Wireless Sensor Networks (WSNs)
WSN Outline

- Introduction, Mote Revolution
- Wireless Sensor Network (WSN) Applications
- WSN Details
- Types of Wireless Sensor Networks (WSNs)
- Tiered Architectures
- Dynamic Cluster Formation
- Power-Aware MAC Protocols
  - SMAC, TMAC, WiseMAC, TRAMA, SCP-MAC, AS-MAC, Crankshaft
Wireless Sensor Networks

- A distributed connection of nodes that coordinate to perform a common task.
- In many applications, the nodes are battery powered and it is often very difficult to recharge or change the batteries.
- Prolonging network lifetime is a critical issue.
- Sensors often have long period between transmissions (e.g., in seconds).
- Thus, a good WSN MAC protocol needs to be energy efficient.
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Case Study in Crossbow Mote Deployment
Water in the Vineyard
Vineyard Installation

- At each Mote location:
  - 2 soil moisture sensors
  - 12” and 24” depth
  - 1 soil temp sensor to calibrate soil moisture sensors
Power Supply

- 2 month max battery life now with 10 minute sampling interval
- Decided to use solar power, always there when doing irrigation. Solar cell $10 in small quantities and need a $.50 regulator.
Vineyard Mote Prototype

- 433MHz Mica2dot
- Solar power supply
- Up to 6 resistive sensor inputs
Network Maps

13 nodes late 2005, 18 nodes in 2006

Irrigation Block Map
Soil Moisture Data

- Red = 12” depth soil moisture
- Green = 24” depth soil moisture
- Note delay deeper
- More frequent, shorter watering keeps water shallow
Figure 1. Assisted-living deployment example, showing connections among sensors, body networks, and backbone nodes.
WSNs for Assisted Living

Figure 2. ALARM-NET architecture components and logical topology.
Two-Tiered WSN Architecture

Figure 3. Query processing stack on sensor devices. The Query Processor parses queries, and starts the Sampler, which reads data from the sensor drivers on schedule, generating data that flows up the processing chain toward the Query Processor for reporting.
Berkeley Fall Detection System

Using smart sensors and a camera phone to detect and verify the fall of elderly persons.

Figure 1: The Information Technology for Assisted Living at Home (ITALH) system overview
Berkeley Fall Detection System

Figure 2: Fall detector system setup

Figure 3: The Berkeley GPSADXL fall sensor
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Another attribute is **scalability and adaptability to change** in network size, node density and topology.

- In general, nodes can die, join later or be mobile.

- Often high bandwidth is **not important**.

- Nodes can take advantage of short-range, multi-hop communication to conserve energy.
Sources of energy waste:
- Idle listening, collisions, overhearing and control overhead and overmitting.
- Idle listening dominates (measurements show idle listening consumes between 50-100% of the energy required for receiving.)

Idle listening: listen to receive possible traffic that is not sent.

Overmitting: transmission of message when receiver is not ready.
### Power Measurements

