Wireless Sensor Networks
4. Medium Access

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- 7. Application
  - Data transmission, e-mail, terminal, remote login
- 6. Presentation
  - System-dependent presentation of the data (EBCDIC / ASCII)
- 5. Session
  - start, end, restart
- 4. Transport
  - Segmentation, congestion
- 3. Network
  - Routing
- 2. Data Link
  - Checksums, flow control
- 1. Physical
  - Mechanics, electrics
MACAW

- Bharghavan, Demers, Shenker, Zhang
  - Palo Alto Research Center, Xerox

- Aim
  - Redesign of MACA
  - Improved backoff
  - Fairer bandwidth sharing using Streams
  - Higher efficiency
    - by 4- and 5-Handshake
MACA 4-Handshake

RTS
MACAW 4-Handshake

CTS
MACAW 4-Handshake
Data
MACAW 4-Handshake

Ack
MACAW
4 Handshake

- Worst-Case blockade
  - Sender sends RTS
  - Receiver is blocked
  - Sender is free
  - But the environment of the sender is blocked
MACAW 4-Handshake

RTS

Reserved Area

Sender

Receiver is blocked

RTS
MACAW 4-Handshake
CTS is missing
MACAW

5 Handshake

- 4-Handshake increases Exposed Terminal Problem
  - Overheard RTS blocks nodes
  - even if there is no data transfer

- Solution
  - Exposed Terminals are informed whether data transmission occurs
  - Short message DS (data send)

- 5 Handshake reduces waiting time for exposed terminals
MACAW
5 Handshake

- Participants
  - Sender sends RTS
  - Receivers answers with CTS
  - Sender sends DS (Data Send)
  - Sender sends DATA PACKET
  - Receiver acknowledges (ACK)

- RTS and CTS announce the transmission duration

- Blocked nodes
  - have received RTS and DS
  - have received CTS

- Small effort decreases the number of exposed terminals
MACAW 5-Handshake
RTS
MACAW 5-Handshake
CTS

- Sender
- Receiver
- CTS
- Reserved area
- blocked

- waits for DS
- waits for DS
MACAW 5-Handshake
DS
MACAW 5-Handshake Data
MACAW 5-Handshake

ACK
Unfair Distribution

- 4 and 5-Handshake create unfair distribution
  - A has a lot of data for B
  - D has a lot of data for C
  - C receives B and D, but does not receive A
  - B can receive A and C, but does not hear D

- A is the first to get the channel
- D sends RTS and is blocked
  - Backoff of D is doubling
- At the next transmission
  - A has smaller backoff
  - A has higher chance for next channel access
Solution
- C sends RRTS (Request for Request to Send)
  - if ACK has been received
- D sends RTS, etc.

Why RRTS instead of CTS?
- If neighbors receive CTS, then they are blocked for a long time
- Possibly, D is not available at the moment
Backoff Algorithms

- After collision wait random time from \{1, .. Backoff\}
- Binary Exponential Backoff (BEB) algorithm
  - Increase after collision
    \[ \text{backoff} = \min\{2 \text{ backoff}, \text{maximal backoff}\} \]
  - Else:
    \[ \text{backoff} = \text{Minimal Backoff} \]
- Multiplicative increase, linear decrease (MILD)
  - Increase:
    \[ \text{backoff} = \min\{1.5 \text{ backoff}, \text{maximal backoff}\} \]
  - Else:
    \[ \text{backoff} = \max\{\text{backoff} - 1, \text{minimal-backoff}\} \]
AIMD → TCP

Competition Control

A → D → B

CWND

Additive Incr.

Multipl. Decre

CWND
Information Dissemination for Backoff-Algorithm

- Backoff parameter are overheard
  - participants adapt the parameters to the overheard backoff values
  - using MILD

- Motivation
  - if a participant has the same backoff value, then the fairness has been reached
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)
Schurgers, Tsiatsis, 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
- sends message

receiver
- wakeup channel
- sleep phase
- ready to receive
- receives message
- data channel
- ready to receive
- acks alarm
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

- 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
- 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

- Only one channel available, no synchronization
- Receiver
  - is awake after sleep period
  - listens channel for messages from
- Transmitter
  - sends long preamble
  - and then the package
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

synchronizer

CTS

B

synchronizer

C

A

sleep phase

SYNC

B

SYNC

C

sleep phase

SYNC

B

awake

awake

awake

awake

awake

awake

awake

awake
Message Transmission

- If a node receives RTS for a foreign node, then it 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

Diagram showing the process of message transmission in S-MAC:

- Node A sends a synchronization signal.
- Node B responds with an RTS signal.
- Node A sends Frame 1.
- Node B acknowledges Frame 1.
- Node B sends Frame 2.
- Node B acknowledges Frame 2.
- Node C is in a sleep phase.
- Node D is in a sleep phase.
- Carrier Sense is used to detect a carrier signal.
Throughput

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