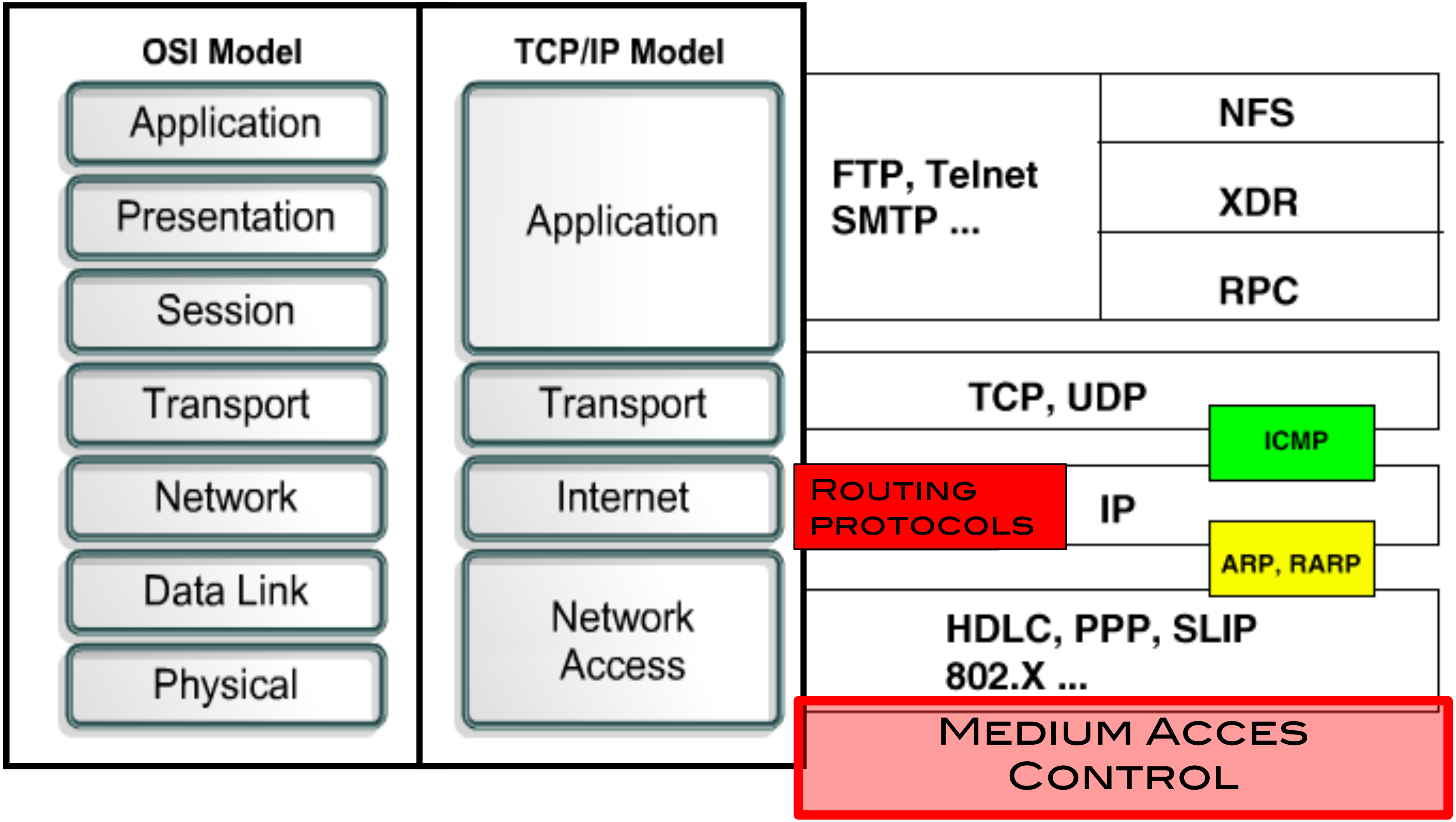
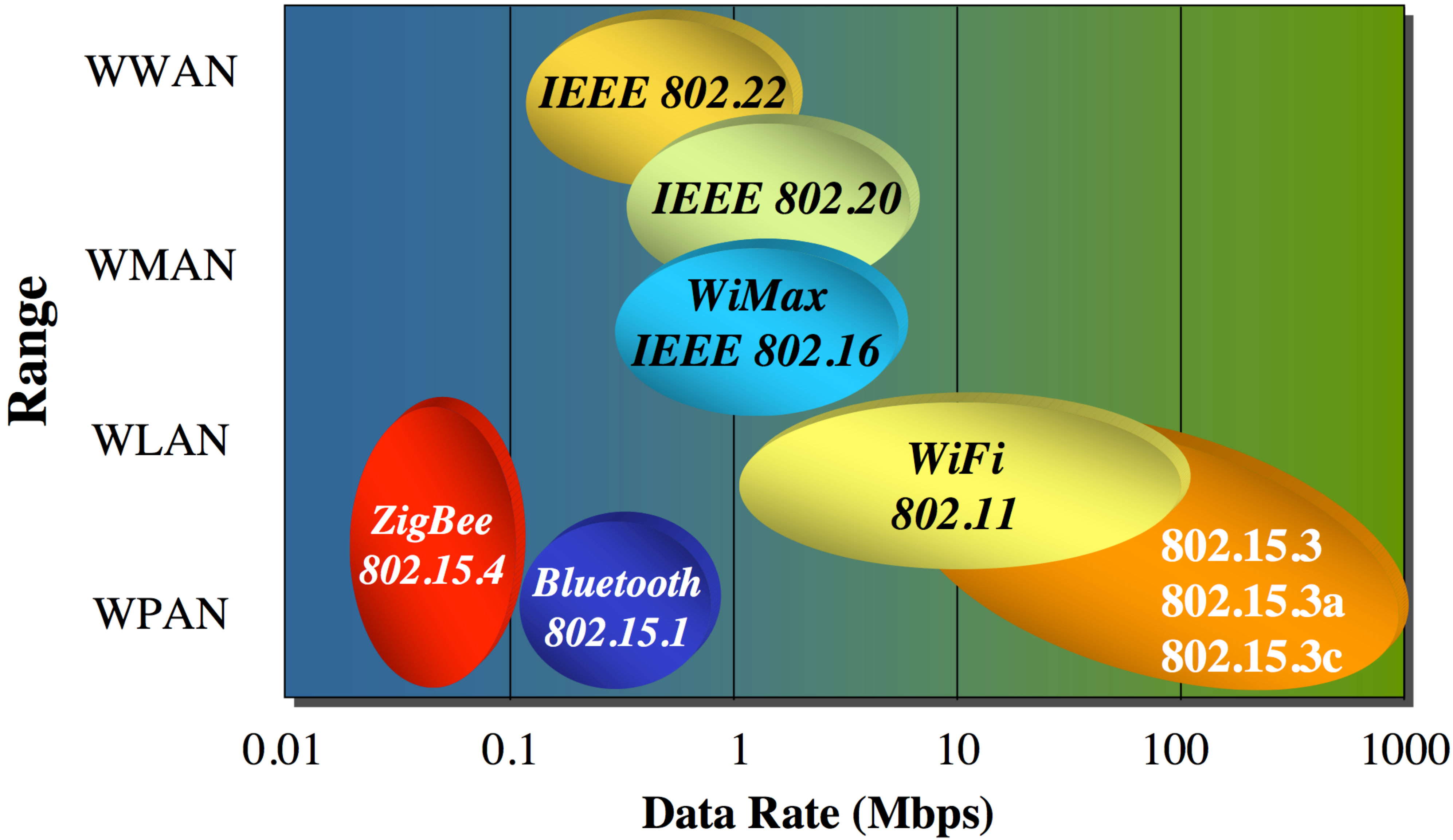
Medium Access Control in Wireless Networks

Prof. Congduc Pham
http://www.univ-pau.fr/~cpham
Université de Pau, France

MAC layer

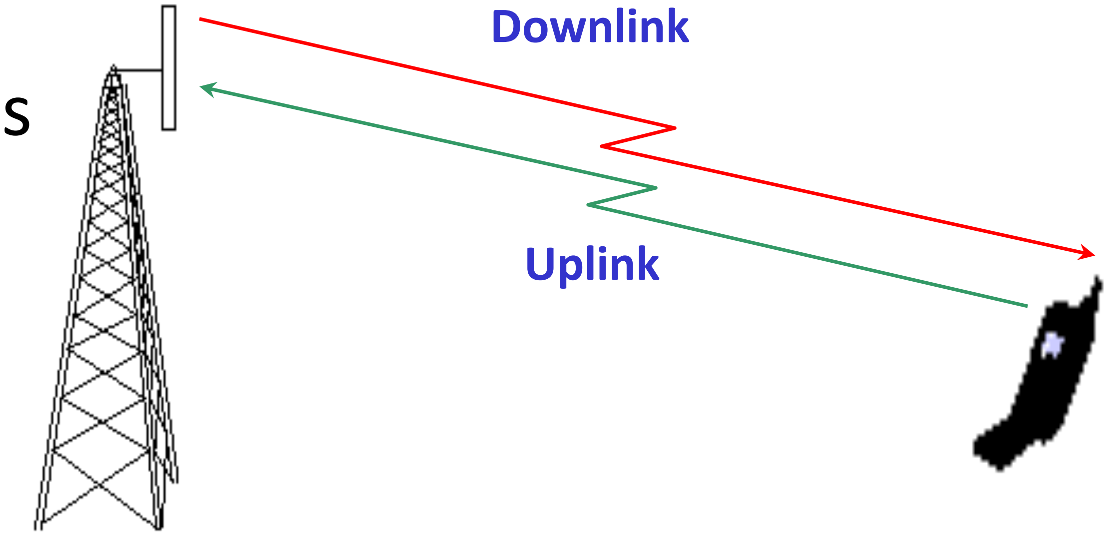

OSI Model
Application
Presentation
Session
Transport
Network
Data Link
Physical
TCP/IP Model
Application
Transport
Internet
Network Access
FTP, Telnet SMTP ...
NFS
XDR
RPC
TCP, UDP
ICMP
Routing protocols
IP
ARP, RARP
HDLC, PPP, SLIP 802.X ...
Medium Acces Control

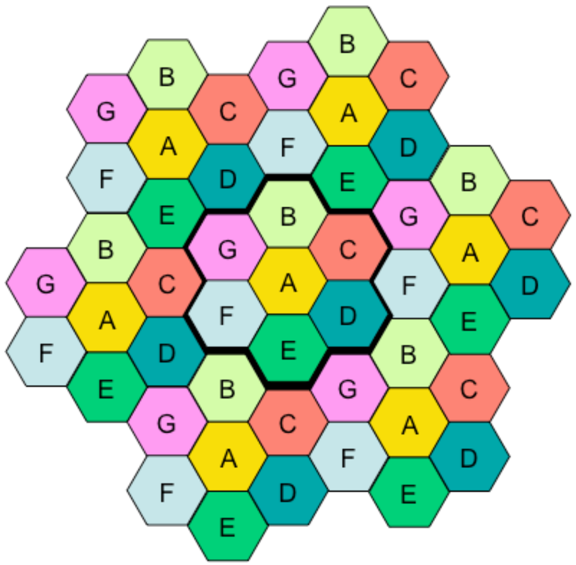
The 802 Wireless Space

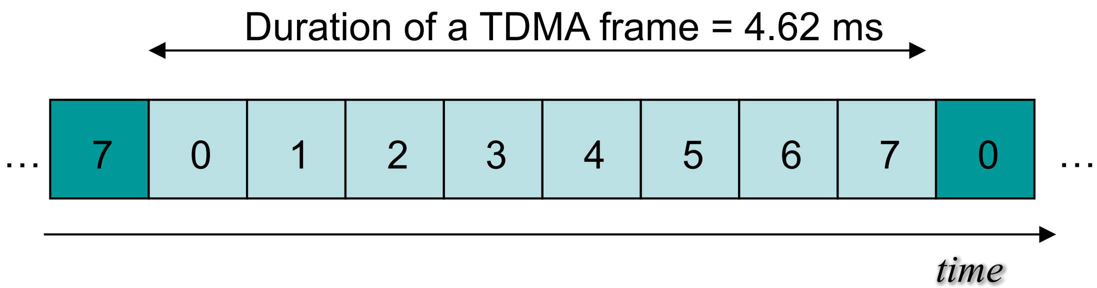


GSM (2G)

