Mobile Computing

Chapter 3: Medium Access Control

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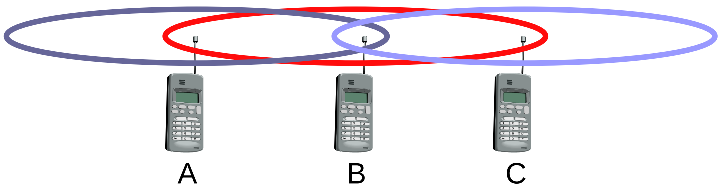
Contents

1. 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"

Hidden and exposed terminals

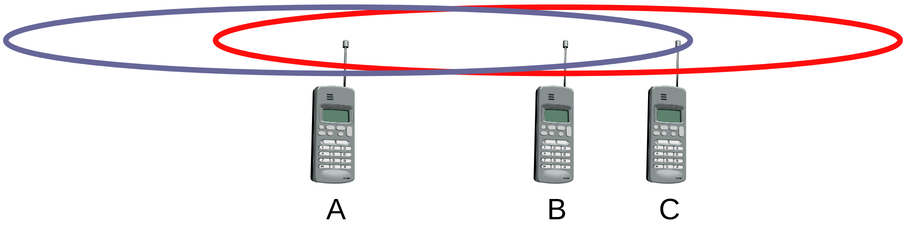
- Hidden terminals : cause collisions
  - A sends to B, C cannot receive A
  - C wants to send to B, C senses a "free" medium (CS fails)
  - collision at B, A cannot receive the collision (CD fails)
  - A is "hidden" for C: C is "hidden" for A



- Exposed terminals: cause unnecessary delay
  - 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
    - A collision at B does not matter because the collision is too weak to propagate to A.
  - C is "exposed" to B

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



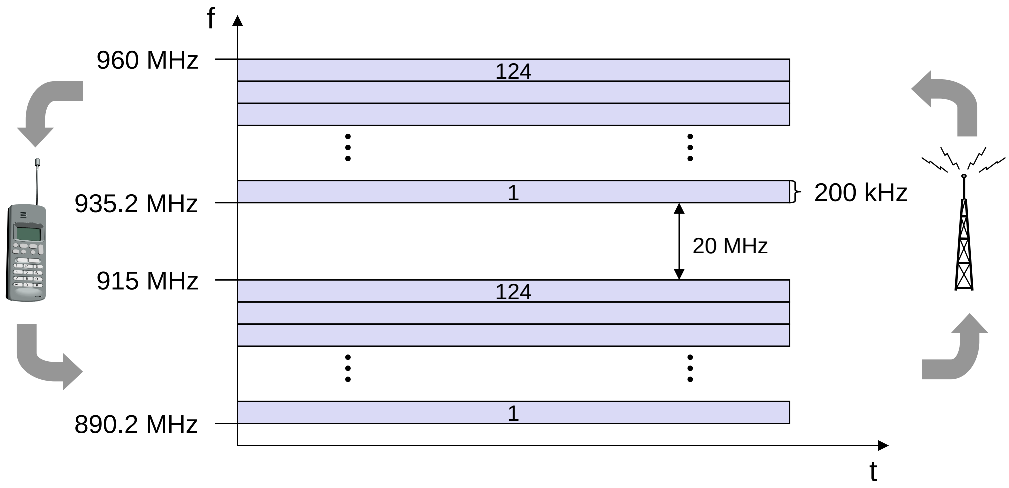
- If C for example was an arbiter (base station) for sending rights, terminal B would drown out terminal A already on the physical layer.
- Also severe problem for CDMA -networks - precise power control needed! (why?)

2. Access methods SDMA/FDMA/TDMA

- SDMA (Space Division Multiple Access)
  - allocating separate space to users in wireless networks.
  - segment space into cells, or sectors with directed antennas
  - SDMA is never used in isolation.
    - But always in combination with one or more other schemes (FDMA, TDMA, CDMA)

- 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)
  - Frequency Division Duplex (FDD)
    - used to divide up-link & down link channels.

