Algorithms for Radio Networks

MAC for WSN
Media ACcess
MAC

- Prevention of collisions on the medium
  - Fair and efficient bandwidth allocation
- MAC for WSN
  - Regulates sleep cycles for participants
  - Reduces waiting time for active reception
- Standard protocols are not applicable for WSN
  - Energy efficiency and sleep times must be added
MACA and WSN

MACA:
• Channel must be monitored for RTS and CTS
• Nodes waking up can disrupt existing communications

Solution in IEEE 802.11:
• Announcement Traffic Indication Message (ATIM)
  - prevents receiver from starting a sleep cycle
  - informs about upcoming packages
  - is sent within the beacon interval
• When no message is pending, then the client can switch off its receiver (for a short time)
STEM

- Schurgers, Tsiatis, Srivastava
- Sparse Topology and Energy Management (STEM)
- Special hardware with two channels
  - Wakeup channel
  - data channel
- no synchronization
- No RTS / CTS
- Suitable for decentralized multi-hop routing
STEM

**sender**

- Wakeup channel
- Alarm
- Data channel
- Sends message

**receiver**

- Wakeup channel
- Sleep phase
- Alarm
- Ready to receive
- Ready to receive
- Receives message
STEM
Sparse Topology and Energy Management Protocol

- **Wakeup channel**
  - sender announces message
  - announcement will be repeated until the receiver acknowledges
  - receiver sleeps in cycles
- **Data channel**
  - is used for undisturbed transmission
- **No RTS / CTS**
- **No carrier sensing**
Discussion STEM

- **Sleep cycles ensure efficiency in the data reception**
  - longer cycles improve energy efficiency
  - but increase the latency
- **Too long sleep cycles**
  - increase the energy consumption at the transmitter
  - lead to traffic congestion in the network
- **Lack of collision avoidance**
  - can result in increased traffic because of long waiting times
  - increase energy consumption
STEM

- STEM
  - can be combined with GAF (Geographic Adaptive Fidelity)
  - GAF reduces the sensor density, by allowing only the activation of one sensor in a small square

- T-STEM
  - STEM adds a busy-signal channel to wake up and to prevent communication from interruption
Preamble Sampling

› Only one channel available and no synchronization

› Receiver
  • wakes up after sleep period
  • listens for messages from channel

› Sender
  • sends a long preamble
  • and then the data packet
Preamble Sampling

sender

receiver

ready to receive

ready to receive

ready to receive

preamble

send message

sleep phase

stays awake

receives message

ready to receive

ready to receive

ready to receive

message
Efficiency of Preamble Sampling

- Few messages
  - Better: long sleep phases
  - Receiver consume most of the total energy
- Many messages
  - Short sleep phases
  - Sender consume most of the total energy
  - We observe for preamble time $T$ and some positive constants $c$, $c'$, $c''$:

$$\text{Energy} = cT + \frac{c'}{T} + c''$$
Sensor-Mac (S-MAC)

- Ye, Heidemann, Estrin
- Synchronized sleep and wake cycles
- MACA (RTS / CTS)
  - for collision avoidance
  - and detection of possible sleep cycles
S-MAC Protocol

- **Active phase**
  - Carrier Sensing
  - Send Sync packet synchronizer short sleep duration with ID and
  - Interval for Request to Send (RTS)
  - Interval for Clear-to-Send (CTS)
Schedule

- Each node maintains Schedule Table
  - with the sleep cycles of known neighbors
- At the beginning listen to the channel for potential neighbors
  - the sender adapts to the sleep cycles of the neighbors
  - if several sleep cycles are noticed, then the node wakes up several times
- If after some time no neighbors have been detected (no sync)
  - then the node turns into a synchronizer
  - and sends its own Sync packets
Synchronized Islands

