Energy-Efficient Channel Access Protocols

Introduction
- Sensor networks are a special class of multi-hop wireless networks.
- Energy conservation is very critical in improving the life time of the networks.
- Some of the interesting features are:
  - Ad hoc deployment.
  - Very low or no mobility.

Motivation
- Major source of energy consumption is the radio.
- Energy wastage due to idle listening and collisions.
- Today’s radios have a special low power standby mode (or sleep mode) to save power.
- Switching the radio to sleep mode whenever possible could achieve potential savings.

Measurement on WLAN Cards

![Graph showing power consumption of a Cisco 400 access point in different modes.](image)
**S-MAC: Sensor MAC**

- Contention based MAC.
- Energy savings by periodic sleep, overhearing avoidance and message passing.
- SYNC packets are used to maintain sleep schedules.
- Less throughput and per-node fairness.

**Sensor Radios (RFM TR1000)**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Power consumption in mW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit</td>
<td>14.55</td>
</tr>
<tr>
<td>Receive</td>
<td>13.50</td>
</tr>
<tr>
<td>Standby</td>
<td>15x 10^6 mW</td>
</tr>
</tbody>
</table>

Table 1: Average power consumption in different modes

<table>
<thead>
<tr>
<th>State</th>
<th>Transmit</th>
<th>Receive</th>
<th>Standby</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>0</td>
<td>29</td>
<td>10</td>
</tr>
<tr>
<td>Power</td>
<td>12</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Standby</td>
<td>16</td>
<td>29</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2: Transition times in µs

**Measurement on WLAN Cards**

![Graph](image)
**S-MAC Overview**
- Time is divided into cycles of listen and sleep intervals.
- Schedules are established such that neighboring nodes have synchronous sleep and listen periods.
- SYNC packets are exchanged periodically to maintain schedule synchronization.

**S-MAC Operation**
- SYNC packets are transmitted only during the SYNC period (long enough to send 1 SYNC packet) of the listen interval.
- Data transmissions are initiated by sending RTS during the DATA period (long enough to send an RTS and overhear a CTS) of the listen interval.

**Schedule Establishment**
- Node listens for a certain amount of time.
- If it does not hear a schedule, it chooses a time to sleep and broadcast this information immediately.
- This node is called the ‘Synchronizer’.
- If a node receives a schedule before establishing its schedule, it just follows the received schedule.
- If a node receives a different schedule, after it has established its schedule, it listens for both the schedules.
S-MAC Features
- Collision Avoidance
  - Similar to 802.11 (RTS/CTS handshake).
- Overhearing Avoidance
  - All the immediate neighbors of the sender and receiver go to sleep.
- Message Passing
  - Long messages are broken down into smaller packets and sent continuously once the channel is acquired by RTS/CTS handshake.
  - Increases the sleep time, but leads to fairness problems.

TRAMA: Traffic Adaptive Medium Access Control Protocol
- Collision freedom by distributed election based on Neighborhood-Aware Contention Resolution (NCR).
- Traffic-adaptive scheduling to increase the channel utilization.
- Radio-mode control for energy efficiency.
Overview
- Single, time-slotted channel access for both data and signaling.
- Organized as sections of random- and scheduled access periods.
- Random access period used for signaling and scheduled access period used for data transmission.

Neighborhood-aware Contention Resolution (NCR)
- Each node maintains two-hop neighbor information.
- For every contention slot, all the nodes compute priorities based on the unique node id, \( n \), and current time slot id, \( t_s \), as:
  \[ p_n = \text{randomhash}(n, t_s) \]
- The node with the highest priority among the two-hop neighborhood is elected as the transmitter.

Time slot organization

NCR
- NCR prevents collisions due to hidden terminals. (A set of protocols based on NCR is developed by Lichun and JJ for scheduling-based channel access in ad hoc networks).
- TRAMA uses NCR to elect the transmitter.
- To elect the receiver TRAMA uses the schedule information announced by the transmitter.
Components of TRAMA

- Neighbor Protocol (NP).
- Schedule Exchange Protocol (SEP).
- Adaptive Election Algorithm (AEA).

Neighbor Protocol

- Main Function: Gather two-hop neighborhood information by using signaling packets.
- Incremental neighbor updates to keep the size of the signaling packet small.
- Periodically operates during random access period.

Packet Formats

<table>
<thead>
<tr>
<th>Type</th>
<th>Source</th>
<th>Target</th>
<th>Origin</th>
<th>SEQ</th>
<th>NEID</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Schedule Exchange Protocol (SEP)

- Schedule consists of list of intended receivers for future transmission slots.
- Schedules are established based on the current traffic information at the node.
- Propagated to the neighbors periodically.
- SEP maintains consistent schedules for the one-hop neighbors.
**Schedule Packet Format**

**Adaptive Election Algorithm (AEA)**

- Decides the node state as either Transmit, Receive or Sleep.
- Uses the schedule information obtained by SEP and a modified NCR to do the election.
- Nodes without any data to send are removed from the election process, thereby improving the channel utilization.

**Experimental Setup**

- Performance analysis by extensive simulation using Qualnet.
- Compared the performance with both contention-based protocols (IEEE802.11, CSMA and S-MAC) and scheduling-based protocols (NAMA).

**Simulation Setup**

- Randomly placed 50 nodes in 500x500m area.
- Typical sensor radio TR1000 with 100m range and 115.2kbps.
- Data size: 512 bytes.
- Two different scenarios.
Scenarios

- Synthetic scenario:
  - Synthetic traffic generated at the MAC level based on Poisson arrivals.
- Data gathering application:
  - Sink collects information from sensors by sending out a query.
  - Different placements for sink.
  - Reverse path routing for sending data back to sink.

Sensor Scenario

Performance Metrics

- Average Packet Delivery Ratio:
  - Ratio of number of packets delivered to the number of packets sent.
- Average Queuing Delay.
- Percentage Sleep Time:
  - Percentage of time nodes can be put to sleep mode.
- Average Length of Sleep Time:
  - A measure of energy savings as longer sleeps involve less switching and hence less transient power consumption due to switching.

Delivery Ratio (Synthetic)
**Energy Savings (synthetic)**

**Percentage Sleep**

**Sleep Interval**

**Energy Savings (sensor)**

**Percentage Sleep**

**Sleep Time**

**Conclusion**

- Significant improvement in delivery ratio in all scenarios when compared to contention-based protocols.
- Significant energy savings compared to S-MAC (which incurs more switching).
- Acceptable latency and traffic adaptive.
**Future Works**

- Traffic predictions to improve the delay performance.
- Predicting the transmitter without transmitting entire bitmaps based on history to reduce scheduling overhead.