FDD/FDMA - GSM

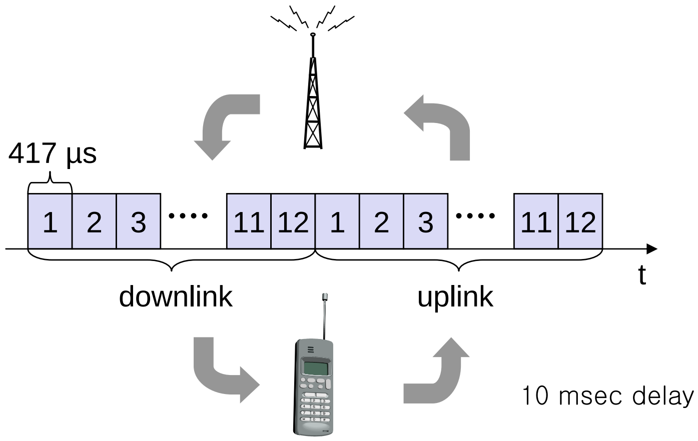


Access methods SDMA/FDMA/TDMA

- 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
  - Fixed : (fixed TDM)
    - Allocating a certain time slot for a channel in a fixed pattern.
  - Dynamic (Aloha)
    - MAC addresses are open used as identification.
    - It is flexible considering varying bandwidth requirements.

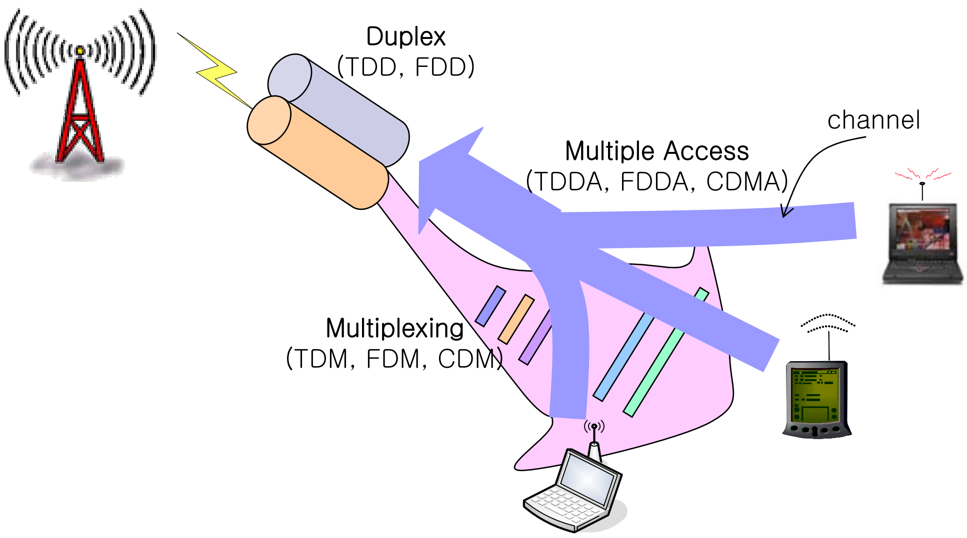
- Fixed TDM
  - results in a fixed bandwidth and delay for each channel
    - wireless phone systems – IS 136 (NA TDMA), GSM, DECT, PHS
  - Base station assigns the fixed time slot pattern.
    - no competition.
  - Time Division Duplex (TDD)
    - assign different slots for uplink and down link using the same frequency.

TDD / TDMA - DECT



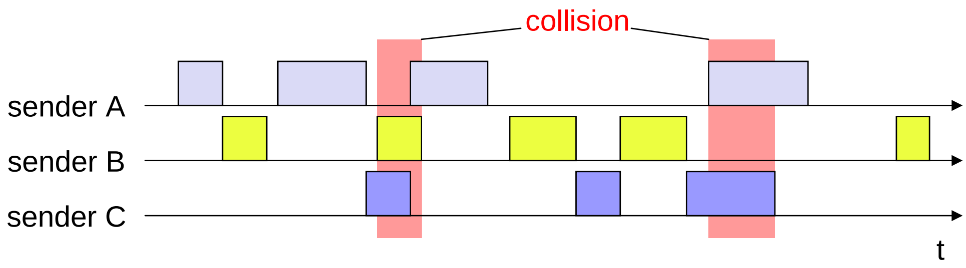
Multiplexing / Multiple Access / Duplex

- Three technologies are open confused.
  - But, conceptually different.
  - In practice, they are combined and there exist many possible combinations.



