EE5726
Embedded Sensor Networks

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Today’s Agenda

- Last Time: Course Overview
- Today: Introduction to wireless sensor networks
  - Definition of WSNs
  - Characteristics of WSNs
  - Research challenges in WSNs
- Next Time: Node architecture and operating systems
  (Chapter 2 of Karl’s book; Chapters 3 & 4 of Dargie’s book)

Wireless Sensor Networks

- Wiki definition:

  A **Wireless Sensor Network (WSN)** consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location…The WSN is built of "nodes" – from a few to several hundreds or even thousands, where each node is connected to one or sometimes several sensors.

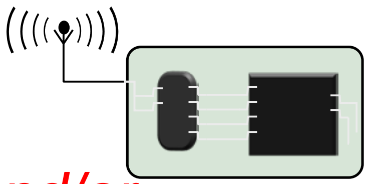
  - *Network nodes*
  - *Sensing tasks*
  - *Wireless data transfer*

WSNs Interact with Environments

- Nodes in computer networks were devices close to a human user, interacting with humans

- Alternative concept:

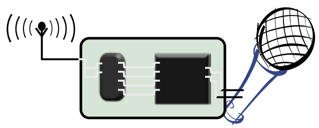
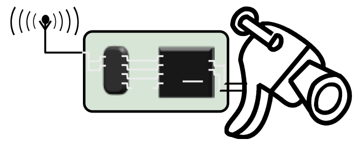
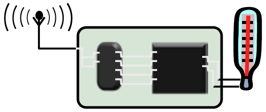
  Instead of focusing interaction with humans, focus on interacting with *environment*

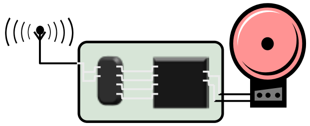
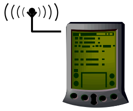
  - Network is *embedded* in environment
  - Nodes in the network are equipped with *sensing and/or actuation* to measure/influence environment
  - Nodes *process information* and communicate it *wirelessly*
- Wireless sensor networks (WSN)
  - *Or*: Wireless sensor & actuator networks (WSAN)

Network Entities

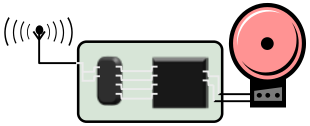
- Sources of data: Perform sensing tasks
  - *Typically equip with different kinds of actual sensors*

- Sinks of data: Interested in receiving data from WSNs
  - *May be part of the WSN or external entity, PDA, gateway, …*


- Actuators: Control some device based on data, usually also a sink
  - *e.g. motors opening or closing a door, or a pump that controls the amount of fuel injected into an engine*



WSN Application Types

- Interaction patterns between sources and sinks classify application types
  - Event detection: Nodes locally detect events (maybe jointly with nearby neighbors), report these events to interested sinks
    - Event classification: additional option in case of multiple events
  - Periodic measurement
    - e.g., Intelligent buildings and structure health monitoring
  - Function approximation: Use sensor network to approximate a function of space and/or time (e.g., temperature map)
    - Use a limited number of samples at each sensor node
    - How and when to update the mapping is application dependent
  - Tracking: Track the position (speed and/or direction) of an observed intruder (e.g., pink elephant in wildlife monitoring)
    - Nodes often have to cooperate for parameter estimation

WSN Characteristics

- Type of service of WSN
  - Not simply move bits from one place to another, rather *provide answers to queries*
  - e.g. *scoping* in time or space is a natural requirement, absent from other networks
  - Paradigm shift from the conventional computer networks
- Quality of service
  - QoS must be “good”: *right answers at the right time*
  - application dependent, e.g., reliable detection, approximation quality
- Energy supply
  - Limited from point of deployment
  - Some form of recharging via energy scavenging from environment
    - *e.g., solar cells, wind power*
- Lifetime
  - The network should operate in a given mission time, or as long as possible
  - Lifetime of individual nodes relatively unimportant
  - Tradeoff between lifetime and quality of service

WSN Characteristics

- Scalability
  - WSNs could have a large number of nodes
  - The network architectures and protocols should be scalable
- Heterogeneity
  - Heterogeneous nodes in terms of computation, communication and sensing, e.g., underwater networks with gateways
- Maintainability
  - e.g., replace batteries
  - unnecessary: e.g., mission lifetime might be very small
  - unattended operation: impossible for maintenance, e.g., application in battle fields
  - WSN has to adapt to changes, self-monitoring, adapt operation to choose different tradeoffs

WSN Design Guidelines

- Data-centric networking
  - *Identities of nodes in WSNs to fulfill tasks are not important, e.g., average temperature of an area*
  - *Switch from the ID-centric paradigm to data-centric paradigm*
- Energy-efficient operation (*key for longevity*)
  - *for communication and computation, sensing, actuating*
- Multi-hop wireless communications
  - *Signal attenuation and node energy constraint prevents long distance transmission*
- Operation locality
  - *Locality should be embraced extensively to ensure network scalability*

WSN Design Guidelines

- Collaboration & in-network processing
  - *Nodes in the network collaborate towards a joint goal*
  - *In-network processing can greatly reduce the amount of data to be transmitted, hence improving efficiency*
  - *e.g., to determine the average temperature of an area*
- Fault tolerance
  - *Robust against node failure (e.g., node energy depletion, or physical damage)*
  - *Redundant deployment*
- Programmability
  - *In-situ re-programming of nodes for task changes*
- Auto-configuration of operational parameters
  - *Manual configuration just not an option given a large number of nodes*
- Exploit tradeoffs between mutually contradictory goals, e.g.,
  - *Energy expenditure vs. information accuracy*
  - *Network lifetime vs. individual node lifetime*
  - *Node density vs. coverage*
  - *…*

Challenges in WSNs

- Network node design:
  - *sensor technology*
  - *wireless communication technology*
  - *power supply/management*
- Network node deployment
- Networking architecture and protocols
- Data query and storage
- Network node clock synchronization and localization
- Network node coordination: in-network processing, collaborative signal processing, etc.
- Fault tolerant and network security
- Mobile networks, e.g., vehicular ad hoc networks
- ...

