IEEE 802.15.4

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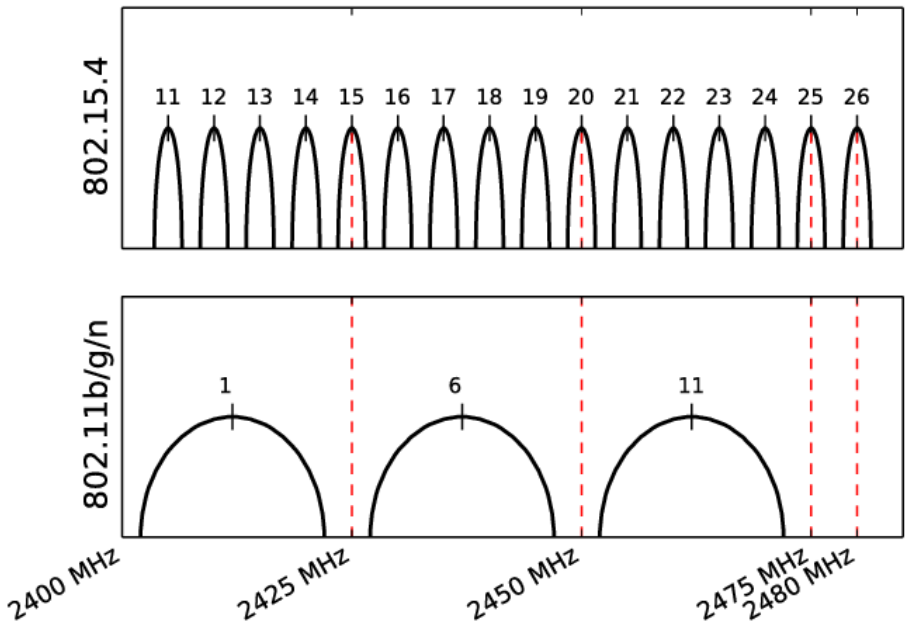
- Defines PHYS and MAC layer for wireless Personal Area networks (PAN)
  - In the license-free ISM radio bands
  - Low range: max. 75m
  - Low rate: max. 250 kbits/s
  - Designed for low-power devices
- What would be the alternatives?
  - IEEE 802.15.1 (Bluetooth). Energy-saving, simplified version: BLE (Bluetooth Low Energy)
  - IEEE 802.11 (WiFi)
  - Advantage of IEEE 802.15.4:
    - networks can form different types of topologies, not only master-slave binding like Bluteooth
    - easier to implement, much less complex than WiFi with its base stations, network associations, etc.

Physical Layer

- In the 868 MHz – 868.6 MHz band (only in Europe)
  - 1 channel (“channel 0”)
  - 20 kbit/s
- In the 902 MHz – 928 MHz band (only in USA)
  - 10 channels (“channels 1 – 10”)
  - 30 kbit/s
- In the 2.4 GHz band
  - 16 channels (“channels 11 – 26)
  - 250 kbit/s
  - Quadrature Phase Shift Keying + Direct-Sequence Spread Spectrum modulation (one form of CDMA)

Physical Layer (2)

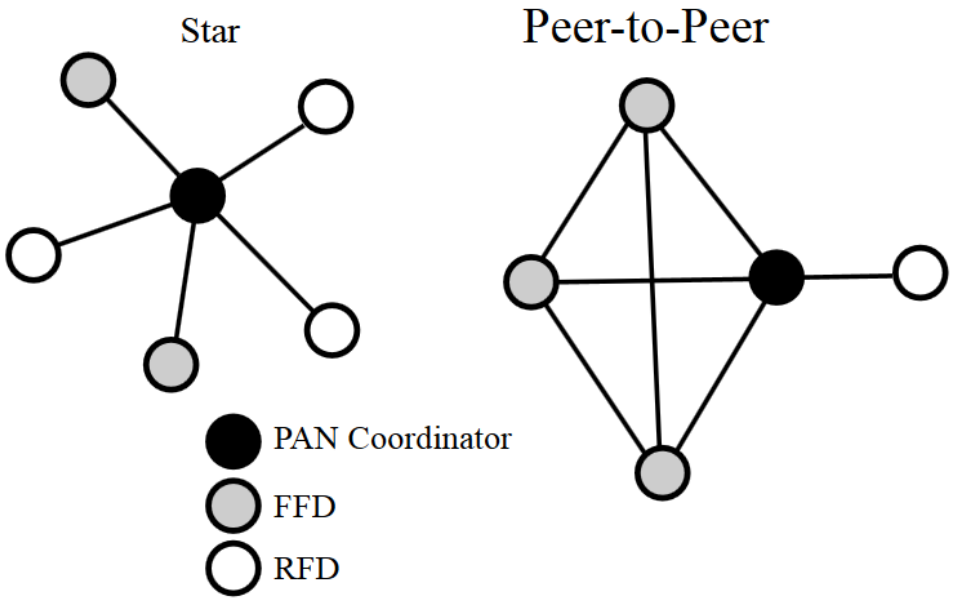
- The devices we use in this course use the 2.4 GHz frequency band
  - Note that a device can only send and receive on one channel at a given time
  - By default, Contiki uses channel 26
- Be carefull: channels 11-14, 16-19, 21-24 of 802.15.4 overlap with the popular channels 1,6,11 of IEEE 802.11b/g (WiFi)



