Mobile Communication: Medium Access Control

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Based on materials by Jochen Schiller

1

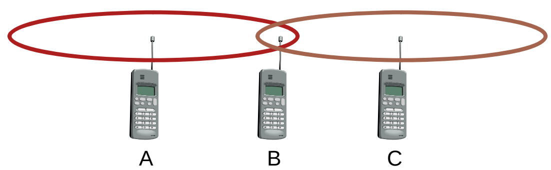
Motivation

- Can we apply media access methods from fixed networks?
- Example from Ethernet: 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 the square of the distance
  - collisions happen at the receiver
  - sender cannot “hear” the collision
  - furthermore, CS might not work if, e.g., a terminal is “hidden”

2

Motivation: hidden 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



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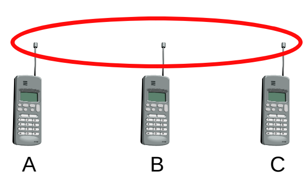
Motivation: exposed terminals

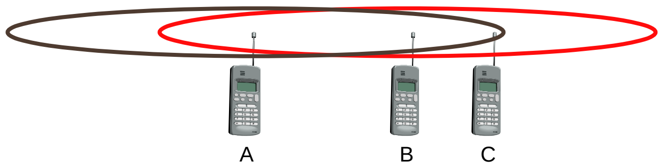
- Exposed terminals
  - B sends to A, C wants to send to another terminal (not A or B)
  - C has to wait, CS signals a medium in use
  - but A is outside the radio range of C, therefore waiting is not necessary
  - C is “exposed” to B



4

Motivation: Near and far terminals

- Terminals A and B send, C receives
  - signal of terminal B drowns out A's signal (recall signal strength proportional to $1/d^2$)
  - 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
- Problem for CDM-networks—precise power control needed!

5

ACCESS METHODS SDMA/FDMA/TDMA

6

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  - segment space into sectors, use directed antennas
  - cell structure

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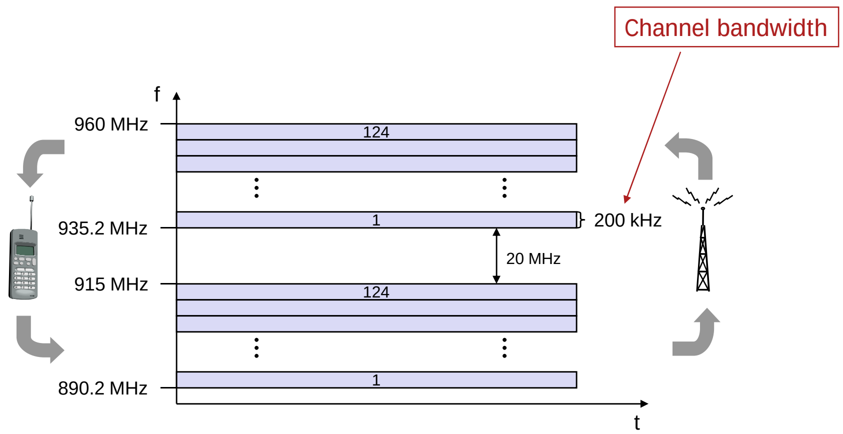
  - cell structure
- FDMA (Frequency Division Multiple Access)
  - assign a certain frequency to a transmission channel
  - **permanent** (e.g., radio broadcast), **slow hopping** (e.g., GSM), **fast hopping** (FHSS, Frequency Hopping Spread Spectrum)
  - **Frequency division duplex (FDD):** different frequencies for uplink and downlink

FDD/FDMA – General scheme, example GSM



$f_d = f_u + 45$ MHz
Ex: $f_d = 935.2$ MHz, $f_u = 890.2$ MHz

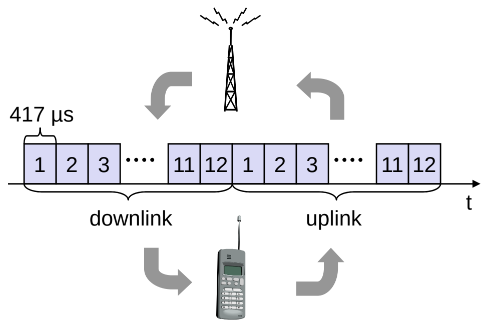
9

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
  - permanent (e.g., radio broadcast), slow hopping (e.g., GSM), fast hopping (FHSS, Frequency Hopping Spread Spectrum)
  - Frequency division duplex (FDD): different frequencies for uplink and downlink
- TDMA (Time Division Multiple Access)
  - assign the fixed sending frequency to a transmission channel for a certain amount of time
- The multiplexing schemes presented previously are now used to control medium access!

