192620010
Mobile & Wireless Networking

Lecture 3:
Medium Access Control

[Schiller, Chapter 3]
[Wikipedia: "Hybrid Automatic Repeat Request"]

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Outline of Lecture 3

- Medium Access Control
  - Motivation
  - Channel partitioning
    - CDMA
    - Duplexing
  - Taking turns
  - Random access
    - Aloha / Slotted Aloha
    - Reservation Aloha
    - Packet reservation multiple access
    - Reservation TDMA
    - CSMA
      - CSMA/CA
      - RTS/CTS
    - Random access and CDMA (UMTS)
- Hybrid ARQ

Motivation

Can we apply media access methods from fixed networks?

Example CSMA/CD

- **C**arrier **S**ense **M**ultiple **A**ccess with **C**ollision **D**etection
- send as soon as the medium is free, listen into the medium if a collision occurs (original method in IEEE 802.3)

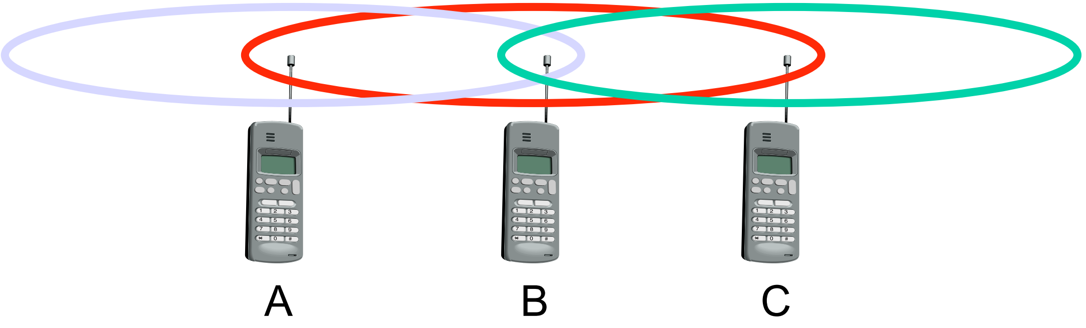
Problems in wireless networks

- signal strength decreases proportional to the square of the distance
- the sender would apply CS and CD, but the collisions happen at the receiver
- it might be the case that a sender cannot “hear” the collision, i.e., CD does not work
- furthermore, CS might not work if, e.g., a terminal is “hidden”

Motivation - hidden and exposed terminals

Hidden terminals

- A sends to B, C cannot receive A
- C wants to send to B, C senses a “free” medium (CS fails)
- collision at B, A cannot receive the collision (CD fails)
- A is “hidden” for C



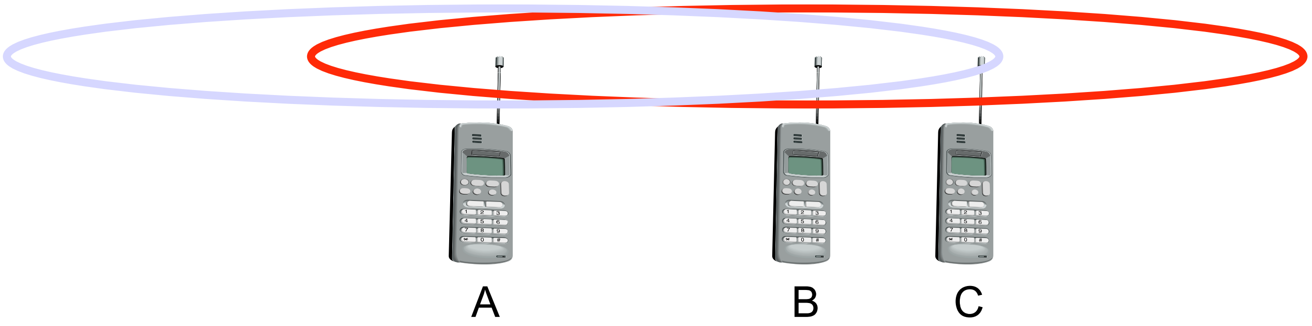
Exposed terminals

- B sends to A, C wants to send to another terminal (not A or B)
- C has to wait, CS signals a medium in use
- but A is outside the radio range of C, therefore waiting is not necessary
- C is “exposed” to B

Motivation - near and far terminals

Terminals A and B send, C receives

- signal strength decreases proportional to the square of the distance
- the signal of terminal B therefore drowns out A’s signal
- C cannot receive A



If C for example was an arbiter for sending rights, terminal B would drown out terminal A already on the physical layer

Also severe problem for CDMA-networks - precise power control needed!

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Channel partitioning protocols

- SDMA (Space Division Multiple Access)
  - segment space into sectors, use directed antennas
  - cell structure
- FDMA (Frequency Division Multiple Access)
  - assign a certain frequency to a transmission channel between a sender and a receiver
  - permanent (e.g., radio broadcast), slow hopping (e.g., GSM), fast hopping (FHSS, Frequency Hopping Spread Spectrum)
  - special case: Orthogonal FDMA (OFDMA)
- TDMA (Time Division Multiple Access)
  - assign the fixed sending frequency to a transmission channel between a sender and a receiver for a certain amount of time
- CDMA (Code Division Multiple Access)
  - assign a code to a transmission channel between a sender and a receiver for a certain amount of time

Code Division Multiple Access (CDMA)

- all terminals send on the same frequency probably at the same time and can use the whole bandwidth of the transmission channel
- each sender has a unique random number, a code, the sender XORs the data with this code
- the receiver can “tune” into this signal if it knows the pseudo random number, tuning is done via a correlation function

- different codes should be orthogonal
  - inner product should be 0
- ideally, code should have good autocorrelation
  - inner product with itself should be large, inner product with shifted version should be low
  - good for synchronization

CDMA example

In the following example let us suppose that a 0 is coded as a positive signal (+1), and a 1 as a negative signal (-1). Now we can represent the XOR operation as simple multiplication.