- *John A. Stankovic, Tarek Abdelzaher, Chenyang Lu, Lui Sha, Jennifer Hou, Real-Time Communication and Coordination in Embedded Sensor Networks, Proceedings of the IEEE, 91(7): 1002-1022, July 2003*

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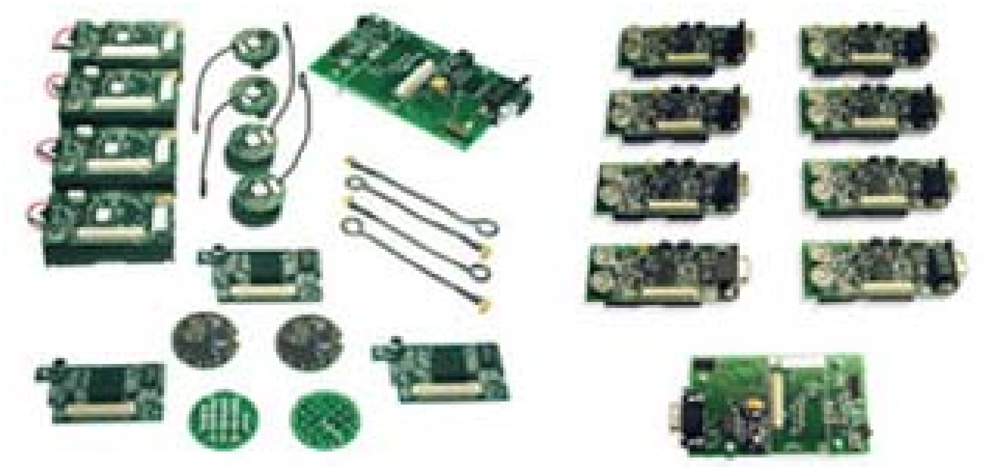
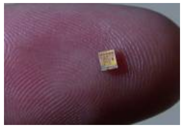
IC Technology

- Technology trend: use of IC technology for increased robustness, lower cost, smaller size




Mica motes (UC Berkeley & Intel)

- The Smart Dust project
  - http://robotics.eecs.berkeley.edu/~pister/SmartDust/
  - Autonomous sensing and communication in a cubic millimeter

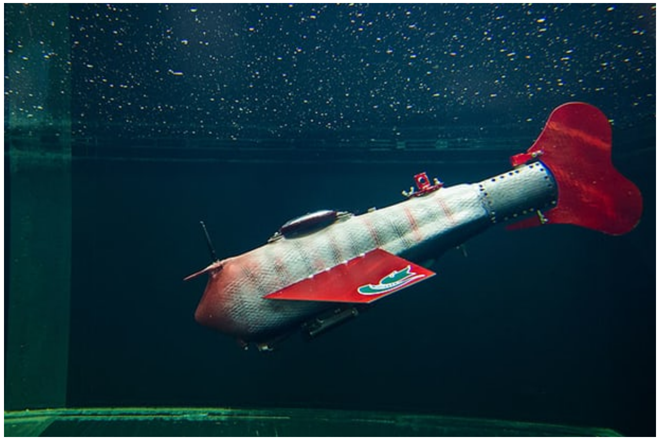


http://wsn.oversigma.com/wiki/index.php?title=WSN_Platforms

Underwater Sensor Nodes

Artificial Jellyfish (URI)

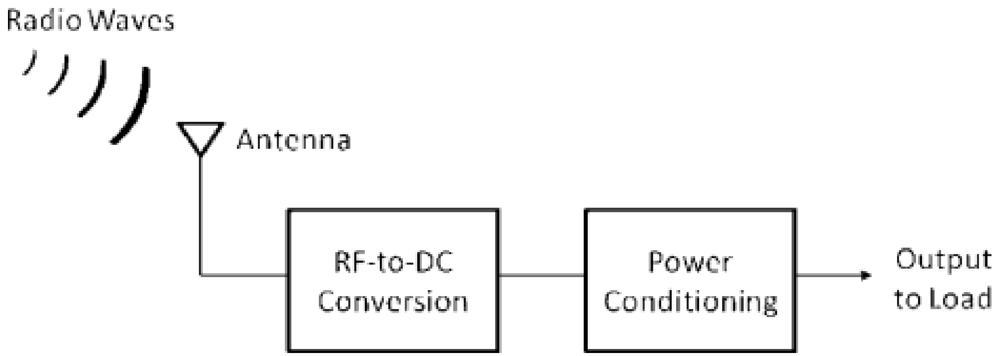
The Navy's New Robot Looks and Swims Just Like a Shark



