Wireless Sensor Networks

10th Lecture

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CoNe
Freiburg

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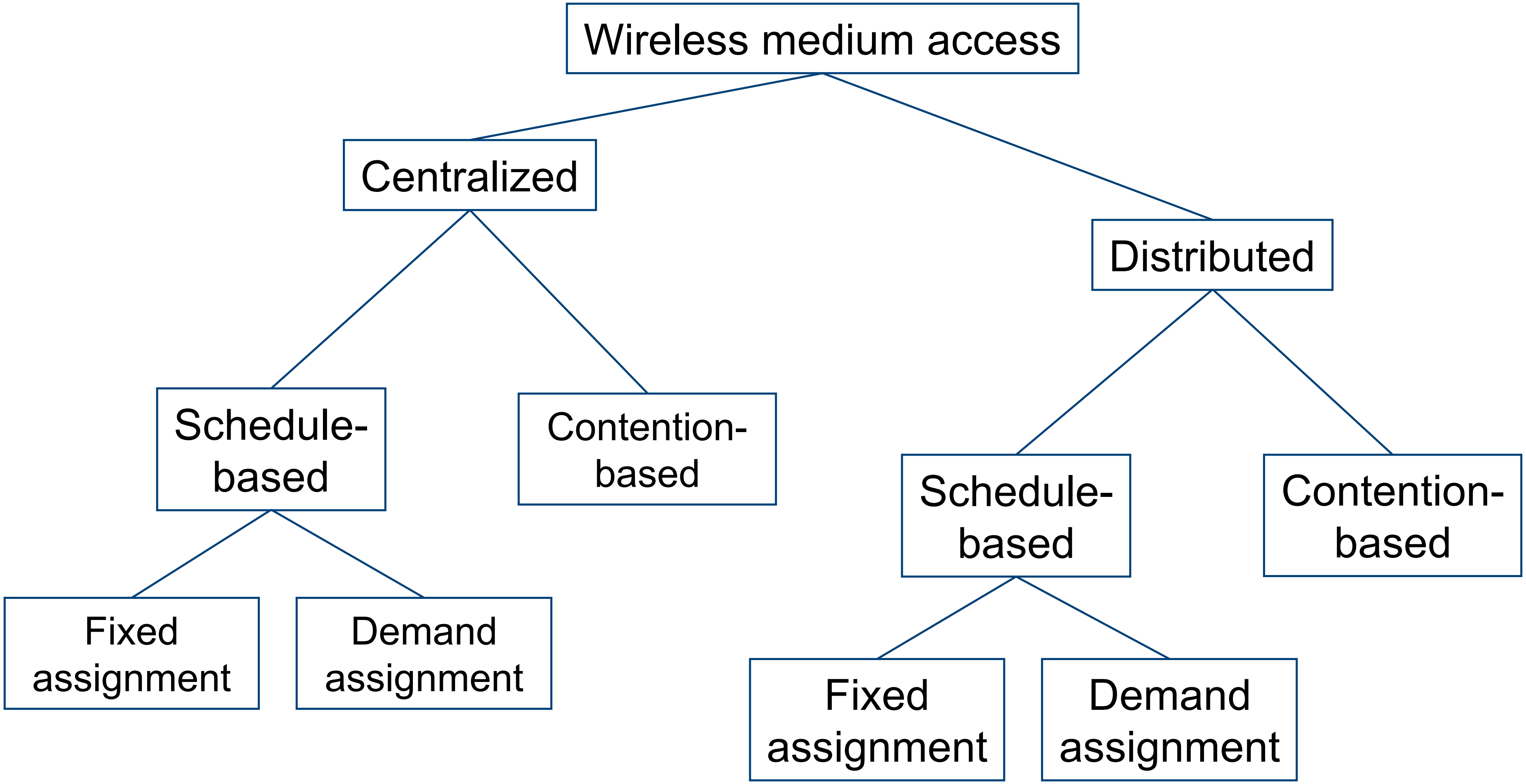
Medium Access Control (MAC)

- **Controlling when to send a packet and when to listen for a packet are perhaps the two most important operations in a wireless network**
  - Especially, idly waiting wastes huge amounts of energy
- **This chapter discusses schemes for this medium access control that are**
  - Suitable to mobile and wireless networks
  - Emphasize energy-efficient operation

Main options



Overview

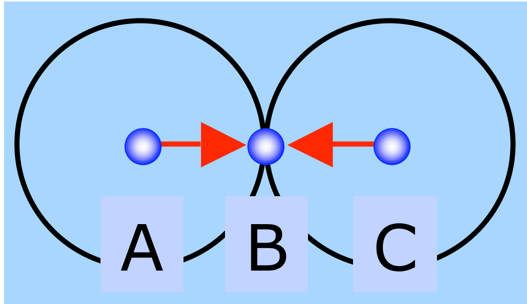
- *Principal options and difficulties*
- **Contention-based protocols**
- **Schedule-based protocols**
- **IEEE 802.15.4**

Overview

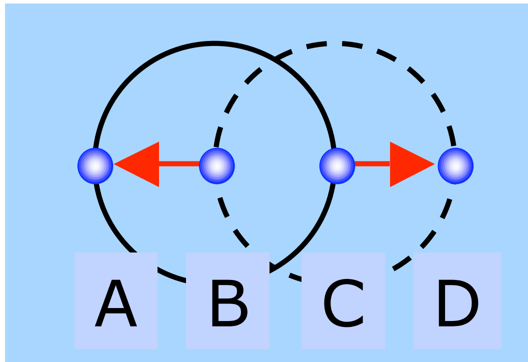
- **Principal options and difficulties**
- *Contention-based protocols*
  - MACA
  - S-MAC, T-MAC
  - Preamble sampling, B-MAC
  - PAMAS
- **Schedule-based protocols**
- **IEEE 802.15.4**