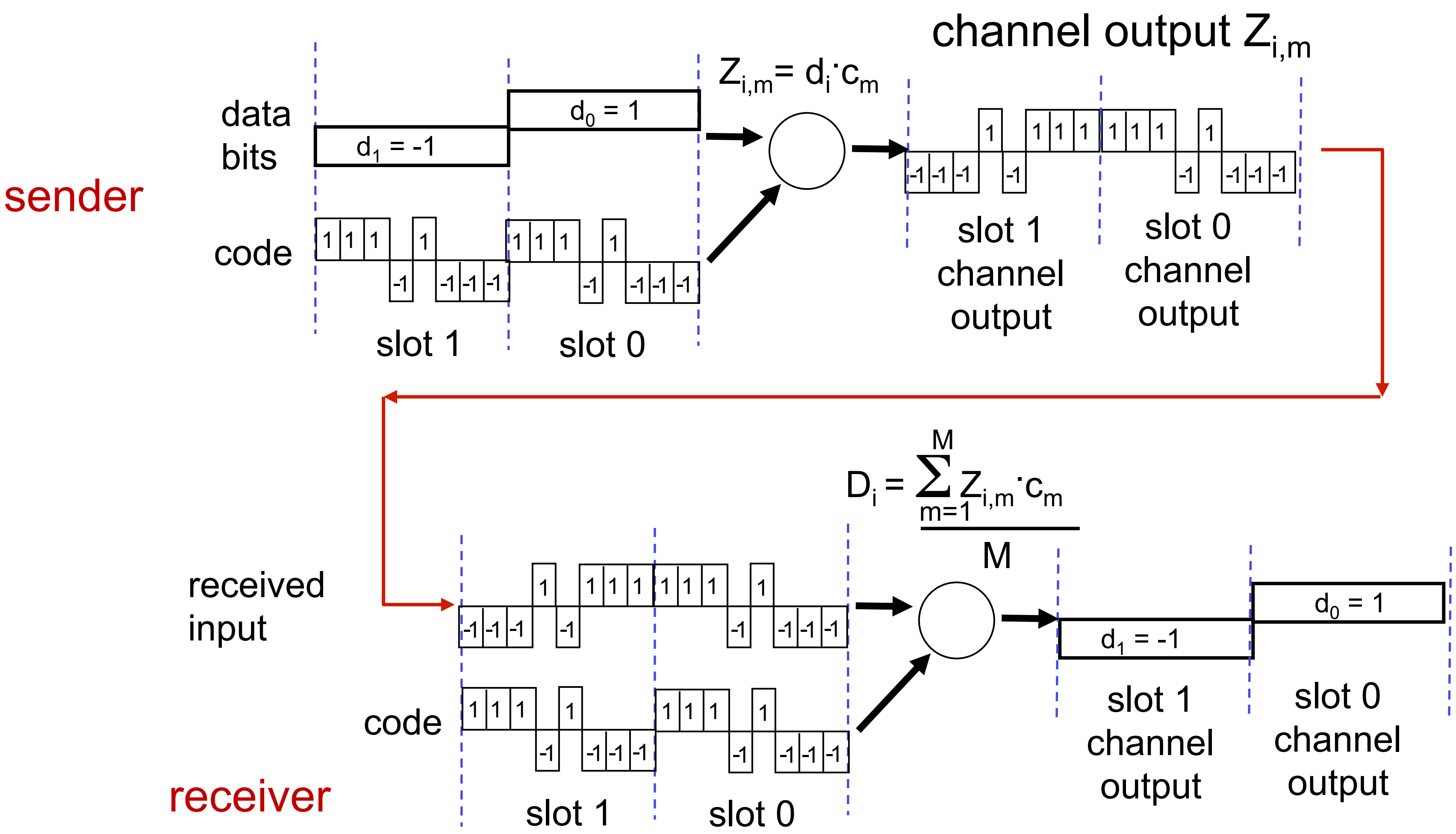
0 XOR 0 = 0 → 1 • 1 = 1

0 XOR 1 = 1 → 1 • -1 = -1

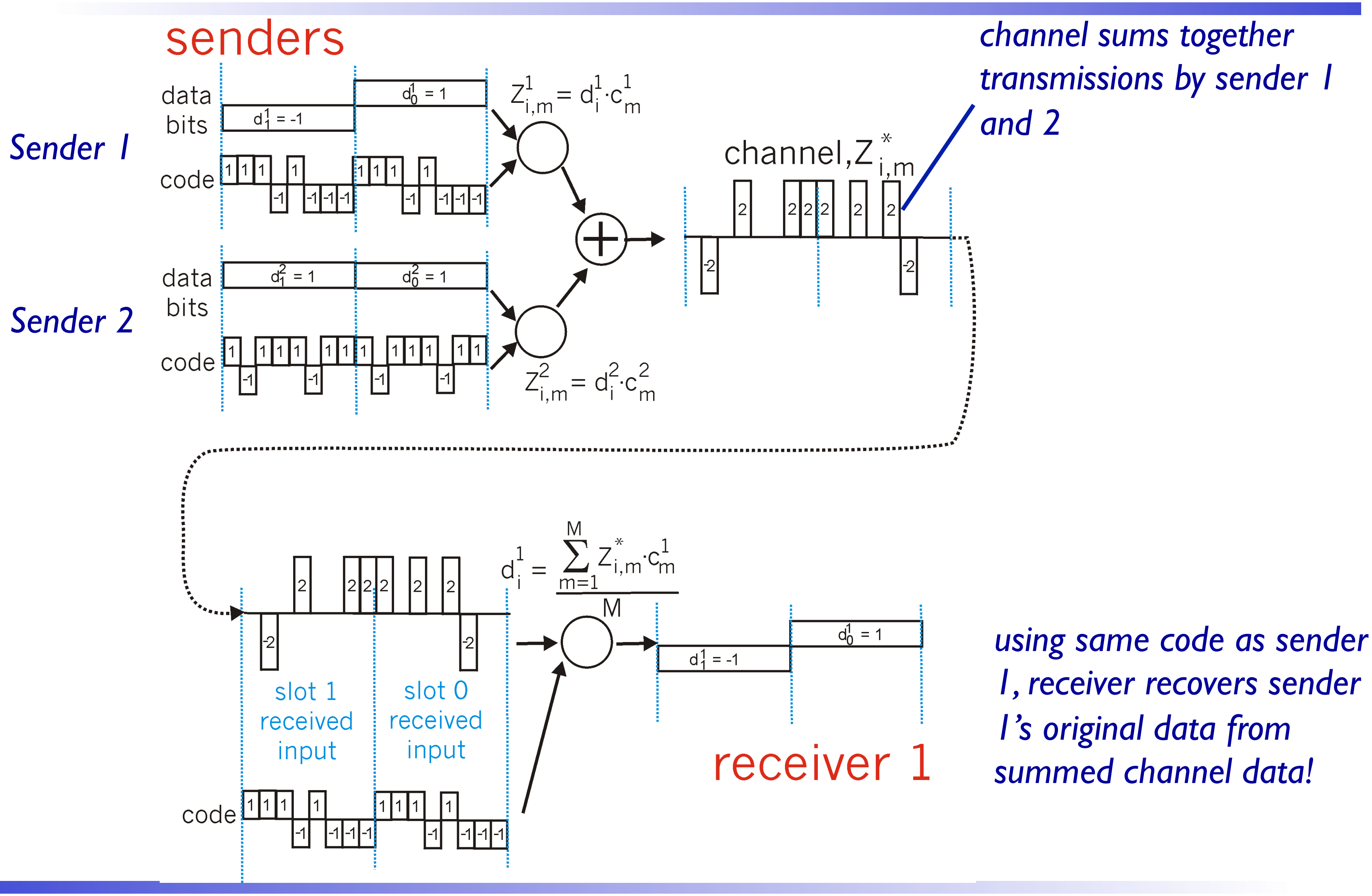
1 XOR 0 = 1 → -1 • 1 = -1

1 XOR 1 = 0 → -1 • -1 = 1

CDMA encode/decode



CDMA: decoding with an interfering transmitter



CDMA

Disadvantages:

- higher complexity of a receiver (receiver cannot just listen into the medium and start receiving if there is a signal)
