Wireless Sensor Networks: An Overview

Vivek P. Mhatre

mhatre@ecn.purdue.edu

http://web.ics.purdue.edu/~mhatre

For ECE 495R

12/07/04

School of Electrical and Computer Engineering

PURDUE UNIVERSITY

What can wireless do for us?

Q: What can wireless do for us? 1973

A: Unwire the telephone $\Rightarrow$ Landlines replaced by cellphones!

Q: What can wireless do for us? 1997

A: Unwire the desktop $\Rightarrow$ Desktops replaced by laptops!

Q: What can wireless do for us? 1999

A: Manage tasks/monitor phenomena **remotely**

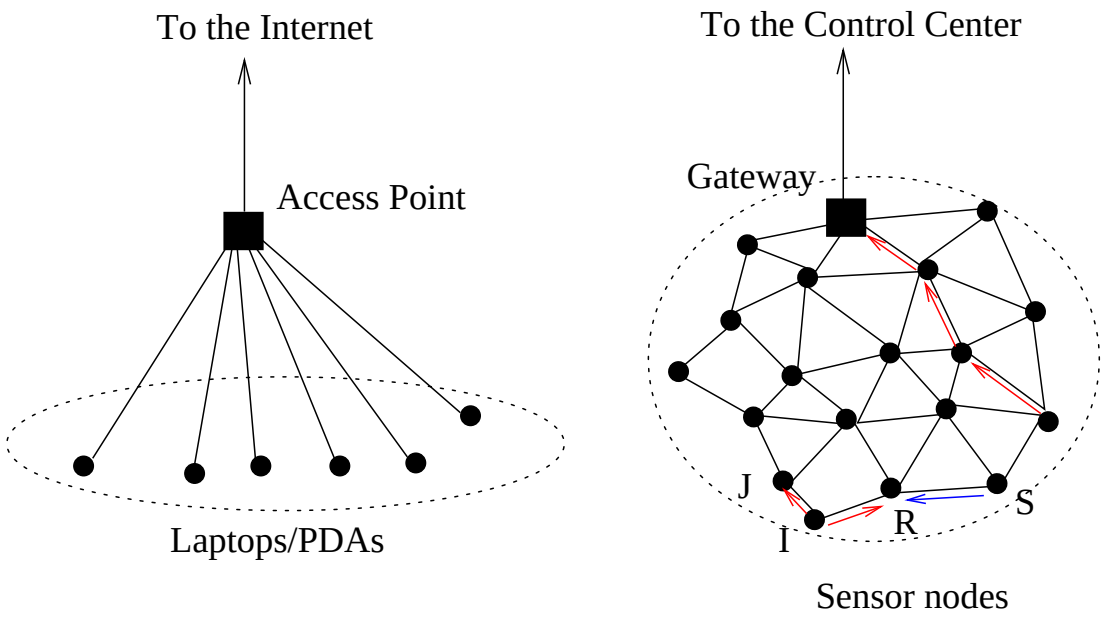
Presentation Outline

- What are Wireless Sensor Networks?
- What are their applications?
- Classification of sensor networks
- Important design challenges in Wireless Sensor Networks: EE, Networking perspective
- Summary

What is a Wireless Sensor Network?

- "Loosely" speaking, a **large** network of wireless computers!
- Each node is inexpensive
- **Hundreds or thousands** of nodes used in a single network
- Nodes are left **unattended**
- Detection or monitoring of an event in a distributed manner
- Deployed for a certain well-defined purpose (**application**)
- Nodes co-operate
- Unlike 802.11 networks on campus!

Single hop mode vs. Multi-hop mode



- Cheap node radios, and vast area to cover ⇒ limited communication range
- Limited communication range ⇒ need for
  - Multi-hop routing
  - Shared wireless channel ⇒ Complicated MAC (Media Access Control)

Sensor Network Applications

Civilian Applications

- Forest fire detection
- Temperature monitoring and vent control in buildings (Hewlett Packard and Notre Dame)
- Habitat monitoring
- Smart homes (Intel)
- Biosensors (Phillips)

Applications: Forest Fire Detection

Forest Fire detection

- Property and life loss every year due to forest fires
- Need to detect fires early, before they spread
- Drop thousands of sensor nodes over fire-prone forests
- If a node detects fire, it sends an alarm message (along with its location) to the Ranger Station
- Nodes use multi-hop communication to cover large forests

Applications: Temperature Control

Temperature monitoring and vent control in (Hewlett Packard and Notre Dame)

- Giant server farms with thousands of server machines in a single large room
- The room needs to be cooled
- Simple solution: A centralized cooling control, and common vents everywhere in the room
- **Problem:**
  - One control does not work well for all machines!
  - Some servers get heated more than others
  - Results in over-heating and eventual burn-out of those machines
  - If you set temperature with respect to over-used servers, too much cooling for under-used servers $\Rightarrow$ energy wasted!