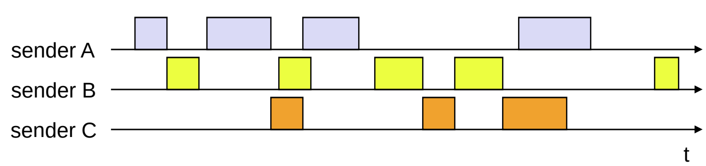
10

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



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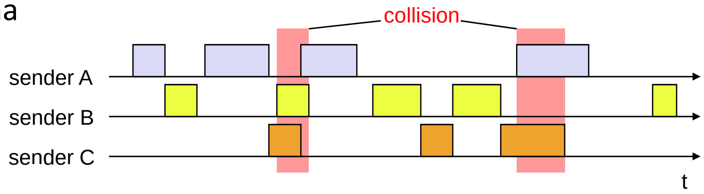

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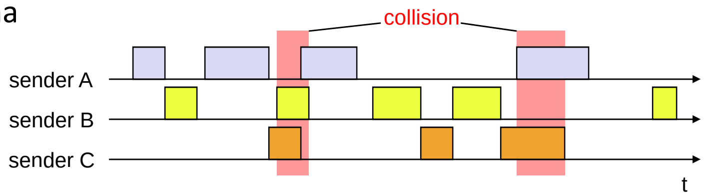

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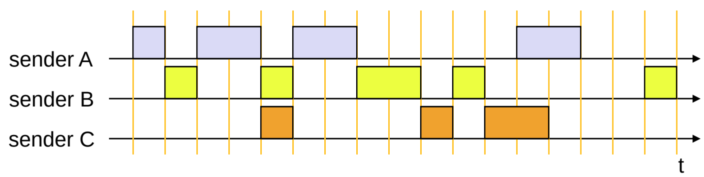

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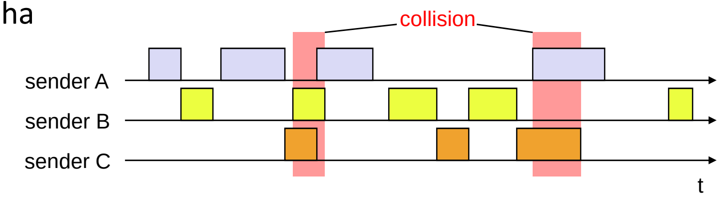

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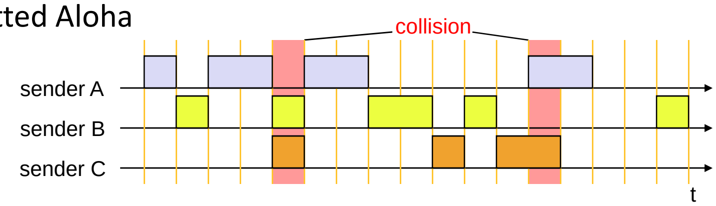

RESERVATION-BASED MAC

DAMA - Demand Assigned Multiple Access

- Channel efficiency only 18% for Aloha, 36% for Slotted Aloha (assuming Poisson distribution for packet arrival and packet length—note a good assumption for Internet!)
- 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*

17

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

18

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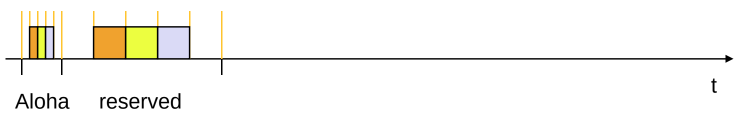

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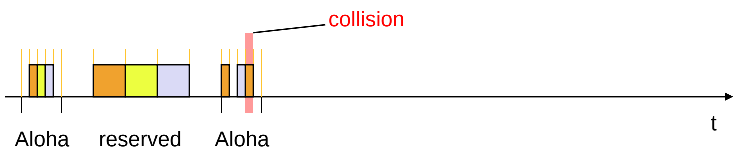

