Sensor networks and applications

Data link layer. Wireless Medium Access Control (MAC) techniques

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  - CSMA – Carrier Sense Multiple Access
  - Polling
  - MD (Mediation Device) protocol
- Sensor network solutions
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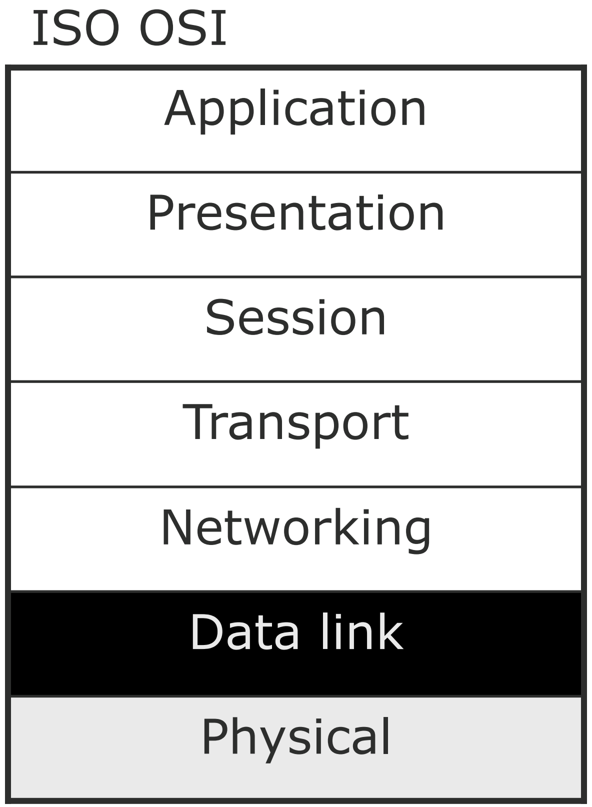
Data link layer

- Main tasks:
  - framing
  - error detection and correction
    - E.g., Hamming code, CRC, Go-Back-n
  - traffic control (flow control)
    - E.g.: ACK, Stop&Wait
  - **MAC – Medium Access Control**



Medium Access Control (MAC)

- Two types of networks:
  1. **point-to-point** communication between any two nodes
  2. **broadcast** channel for all nodes
- The channel is dedicated in point-to-point communication, so there is no need for MAC.
- The main question in using broadcast channel:
  „Who is the winner to have the right to use the channel?”
- *Alternative naming:*
  - *Multiple Access*
  - *Random Access*

Medium Access Control (MAC)

- The channel allocation can be **static** or **dynamic**
- **Static** allocation solutions:
  - frequency division (FDM – Frequency Division Multiplexing)
  - time division (TDM – Time Division Multiplexing)
  - code division (CDM – Code Division Multiplexing)

  Disadvantage: For high number of nodes and/or uneven traffic load the utilization drops dramatically.
- By **Dynamic** channel allocation, channel access can be controlled to take into account the varying needs.

MAC – Assumptions, requirements

- **Assumptions** for channel allocation:
  - *N* independent nodes communicate
  - Single channel, all nodes transmit and receive on this same channel
  - Collision: If two frames overlap in time, the signals are mixed, collision occurs.
  - Collision can be detected by all nodes.
  - Time can be continuous or sliced.
  - Channel monitoring: Are the nodes able to sense if someone else already uses the channel?

MAC – Assumptions, requirements

- Spec. WSN **requirements**:
  - The nodes can be active only during the fraction of time (energy saving)
  - The accuracy of frequency generators (MEMS, cheap crystals) are low, thus time sharing techniques are not effective.
  - Simple, cheap solutions which are easy to implement.