- all signals should have the same strength at a receiver

Advantages:

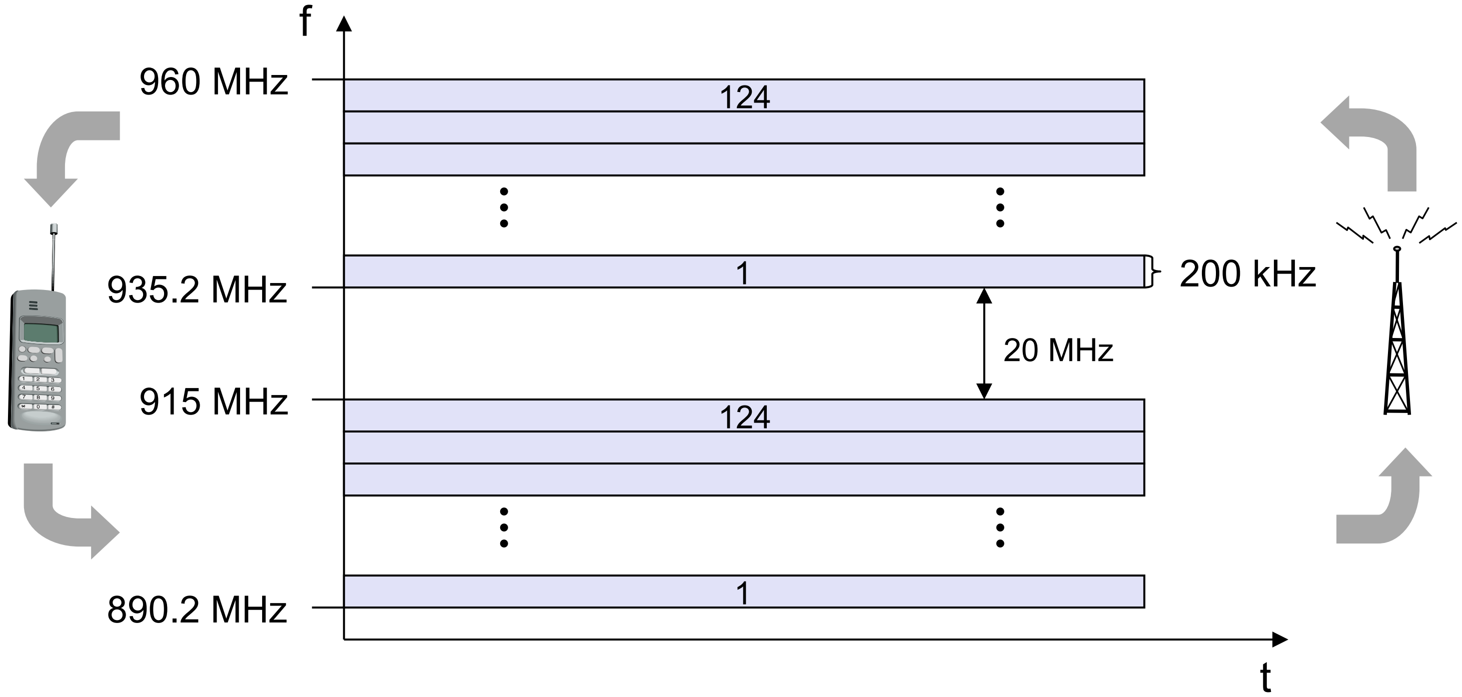
- all terminals can use the same frequency, no planning needed
- huge code space (e.g. 2^{32}) compared to frequency space
- interferences (e.g. white noise) is not coded
- forward error correction and encryption can be easily integrated

