Wireless Sensor Networks

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These slides are available on-line at:

http://www.cse.wustl.edu/~jain/cse574-06/

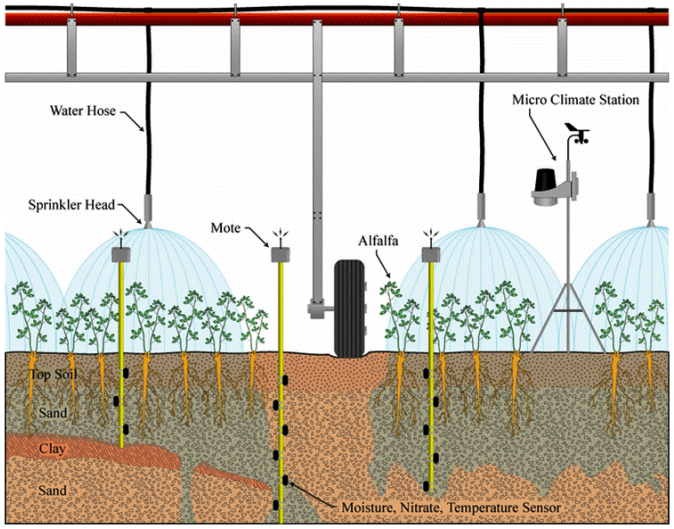
Overview

- Sensor Applications
- Sensor Network Architecture
- Data Dissemination
- MAC Protocols for Sensor Networks
- Location Discovery
- Quality of a Sensor Network
- Time Synchronization
- Transport Layer Issues
- Sensor Network Security
- Real-Time Communication

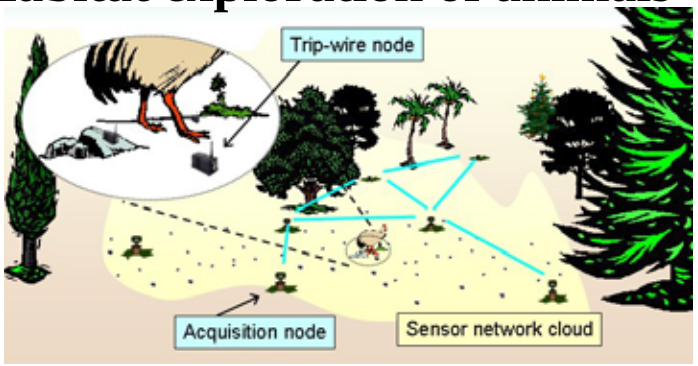
Sensor Applications

Battlefield Surveillance
Chemical, Biological Weapons

Crops and Agriculture
Forest Fires and Flood Detection



Forest Fires and Flood Detection
Habitat exploration of animals



Patient heart rate, blood pressure

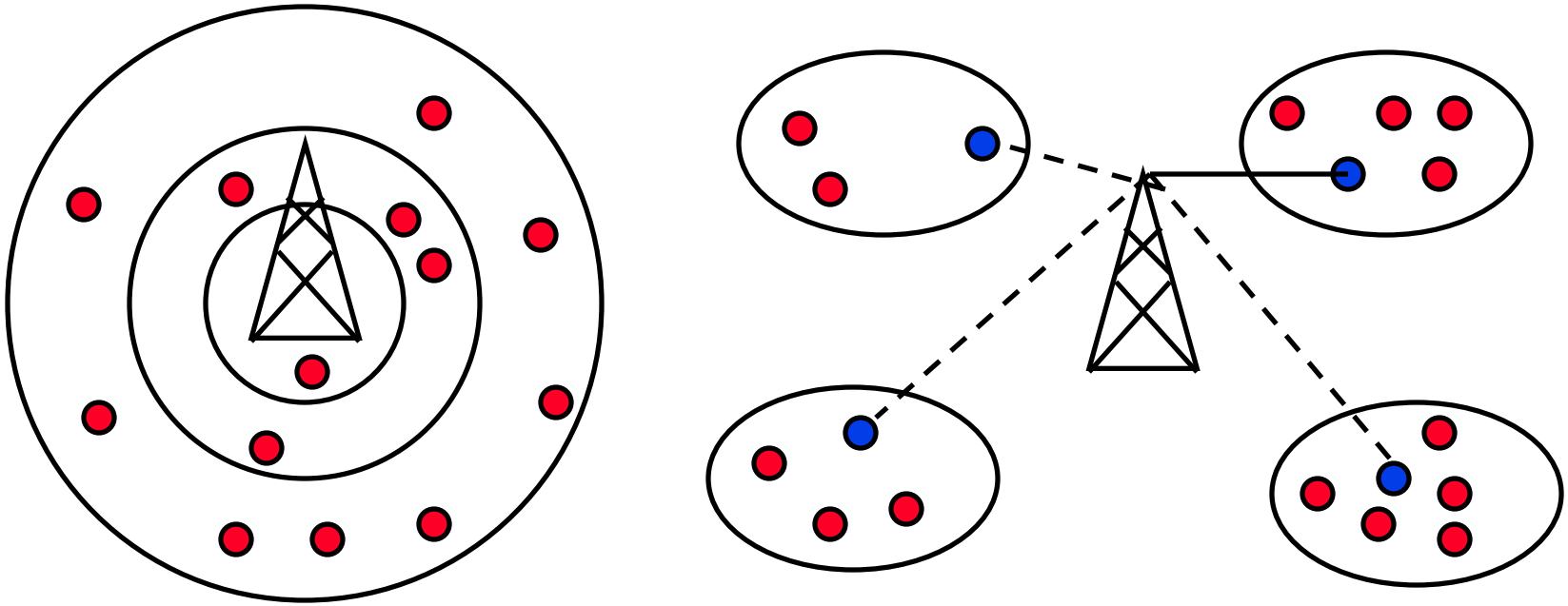
Sensor (vs. Ad-Hoc)

