

Mobile Communications

Chapter 3: Medium Access

Motivation

SDMA, FDMA, TDMA, CDMA

Aloha, reservation schemes

Collision avoidance, MACA

Polling

Comparison

Motivation

Can we apply media access methods from fixed networks?

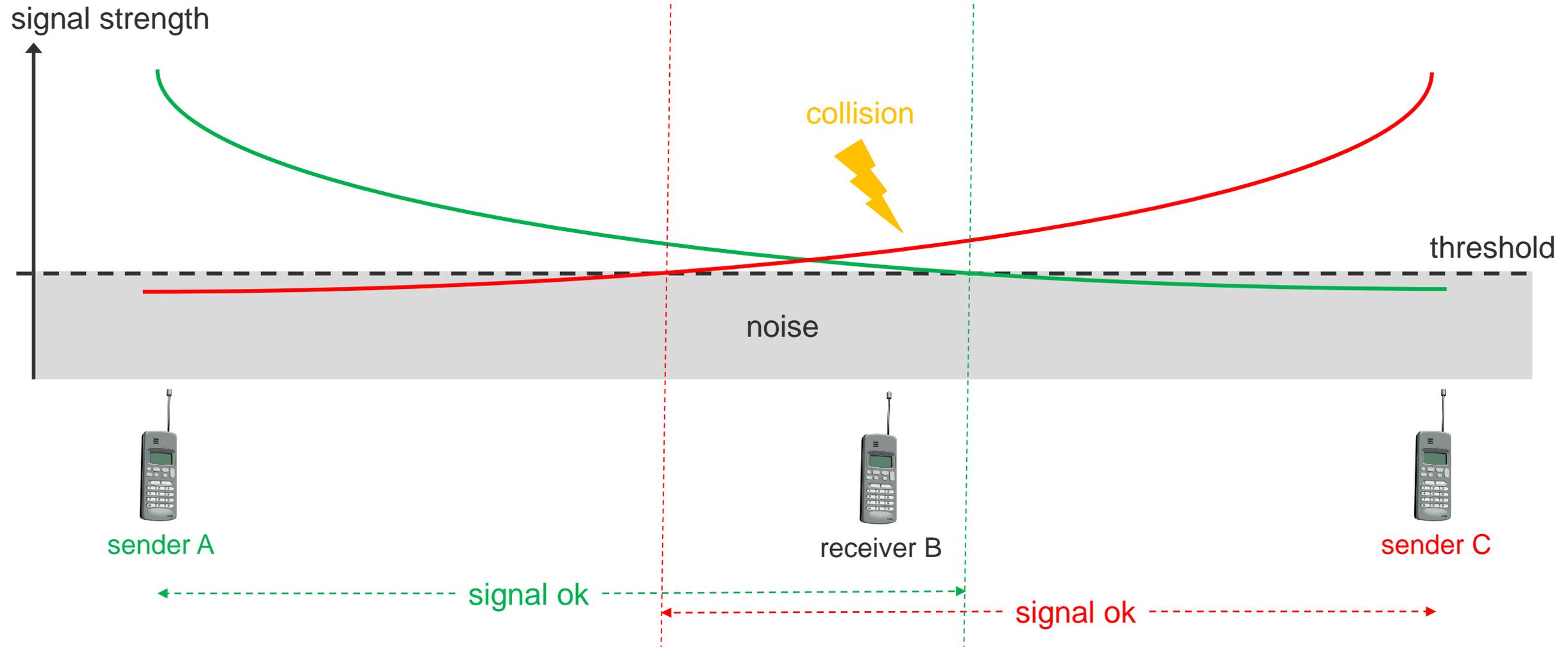
Example CSMA/CD

- **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 (legacy method in IEEE 802.3)

Problems in wireless networks

- signal strength decreases proportional to (at least) 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”

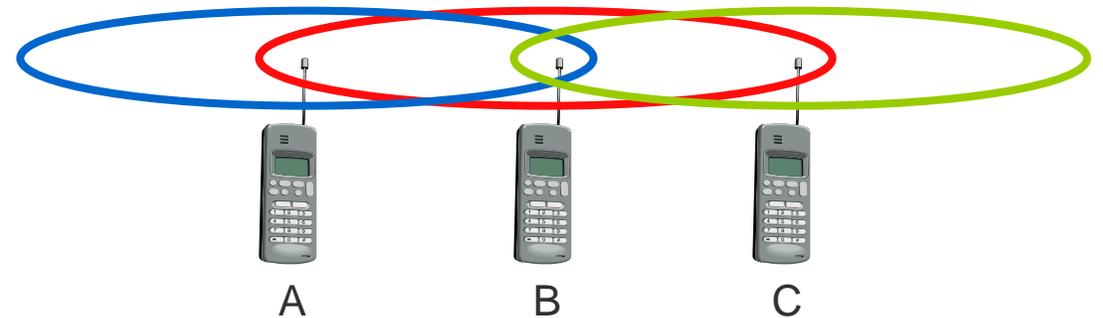
Problem of CSMA/CD in wireless communication



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



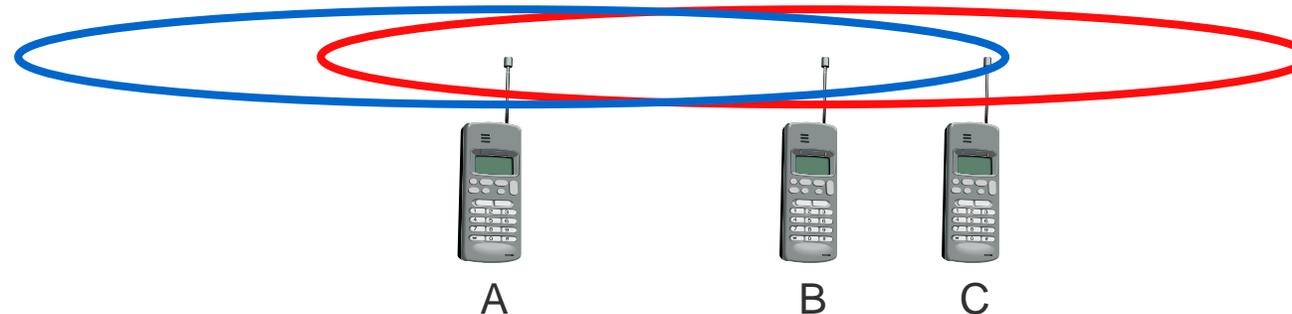
Exposed terminals

- 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!

