Kiel University
Christian-Albrechts-Universität zu Kiel

Research Group
Distributed Systems

# Internet of Things & Wireless Networks

## Media Access - Lectures 5

(Matches Chapter 3 in the Course Book)

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Lecture today via Video from Jochen Schiller, FU Berlin

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# Mobile Communications
# Chapter 3: Media Access

# 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)

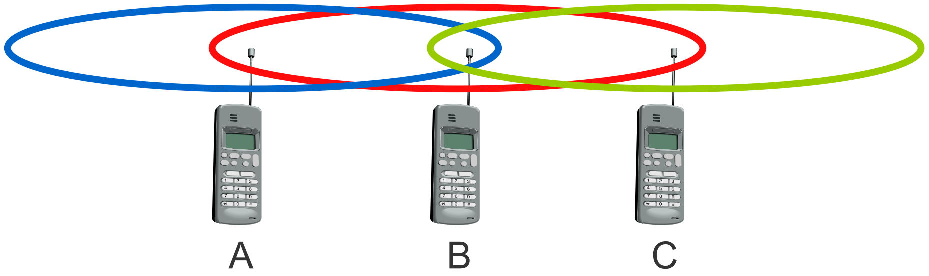
Problems in wireless networks

- 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”

# 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



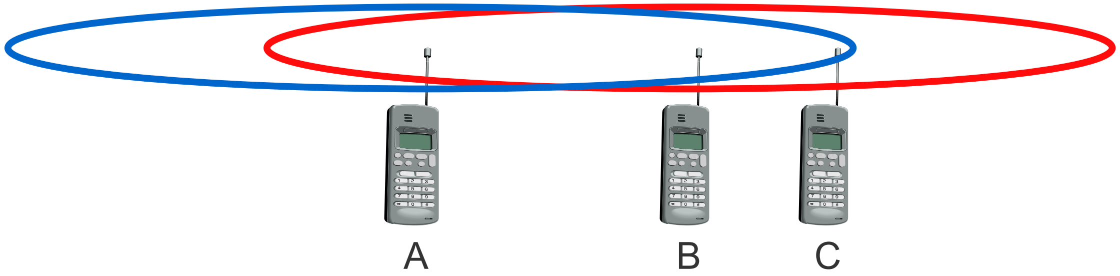

Exposed terminals

- 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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# 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)

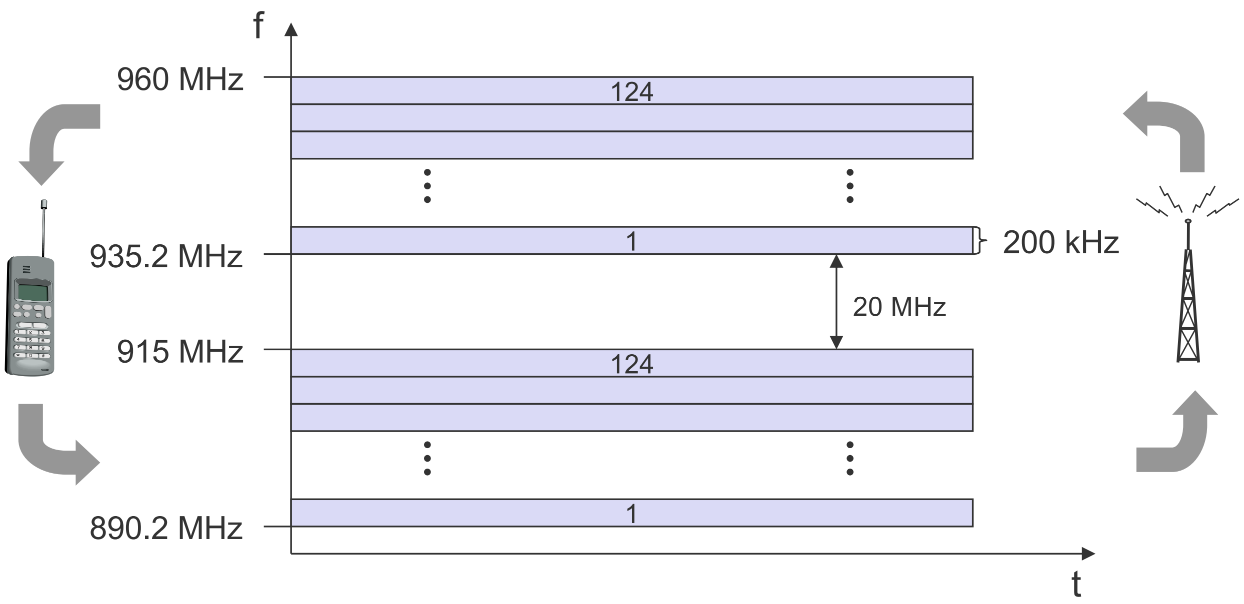
TDMA (Time Division Multiple Access)

