System Architecture Directions for Networked Sensors

By Jason Hill, et al. (Berkeley, 2000)

Presented by Matt Miller
November 6, 2003

Motivation

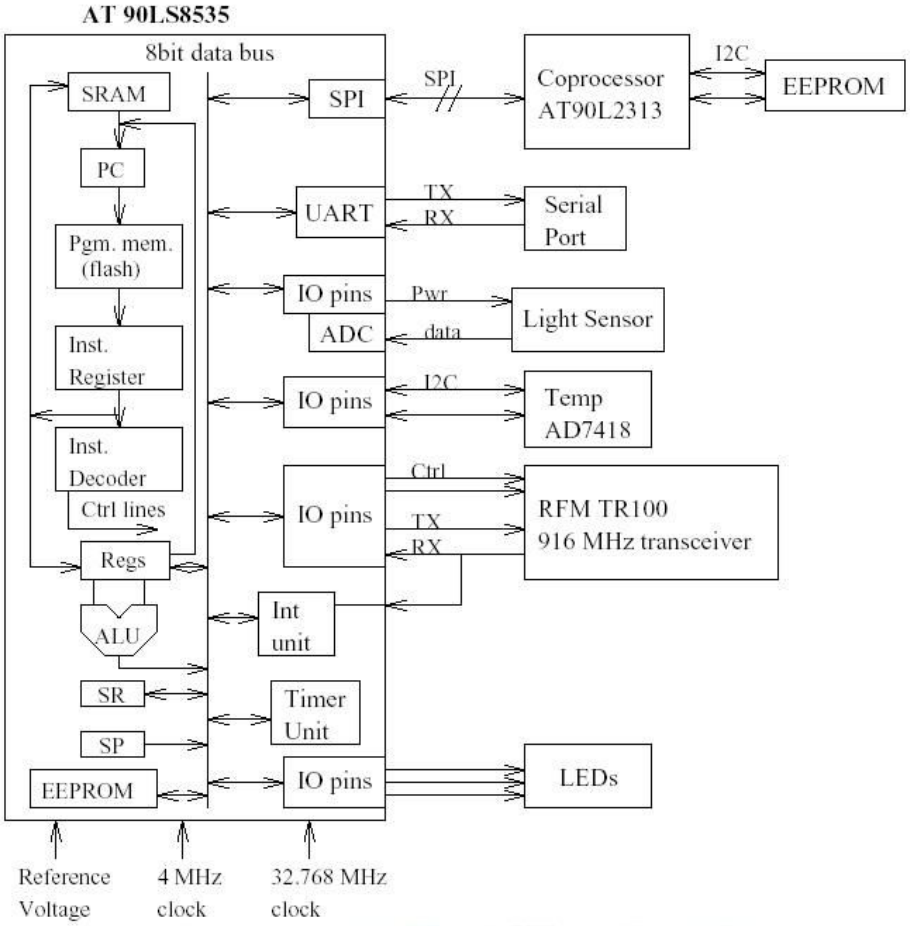
- General purpose operating systems are not appropriate for sensor networks
- Sensor networks require a task specific OS
  - Concurrency intensive
    - Multiple flows move through sensor in parallel
  - Modular design
    - Components connect easily to facilitate application specific additions/modifications

Sensor Characteristics

- Memory and Power Limited
  - Should enter low-power states aggressively and avoid maintaining too much process state
- Concurrency
  - Little idle time once processing begins
  - Multiple flows
- Design Diversity
  - Need framework to allow specialized apps to be developed quickly and facilitate code reuse
- Robust