Medium Access Control (MAC) techniques

- Wireless MAC techniques
  - ALOHA
  - CSMA – Carrier Sense Multiple Access
  - Polling
  - MD (Mediation Device) protocol
- Sensor network solutions
  - WINS
  - PicoRadio
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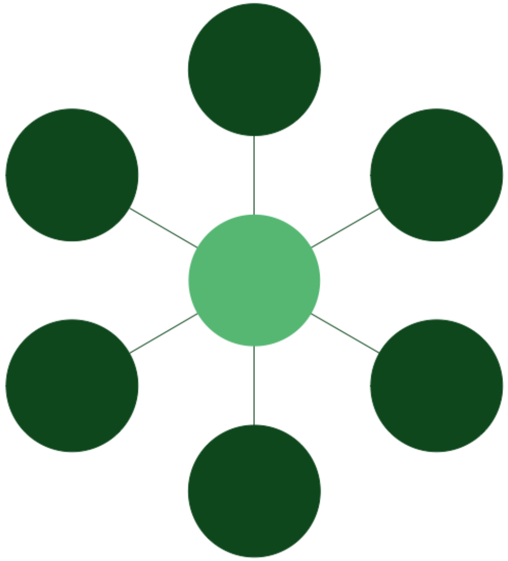
ALOHA

- The first random access wireless MAC.
- Star topology, the controller is in the middle.
- Separate channels for up- and downlink traffic
- The nodes access the channle asynchronously.
- After collision, the nodes re-try after a random back-off..

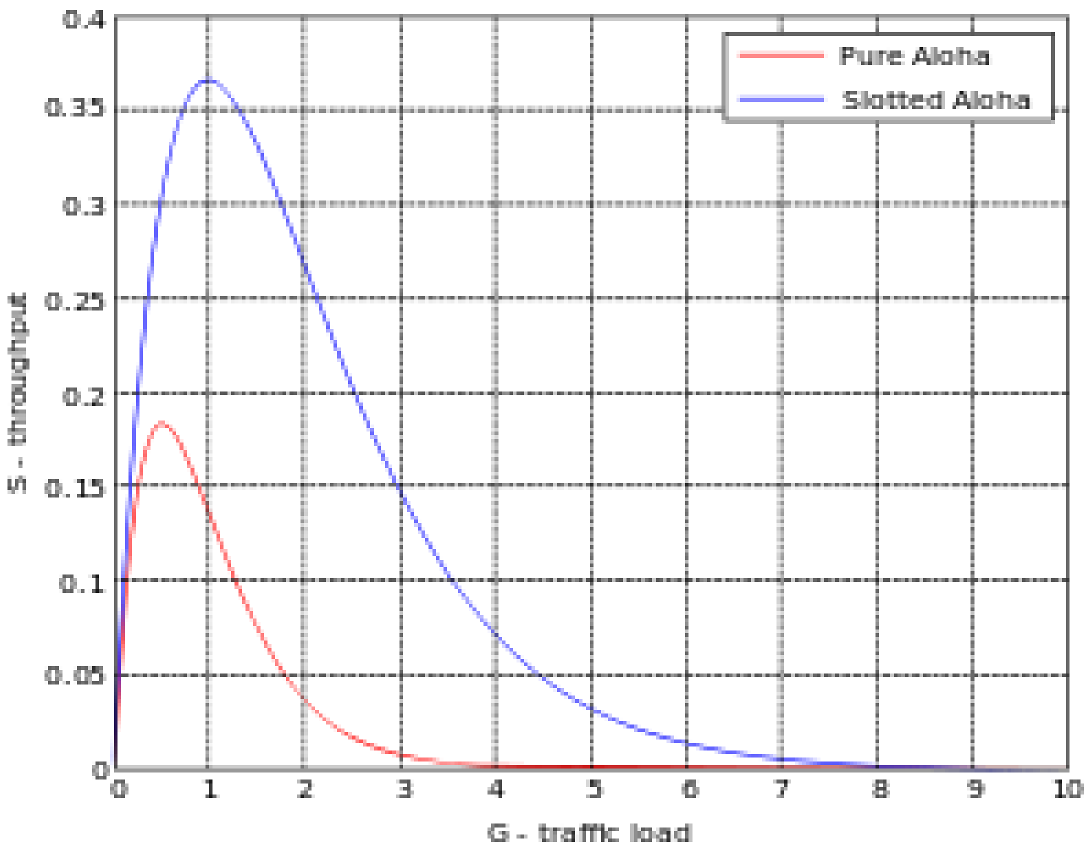


ALOHA

- Throughput assuming Poisson arrival process:

  Ge^{-2G}, where *G* is the offered traffic load.

