

MEDIUM ACCESS CONTROL IN WIRELESS SENSOR NETWORKS & CHALLENGES

AUTUMN SCHOOL
“SENSOR NETWORKS, MEASURES &
ENVIRONMENT”

LABSTICC, UBO, BREST
OCTOBER 26TH, 2012



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LES COUCHES D'ACCÈS AU SUPPORT DANS LES RÉSEAUX DE CAPTEURS SANS FILS ET LES DÉFIS ASSOCIÉS

ÉCOLE D'AUTOMNE
"RÉSEAUX DE CAPTEURS, MESURES ET
ENVIRONNEMENT"

LABSTICC, UBO, BREST

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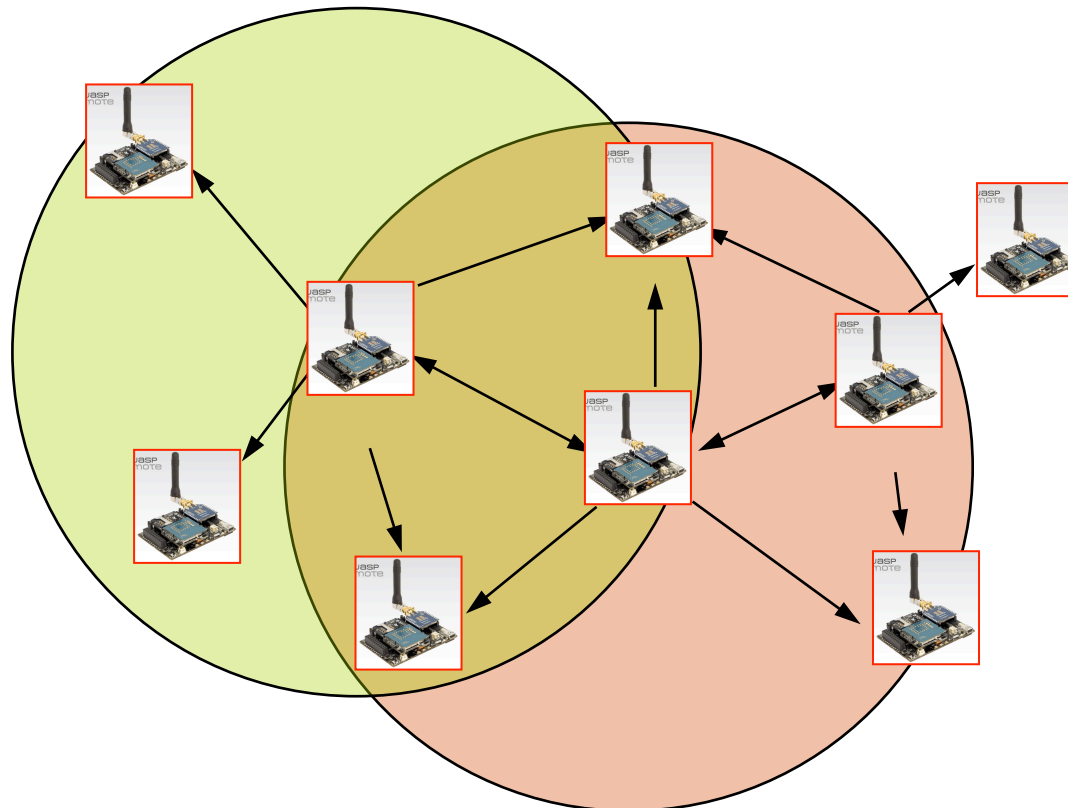


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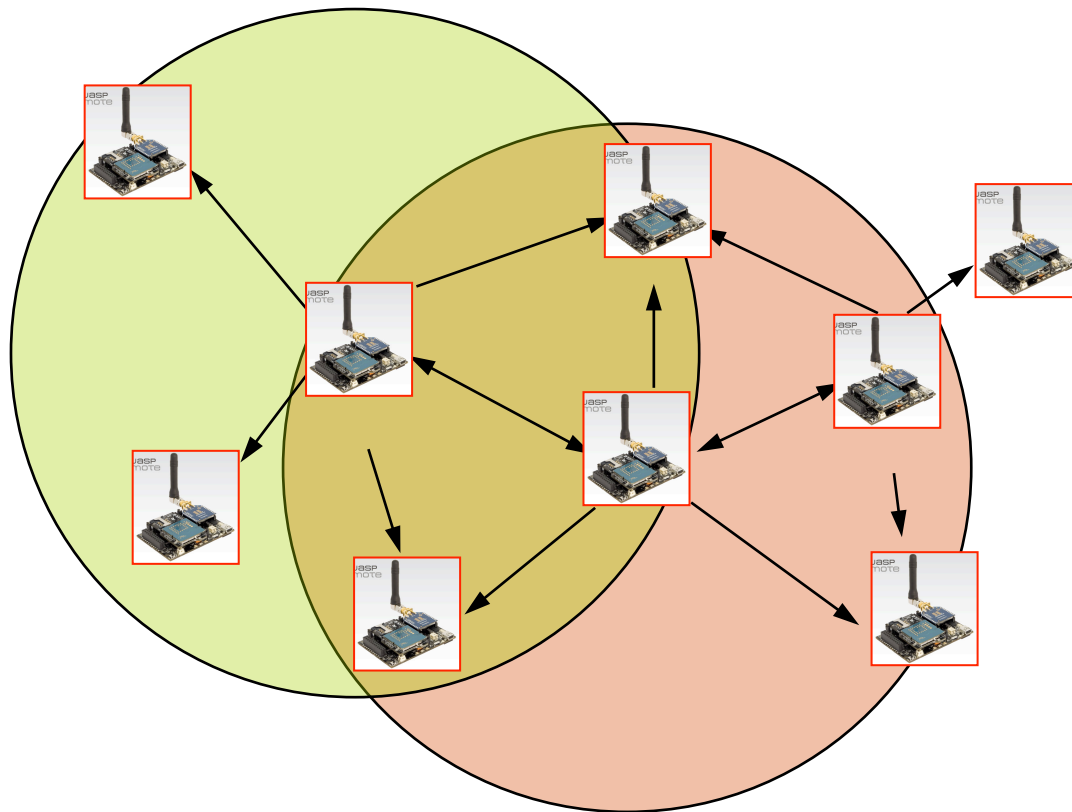


WSN ARE AD-HOC NETWORKS

- ❑ INFRASTRUCTURE-LESS NETWORKS
- ❑ MANET (MOBILE ADHOC NETWORKS)