- assign the fixed sending frequency to a transmission channel between a sender and a receiver for a certain amount of time

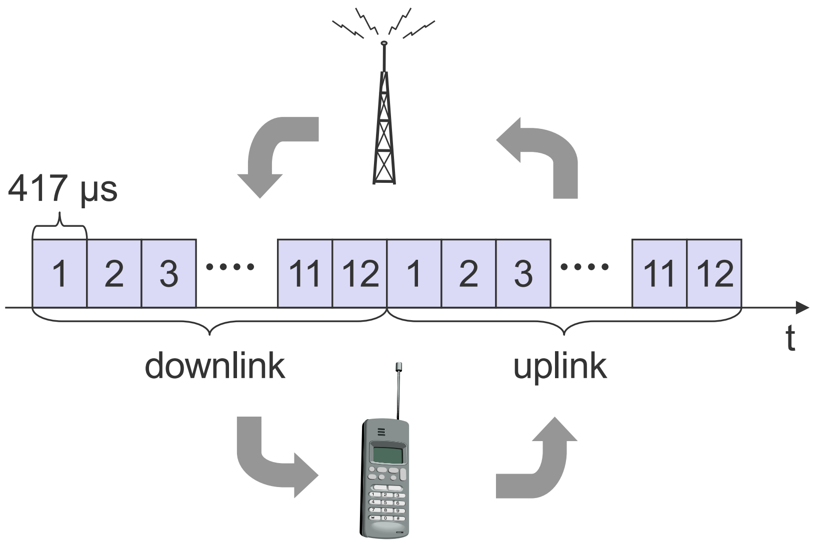
The multiplexing schemes presented in chapter 2 are now used to control medium access!