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
<th>CC1000</th>
<th>CC2420</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{tx}$</td>
<td>Power in transmitting</td>
<td>31.2mW</td>
<td>52.2mW</td>
</tr>
<tr>
<td>$P_{rx}$</td>
<td>Power in receiving</td>
<td>22.2mW</td>
<td>56.4mW</td>
</tr>
<tr>
<td>$P_{listen}$</td>
<td>Power in listening</td>
<td>22.2mW</td>
<td>56.4mW</td>
</tr>
<tr>
<td>$P_{sleep}$</td>
<td>Power in sleeping</td>
<td>3μW</td>
<td>3μW</td>
</tr>
<tr>
<td>$P_{poll}$</td>
<td>Power in channel polling</td>
<td>7.4mW</td>
<td>12.3mW</td>
</tr>
<tr>
<td>$t_{pl}$</td>
<td>Avg. time to poll channel</td>
<td>3ms</td>
<td>2.5ms</td>
</tr>
<tr>
<td>$t_{cs1}$</td>
<td>Avg. carrier sense time</td>
<td>7ms</td>
<td>2ms</td>
</tr>
<tr>
<td>$t_B$</td>
<td>Time to Tx/Rx a byte</td>
<td>416μs</td>
<td>32μs</td>
</tr>
<tr>
<td>$T_p$</td>
<td>Channel polling period</td>
<td>Varying</td>
<td>Varying</td>
</tr>
<tr>
<td>$T_{data}$</td>
<td>Data packet period</td>
<td>Varying</td>
<td>Varying</td>
</tr>
<tr>
<td>$r_{data}$</td>
<td>Data packet rate ($1/T_{data}$)</td>
<td>Varying</td>
<td>Varying</td>
</tr>
<tr>
<td>$L_{data}$</td>
<td>Data packet length</td>
<td>50B</td>
<td>50B</td>
</tr>
<tr>
<td>$n$</td>
<td>Number of neighbors</td>
<td>10</td>
<td>10</td>
</tr>
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</table>

Table 1. Symbols used in radio energy analysis, and typical values for the Mica2 radio (CC1000) and an 802.15.4 radio (CC2420)
WSN Communication Patterns

- **Broadcast**: e.g., Base station transmits to all sensor nodes in WSN.
- **Multicast**: sensor transmit to a subset of sensors (e.g. cluster head to cluster nodes).
- **Convergecast**: when a group of sensors communicate to one sensor (BS, cluster head, or data fusion center).
- **Local Gossip**: sensor sends message to neighbor sensors.
Wireless Sensor Networks

- **Duty cycle**: ratio between listen time and the full listen-sleep cycle.

- **Central approach** - lower the duty cycle by turning the radio off part of the time.

- Three techniques to reduce the duty cycle:
  - TDMA
  - Schedule contention periods
  - LPL (Low Power Listening)
Techniques to Reduce Idle Listening

- **TDMA** requires cluster-based or centralized control.
- **Scheduling** - ensures short listen period when transmitters and listeners can rendezvous and other periods where nodes sleep (turn off their radios).
- **LPL** - nodes wake up briefly to check for channel activity without receiving data.
  - If channel is idle, node goes back to sleep.
  - If channel is busy, node stays awake to receive data.
  - A long preamble (longer than poll period) is used to assure than preamble intersects with polls.
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Figure 1: The Mote Herding architecture and its components, the flock, the shepherd and the herd [Stathopoulos]
Dynamic Cluster Formation
Choosing Cluster Heads/Forming Clusters

Two-tier scheme:

- A fixed number of cluster heads that communicate with BS (base station).
- Nodes in cluster communicate with head (normally TDMA).
- TDMA allows fixed schedule of slots for sensor to send to cluster head and receive head transmissions.
Choosing Cluster Heads / Forming Clusters

- Periodically select new cluster heads to minimize power consumption and maximize WSN lifetime.
- More complex problem when size of cluster changes dynamically.
- As time goes by, some sensor nodes die!
- Not worried about coverage issues!
Dynamic Cluster Formation

- TDMA cluster algorithms:
  - LEACH, Bluetooth, ...

- Rick Skowyra’s MS thesis:
  'Energy Efficient Dynamic Reclustering Strategy for WSNs'
  - 'Leach-like' with a fitness function and periodic reclustering.
  - He designed a distributed genetic algorithm to speed the reclustering time.
Power-Aware MAC Protocols
<table>
<thead>
<tr>
<th>Year</th>
<th>Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>PAMAS</td>
</tr>
<tr>
<td>1998</td>
<td>SMAC</td>
</tr>
<tr>
<td>1999</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>LPL, NPSM</td>
</tr>
<tr>
<td>2002</td>
<td>TMAC, TinyOS, EMACs, TRAMA, Sift</td>
</tr>
<tr>
<td>2003</td>
<td>BMAC, DMAC, DSMAC, LMAC, WiseMAC</td>
</tr>
<tr>
<td>2004</td>
<td>PMAC, ZMAC, SP</td>
</tr>
<tr>
<td>2005</td>
<td>SCP-MAC</td>
</tr>
<tr>
<td>2006</td>
<td>Crankshaft</td>
</tr>
<tr>
<td>2007</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>AS-MAC</td>
</tr>
<tr>
<td>2011</td>
<td>BAS-MAC</td>
</tr>
</tbody>
</table>
Power Aware MAC Protocols