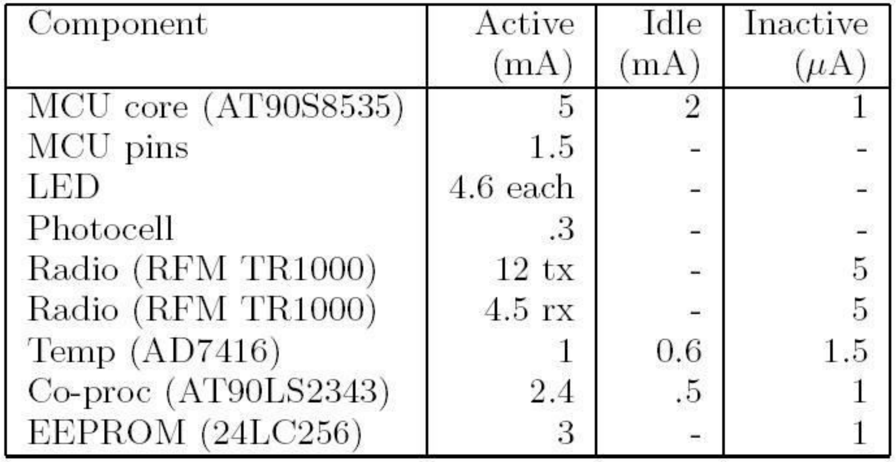
Hardware

- CPU: 4MHz
- Memory: 8KB flash (data), 512 B SRAM (program)
- Network: 19.2 Kbps
- Input: temperature and light sensors
- Output: 3 LEDs
- Serial Interface



Power Characteristics

- Biggest energy drain is radio
- About 3 orders of magnitude between idle and inactive!
- No transition costs documented

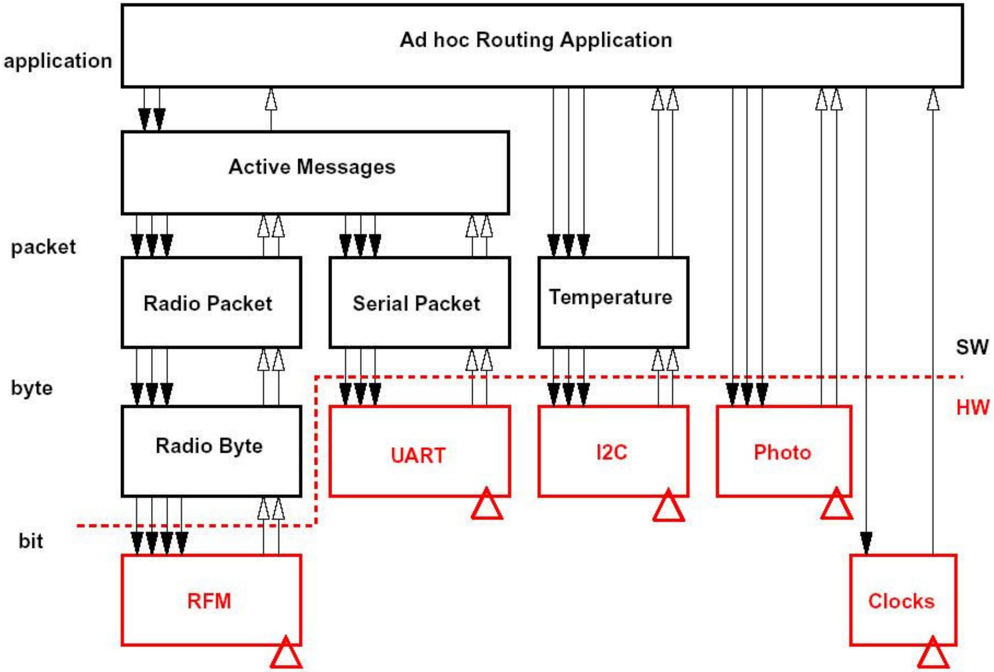


Component	Active (mA)	Idle (mA)	Inactive (μA)
MCU core (AT90S8535)	5	2	1
MCU pins	1.5	-	-
LED	4.6 each	-	-
Photocell	.3	-	-
Radio (RFM TR1000)	12 tx	-	5
Radio (RFM TR1000)	4.5 rx	-	5
Temp (AD7416)	1	0.6	1.5
Co-proc (AT90LS2343)	2.4	.5	1
EEPROM (24LC256)	3	-	1

Active == Peak Load

TinyOS Structure

- Two-level scheduler and directed graph of components
- Component parts
  - Command handlers
    - Respond to higher components
  - Event handlers
    - Respond to lower components
  - Fixed-size frame
    - Size of component is known at compile time
  - Set of tasks
    - Functions to do arbitrary computation



TinyOS Concurrency

- Commands and tasks are non-blocking
- Tasks have run-to-completion semantics
  - Allows single stack instead of one per execution context
- Tasks are atomic (w.r.t. other tasks), but can be pre-empted by events
  - Simulates concurrency within components
- Simple FIFO task scheduler that sleeps when empty

TinyOS Modularity

- Commands and events give API which allows components to be reused
- The HW/SW boundary can easily be shifted since components are state machines with specified I/O connections
- Crossing component boundaries is quick

Discussion

- Is the concurrency model general enough for sensor applications? Are there applications whose performance would be significantly degraded without blocking?
- Are there scalability issues in the “graph of components” model?
- Will the benefits of TinyOS offset the costs of learning a new programming paradigm for users familiar with C semantics?