- Large scale
- Batteries may not be replaceable
- May not have global identifiers
- Queries may be data centric rather than address centric:
  - Who's temperature is more than 95 degree vs. What is your temperature?

  $\Rightarrow$ Geographical routing, Data fusion, Data aggregation

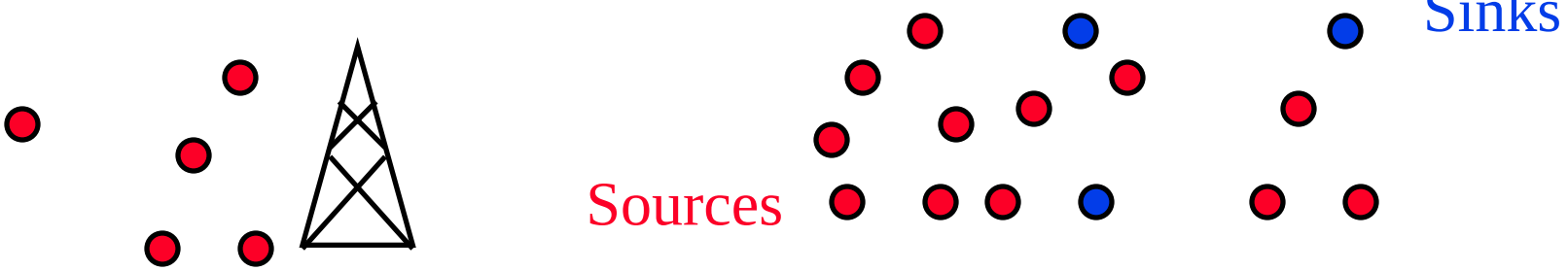
Sensor Network Architecture

1. **Layered**: Base station, one-hop layer, 2-hop layer, ...
2. **Clustered**: Nodes elect and communicate through cluster heads