Applications: Temperature Control

Sensor Network solution to temperature control problem:

- Attach a temperature monitoring sensor node to each machine
- A vent-control sensor node (mechanical control over the extent of vent opening) for each machine
- Feedback loop between measurement sensor and vent control sensor
- Better temperature control over a finer scale
- Results in more efficient cooling and less machine burn-outs!!
- Several engineering issues involved

Sensor Network Applications

Civilian Applications

- **Forest fire detection**
- **Temperature monitoring and vent control in buildings (Hewlett Packard)**
- Habitat monitoring
- Smart homes (Intel)
- Biosensors (Phillips)

Sensor Network Applications

Military Applications

- Surveillance
- Target detection
- Monitoring forces

Applications: Surveillance

Surveillance

- Original idea of **Smart Dust**, DARPA and UC Berkeley
- Tiny sensor nodes (dust-like) scattered over a battle-field/sensitive area
- Nodes form a multi-hop wireless network
- Nodes report enemy activity (if any) to a central base station/UAV

Sensor Network Applications

Military Applications

- **Surveillance**
- Target detection
- Monitoring forces

Sensor Network Applications

(a) Intrusion Detection

(b) Traffic monitoring and control

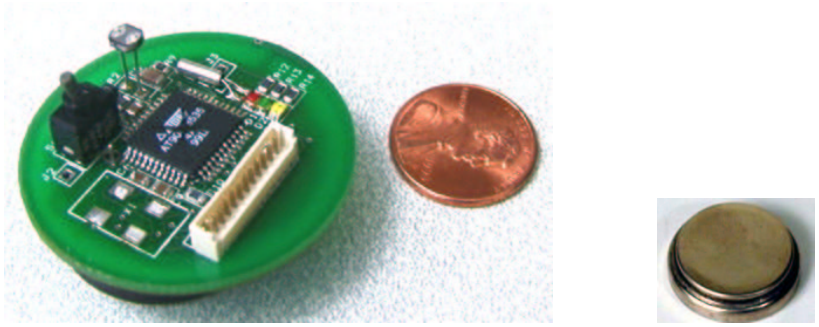
Commercial Applications

- **Intrusion detection**
- **Traffic monitoring and control**
- Inventory Control
- Precision Agriculture

Sensor Nodes

- Characteristics of a sensor node:
  - small size, to easily blend with the environment
  - a battery
  - limited processing capabilities (CPU)
  - **wireless** communication capabilities
  - one or more sensors (temperature, magnetic, light, etc.)

Sensor Nodes (contd.)



(c) (d)

Figure 1: A typical sensor node: Berkeley Mote, and its battery

- Size: 4cm×4cm
- CPU: 4 MHz, 8bit
- Battery: 560 mAh
- 512 Bytes RAM, 8KB ROM, OS (TinyOS) memory footprint of 4KB
- Radio: 900 MHz, 19.2 Kbps, range of 10-100 ft

Classification of Sensor Networks

- Application determines design requirements, and hence the classification
- Basically two types of networks
  - **Rare Event Detection:** e.g., Forest fire detection, Intrusion detection
  - **Periodic Data Gathering:** e.g., Temperature monitoring, Traffic Monitoring, Biosensors, Inventory Control
- Different design challenges for different classes of networks
- Will focus on Rare Event Detection applications in the rest of this talk

Design Challenges

Case Study: Forest Fire Detection

- Thousands of nodes scattered over a forest
- Node hardware is cheap $\Rightarrow$ nodes likely to fail randomly
- Range of each node 10 ft., use multi-hop communication

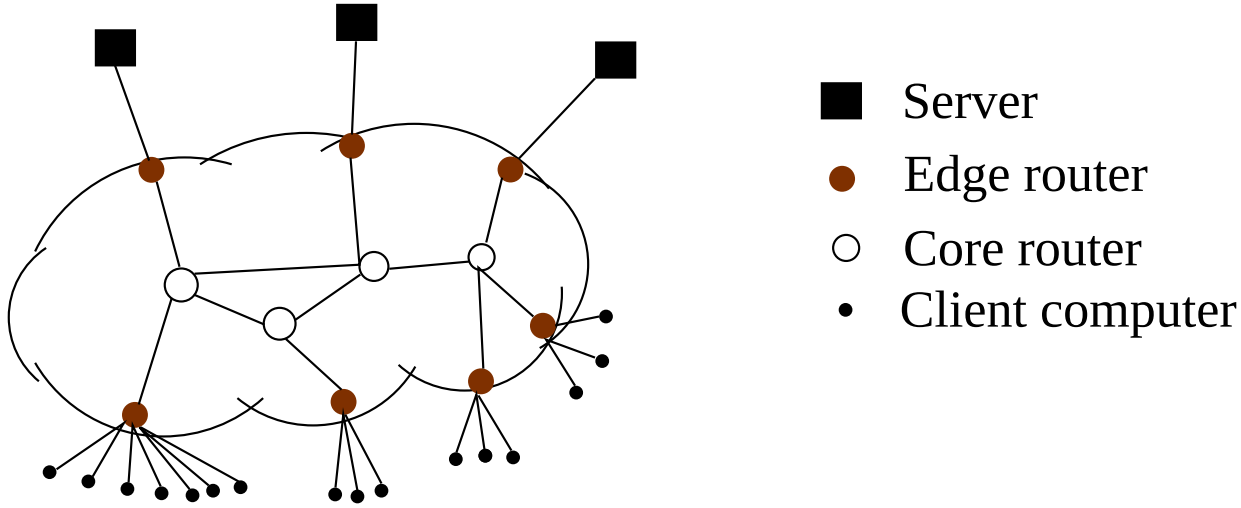
  $\Rightarrow$ **Routing**
- Timely delivery of messages, avoid unnecessary collisions

  $\Rightarrow$ **MAC**
- Most important constraint: **Limited battery energy**

  $\Rightarrow$ Energy efficient protocols with minimum communication overheads
- Other issues: Network initialization, Node localization, etc.