Three approaches to saving power:

1. **TDMA**: TRAMA, EMACs, LMAC

2. **Schedule**: PAMAS, SMAC, TMAC, DMAC, PMAC, SCP-MAC, Crankshaft, AS-MAC

3. **Low Power Listening**: LPL, BMAC, WiseMAC

**Cross-Layering**: SP, BSD
Sensor-MAC (S-MAC)

- All nodes periodically listen, sleep and wakeup. Nodes listen and send during the active period and turn off their radios during the sleep period.

- The beginning of the active period is a SYNC period used to accomplish periodic synchronization and remedy clock drift. Nodes broadcast SYNC frames.

- Following the SYNC period, data may be transferred for the remainder of the fixed-length active period using RTS/CTS for unicast transmissions.
Sensor-MAC (S-MAC)

- Long frames are fragmented and transmitted as a burst.

- SMAC controls the duty cycle to **tradeoff energy for delay**.

- However, as **density** of WSN grows, SMAC incurs additional overhead in maintaining neighbors’ schedules.
Figure 1: The S-MAC duty cycle; the arrows indicate transmitted and received messages; note that messages come closer together.
Timeout-MAC (T-MAC)

- TMAC employs an adaptive duty cycle by using a very short listening window at the beginning of each active period.

- After the SYNC portion of the active period, RTS/CTS is used in a listening window. If no activity occurs within a timeout interval (15 ms), the node goes to sleep.

- TMAC saves power at the cost of reduced throughput and additional delay.
Figure 2: The basic T-MAC protocol scheme, with adaptive active times.
Scheduled Channel Polling (SCP-MAC)

- With channel polling (the **LPL scheme**), receiver efficiency is gained through cost to sender.
- LPLs are very sensitive to tuning for neighborhood size and traffic rate.
- By synchronizing channel polling times of all neighbors, long preambles are eliminated and ultra-low duty cycles (below the LPL 1-2% limits) are possible.
Scheduled Channel Polling (SCP-MAC)

- The issue is knowing my neighbors’ schedule information.
- SCP piggybacks schedule info on data packets when possible or a node broadcasts its schedule in a **SYNC** packet in synch period (as in SMAC).
- Knowing schedules $\Rightarrow$ short wakeup tone.
- Optimal synchronization reduces overhearing.
SCP-MAC

(a) Low-power listening (LPL)

(b) Synchronized channel polling (SCP)

Figure 1. Sender and receiver synchronization schemes.
**TABLE I. COMPARISON OF MAC PROTOCOLS**

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>S-MAC / T-MAC / DSMAC</td>
<td>No</td>
<td>All</td>
<td>CSMA</td>
<td>Good</td>
</tr>
<tr>
<td>WiseMAC</td>
<td>No</td>
<td>All</td>
<td>np-CSMA</td>
<td>Good</td>
</tr>
<tr>
<td>TRAMA</td>
<td>Yes</td>
<td>All</td>
<td>TDMA / CSMA</td>
<td>Good</td>
</tr>
<tr>
<td>SIFT</td>
<td>No</td>
<td>All</td>
<td>CSMA/CA</td>
<td>Good</td>
</tr>
<tr>
<td>DMAC</td>
<td>Yes</td>
<td>Convergecast</td>
<td>TDMA / Slotted Aloha</td>
<td>Weak</td>
</tr>
</tbody>
</table>
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