Wireless Sensor Networks: Research Challenges and Future Directions

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Recap

- Lecture 1
  - Basic background and Introduction
  - A deeper look
    - Sensor node hardware
      - Example devices
    - Sensor node software
      - Operating system
      - Programming language
  - Research challenges in brief
- Lecture 2
  - Research Challenges
    - Data Storage
    - Data Dissemination

Lecture 3: Outline

- Research Challenges
  - Power Management
- Future Directions in WSNs
- Conclusion

Power Management Techniques

- Application Layer
- Transport Layer
- Network Layer
- Data Link Layer
- MAC Layer
- Physical Layer

Application Layer

- Load partitioning
  - Process power intensive computation at the base station
- Use of *proxies* to inform applications of change in battery power
  - When in need, applications can limit their functionality and only provide most essential features
- Application specific techniques
  - Video processing
    - Use compression techniques to reduce number of bits transmitted
  - Database
    - Reduce power consumption during data retrieval, indexing, as well as querying operations

Transport Layer

- Reduce the number of retransmissions necessary due to packet loss
  - Packet loss may not be due to congestion, but due to a faulty link
  - Example: *TCP-Probing*
    - On packet loss, do not retransmit, instead "probe" the network
      - Probe segments are composed of only segment header
    - Probe terminates when network conditions have improved sufficiently

Data Link Layer

- Packet scheduling
  - Schedule multiple packet transmissions to occur back to back
    - Reduces overhead associated with sending each packet individually
    - Preamble bytes are sent to announce its presence on the radio channel
      - Subsequent packets "piggyback" this announcement
- Modified ARQ (Automatic Repeat Request) and FEC (Forward Error Correction) schemes
  - Use better channel encoding leading to more redundancy
  - Do not use a "one-size-fits-all" approach
    - Customize scheme to fit traffic type and channel conditions
  - Energy-efficiency is more important than throughput

Physical Layer

- CPU Voltage scaling
  - Run at reduced voltage as necessary
- Remote Access Switch (RCS)
  - A low power radio circuit is used to detect a certain type of activity on the channel
    - When this activity is detected, the circuit wakes up the system for reception of a packet
- Energy harvesting techniques
  - Gather energy from its surrounding environment

MAC Layer

- Sleep scheduling protocols
  - Idle power wasted on the radio while there is nothing to receive
  - Types
    - Synchronous
      - Relies on clock synchronisation between all nodes in the network
      - E.g.: S-MAC
    - Asynchronous
      - Does not rely on a synchronised clock
      - Uses preamble bytes as the starting point for incoming data stream
      - E.g.: LPL (Low Power Listening)

S-MAC

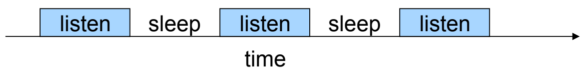
- Motivation
  - Collision
    - Corrupted packets must be retransmitted
  - Overhearing
    - Receive packets destined for others
  - Control packet overhead
  - Idle listening
    - Dominant factor in energy consumption

S-MAC

- Goal
  - Reduce energy consumption ☺
- Solutions
  - Collision avoidance
  - Overhearing avoidance
    - Switch off radio when transmission is not meant for that node
  - Control overhead – message passing
  - Idle listening
    - Periodic listen and sleep

S-MAC

- Problem: Idle listening
- Solution: Periodic listen and sleep
  - Turn off radio when sleeping



- Each node maintains a schedule table that stores schedules of its neighbours
- Schedule is agreed to by nodes by running an algorithm upon startup

S-MAC

- Collision avoidance is achieved by following 802.11 ad-hoc procedures
- Reducing control overhead
  - Don't interleave different messages
    - Long message is sent in a burst
    - Medium is reserved for entire message
- Overhearing avoidance
  - Interfering nodes go to sleep after hearing RTS/ CTS message
  - Time to sleep is provided in the packet

S-MAC: Drawbacks

- Clock synchronisation is required
  - Protocol to synchronise (in the event of clock skew) is expensive
- During message passing, node-to-node fairness is reduced
  - Nodes with small packets to send will have to wait till message burst has been transmitted
- Overhearing avoidance scheme does not take network path into account
  - Nodes that go to sleep may be required to be awake as part of another routing path
    - Loss of packets

Network Layer

- Achieve energy-efficient routing
  - Backbone based
    - Some nodes are chosen to remain active at all times (backbone nodes)
    - Backbone nodes are used to establish a path between all sources and destinations
    - Energy savings are achieved by allowing non-backbone nodes to sleep periodically
    - E.g.: SPAN, ASCENT
  - Topology control based
    - Reduce transmission power of all nodes in the network so that it stays connected
    - E.g.: GAF, PEAS