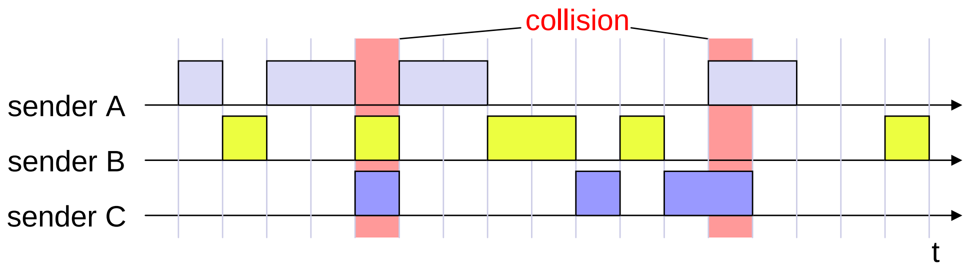
3. Aloha

- Mechanism
  - random, distributed (no central arbiter), time-multiplex
  - Slotted Aloha additionally uses time-slots, sending must always start at slot boundaries
- Aloha
  - neither coordinates medium access nor does it resolve contention on the MAC layer (left to higher layers)
  - works fine for a light load.



Slotted Aloha

- Slotted Aloha
  - All sender have to be synchronized.
  - Transmission can only start at the beginning of a time slot.
  - Slotting doubles the throughput (36%)
  - does not guarantee bandwidth or delay to each user.



4. Carrier Sense Multiple Access (CSMA)

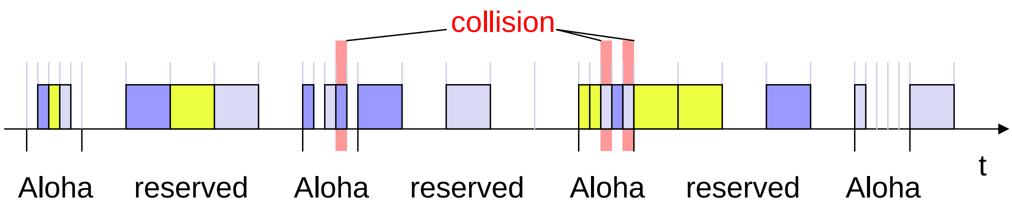
- simple improvement to the basic Aloha
  - sensing the carrier before accessing the medium
    - accessing the medium only if the carrier is idle.: decrease collision probability.
    - used in Wireless LAN system
- Non-persistent CSMA
  - Sending immediately if medium is idle.
  - If it is busy, the station pauses a random amount of time before sensing again.
- P-persistent CSMA
  - only transmit with a probability of p,
  - with 1-p the station deferring to the next slot .
- CAMA/CA
  - IEEE 802.11

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
  - Collisions may occur during the reservation periods.
  - reservation also causes higher delays
    - because of reservation periods
  - typical scheme for satellite links
- Examples for reservation algorithms:
  - *Explicit Reservation according to Roberts (Reservation-ALOHA)*
  - *Implicit Reservation (PRMA)*
  - *Reservation-TDMA*

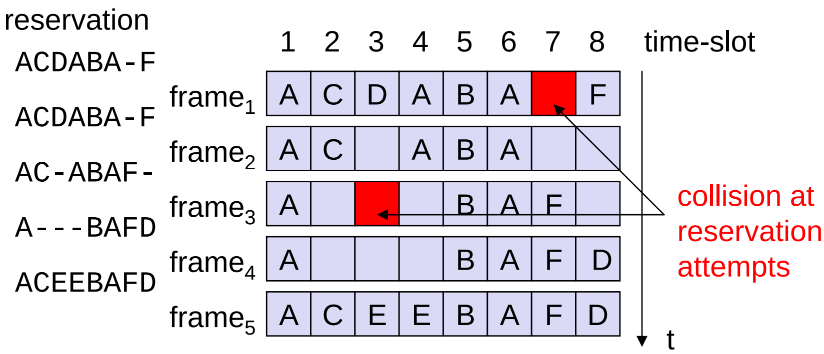
Access method DAMA: Explicit Reservation