Problems for the MAC-Protocol

- **Hidden Terminal Problem**



- **Exposed Terminal Problem**



Distributed, contention-based MAC

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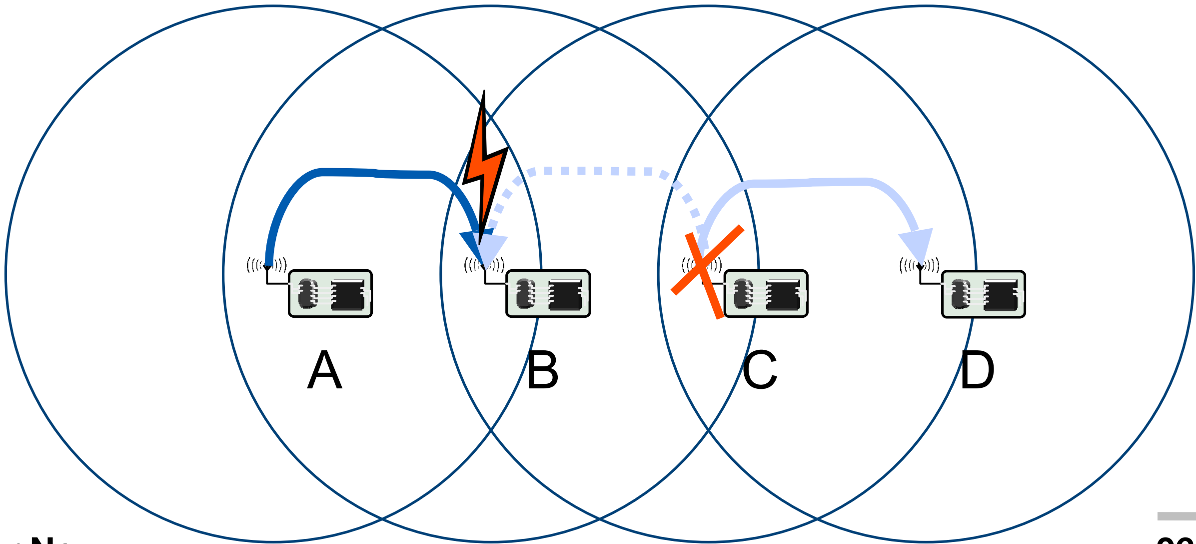
- **Basic ideas for a distributed MAC**
  - ALOHA – no good in most cases
  - Listen before talk ***(Carrier Sense Multiple Access, CSMA) –*** better, but suffers from ***sender*** not knowing what is going on at ***receiver***, might destroy packets despite first listening for a

⇒ **Receiver additionally needs some possibility to inform possible senders in its vicinity about impending transmission (to "shut them up" for this duration**

Hidden terminal scenario:



Also: recall exposed terminal scenario

Main options to shut up senders

- **Receiver informs potential interferers** *while* **a reception is on-going**
  - By sending out a signal indicating just that
  - Problem: Cannot use same channel on which actual reception takes place

    ⇒ Use separate channel for signaling
  - ***Busy tone*** protocol
- **Receiver informs potential interferers** *before* **a reception is on-going**
  - Can use same channel
  - Receiver itself needs to be informed, by sender, about impending transmission
  - Potential interferers need to be aware of such information, need to store it

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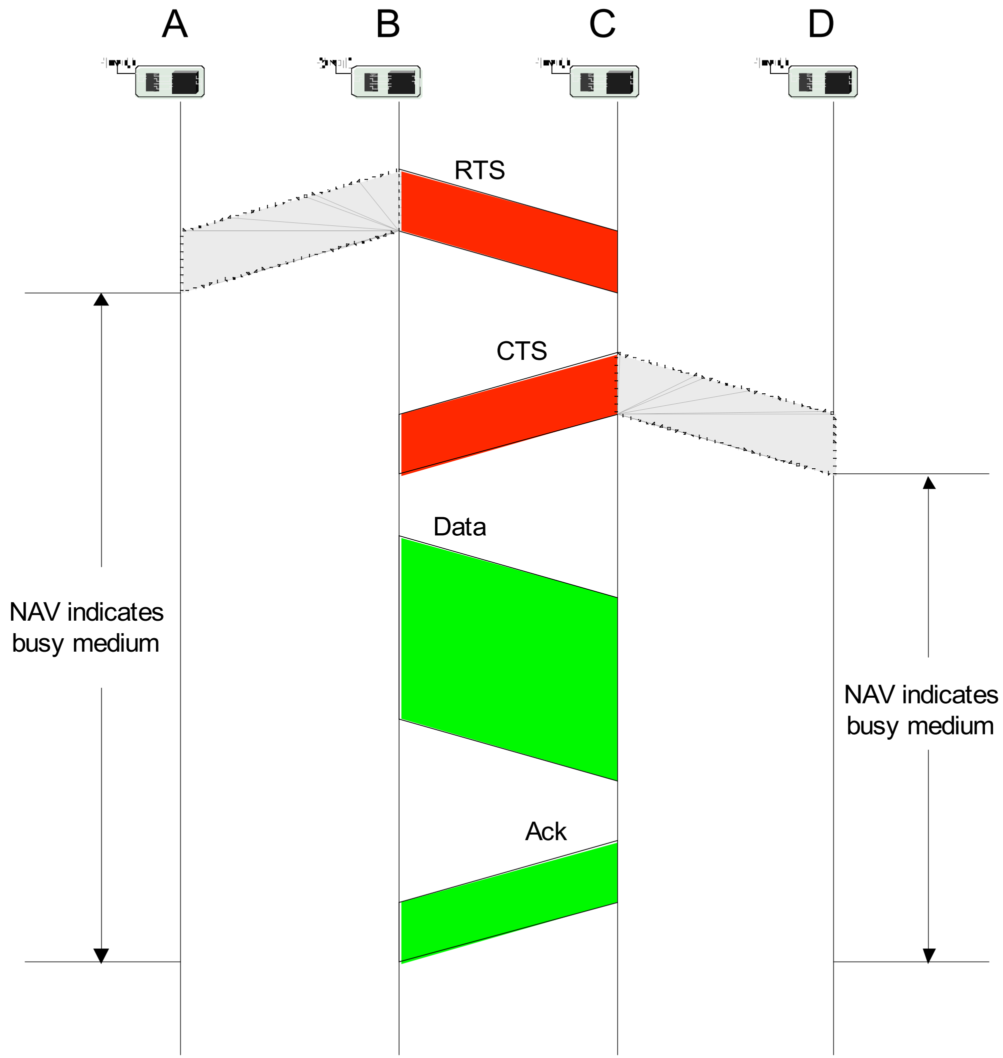
Multiple Access with Collision Avoidance (MACA)