Duplexing

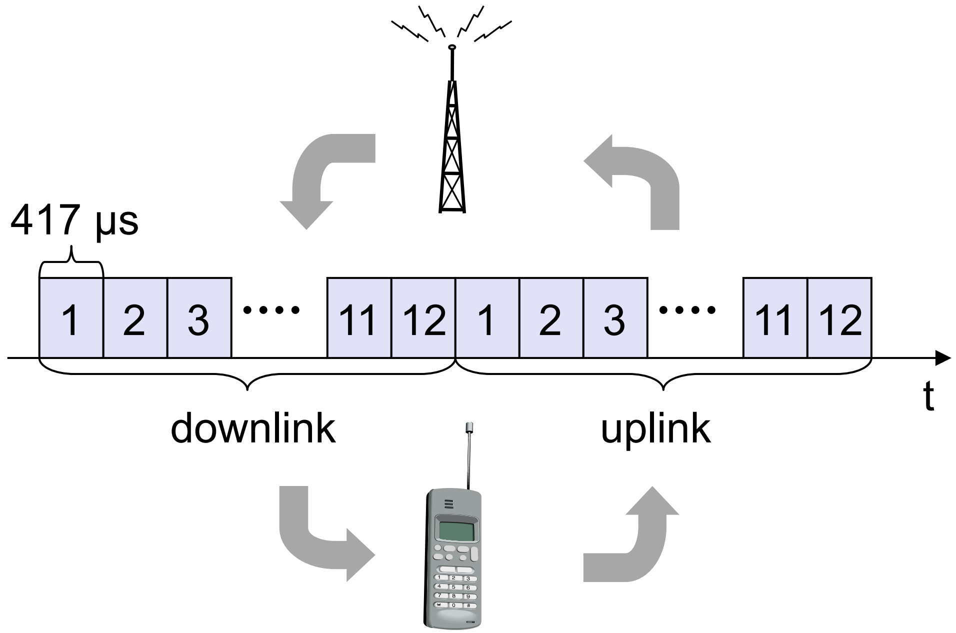
- Simultaneous transmission and reception of up and down-link channels
- Time and frequency domain techniques:
  - FDD: Frequency division duplex
  - TDD: Time division duplex

(Code division duplex would give an extreme near-far problem)

FDD/FDMA - general scheme, example GSM



TDD/TDMA - general scheme, example DECT



Comparison SDMA/TDMA/FDMA/CDMA

Approach	SDMA	TDMA	FDMA	CDMA
Idea	segment space into cells/sectors	segment sending time into disjoint time-slots, demand driven or fixed patterns	segment the frequency band into disjoint sub-bands	spread the spectrum using orthogonal codes
Terminals	only one terminal can be active in one cell/one sector	all terminals are active for short periods of time on the same frequency	every terminal has its own frequency, uninterrupted	all terminals can be active at the same place at the same moment, uninterrupted
Signal separation	cell structure, directed antennas	synchronization in the time domain	filtering in the frequency domain	code plus special receivers
Advantages	very simple, increases capacity per km?	established, fully digital, flexible	simple, established, robust	flexible, less frequency planning needed, soft handover
Dis-advantages	inflexible, antennas typically fixed	guard space needed (multipath propagation), synchronization difficult	inflexible, frequencies are a scarce resource	complex receivers, needs more complicated power control for senders
Comment	only in combination with TDMA, FDMA or CDMA useful	standard in fixed networks, together with FDMA/SDMA used in many mobile networks	typically combined with TDMA (frequency hopping patterns) and SDMA (frequency reuse)	still faces some problems, higher complexity, lowered expectations; will be integrated with TDMA/FDMA

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Taking turns protocols

- If one terminal can be heard by all others, this "central" terminal (master or base station) can poll all other terminals according to a certain scheme
  - master-slave scheme
  - now all schemes known from fixed networks can be used (typical mainframe - terminal scenario)
  - round robin, random, reservation based

- Used in Bluetooth, IEEE802.11 (option), LTE

- Downlink from the master / base station (centralized) scheduling can be used.