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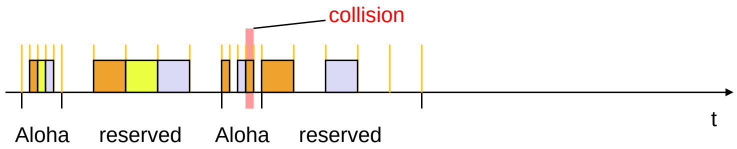

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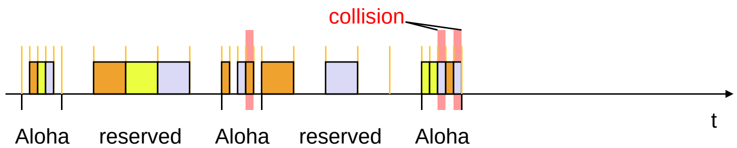

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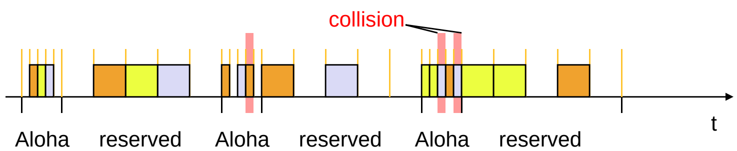

23

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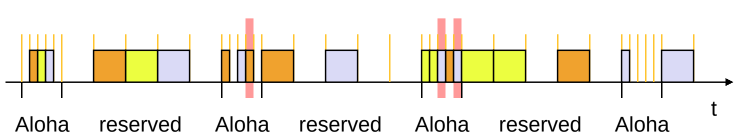
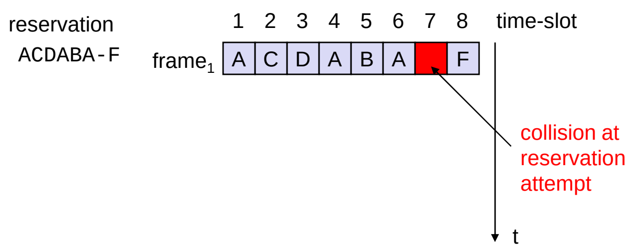


24

Access method DAMA: Implicit Reservation 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 as long as the station has data to send
  - competition for slots starts again as soon as the slot was empty in the last frame



25

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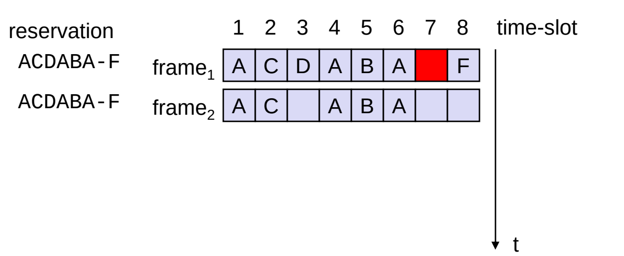

26

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reservation		1	2	3	4	5	6	7	8	time-slot
ACDABA-F	$frame_1$	A	C	D	A	B	A		F	
ACDABA-F	$frame_2$	A	C		A	B	A			
AC-ABAF-	$frame_3$	A				B	A	F		collision at reservation attempt

t

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A---BAFD	$frame_4$	A				B	A	F	D	

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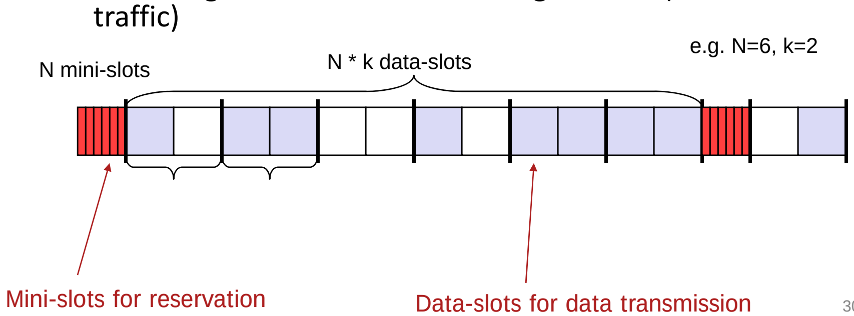
A---BAFD	$frame_4$	A				B	A	F	D
ACEEBAFD	$frame_5$	A	C	E	E	B	A	F	D

time-slot, t

29

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)