- multiplexing scheme plus algorithm ➔ Multiple Access method

# FDD/FDMA - general scheme, example GSM



# TDD/TDMA - general scheme, example DECT

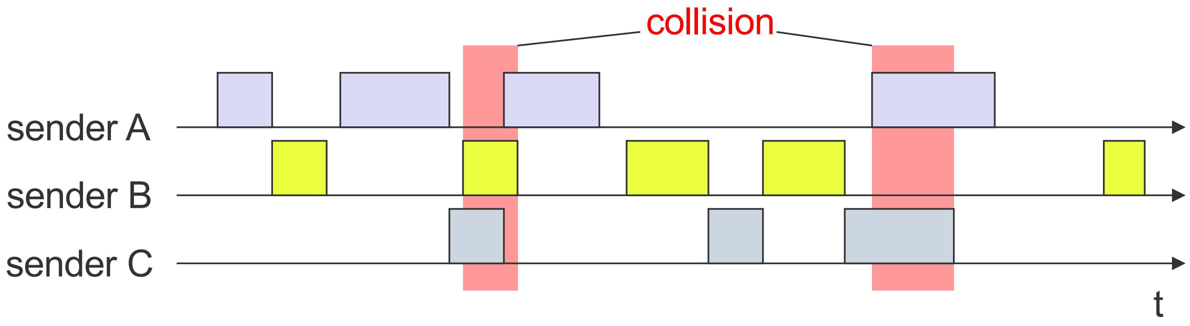


# Aloha/slotted aloha

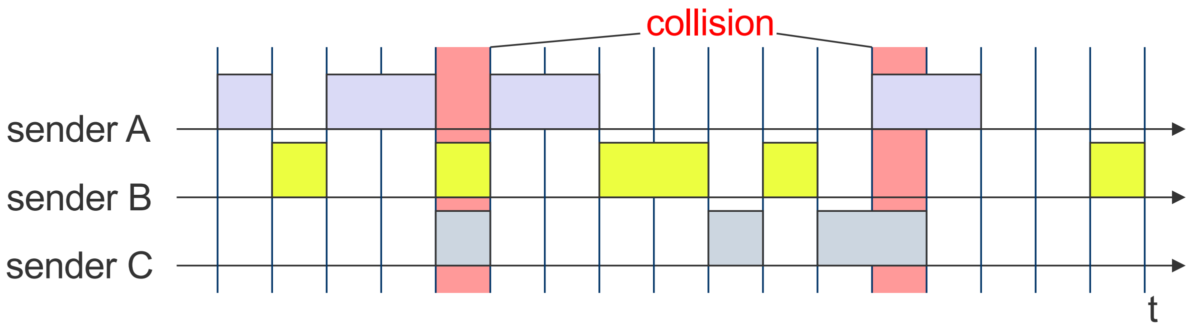
Mechanism

- 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

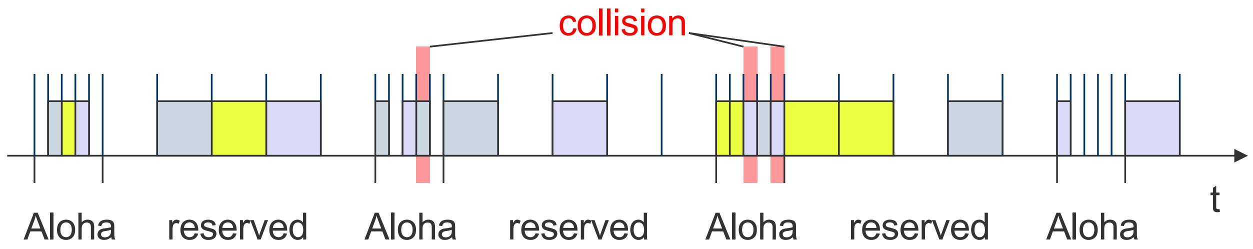
Examples for reservation algorithms:

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

# Access method DAMA: Explicit Reservation

Explicit Reservation (Reservation Aloha):

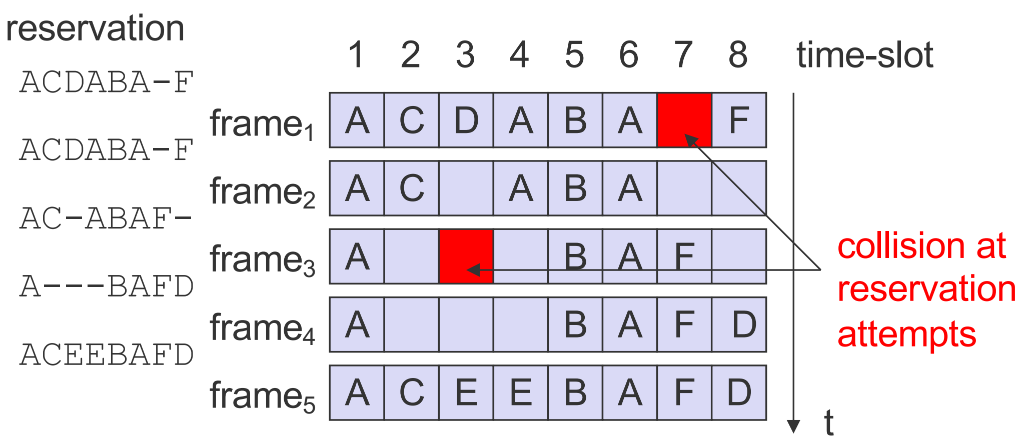
- two modes:
  - ALOHA mode for reservation:
    competition for small reservation slots, collisions possible
  - reserved mode for data transmission within successful reserved slots (no collisions possible)
- it is important for all stations to keep the reservation list consistent at any point in time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



# Access method DAMA: PRMA

Implicit reservation (PRMA - Packet Reservation MA):

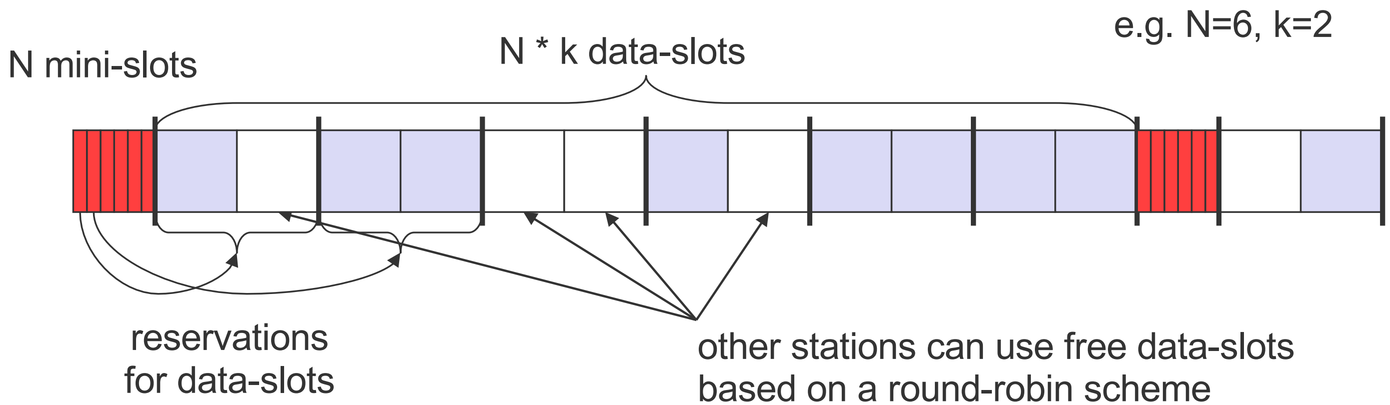
- a certain number of slots form a frame, frames are repeated
- stations compete for empty slots according to the slotted aloha principle
- once a station reserves a slot successfully, this slot is automatically assigned to this station in all following frames as long as the station has data to send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