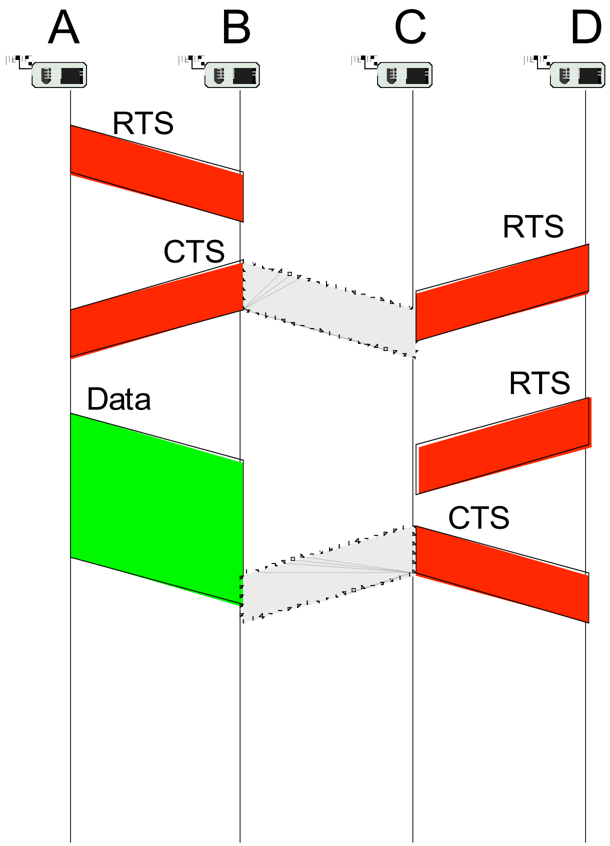
- **Sender B asks receiver C whether C is able to receive a transmission**
  Request to Send (RTS)
- **Receiver C agrees, sends out a** *Clear to Send* **(***CTS***)**
- **Potential interferers overhear either RTS or CTS and know about impending transmission and for how long it will last**
  - Store this information in a ***Network Allocation Vector***
- **B sends, C acks**

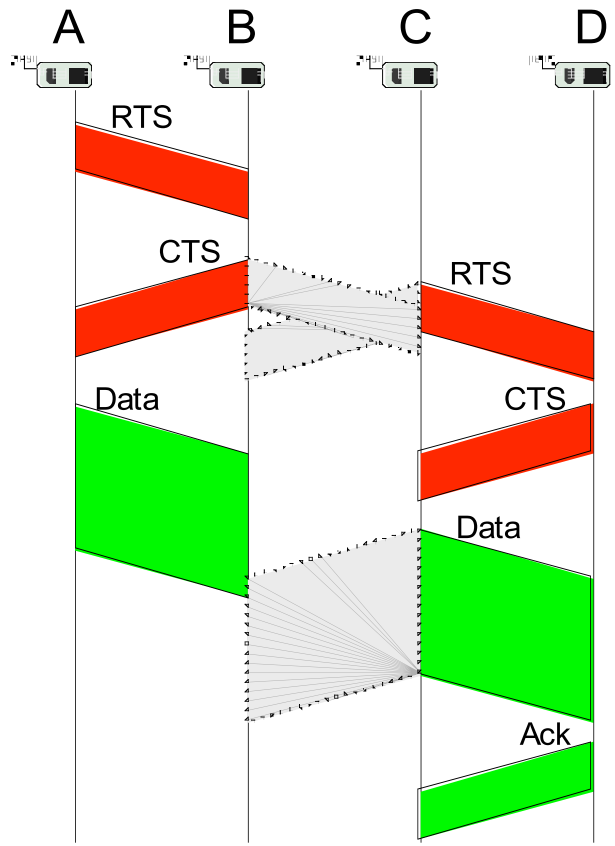
⇒ *MACA protocol* **(used e.g. in** *IEEE 802.11***)**



RTS/CTS

- RTS/CTS ameliorate, but do not solve hidden/exposed terminal problems
- Example problem cases:





MACA Problem: Idle listening

- **Need to sense carrier for RTS or CTS packets**
  - In some form shared by many CSMA variants; but e.g. not by busy tones
  - Simple sleeping will break the protocol
- **IEEE 802.11 solution: ATIM windows & sleeping**
  - Basic idea: Nodes that have data buffered for receivers send ***traffic indicators*** at pre-arranged points in time
  - Receivers need to wake up at these points, but can sleep otherwise
- **Parameters to adjust in MACA**
  - Random delays – how long to wait between listen/transmission attempts?
  - Number of RTS/CTS/ACK re-trials?
  - …

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  - …

Centralized medium access

- **Idea: Have a central station control when a node may access the medium**
  - Example: Polling, centralized computation of TDMA schedules
  - Advantage: Simple, quite efficient (e.g., no collisions), burdens the central station

- **Not directly feasible for non-trivial wireless network sizes**
- **But: Can be quite useful when network is somehow divided into smaller groups**
  - Clusters, in each cluster medium access can be controlled centrally – compare Bluetooth piconets, for example

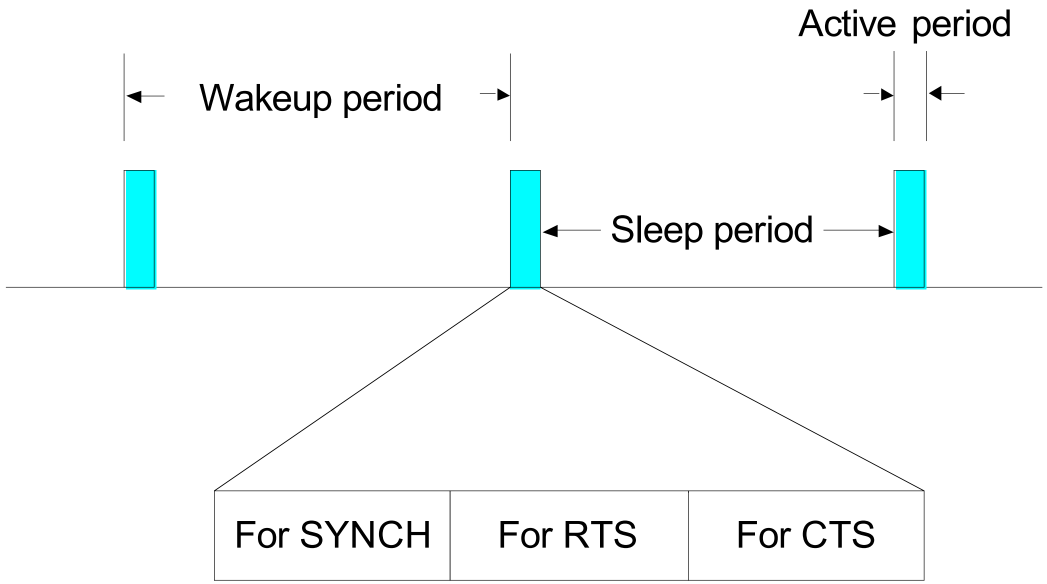
⇒ **Usually, distributed medium access is considered**