Channels

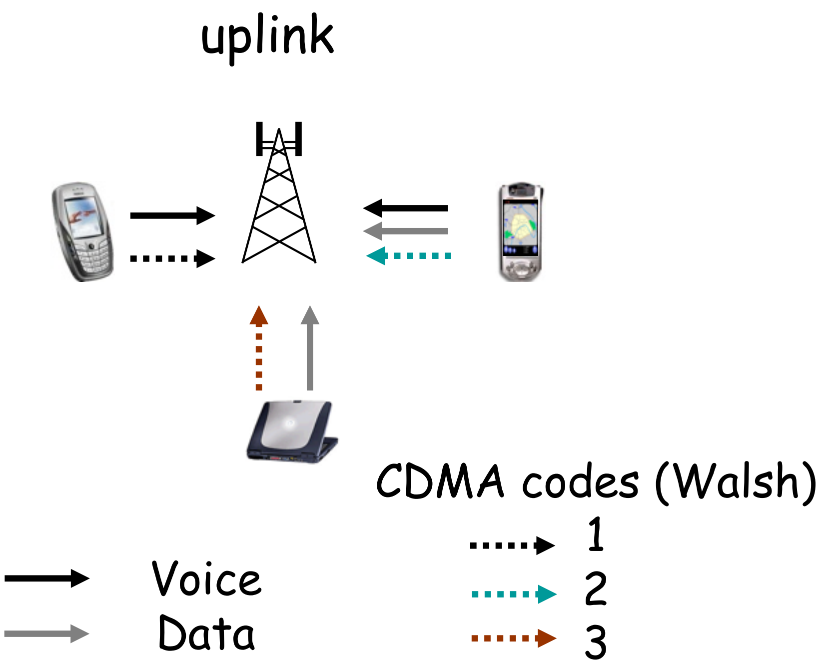






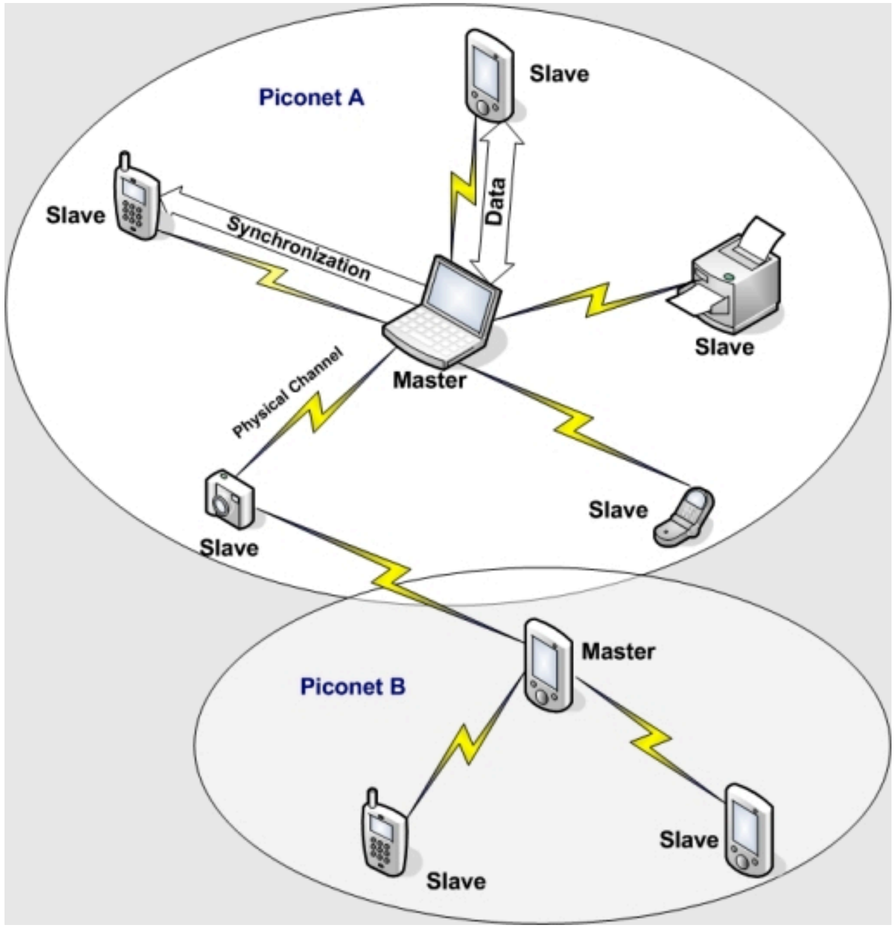
3G and Beyond

- 3G and beyond use CDMA techniques



Bluetooth, 802.15.1

- GFSK
- Bluetooth 2
  - π/4-DQPSK
  - 8DPSK
- Master-slave, Piconet organization
- Master will poll slaves for data

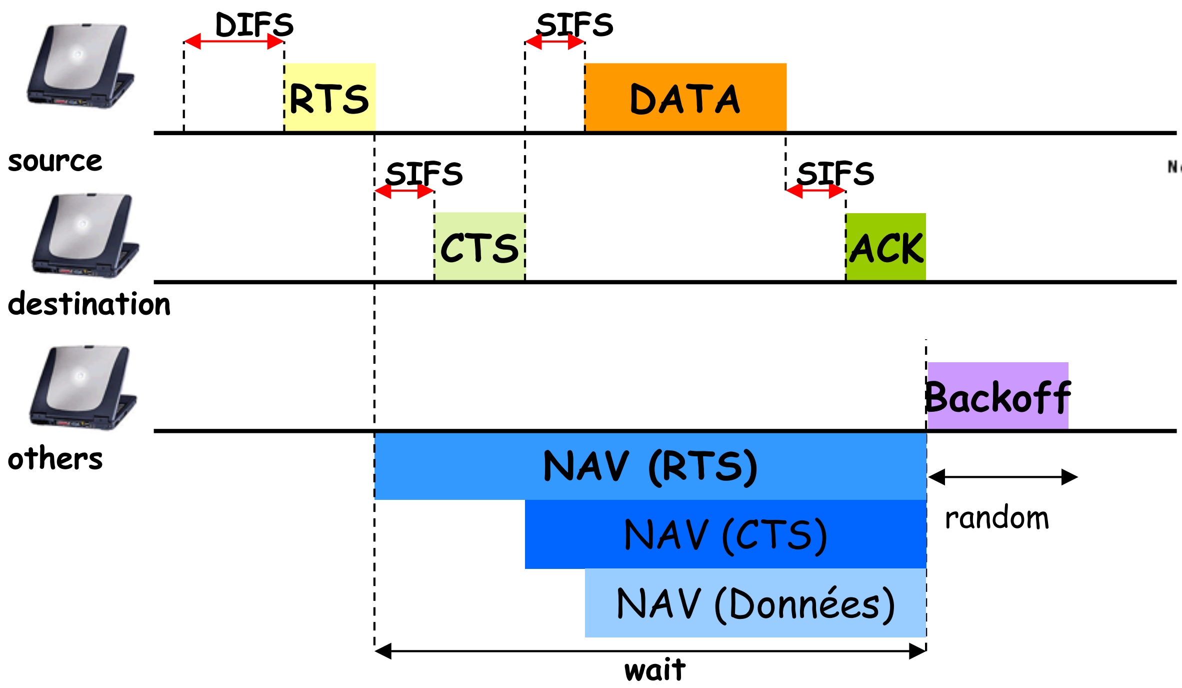


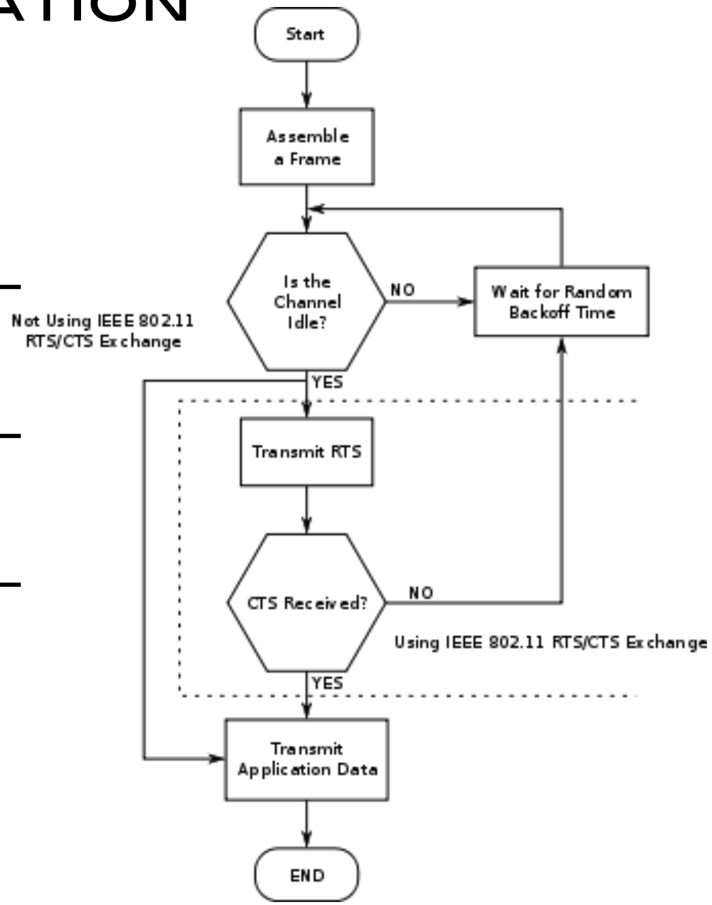
Wifi 802.11

- Uses CSMA/CA, a contention-based access method

CSMA/CA

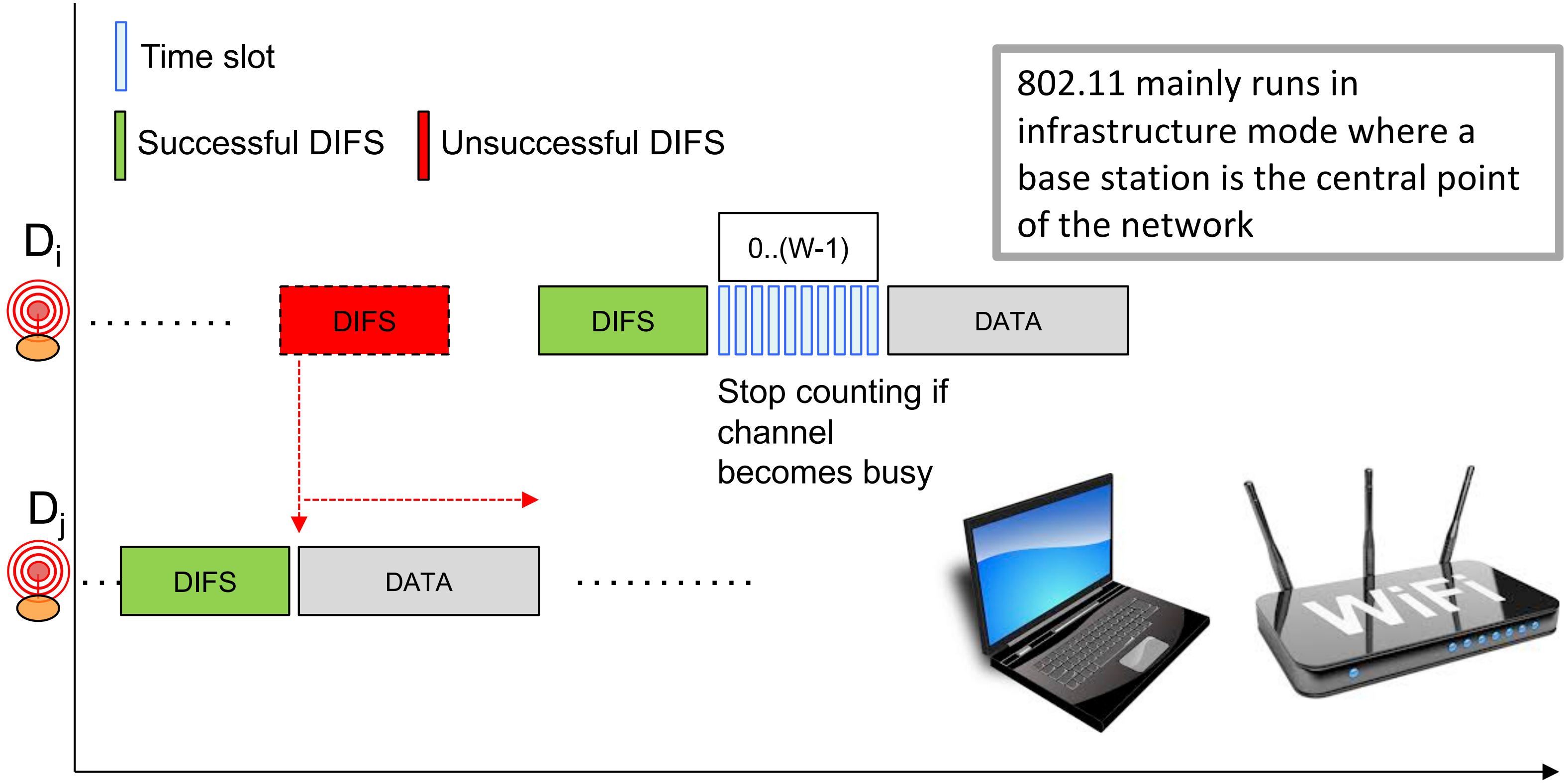
- Collision Avoidance with RTS/CTS to limit the hidden terminal problem
- DCF (Distributed Coordination Function)