- 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



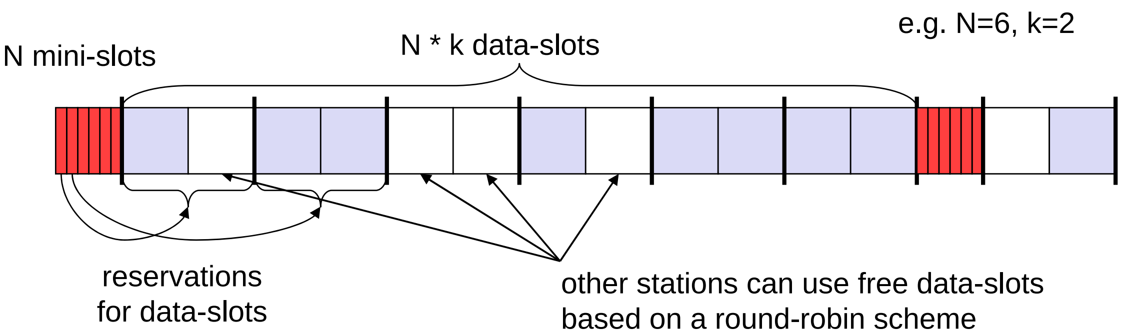
Access method DAMA: PRMA

- 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)

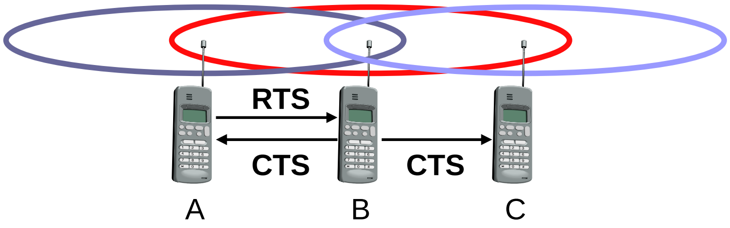


MACA - collision avoidance

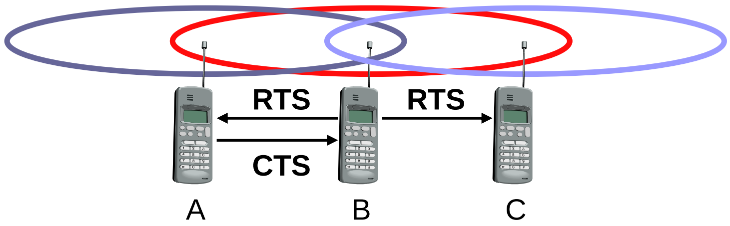
- MACA (Multiple Access with Collision Avoidance)
  - solves hidden terminal problem
  - does not need a base station
  - still random access but dynamic reservation
- short signaling packets for collision avoidance
  - RTS (request to send): a sender request the right to send from a receiver with a 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

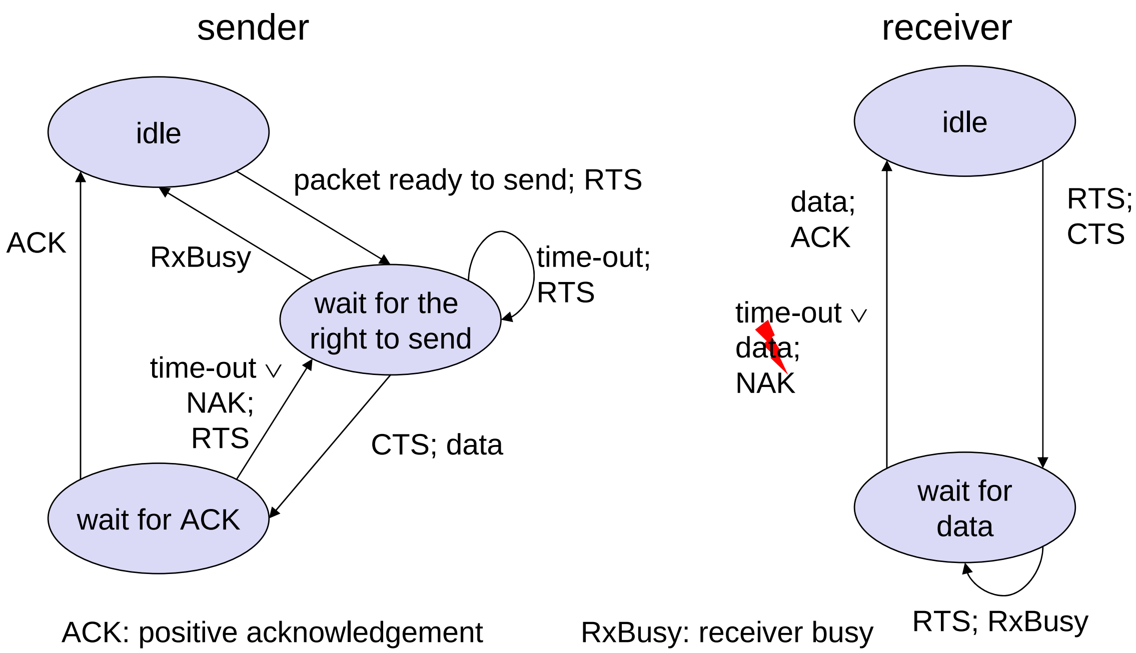
- MACA avoids the problem of hidden terminals
  - A and C want to send to B
  - A sends RTS first
  - C waits after receiving CTS from B