Access methods SDMA/FDMA/TDMA

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)

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

PDMA (Polarization Division Multiple Access)

- assign a certain polarization to a transmission channel using, e.g. specialized antennas

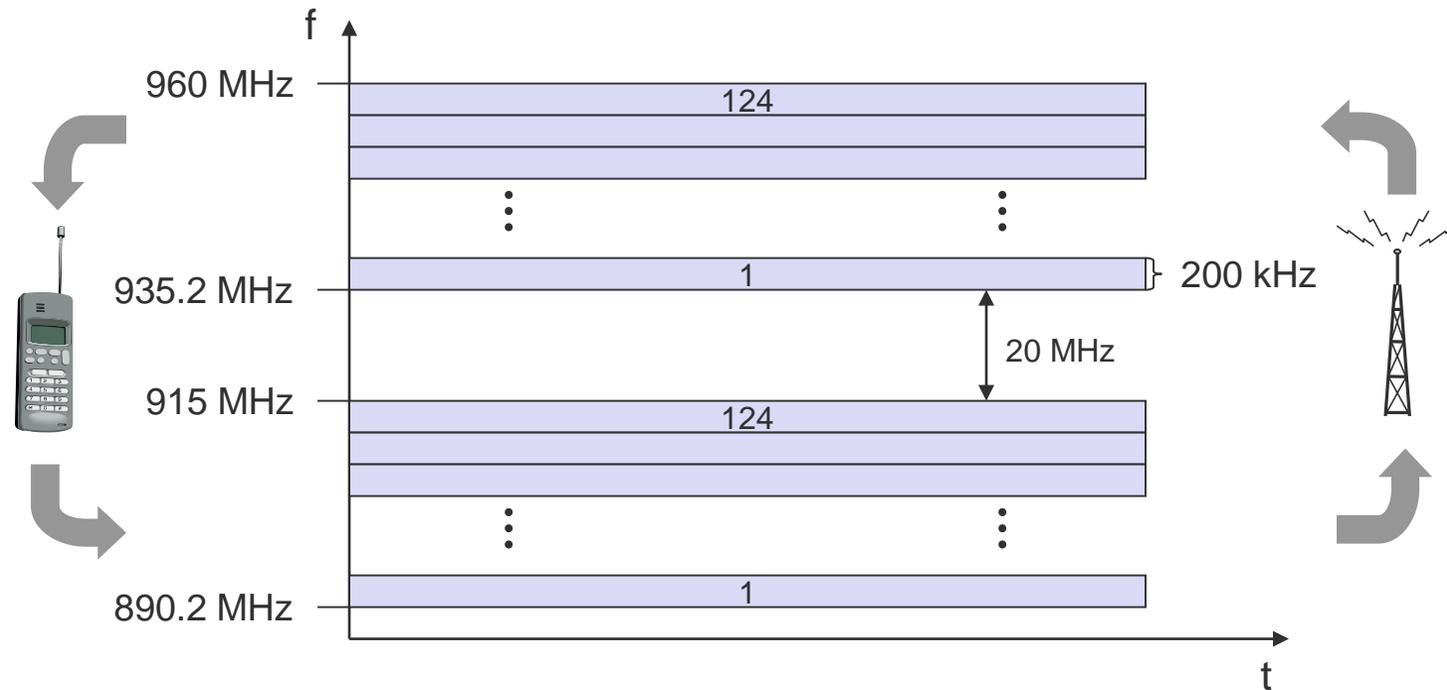
The multiplexing schemes presented in chapter 2 are now used to control medium access!

- multiplexing scheme plus algorithm → Multiple Access method

FDD/FDMA - general scheme, example GSM

FDM used twice

- FDD (Frequency Division Duplex)
 - separation of the direction (uplink/downlink) using different frequencies
- FDMA
 - separation of different channels using different frequencies



OFDMA – Orthogonal frequency-division multiple access

Use OFDM for multiple access, i.e. assign sub-carriers to individual users for a certain time

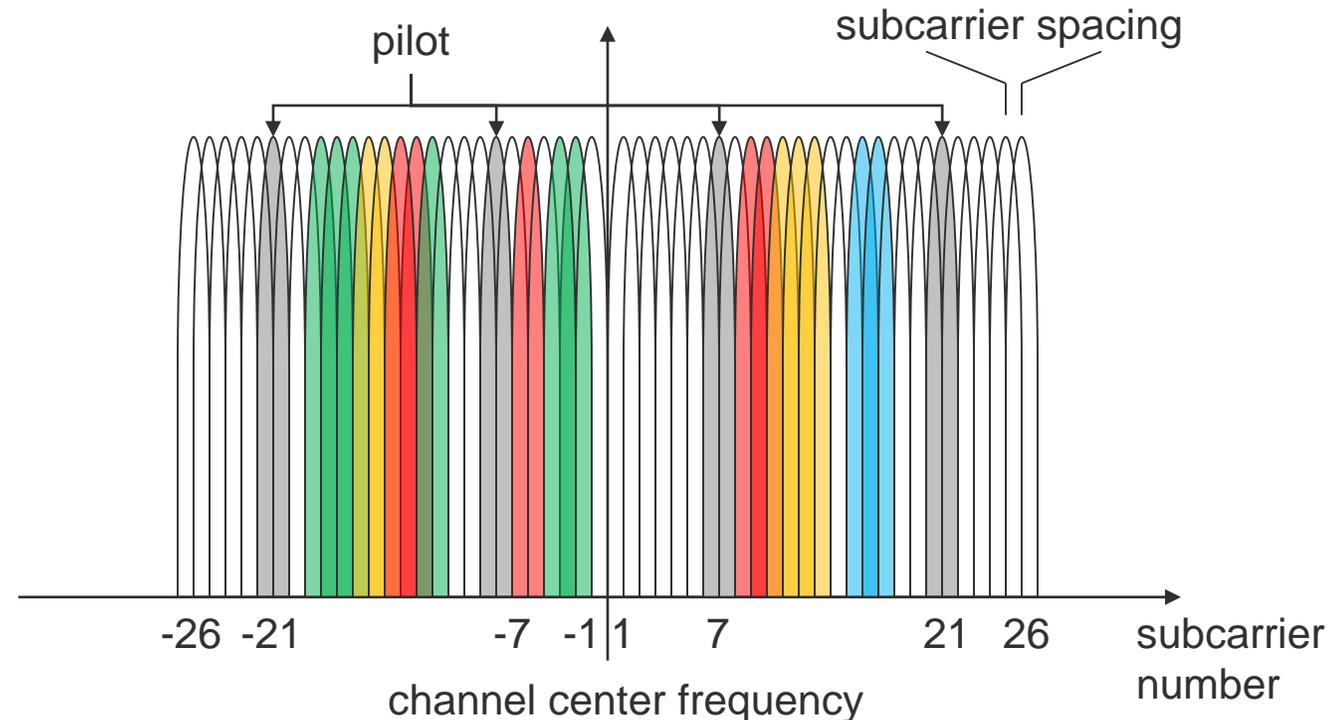
- can be seen as combination of FDM and TDM
- OFDM uses FDM with “orthogonal” carriers, i.e. multiple closely spaced subcarrier signals with overlapping spectra are transmitted to carry data in parallel (See e.g. DVB, DAB+, DSL, IEEE 802.11a, ...)
- used in e.g. IEEE 802.11ax, LTE, 5G New Radio

Advantages

- high flexibility (data rates, frequencies, QoS)
- can fill white spaces (see CR)
- good robustness wrt. fading and interference
- shorter/constant delay

Disadvantages

- more complex electronics with FFT, FEC
- frequency-selective fading if few subcarriers used
- co-channel interference from neighboring cells