CSMA/CA IN IMAGE

802.11 mainly runs in infrastructure mode where a base station is the central point of the network

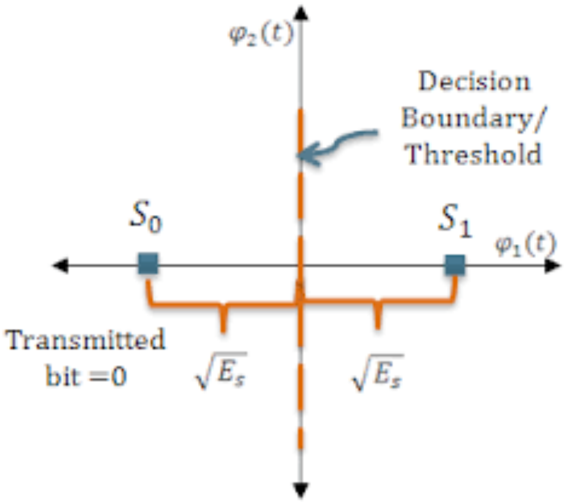


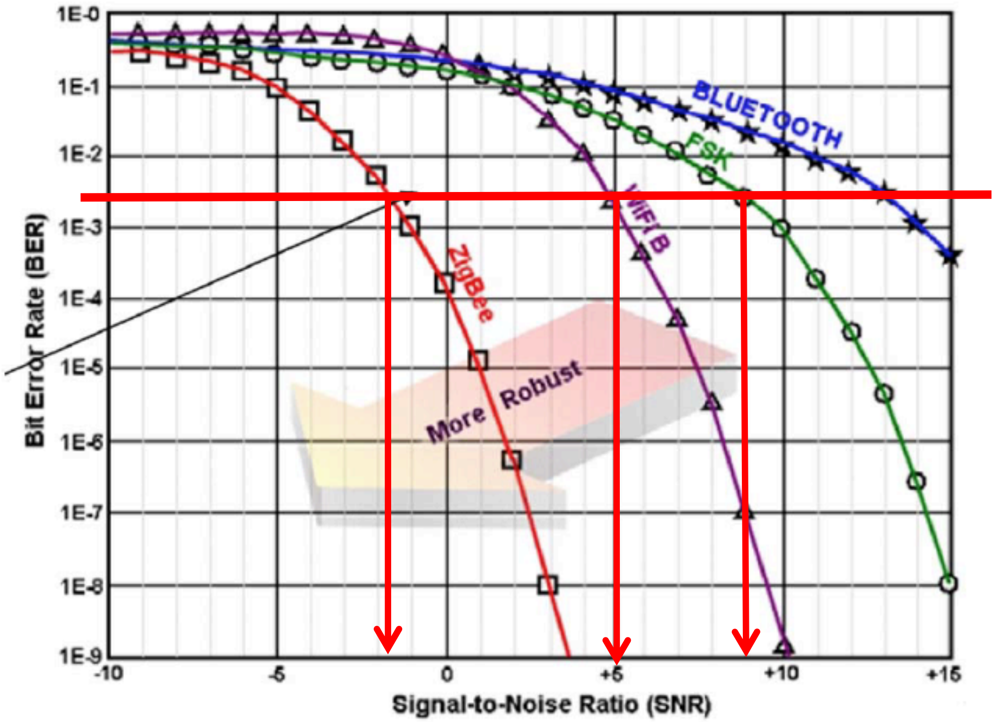
What technology for small devices?

- TDMA is possible but wastes a lot of resources, difficult to scale
- FDMA is not very flexible for dynamic, spontaneous ad-hoc networks
- CDMA is not very suitable for ad-hoc network, without master or base stations
- Wifi consumes a lot of energy, but the contention-based access seems the most suitable

IEEE 802.15.4 in ISM 2.4GHz

- Low-power radio in the 2.4GHz band offering 250kbps throughput at physical layer
- Power transmission from 1mW to 100mW for range from 100m to about 1km is LOS
- BPSK, used as physical layer in ZigBee





Review of Medium busy time

- Depends on the radio throughput
- Examples with a 100-bytes pkt
  - 100 bytes = 800 bits
  - Ethernet 10Mbps: $800/10.10^6$=80us
  - Ethernet 100Mbps: $800/100.10^6$=8us
  - WIFI 11Mbps: $800/10.10^6$=72us
  - WIFI 54Mbps: $800/54.10^6$=14.8us
  - 802.15.4 350kbps: $800/250.10^3$=3.2ms
- If 3.2ms is a 10-meter bus
  - 72us is a 20cm rule!
  - 14.8us is a 4cm toy car!

Principles

- IEEE 802.15.4 MAC
  - To/From coordinator node
  - Peer-to-peer
- The coordinator mode defines a star tolopogy and severals MAC mechanisms can be used: beacon and non-beacon mode, GTS,...
- Peer-to-Peer data transfer model allows any node to communicate with other nodes provided that they are in (radio) communication range. Only non-beacon unslotted CSMA/CA is used.

Supported topologies

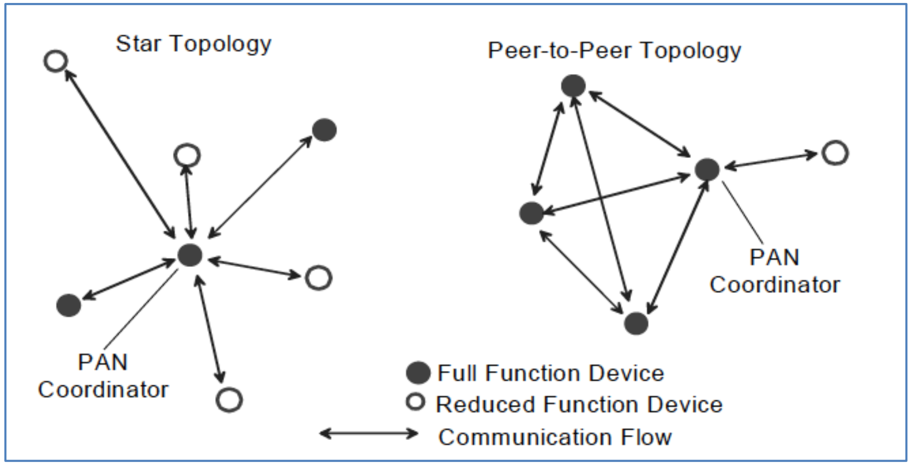


Figure from IEEE document standard on 802.15.4

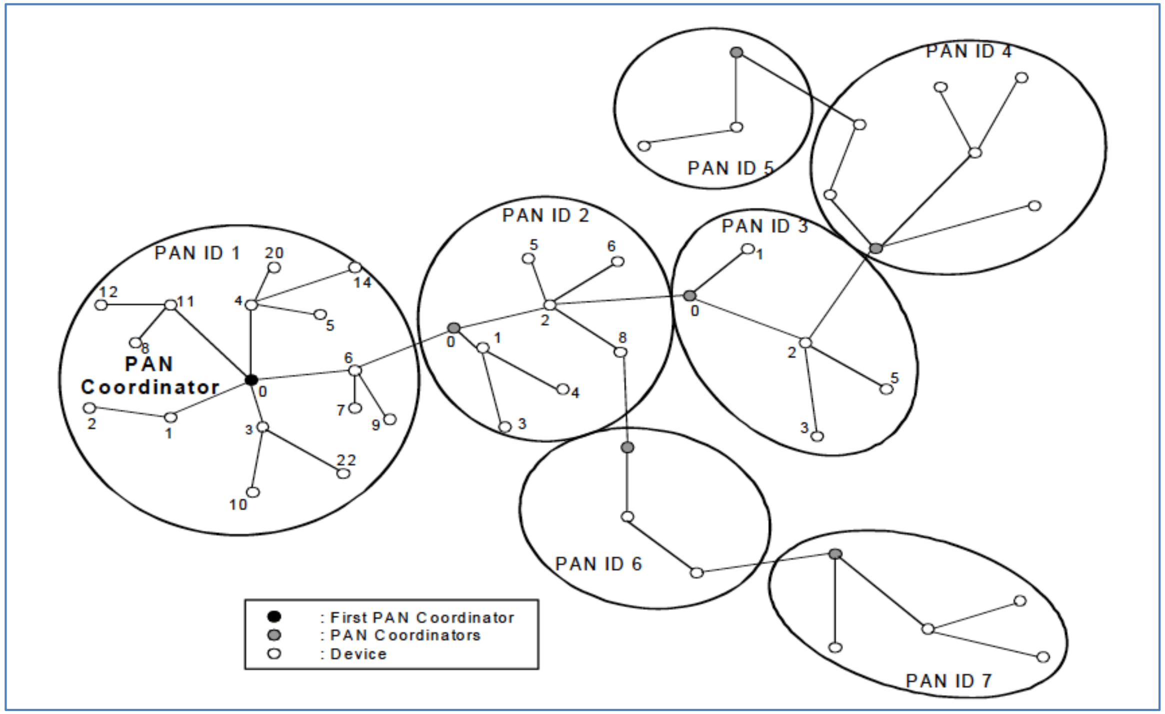
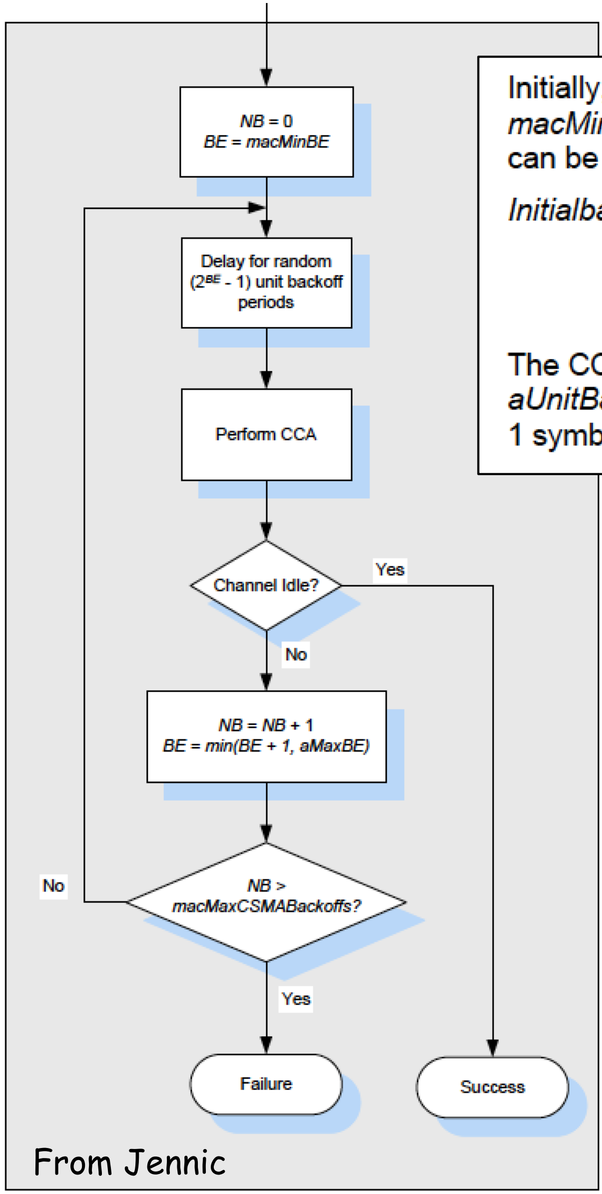