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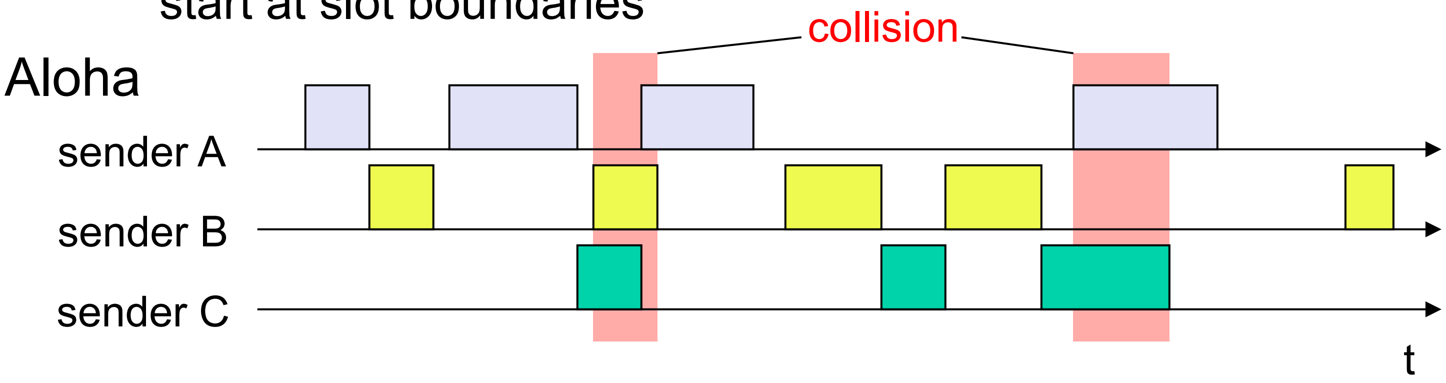
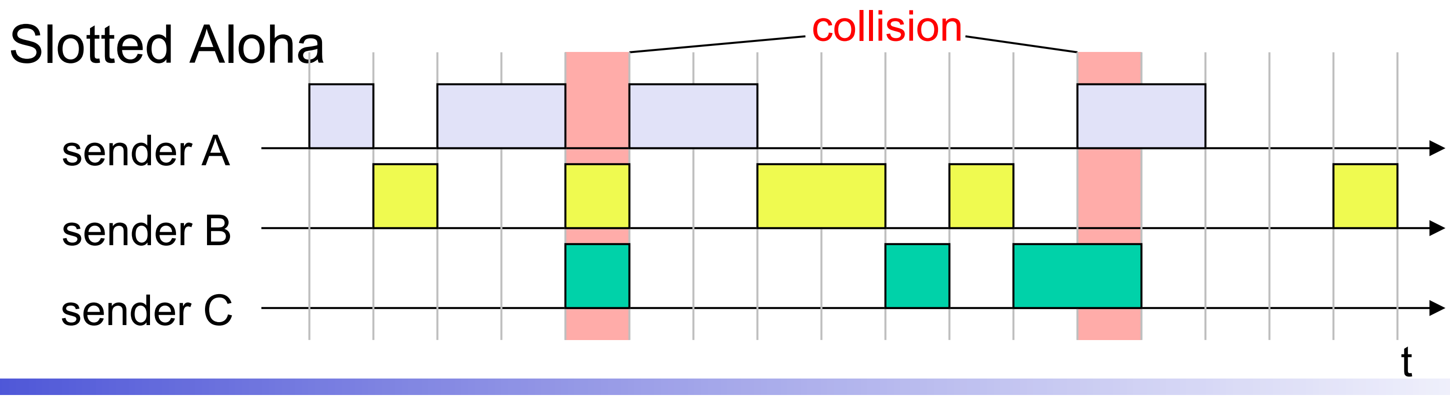
Aloha / Slotted Aloha

Mechanism

- random, distributed (no central arbiter), time-multiplex
- no carrier sense, retransmission (after collision) with probability *p*
- Slotted Aloha additionally uses time-slots, sending must always start at slot boundaries





Reservations in dynamic TDM

Channel efficiency only 18% for Aloha, 36% for Slotted Aloha (assuming Poisson distribution for packet arrivals)

Reservation can increase efficiency to 80%

- a sender *reserves* a future time-slot
- sending within this reserved time-slot is possible without collision
- reservation also causes higher delays
- typical scheme for satellite links

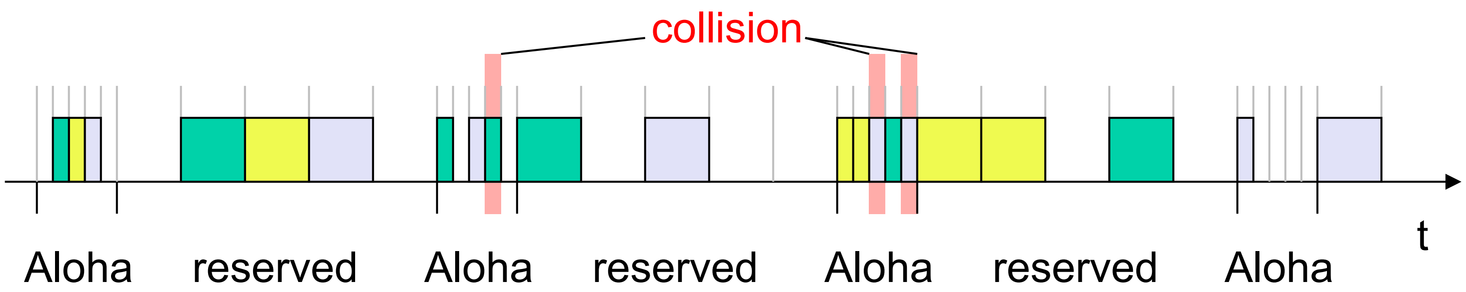
Examples for reservation algorithms:

- *Explicit Reservation (Reservation-ALOHA)*
- *Implicit Reservation (PRMA)*
- *Reservation-TDMA*

Explicit Reservation

Reservation Aloha / DAMA (Demand Assigned Multiple Access)

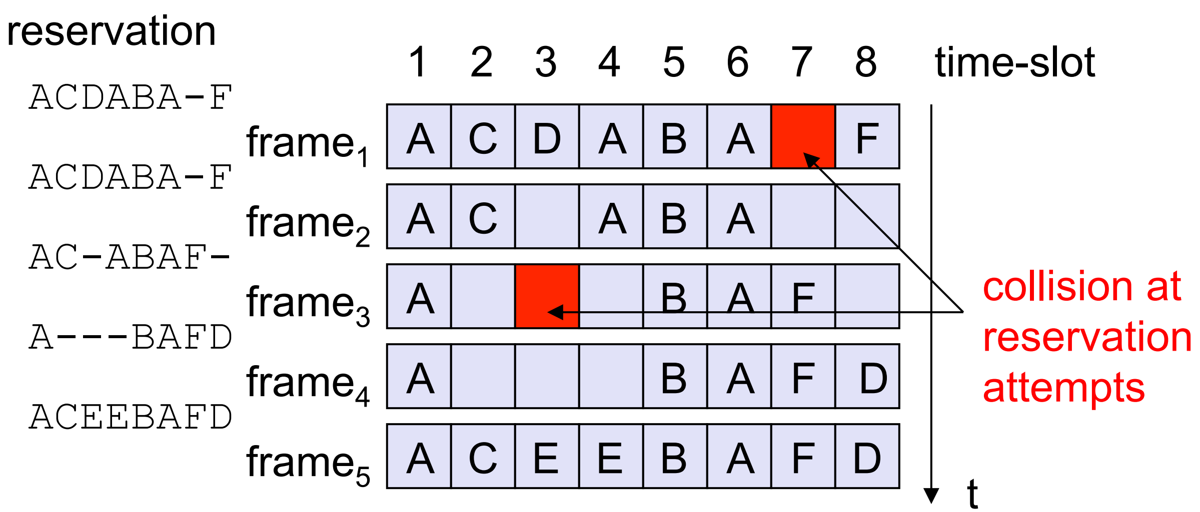
- two modes:
  - ALOHA mode for reservation:
    competition for small reservation slots, collisions possible
  - reserved mode for data transmission within successful reserved slots
    (no collisions possible)
- synchronization needed (of reserved / reservation slots)
- it is important for all stations to keep the reservation list consistent at any point in time



Implicit reservation

Packet Reservation Multiple Access (PRMA)

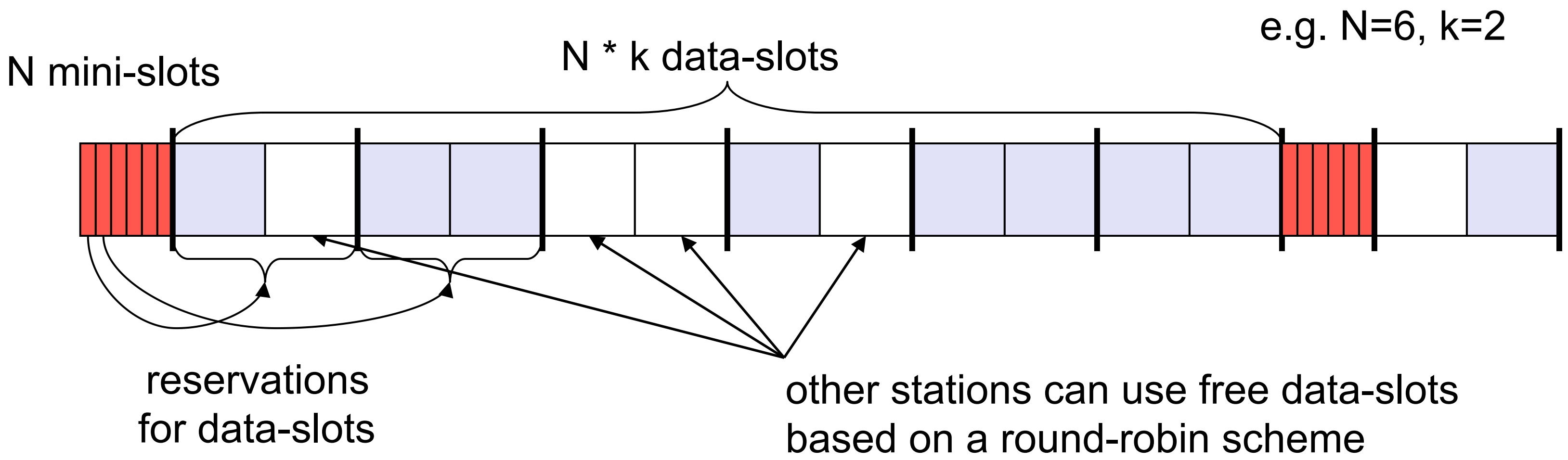
- a certain number of slots form a frame, frames are repeated
- stations compete for empty slots according to the slotted aloha principle
- once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has data to send
- competition for this slots starts again as soon as the slot was empty in the last frame