- 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



MACA variant: DFWMAC in IEEE802.11



ACK: positive acknowledgement
NAK: negative acknowledgement

RxBusy: receiver busy

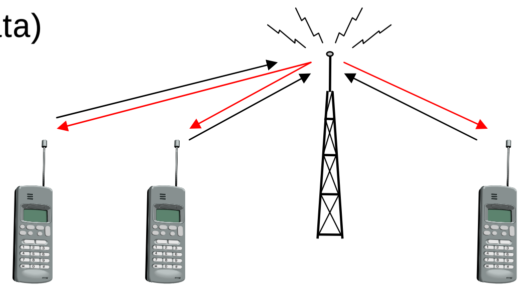
Polling mechanisms

- If one terminal can be heard by all others, this “central” terminal (e.g., 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.
  - 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 (Cellular Digital Packet Data)
  - (USA, integrated into AMPS)



6. 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 (chipping sequence), 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.

- Good code for CDMA
  - should be orthogonal to other codes
    - orthogonal: for two vectors their inner product is 0.
  - should have a good autocorrelation
    - autocorrelation: absolute value of the inner product of a vector multiplied with itself.

Access method CDMA

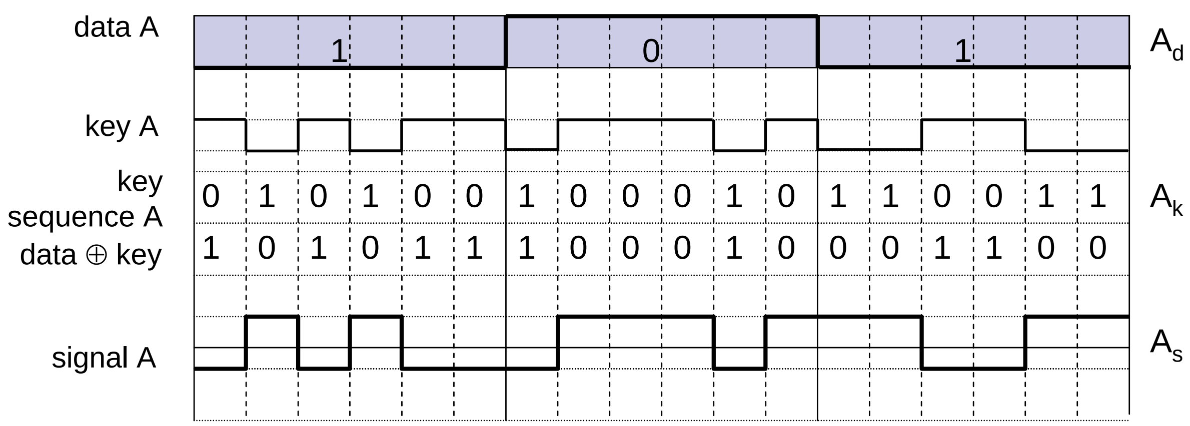
- Disadvantages:
  - higher complexity of a receiver (receiver cannot just listen into the medium and start receiving if there is a signal)
  - All signals should have the same strength at a receiver