ASCENT: Adaptive Self-Configuring sEnsor Networks Topologies

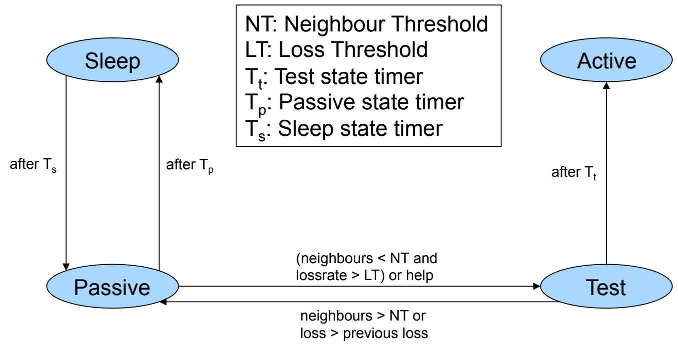
- Motivation
  - WSNs have a high density of nodes
    - This redundancy allows the network to remain functional without all nodes participating
- Solution
  - Intentionally limit the number of communicating nodes at a given time
    - Save total network energy and energy usage of active nodes

ASCENT: States

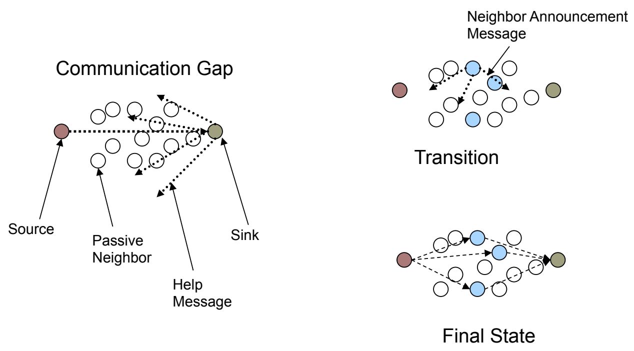
- Active
  - Forwards data and routes packets
- Test
  - Sends neighbor announcement message
  - Monitors network for neighbors and data loss rates
  - Forwards data and routes packets
- Passive
  - Monitors network for neighbors and data loss rates
- Sleep
  - Turns radio off and goes to sleep

Courtesy: James Watson, Virginia Tech

ASCENT: State Transitions



ASCENT in Action



Courtesy: James Watson, Virginia Tech

ASCENT: Drawbacks

- Does not deal with unexpected node failures
  - What happens if an active node fails unexpectedly ?
- In a very dense network, the per-node information would be very large to maintain

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Future Directions

- To recap:
  - Wireless sensor networks are an emerging technology with enormous potential
  - WSNs have found a footing not only in commercial applications, but also in research as well
  - This is all very well, but what now ?

Future Directions: Technical Challenges

- Noisy Sensors
  - Sensor readings can be inaccurate
  - E.g.: Relative humidity sensor – accuracy of ± 5%, ± 8% at 90% relative humidity
- Wireless channel conditions and environmental factors
  - Noisy, interference, link contention
- Research issues
  - Achieve high quality perception
    - How can we get accuracy, variety, detail & coverage simultaneously ?
    - How do we retain acceptable performance ?

Courtesy: Phil Gibbons, SenSys '08 keynote

Future Directions: Deployment Challenges

- Sensor networks will grow in size
  - Lower cost, better protocols
- Heterogeneous sensors
- Mobile sensors
- Research issues
  - How do we combine sensors with different functions ?
  - How can we achieve interoperability ?
    - Do we need a standardised interface ?
  - How do we use the functionality provided by other sensors ?
  - How can we achieve data replication?

Future Directions: Underwater Sensor Networks

- Research issues
  - How can we increase network capacity?
    - Data compression?
  - How can we communicate in hostile environments?
  - Cross-layer optimization
  - How can we provide location information?

Future Directions: Global Mobile Sensor Network

- Use smart phones to form a global sensor network
  - 3-axis accelerometer, GPS, Microphone, Camera, Digital Compass, Bluetooth, ….. – significantly more capable than "sensors"
  - Answer lots of questions and build cool new applications
    - What is the air quality of a neighbourhood, school, town, or city?
    - Where are my friends and what are they doing right now?

Courtesy: Andrew Campbell, Percom '09 keynote

Future Directions: Context Awareness

- Research issues
  - How do we build context organizers ?
  - How can we be minimally intrusive, both in privacy and overhead ?
  - Which context matters most in everyday settings ?
    - Application specific or generic ?
  - How will applications, interfaces and interaction techniques be optimised to leverage context ?

Courtesy: Phil Gibbons, SenSys '08 keynote

Future Directions: Security Challenges

- Research issues
  - Concerns about misuse and privacy
  - What kind of data are we trying to protect ?
  - Authentication vs. privacy
  - Protect against unauthorised code
    - Sensor virus ☺

Conclusion

- Focussed on Power management
- Presented future direction and challenges of WSNs

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☺ Questions ☺