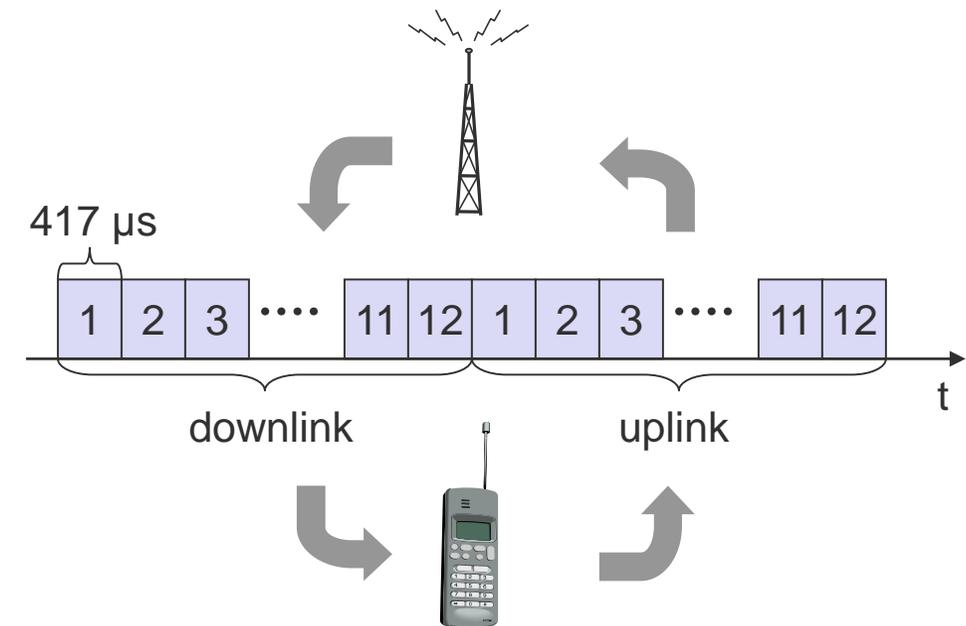
TDD/TDMA - general scheme, example DECT

TDM used twice

- TDD (Frequency Division Duplex)
 - separation of the direction (uplink/downlink) using different time periods
- TDMA
 - separation of different channels using different time-slots

Please note!

- other combinations can also make sense
- TDD, TDMA, FDM: WLANs following 802.11 offering several channels, up- and downlink on same channel, users separated in time
- FDD, TDMA: GSM when looking at users on a certain channel, up- and downlink separated in frequency, users separated in time
- ...



Questions & Tasks

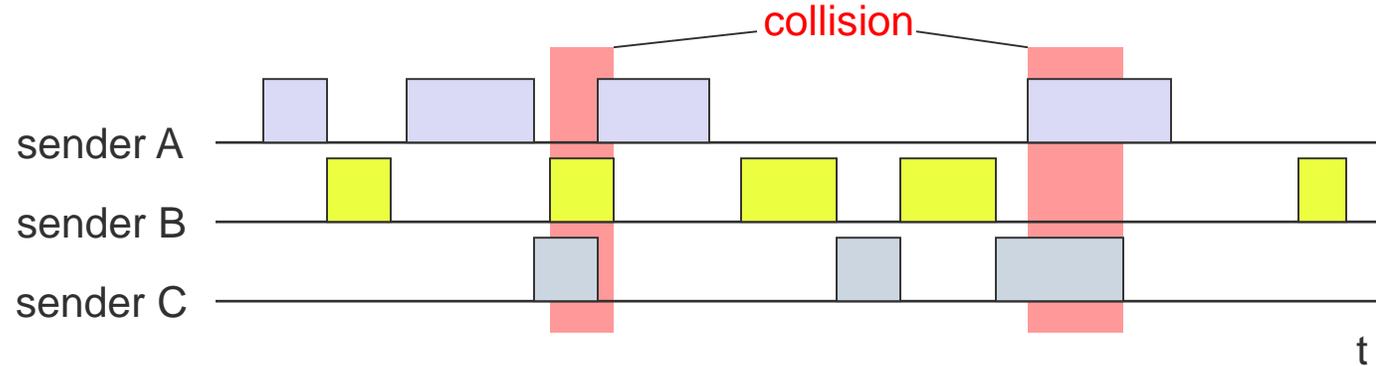
- What is the main physical reason for the failure of many MAC schemes known from wired networks? What is done in wired networks to avoid this effect?
- What is the basic prerequisite for applying FDMA? How does this factor increase complexity compared to TDMA systems?
- Who is responsible for MAC if we consider the whole frequency spectrum as presented in chapter 1?
- Considering duplex channels, what are alternatives for implementation in wireless networks? What about typical wired networks?
- Assume all stations can hear all other stations. One station wants to transmit and senses the carrier idle. Why can a collision still occur after the start of transmission?

Aloha/slotted aloha

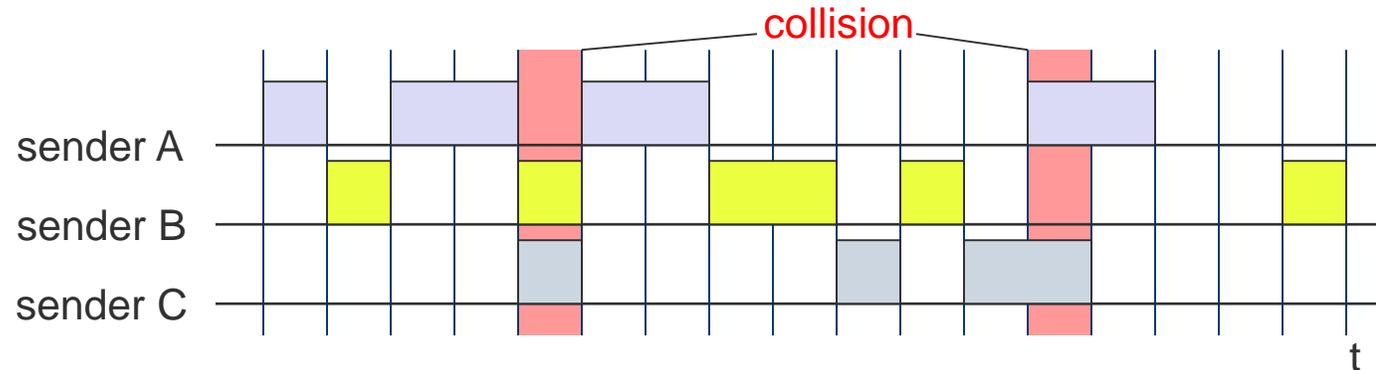
Mechanism

- random, distributed (no central arbiter), time-multiplex
- Slotted Aloha additionally uses time-slots, sending must always start at slot boundaries

Aloha



Slotted Aloha



DAMA - Demand Assigned Multiple Access

Channel efficiency only 18% for Aloha, 36% for Slotted Aloha

- assuming Poisson distribution for packet arrival and packet length

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 according to Roberts (Reservation-ALOHA)*
- *Implicit Reservation (PRMA)*
- *Reservation-TDMA*

Access method DAMA: Explicit Reservation

Explicit Reservation (Reservation Aloha):