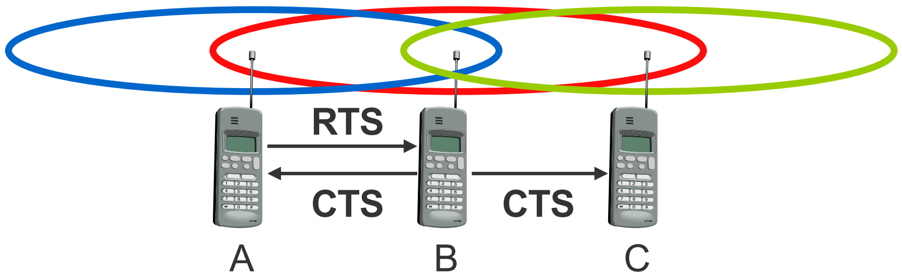
Signaling packets contain

- sender address
- receiver address
- packet size

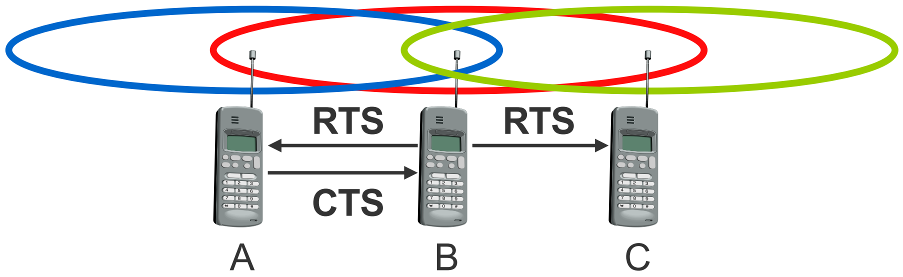
Variants of this method can be found in IEEE802.11 as DFWMAC (Distributed Foundation Wireless MAC)

# 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)

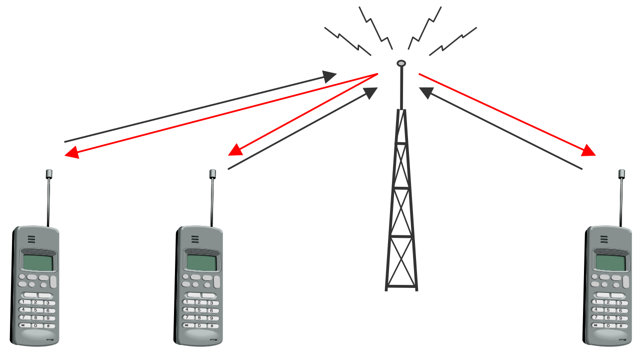
Example: Randomly Addressed Polling

- 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)
- mechanism used, e.g., for CDPD (USA, integrated into AMPS)