Reservation-TDMA

Reservation Time Division Multiple Access

- every frame consists of *N* mini-slots and *x* data-slots
- every station has its own mini-slot and can reserve up to *k* data-slots using this mini-slot (i.e. $x = N * k$).
- other stations can send data in unused data-slots according to a round-robin sending scheme or uncoordinated Aloha (best-effort traffic)



Carrier Sense Multiple Access (CSMA)

- "Listen before Speak"
- Not always possible:
  - satellite systems
  - hidden terminal problem
- Collision detection ("listen while speak") does not work in wireless:
  - ➔ cost of collision is high (only detected after transmitting entire packet and not receiving ack)

➔ Try to avoid collisions:

- non-persistent CSMA
  wait random amount of time if medium is busy
- p-persistent CSMA
  transmit with probability *p* if medium is idle,
  defer 1 "slot" with probability 1-*p*
- CSMA/CA (CSMA with Collision Avoidance)

CSMA/CA (CSMA with Collision Avoidance)

- if medium idle:
  - transmit
- otherwise
  - wait until medium becomes idle
  - wait until the medium is idle for a randomly taken time (uniform from back-off window)
  - count-down may be suspended by transmissions of others
  - retransmission doubles back-off window

- Used in IEEE 802.11 Wireless LAN
  - detailed explanation later

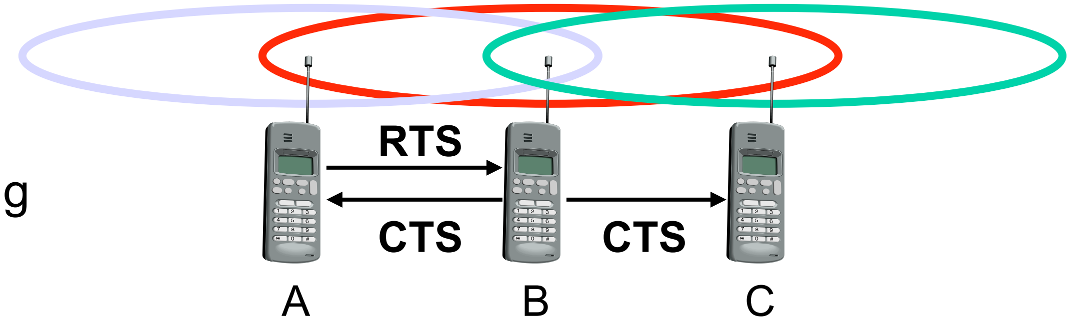
CSMA: Dealing with hidden and exposed terminals

- MACA (Multiple Access with Collision Avoidance) uses short signaling packets for collision avoidance
  - RTS (request to send): a sender request the right to send from a receiver with a short RTS packet before it sends a data packet
  - CTS (clear to send): the receiver grants the right to send as soon as it is ready to receive
- Signaling packets contain
  - sender address
  - receiver address
  - packet size
- Used in IEEE 802.11 Wireless LAN (option)

MACA examples

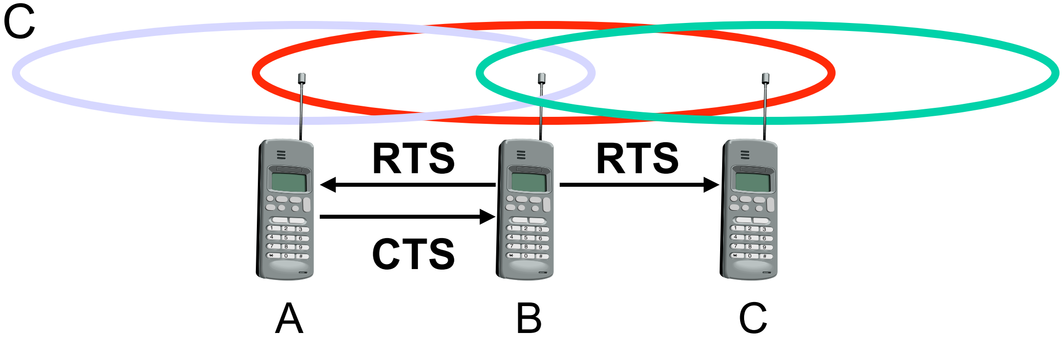
MACA avoids the problem of hidden terminals

- A and C want to send to B
- A sends RTS first
- C waits after receiving CTS from B



MACA avoids the problem of exposed terminals

- B wants to send to A, C to another terminal
- now C does not have to wait for it cannot receive CTS from A



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Random Access in UMTS

Used to get resources (e.g. code) from the base station, when the mobile starts to communicate.