- The maximum throughput : 1/(2e)=0.184.
- Spec: With slotetd ALOHA the throughput can be increased.
- Using a star topology with a controller in the center is not suitable for WSNs.



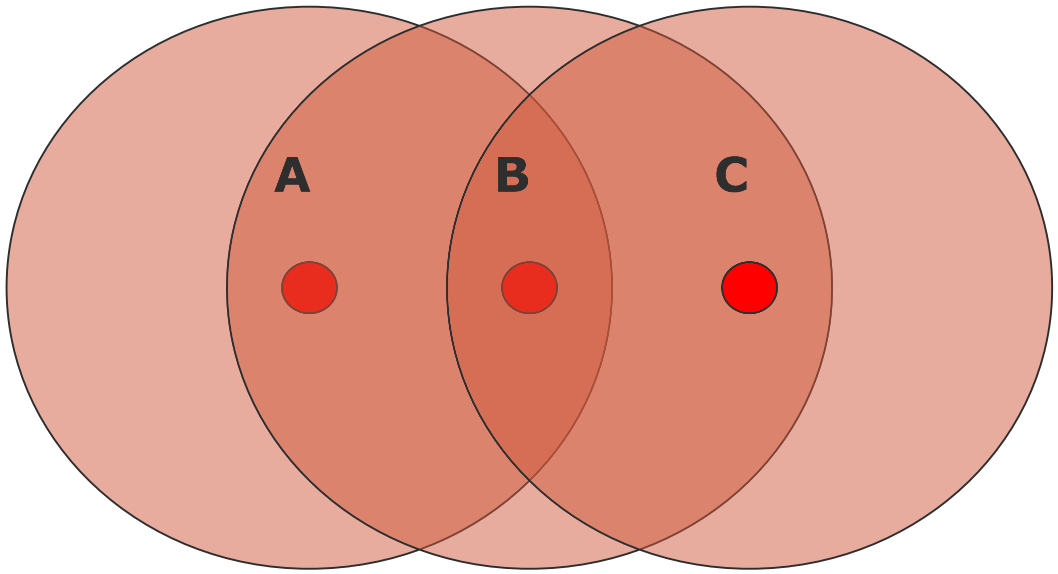
CSMA – Carrier Sense Multiple Access

- CSMA-based protocol family, tries to improve ALOHA’s channel-utilization problem.
- Idea: **All nodes sense the channel before trying to send a packet. They only start transmission if the channel is free.**
- non-persistent CSMA:
  - When the channel is free, the packet is transmitted.
  - When the channle is busy, it waits for random time, then tries again.

  Drawback:
  - The channel is not utilized during random back-offs.
  - When the channel becomes free, more than one nodes can try to access it immediately.
- *p-persistent* CSMA:
  - When the channel is free, the node transmits immediately with probability p, otherwise it backs-off (waits) with probability (1-p).
  - The optimal value for parameter p is the function of traffic load.