Schedule- vs. contention-based MACs

- *Schedule-based* **MAC**
  - A ***schedule*** exists, regulating which participant may use which resource at which time (TDMA component)
  - Typical resource: frequency band in a given physical space (with a given code, CDMA)
  - Schedule can be ***fixed*** or computed ***on demand***
    - Usually: mixed – difference fixed/on demand is one of time scales
  - Usually, collisions, overhearing, idle listening no issues
  - Needed: time synchronization!
- *Contention-based* **protocols**
  - Risk of colliding packets is deliberately taken
  - Hope: coordination overhead can be saved, resulting in overall improved efficiency
  - Mechanisms to handle/reduce probability/impact of collisions required
  - Usually, ***randomization*** used somehow

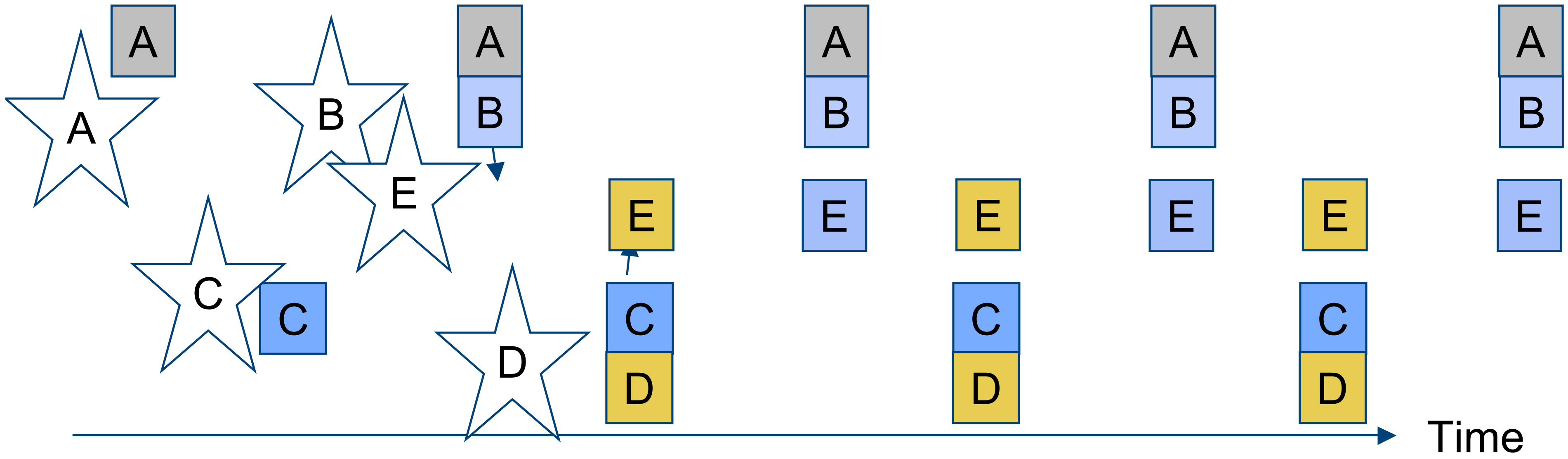
Sensor-MAC (S-MAC)

- **MACA's idle listening is particularly unsuitable if average data rate is low**
  - –Most of the time, nothing happens
- **Idea: Switch nodes off, ensure that neighboring nodes turn on simultaneously to allow packet exchange (rendez-vous)**
  - –Only in these ***active periods***, packet exchanges happen
  - –Need to also exchange wakeup schedule between neighbors
  - –When awake, essentially perform RTS/CTS
- **Use SYNCH, RTS, CTS phases**



S-MAC synchronized islands

- Nodes try to pick up schedule synchronization from neighboring nodes
- If no neighbor found, nodes pick some schedule to start with
- If additional nodes join, some node might learn about two different schedules from different nodes
  - "Synchronized islands"
- To bridge this gap, it has to follow both schemes