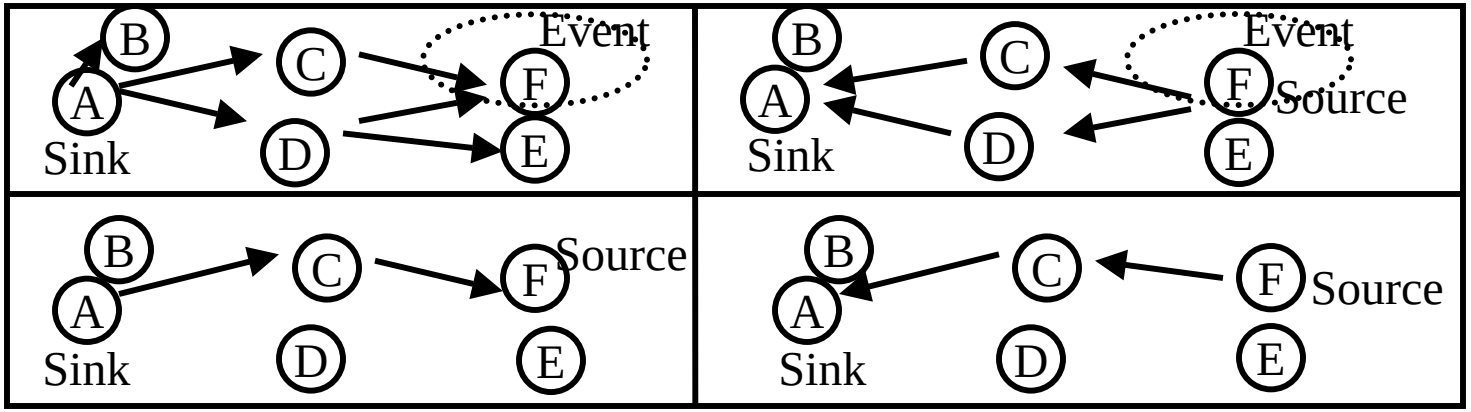
Data Dissemination

- *Sources*, *Sinks*, and *Events*
- **Data Gathering**: Sources send periodically to central collection points (base station)
- **Data Diffusion**: Sinks propagate their interests (type of data or event) Nodes cache interests and report events when detected
  - **Flooding**: *Implosion* (duplicate messages),
    overlap (multiple sources),
    blind (no consideration of energy or resources)
  - **Gossiping**: Randomly select a neighbor



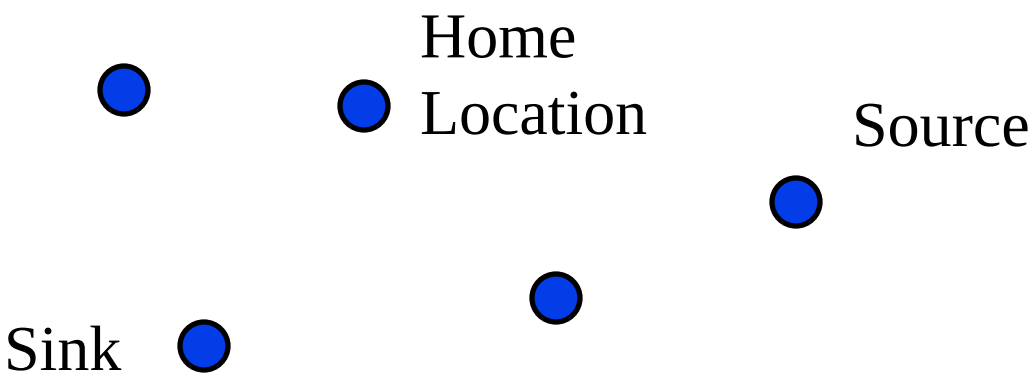
Directed Diffusion

- Sensor nodes generate queries. Flooded to entire network.
- Intermediate node cache the queries and the previous neighbor
- A gradient (= rate) is applied at each hop to the query
- Data is propagated along the reverse path proportional to the gradient
- Sink can reinforce a path by requesting higher rates along that path



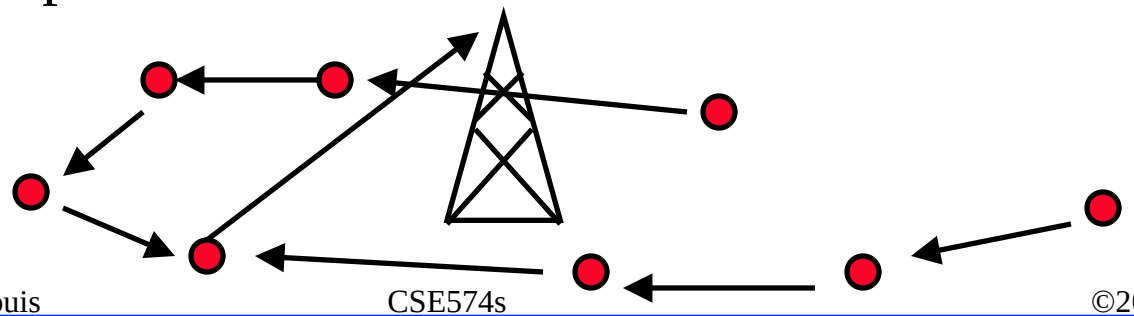
Geographic Hash table

- Query (key) is hashed in a (x,y) coordinate and is sent to a node nearest to that coordinate ⇒ Home Location (k)
- The data is hashed and sent to its home location from where it is propagated to the sinks ⇒ Uniform Storage load
- Redundancy can be used for home location



Data Gathering

- Gathering ⇒ From all sensor nodes to the BS
- Minimize delay × energy
- **PEGASIS**: Power-Efficient Gathering for Sensor Information Systems
  - Each nodes combines its data in the message and sends to its nearest neighbor not visited before
  - Starting from the farthest node
  - Ending at the leader which passes it to the base
  - A Token is passed backwards from the leader



