Wireless Sensor Networks

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Audio/Video recordings of this lecture are available at:

http://www.cse.wustl.edu/~jain/cse574-08/

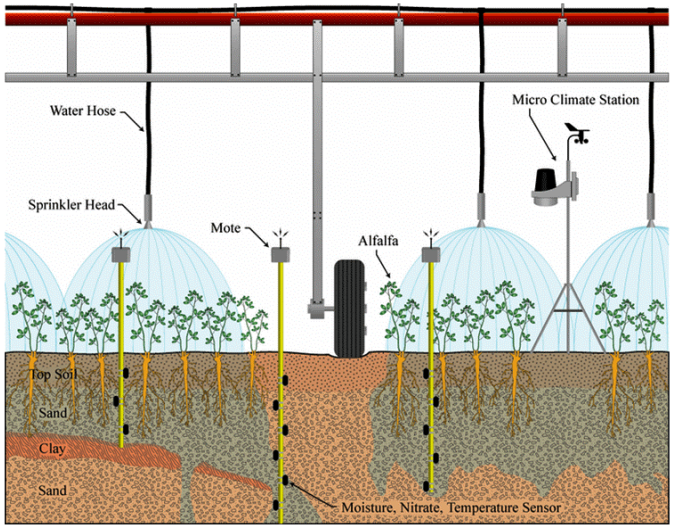
Overview

- 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

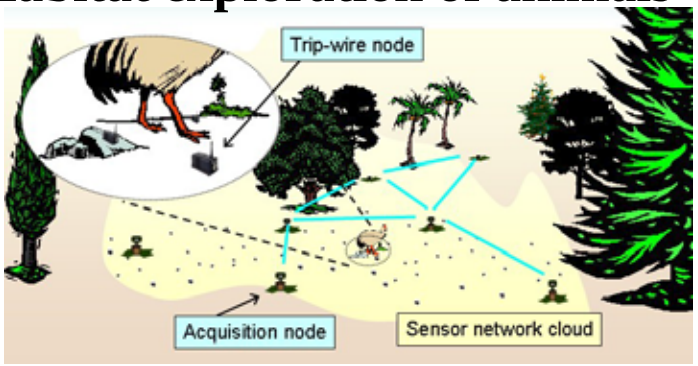
Sensor Applications

Battlefield Surveillance
Chemical, Biological Weapons

Crops and Agriculture
Forest Fires and Flood Detection



Habitat exploration of animals



Patient heart rate, blood pressure

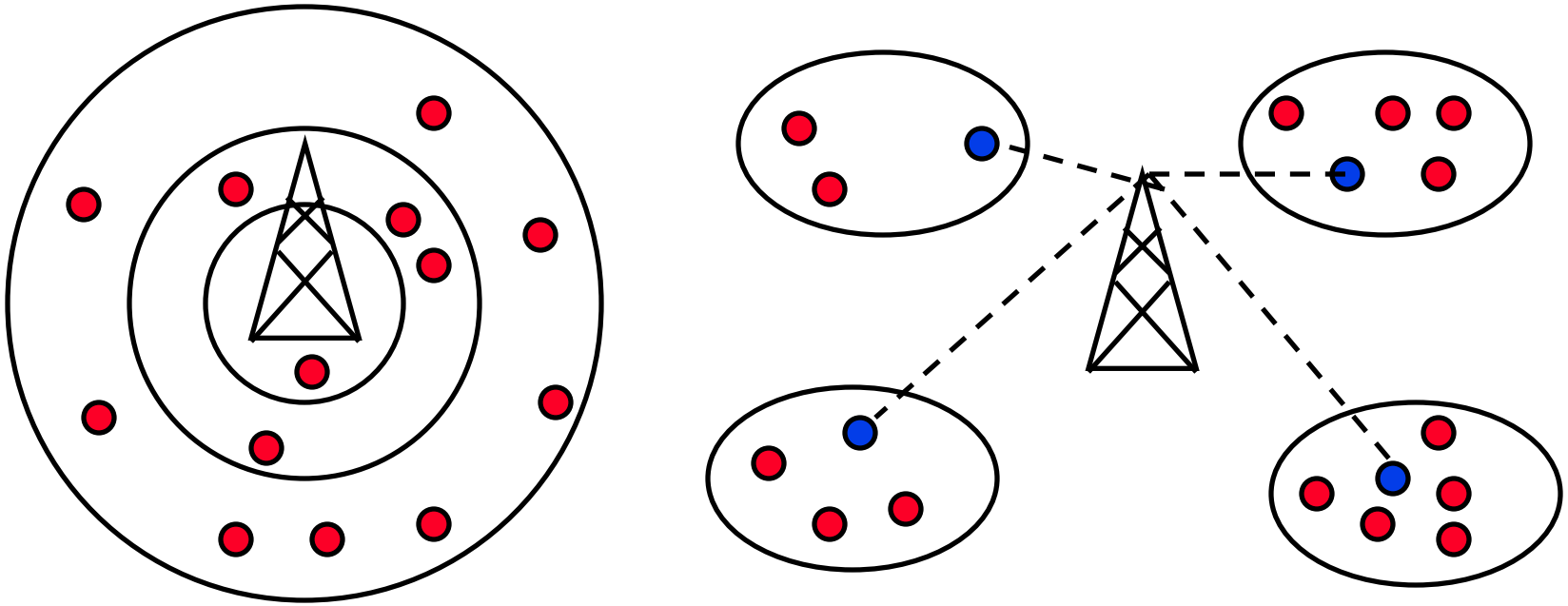
Sensor (vs. Ad-Hoc)