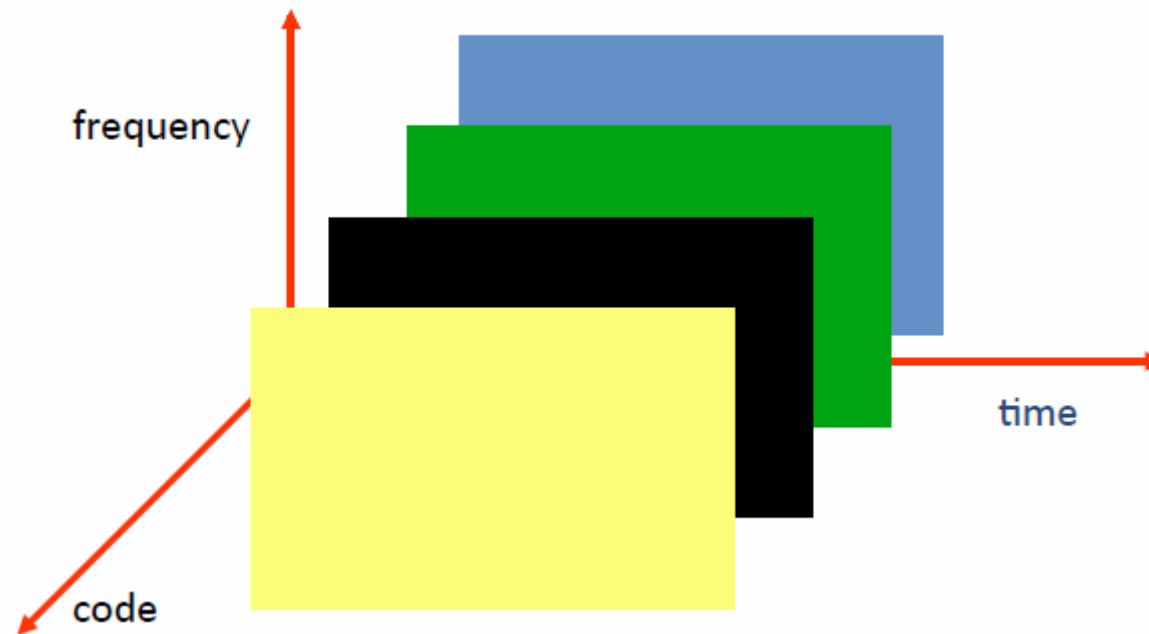
WIRELESS MEDIUM IS A SHARED MEDIUM



Collisions when multiple transmissions

Need to control access to the medium

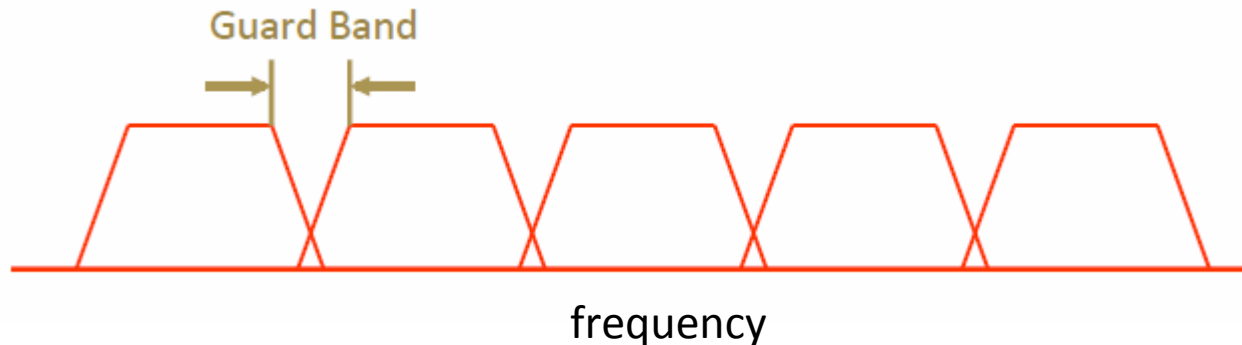
MULTIPLE ACCESS SCHEMES



3 ORTHOGONAL SCHEMES:

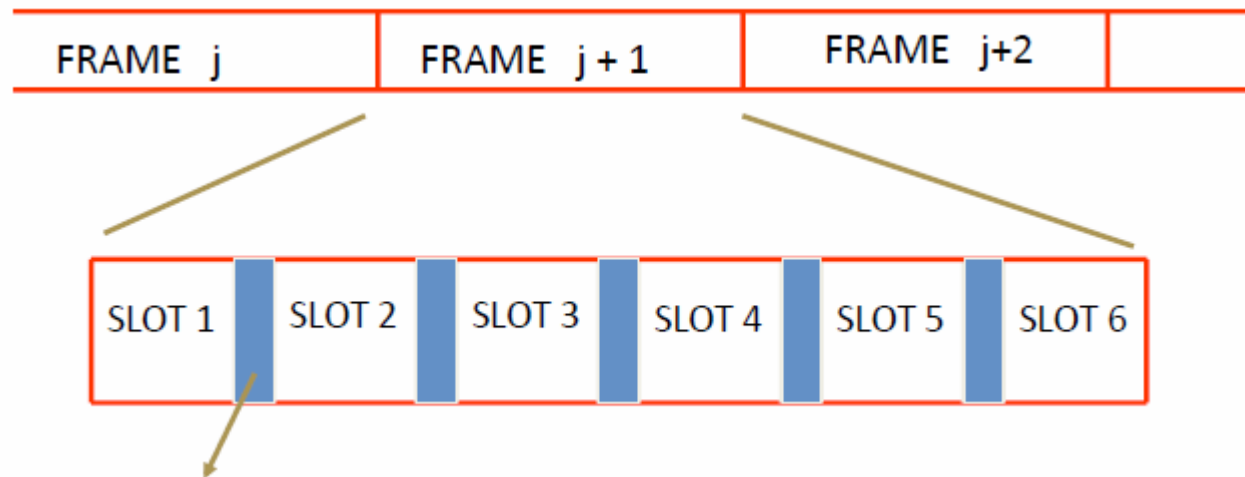
- FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)
- TIME DIVISION MULTIPLE ACCESS (TDMA)
- CODE DIVISION MULTIPLE ACCESS (CDMA)

FREQUENCY DIVISION MULTIPLE ACCESS



- ❑ Each mobile is assigned a separate frequency channel for the duration of the call
- ❑ Sufficient guard band is required to prevent adjacent channel interference
- ❑ Usually, mobile terminals will have one downlink frequency band and one uplink frequency band
- ❑ Different cellular network protocols use different frequencies
- ❑ Frequency is a precious and scarce resource. We are running out of it

TIME DIVISION MULTIPLE ACCESS

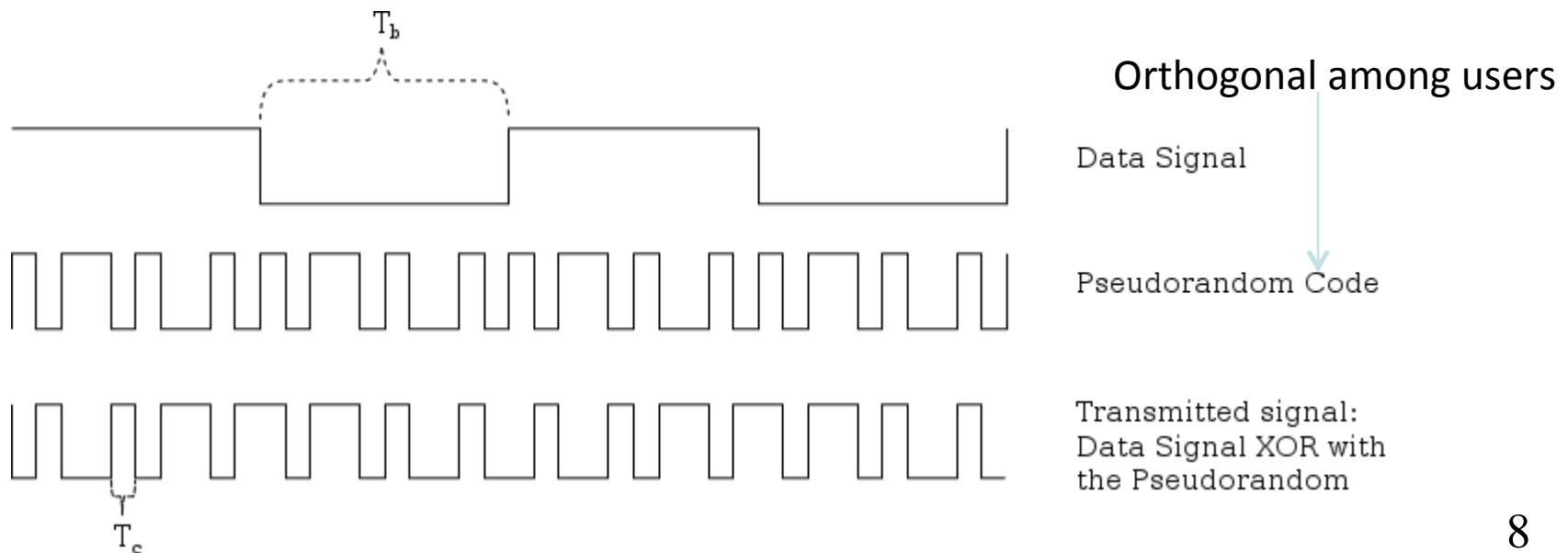


Guard time – signal transmitted by mobile terminals at different locations do not arrive at the base station at the same time

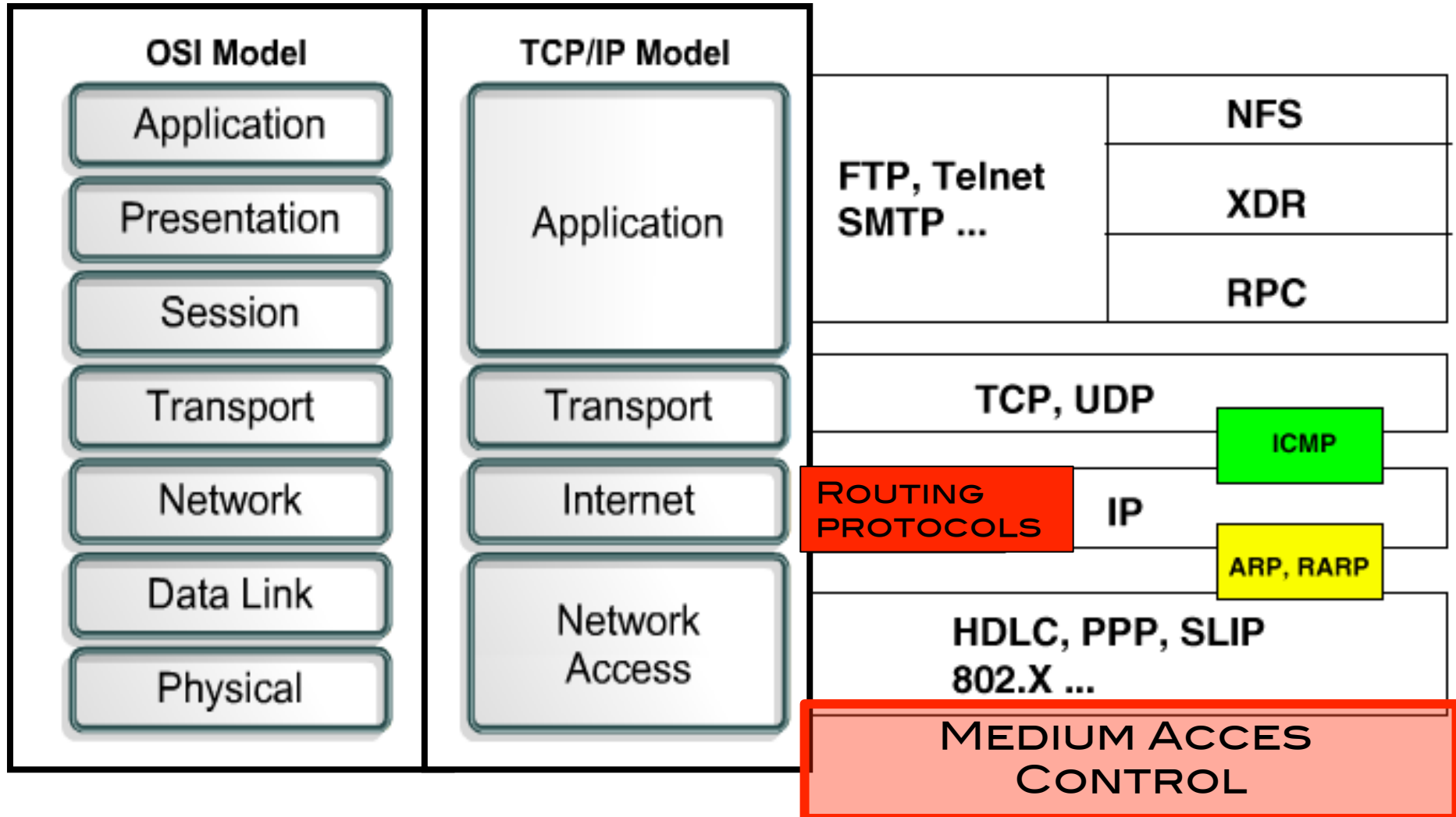
- TIME IS DIVIDED INTO SLOTS AND ONLY ONE NODE TRANSMITS DURING EACH SLOT
- EACH USER IS GIVEN A SPECIFIC SLOT. NO COMPETITION