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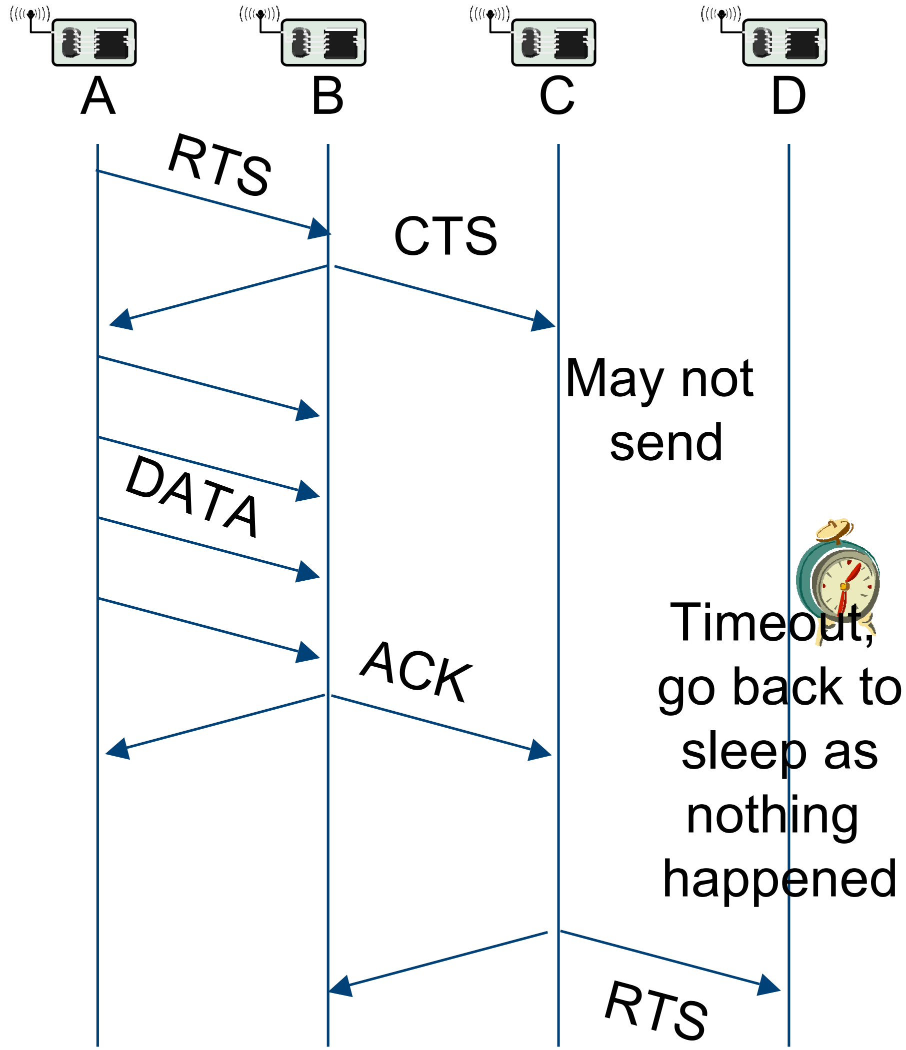
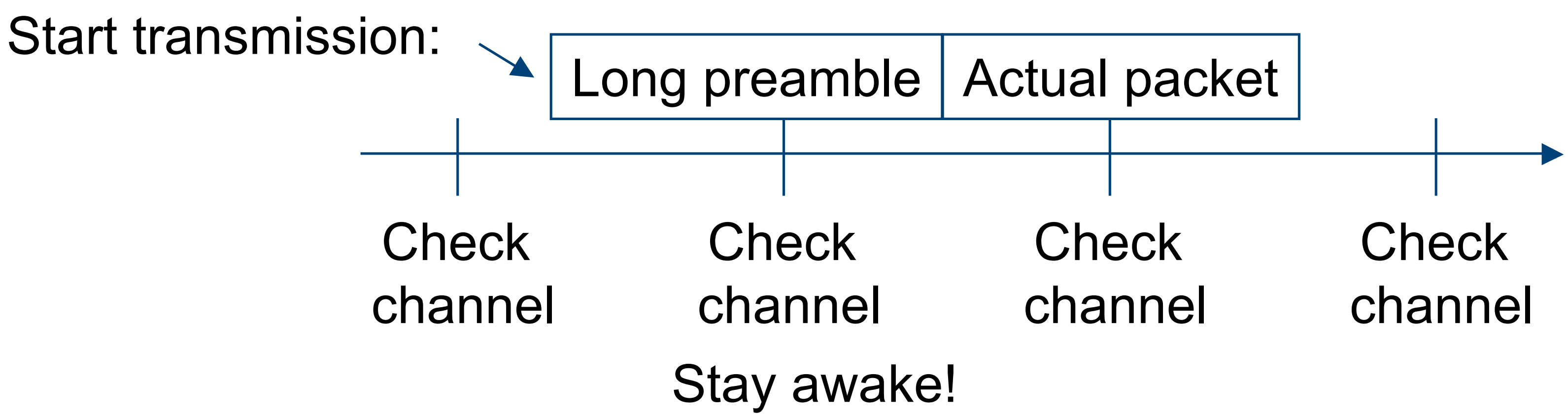
Timeout-MAC (T-MAC)

- **In S-MAC, active period is of constant length**
- **What if no traffic actually happens?**
  - Nodes stay awake needlessly long
- **Idea: Prematurely go back to sleep mode when no traffic has happened for a certain time (=timeout) ! T-MAC**
  - Adaptive duty cycle!
- **One ensuing problem: Early sleeping**
  - C wants to send to D, but is hindered by transmission A! B
  - Two solutions exist – homework!



Preamble Sampling

- **So far: Periodic sleeping supported by some means to synchronize wake up of nodes to ensure rendez-vous between sender and receiver**
- **Alternative option: Don't try to explicitly synchronize nodes**
  - Have receiver sleep and only periodically sample the channel
- **Use** *long preambles* **to ensure that receiver stays awake to catch actual packet**
  - Example: WiseMAC



B-MAC

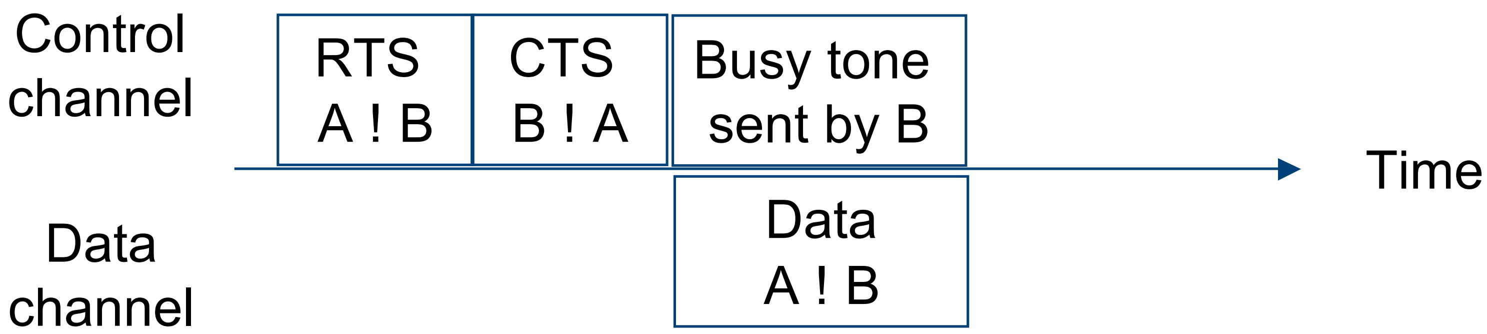
- **Combines several of the above discussed ideas**
  - Takes care to provide practically relevant solutions
- **Clear Channel Assessment**
  - Adapts to noise floor by sampling channel when it is assumed to be free
  - Samples are exponentially averaged, result used in gain control
  - For actual assessment when sending a packet, look at five channel samples – channel is free if even a single one of them is significantly below noise
  - Optional: random backoff if channel is found busy
- **Optional: Immediate link layer acknowledgements for received packets**