Figure from IEEE document standard on 802.15.4

Non-beacon unslotted CSMA & CCA



Initially, the back-off exponent *BE* is set to *macMinBE*. Using the default value of 3 for *macMinBE* and assuming the channel is found to be free, the worst-case channel access time can be calculated as:

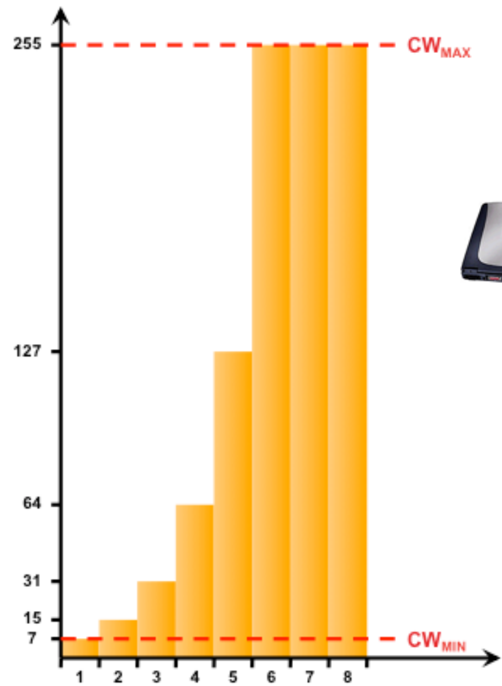
InitialbackoffPeriod + *CCA* = $(2^3 - 1)$ x *aUnitBackoffPeriod* + *CCA*

= 7 x 320 μs + 128 μs

= 2.368 ms

The CCA detection time is defined as 8 symbol periods.
aUnitBackoffPeriod is defined as 20 symbol periods.
1 symbol period is equal to 16 μs.

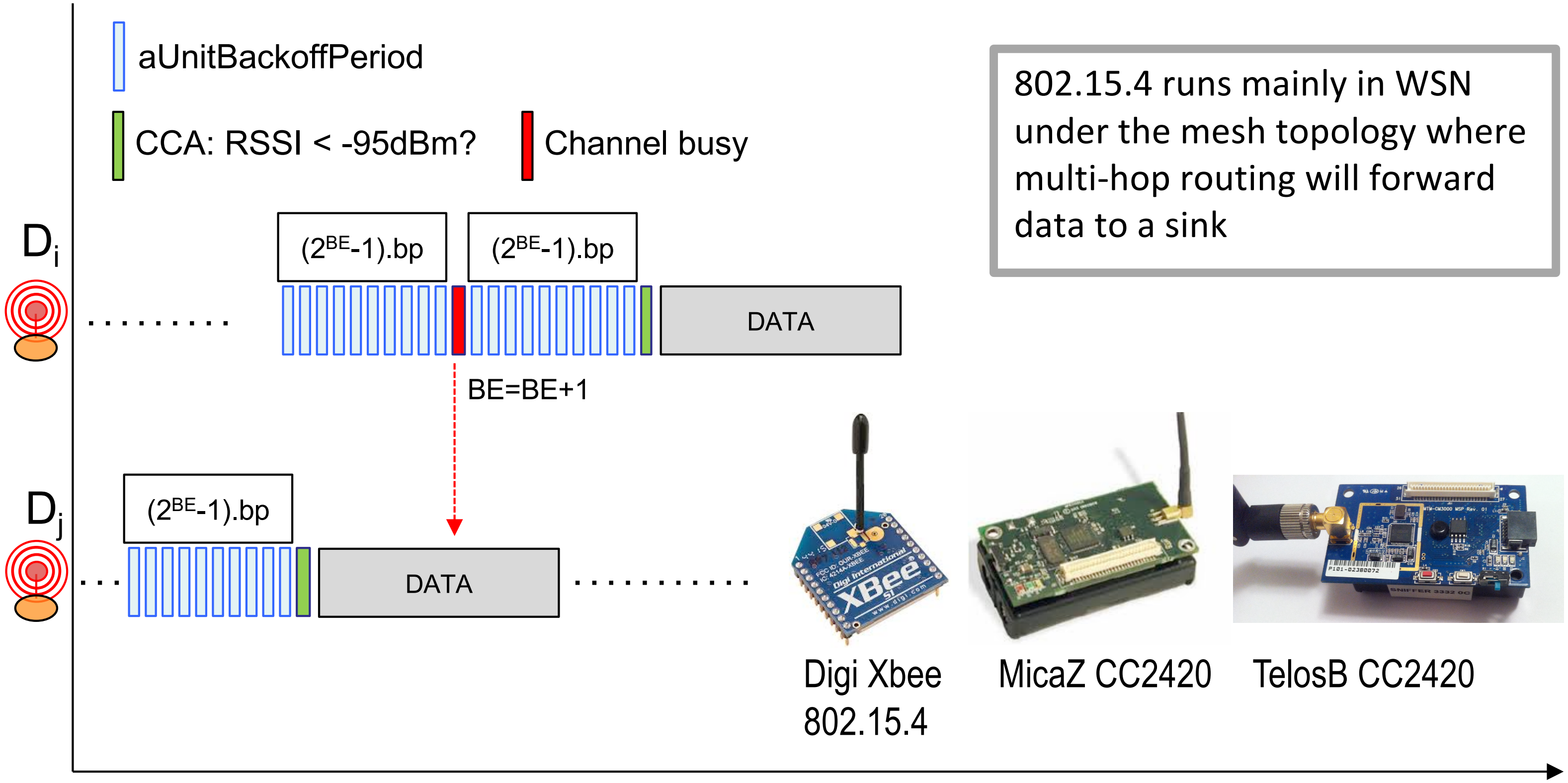
From Jennic



802.15.4 CCA is somehow similar to WIFI DIFS interframe spacing

Unslotted CSMA/CA in IMAGE

- BE=macMinBE=3; <macMaxBE
- NB=0; <macMaxCSMABackoff



DIFFERENT FROM 802.11 CSMA/CA

- Compared to IEEE 802.11, IEEE 802.15.4 always implements a backoff timer prior to any transmission and simply increases the backoff timer interval each time the channel is found busy for the same packet, without constantly checking the channel to know when it is going back to idle.

Reasons?

- simply increasing the backoff timer interval is less energy consuming than determining the end of the current transmission, especially if the transmission of a packet can take a long time (802.15.4 usually runs at 250kbps while 802.11 runs at 11Mbps and above).
- Another reason is because the node and traffic density of IEEE 802.15.4 networks is expected to be much smaller than those of WiFi networks.
- 802.15.4 for WSN mainly runs under mesh topology (i.e. P2P and without central coordinator) with a shorter radio range (i.e. low transmit power), therefore the spatial reuse is higher, contributing again to decrease the traffic density at any given point in the network.

Beacon-enabled PAN

- "The standard allows the optional use of a superframe structure. The format of the superframe is defined by the coordinator."
- "The superframe is bounded by network beacons sent by the coordinator (see Figure 4a) and is divided into 16 equally sized slots. Optionally, the superframe can have an active and an inactive portion (see Figure 4b)."
- "The beacon frame is transmitted in the first slot of each superframe. If a coordinator does not wish to use a superframe structure, it will turn off the beacon transmissions."

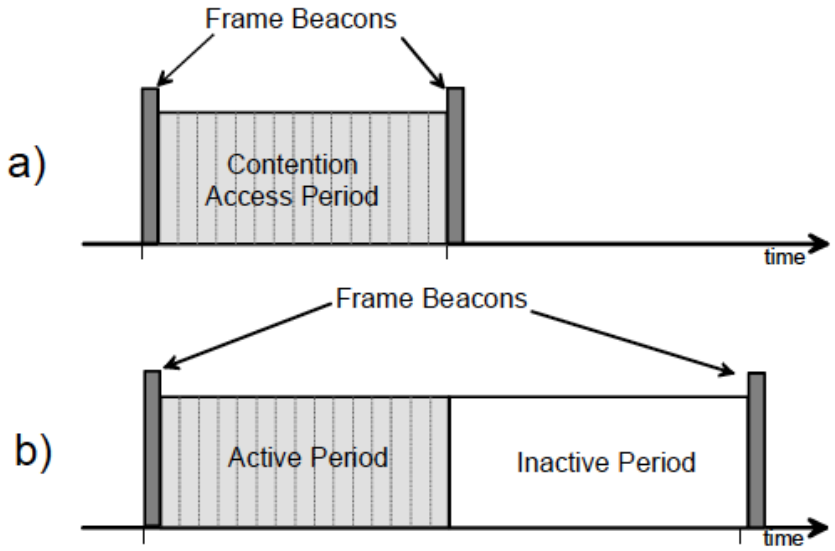


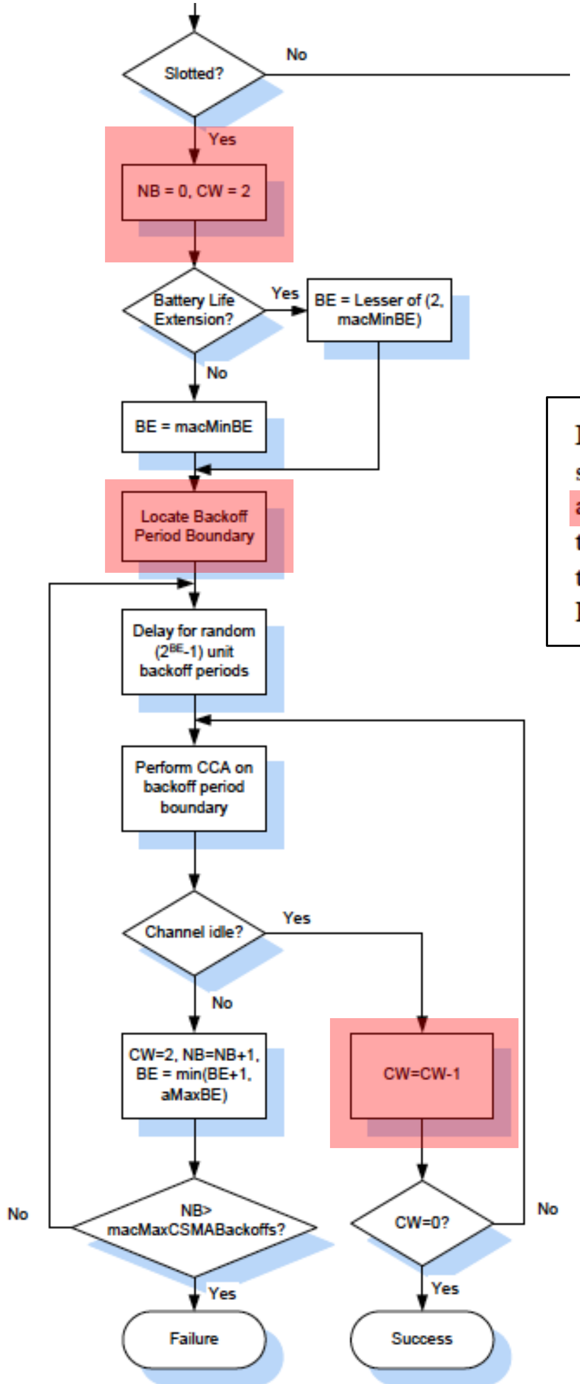
Figure 4—Superframe structure without GTSs

Figure and text from IEEE document standard on 802.15.4

Beacons-mode and CAP

- "The beacons are used to synchronize the attached devices"
- "Beacon-enabled PANs use a slotted CSMA-CA channel access mechanism, where the backoff slots are aligned with the start of the beacon transmission."
- "Any device wishing to communicate during the contention access period (CAP) between two beacons competes with other devices using a slotted CSMA-CA mechanism."

