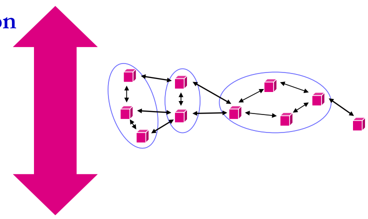
EE360: Lecture 15 Outline
Sensor Network Protocols

- Announcements
  - 2nd paper summary due March 7
  - Reschedule Wed lecture: 11-12:15? 12-1:15? 5-6:15?
  - Project poster session March 15 5:30pm?
  - Next HW posted by Wed, due March 16
- Overview of sensor network protocols
- Protocol tradeoffs
  - Access
  - Routing
  - Data dessemination
- Energy-Efficient Protocols

Crosslayer Protocol Design in Sensor Networks

- Application
- Network
- Access
- Link
- Hardware



Energy consumption at each layer of the protocol stack must be considered in the design

Wireless Sensor Network Protocols

- Primary theme: building long-lived, massively-distributed, physically-coupled systems:
  - Coordinating to minimize duty cycle and communication
    - Adaptive MAC
    - Adaptive Topology
    - Routing
  - In-network processing
    - Data centric routing
    - Programming models

Protocol Tradeoffs under Energy Constraints

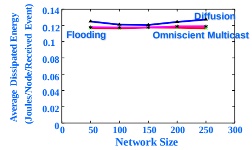
- Hardware
  - Models for circuit energy consumption highly variable
  - All nodes have transmit, sleep, and transient modes
  - Dense networks must consider TX+processing energy
- Link
  - High-level modulation costs transmit energy but saves circuit energy (shorter transmission time)
  - Coding costs circuit energy but saves transmit energy
  - Tradeoffs for other techniques (MIMO, relaying, etc.)
- Access
  - Time-division vs. code-division under energy constraints
  - How to avoid collisions
- Routing:
  - Circuit energy costs can preclude multihop routing

Medium Access Control in Sensor Nets

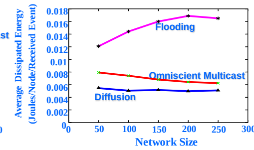
- Important attributes of MAC protocols
  1. Collision avoidance
  2. Energy efficiency
  3. Scalability in node density
  4. Latency
  5. Fairness
  6. Throughput
  7. Bandwidth utilization

MAC Impact on Sensor Networks
(Intanago et al, 2000)

- Major sources of energy waste
  - Idle listening when no sensing events, Collisions, Control overhead, Overhearing

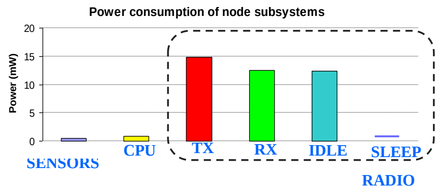


Over 802.11-like MAC



Over energy-aware MAC

Identifying the Energy Consumers



$E_{TX} \approx E_{RX} \approx E_{IDLE} >> E_{SLEEP}$

- Need to shutdown the radio

Energy Efficiency in MAC

- Major sources of energy waste
  - Idle listening
    - Long idle time when no sensing event happens
    - Collisions
    - Control overhead
    - Overhearing

    (Collisions, Control overhead, Overhearing: Common to all wireless networks)
- Try to reduce energy consumption from all above sources
- TDMA requires slot allocation and time synchronization
- Combine benefits of TDMA + contention protocols

Periodic Listen and Sleep

- Schedule maintenance
  - Remember neighbors' schedules
    — to know when to send to them
  - Each node broadcasts its schedule every few periods
  - Refresh on neighbor's schedule when receiving an update
  - Schedule packets also serve as beacons for new nodes to join a neighborhood

Collision Avoidance

- Problem: Multiple senders want to talk
- Options: Contention vs. TDMA
- Possible Solution: Similar to IEEE 802.11 ad hoc mode (DCF)
  - Physical and virtual carrier sense
  - Randomized backoff time
  - RTS/CTS for hidden terminal problem
  - RTS/CTS/DATA/ACK sequence

Overhearing Avoidance

- Problem: Receive packets destined to others
- Solution: Sleep when neighbors talk
  - Basic idea from PAMAS (Singh 1998)
  - But we only use in-channel signaling
- Who should sleep?
  - All immediate neighbors of sender and receiver
- How long to sleep?
  - The *duration* field in each packet informs other nodes the sleep interval