B-MAC II

- **Low Power Listening (= preamble sampling)**
  - Uses the clear channel assessment techniques to decide whether there is a packet arriving when node wakes up
  - Timeout puts node back to sleep if no packet arrived
- **B-MAC does *not* have**
  - Synchronization
  - RTS/CTS
  - Results in simpler, leaner implementation
  - Clean and simple interface
- **Currently: Often considered as the** *default WSN MAC* **protocol**

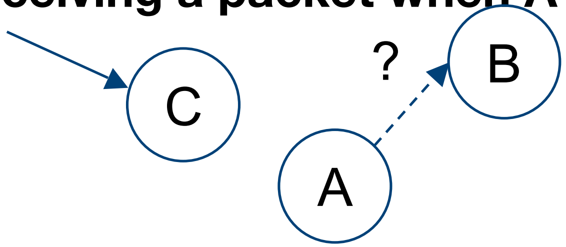
Power Aware Multi-Access with Signaling – PAMAS

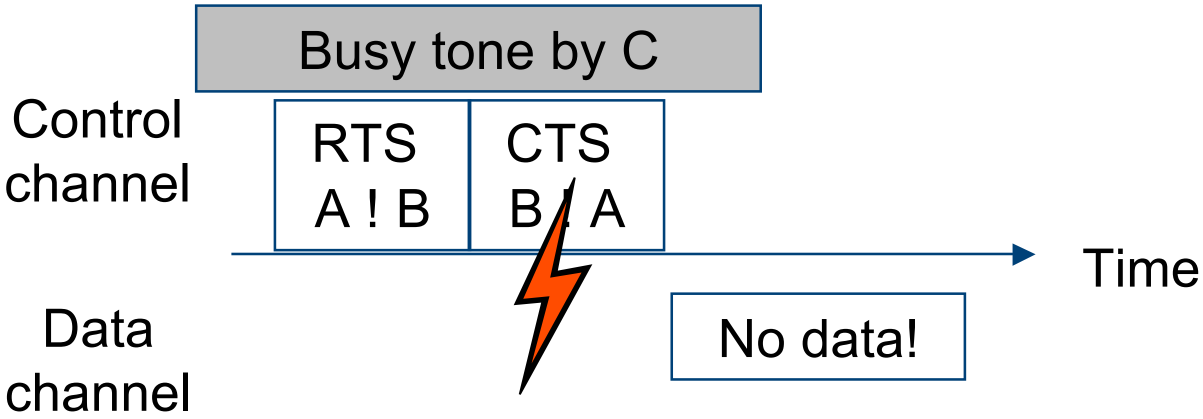
- **Idea: combine busy tone with RTS/CTS**
  - Results in detailed overhearing avoidance, does not address idle listening
  - Uses separate ***data*** and ***control channels***
- **Procedure**
  - Node A transmits RTS on control channel, does not sense channel
  - Node B receives RTS, sends CTS on control channel if it can receive and does not know about ongoing transmissions
  - B sends busy tone as it starts to receive data



PAMAS – Already ongoing transmission

- **Suppose a node C in vicinity of A is already receiving a packet when A initiates RTS**
- **Procedure**
  - A sends RTS to B
  - C is sending busy tone (as it receives data)
  - CTS and busy tone collide, A receives no CTS, does not send data





Similarly: Ongoing transmission near B destroys RTS by busy tone

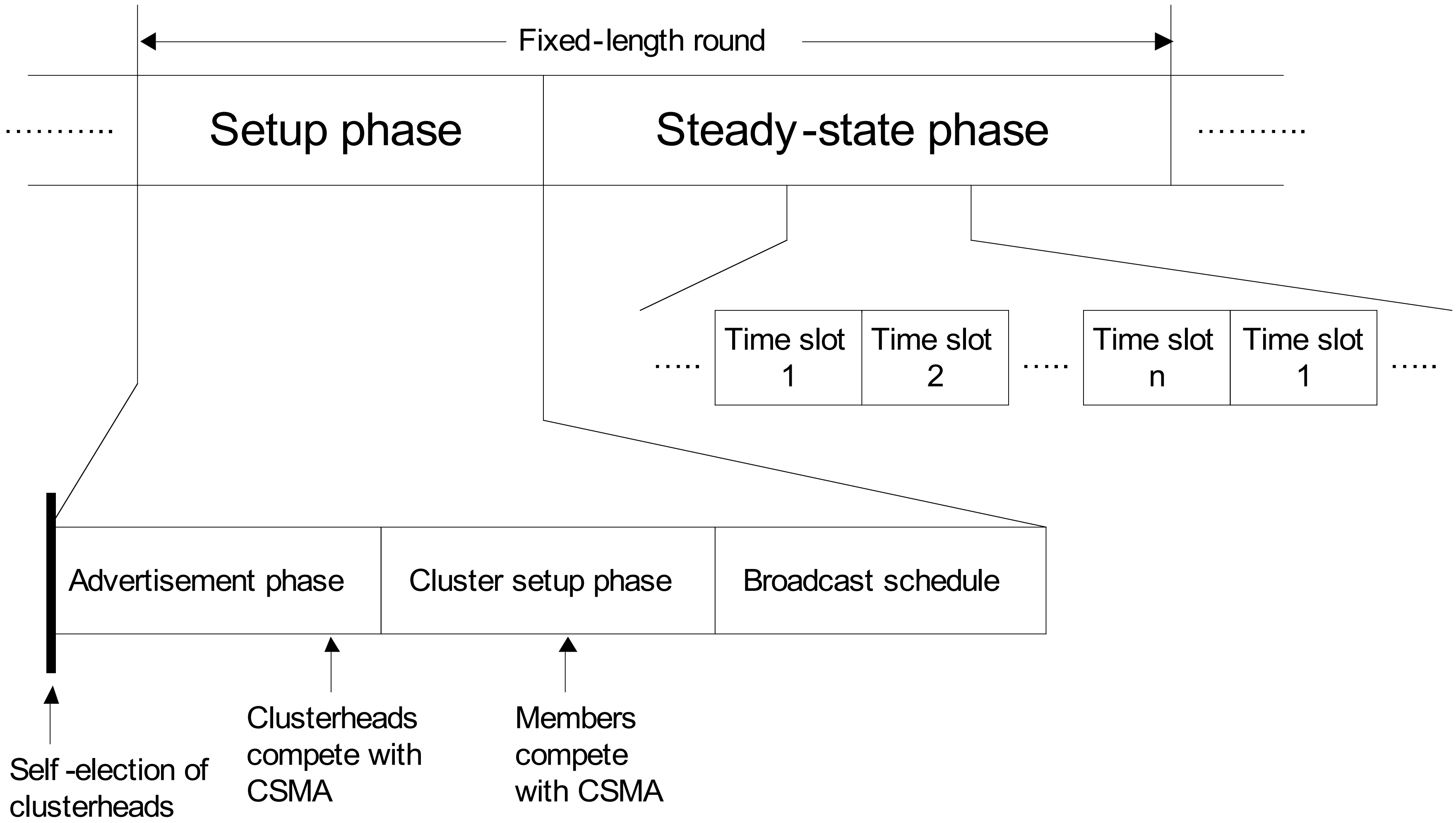
Overview

- **Principal options and difficulties**
- **Contention-based protocols**
- *Schedule-based protocols*
  - LEACH
  - SMACS
  - TRAMA
- **IEEE 802.15.4**