Text from IEEE document standard on 802.15.4



Slotted CSMA

In slotted CSMA-CA, two CCAs, each starting at the beginning of a backoff period, have to be performed

In slotted CSMA-CA, the backoff period boundaries of every device in the PAN shall be aligned with the superframe slot boundaries of the PAN coordinator, i.e., the start of the first backoff period of each device is aligned with the start of the beacon transmission. In slotted CSMA-CA, the MAC sublayer shall ensure that the PHY commences all of its transmissions on the boundary of a backoff period. In unslotted CSMA-CA, the backoff periods of one device are not related in time to the backoff periods of any other device in the PAN.

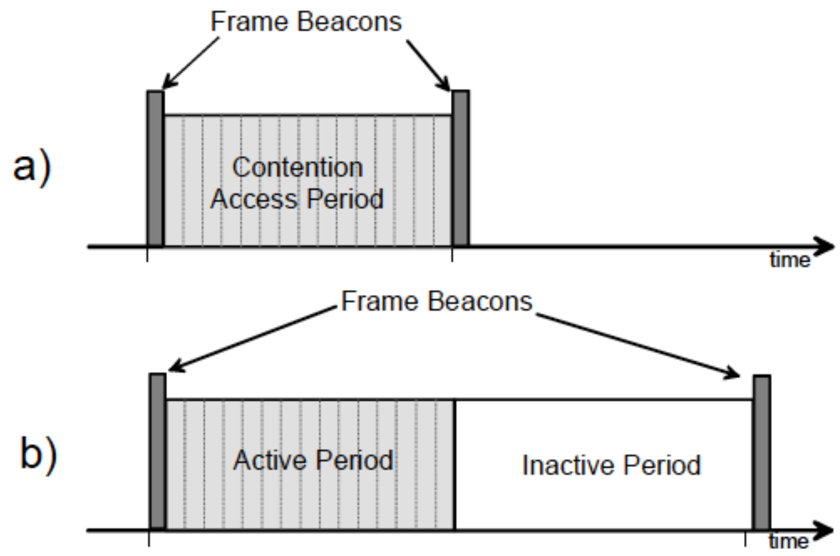


Figure 4—Superframe structure without GTSs

Hybrid access

- "For low-latency applications or applications requiring specific data bandwidth, the PAN coordinator may dedicate portions of the active superframe to that application. These portions are called guaranteed time slots (GTSs)."
- "The GTSs form the contention-free period (CFP), which always appears at the end of the active superframe starting at a slot boundary immediately following the CAP, as shown in Figure 5."
- "All contention-based transactions is completed before the CFP begins. Also each device transmitting in a GTS ensures that its transaction is complete before the time of the next GTS or the end of the CFP."

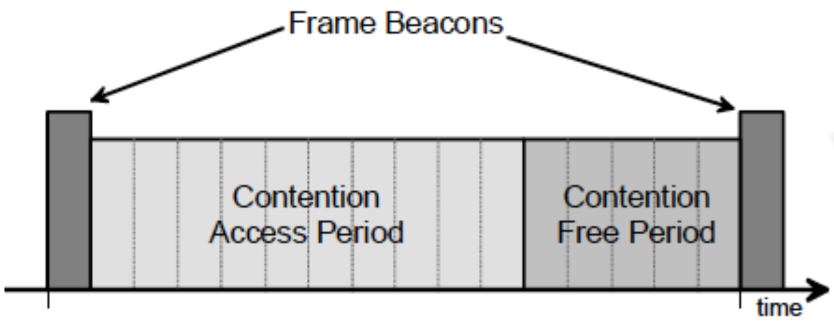


Figure 5—Superframe structure with GTSs

GTS mode needs a PAN coordinator which will allocate up to 7 GTS slots in the frame. Nodes can reserved a given number of GTS slots to send data to the PAN coordinator, which acts as the sink.

Figure and text from IEEE document standard on 802.15.4

Superframe definition

- The structure of the superframe is described by the values of macBeaconOrder and macSuperframeOrder.
- The MAC PIB attribute macBeaconOrder , describes the interval at which the coordinator shall transmit its beacon frames. The value of macBeaconOrder, BO , and the beacon interval, BI, are related as follows: for 0≤ BO ≤ 14, BI = aBaseSuperframeDuration * 2^{BO} symbols.
- PANs that do not wish to use the superframe structure (referred to as a non beacon-enabled PAN) shall set both macBeaconOrder and macSuperframeOrder to 15. Transmissions use unslotted CSMA/CA and GTSs shall no be permitted.

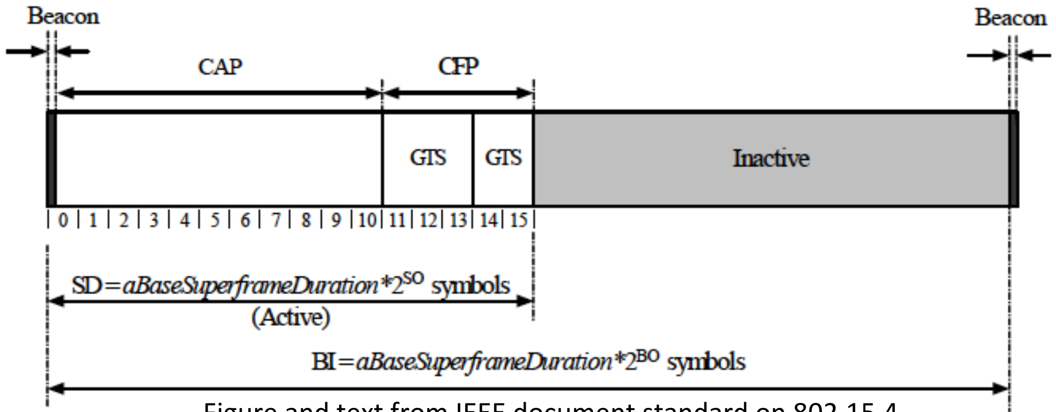


Figure and text from IEEE document standard on 802.15.4

Beacon, Data and ACK frame structure

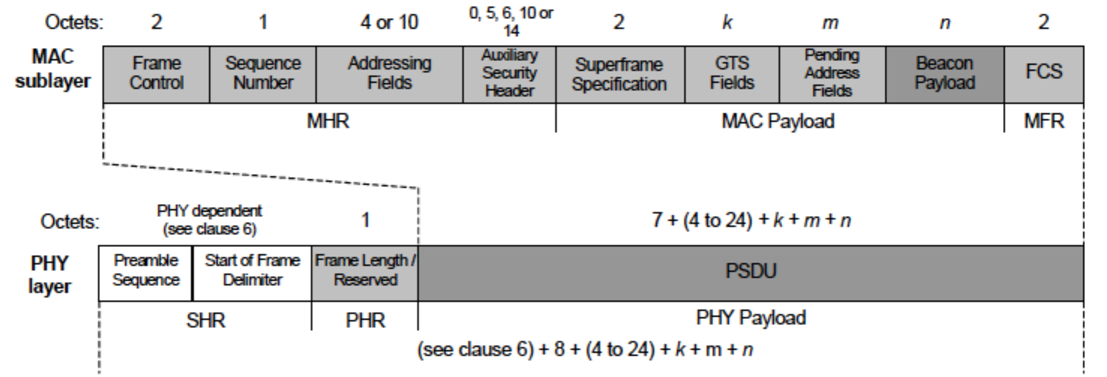


Figure 10—Schematic view of the beacon frame and the PHY packet

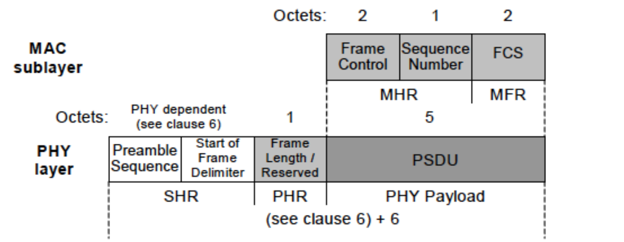


Figure 12—Schematic view of the acknowledgment frame and the PHY packet

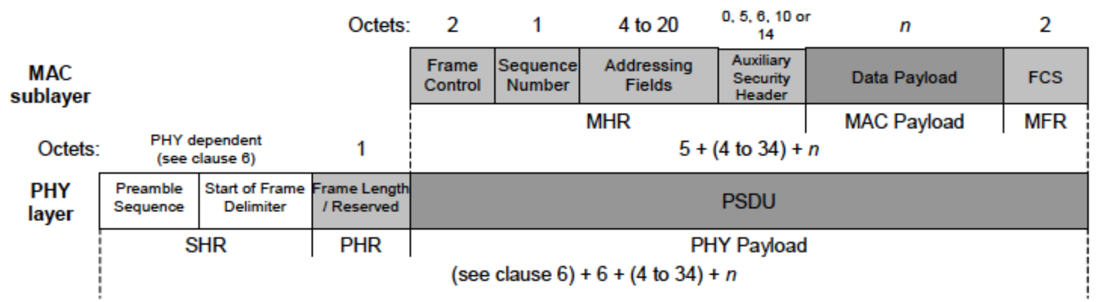


Figure 11—Schematic view of the data frame and the PHY packet

802.15.4 DATA FRAME

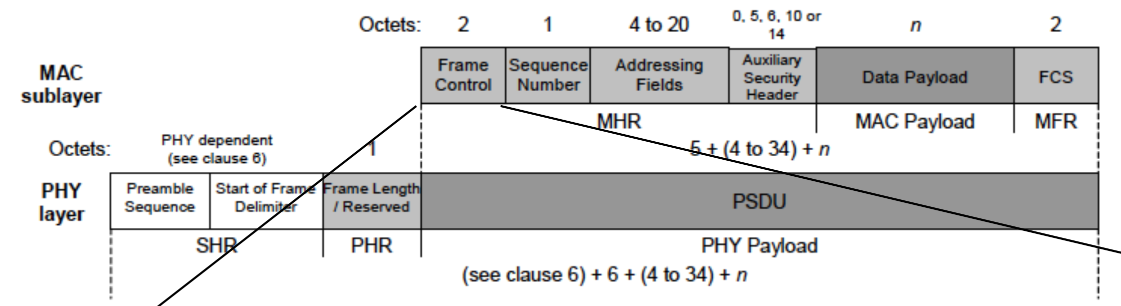


Figure 11—Schematic view of the data frame and the PHY packet

Bits: 0–2	3	4	5	6	7–9	10–11	12–13	14–15
Frame Type	Security Enabled	Frame Pending	Ack. Request	PAN ID Compression	Reserved	Dest. Addressing Mode	Frame Version	Source Addressing Mode

802.15.4 Reliability

- Data frames sent in unicast can required ACKs
- ACKs must be sent 192us after frame reception (no CSMA/CA)
- At the sender side there are 3 retries if no ACK have been received