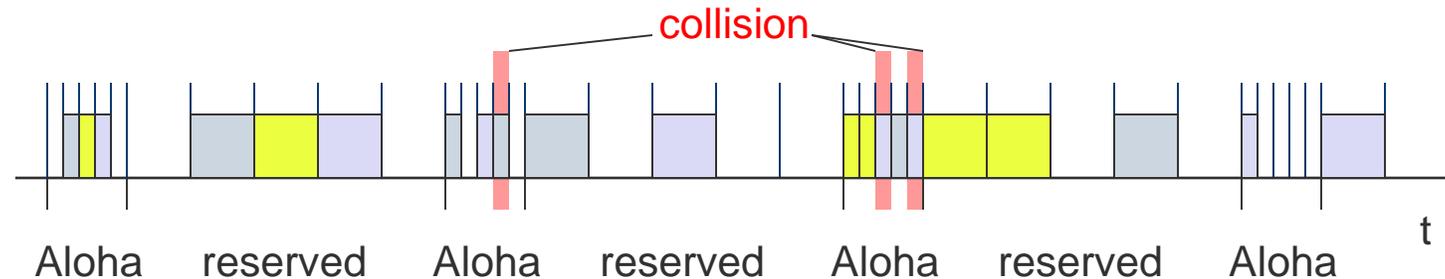
- two modes:

- ALOHA mode for reservation:

- competition for small reservation slots, collisions possible

- reserved mode for data transmission within successful reserved slots (no collisions possible)

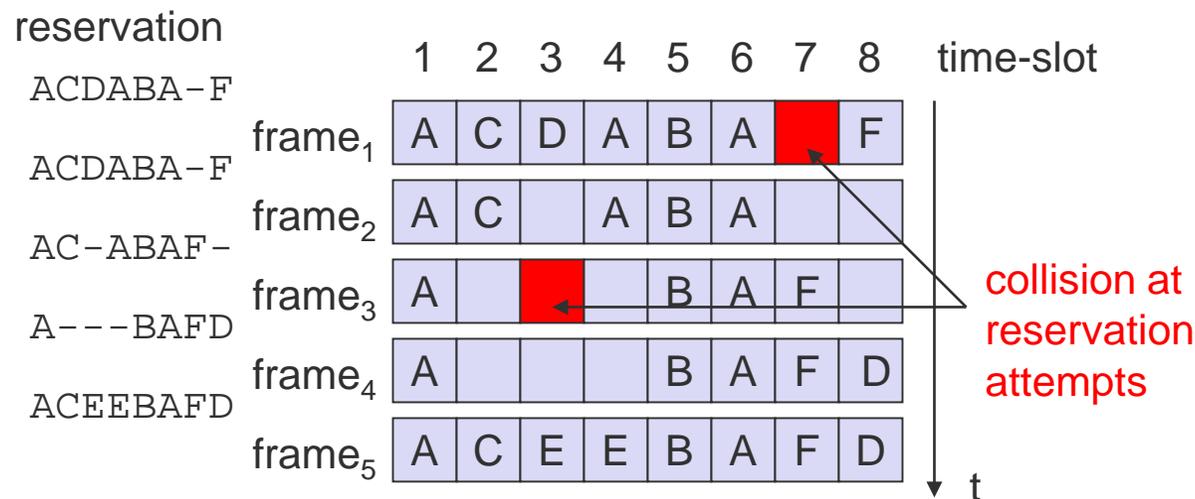
- it is important for all stations to keep the reservation list consistent at any point in time and, therefore, all stations have to synchronize from time to time



Access method DAMA: PRMA

Implicit reservation (PRMA - Packet Reservation MA):

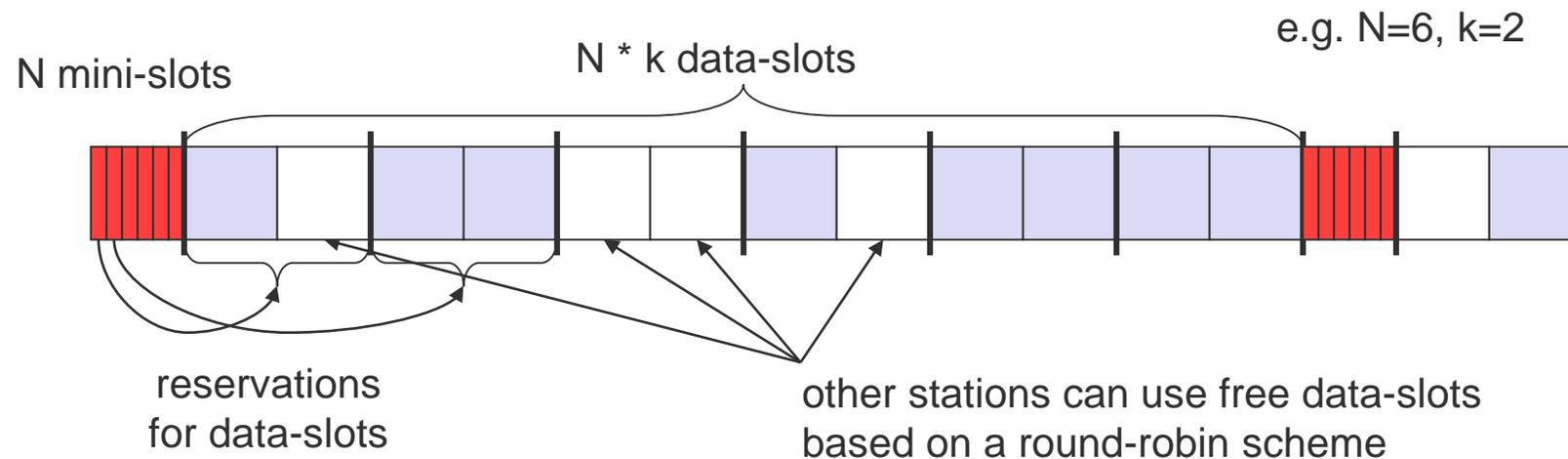
- a certain number of slots form a frame, frames are repeated
- stations compete for empty slots according to the slotted aloha principle
- once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has data to send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



Access method DAMA: 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 (best-effort traffic)



MACA - collision avoidance

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

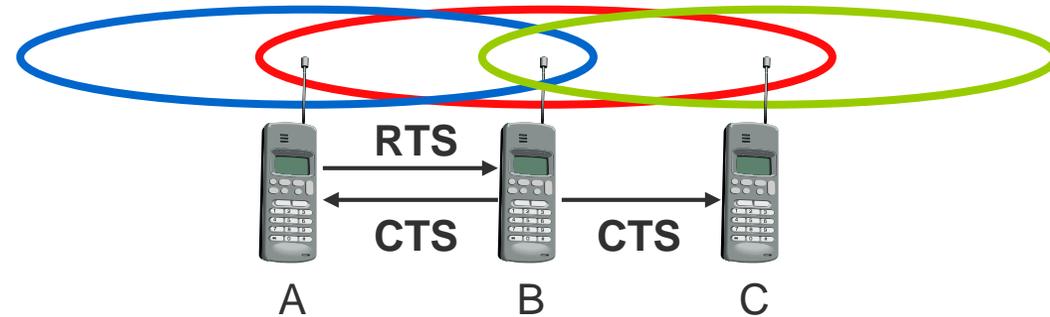
- sender address
- receiver address
- packet size

