

Wireless Sensor Networks

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Audio/Video recordings of this lecture are available at:

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



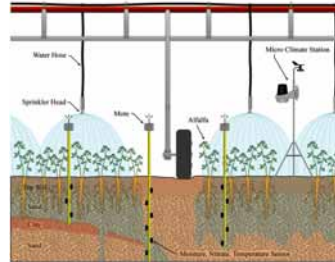
- Sensor Applications
- Sensor Network Architecture
- Data Dissemination
- MAC Protocols for Sensor Networks
- Location Discovery
- Quality of a Sensor Network
- Time Synchronization
- Transport Layer Issues
- Sensor Network Security
- Real-Time Communication

Sensor Applications

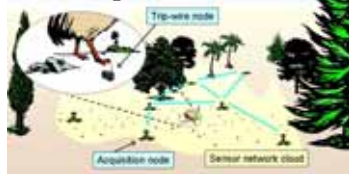
Battlefield Surveillance Chemical, Biological Weapons



Crops and Agriculture Forest Fires and Flood Detection



Habitat exploration of animals



Patient heart rate, blood pressure



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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?
- ⇒ Geographical routing, Data fusion, Data aggregation

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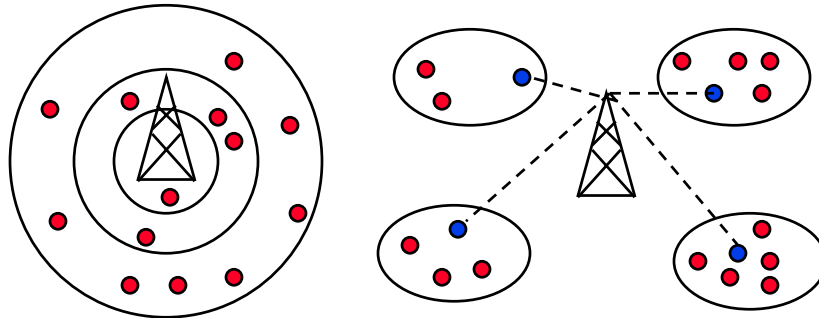
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Sensor Network Architecture

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



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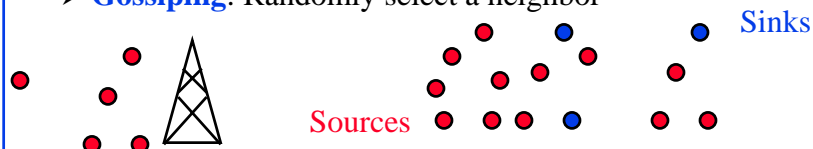
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Data Dissemination

- ❑ *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



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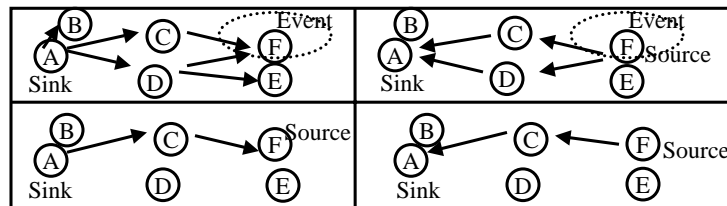
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Directed Diffusion

- ❑ 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



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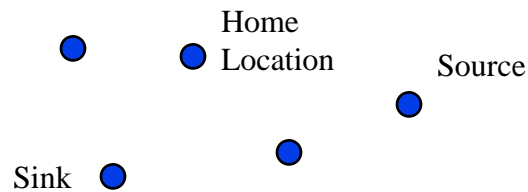
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Geographic Hash table

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



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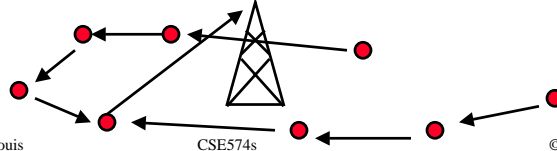
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Data Gathering

- ❑ Gathering \Rightarrow From all sensor nodes to the BS
- ❑ Minimize delay \times 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



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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 \gg Data rate
 - Neighbors synchronize and agree on times for transmission
 - Only neighbors synchronize \Rightarrow Synch energy saved
 - Sleep when not transmitting \Rightarrow Further energy savings
- ❑ TDMA, FDMA, TDMA/FDMA, CSMA are also possible
 - ❑ Bluetooth, 802.11, and ZigBee are MACs used in practice

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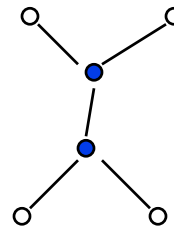
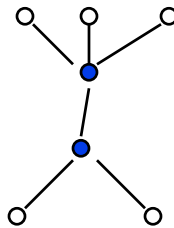
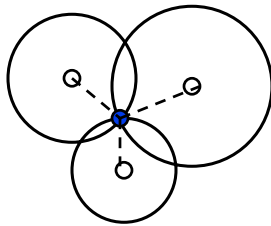
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Location Discovery

- ❑ 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



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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 \Rightarrow 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>

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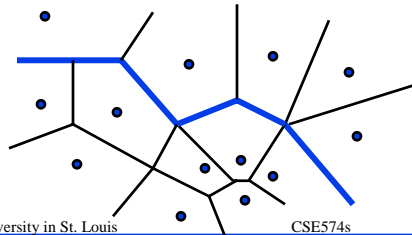
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Quality of a Sensor Network

- ❑ 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



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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

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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

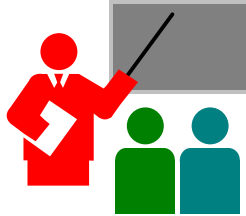
Localized Encryption and Authentication Protocol (LEAP)

- ❑ All nodes have an individual key shared with BS
- ❑ All nodes also have a group key
- ❑ Group key and Sensor ID \Rightarrow Master key of the sensor
- ❑ Hello to neighbor using group key and ID
 \Rightarrow Master key of neighbors
- ❑ Master keys of two neighbors \Rightarrow Shared key between neighbors
- ❑ Group is then erased \Rightarrow 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 \Rightarrow 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 \Rightarrow Void
- ❑ Void avoidance \Rightarrow Issue a back-pressure with infinite delay
 \Rightarrow 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 .