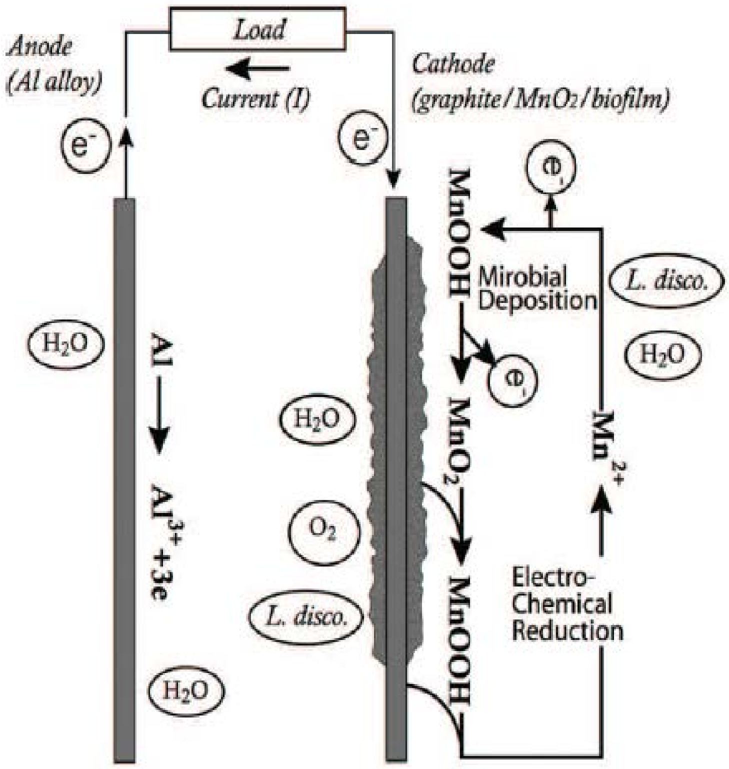
Robofish (MSU)

Energy Harvesting

- Solar power, wind, thermal energy, etc
- RF energy harvesting



- Biomass-based energy harvesting



IEEE Access Journal -- Energy Harvesting and Scavenging [CFP]

- Topics of interest include, but not limited to the following:
  - Battery Recharging Techniques
  - Harvesting Technologies (Solar Cells, Peizoelectric, Electrostatic, Bio Fuel Cell)
  - Analysis of Energy Sources (walking, body heat, heart beat etc) in Body Area Networks
  - Solar Energy based Battery Recharging
  - Bio Chemical Energy Harvesting Sources
  - Bio Mechanical Energy Harvesting Sources
  - Ambient Energy Harvesting Sources
  - Wind Energy based Battery Recharging
  - Head Energy based Battery Recharging
  - Wireless Power Transfer
  - Inductive Coupling Methods of Energy Harvesting
  - Magnetic Resonance based Methods of Energy Harvesting
  - Energy Harvesting in Wireless Body Area Networks
  - Energy Harvesting in Cellular Networks
  - Energy Harvesting in Cognitive Cellular Systems
  - Energy Harvesting in Wireless Sensor Networks
  - Standardization Activities for Energy Harvesting in Communication Networks
  - Spectrum Related Issues for Energy Harnessing
  - Security and Privacy Issues of Energy Harvesting
  - Algorithms and Protocols for Energy Harvesting

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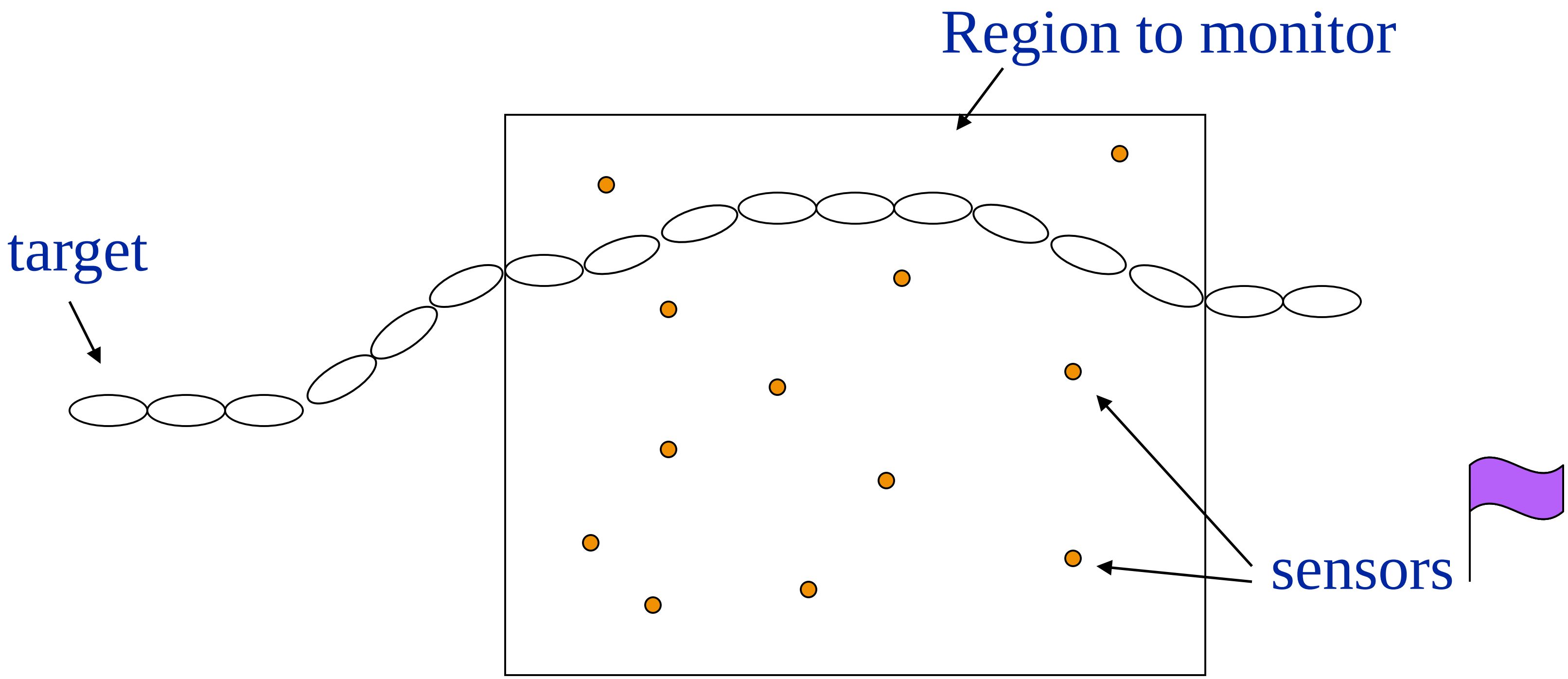
Deployment Options for WSN