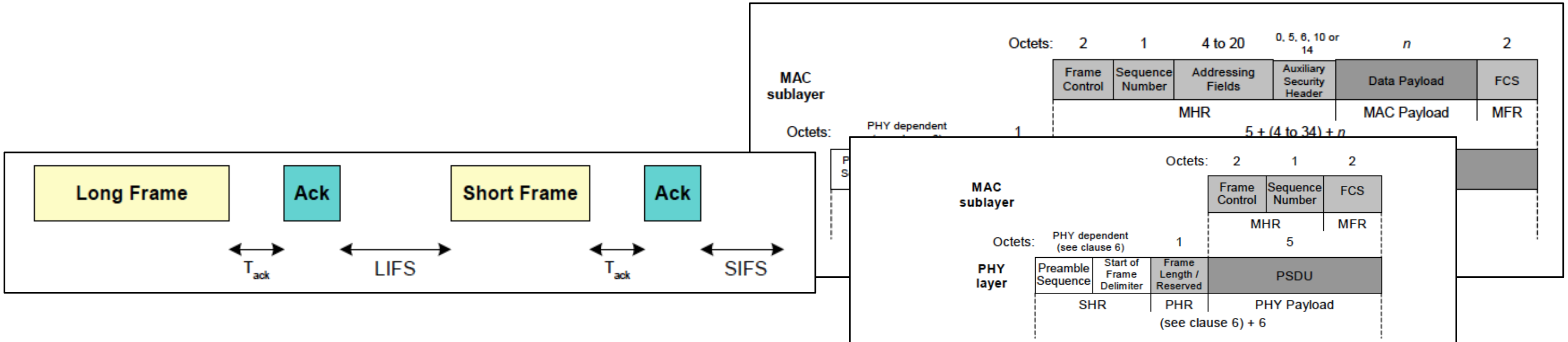


Figure 12—Schematic view of the acknowledgment frame and the PHY packet

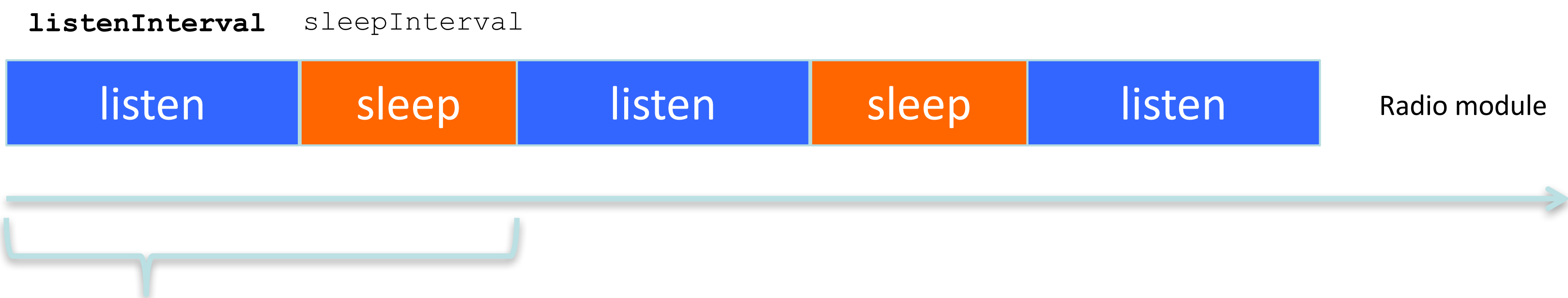
802.15.4 MAC is far from perfect

- Radio circuits, if always on, can consume all the battery's energy
- WSN have a very sporadic behavior: idle for a long period of time, then burst of data
- Passive listening, i.e. receiving a packet that is not for you, can consumes as much as energy than packet transmission!

Duty-cycled MAC
based on CSMA(/CA), with optional beacons

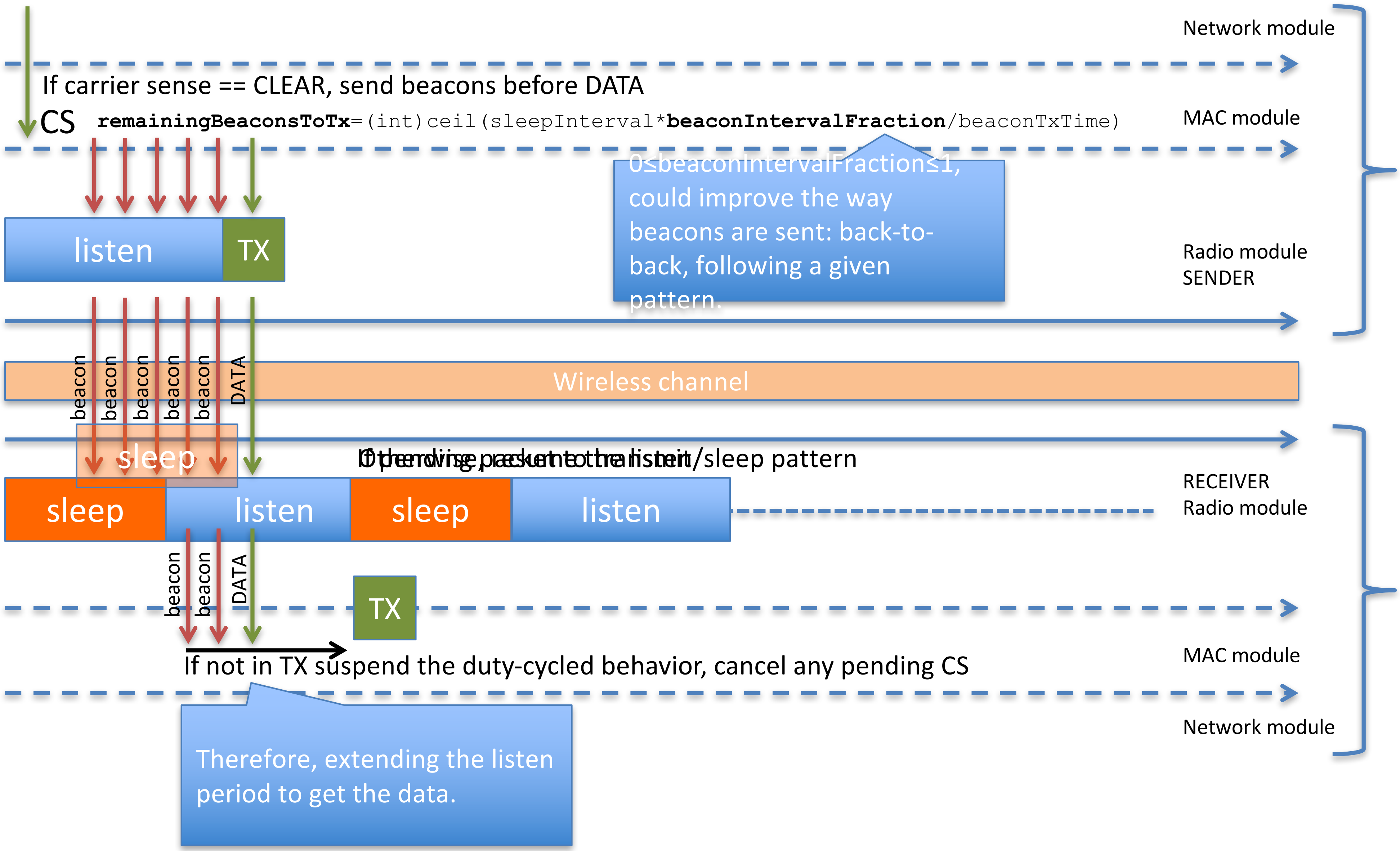
Principles

- Alternate « listen » and « sleep » periods. In « sleep » period, the radio is shut off to save energy
- Note: most of duty-cycled MAC **means duty-cycling the radio module**, not the MAC module
- Optional beacons can be used as a « preamble » to inform the receiver of imminent data packet arrival. This preamble length should usually be at least longer than the sleep period (cf LPL)

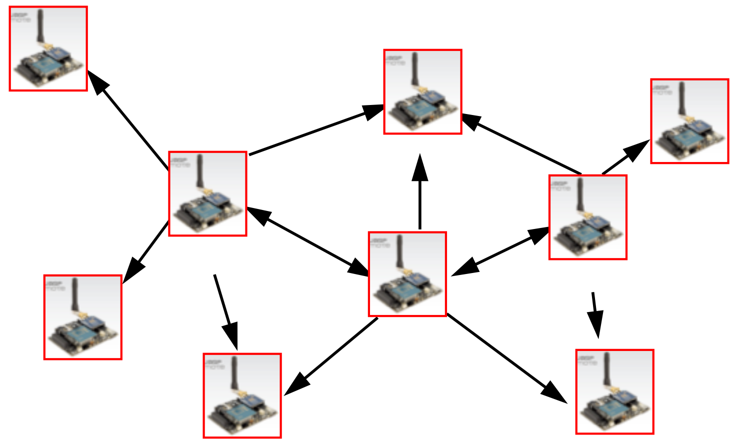


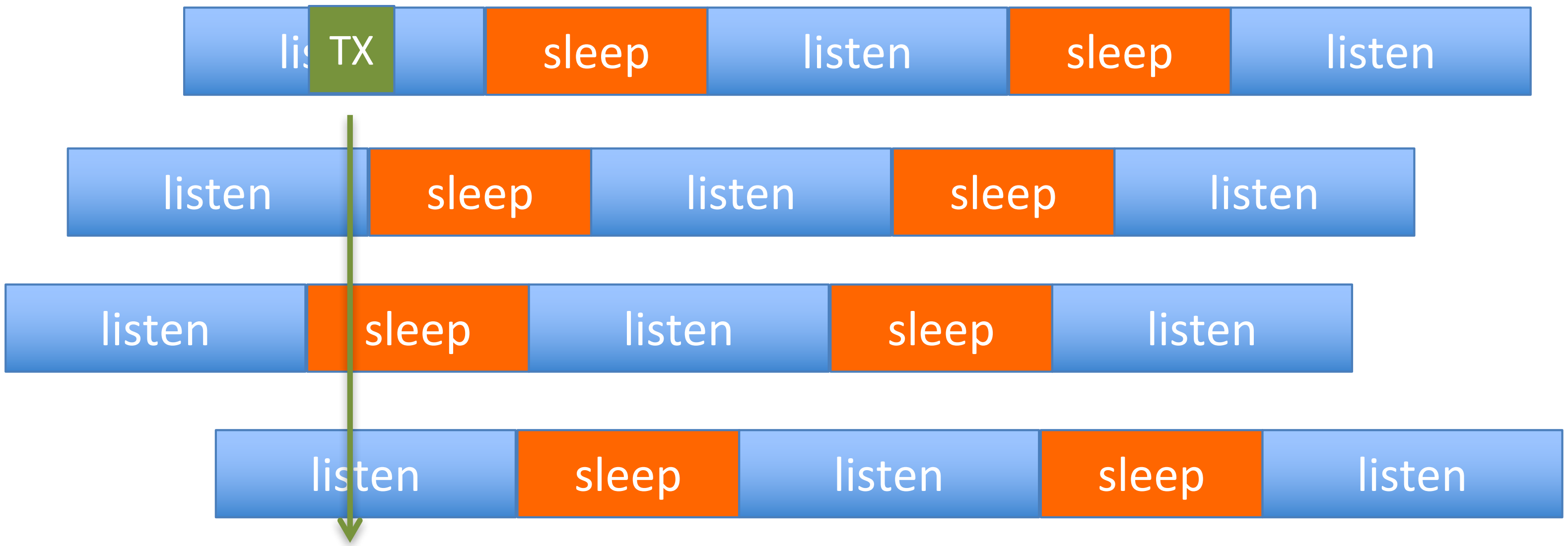

```
cycleLength=listenInterval+sleepInterval
listenInterval=dutyCycle*cycleLength -> cycleLength=listenInterval/dutyCycle
sleepInterval=listenInterval/dutyCycle-listenInterval
-> sleepInterval=listenInterval*(1-dutyCycle)/dutyCycle
```

Example with optional beacons



Multi-hop is challenging!