- 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

CDMA in theory

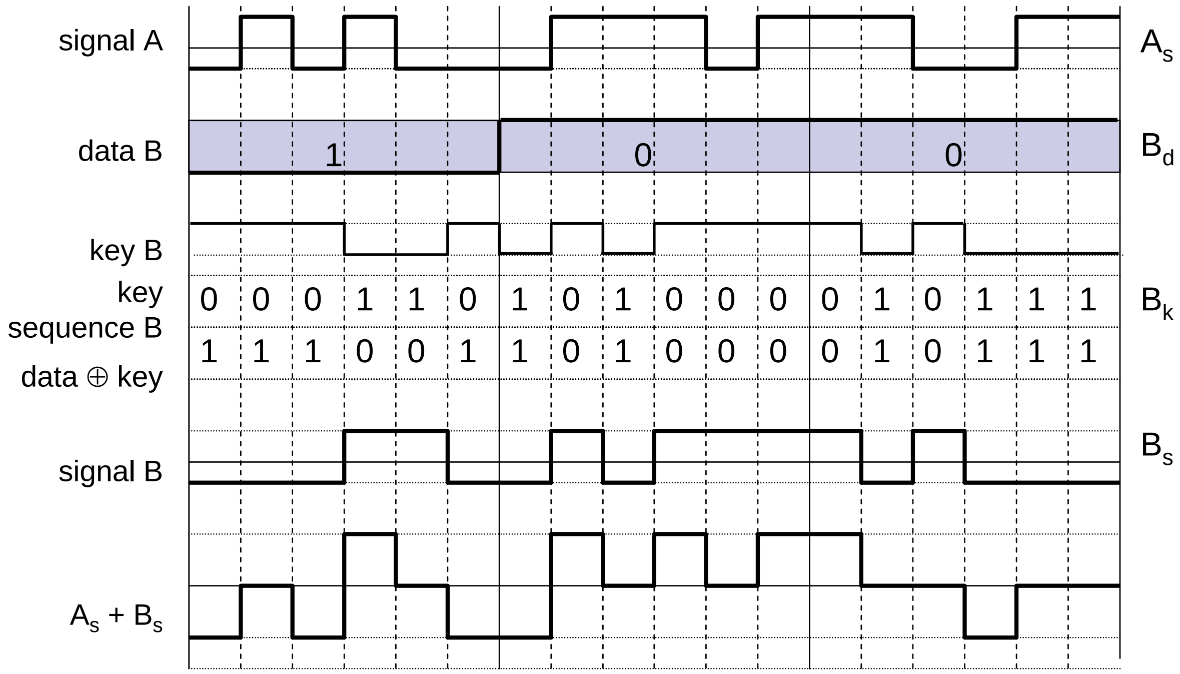
- Sender A
  - sends A_d = 1, key A_k = 010011 (assign: „0“= -1, „1“= +1)
  - sending signal $A_s = A_d * A_k$ = (-1, +1, -1, -1, +1, +1)
- Sender B
  - sends B_d = 0, key B_k = 110101 (assign: „0“= -1, „1“= +1)
  - sending signal $B_s = B_d * B_k$ = (-1, -1, +1, -1, +1, -1)
- Both signals superimpose 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) • 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) • B_k = -2 + 0 + 0 - 2 - 2 + 0 = -6, i.e. „0“

CDMA on signal level (1)