- Random deployment:
  - e.g., dropped from an aircraft over a forest fire
  - Usually uniform random distribution for nodes over finite area is assumed
- Regular deployment: well planned, fixed
  - e.g., in machinery maintenance or structure health monitoring
  - Not necessarily has a geometric structure, but that is often a convenient assumption
- Mobile sensor nodes:
  - Can move to compensate for deployment shortcomings
  - Can actively seek out “interesting” areas
  - Can be passively moved around by some external force (wind, water)

Sensor Deployment and Area Coverage



How to deploy sensors for target detection and tracking?
How to evaluate detection/tracking performance of a given sensor deployment?

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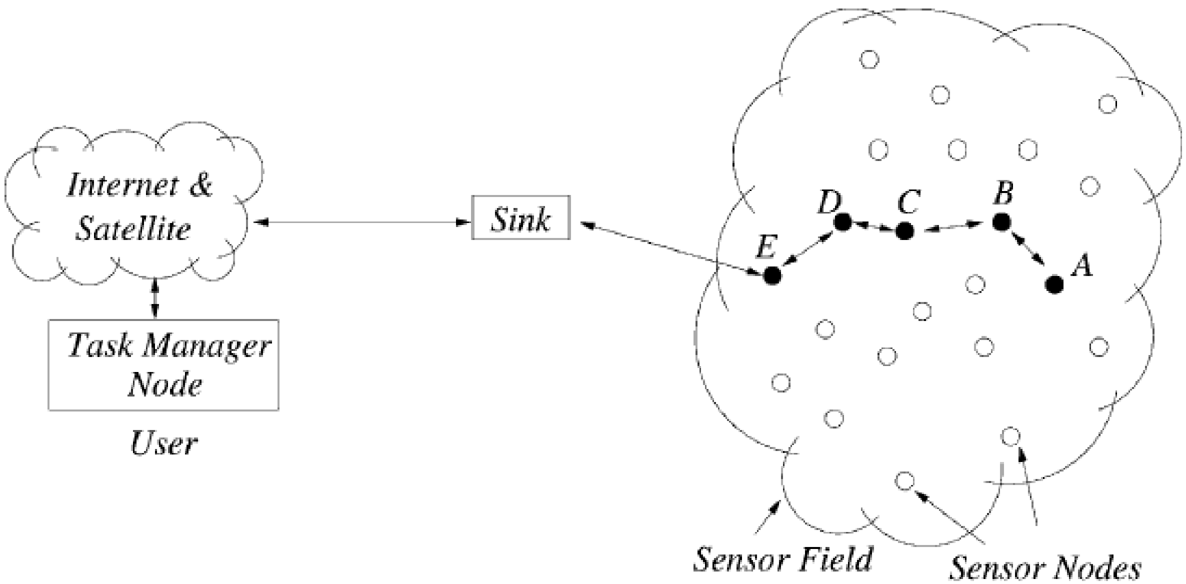
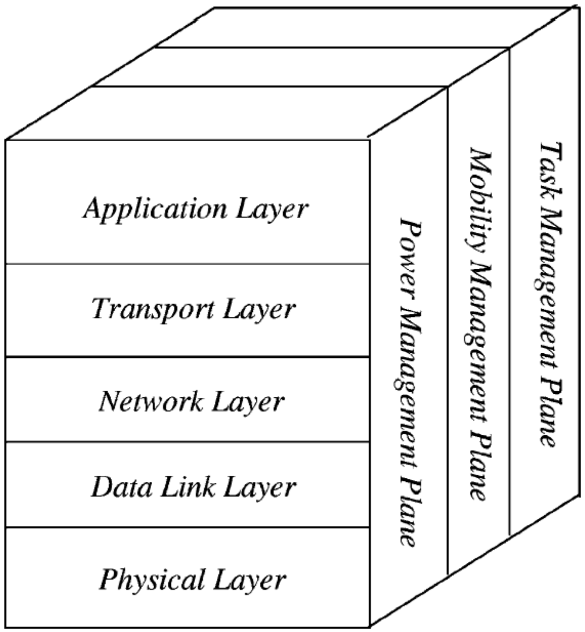
Networking Research Challenges

- Multihop *infrastructureless* architecture
- Resource constraints call for more tightly integrated layers
  - *cross-layer design*
- Network architecture
  - *Protocol stack and sensor network management modules*





Component-based Protocol Stack

- Component-based protocol stack
  - *The monolithic layers are broken up into small, self-contained "components"*
  - *Each component only fulfills one well-defined function*
  - *Components can be "wired" together*
  - *Components' interactions are not confined to immediate neighbors, but can be with any other component - Cross-layer optimization*
- A collection of components:
  - Physical-layer protocols
  - MAC protocols
  - Link-layer protocols
  - Routing protocols
  - Transport layer protocols
  - Time synchronization
  - Localization
  - Topology control