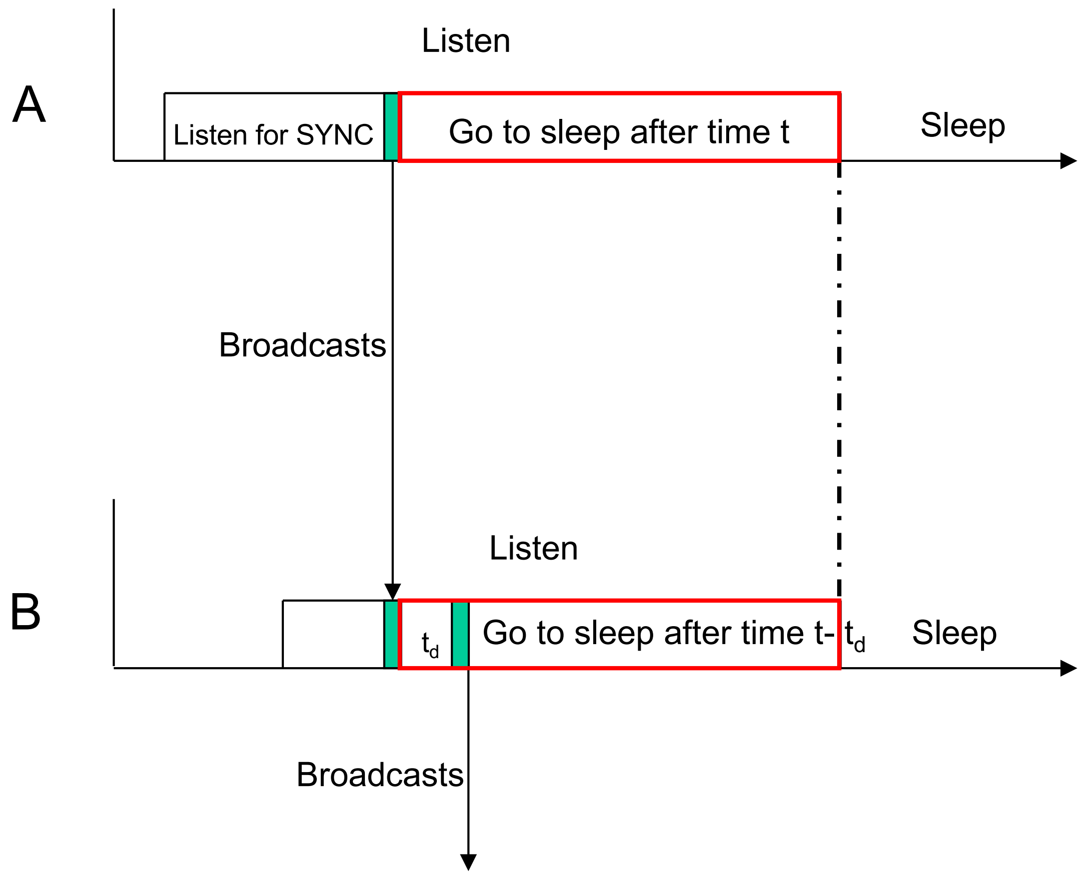
Synchronized MAC:
SMAC, TMAC,...

S-MAC - Sensor MAC

- Nodes periodically sleep such as duty-cycled approach
- Proposes a synchronization mechanisms between neighboring nodes to leverage the issues related to unsynchronous duty-cycled approaches
- Synchronization issues can become tough, nodes can be synchronized to 2 masters

Listen/Sleep Schedule Assignment

Choosing Schedule (1)



Synchronizer

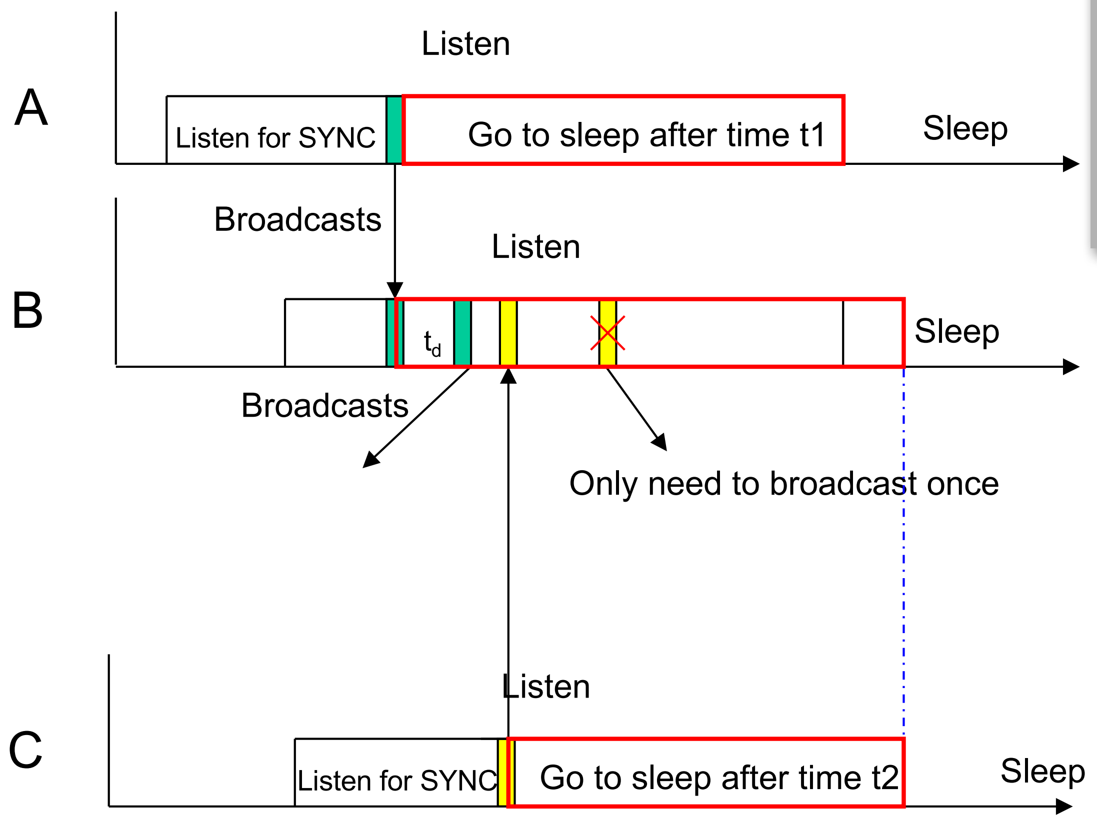
- Listen for a mount of time
- If hear no SYNC, select its own SYNC
- Broadcasts its SYNC immediately

Follower

- Listen for a mount of time
- Hear SYNC from A, follow A's SYNC
- Rebroadcasts SYNC after random delay t_d

Listen/Sleep Schedule Assignment

Choosing Schedule (2)

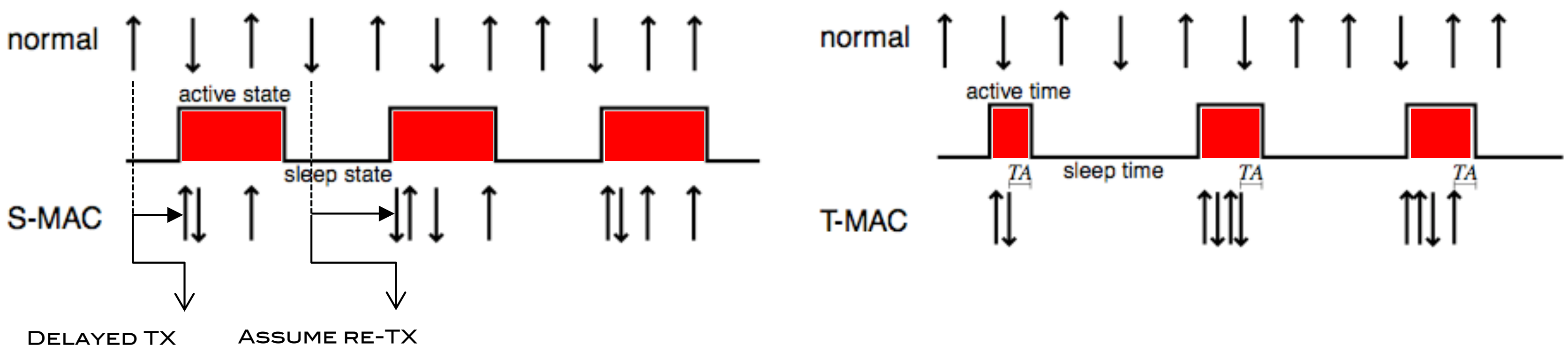


1. B receives A's schedule and rebroadcast it.
2. Hear different SYNC from C
3. Adapt both schedules

Nodes only rarely adopt multiple schedules but 2 schedules is useful to enable data transfers between parts of the network

T-MAC - Timeout MAC

- Transmit all messages in bursts of variable length and sleep between bursts
- Synchronization similar to S-MAC but reduces the listening period if no activity is detected

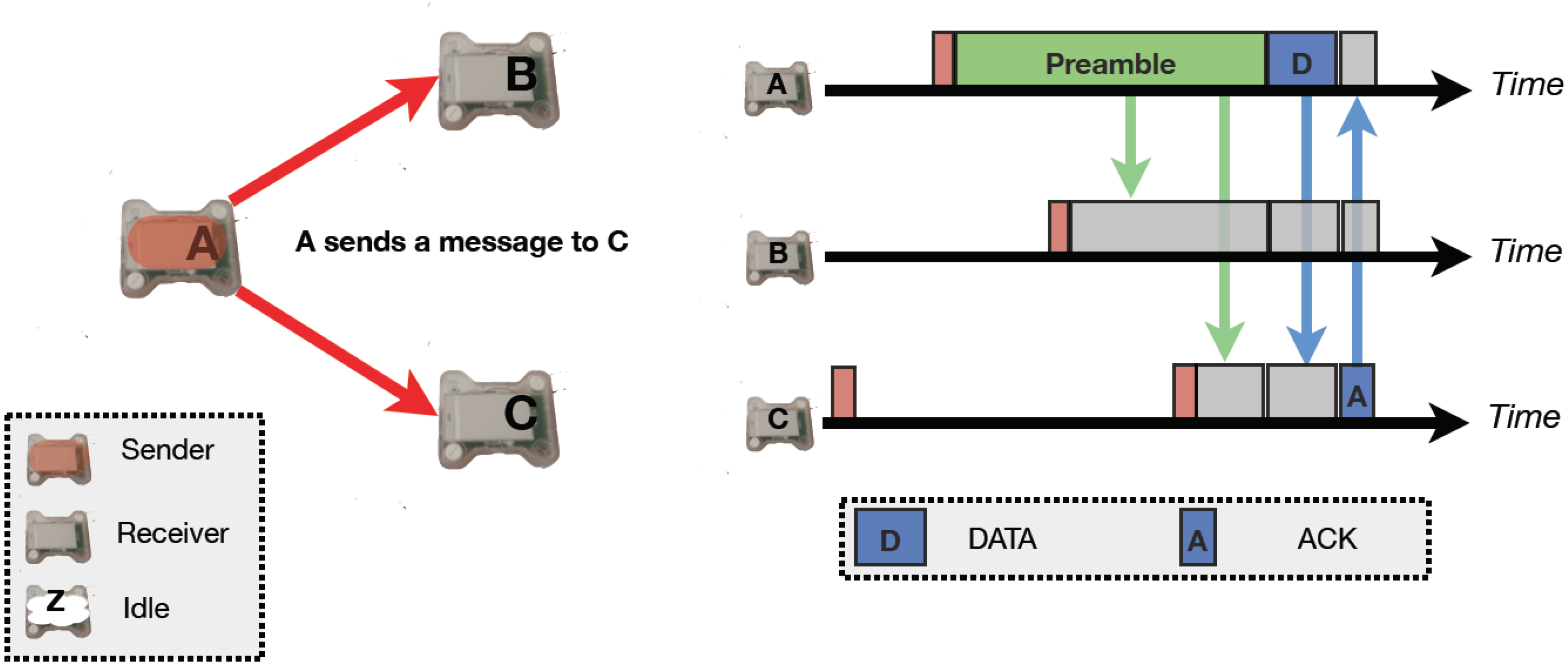


Low Power Listening MAC: LPL, BMAC, XMAC, ...