CODE DIVISION MULTIPLE ACCESS

- ❑ Use of orthogonal codes to separate different transmissions
- ❑ Each symbol of bit is transmitted as a larger number of bits using the user specific code – Spreading
 - ❑ Bandwidth occupied by the signal is much larger than the information transmission rate
 - ❑ But all users use the same frequency band together



REVIEW OF COMMUNICATION ARCHITECTURE



OTHER WIRELESS NETWORK TECHNOLOGIES

- MOBILE PHONE

 - GSM,

 - 3G

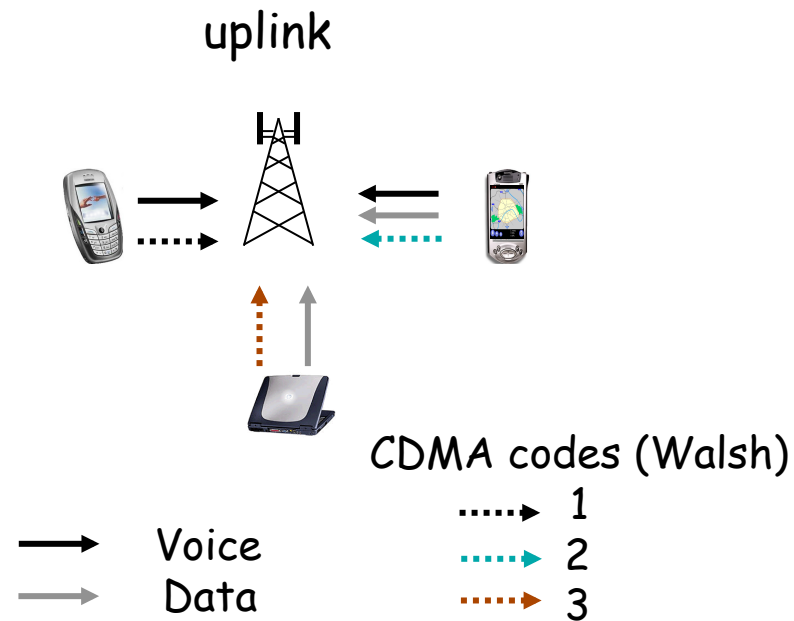
 - LTE, 4G,...

- BLUETOOTH

- WIFI 802.11

3G AND BEYOND

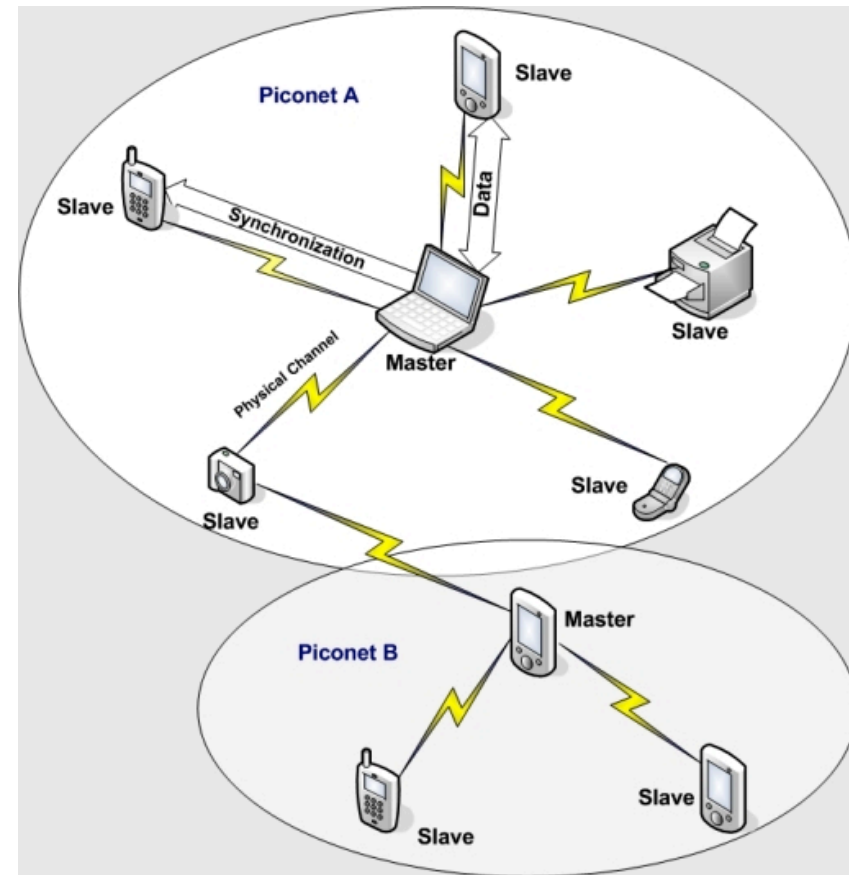
□ 3G AND BEYOND USE CDMA TECHNIQUES



BLUETOOTH



- ❑ 802.15 :
PERSONAL AREA
NETWORK
 - ❑ 802.15.1 -> 802.15.3
- ❑ MASTER-SLAVE,
PICONET
ORGANIZATION
- ❑ MASTER WILL
POLL SLAVES FOR
DATA



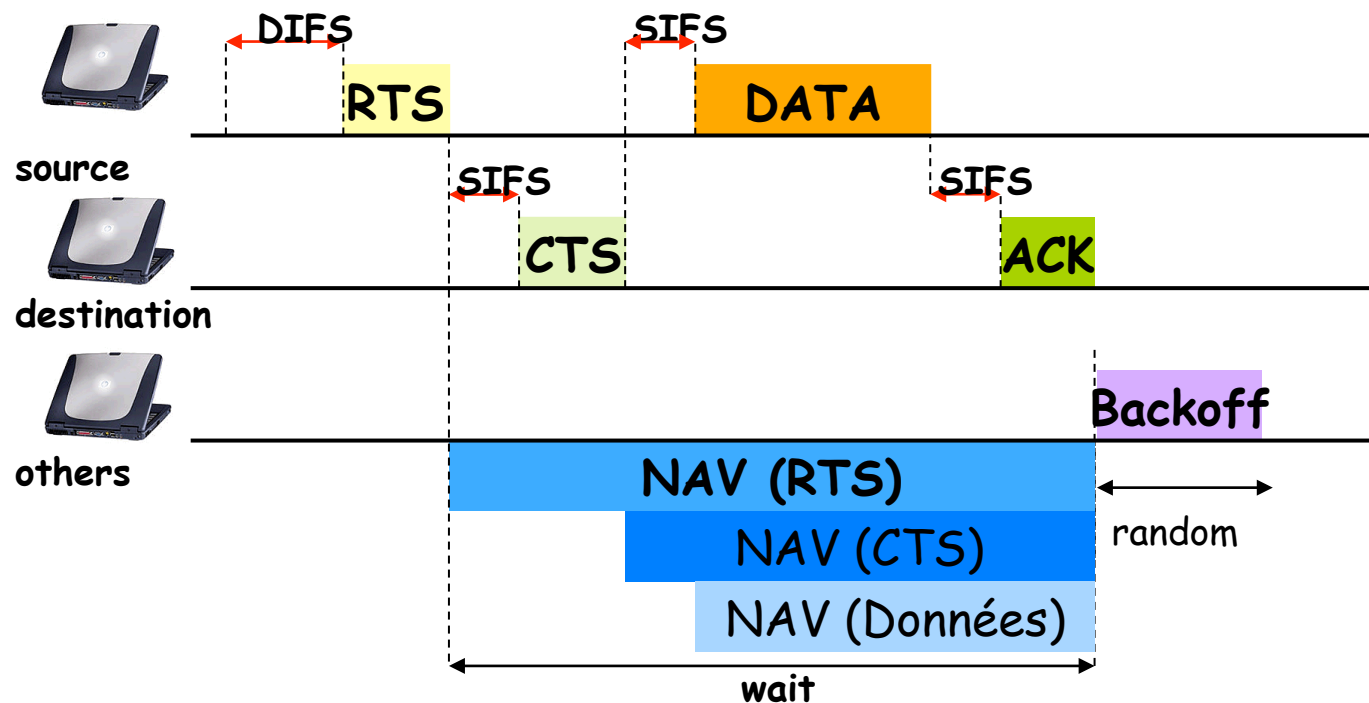
WiFi 802.11



- 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)



WHAT TECHNOLOGY FOR WSN?

- ❑ 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

Medium Access Control in IEEE 802.15.4

Principles

- IEEE 802.15.4 MAC defines the following data transfer models
 - To/From coordinator node
 - Peer-to-peer
- The coordinator mode defines a star topology and several 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. Non-beacon unslotted CSMA/CA is used.