Low-Energy Adaptive Clustering Hierarchy (LEACH)

- **Given: dense network of nodes, reporting to a central sink, each node can reach sink directly**
- **Idea: Group nodes into "*clusters*", controlled by *clusterhead***
  - Setup phase; details: later
  - About 5% of nodes become clusterhead (depends on scenario)
  - Role of clusterhead is rotated to share the burden
  - Clusterheads advertise themselves, ordinary nodes join CH with strongest signal
  - Clusterheads organize
    - CDMA code for all member transmissions
    - TDMA schedule to be used within a cluster
- **In steady state operation**
  - CHs collect & aggregate data from all cluster members
  - Report aggregated data to sink using CDMA

LEACH rounds



SMACS

- **Given:**
  - Many radio channels
  - Superframes of known length (not necessarily in phase, but still time synchronization required!)
- **Goal: set up directional *links* between neighboring nodes**
  - Link: radio channel + time slot at both sender and receiver
  - Free of collisions at receiver
  - Channel picked randomly, slot is searched greedily until a collision-free slot is found
- **Receivers sleep and only wake up in their assigned time slots, once per superframe**
- **In effect: a local construction of a schedule**

TRAMA

- **Nodes are time synchronized**
- **Time divided into cycles, divided into**
  - Random access periods
  - Scheduled access periods
- **Nodes exchange neighborhood information**
  - Learning about their two-hop neighborhood
  - Using ***neighborhood exchange protocol***: In random access period, send small, incremental neighborhood update information in randomly selected time slots
- **Nodes exchange schedules**
  - Using ***schedule exchange protocol***
    - A node send update list of receivers for packets its has in Q
  - Based on this information it run ***distributed schedule algorithm***
    - For each time slot … the transmitting and receiving nodes and nodes can go to sleep.

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TRAMA – adaptive election

- **Given: Each node knows its two-hop neighborhood and their current schedules**
- **How to decide which slot (in scheduled access period) a node can use?**
  - Use ***node identifier*** x and globally known ***hash function*** h
  - For time slot t, compute ***priority*** p = h (x © t)
  - Compute this priority for next k time slots for node itself and all two-hop neighbors
  - Node uses those time slots for which it has the highest priority

Priorities of node A and its two neighbors B & C

	t = 0	t = 1	t = 2	t=3	t = 4	t = 5
A	14	23	9	56	3	26
B	33	64	8	12	44	6
C	53	18	6	33	57	2

TRAMA – possible conflicts

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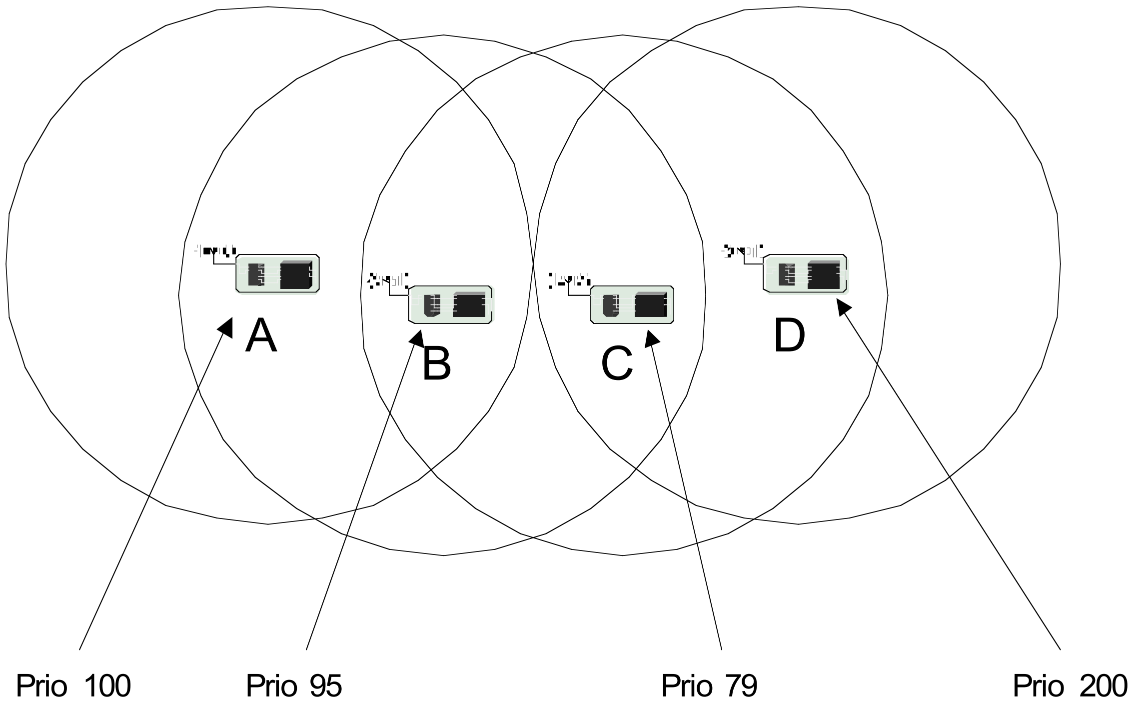
- **When does a node have to receive?**
  - Easy case: one-hop neighbor has won a time slot and announced a packet for it
  - But complications exist – compare example
- **What does B believe?**
  - A thinks it can send
  - B knows that D has higher priority in its 2-hop neighborhood!
- **Rules for resolving such conflicts are part of TRAMA**