# 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 $B_s = B_d * B_k = (-1, -1, +1, -1, +1, -1)$

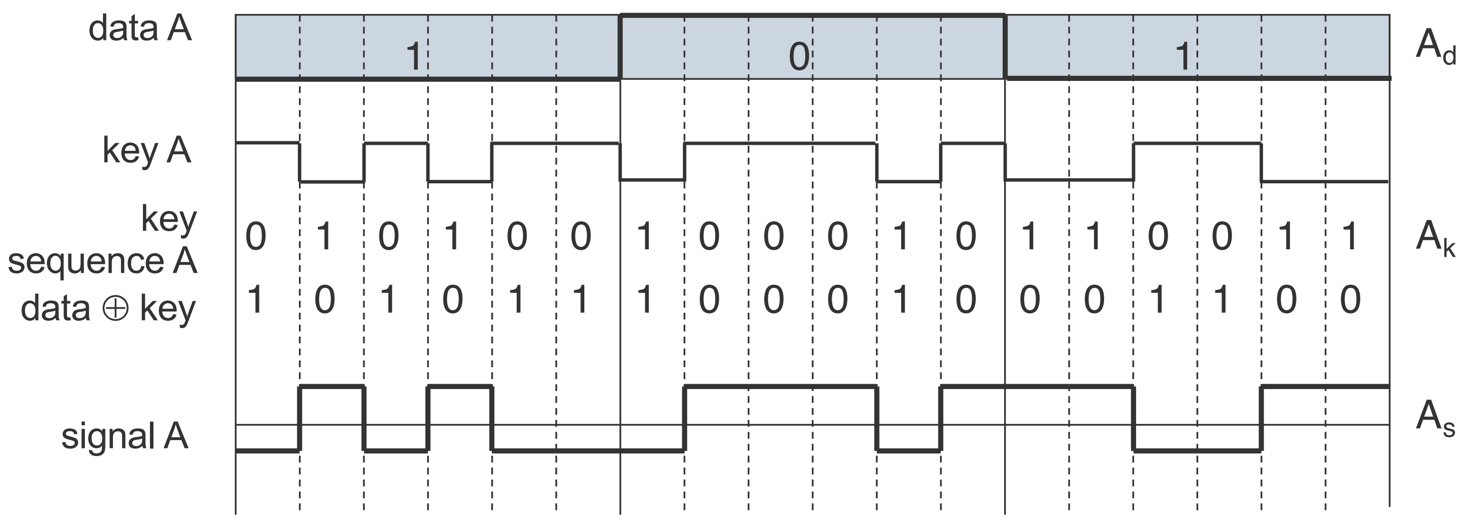
Both signals superimpose in space

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

Receiver wants to receive signal from sender A

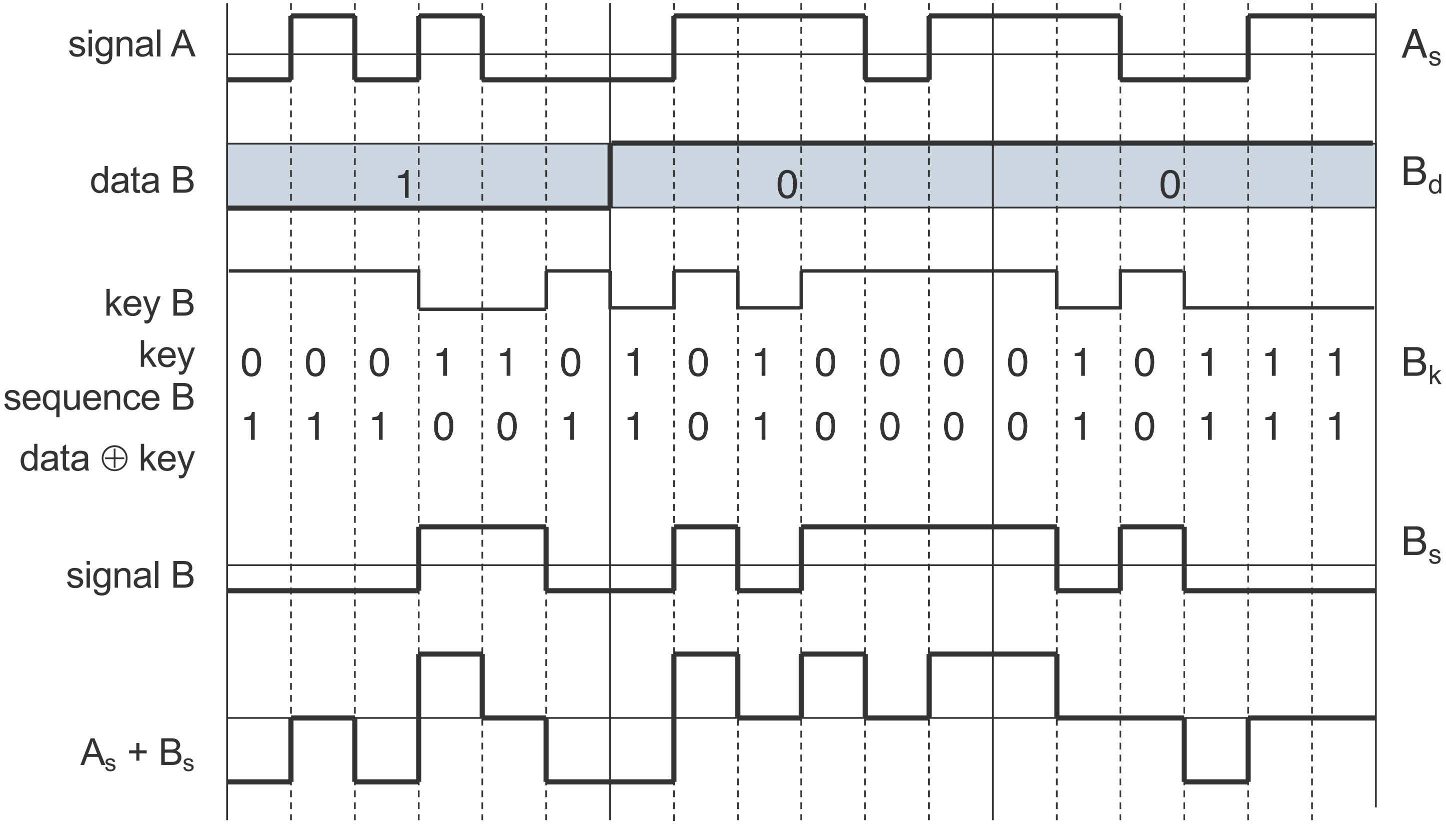
- apply key $A_k$ bitwise (inner product)
    - $A_e = (-2, 0, 0, -2, +2, 0) \bullet A_k = 2 + 0 + 0 + 2 + 2 + 0 = 6$
    - result greater than 0, therefore, original bit was “1”
- receiving B
    - $B_e = (-2, 0, 0, -2, +2, 0) \bullet B_k = -2 + 0 + 0 - 2 - 2 + 0 = -6$, i.e. “0”