Supported topologies

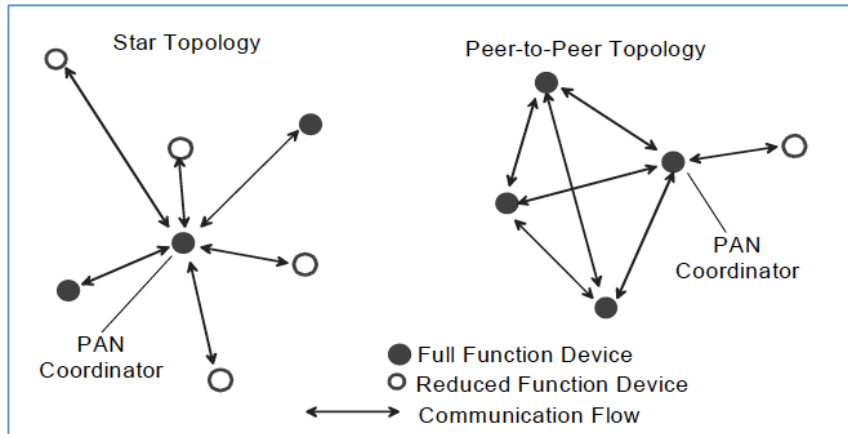


Figure from IEEE document standard on 802.15.4

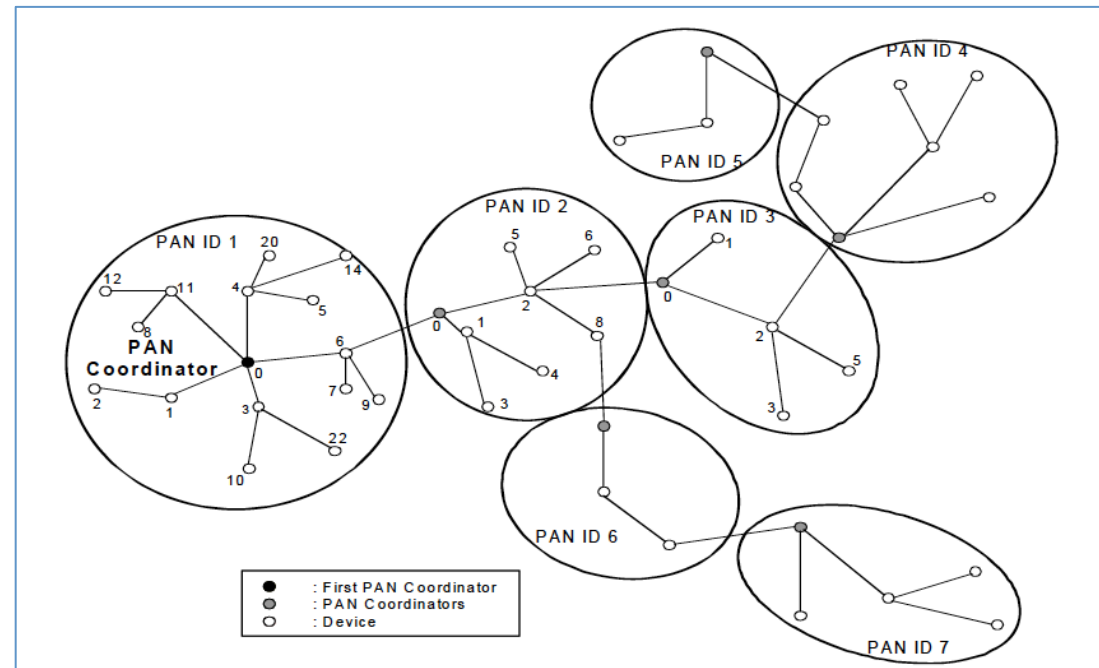


Figure from IEEE document standard on 802.15.4

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.”

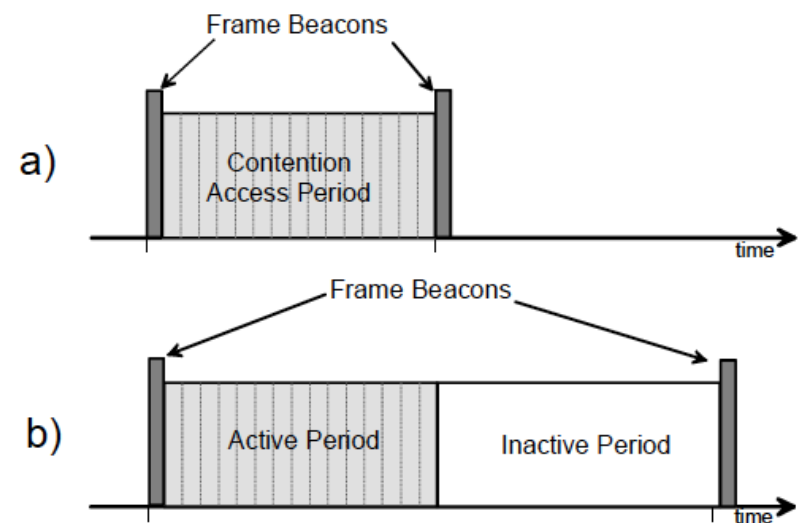


Figure 4—Superframe structure without GTSSs

Figure and text from IEEE document standard on 802.15.4

Beacons-mode and CAP

- “The beacons are used to synchronize the attached devices, to identify the PAN, and to describe the structure of the superframes.”
- “Beacon-enabled PANs use a slotted CSMA-CA channel access mechanism, where the backoff slots are aligned with the start of the beacon transmission. The backoff slots of all devices within one PAN are aligned to the PAN coordinator”
- “Any device wishing to communicate during the contention access period (CAP) between two beacons competes with other devices using a slotted CSMA-CA mechanism. All transactions are completed by the time of the next network beacon.”

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.”

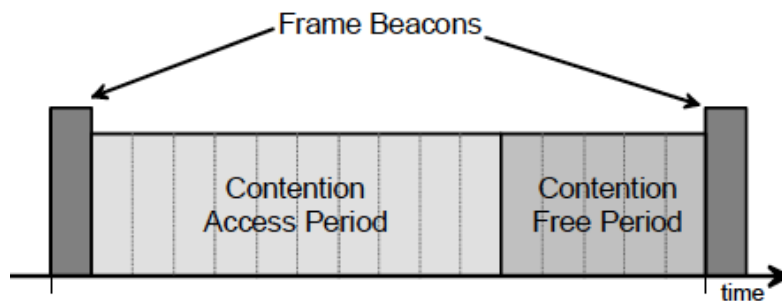


Figure 5—Superframe structure with GTSs

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.

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 $0 \leq BO \leq 14$, $BI = aBaseSuperframeDuration * 2^{BO}$ 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.

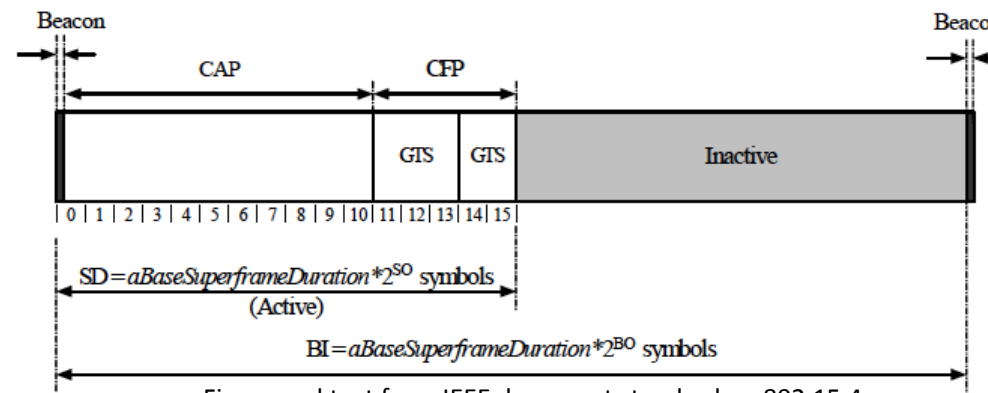
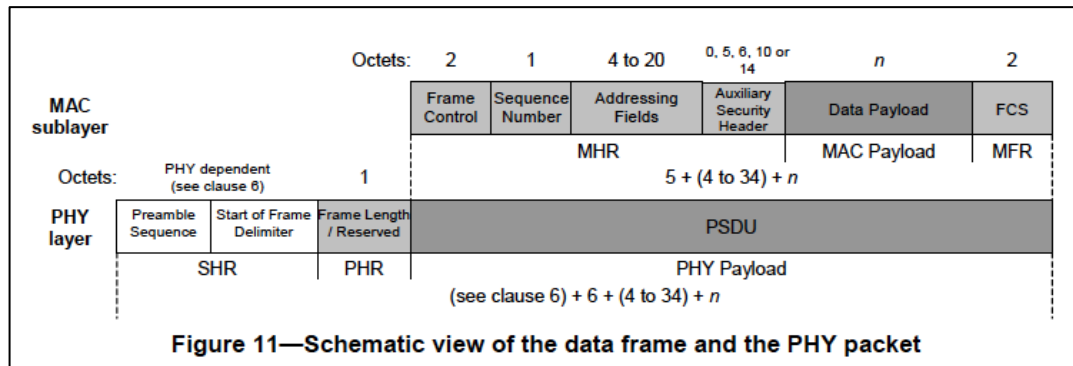
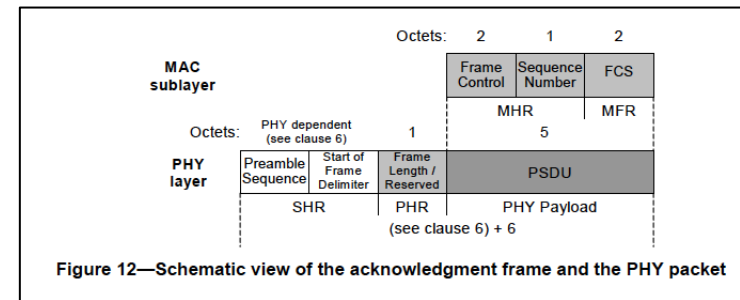
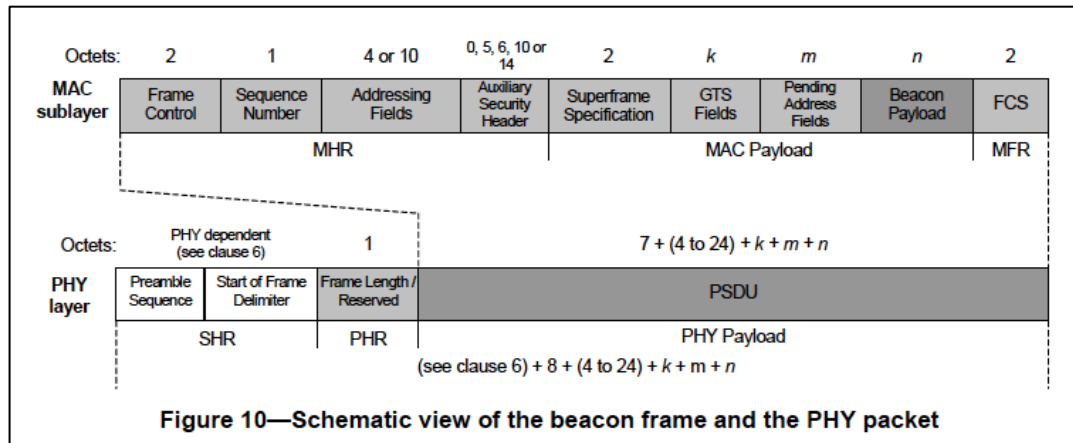