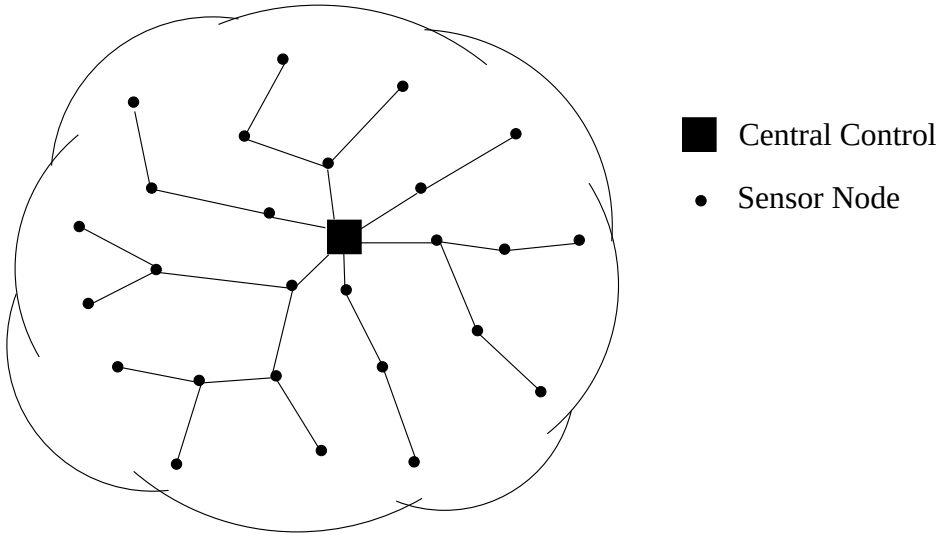
Routing

- Routing in the Internet
  - For **any-to-any** communication
  - Prefix based
  - Periodic exchange of routing information between neighboring nodes



Routing (contd.)

- Routing in Sensor Networks
  - For **many-to-one** communication (e.g., sensor nodes to Ranger Station)
  - Minimize control packet overheads for energy efficiency
  - **Limited memory** ⇒ cannot have elaborate routing tables
  - Protocols should be **energy-aware**, e.g., for the next hop node, choose the node which has the most residual battery energy
  - Protocols should be tolerant to frequent node failures



MAC (Media Access Control)

MAC determines how nodes co-ordinate and access the **common** wireless channel

- MAC in WLANs, i.e., 802.11
  - Energy efficiency is not all that important
  - Protocol handshake overheads are high
- MAC in Sensor Networks
  - Multi-hop communication $\Rightarrow$ a node does not know when its neighbor will send a packet to it for relaying
  - **Idle mode:** A nodes should keep its radio ON in anticipation of incoming packets
  - **Problem:** Idle mode energy consumption of a radio is high
  - **Solution:** Duty Cycle (radio turned ON/OFF periodically)

MAC (contd.)

Duty cycle results in **Latency-Energy** trade-off

Two extremes:

- Node radios stay ON all the time
  - Nodes can instantly report a fire
  - But the battery (and hence the network) will die soon
- Node radios stay ON for 1min after every 10 min
  - The battery (and hence the network) will last almost 10 times longer!!
  - But nodes will take at least 10 min to report a fire
  - Latency even higher if no synchronization among nodes
  - Synchronization requires communication which in turn requires energy!

Moral of the story: Engineering is almost always a story of trade-offs!!

Importance of Energy Efficiency

- Desired lifetime of forest fire detection sensor networks is **a few years**
- Manually changing node battery not feasible
- Re-deploy new set of nodes (possible since nodes are expected to be cheap)
- To make best use of available battery power, design low power MAC, Routing, Coding and Modulation schemes
- Use power scavenging techniques like solar cells

Summary

- **Protocol Design:** How to design a routing protocol so as to utilize every last milli Joule of energy in every node?
- **Protocol Design:** How to design a MAC protocol so as to get the latency-energy tradeoff for a given application?
- **Mathematical Modeling and Analysis:** Modeling energy expenditure for MAC, routing, sensing, etc. and battery dimensioning
- Hardware design of sensor nodes
- OS design
- Lots of other interesting modeling as well as protocol-design issues!

Reference

- I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless Sensor Networks: A Survey", *Computer Networks (Elsevier) Journal*, Vol. 38, No. 4, pp. 393-422, March 2002.

Questions

Thank You!!