Reservation Aloha with CDMA and power ramp-up

- Send preamble at low power: special signature of 16 chips (repeated 256 times) (16 orthogonal codes available) to BS. 16 signatures available, 15 slots available

- If ACK (using signature): continue accessing the medium
- If NACK (using signature): back-off, try with different signature
- If no response: repeat access with increased power

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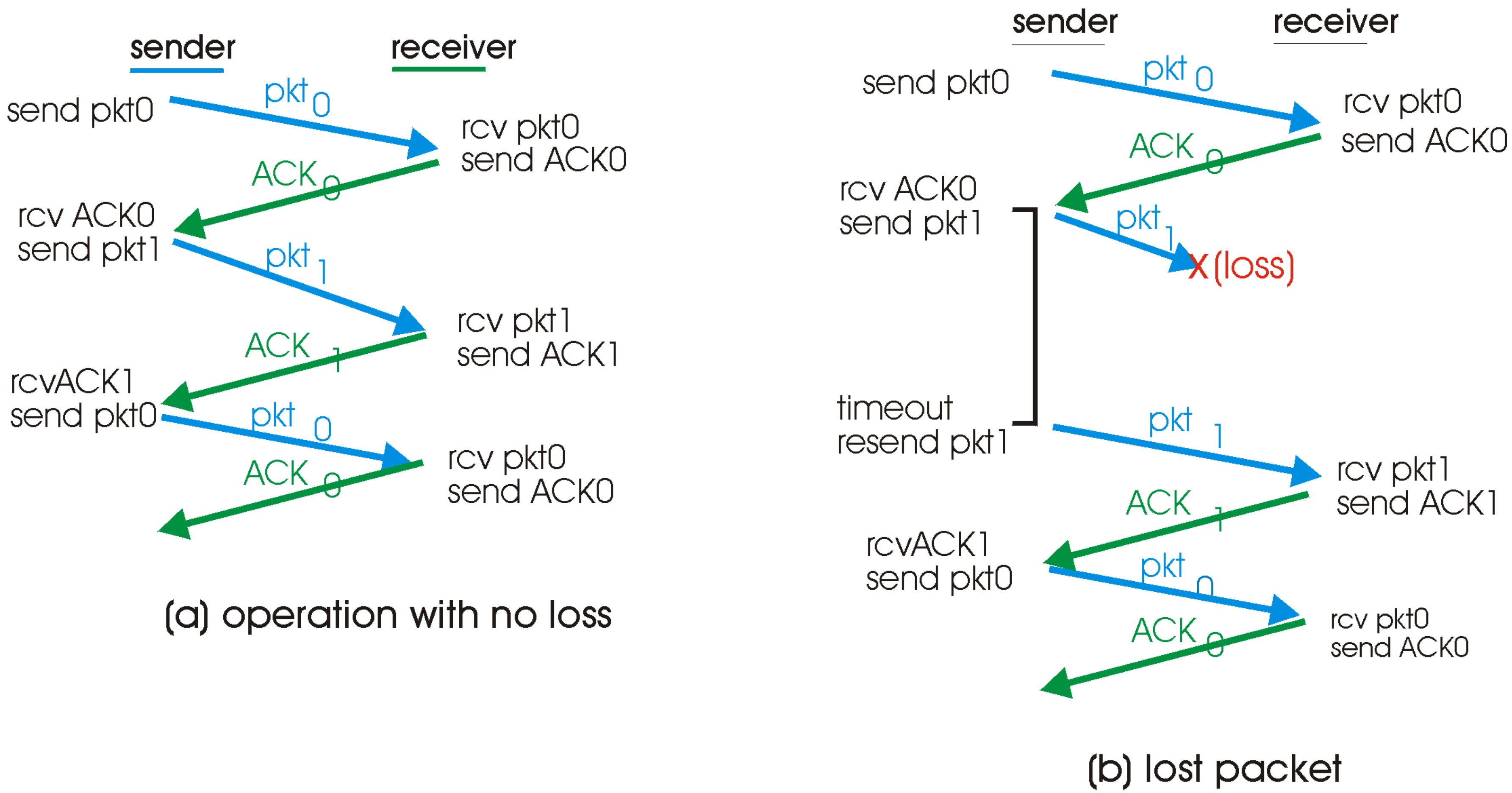
Hybrid ARQ (1/3)

ARQ: Automatic Repeat reQuest



Hybrid ARQ (2/3)

- ARQ needs error detection (ED) bits, added to the data, to detect errors typically CRC code, typically few bits (e.g. 16)
- Hybrid ARQ also uses Forward Error Correction (FEC) bits, to correct errors e.g., Turbo code, typically many bits (e.g. 2x number of data bits)

Type 1 HARQ:

- each message: data + FEC + ED
- Receiver first applies error correction and then checks with ED
  - if ED is OK → return ACK
  - otherwise → discard message and return NACK (or wait for time-out)
- Sender receives NACK (or time-out)? → retransmit packet

Type 2 HARQ:

- 1st message: only data + ED
- Receiver:
  - if ED is OK → return ACK
  - otherwise → store message and return NACK (or wait for time-out)
- Sender receives NACK (or time-out)? → send 2nd (or 3rd) message with FEC
- Receiver tries to combine messages, and decode data until ED is OK

Hybrid ARQ (3/3)

HARQ type I compared to ARQ:

- Bad channel: much higher throughput
- Good channel: more overhead (FEC bits) → lower throughput

HARQ type II compared to ARQ / HARQ type 1:

- Bad channel: much higher throughput compared to ARQ
- Good channel: no extra overhead → throughput as in ARQ

HARQ type II is very good for unknown / varying channels

To increase throughput of stop-and-wait ARQ, because of idling:

- multiple parallel HARQ processes (e.g., in UMTS HSDPA)
- use selective repeat