Figure and text from IEEE document standard on 802.15.4

Beacon, Data and ACK frame structure



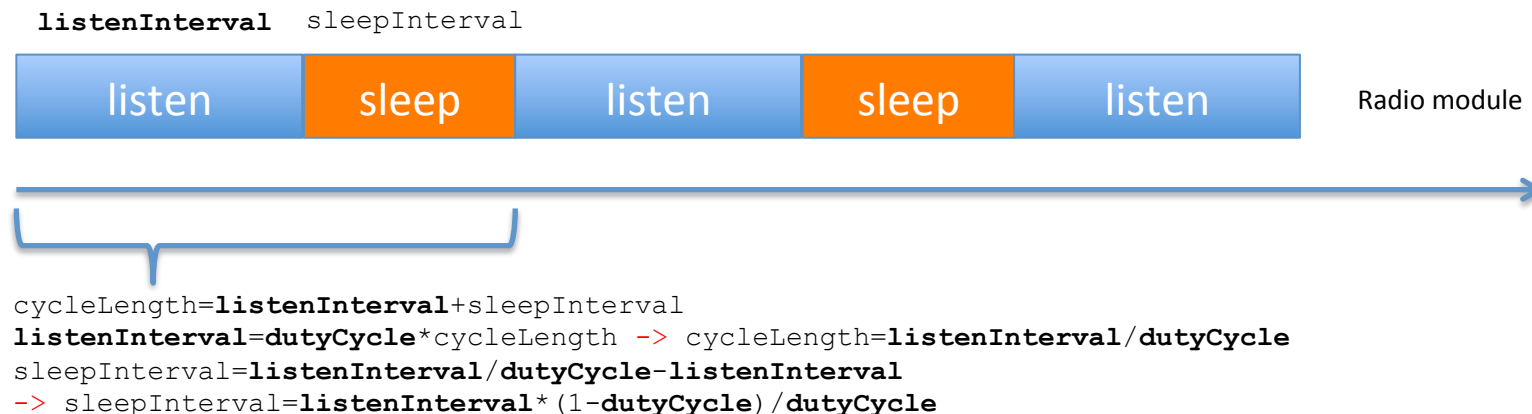
802.15.4 MAC IS FAR FROM PERFECT

- ❑ 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!

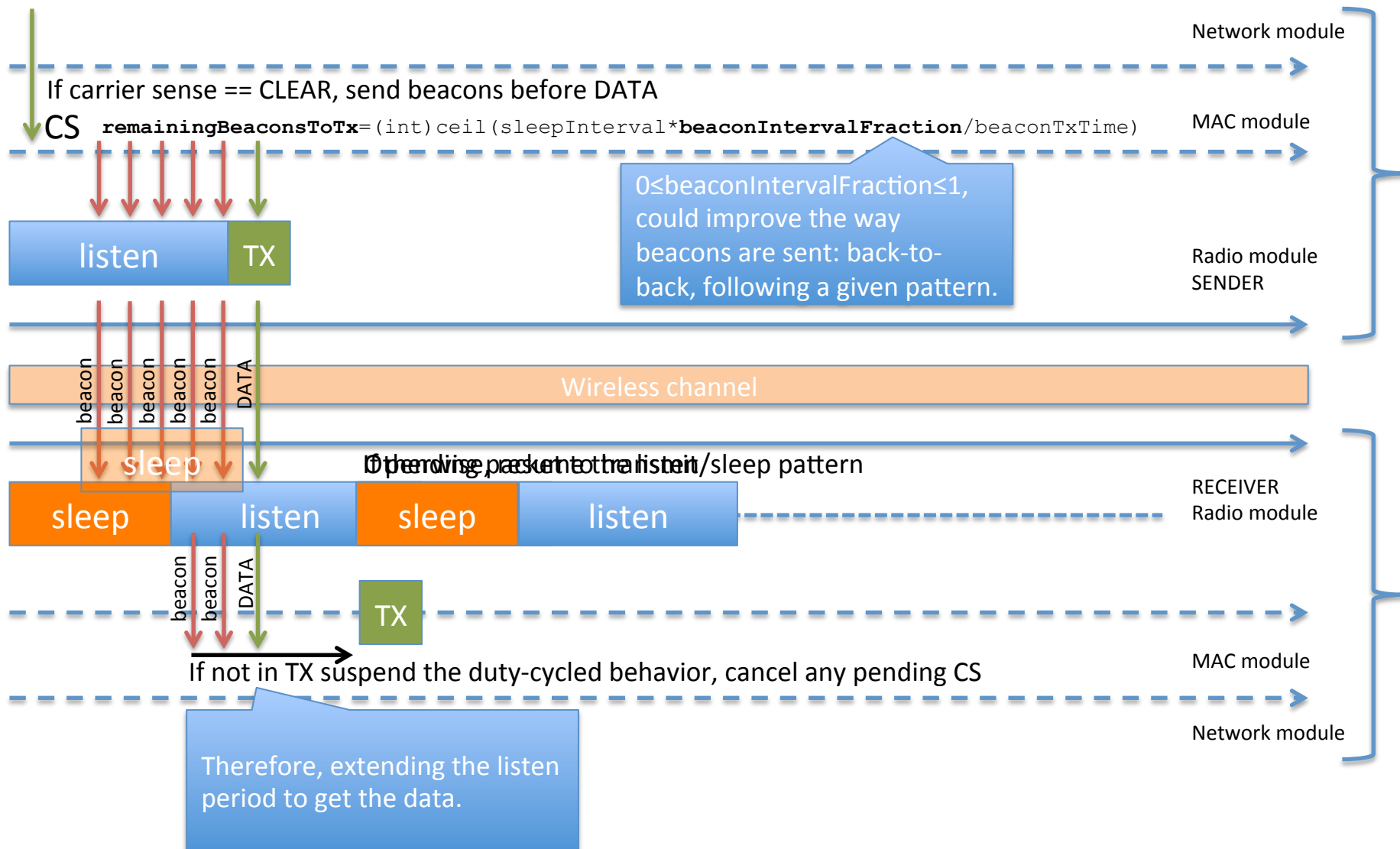
Duty-cycled MAC
based on CSMA(/CA), with optional
beacons

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. See the Low Power Listening section for more information.



Example with optional beacons



Synchronized MAC:
SMAC, TMAC,...