Variants of this method can be found in IEEE802.11 as DFWMAC (Distributed Foundation Wireless MAC)

MACA examples

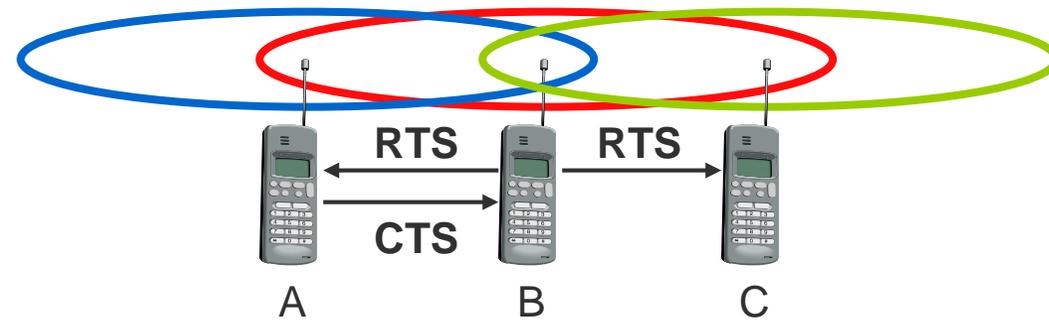
MACA avoids the problem of hidden terminals

- 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



Polling mechanisms

If one terminal can be heard by all others, this “central” terminal (a.k.a. base station) can poll all other terminals according to a certain scheme

- now all schemes known from fixed networks can be used (typical mainframe - terminal scenario)

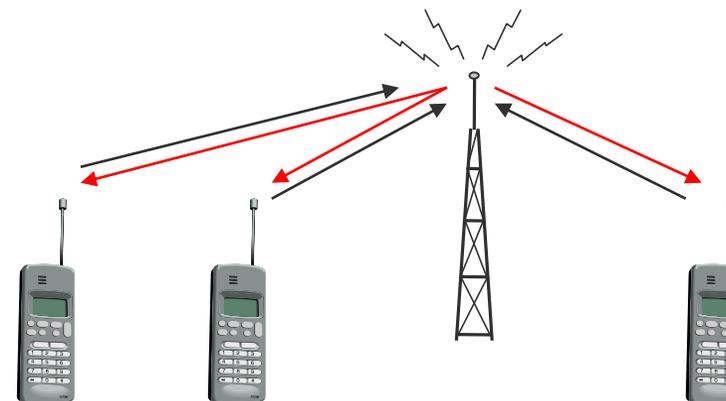
Example: Randomly Addressed Polling

- base station signals readiness to all mobile terminals
- terminals ready to send can now transmit a random number without collision with the help of CDMA or FDMA (the random number can be seen as dynamic address)
- the base station now chooses one address for polling from the list of all random numbers (collision if two terminals choose the same address)
- the base station acknowledges correct packets and continues polling the next terminal
- this cycle starts again after polling all terminals of the list

ISMA (Inhibit Sense Multiple Access)

Current state of the medium is signaled via a “busy tone”

- the base station signals on the downlink (base station to terminals) if the medium is free or not
- terminals must not send if the medium is busy
- terminals can access the medium as soon as the busy tone stops
- the base station signals collisions and successful transmissions via the busy tone and acknowledgements, respectively (media access is not coordinated within this approach)
- classical mechanism used, e.g., for CDPD (USA, integrated into AMPS)



Questions & Tasks

- Recall the problem of hidden and exposed terminals. What happens in the case of such terminals if Aloha, slotted Aloha, reservation Aloha, or MACA is used?
- What are the advantages of a fixed TDM pattern compared to random, demand driven TDM? Compare the efficiency in the case of several connections with fixed data rates or in the case of varying data rates. Now explain why traditional mobile phone systems use fixed patterns, while computer networks generally use random patterns. The major part of data being transmitted is computer-generated data. How has this fact changed mobile phone systems?
- What are benefits of reservation schemes? How are collisions avoided during data transmission, why is the probability of collisions lower compared to classical Aloha? What are disadvantages of reservation schemes?
- How can MACA still fail in case of hidden/exposed terminals? Think of mobile stations and changing transmission characteristics.

Access method CDMA

CDMA (Code Division Multiple Access)

- 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, the sender XORs the signal with this random number
- the receiver can “tune” into this signal if it knows the pseudo random number, tuning is done via a correlation function

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

CDMA in theory (very simplified)

Sender A

- sends $A_d = 1$, key $A_k = 010011$ (assign: “0”= -1, “1”= +1)
- sending signal $A_s = A_d * A_k = (-1, +1, -1, -1, +1, +1)$

Sender B

- sends $B_d = 0$, key $B_k = 110101$ (assign: “0”= -1, “1”= +1)
- sending signal $B_s = B_d * B_k = (-1, -1, +1, -1, +1, -1)$