Next Century Challenges: Mobile Networking for "Smart Dust"

By J.M. Kahn, et al. (Berkeley, 1999)

Presented by Matt Miller
November 6, 2003

Motivation

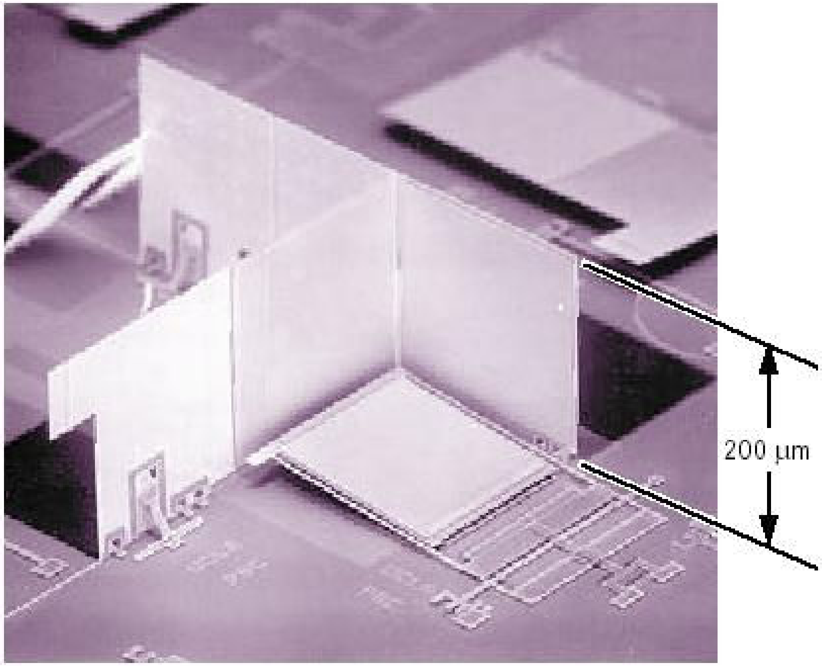
- How small and power efficient can a sensor be?
  - Goal: a few cubic millimeters with about 1 Joule of stored energy
- Focus of paper is ultra-low power communication

Communication Hardware

- Radio Frequency (RF)
  - Power hog because of complex circuits
  - Requires significant antenna space
- Free-Space Optics
  - Laser beams are transmitted
  - Simple, low power circuitry
  - Base station (BS) can decode multiple transmissions simultaneously (provided adequate physical distance between transmitters)