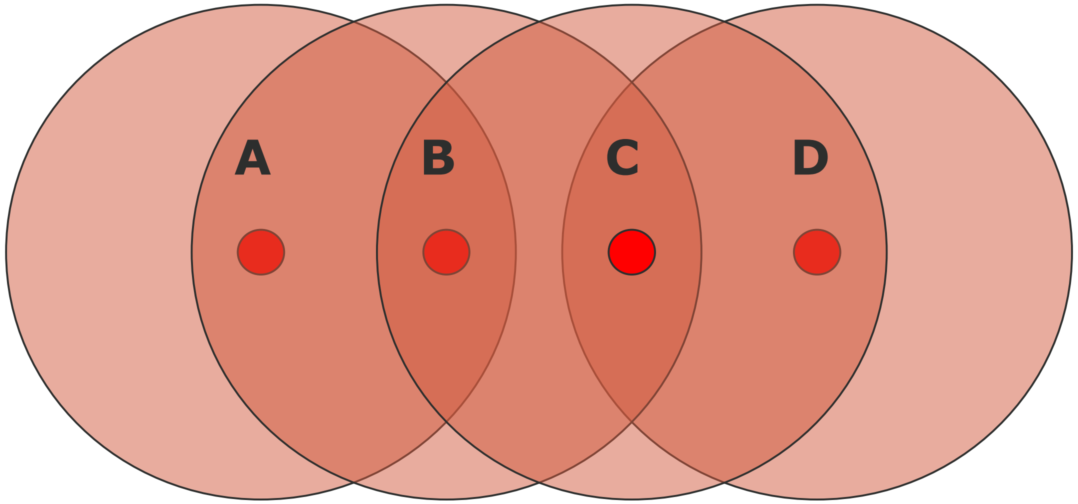
CSMA – hidden terminal problem

- A transmits to B.
- C wants to transmit to B. Checks channel availability, it finds it empty, and starts transmitting.
- B is interferenced, packets are dropped.



CSMA – exposed terminal problem

- B transmits to A.
- C wants to transmit to D. Checks channel availability, finds it busy, then backs-off.
- The communication C-D cannot happed, altough B would not cause any interference for D.



CSMA with busy signal

- The problem of hidden and exposed terminals can decrease channel utilization considerably in WLAN systems.
- Solution: Transmission of „busy signal” on secondary channel
  - The node that is receiving sends a busy signal on a separate channel.
  - All nodes check the busy signal as well before start transmission.
- Drawback:
  - The nodes must be capable of sending and receiving at the same time. (Higher compleity, higher energy consumptions, higher price)
  - The bandwidth requirement is higher because of two separate channels.

MACA – Multiple Access with Collision Avoidance

- **<u>Idea</u>: RTS-CTS („request-to-send” – „clear-to-send”) jelzéscsere prior communication.**
  - The sender sends an RTS packet to the receiver.
  - If not busy, the receiver sends back a CTS packet.
  - The sender starts data transmittion.
- Further variations for RTS-CTS handshake:
  - CSMA/CA (Collision Avoidance): IEEE 802.11 WLAN standard
  - MACAW: Xerox Palo Alto research Center
  - FAMA (Floor Aquisition Multiple Access)

CSMA in sensor networks

- When using CSMA, the problem is that the nodes must sense the channel for a certain time before transmission.
- Without global time sync, a particular node must listen to its different neighbors at different times. There is **no time for sleeping** when the number of neighbors is large
- Achiving global time synchronization in an ad-hoc, multi-hop network with arbitrary topology is not an easy task!

Polling

- Polling can be an alternative to CSMA
  - When polling is used, a node can only transmit data if a master node allows it to do so..
  - This requires that the master node polls all nodes from time to time.
  - If a node signals that it wants to transmit, the task for the master is to determine when it can do it..
  - Channel access is controlled by the master.

Polling

- **Advantages**:
  - **Deterministic timing**, no random delay (meaning small jitter).
  - The centralized control makes it possible to allocate the channel felxibly and according to actual needs (**QoS**).
  - **Fair** access to the channel can be achieved.
  - Avoids the hidden terminal problem.

Polling

- **Disadvantages** in WSNs:
  - The load on master node is high.
  - Nodes must listen to polls, sending negative answers for polling as well.
  - The polling time increases with the number of nodes.
    (Having hundreds or thousands of nodes it can be time consuming!)
  - The architecture assumes that all nodes are within radio range of the master.
    (single-hop communication).

- <u>Note.</u>: There are extensions for multi-hop solutions.

Polling

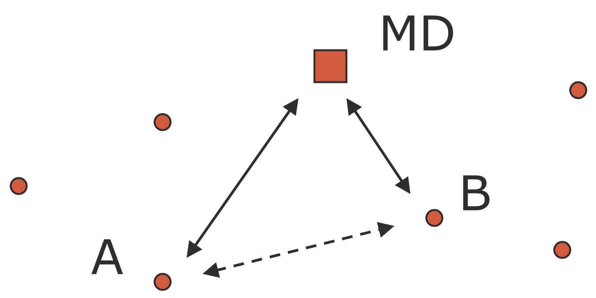
- **Bluetooth** uses polling algorithm as well.
  - Single-hop,
  - maximum 7 slave nodes,
  - synchronous transmission (e.g., real-time voice)
  - Three energy saving modes:
    - HOLD: sleeps for a fixed time but remains in sync
    - SNIFF: wakes up from time to time for a few polls
    - PARK: sleeps for a longer period

  - Managing the different modes are far from being a trivial task.