Principles

- Low Power Listening usually refers to the usage of a preamble to announce an imminent data packet
- Can be similar to duty-cycled with beacon packet, but strictly speaking, LPL needs radio capabilities to listen for the preamble with a lower energy consumption
- Need to distinguish preamble from noise floor

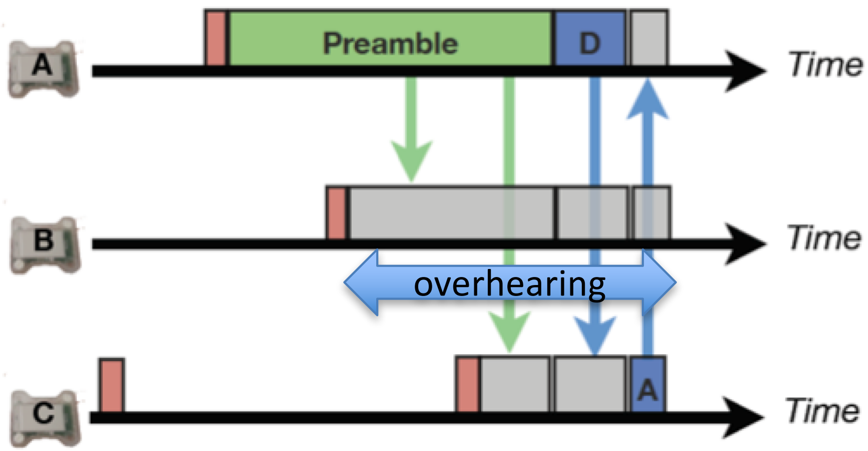
LPL ILLUSTRATED



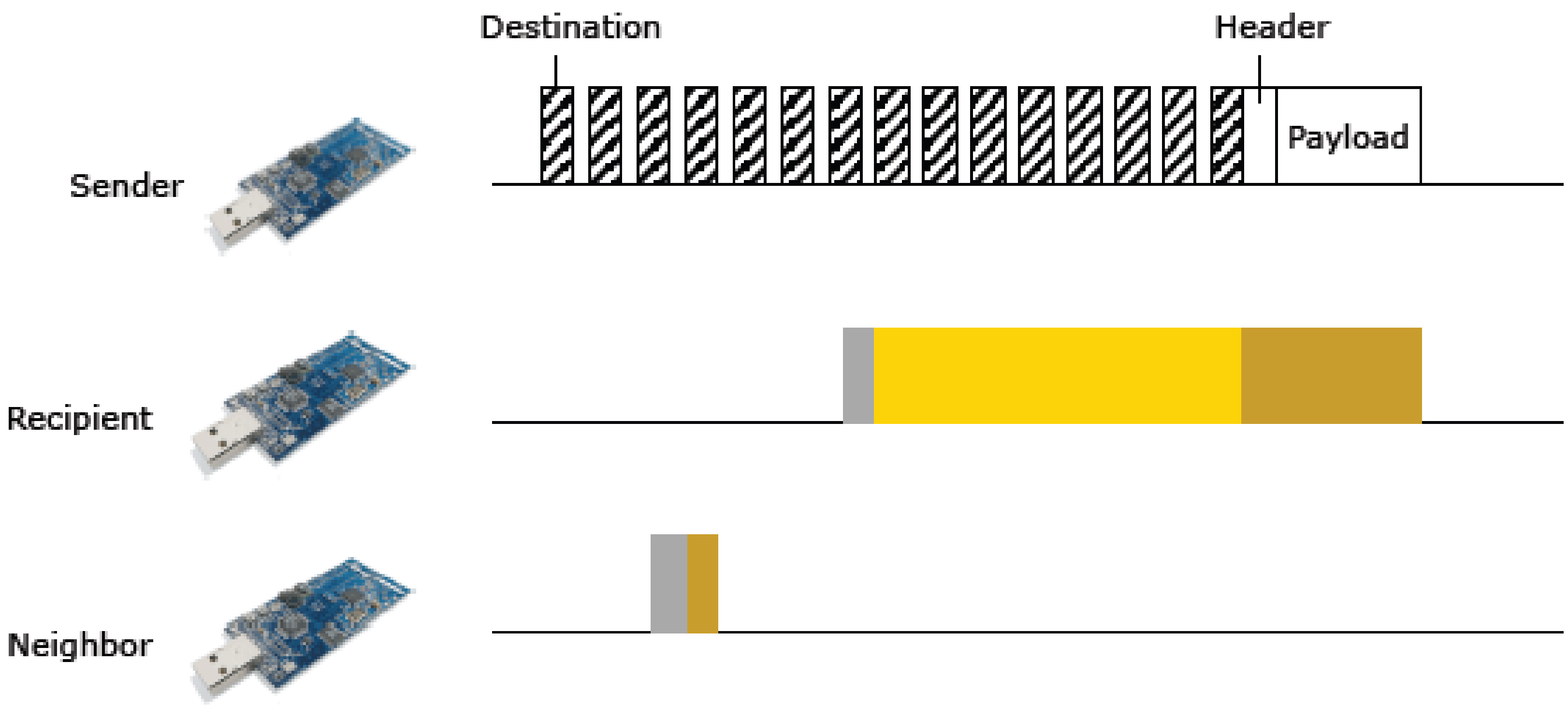
From R. Kuntz

B-MAC

- Berkeley-MAC, based on LPL
- Improved LPL with Clear Channel Assessment
  - Measures the SNR by taking a moving average when there seems to be no traffic
  - Reduces the number of false negative
- Known problems
  - Long preamples are constly for the sender
  - High cost of collisions due to long preamples
  - Still the overhearing problem

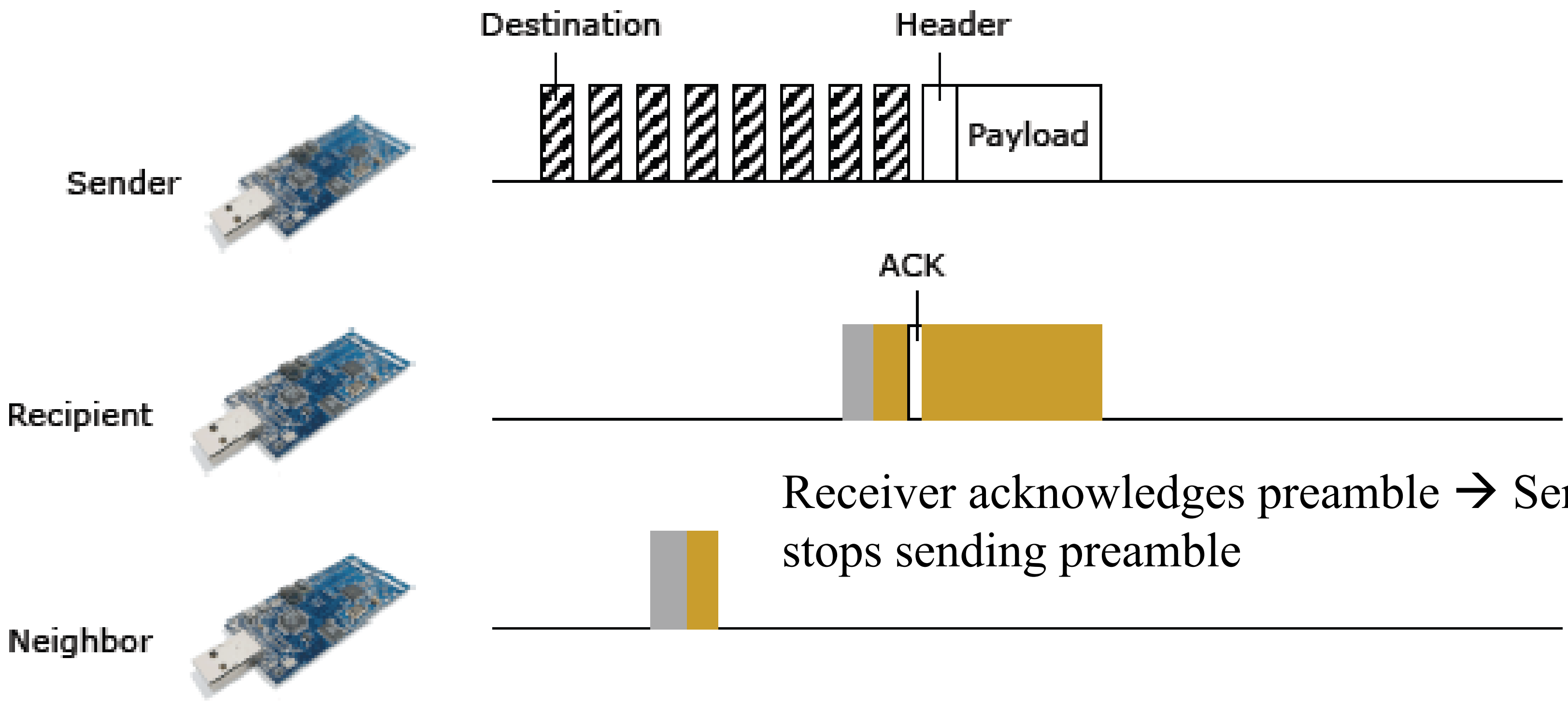


Overhearing avoidance



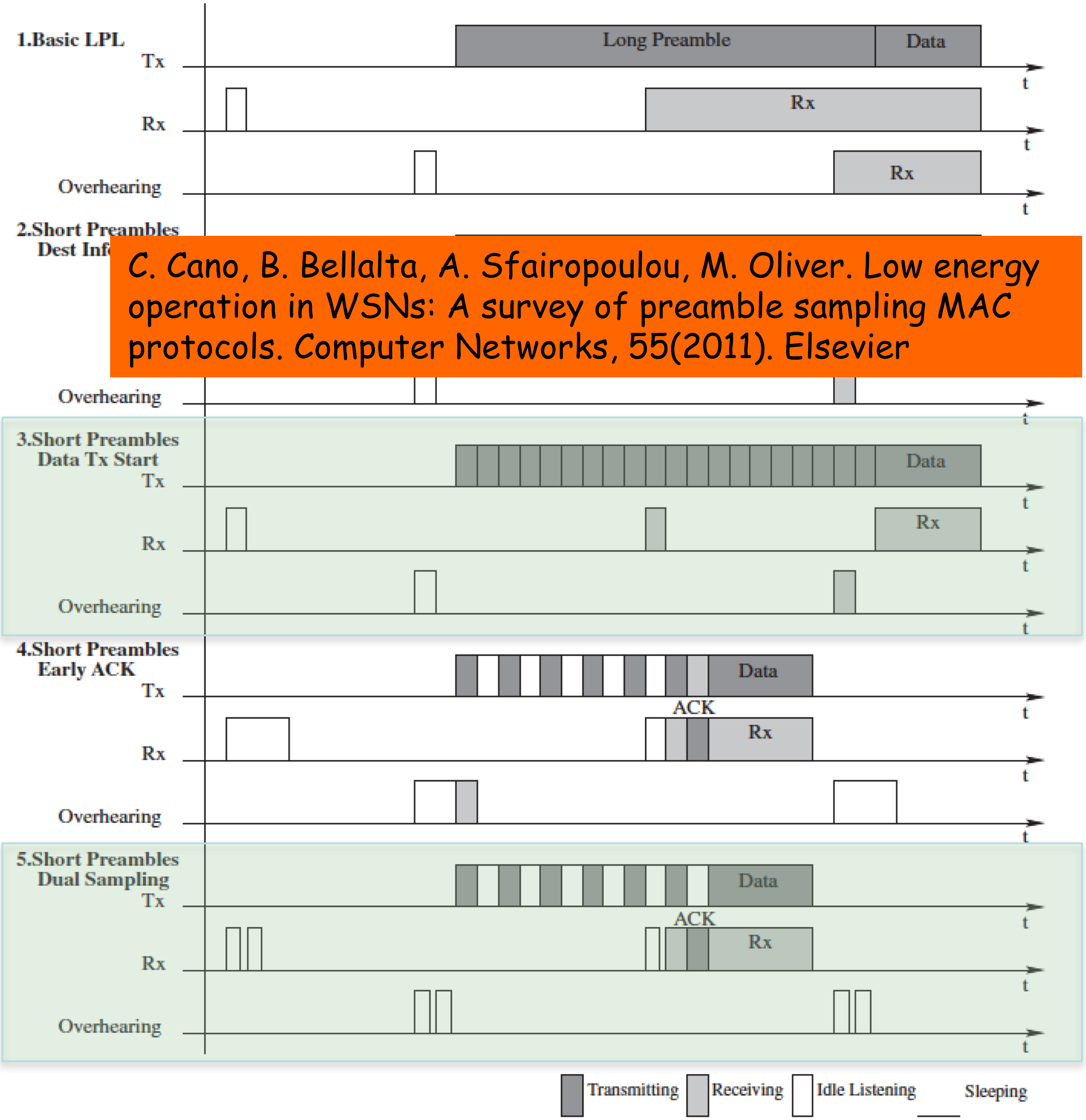
- ❑ Include destination address in short preambles
- ❑ Non-receiver avoids overhearing

Early ACK



Receiver acknowledges preamble → Sender stops sending preamble

LOT'S OF VARIANTS!!



C. Cano, B. Bellalta, A. Sfairopoulou, M. Oliver. Low energy operation in WSNs: A survey of preamble sampling MAC protocols. Computer Networks, 55(2011). Elsevier

Lot's of variants, con't

- Packet-dependent behavior
- Duty-cycle length adaptation
  - Based on traffic load
  - Based on topology information
- Adapted for broadcast traffic
  - Hash of data in short packets
  - Identify « best » receiver for early ACK
- Combined with synchronized approaches