Passive Transmission

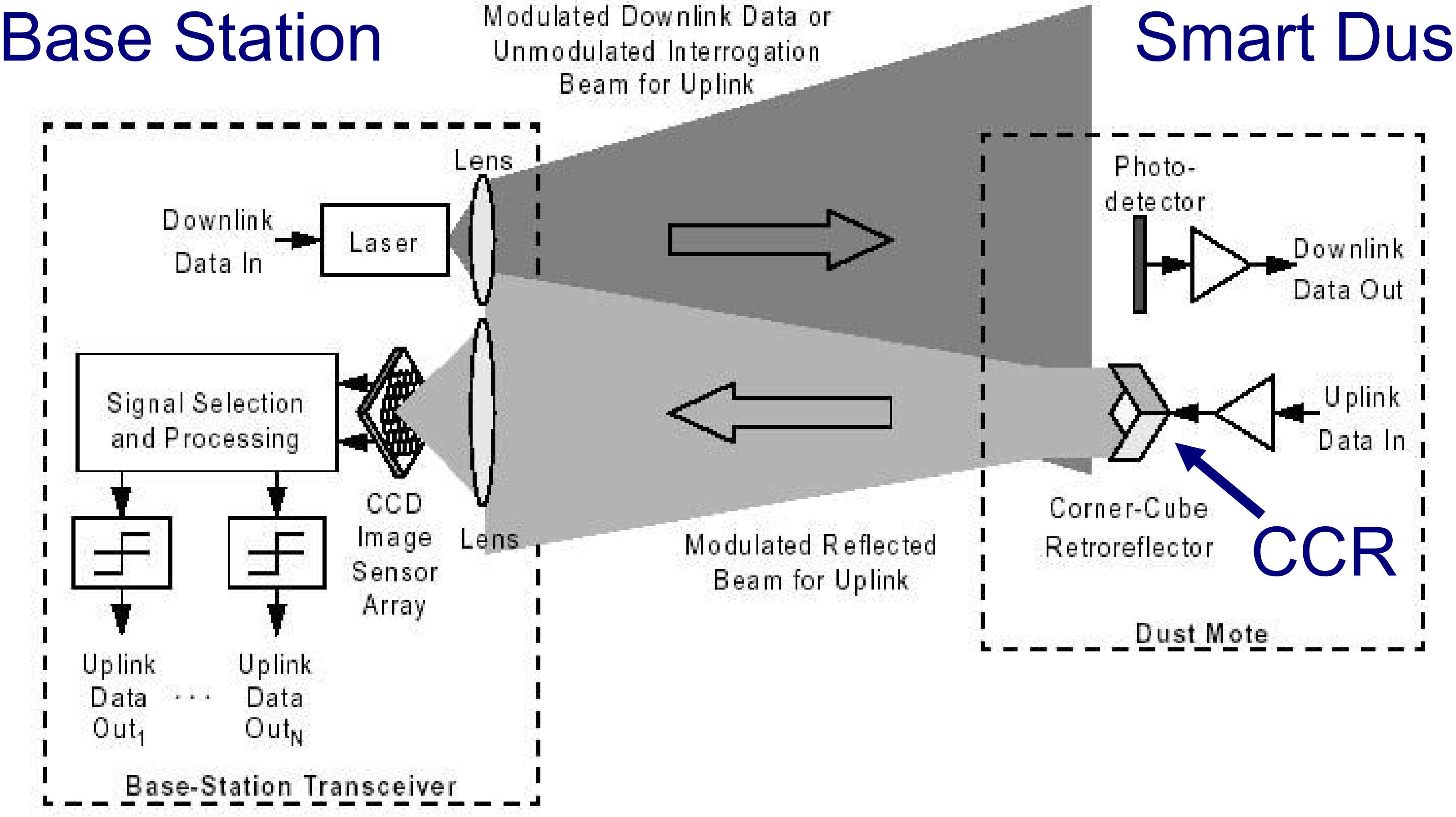
- A corner-cube retroflector (CCR) can reflect a transmission being received from an external light source
- The reflected light can be modulated into a signal => ultra low power transmission
- Capable of 1 Kbps bit rate and 150 m range



Proposed Network

High Power
Base Station

Low Power
Smart Dust



CCR

Challenge: Line-of-Sight Requirement

- Communication is not possible with obstacles
- Proposed solution: multihop routing
  - BS can probe motes, if probe is not received, the mote can switch to multihop routing
  - Increases packet latency and requires active transmissions from motes further than one-hop from BS
  - No protocols proposed

Challenge: Directional Links

- Transmitter must be pointed in direction of receiver
  - Only about a 10% chance of being able to passively transmit back to BS
- Proposed solutions
  - Add more CCRs
  - Use MEMS-based steering for single CCR
- Asymmetric links
  - ACKs should be used

Challenge:
Energy, Rate, Distance Tradeoffs

- Energy/bit minimized at receiver if packets sent in short bursts at high rate
- Bit rate at sender can be exponentially increased as distance decreases
  - Transmit at a higher bit rate over shorter, multiple hops
- Does not consider fixed energy cost per transmission

Discussion

- Broadcasts are widely used in wireless networks and inherently difficult with directional links
- Line-of-sight and minimum spacing between receivers seem to directly contradict idea of motes freely floating through space
- Effects of MEMS-steering on energy and latency
- Free-space optic performance degrades in foggy or very sunny weather
- How secure is the equipment compared to RF?
  - Signal interception can be easily detected, but could also lead to easier denial-of-service.

Next Century Challenges: Scalable Coordination in Sensor Networks

By Deborah Estrin, et al. (USC, 1999)

Presented by Matt Miller
November 6, 2003

Motivation

- Proposes protocol design paradigm given the characteristics of sensor networks
  - Large networks
    - Broadcasting to all nodes is not feasible
  - Frequent failure
    - Network should be designed to function with many individual failures
  - Dynamic
    - Topology, connectivity, and sensing task may change frequently
- Localized algorithms achieve a desired global objective while individual communication is restricted to a small, local neighborhood