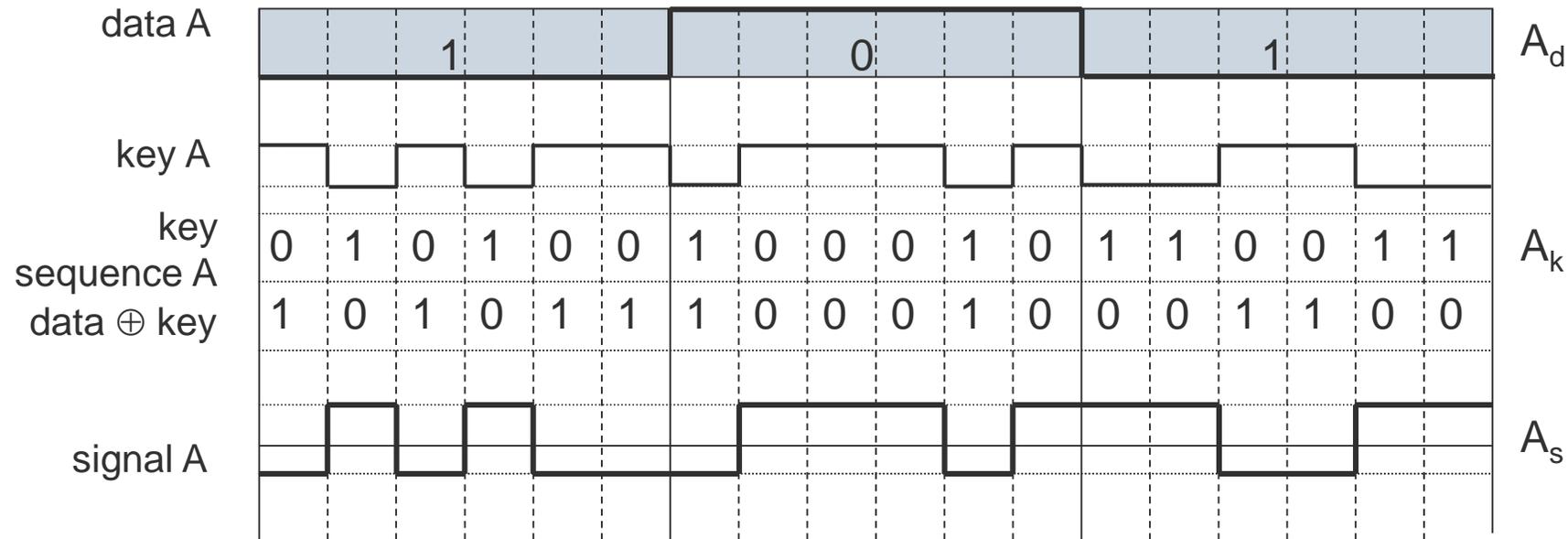
Both signals superimpose in space

- interference neglected (noise etc.)
- $A_s + B_s = (-2, 0, 0, -2, +2, 0)$

Receiver wants to receive signal from sender A

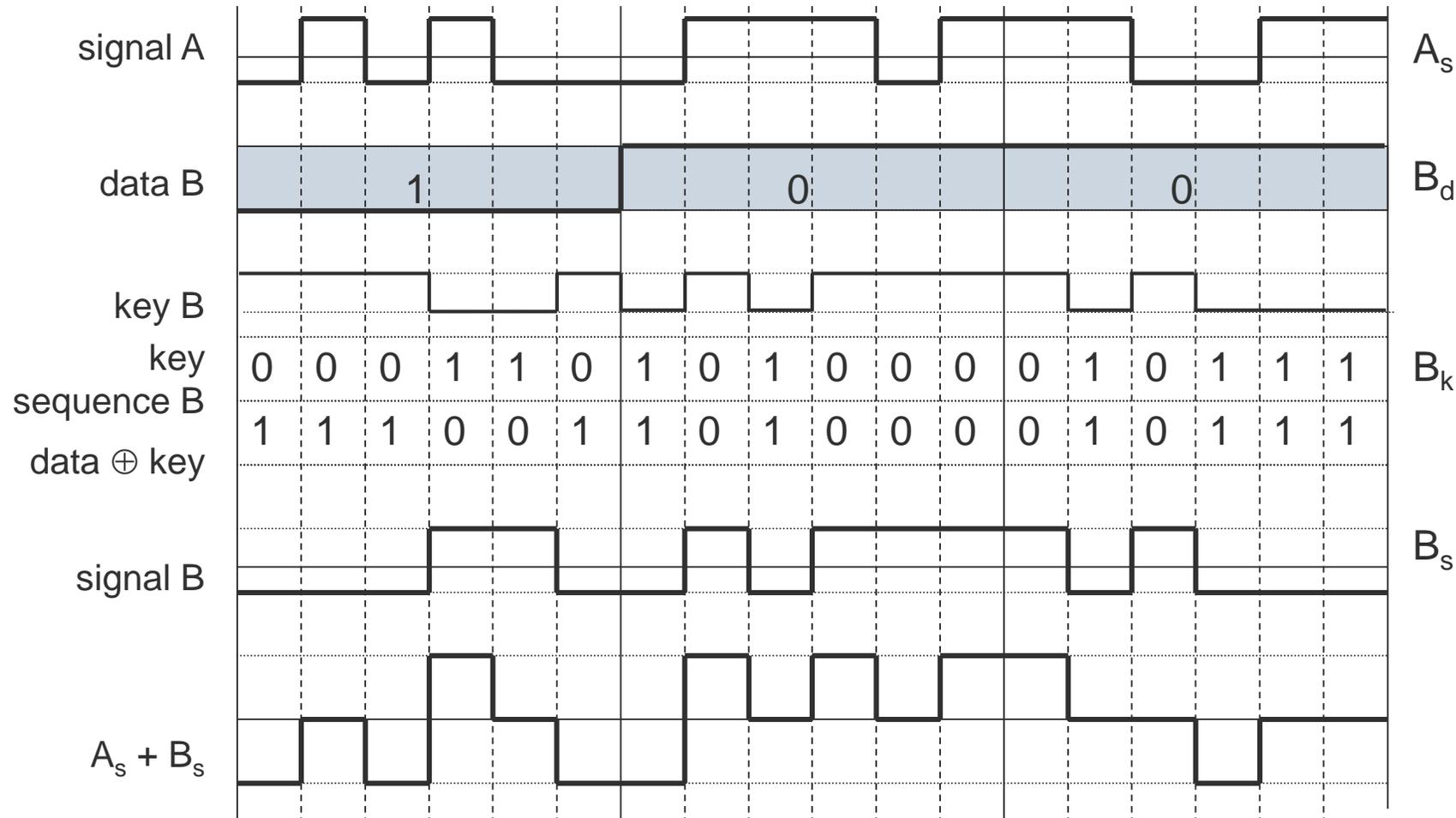
- apply key A_k bitwise (inner product)
 - $A_e = (-2, 0, 0, -2, +2, 0) \bullet A_k = 2 + 0 + 0 + 2 + 2 + 0 = 6$
 - result greater than 0, therefore, original bit was “1”
- receiving B
 - $B_e = (-2, 0, 0, -2, +2, 0) \bullet B_k = -2 + 0 + 0 - 2 - 2 + 0 = -6$, i.e. “0”

CDMA on signal level I (still pretty simplified)