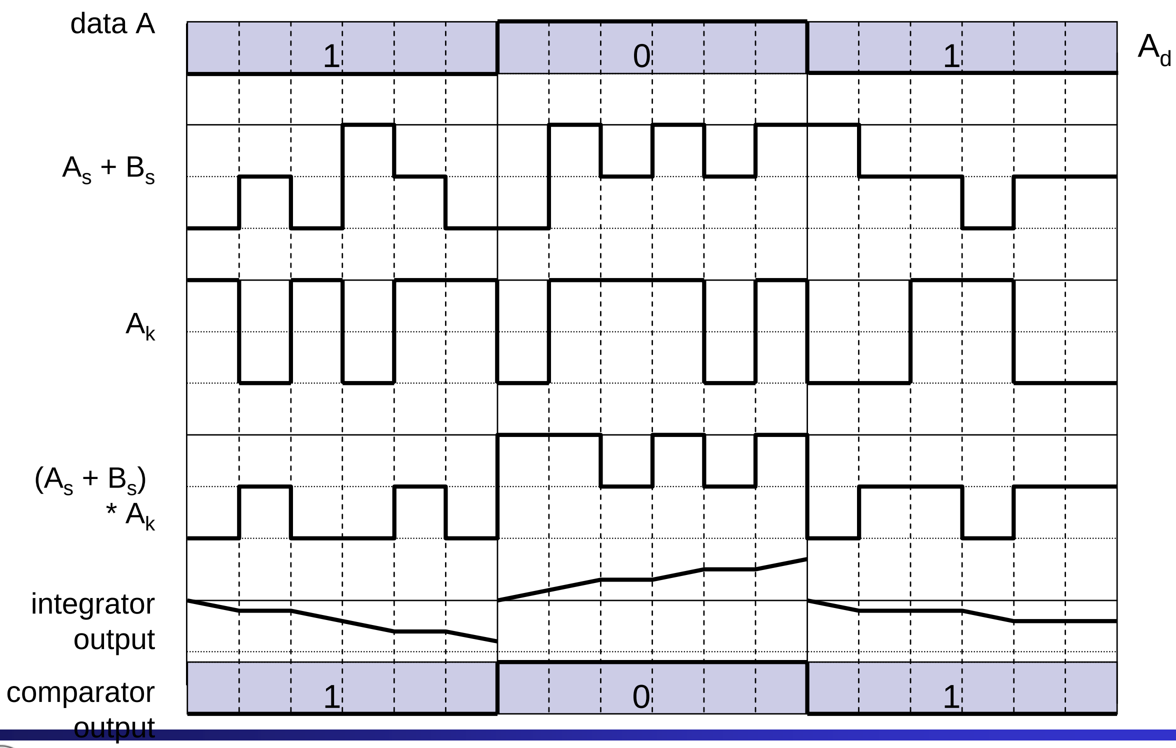


Real systems use much longer keys resulting in a larger distance between single code words in code space.

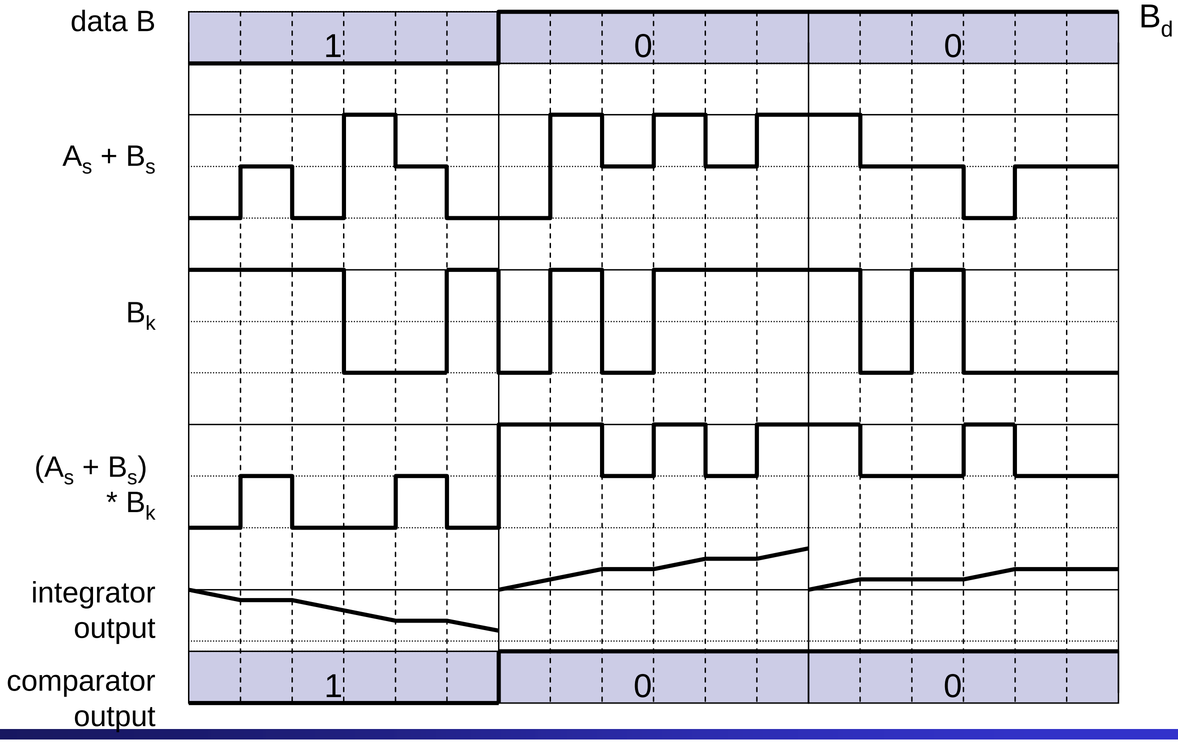
CDMA on signal level (2)