- 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

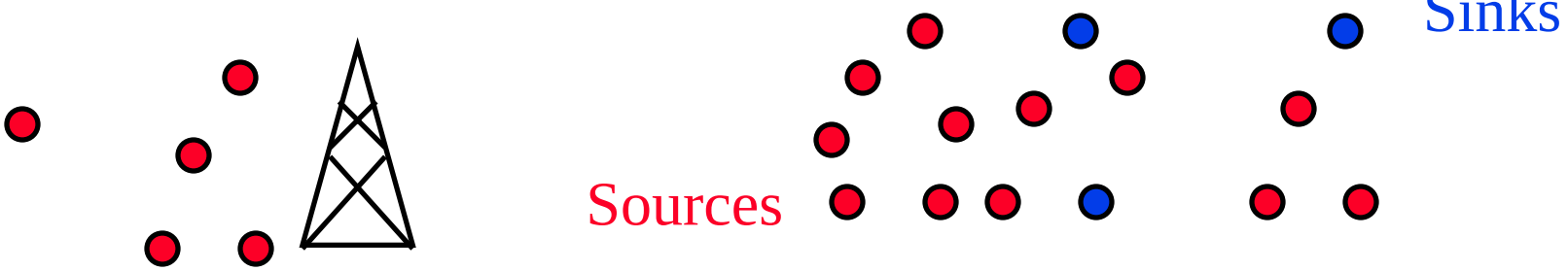
Sensor Network Architecture

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



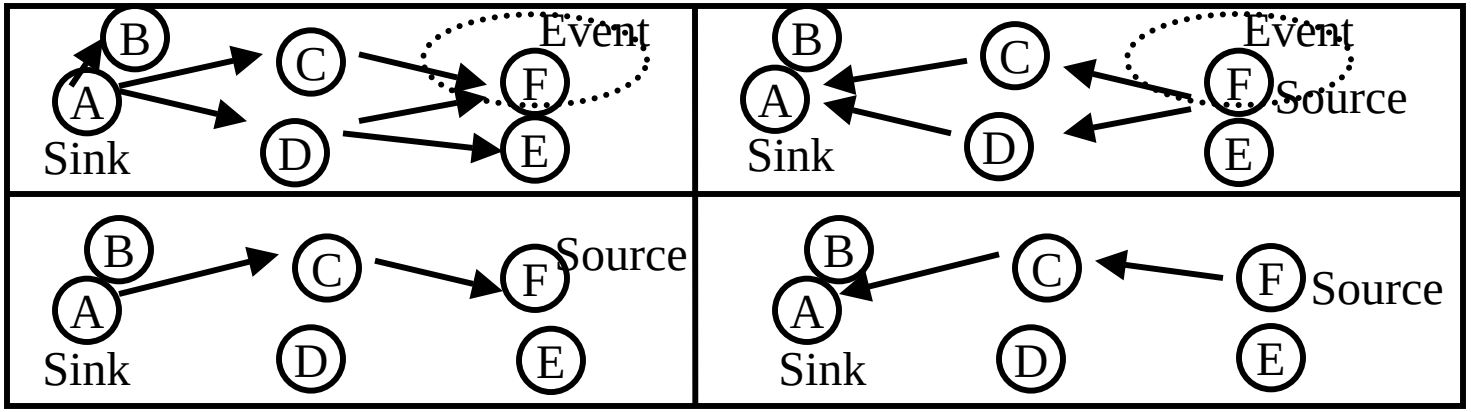
Data Dissemination

- *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