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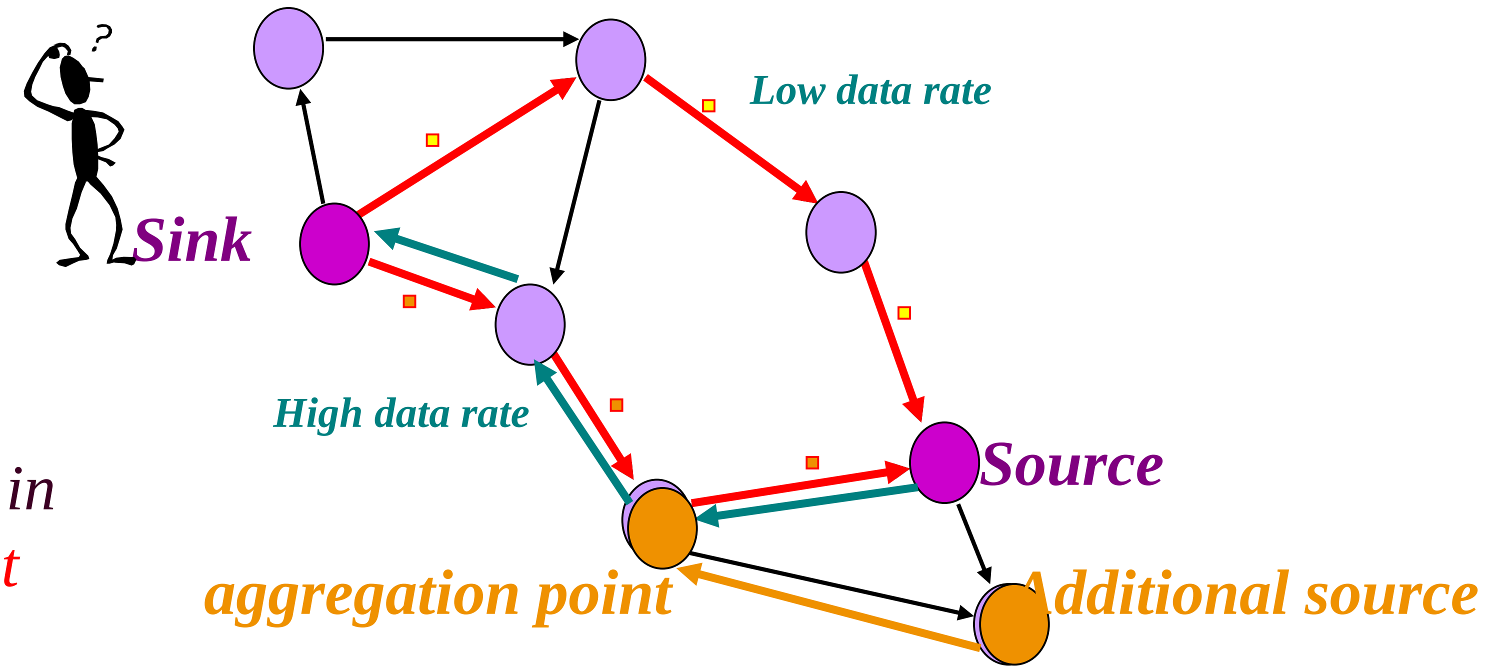
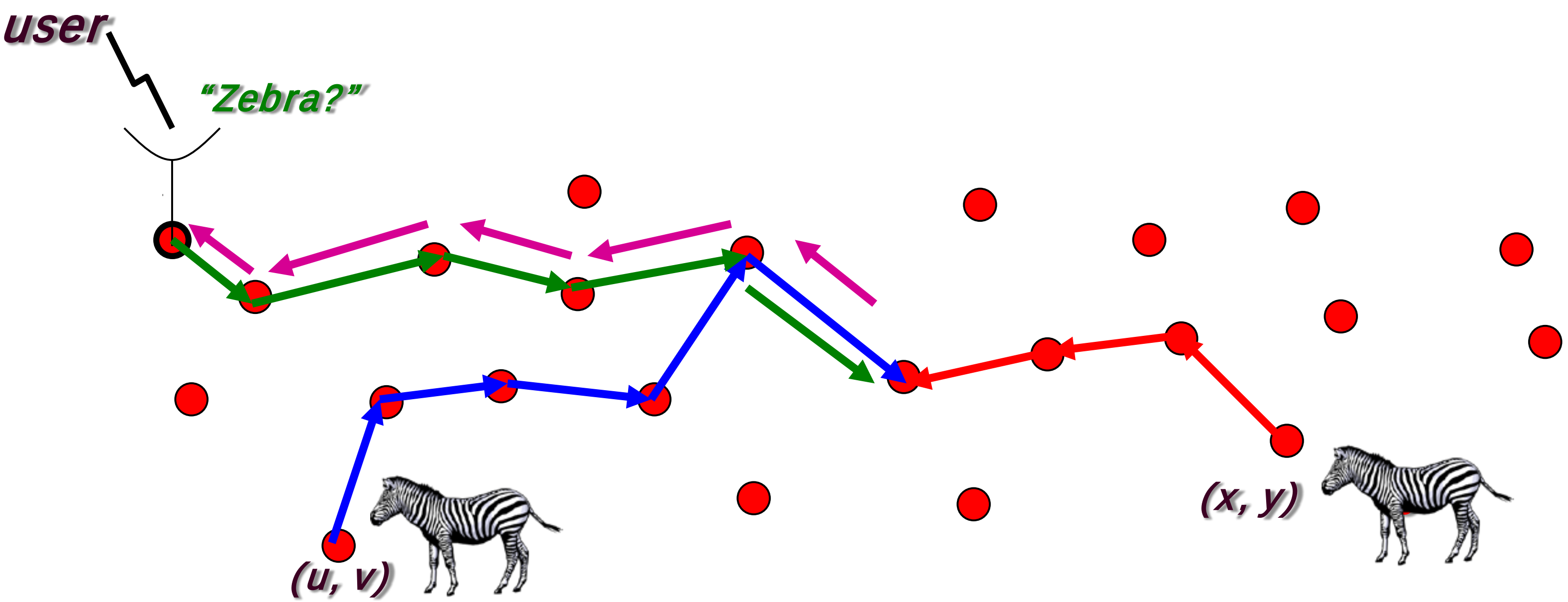
Data Query