30

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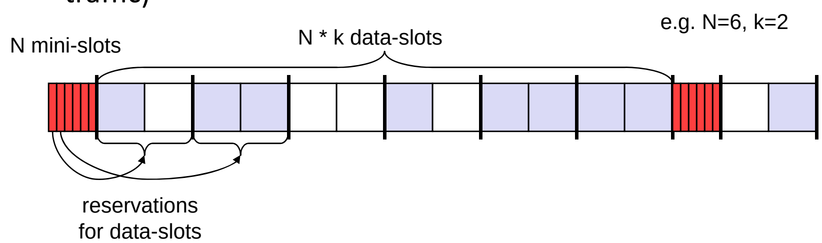

31

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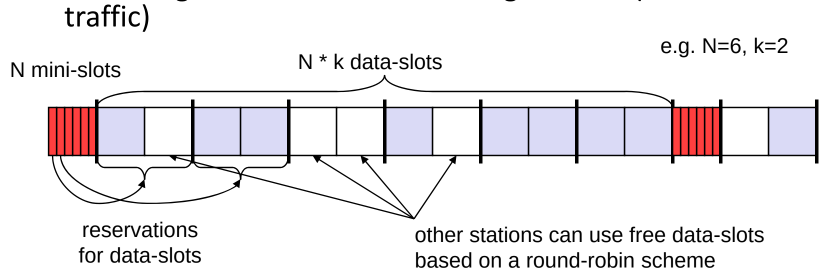

32

Back up

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- How do these schemes handle hidden terminals?
  - They don't
  - Central base station means that they do not face that problem
  - If terminal is hidden from base station, it cannot communicate
- In less centralized cases e.g. ad hoc networks, use MACA…

35

COLLISION AVOIDANCE

36

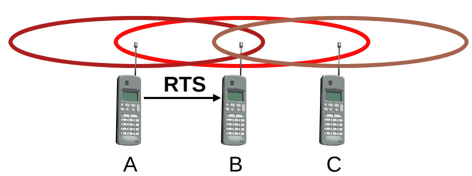
MACA - collision avoidance

- MACA (Multiple Access with Collision Avoidance) uses short signaling packets for collision avoidance
  - RTS (request to send): control packet from sender to receiver
  - CTS (clear to send): control packet from receiver to sender
- 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)

37

MACA Examples

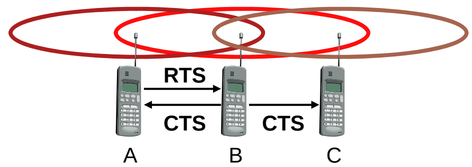
- MACA avoids the problem of hidden terminals
  - A and C want to send to B
  - A sends RTS first



38

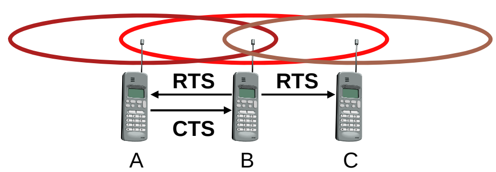
MACA Examples

- 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

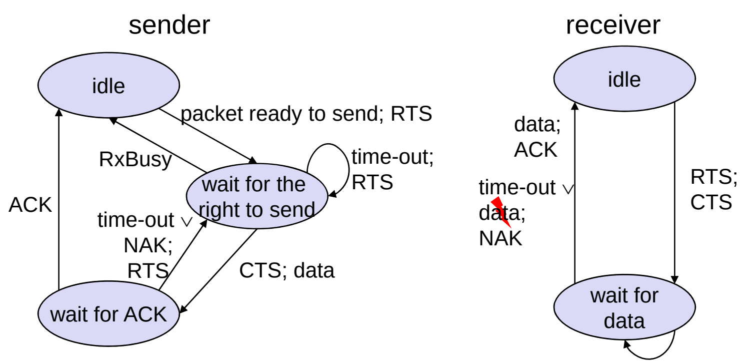


MACA Examples

- MACA avoids the problem of exposed terminals
  - B wants to send to A
  - C wants to send to another terminal
  - C does not have to wait, since it cannot receive CTS from A



MACA variant: DFWMAC in IEEE802.11



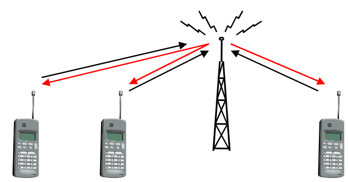
ACK: positive acknowledgement
NAK: negative acknowledgement
RxBusy: receiver busy