Message Passing

- Problem: In-network processing requires *entire* message
- Solution: Don't interleave different messages
  - Long message is fragmented & sent in burst
  - RTS/CTS reserve medium for entire message
  - Fragment-level error recovery
    — extend Tx time and re-transmit immediately
- Other nodes sleep for whole message time

Routing

- Given a topology, how to route data?
  - MANET: Reactive[DSR], proactive[AODV], TORA, GPSR[KarpKung00]
  - Location-aided routing: Geocast[Navas97], Cartesian-LAR, [KOVaidya98]
  - Energy-budget routing
  - Geographical Routing (GRAB, curve routing)
  - Data-directed routing

GRAB: Field Based Minimum Cost Forwarding (Lu et al 2002)

- Each node broadcasts only once
- Cost Function is a measure of how expensive it is to get a message back to the sink.
  - Could be based on Energy needed in radio communication, hop count, or other considerations
- Node Cost
  - Each node keeps best estimate on its minimum cost.
  - Estimate updated upon receipt of every ADV message.
  - ADV message forwarding deferred for time proportional to nodes cost estimate.

Energy-Budget Routing

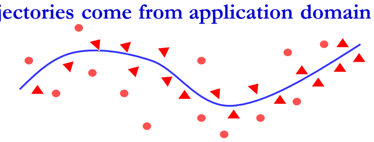
- A node with interesting data broadcasts two things (besides data)
  - Total budget to get back to sink.
  - Amount of budget used in initial broadcast.
- A node receiving a data message will only forward a data message if

  Total Budget ≥ Budget Spent So Far + My Cost
  - If the inequality holds then Budget Spent So Far is updated.
  - Otherwise the message is dropped.

Routing on a Curve

(Nath et al 2002)

- Route trajectories based on network structure
- By definition, network structure mimics physical structure that is instrumented
  - Stress along a column
  - Flooding along a river
  - Pollution along a road
- Trajectories come from application domain



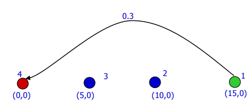
Minimum-Energy Routing Optimization Model

$$\begin{aligned} \text{Min} \quad & f_0(x_1, x_2, \ldots) \\ \text{s.t.} \quad & f_i(x_1, x_2, \ldots) \le 0, \quad i = 1, \cdots, M \\ & g_j(x_1, x_2, \ldots) = 0, \quad j = 1, \cdots, K \end{aligned}$$

- The cost function $f_0(.)$ is energy consumption.
- The design variables $(x_1, x_2, \ldots)$ are parameters that affect energy consumption, e.g. transmission time.
- $f_i(x_1, x_2, \ldots) \le 0$ and $g_j(x_1, x_2, \ldots) = 0$ are system constraints, such as a delay or rate constraints.
- If not convex, relaxation methods can be used.
- Focus on TD systems

Minimum Energy Routing

- Transmission and Circuit Energy



Red: hub node
Blue: relay only
Green: source

$R_1 = 60\,pps$

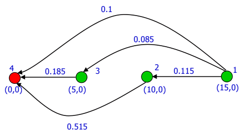
$R_2 = R_3 = 0$

$\upsilon = 100 bits$

Multihop routing may not be optimal when circuit energy consumption is considered

Relay Nodes with Data to Send

- Transmission energy only



Red: hub node
Green: relay/source

$R_1 = 60\, pps$

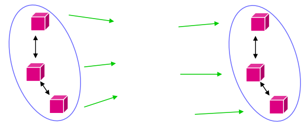
$R_2 = 80\, pps$

$R_3 = 20\, pps$

- Optimal routing uses single and multiple hops

- Link adaptation yields additional 70% energy savings

Cooperative MIMO for Sensors



- Nodes close together can cooperatively transmit
  - Form a multiple-antenna transmitter
- Nodes close together can cooperatively receive
  - Form a multiple-antenna receiver
- Node cooperation can increase capacity, save energy, and reduce delay.

Summary

- Protocol designs must take into account energy constraints
- Efficient protocols tailored to the application
- For large sensor networks, in-network processing and cooperation is essential
- Cross-layer design critical

Presentation

- "Energy-efficiency of MIMO and cooperative MIMO techniques in sensor networks"
- S. Cui, A.J. Goldsmith, and A. Bahai
- *Presented by Yizheng Liao*