"How many vehicles do you observe in the southeast quadrant?"

Data Storage



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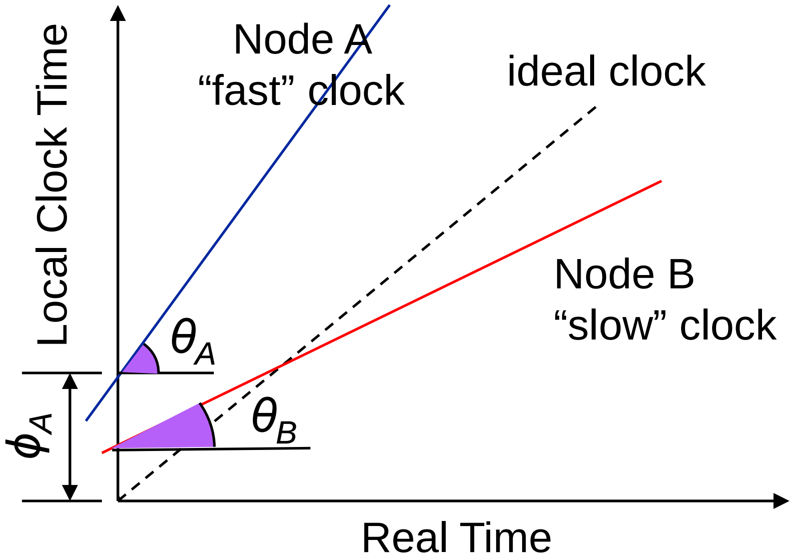
Clock Synchronization

- Common time scale among sensor nodes is important
  - *identify causal relationships between events in the physical world*
  - *support the elimination of redundant data*
  - *facilitate sensor network operation and protocols*
    - *Protocols: TDMA, S-MAC with coordinated wakeup, ...*
    - *Distributed debugging: timestamping of distributed events is needed to figure out their correct order of appearance*

Actual oscillators have deviations from nominal oscillation frequency

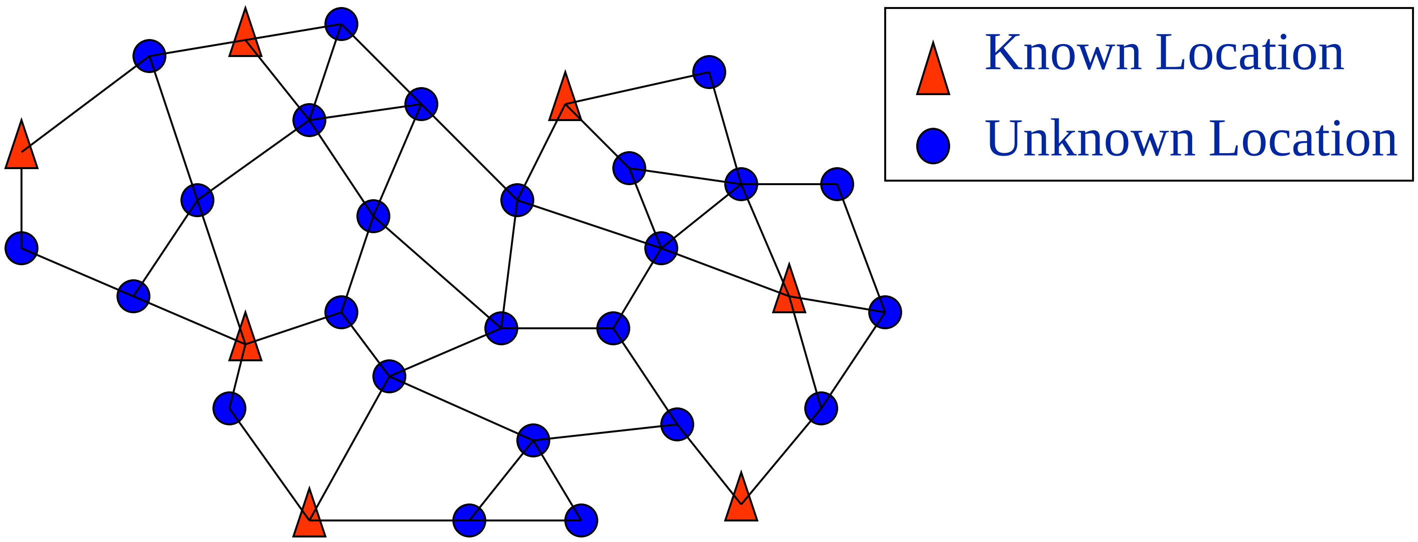


Sensor Node Localization

- Node locations are essential for networking and collaborative processing
  - *localization of targets and events*
  - *geographical forwarding and addressing*
- GPS provides solution when available
  - *GPS not always available, e.g., too "costly," too bulky*
    - *e.g., Indoor and underwater environments*
  - *need to develop localization techniques*

Sensor Node Localization

- Given a network of sensor nodes where a few nodes know their location, how do we calculate the location of other nodes?