# CDMA on signal level I (still pretty simplified)

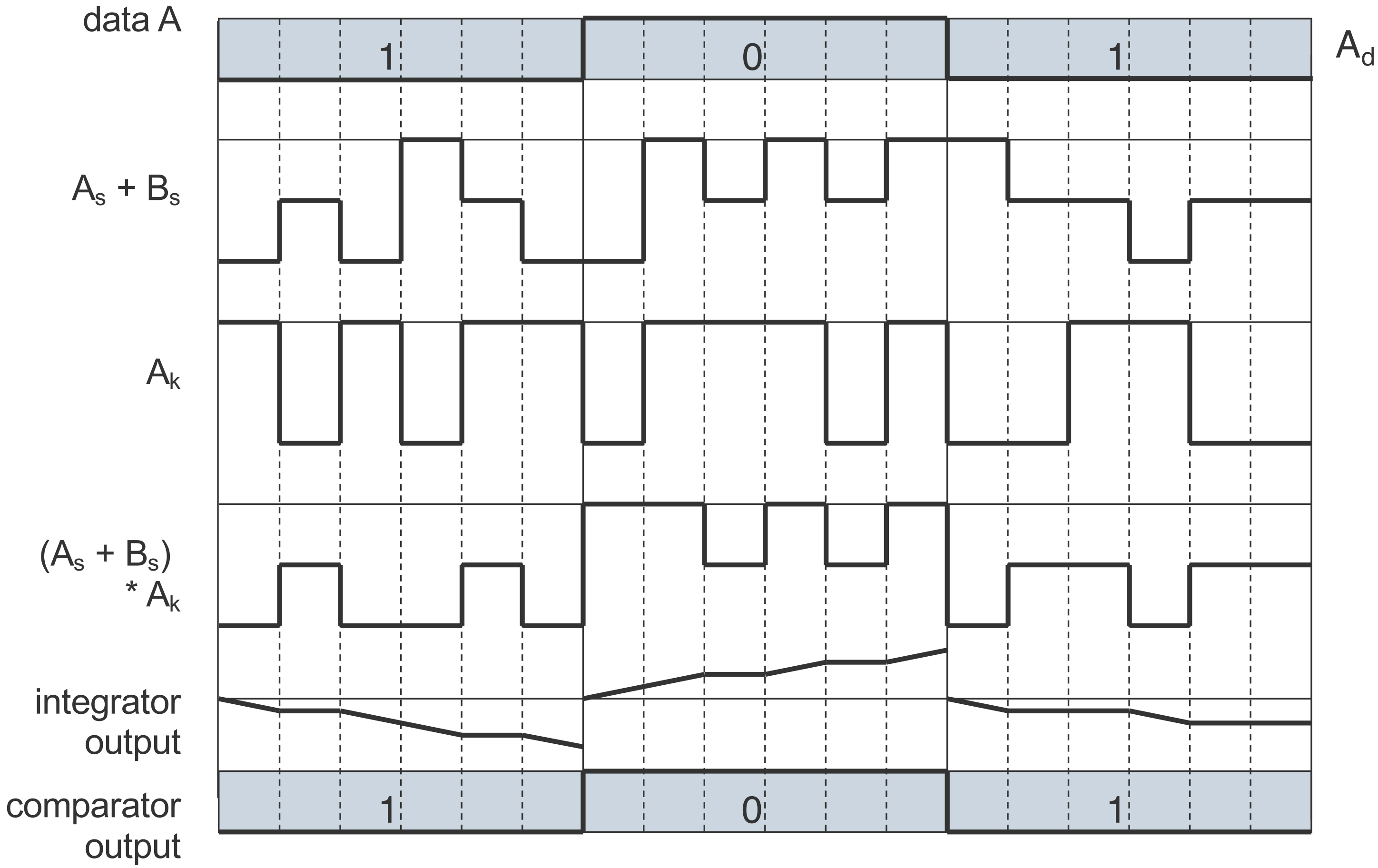



Real systems use much longer keys resulting in a larger distance between single code words in code space.