Potential Applications

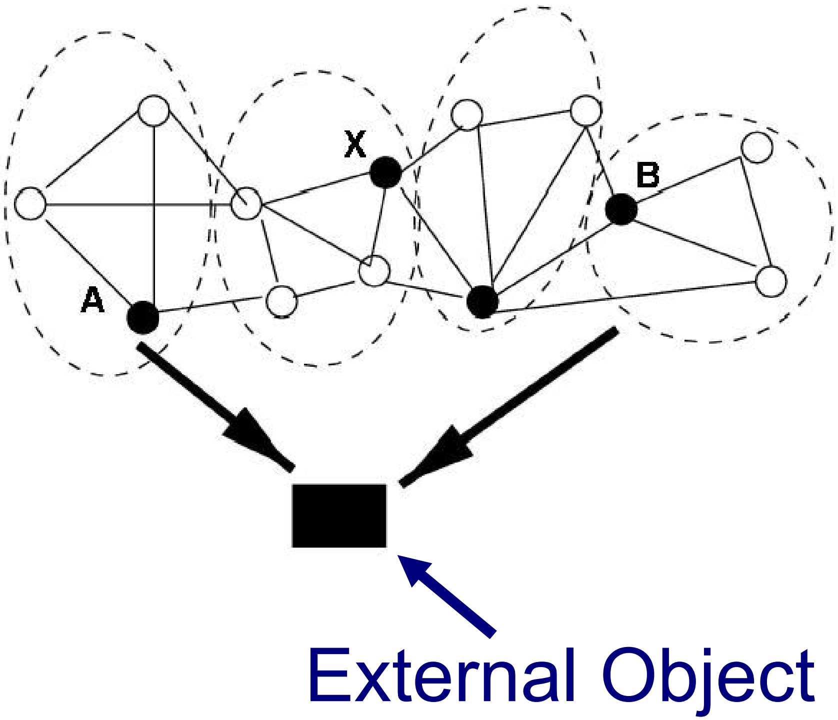
- Sensors attached to inventory proactively update data as opposed to manual bar code scanning
- Mapping disaster areas for emergency response teams and evacuation
- Information is diffused through vehicle traffic to learn of traffic jams, driving conditions, etc.

Differences from Traditional Networks

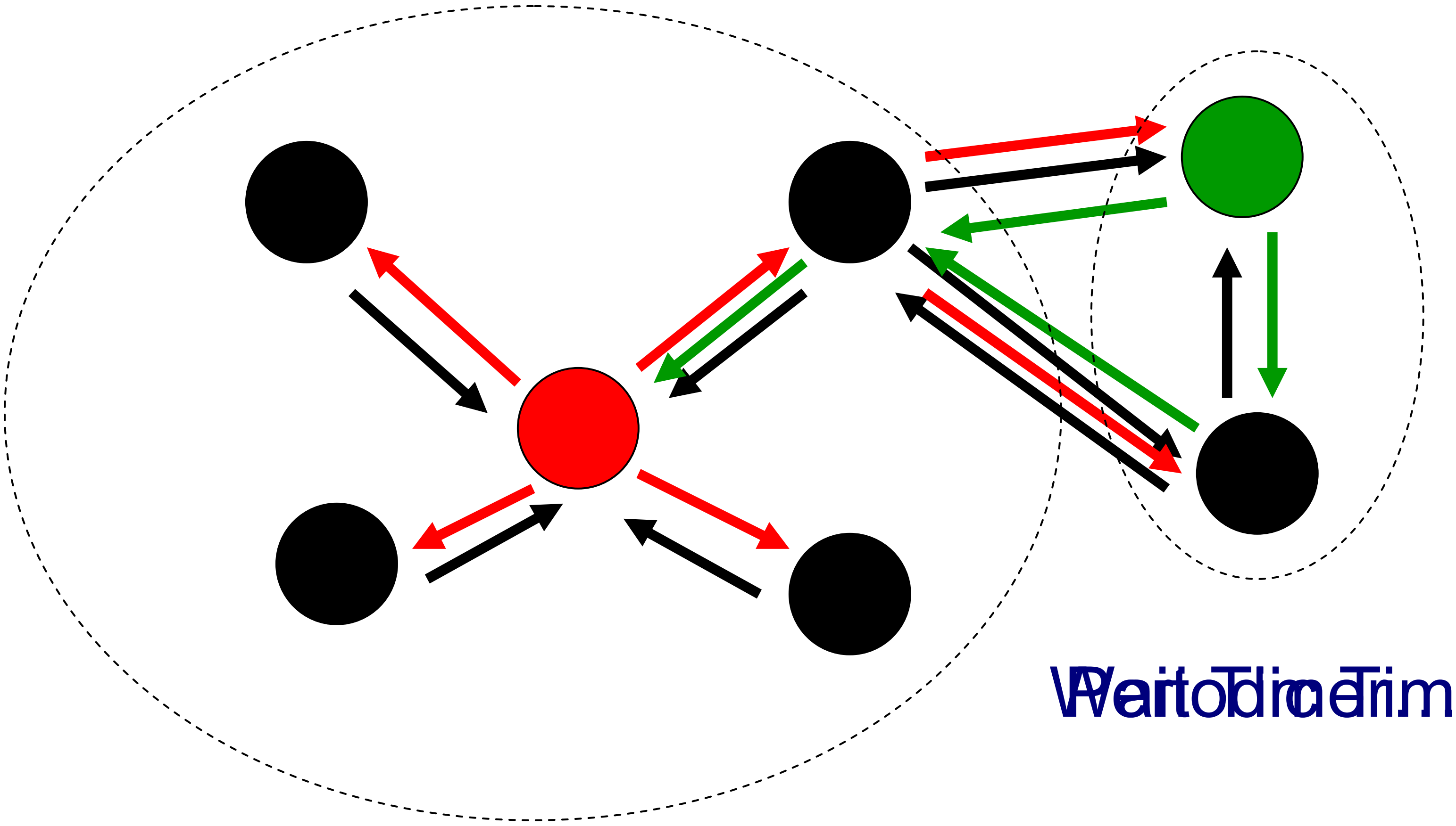
- Sensors coordinate to achieve global objective, such as determining the velocity of an object
- Nodes will be largely unattended and should work exception-free
- Topology will generally have some degree of randomness
- Moving data, not communicating with individual nodes
- Not general purpose