S-MAC - Sensor MAC

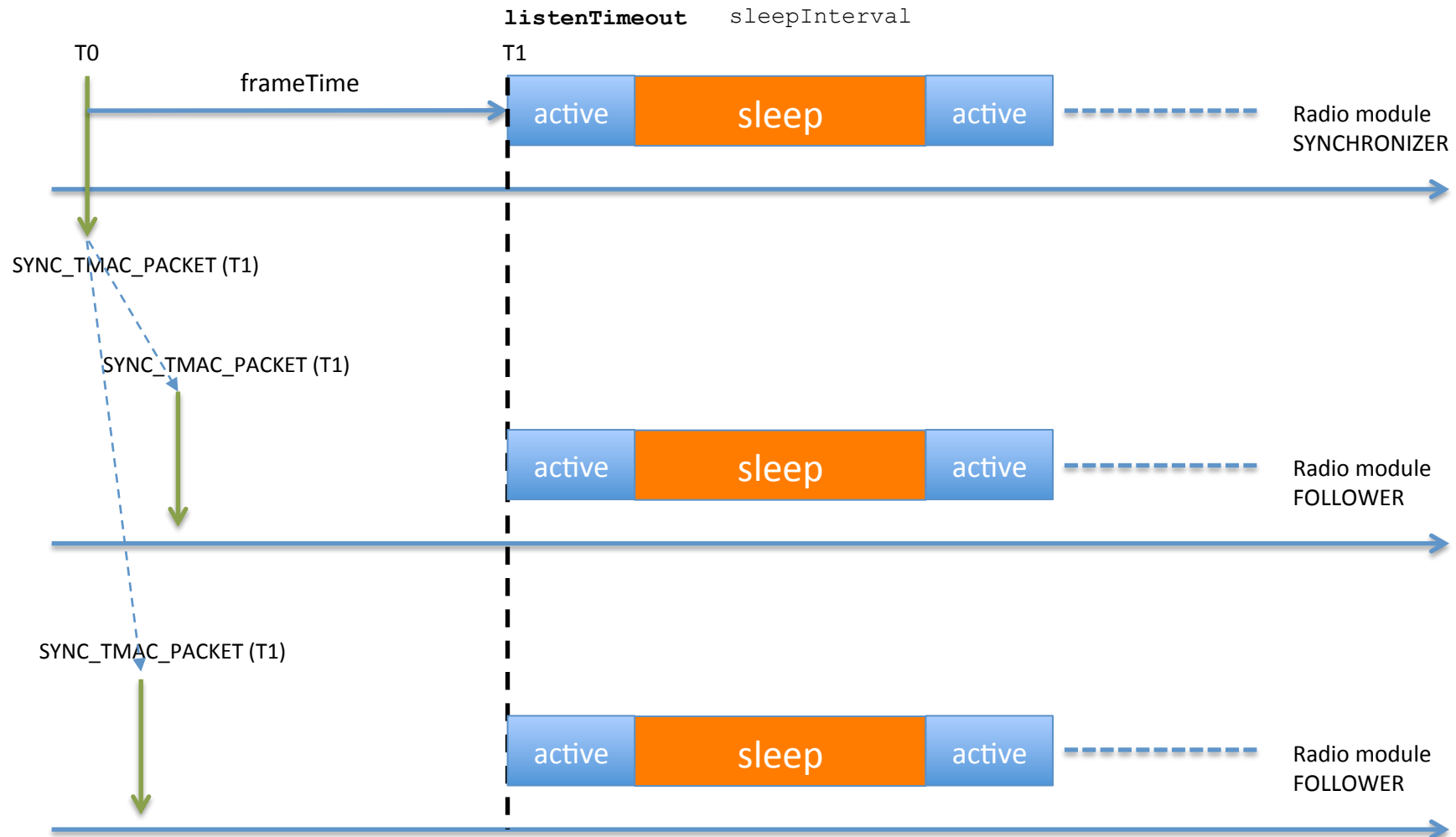
- Nodes periodically sleep such as duty-cycled approach
- Proposes a synchronization mechanisms between neighboring nodes to leverage the issues related to unsynchronous duty-cycled approaches
- Synchronization issues can become tough, nodes can be synchronized to 2 masters

Choosing and Maintaining Schedules

- Each node maintains a schedule table that stores schedules of all its known neighbors.
- To establish the initial schedule (at the startup) following steps are followed:
 - A node first listens for a certain amount of time.
 - If it does not hear a schedule from another node, it randomly chooses a schedule and broadcast its schedule immediately.
 - This node is called a SYNCHRONIZER.

- If a node receives a schedule from a neighbor before choosing its own schedule, it just follows this neighbor's schedule.
- This node is called a FOLLOWER and it waits for a random delay and broadcasts its schedule.
- If a node receives a neighbor's schedule after it selects its own schedule, it adopts to both schedules and broadcasts its own schedule before going to sleep.

Synchronizing with schedules



Timing Relationship of Possible Situations

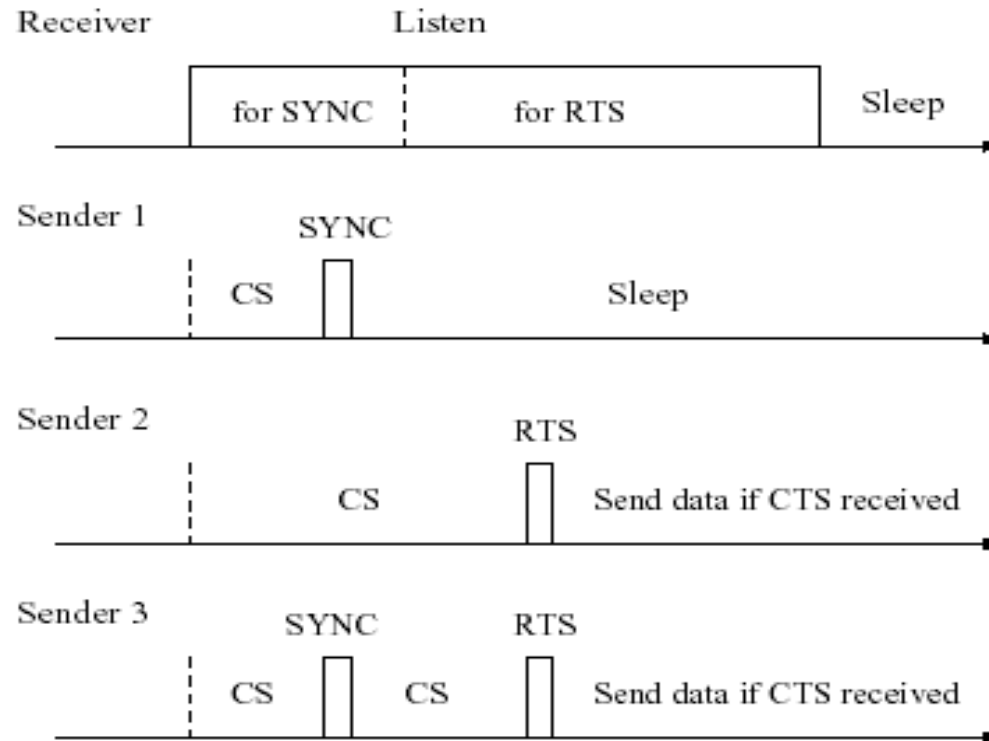
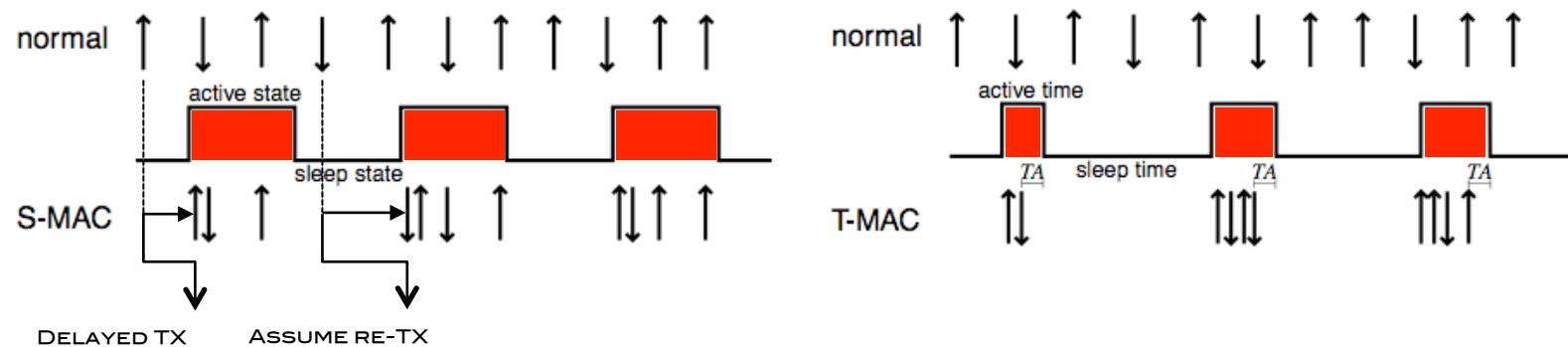


Fig. 3. Timing relationship between a receiver and different senders. CS stands for carrier sense.

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

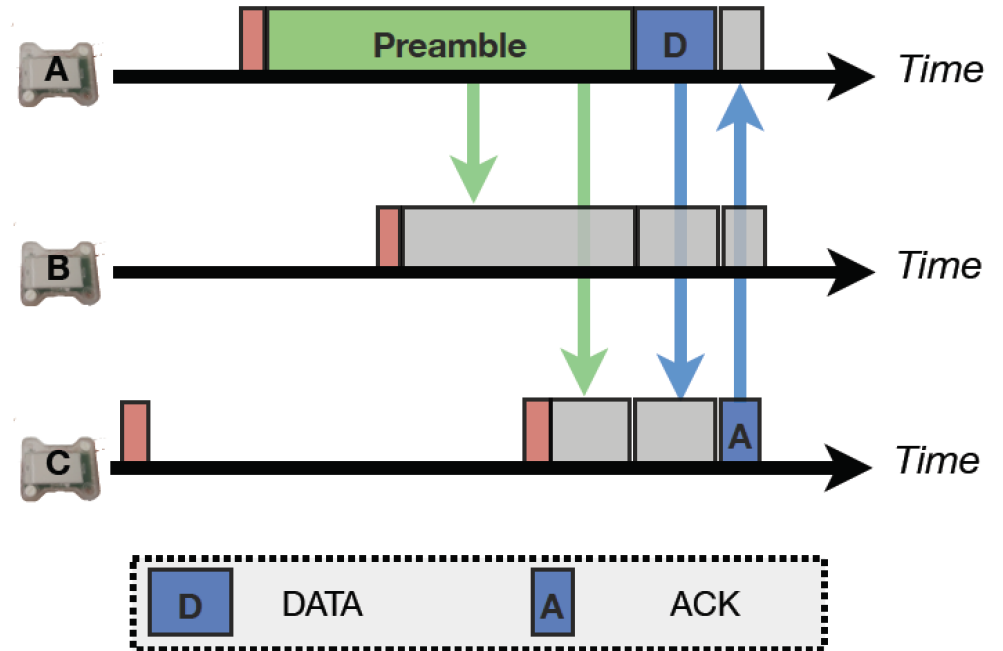
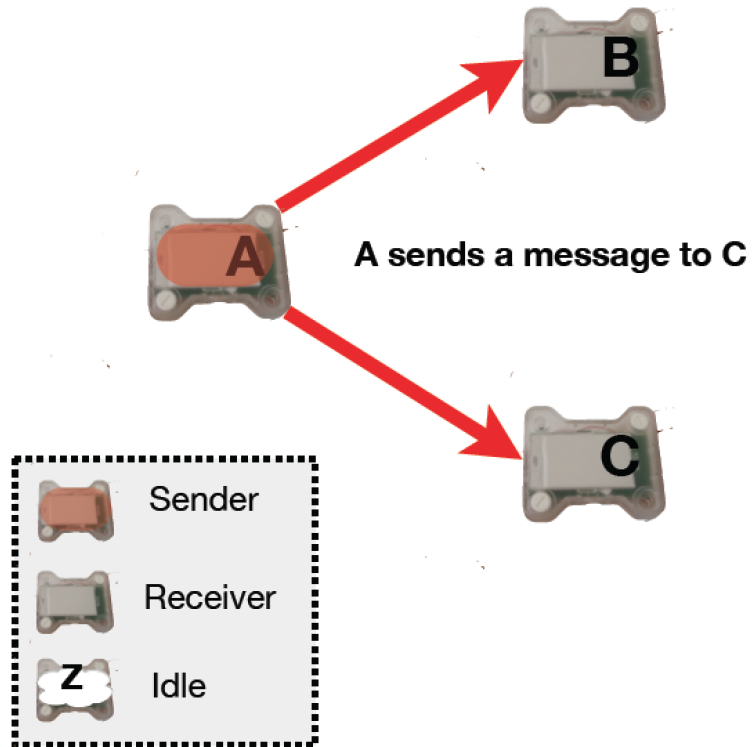