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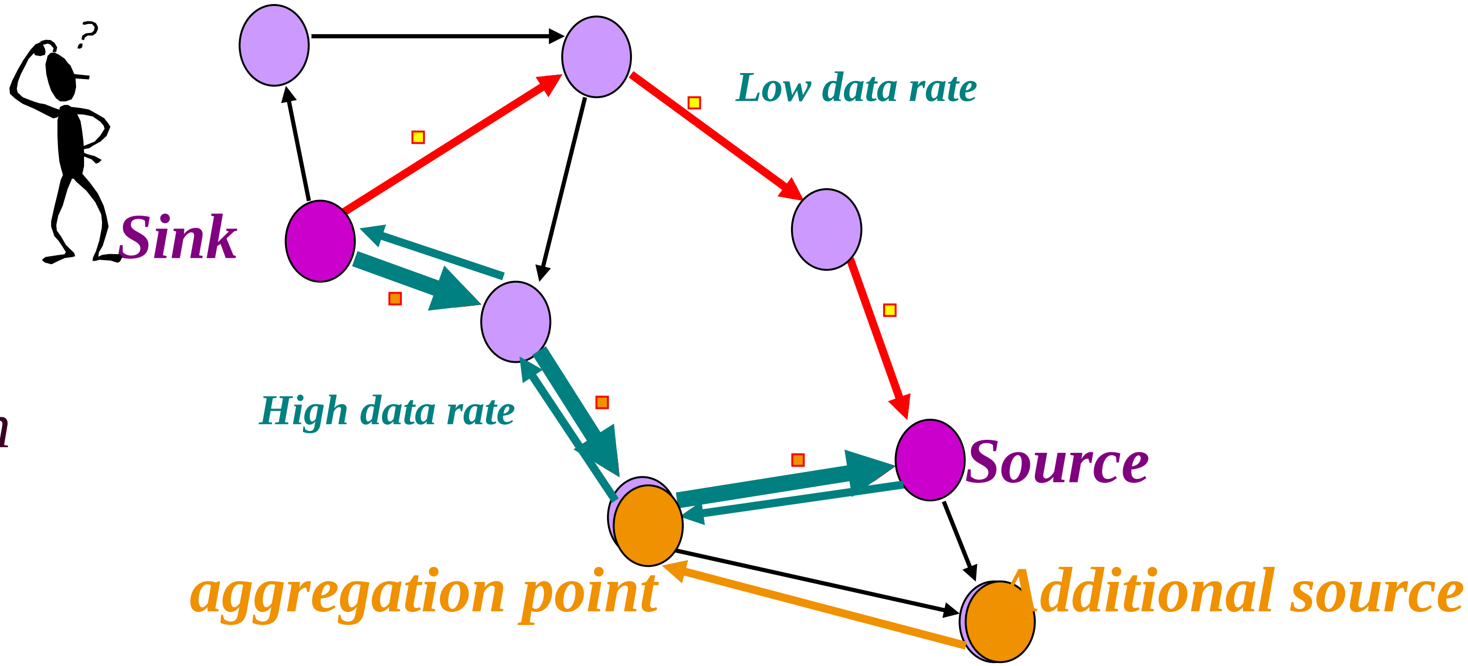
In-Network Processing

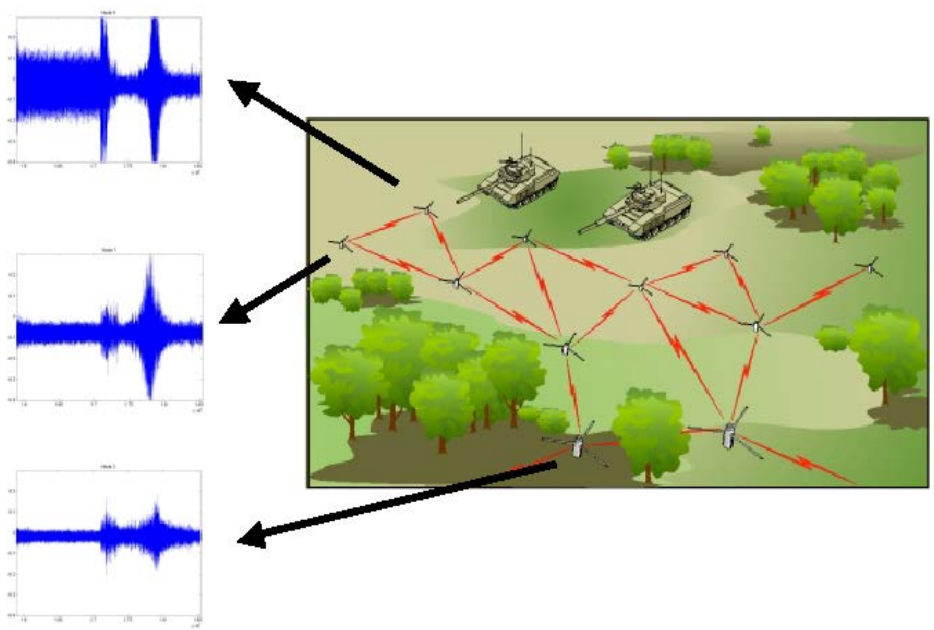
- Communication is expensive
  - *Power, bandwidth*
- Perform (data) processing in network
  - *close to (at) data*
  - *forward fused/synthesized results*



"How many vehicles do you observe in the southeast quadrant?"