MAC Protocols for Sensor Networks

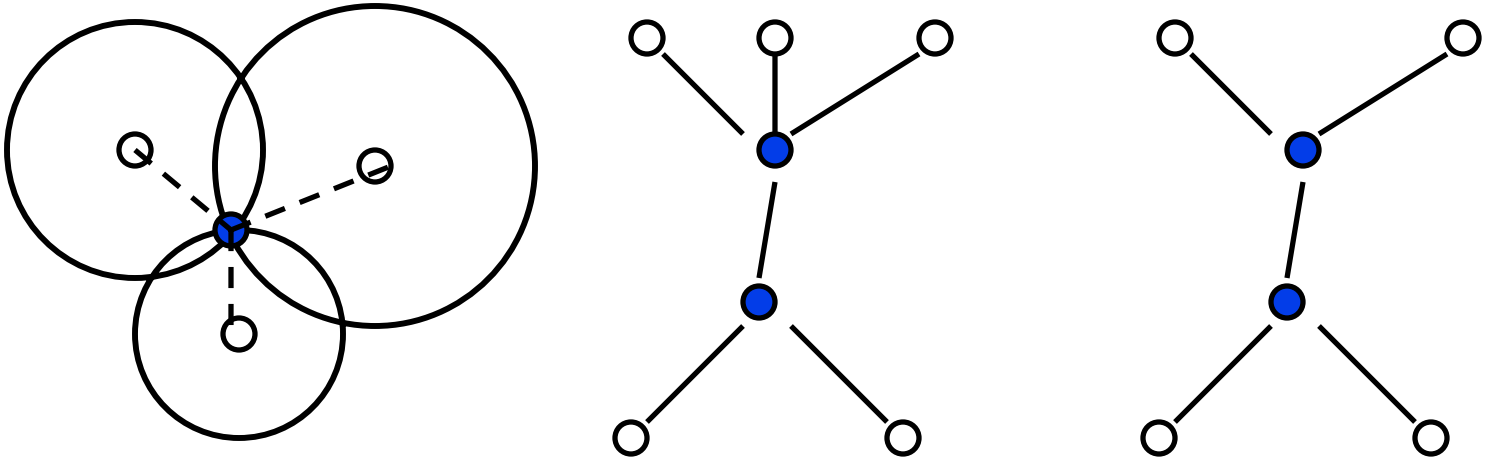
Three types:

1. Fixed Allocation: Predetermined assignment
2. Demand Based: Based on need
3. Contention based: No delay guarantee

- **Self-Organizing MAC for Sensors** (SMACS):
  - Capacity >> Data rate
  - Neighbors synchronize and agree on times for transmission
  - Only neighbors synchronize ⇒ Synch energy saved
  - Sleep when not transmitting ⇒ Further energy savings
- TDMA, FDMA, TDMA/FDMA, CSMA are also possible
- Bluetooth, 802.11, and ZigBee are MACs used in practice

Location Discovery

- Location Stamp on data
- **Indoor Localization**: Reference nodes in each location
- **Atomic Multi-Lateration**: Need 3 references
- **Iterative Multi-Lateration**: Nodes with known location become references for others
- **Collaborative Multi-Lateration**: Use quadratic equations

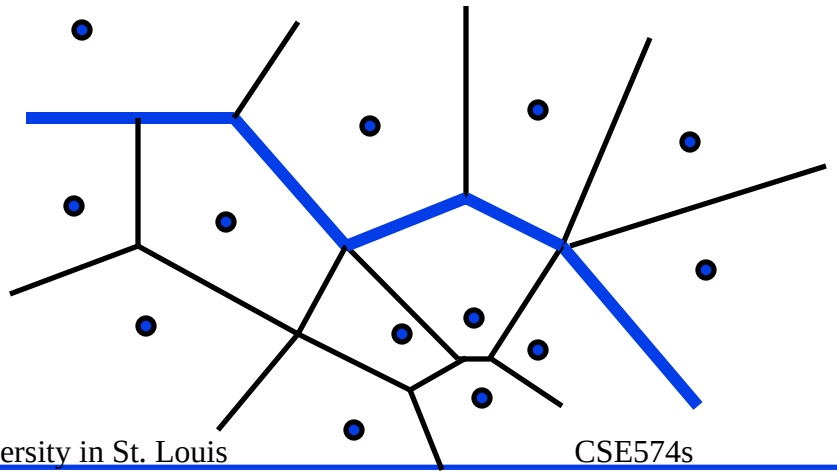


Global Positioning System (GPS)