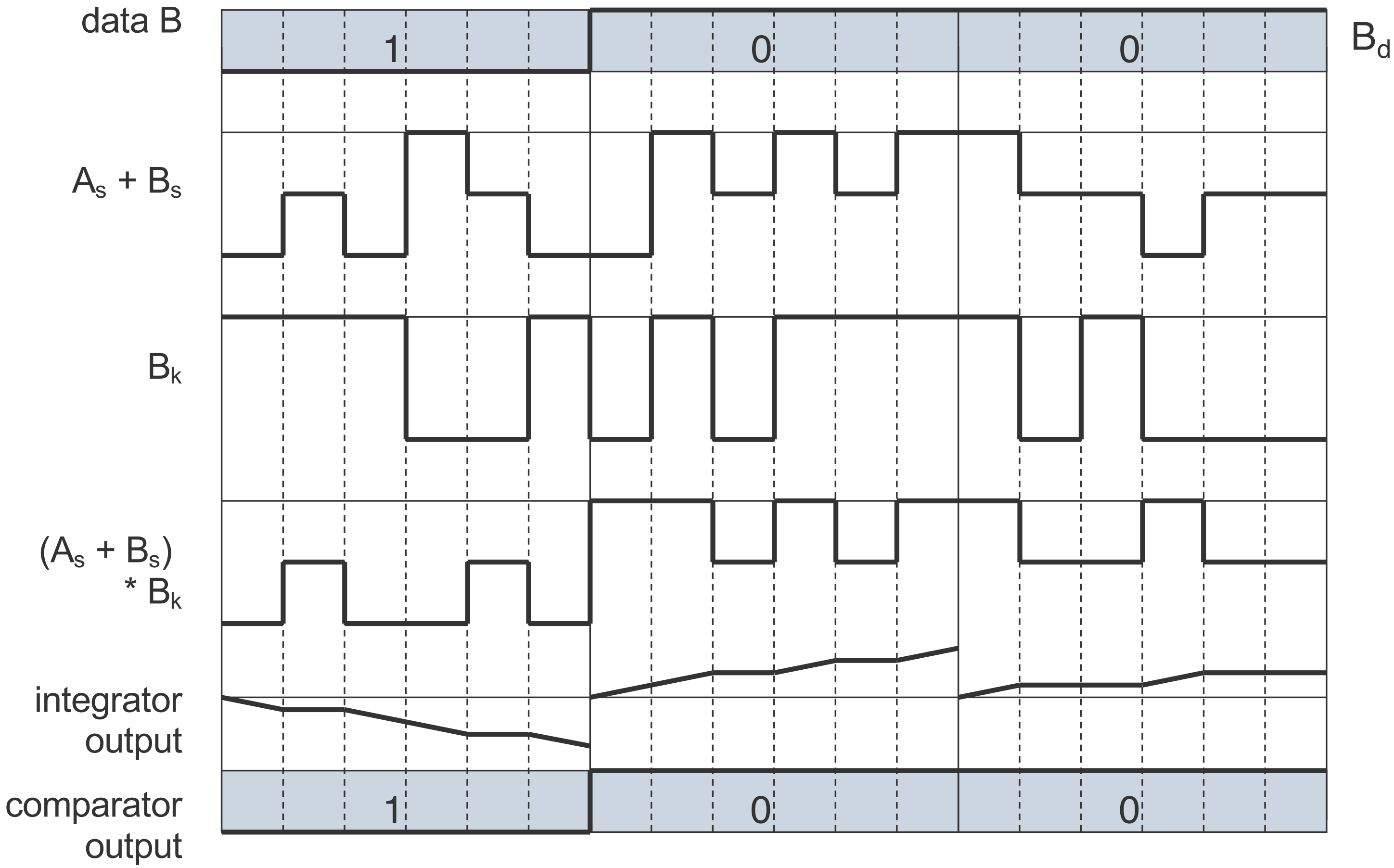
# CDMA on signal level II



# CDMA on signal level III



# CDMA on signal level IV



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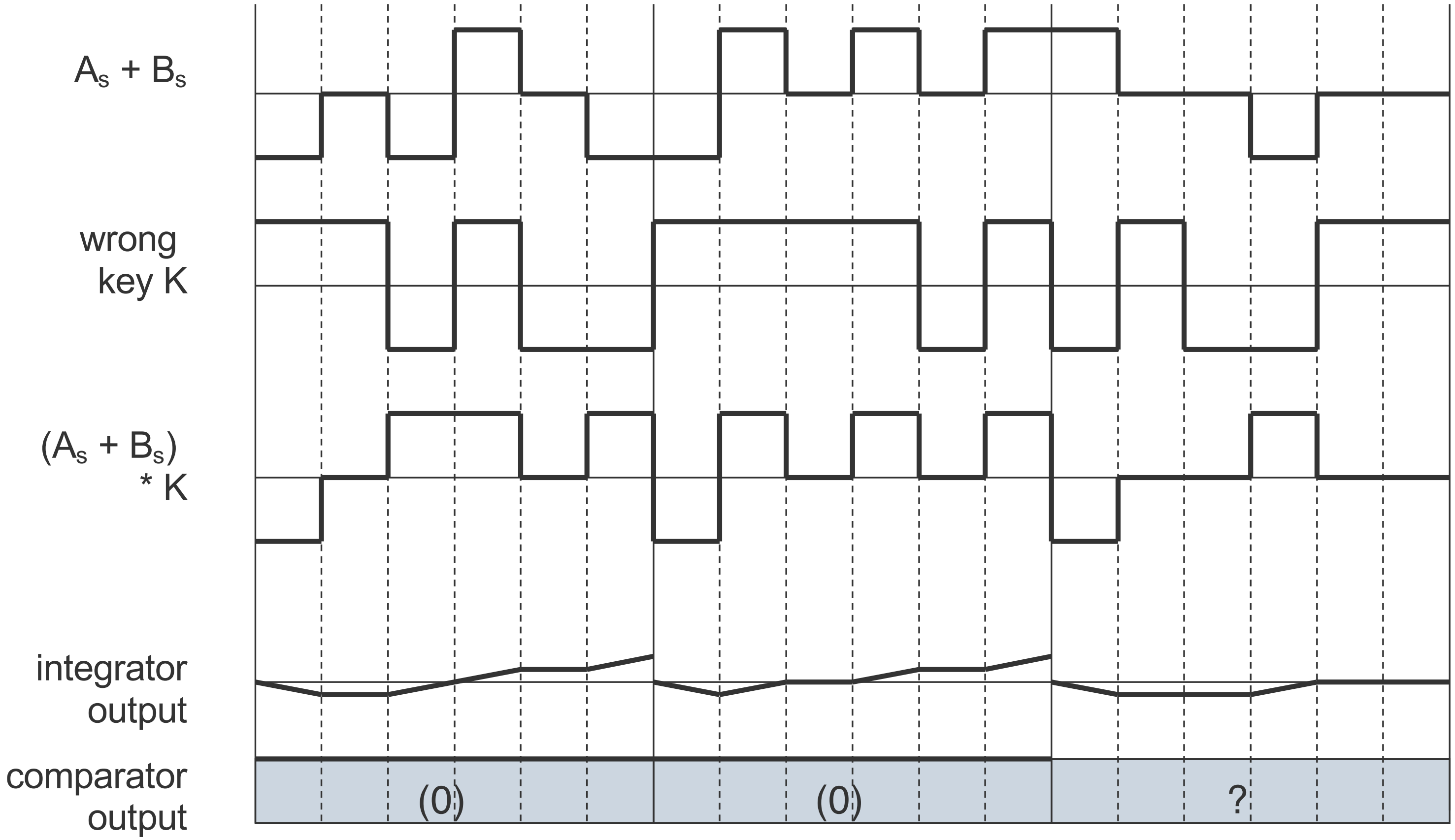