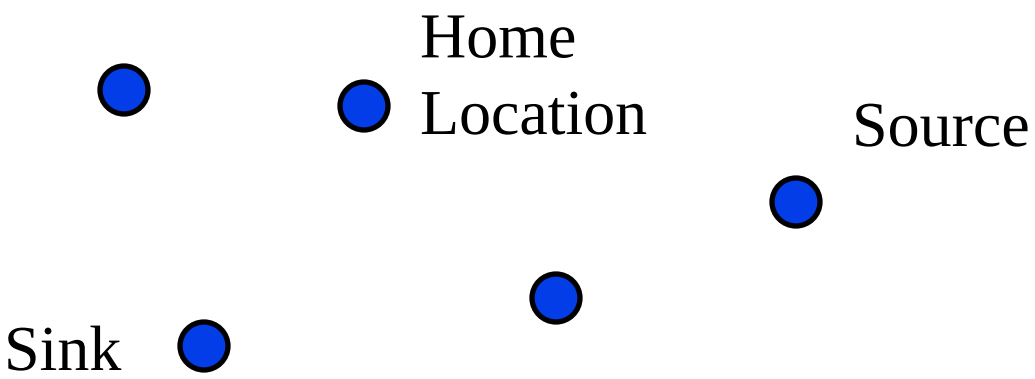
Directed Diffusion

- 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



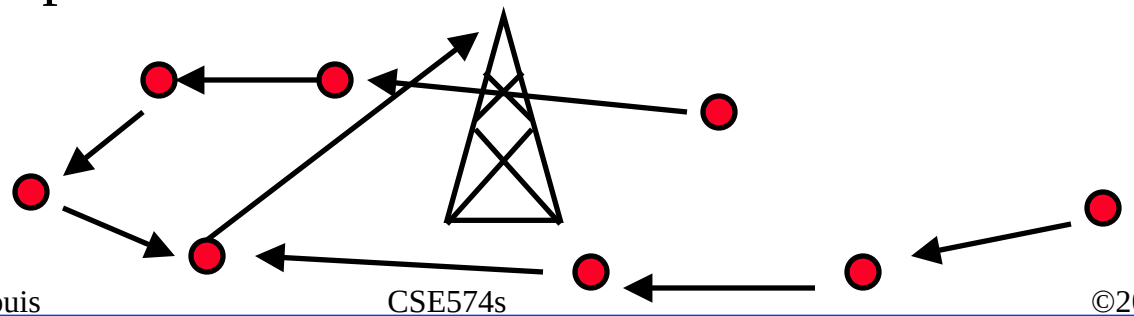
Geographic Hash table

- 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

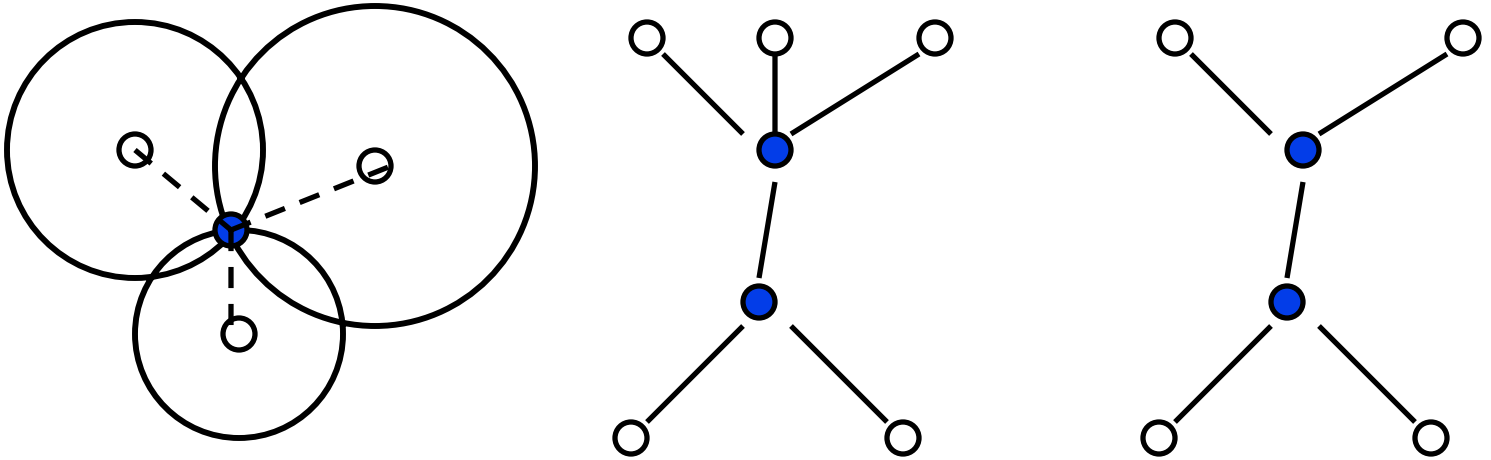
Three types:

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