Low Power Listening MAC: LPL, BMAC, XMAC, ...

Principles

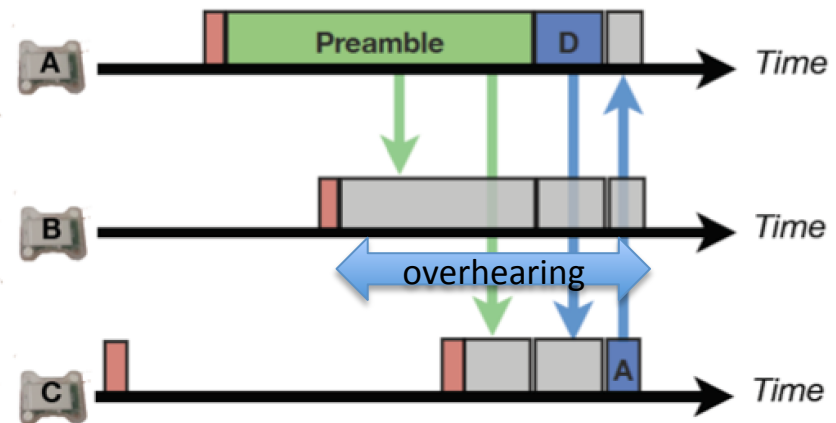
- Low Power Listening usually refers to the usage of a preamble to announce an imminent data packet
- Can be similar to duty-cycled with beacon packet, but strictly speaking, LPL needs radio capabilities to listen for the preamble with a lower energy consumption
- Need to distinguish preamble from noise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

LPL illustrated

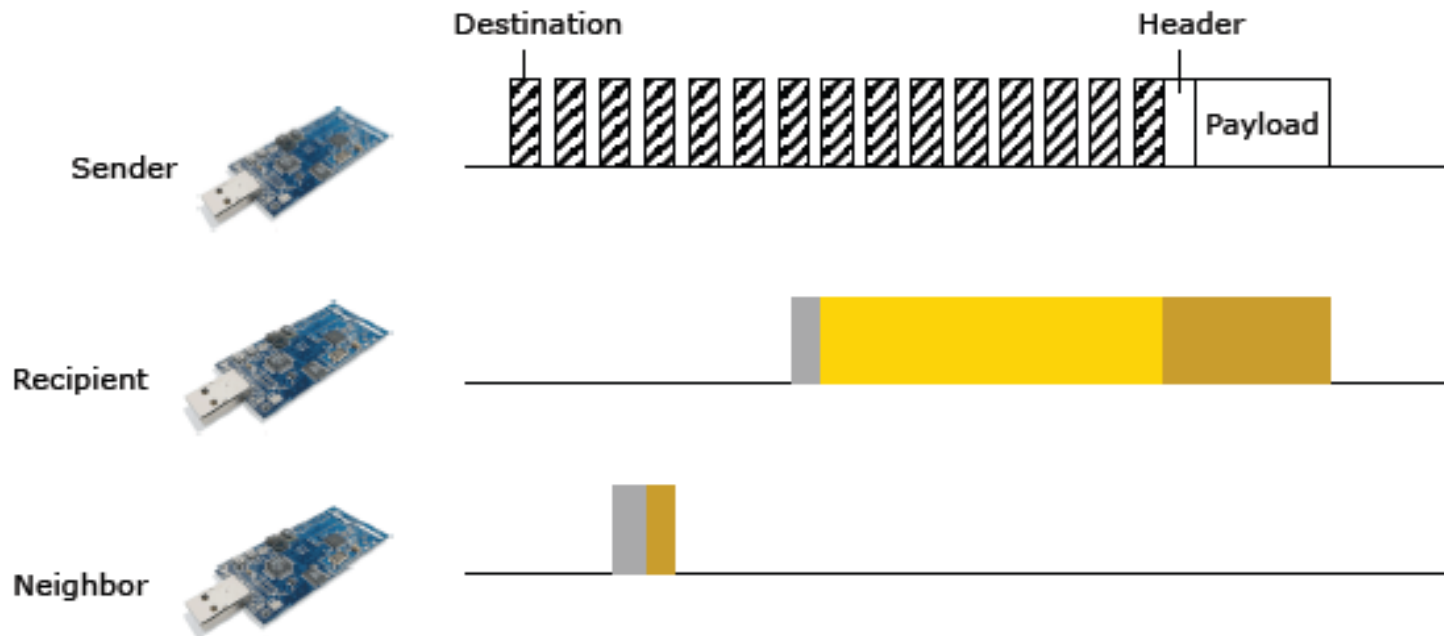


B-MAC

- 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 preambles are costly for the sender
 - High cost of collisions due to long preambles
 - Still the overhearing problem

