EE 579: Wireless and Mobile Networks Design & Laboratory

Lecture 8

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Lecture notes and course design based upon prior semesters taught by Bhaskar Krishnamachari and Murali Annavaram.
Outline

- Administrative Stuff
- MAC Protocols for Sensor Networks
- Data Gathering (Convergecast) - Throughput-Delay Trade-off
Recap

- Collection of low-power devices “sensor nodes”
- Small, inexpensive, with constrained power
- Organized in a cooperative network
- Communicate wirelessly in multi-hop routing
- Heavy deployment
- Dynamic topology
Recap

Components and Schematic of a Node

- Processor
- Memory
- RF Radio
- Power Source
- Sensor
- GPS

Power Source: Battery/Harvest
Recap
Communication Patterns

- **Broadcast**
  - Base station transmits message to all its immediate neighbors

- **Convergecast**
  - A group of sensors communicates to a specific sensor

- **Local gossip**
  - A sensor node sends a message to its neighboring nodes within a range
Power Consumption

One of the biggest challenges

- Sensors have a limited source of power and it’s hard to replace or recharge, e.g., sensors deployed in the battle field, sensors in a large forest

<table>
<thead>
<tr>
<th>Radio mode</th>
<th>Power consumption (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit ($T_x$)</td>
<td>14.88</td>
</tr>
<tr>
<td>Receive ($R_x$)</td>
<td>12.50</td>
</tr>
<tr>
<td>Idle</td>
<td>12.36</td>
</tr>
<tr>
<td>Sleep</td>
<td>0.016</td>
</tr>
</tbody>
</table>
Sources of Power Consumption

Useful power consumption

- Transmitting or receiving data
- Processing queries requests
- Forwarding queries and data to the neighbours
Sources of Power Consumption

Wasteful power consumption

- Idle listening to the channel
  - Waiting for possible traffic

- Retransmitting because of collision
  - Two packets arrived at the same time at the same sensor

- Overhearing
  - When a sensor received a packet doesn’t belong to it

- Generating and handling control packets.
Sources of Power Consumption

- How to minimize the energy consumption of sensor nodes while meeting application requirements?

- Use Protocols that aim mainly to increase the sleep periods as much as possible
Hidden Terminal Problem

- Another sender’s presence is hidden from the intended sender, and therefore simultaneous transmissions from both of them to the same receiver cause collision.

- How to avoid? - Use of additional signaling packets
  - Sender asks receiver whether it is able to receive a transmission - Request to Send (RTS)
  - Receiver agrees, sends out a Clear to Send (CTS)
  - Sender sends, receiver sends Acknowledgements (ACKs)
Hidden Terminal Problem

- A pictorial representation of how to avoid

\[ S_1 \]

\[ R \]

\[ S_2 \]

1. RTS
2. CTS
3. DATA
4. ACK

Detect Collision
Find Transmission Complete
Hidden Terminal Problem

- Problems with RTS/CTS?
Hidden Terminal Problem

- Problems with RTS/CTS?
  - When RTS/CTS messages are sent by different nodes
Hidden Terminal Problem

- Problems with RTS/CTS?
  - When RTS/CTS messages are sent by different nodes
  - When multiple CTS messages are granted to different neighboring nodes
Exposed Terminal Problem

- An exposed node is one that is in the range of the transceiver but not the receiver
  - Sender mistakenly thinks that the medium is in use, and it unnecessarily defers transmission

- How to avoid?
  - When a node hears an RTS but not a corresponding CTS, it can deduce that it is an exposed terminal and is permitted to transmit
  - Directional antennas
Exposed Terminal Problem

- A pictorial representation of how to avoid

Exposure Terminal Problem

Exposed Terminal $S_2$
Wireless MAC Protocols

Conventional MAC Protocols

- CSMA
- CSMA/CA
- IEEE 802.11
Wireless MAC Protocols

CSMA
- Non Persistent: if the device detects activity on the channel, it performs a back-off by waiting before attempting to transmit
- P-persistent: if it detects an activity on the channel, it continues to sense the channel instead of delaying

- CSMA requires devices to remain in the “receive state” when not transmitting

Disadvantages
- Transceiver consumes energy too quickly
Wireless MAC Protocols

CSMA/CA
- Control messages were introduced such as (RTS/CTS) to reserve the channel
- Source first performs CSMA algorithm
- If it determines an appropriate time for transmission, it sends RTS
- Then, the destination responds with CTS

Disadvantages
- Might still have some collision in RTS
IEEE 802.11

- Infrastructure mode
  - Devices communicate through a central entity called an access point (AP) using the point coordination function (PCF)

- Ad hoc mode
  - Devices communicate with each other directly using the distributed coordination function (DCF)

- Both the PCF and DCF use a channel access mechanism similar to CSMA/CA and use ACKs for reliability

- In addition to physical carrier sensing, IEEE 802.11 devices perform virtual carrier sensing “NAV”
IEEE 802.11 Disadvantages

- Devices consume large amounts of energy due to the high percentage of time spent listening without receiving messages.