Source: V. Kotsiou et al.

Network Topology

- Two types of nodes:
  - Full Functional Devices: can act as PAN coordinators
  - Reduced Functional Devices: simple & cheep
- Different topologies supported:



Source: Wikimedia

- Many upper-layer protocols define their own topologies on top of the Peer-to-Peer topology

Addresses

- 64-bit unique MAC address
- To save space in the frame header:
  - Nodes get 16-bit short address assigned by coordinator when joining the network
  - Short address is only valid inside PAN
- Inter-PAN communication possible:
  - Frames can contain an (optional) 16-bit PAN identifier

Frame Format

octets: 2	1	0/2	0/2/8	0/2	0/2/8	variable	2
Frame control	Sequence number	Destination PAN identifier	Destination address	Source PAN identifier	Source address	Frame payload	Frame sequence check

bits: 0–2	3	4	5	6	7–9	10–11	12–13	14–15
Frame type	Security enabled	Frame pending	Ack. requested	Intra PAN	Reserved	Dst addr mode	Reserved	Src addr mode

Source: Jürgen Schönwälder

- Maximum frame size: only 127 bytes!
- Different frame types: Beacon frames, Command frames, Data frames, ACK frames
- Optional frame encryption supported with various ciphers, e.g. AES-CCM 128 bit
  - Frame header is authenticated, payload is encrypted
  - Key management must be provided by higher layers

Medium Access Control

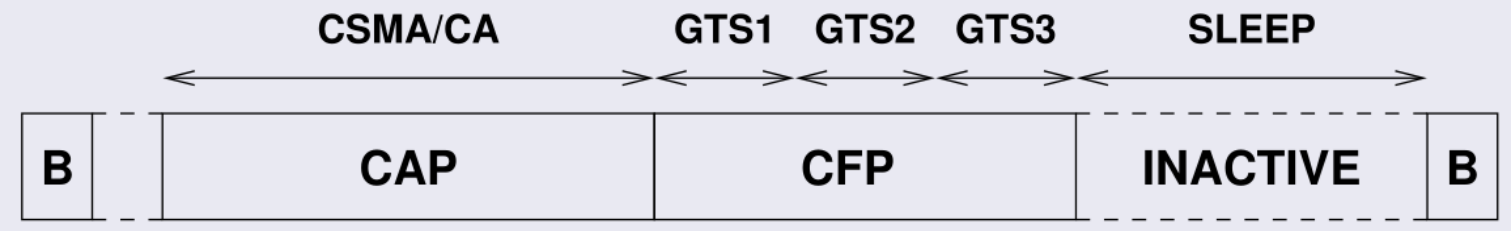
- Typically implemented in software (feasible since slow)
- CSMA/CA
  1. Wait until channel is idle: measure signal strength at antenna
  2. Once channel is free: first wait random backoff interval (0-2.24ms), then start sending
  3. Receiver checks CRC: if wrong, frame is discarded
- MAC layer can send ACK frame
  - ACK frames are optional. Many upper-layer protocols (e.g. TCP) implement their own ACK mechanism

Unslotted Mode

- In unslotted mode, only CSMA/CA is used
- Advantage:
  - Very simple to implement
- But:
  - Receiver has to listen continuously (60mW) and can’t sleep (<5mW)
  - Not suitable for real-time applications due to delays caused by collisions