Comparison: TRAMA, S-MAC

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- **Comparison between TRAMA & S-MAC**
  - Energy savings in TRAMA depend on load situation
  - Energy savings in S-MAC depend on duty cycle
  - TRAMA (as typical for a TDMA scheme) has higher delay but higher maximum throughput than contention-based S-MAC

- **TRAMA disadvantage:**
  - substantial memory/CPU requirements for schedule computation

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Overview

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IEEE 802.15.4

- **IEEE standard for low-rate WPAN applications**
- **Goals: low-to-medium bit rates, moderate delays without too stringent guarantee requirements, low energy consumption**
- **Physical layer**
  - 20 kbps over 1 channel @ 868-868.6 MHz
  - 40 kbps over 10 channels @ 905 – 928 MHz
  - 250 kbps over 16 channels @ 2.4 GHz
- **MAC protocol**
  - Single channel at any one time
  - Combines contention-based and schedule-based schemes
  - Asymmetric: nodes can assume different roles

IEEE 802.15.4 MAC overview

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- **Star networks:** *devices* **are associated with** *coordinators*
  - Forming a PAN, identified by a PAN identifier
- **Coordinator**
  - Bookkeeping of devices,
  - address assignment
  - generate beacons
  - Talks to devices and peer coordinators
- **Beacon-mode superframe structure**
  - GTS assigned to devices upon request

Superframe structure and GTS management

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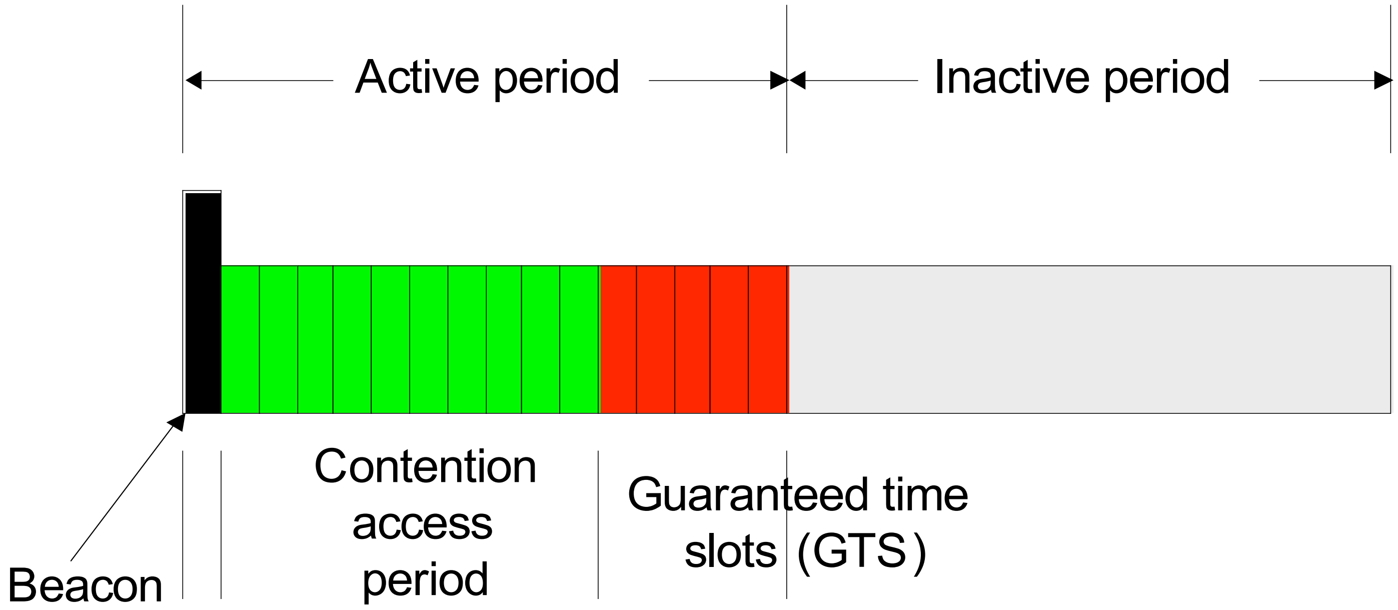
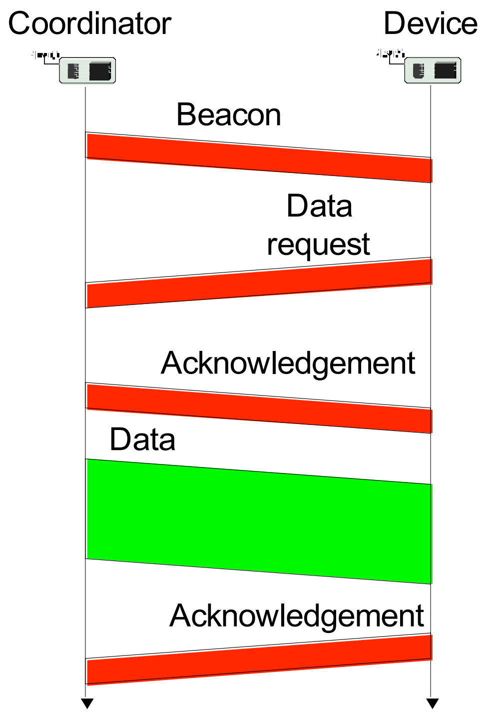


Data transfer procedures

- **Case 1: Device has a GTS and wants to send data then …**
- **Case 2: Device has a CTS and coordinator wants to send data then…**
- **Case 3: Device does not has a GTS and want to send data then …**
- **Case 4: Coordinator cannot use (or do not have) CTS..**
  - Device can be sleeping…



Wakeup radio MAC protocols

- **Simplest scheme: Send a wakeup "burst", waking up all neighbors ! Significant overhearing**
  - Possible option: First send a short ***filter packet*** that includes the actual destination address to allow nodes to power off quickly
- **Not quite so simple scheme: Send a wakeup burst including the receiver address**
  - Wakeup radio needs to support this option
- **Additionally: Send information about a (randomly chosen) data channel, CDMA code, … in the wakeup burst**
- **Various variations on these schemes in the literature, various further problems**
  - One problem: 2-hop neighborhood on wakeup channel might be different from 2-hop neighborhood on data channel
  - Not trivial to guarantee unique addresses on both channels

Thank you

(and thanks go also to Holger Karl for providing slides)

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