Polling mechanisms

- If one terminal can be heard by all others, this “central” terminal (a.k.a. base station) can poll all other terminals according to a certain scheme
  - all schemes known from fixed networks can be used (e.g. VTAM)
- Example: Randomly Addressed Polling
  - base station signals readiness to all mobile terminals
  - terminals ready to send can transmit a random number
    - Use CDMA or FDMA to avoid collision
    - random number = dynamic address
  - base station chooses one address from list of random numbers
    - collision if two terminals choose the same address
  - base station acknowledges correct packet and continues polling the next terminal
  - 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 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



43

ACCESS METHOD CDMA

44

Access Method CDMA

- CDMA (Code Division Multiple Access)
  - all terminals send on the same frequency and can use the whole bandwidth of the channel
  - sender XORs their signal with their unique random number
  - receiver can “tune” into this signal if it knows the random number (correlation function)
- Disadvantages:
  - higher complexity of a receiver
  - 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
  - interference (e.g. white noise) is not coded
  - forward error correction and encryption can be easily integrated

45

CDMA in theory

- Sender A
  - sends Ad = 1, key Ak = 010011 (assign: “0”= -1, “1”= +1)
  - sending signal As = Ad * Ak = (-1, +1, -1, -1, +1, +1)

46

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- Sender B
  - sends Bd = 0, key Bk = 110101 (assign: “0”= -1, “1”= +1)
  - sending signal Bs = Bd * Bk = (-1, -1, +1, -1, +1, -1)

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- Both signals superimpose in space
  - interference neglected (noise etc.)
  - As + Bs = (-2, 0, 0, -2, +2, 0)

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  - As + Bs = (-2, 0, 0, -2, +2, 0)
- Receiver wants to receive signal from sender A
  - apply key Ak bitwise (inner product)
    - Ae = (-2, 0, 0, -2, +2, 0) • Ak = 2 + 0 + 0 + 2 + 2 + 0 = 6
    - result greater than 0, therefore, original bit was “1”

49

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    - result greater than 0, therefore, original bit was “1”
  - receiving B
    - Be = (-2, 0, 0, -2, +2, 0) • Bk = -2 + 0 + 0 - 2 - 2 + 0 = -6, i.e. “0”

50

SAMA - Spread Aloha Multiple Access

- Aloha has very low efficiency, CDMA needs complex receivers to be able to receive different senders at the same time
- Idea: use spread spectrum with only one single code (chipping sequence) for spreading for all senders accessing according to aloha

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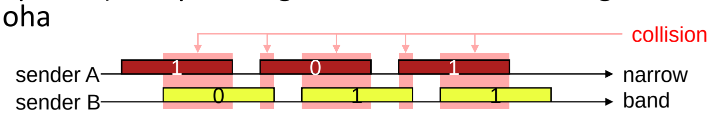
- Idea: use spread spectrum with only one single code (chipping sequence) for spreading for all senders accessing according to aloha



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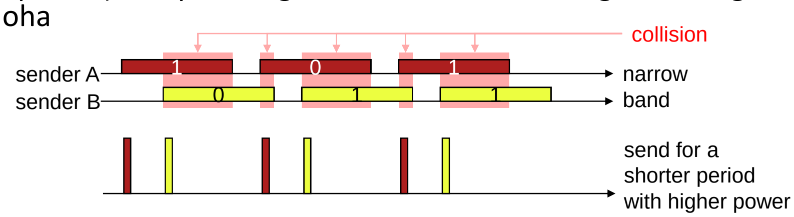

53

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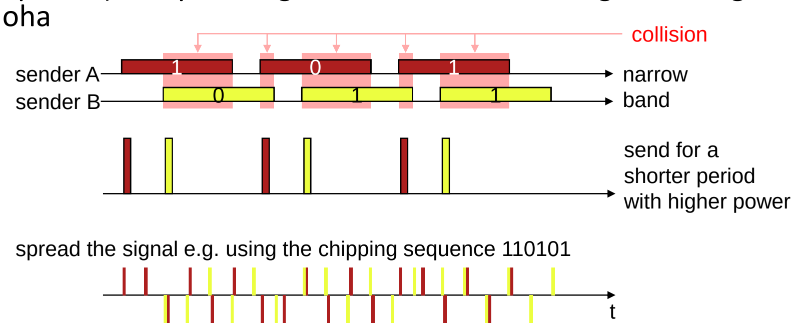

Problem: find a chipping sequence with good characteristics

54

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

55