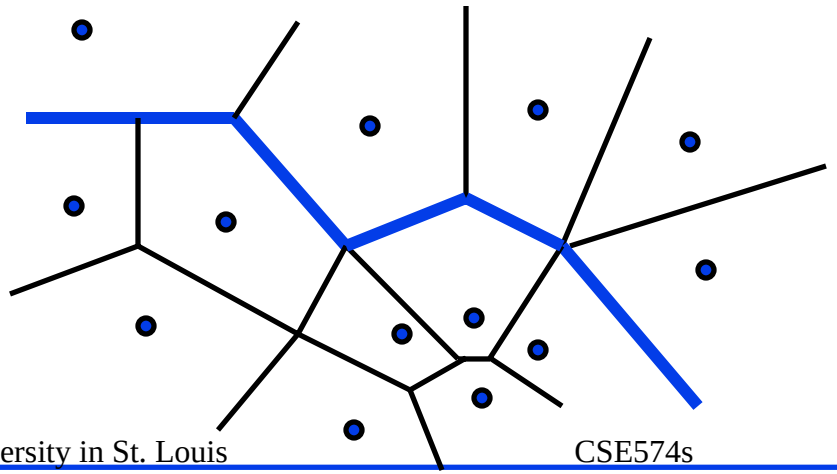


Global Positioning System (GPS)

- 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

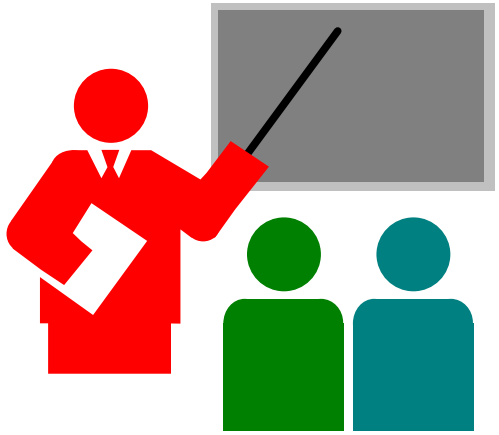
Localized Encryption and Authentication Protocol (LEAP)

- 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.