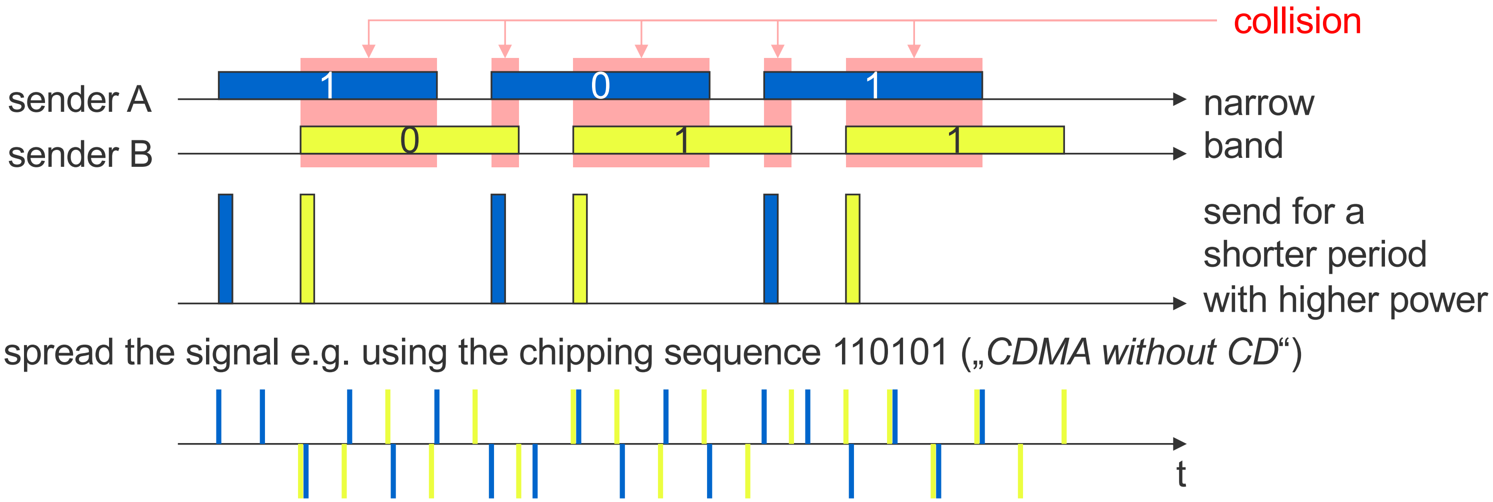
# CDMA on signal level V



# 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 km² | 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) | higher complexity, lowered expectations; integrated with TDMA/FDMA |