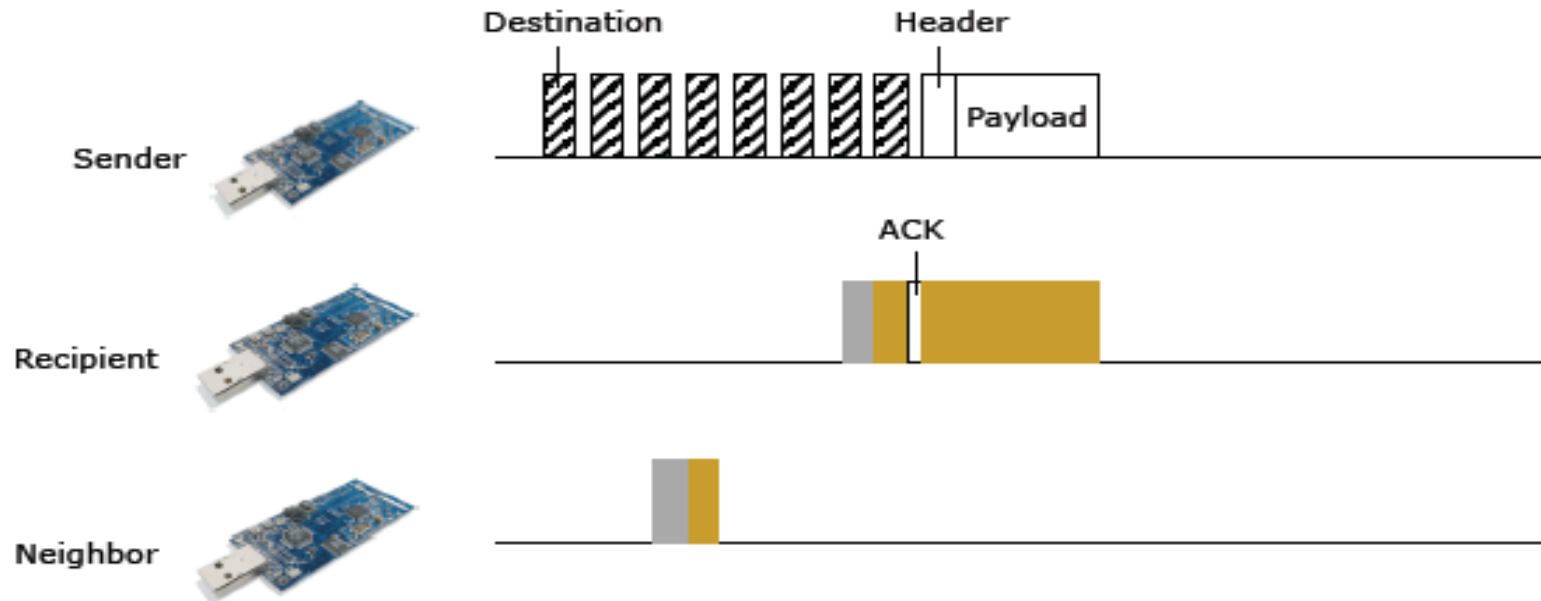


Overhearing avoidance



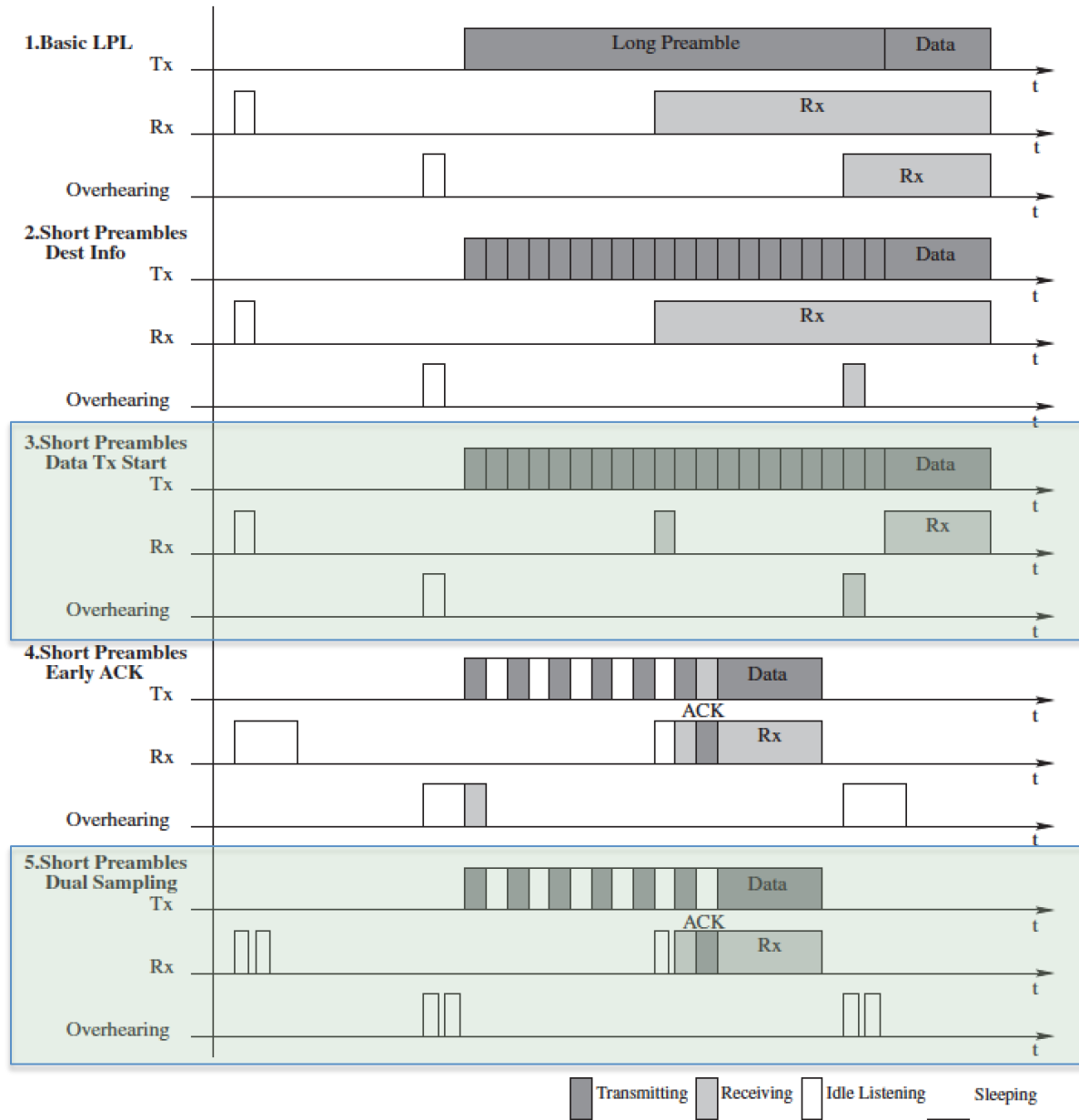
- Include destination address in short preambles
- Non-receiver avoids overhearing

Early ACK



- Receiver acknowledges preamble → Sender stops sending preamble

Lot's of variants!!



C. Cano, B. Bellalta, A. Sfairpoulou, 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

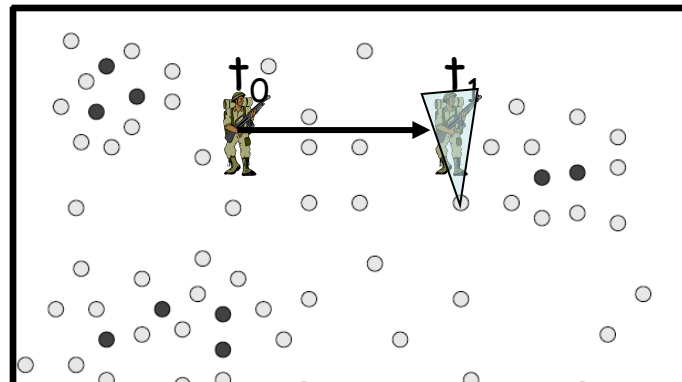
- Packet-dependent behavior
- Duty-cycle length adaptation
 - Based on traffic load
 - Based on topology information
- Adapted for broadcast traffic
 - Hash of data in short packets
 - Identify « best » receiver for early ACK
- Combined with synchronized approaches

CHALLENGES FOR MAC PROTOCOLS IN WSN (1)

- ❑ ENERGY EFFICIENCY
- ❑ LOW LATENCIES
- ❑ FAIRNESS



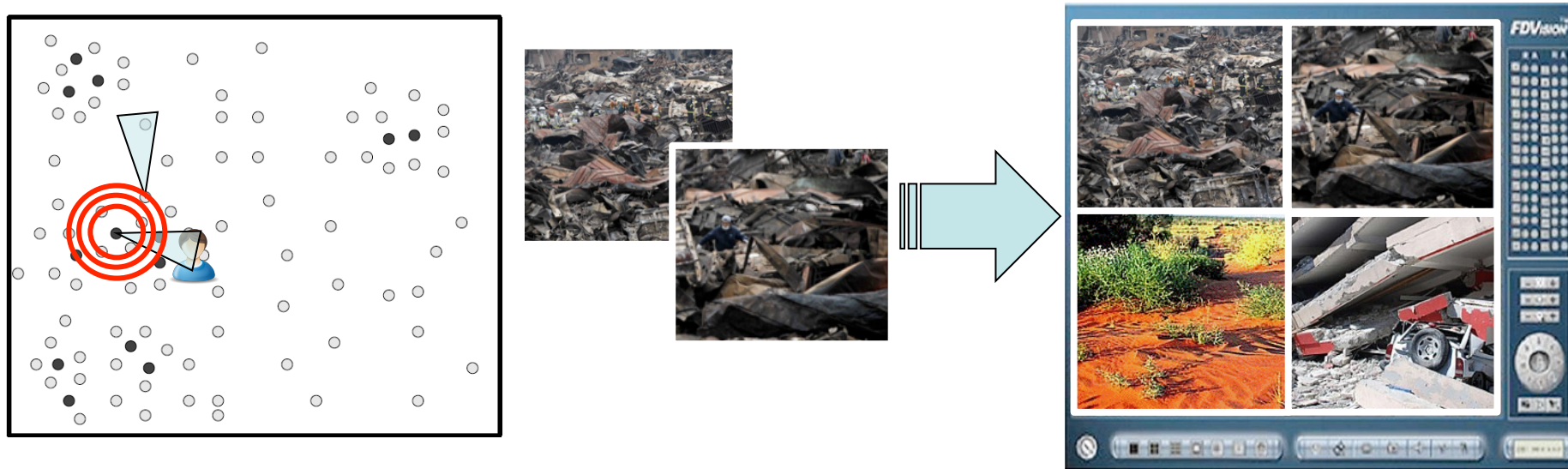
A CHALLENGE FOR MISSION-CRITICAL APPLICATION



CHALLENGES FOR MAC PROTOCOLS IN WSN (2)

- ❑ SYNCHRONOUS MAC
 - ❑ ADDS LATENCY
 - ❑ DIFFICULT TO MAINTAIN SYNC ALONG THE PATH
- ❑ DUTY-CYCLE LENGTH ADAPTATION
 - ❑ HOW TO ADAPT?
 - ❑ BOTH TRAFFIC-BASED OR TOPOLOGY-BASED DO NOT TAKE INTO ACCOUNT CRITICALITY

IMAGE SENSORS FOR MISSION-CRITICAL SURVEILLANCE



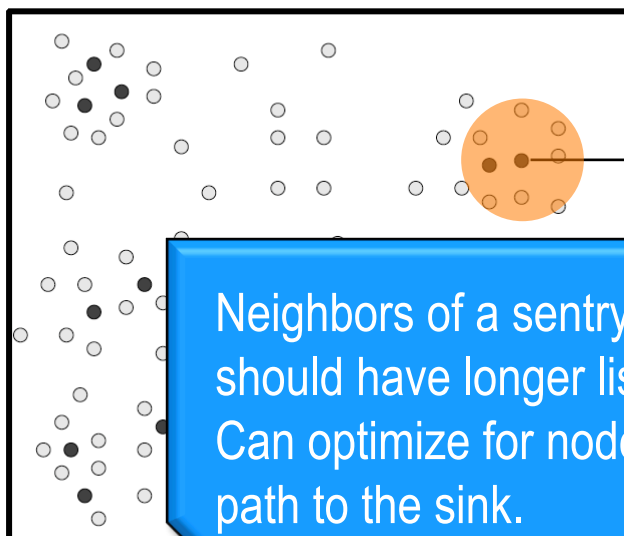
- ❑ INTRUSION DETECTION, IDENTIFICATION, DISAMBIGUATION
- ❑ SITUATION AWARENESS

OUR CURRENT RESEARCH ON MAC LAYER

□ DUTY-CYCLED MAC (E.G. SMAC)



□ LINK THE LISTENING TIME TO THE CRITICALITY MODEL



Neighbors of a sentry nodes should have longer listening time. Can optimize for nodes on the path to the sink.