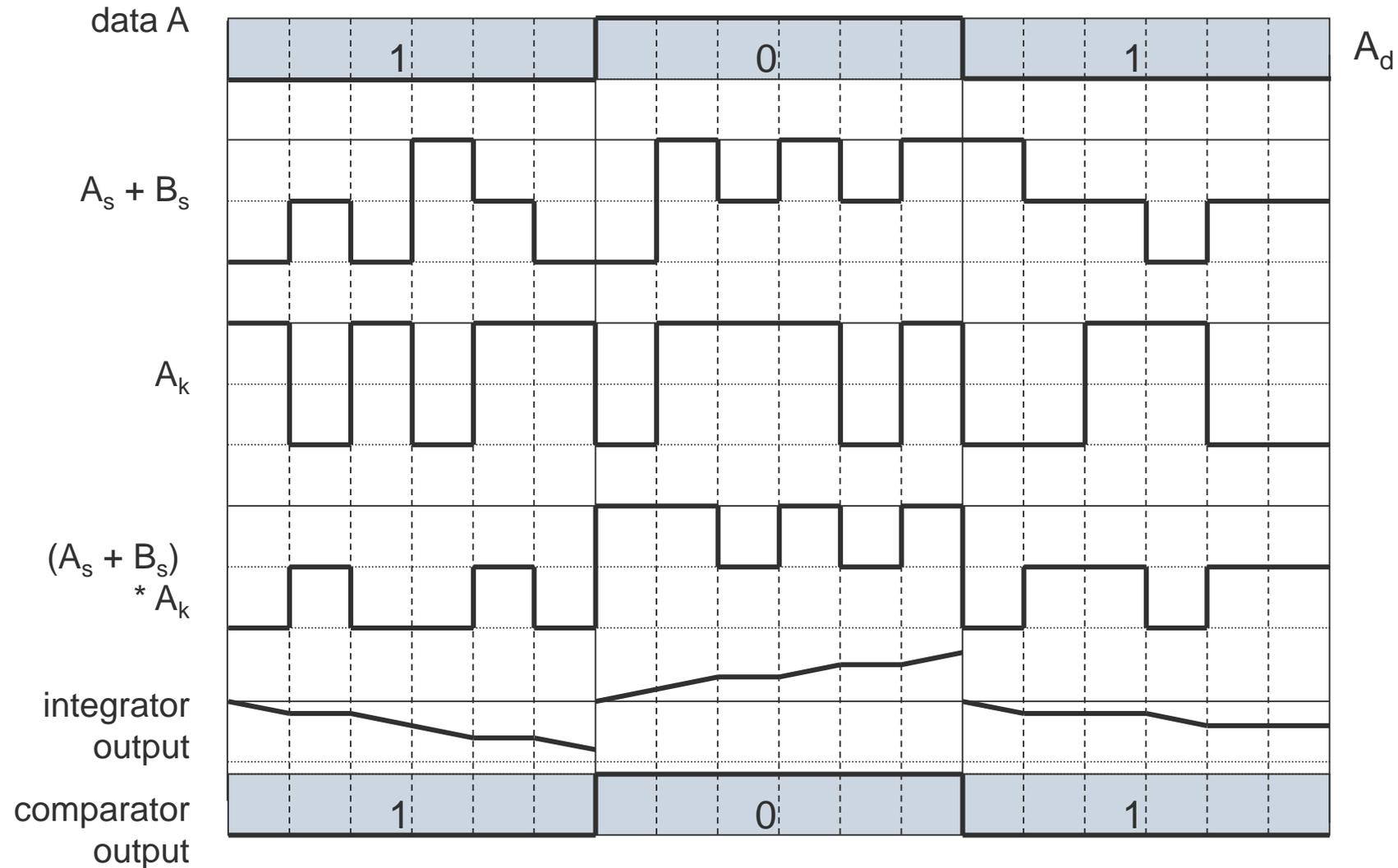


Real systems use much longer keys resulting in a larger distance between single code words in code space.