A

B

C

synchronizer

sleep phase

A

SYNC

sleep phase

SYNC

B

awake awake awake awake awake

SYNC

SYNC

SYNC

C

awake awake awake awake awake

awake

SYNC

SYNC

SYNC
Message Transmission

- If a node receives RTS for a foreign a node is a,
  - then he goes to sleep for the announced time
- **Packet is divided into small frames**
  - be individually acknowledged with (ACK)
  - all frames are announced with only one RTS / CTS interaction
  - If ACK fails, the packet is immediately resent
- **Small packets and ACK should avoid the hidden terminal problem**
- **All frames contain the planned packet duration in the header**
Message Transmission
S-MAC

A

Synchro-
nization

RTS

Frame 1

Frame 2

B

Synchro-
nization

CTS

ACK

ACK

C

Synchro-
nization


sleep phase

D

Carrier
Sense

sleep phase
Timeout-MAC (T-MAC)

- T. van Dam, K. Langendoen

Main goal
- extension of the MACA-protocol to save energy

Method
- Traffic dependent sleep cycles
- New: FRTS-Signal (Future Request to Send)
  - informs about future message
  - Allows adapted sleep phases of the receiver
T-MAC

A message

B collision

C collision

D

A

RTS

pause

message

B

CTS

ACK

C

FRTS

sleep phase

RTS

pause

message

D

receive

sleep phase

CTS

ACK
Comparison of S-MAC and T-MAC

- FRTS solves problems that are increased by adapted sleep cycles
  - e.g. Early Sleeping i.e., Falling asleep because sender is blocked by foreign CTS
- Simulation indicates significant energy reduction
  - also improve the throughput

B-MAC

- **Polastre, Hill, Culler**

- **B-MAC (Berkeley-MAC)**
  - no synchronization
  - Clear Channel Assessment
  - Evaluation of RSSI compared to noise
  - Hardware-oriented implementation
  - Very simple, low memory and power consumption
B-MAC

- **Low Power Listening**
  - Preamble Sampling
  - Special wake-up protocol
  - adapted to hardware with low power consumption
  - Node goes into sleep mode after test
- **optional**
  - RTS / CTS
  - Acknowledgments
- **De-facto standard for WSN MAC Protocols**
Low Power Listening

(a) sleep  (b) init radio  (c) radio crystal startup  (d) \( \mu \text{c} \)  (e) \( \text{rx} \)  (f) \( \text{adc} \)  (g) sleep

Polastre, Hill, Culler, Versatile Low Power Media Access for Wireless Sensor Networks, SenSys'04
## Memory Consumption

### B-MAC and S-MAC

<table>
<thead>
<tr>
<th>Protocol</th>
<th>ROM</th>
<th>RAM</th>
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<tbody>
<tr>
<td>B-MAC</td>
<td>3046</td>
<td>166</td>
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<tr>
<td>B-MAC w/ ACK</td>
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<td>168</td>
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<tr>
<td>B-MAC w/ LPL</td>
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<tr>
<td>B-MAC w/ LPL &amp; ACK</td>
<td>4386</td>
<td>172</td>
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<tr>
<td>B-MAC w/ LPL &amp; ACK + RTS-CTS</td>
<td>4616</td>
<td>277</td>
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<tr>
<td>S-MAC</td>
<td>6274</td>
<td>516</td>
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</tbody>
</table>

Polastre, Hill, Culler, Versatile Low Power Media Access for Wireless Sensor Networks, SenSys’04
Comparison of Energy Consumption

Polastre, Hill, Culler, Versatile Low Power Media Access for Wireless Sensor Networks, SenSys’04
Throughput

Polastre, Hill, Culler, Versatile Low Power Media Access for Wireless Sensor Networks, SenSys'04
Outlook MAC in WSN

- Many other protocols in WSN
  - LEACH, TRAMA, PAMAS, SMACS, ...

- Very large diversity of protocols
  - very simple and very complex protocols
  - very specialized for certain hardware or not at all
  - TDMA, CDMA, clustering, multi-hop, single-hop, ...

- Further reading
Algorithms for Radio Networks

MAC for WSN

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