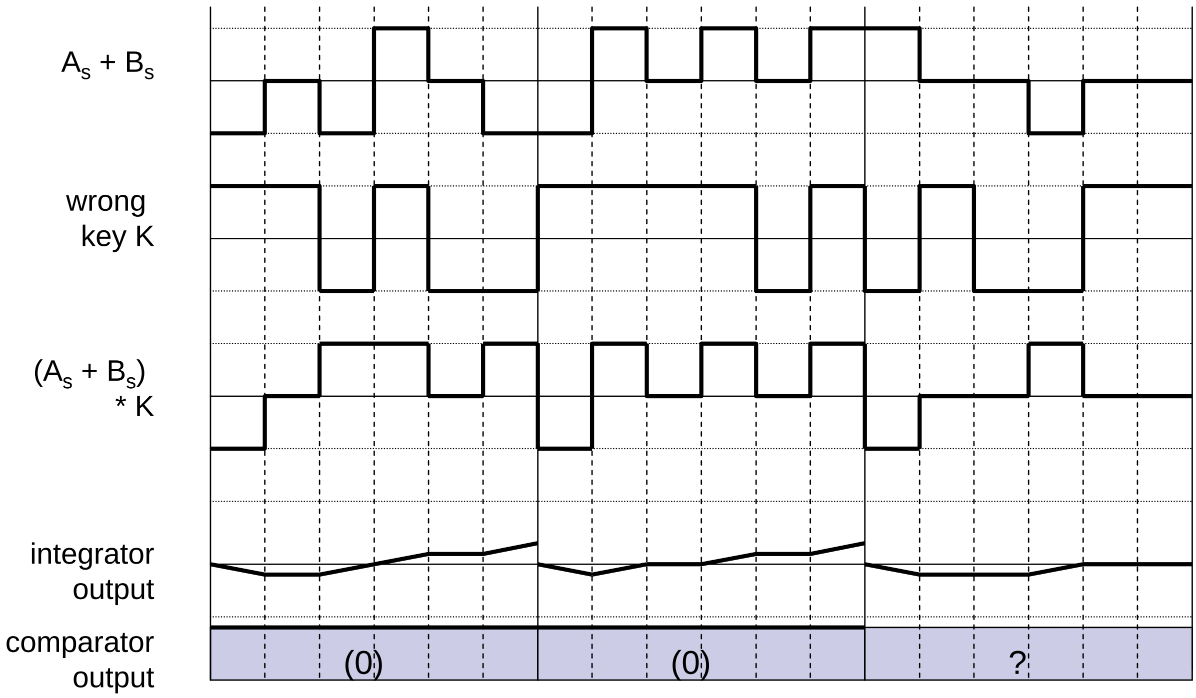
CDMA on signal level (3)



CDMA on signal level (4)

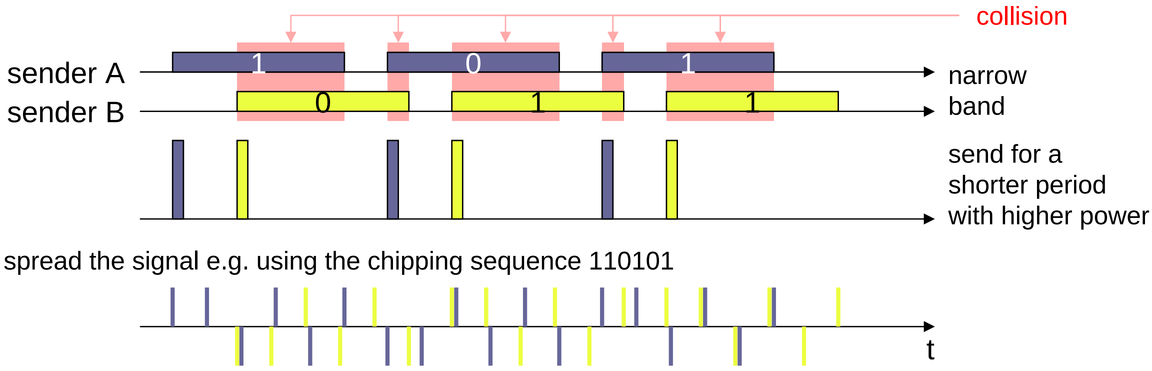


CDMA on signal level (5)



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
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