Slotted Mode

- Superframe structure



Source: Jürgen Schönwälder

B = Beacon frame periodically sent by coordinator

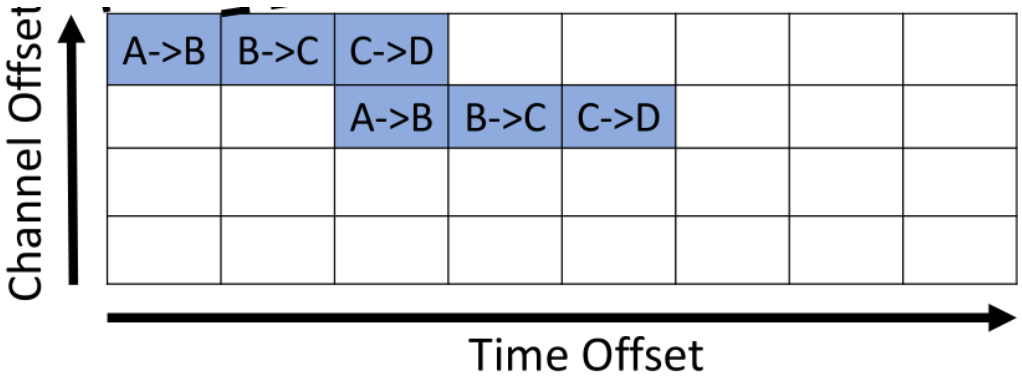
CAP = "Contention Access Period" = CSMA/CA period

CFP = "Contention Free Period" = Guaranteed timeslots assigned by coordinator to nodes

- Properties:
  - Complex. Requires coordinator to assign timeslots.
  - Allows real-time applications: nodes know exactly when they can send without collisions
  - Nodes can sleep during inactivity period

Time Slotted Channel Hopping (TSCH)

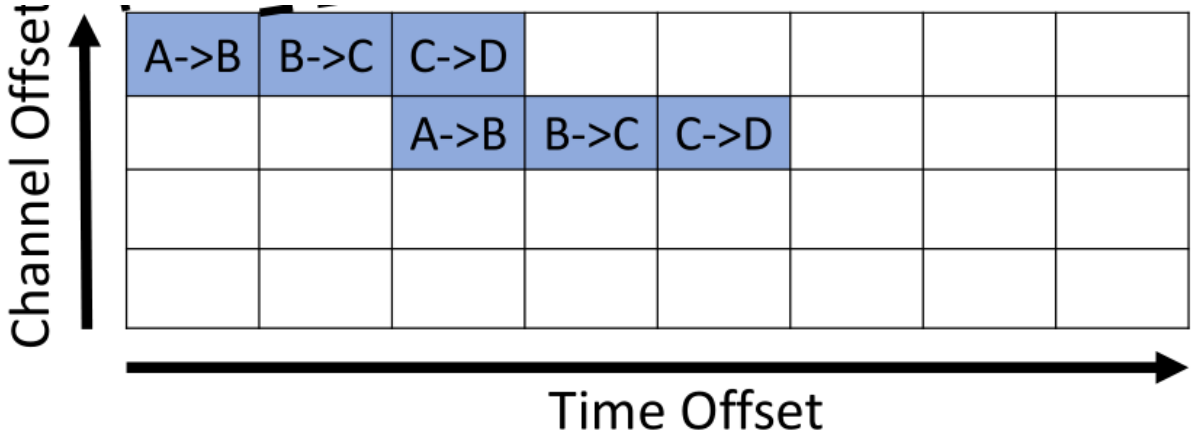
- In Unslotted and Slotted Mode, all devices use the same channel
- In TSCH, all 16 IEEE 802.15.4 channels are used with timeslots
  - typical timeslot length: 10ms (= 1 frame)
  - a timeslot can be shared with other nodes (with CSMA/CA) or be exclusively dedicated to a sender node
- A scheduling scheme decides which timeslots are used by which sender→receiver pair
- Example scheduling (with dedicated timeslots):



Source: Duquennoy et al., 2017

Time Slotted Channel Hopping (TSCH) (2)

- TSCH uses channel hopping: the scheduling cycle repeats, but on a different frequency in each cycle!



- Advantages of TSCH:
  - Thanks to channel hopping, if a channel (a certain frequency band) has a lot of external interferences, the impact on the communication is smaller
  - Nodes know exactly when they have to wake up to send or receive. They can sleep during the other timeslots

Time Slotted Channel Hopping (TSCH) (3)

- How is the scheduling determined?
- Many implementations possible. Active research topic!
  - Static approach: schedule predetermined by owner
  - Centralized approach: Nodes send their communication requests to a scheduler (e.g. the PAN coordinator device) which calculates a schedule and sends it to all nodes
  - Decentralized approach: nodes exchange information about their communication demands
- TSCH development happens in Contiki-NG:
  https://github.com/contiki-ng/contiki-ng/wiki/Documentation:-TSCH-and-6TiSCH

Above IEEE 802.15.4

- IEEE 802.15.4 only defines PHYS and MAC layer
- What to run on top of it?
  - Rime (protocol stack in old Contiki 3.0)
  - ISA100 (used in industrial automation)
  - WirelessHART
  - MiWi
  - ZigBee: used in some Smart Home products. Not free. Defines protocols as well as a high-level application framework.
  - IPv6 with 6LoWPAN (more on this next week)