MD – Mediation Device protocol

- A node „sleeps” during 99.9% of network operation time.

  → Detecting and synchronize with the nodes during the very short active time is hard!



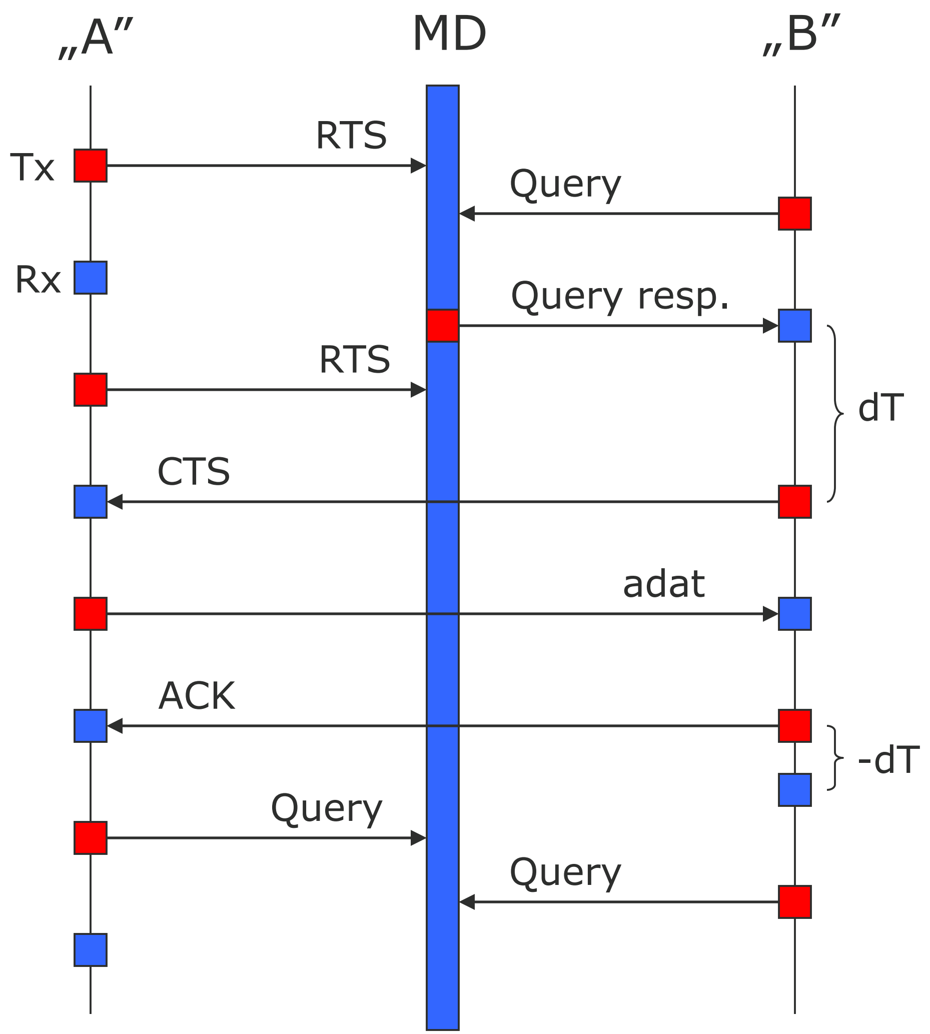
- Possible solution: **mediation device (MD)**
  - The MD mediates between two network nodes.
  - Capable of receiving, storing and sending control messages.
  - Always monitors the channel, it has enough energy for that.

MD protocol

- In normal mode all nodes send a short (< 1ms) „becon” packet to the MD periodically (in every 2 sec), then listen to the channel for a short time.
- Query-beacon: node ID, nothing to send, free.
- The MD receives all node’s beacon, while the nodes are not synchronized together (non-slotted ALOHA)
- If a node wants to send, it sends RTS beacons periodically instead of the query-beacons.
- RTS-beacon: node ID, target ID

MD protocol

1. „A” sends RTS beacons to MD.
2. MD notifies „B”, and sends A’s timing.
3. „B” synchronizes with „A”, and sends a CTS packet directly to „A” after the next RTS.
4. After an ACK the communication starts between „A” and „B”.