Collaborative Signal Processing

- Collaborative Signal Processing
  - A single node covers a limited field, therefore *more than one sensor nodes need to cooperate* to process space-time signals together *to obtain a global view*
  - Distributive processing: raw signals are processed locally while only transmitting requested higher level information



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Security Issues

Sensor network layers and DoS defenses.

Network layer	Attacks	Defenses
Physical	Jamming	Spread-spectrum, priority messages, lower duty cycle, region mapping, mode change
	Tampering	Tamper-proofing, hiding
Link	Collision	Error-correcting code
	Exhaustion	Rate limitation
	Unfairness	Small frames
Network and routing	Neglect and greed	Redundancy, probing
	Homing	Encryption
	Misdirection	Egress filtering, authorization, monitoring
	Black holes	Authorization, monitoring, redundancy
Transport	Flooding	Client puzzles
	Desynchronization	Authentication

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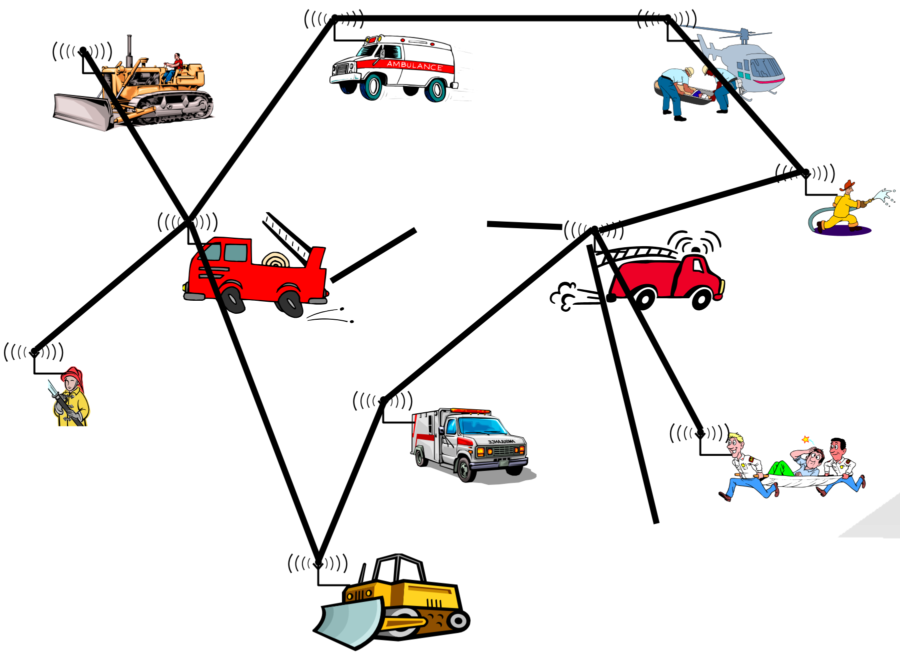
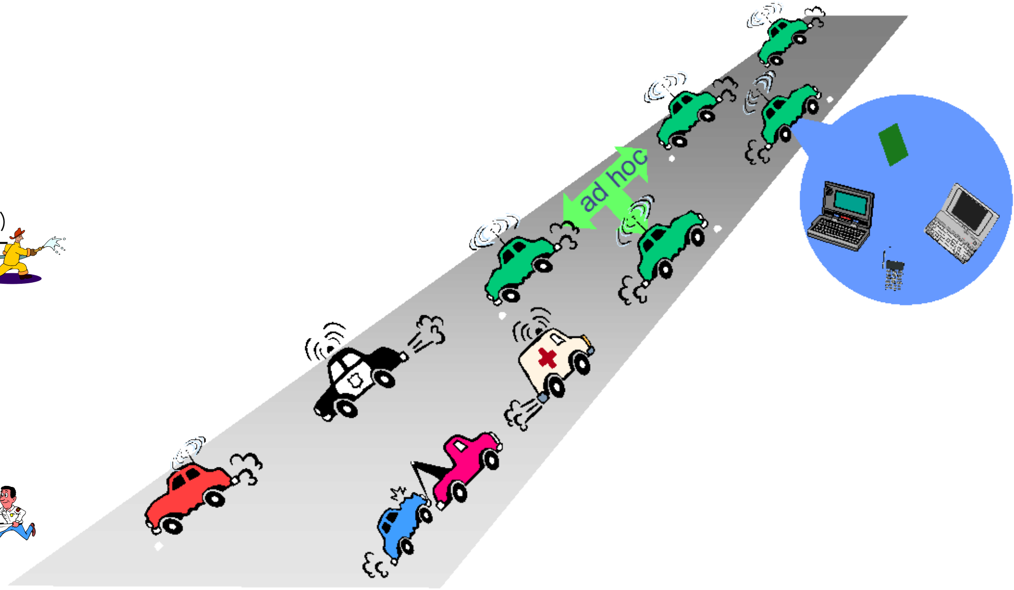
Example of Mobile Sensor Networks

- Disaster recovery
  - *Mobile sensor networks in Houghton in snow seasons?*
- Car-to-car communication





How to accommodate the dynamic network topology in networking protocols?

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Road Map

- Introduction to wireless sensor networks
- Single node hardware and software architecture (next week)
- WSN architecture
- Techniques to address the design challenges:
    - *Point-to-point wireless communication techniques*
    - *Medium access protocols*
    - *Link-layer protocols*
    - *Routing protocols*
    - *Data-centric query and storage*
    - *Clock synchronization and localization*
    - *Advanced research topics*

Summary

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  - Research challenges in WSNs
  - Any questions?
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