Example Localized Algorithm

- Goal is to locate external object
- Accuracy is achieved by choosing widest possible baseline among sensing nodes
- For energy efficiency and aggregation, clustering is used
- Only cluster-heads do location
- Cluster-head elects self to do location if all neighboring cluster-heads lie on same side of straight line from cluster-head to object



Two-Level Hierarchy Election Example



Wait Timer…

Periodic Timer…

Discussion

- Are localized algorithms anything new?
- How does the traditional network stack need to be modified for sensors (or does it)?
- How should energy be optimized in sensor networks? (e.g., first node death, first partition, uniform, etc.)
- What is the relationship in the tradeoff between latency and energy?
- How should time synchronization be dealt with in sensor networks?

Research Challenges in Environmental Observation and Forecasting Systems

By David C. Steere, et al.
(Oregon Grad. Inst., 2000)

Presented by Matt Miller
November 6, 2003

Motivation

- Provides a case study for an Environmental Observation and Forecasting System (EOFS)
- Identifies areas of future work for such systems
- The sensors transmit measurements from river estuary to central location
  - Computations are used for control of vessels, search and rescue, and ecosystem research

EOFS Hardware

- 133 MHz CPU with 32 MB RAM
- Power from electric grid (near shore stations) and solar cells
- Radio is 115 Kbaud
- MAC and routing manually configured

EOFS Characteristics

- Computation and aggregation done at centralized sink
- Amount of data generated is greater than the network capacity
- QoS is needed to limit latency and jitter
- Stations are power-constrained
- Little concurrency
- Need to be robust

EOFS Challenges

- Adaptability
  - Should choose optimal use of computation, energy, and bandwidth based on sensor use
- Periodic Line-of-Sight Disruptions
  - Loss of connectivity due to waves
- Minimize control traffic
- Communication energy usage

Acoustic Modems

- How to communicate from ocean floor sensors to surface?
- Distance could be several kilometers, so cables are impractical
- Prototypes of acoustic modems developed
  - Uplink bit rate = 300 – 600 bps!
  - Downlink bit rate = 40 bps!

Web Interface to Sensor Data

[CORIE Web Page]

Biomedical Sensor Applications by Schwiebert, et al. (2001)

- Artificial retina
  - Sensors on retina receive signals from camera and trigger chemical reactions the brain can interpret
- Glucose monitor
  - Less invasive than current pin prick technique
  - Could automate glucose injection

Biomedical Sensor Applications

- Organ monitors
  - Could monitor vital aspects of organs to determine how to increase preservation time
- Cancer detection
  - Early detection is vital in decreasing deaths
  - Sensors regularly monitor warning signs
- General health monitors
  - Swallow a pill and have your vital signs monitored
  - Could be useful for astronauts, soldiers, firefighters, etc.