Sensor Networks

Part 1: Overview

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Mark Coates

Mike Rabbat

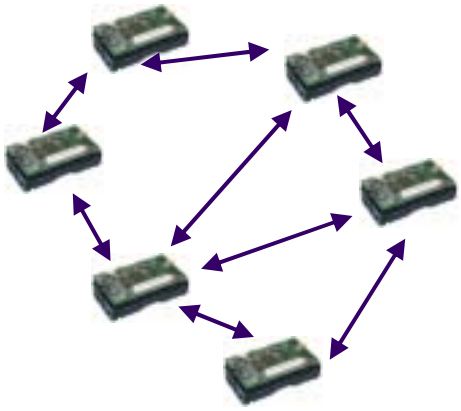
Wireless Sensor Networks

- Integration of sensing, signal processing and RF capability on very small devices
  - MEMS components such as sensors and actuators
  - Microprocessors for signal processing, network management and application software
  - Power supply and RF transceiver

Crossbow MICAz mote

Wireless Sensor Networks

- Multiple motes coordinated to perform a task
  - (monitoring, tracking, data gathering)
- Low-power operation is critical
- Each device has limited capabilities – small range, memory restrictions, imperfect sensors
- Use distributed signal processing to coordinate all devices to perform desired task



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Applications

- Medical monitoring (e.g., heart rate, glucose level) and localized drug delivery
- Monitoring structural integrity in buildings
- Tracking vehicles, people, chemical agents, pollution, weather phenomena
- Seismic monitoring, contaminant/pollution monitoring
- Precision agriculture

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Sensor Network Advantages

- Improved Signal-to-Noise Ration (SNR)
  - combine sources with different spatial perspectives.
- Greater fault tolerance through redundancy
- Coverage of large area
- Multiple sensor types can improve performance
- Sensors close to object/phenomena of interest can overcome environmental noise effects
- Can be deployed in regions where infrastructure for replenishing energy is not available

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What makes a wireless sensor network unique?

- Cellular networks, ad-hoc networks are designed to
  - Optimize QoS & Provide high bandwidth
  - Provide good throughput/delay characteristics under medium/high mobility conditions
  - Energy consumption of secondary importance
- Sensor networks
  - Many nodes, autonomous operation
  - Generally stationary devices (or low mobility)
  - Traffic periodic or intermittent, low data rate, frequently uni-directional
  - Energy management is critical
- Sensing application cannot be ignored !

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Sensor Network Uniqueness

- Data-centric networks
  - Identity/address of a sensor node is not critical – its data is the important aspect
- Application specific
  - Intermediate nodes can perform data-aggregation or in-network processing
  - Network operation driven by global objectives; not by individual data transfers.
- Resource constraints call for more tightly integrated layers

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Sensor Network Operational Challenges

- Adaptive, self-configuring systems that respond to an unpredictable environment
- Data processing inside the network
  - Perform computation where data is measured to extract information (compress)
  - Important to reduce communication overhead
  - Distributed control and signal processing
- Untethered, unattended large-scale systems
  - Low-duty cycle design
  - Preserve energy by minimizing communication

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Architectural decisions

- Small size, rugged design, energy-efficient operation and low cost
- Limited transmission range -> multi-hop network
- Communication is energy-expensive
  - 3 J energy to transmit 1Kb over 100m – equivalent to 300 million instructions for a 100 Mops processor
  - Rough energy rule: 1 bit = 1000 instructions
  - Local processing of information to limit amount of data that must be exchanged

Strategies

- Cooperative signal processing
  - Collaboration enhances energy efficiency
  - Substantial redundancy in data from closely-spaced sensors
- Exploit redundancy of hardware elements
  - Deploy higher density of nodes than necessary
  - Adjust duty cycle so neighbouring nodes are not always active
- Adaptive signal processing
  - Maintain balance between energy, accuracy and rapidity of results
- Hierarchical architecture
  - Higher energy, more powerful devices act as cluster heads
  - Cluster heads control operation of a set of more limited devices

Algorithm and Protocol design

- Optimal solution frequently has associated communication cost that outweighs benefit it provides
- Localized (suboptimal) algorithms are desirable
  - Local communication to achieve global objective
  - Clustering/hierarchical approaches to simplify the task
- End-to-end, Internet style protocols are inappropriate
  - Queries on Internet involve search engine, substantial indirection between name and address
  - Too much communication and search overhead
  - General purpose functionality is not necessary for these specialized applications.

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Network Architecture - Elements

- External database, queries
- Application and query processing; distributed signal processing
- Data dissemination and caching, routing.
- Connectivity management
- MAC, Synchronization, Localization
- Physical Layer: RF, sensing, actuation.

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Hardware - power, Microprocessors, storage

- Device hardware
  - Microprocessor, memory, ADC, sensors, transceiver, controllers, energy source.
- Simple, miniaturized microcontrollers
  - 10 Kbytes RAM, 100 Kbytes ROM
  - operate near 1mW at 10 MHz
  - Standby mode: 1 microWatt
  - Duty cycle approx. 1-2 percent -> few microWatts
- Power
  - Solar cells – 10 to 100 microWatts per square cm
  - Vibration – 100 microWatts
- Battery
  - 1 cubic-cm = 1000 mAmp-hours

(Micro-) sensors

- Passive or active (much higher energy)
- Single unit or array-based
- Examples:
  - Passive units – temperature, light, seismic, acoustic, infrared, strain etc.
  - Passive arrays – imaging (visible, infrared), chemical
  - Active (element or array): radar, sonar