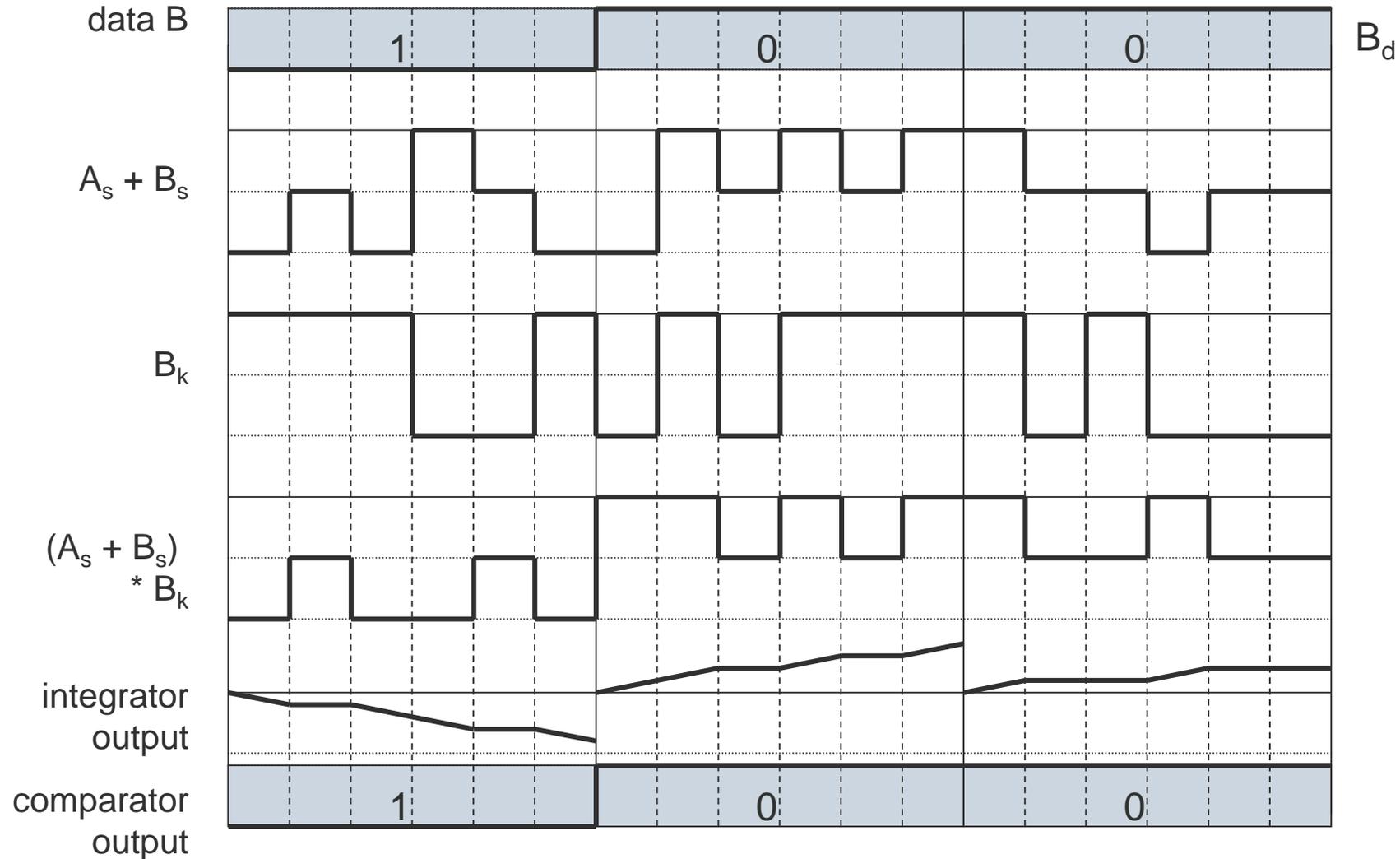
CDMA on signal level II



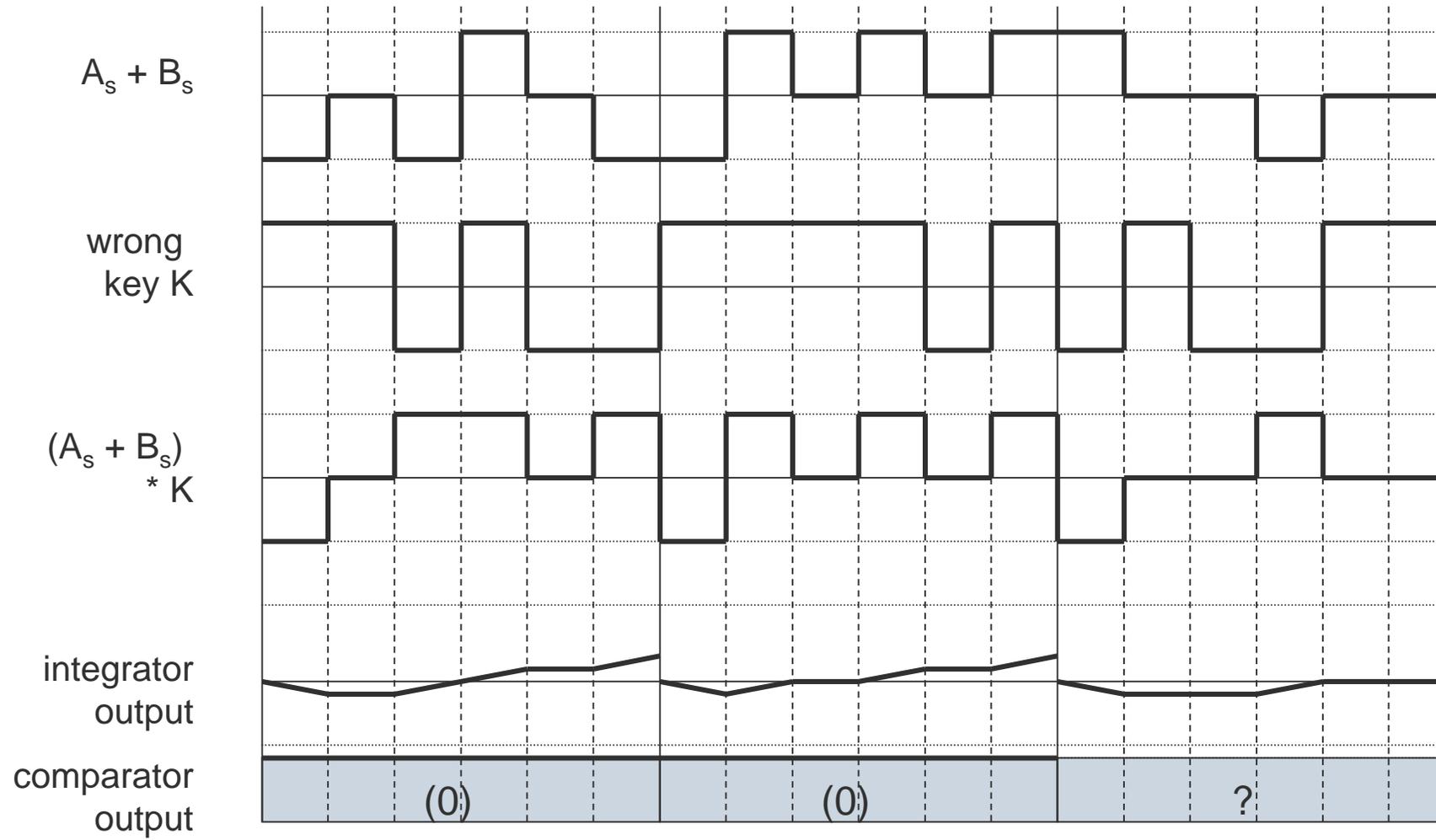
CDMA on signal level III



CDMA on signal level IV



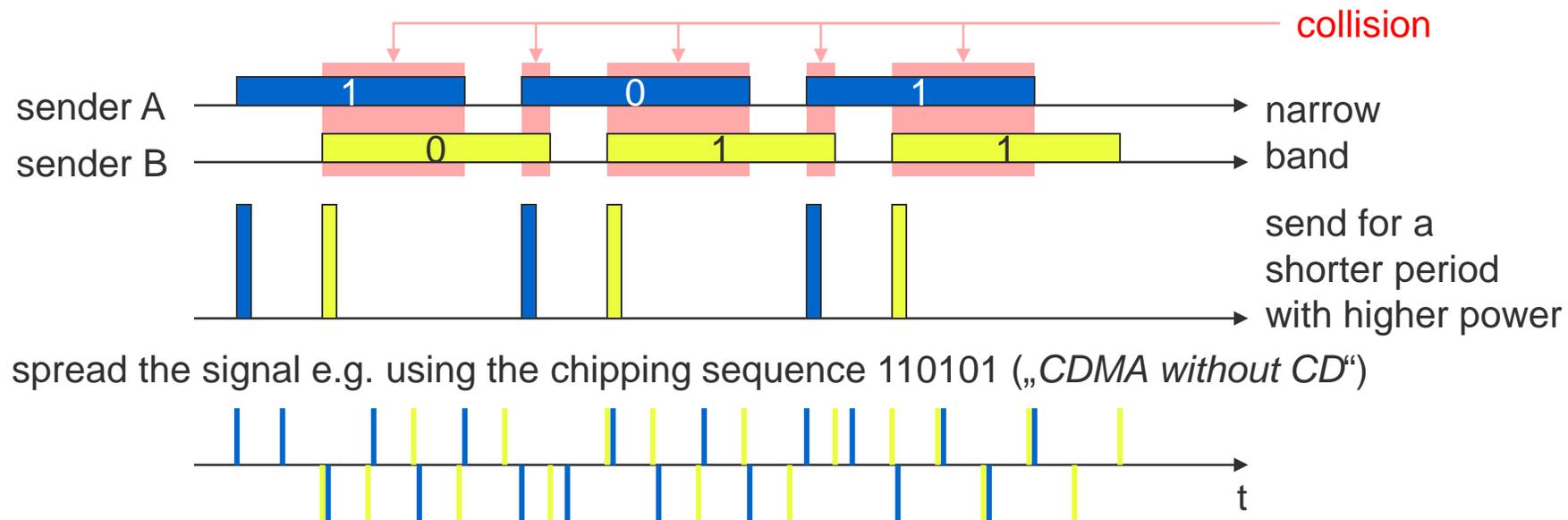
CDMA on signal level V



SAMA - Spread Aloha Multiple Access

Aloha has only a very low efficiency, CDMA needs complex receivers to be able to receive different senders with individual codes at the same time

Idea: use spread spectrum with only one single code (chipping sequence) for spreading for all senders accessing according to aloha



Problem: find a chipping sequence with good characteristics

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 ²	established, fully digital, flexible	simple, established, robust	flexible, less frequency planning needed, soft handover
Disadvantages	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), flexible OFDMA	higher complexity, lowered expectations; integrated with TDMA/FDMA

Questions & Tasks

- How does the near/far effect influence TDMA systems? What happens in CDMA systems? What are countermeasures in TDMA systems, what about CDMA systems?
- Who performs the MAC algorithm for SDMA? What could be possible roles of mobile stations, base stations, and planning from the network provider?
- Explain the term interference in the space, time, frequency, and code domain. What are countermeasures in SDMA, TDMA, FDMA, and CDMA systems?
- Which of the MAC schemes can give hard guarantees related to bandwidth and access delay?
- How are guard spaces realised between users in CDMA?
- Redo the simple CDMA example, but now add random 'noise' to the transmitted signal $(-2,0,0,-2,+2,0)$. Add, for example, $(1,-1,0,1,0,-1)$. In this case, what can the receiver detect for sender A and B respectively? Now include the near/far problem. How does this complicate the situation? What would be possible countermeasures?