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**Diagram:**

- **Sender node:**
  - DIFS
  - RTS
  - SIFS
  - DATA

- **Receiver node:**
  - SIFS
  - CTS
  - SIFS
  - ACK
  - NAV(CTS)
  - NAV(RTS)
  - Contention Window

- **Other nodes:**
  - NAV(CTS)
  - NAV(RTS)

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**802.11 Data Transfer**
Differences and Constraints

Traditional MAC protocol provides
- High throughput
- Low latency
- Fairness
- Mobility
- But have little consideration for energy

Improved MAC protocol provides
- Best performance of smallest amount of energy
Attributes of WSN MAC

More important
- Energy conservation
- Scalability and adaptively

Less important
- Throughput
- Fairness
- Latency

MAC protocol must achieve
- Establish communication link between the sensor nodes
- To share the communication medium fairly and efficiently
WSN MAC Protocols

Medium Access Control

- Unscheduled MAC
- Scheduled MAC
Unscheduled WSN MAC Protocols

- Before sending a message, a sensor listens to the medium. If it’s busy, wait a random time then retry again and if it’s free then it will send the message.

- Advantages
  - Can adapt for changes in the node density, traffic load, or the topology better than scheduled MAC protocols.
  - Sensors don’t have to be synchronized together.

- Disadvantages
  - Worse than scheduled MAC protocols from power saving perspective since all sensors listen to the channel.
Unscheduled WSN MAC Protocols

PAMAS (Power Aware Multi-Access)
- Uses multiple transceivers on each node
- Separate control and data channels
Unscheduled WSN MAC Protocols

Advantages
- Prevent collision
- Avoids exposed terminal problem

Disadvantages
- Multiple radio requirement
- Increase energy consumption
- Increase device complexity and cost
Unscheduled WSN MAC Protocols

STEM (Sparse Topology and Energy Management)
- Uses two channels, a wakeup channel and a data channel
- Requires two transceivers at each node

STEM duty cycle for single node

Wakeup channel

Data channel
Unscheduled WSN MAC Protocols

STEM (Sparse Topology and Energy Management)
- Two flavors

- **STEM-B**
  - Node which wishes to transmit sends beacon on the wakeup channel
  - Beacon contains both transmitter and receiver address
  - Low latency

- **STEM-T**
  - Tx sends busy tone on wakeup channel for long enough to hit the receiver’s listen period
  - No address in busy tone - all nodes hearing “busy” shift to data channel, but only intended node replies
  - Higher latency and results in overhearing
B-MAC
- Uses a tone to wake up sleeping neighbors, similar to STEM-T
- Uses very long preambles - dominates energy usage
- Suffers from overhearing problem
Wise MAC

- Uses to B-MAC, but reduces energy consumption by
  - Minimizing (adaptive) preamble length
  - Having nodes remember the sampling schedules of neighbors
  - Disadvantage - cost of an extra field in the ACK message and the memory required to store neighbor’s sampling offsets.
Scheduled WSN MAC Protocols
Attempts to reduce the energy consumption by coordinating sensor nodes with a common schedule

**Advantages**
- Saves from wasting energy by turning off the radio outside the allocated time slot
- Limits collision, idle listing, and overhearing

**Disadvantages**
- When new nodes join, they must wait till they learn - some delay
- Cost of increased messages
- Not flexible to changes in sensor density or movements
- All sensors should be well synchronized
Scheduled WSN MAC Protocols

S-MAC (Sensor-MAC)
- Inspired by PAMAS, but in-channel signaling
- Nodes periodically go to a fixed listen/sleep cycle
- Virtual clustering to synchronize nodes on a common slot
- Energy is still wasted during listen period, as the sensor remains awake even if there is no reception/transmission
Scheduled WSN MAC Protocols

S-MAC (Sensor-MAC)

Timing relationship between different senders
Scheduled WSN MAC Protocols

T-MAC (Timeout-MAC)
- Introduces adaptive duty cycling to improve S-MAC
  - Frees the application from the burden of selecting an appropriate duty cycle
  - Automatically adapts to traffic fluctuations

- Borrows virtual clustering from S-MAC for synchronization
  - Operates on a fixed length slot (615 ms)
  - Uses a time-out mechanism to dynamically determine the end of the active period

- Downside
  - Aggressive power-down policy (nodes often go to sleep too early)
Scheduled WSN MAC Protocols

D-MAC (Data Gathering-MAC)
- Uses adaptive duty cycling like T-MAC
  - 1 receive, 1 send, and n sleep slots
- Low node-to-sink latency: convergecast
- Divides time into short slots (10 ms) and runs CSMA/CA within each slot

Convergecast tree with matching, staggered DMAC slots
In Summary

There is no unique “best” MAC protocol for WSN. Each one is customized for specific applications.