Distributed MD protocol

- Disadvantages of MD protocol:
  - All nodes must be within radio range.
  - The MD is always on, monitoring the channel.
  - The centralized system is not robust.
- Solution: distributed MD protocol
  - All nodes share the role of an MD.
  - Each node switches itself to MD mode from time to time, independently from the others, triggered by a random variable.
  - When a node switches to MD mode, it stays active for a full beacon period and collects its neighbors data (ID, timing info).
  - Communication pairs are set-up by the actual MD node.

Distributed MD protocol

- Advantage:
  - No dedicated MD node.
- Drawback:
  - The delay is not fixed. (Before the transmission there should be at least one neighbor in MD mode.)
  - If there are more than one node in MD mode, all of the would respond to a query beacon, resulting in collision.
- Variations:
  - If a node switches to MD mode and maps its neighbors, it announces this after the period ends. All other nodes in MD mode hear this and......

1. go back to normal mode.
2. carry on monitoring, which beacons are acknowledged by the first MD node. There can be nodes that are outside of the radio range of the first MD. In this case they act as MD for these nodes.

Medium Access Control (MAC) techniques

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WINS solution

- **Polling** technique in **relative TDMA** systems.
  - Multi-hop system.
  - no global „beacon”.
  - The TDMA frame is asynchronous between nodes.
  - All nodes agree pairwise with a time slot suitable for both of them.
- **Disadvantages**:
  - There can be many, randomly allocted time slots in a TDMA frame in a dense network.
- **Advantages**:
  - Easy to implement.
  - Suitable for real-time traffic transmission because of the controlled jitter.

PicoRadio

- Proposal for a multi-channel (~30), **code division** multiple access (**CDMA**).
  - All nodes and their neighbors get different codes.
  - Using Orthogonal CDMA codes there are no collisions.
  - Nodes are asynchronous, thus there is no chance to go to sleep, they have to monitor the channel all the time.

- Ultra-low-power „wake-up radio”
  - 1 μW active energy consumption
  - Simple RF amplifier + filter + detector
  - Listens to the channel and wakes up the node if it receives a „wake-up” beacon.

S-MAC

- Wei Ye, John Heidemann, Deborah Estrin, „**An Energy-Efficient MAC Protocol for Wireless Sensor Networks**”, *Proc. of Infocom 2002*, pp. 1567-1576, New York, USA, June 2002

- Wei Ye, John Heidemann, Deborah Estrin, „**Medium Access Control With Coordinated Adaptive Sleeping for Wireless Sensor Networks**”, *IEEE/ACM Transactions on Networking*, 12(3):493-506, June 2004

S-MAC

- S-MAC = Sensor Medium Access Control

- Goal: MAC protocol suitable for sensor networks, that is...
  - energy efficient,
  - self-configuring,
  - scalable and adaptive
    - E.g., the networ size, topology and node density can change.

- Note: Node „fairness” and low delay are not primary requirements.

S-MAC - assumptions

- Modeling assumptions for the sensor network and applications:
  - Many, small nodes deployed randomly.
  - Multi-hop communication.
  - Communication between peers (p2p) (Not towards a dedicated base station)
  - The network must be self-managing
  - The whole network is deployed for a single application.
    - E.g., the Internet is not so!
  - There can be long idle periods in the application.
  - The application is delay tolerant.
    - E.g., not real-time monitoring systems.

S-MAC: Source of energy loss

Critical aspects of energy :

- **Collisions**.
  - If a packet is damaged, it must be re-sent.
  - (Increases delay as well.)
- **Overhearings**.
  - Receiving packets targeted for someone else.
- **Additional control packets**.
  - Receiving and transmitting control information that is „not useful data”.
- **Idle listening**.
  - Waiting for potential packets, listening to the channnel.

S-MAC building blocks

The 4 main building blocks:

- **Periodic listening and sleeping**.
- **Collision avoidance**.
- **Overhearing avoidance**.
- **Message relaying**.
  - For efficient handling of long messages.

(to be cont'd.)