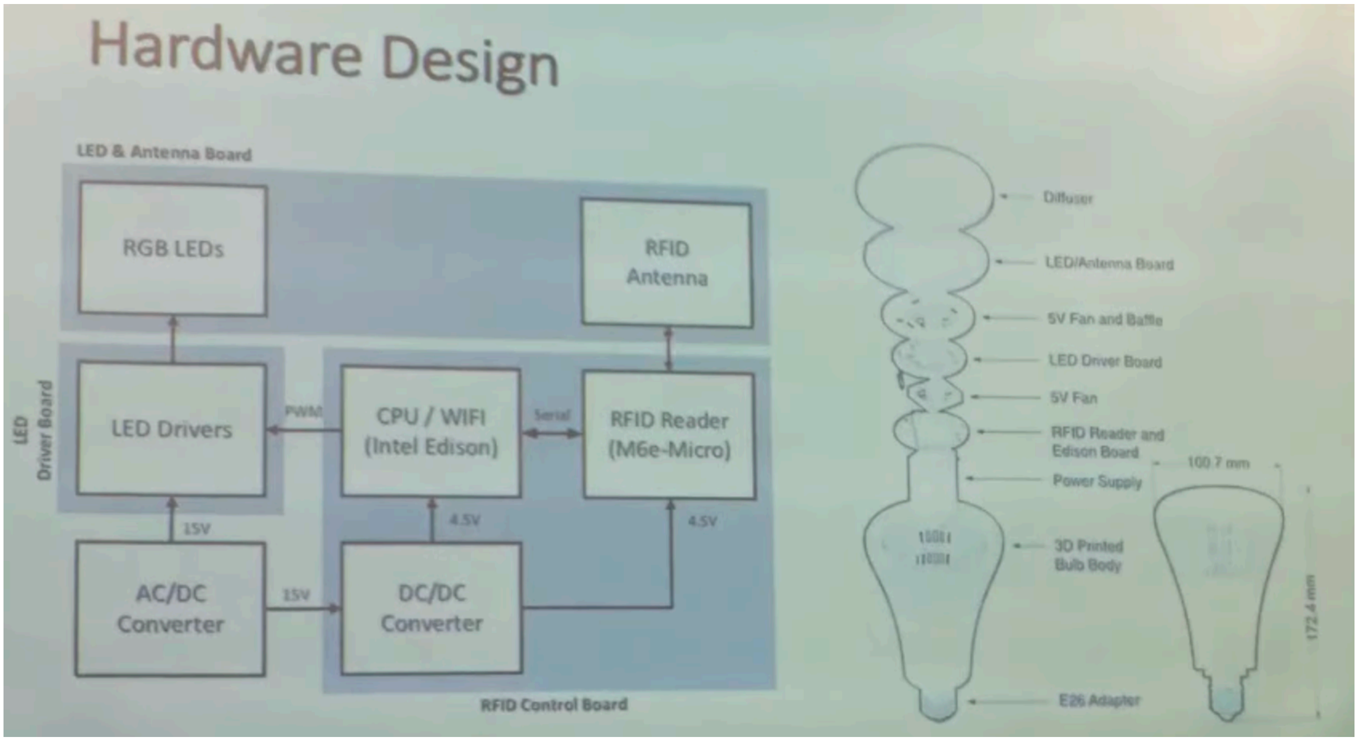
- Routing power and communications to readers is difficult
- Antennas need to be large to achieve good coverage
- Antennas need line of sight to tags

Idea: reuse home infrastructure, by incorporating a RFID reader in a lightbulb.

22.4.1.1 Setup Overview

- Install light bulbs and associate with Wi-Fi AP
- Install tags and register with backend server
- Interpret data, which can be used to actuate lighting and UI

22.4.1.2 Hardware Design



22.4.1.3 Interactive RFID Tags

- Location
- Thermostat
- Touch
- Temperature
- Contact switch

22.4.1.4 Classes of Applications

To showcase the applications enabled by networks of RFID lightbulbs, three application categories were explored that leverage the scale of coverage and immediate feedback that RFID lightbulbs provide.

- Navigation
- Infrastructure Monitoring
- Prepackaged Content

22.5 Summary

"Greening" of computing for IoT and Health:

- Designing energy efficient hardware and software.

Computing for greening:

- Use of IT for monitoring, analytics, and control
- Use of intelligent software for power management
- Forecasting for reasonable energy harvesting

Emerging IoT technologies:

- Battery-free sensing with RFID sensors
- 5G networks