- US Department of Defense $12B
- Man made stars
- 24 Satellites and their ground stations
- Triangulation
- Measures travel time of radio signal ⇒ Distance
- Satellites broadcast current time and their location using a Direct Sequence Code
- 1023 chips per bit
- 3 satellites give (x, y, z)
- 4 satellites give (x, y, z, t)
- Correct for any delays experienced through the atmosphere
- http://www.edu-observatory.org/gps/tutorials.html

Quality of a Sensor Network

- Quality = Coverage + Exposure
- **Exposure**: Ability to observe a target.
  Ability decreases with the distance from the target
- **Coverage**: How well is the region covered with sensors
  Find the least covered path that could be followed by enemy
- **Voronoi Diagram**: Cost = Distance from nearest sensor
  Find the maximum cost path.
- Opposite Problem: Find the best covered path



Sensor Standards

- 802.11, Bluetooth, ZigBee
- IEEE 1451: Smart Transducer Interface for Sensors and Actuators
  - Seven parts 1451.0 through 1451.6 dealing with different issues
  - 1451.5 is wireless interface - specifies 802.11, bluetooth and ZigBee

Time Synchronization

- GPS not accessible inside buildings, under water.
- Send a time stamp to neighbor
- One-way Delay = Send Time (Preparing the message) + Access Time (media access) + propagation time + receive time (processing at receiver)
- Best to timestamp the message at the PHY layer of the receiver
- **Post Facto Synchronization**:
  - Announce time along with the event.
  - Everyone else synchronizes to it
  - Leader periodically sends sync messages, which are flooded
  - Distributed election of the leader based on a random number
- Resynchronization: Upon merger of partitions. Better to advance the clock

Transport Layer Issues

- Reliable transmission of data from sources to sinks

PSFQ:

- Ask previous hop to retransmit if error $\Rightarrow$ Fetch
- Forward to next hops $\Rightarrow$ Pump
- Pump slowly and fetch quickly (PSFQ)
  $\Rightarrow$ Minimize storage, maximize reliability
- Farthest node sends a report of delivery status to the source.
- Intermediate nodes append their status to the same message.

Sensor Network Security

- Public key too compute intensive

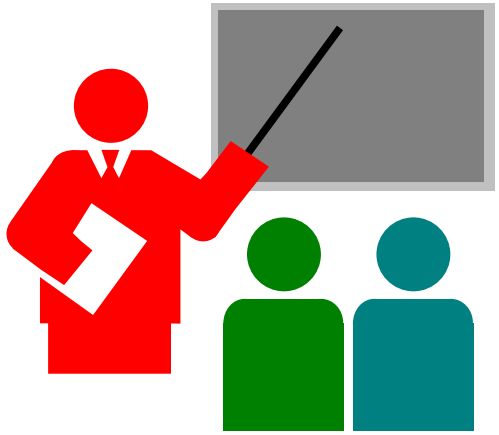
Localized Encryption and Authentication Protocol (LEAP)

- All nodes have an individual key shared with BS
- All nodes also have a group key
- Group key and Sensor ID ⇒ Master key of the sensor
- Hello to neighbor using group key and ID
  ⇒ Master key of neighbors
- Master keys of two neighbors ⇒ Shared key between neighbors
- Group is then erased ⇒ No replay attack
- Immediate neighbors form a cluster.
  One node generates a cluster key and sends to all members.
- Assumes network setup is fast and so intruders can't affect initialization.

Real-Time Communication

- SPEED: Geographical routing ⇒ Send packets to neighbors in the direction of the destination
- Nodes send delay feedback backwards as packets are forwarded
- Nodes can also send a backpressure message if delay too high
- Select the neighbor with least delay
- If no neighbor can meet the delay constraint, the packet is dropped
- No node close to the destination ⇒ Void
- Void avoidance ⇒ Issue a back-pressure with infinite delay
  ⇒ Search for alternate paths

Summary



- Data diffusion queries are to a zone and to individual nodes
- Location Discovery is by triangulation or multi-lateration
- Quality of a Sensor Network is measured by coverage and exposure
- Time Synchronization by exchanging timestamps
- Transport: Pump slowly and fetch quickly increases reliability
- Real-Time Communication using deadline based forwarding

Reading Assignment

- Read Chapter 12 of Murthy and Manoj

Homework

A node X receives three beacons from nodes A, B, and C at (0, 0, 0), (2, 6, 0), and (3, 4, 0), respectively. From the received signal strengths, it determines the distances to A, B, and C to be $\sqrt{26}$, $\sqrt{6}$, and $\sqrt{11}$, respectively. Find the coordinates of X.