MAC PROTOCOLS

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AP/CSE

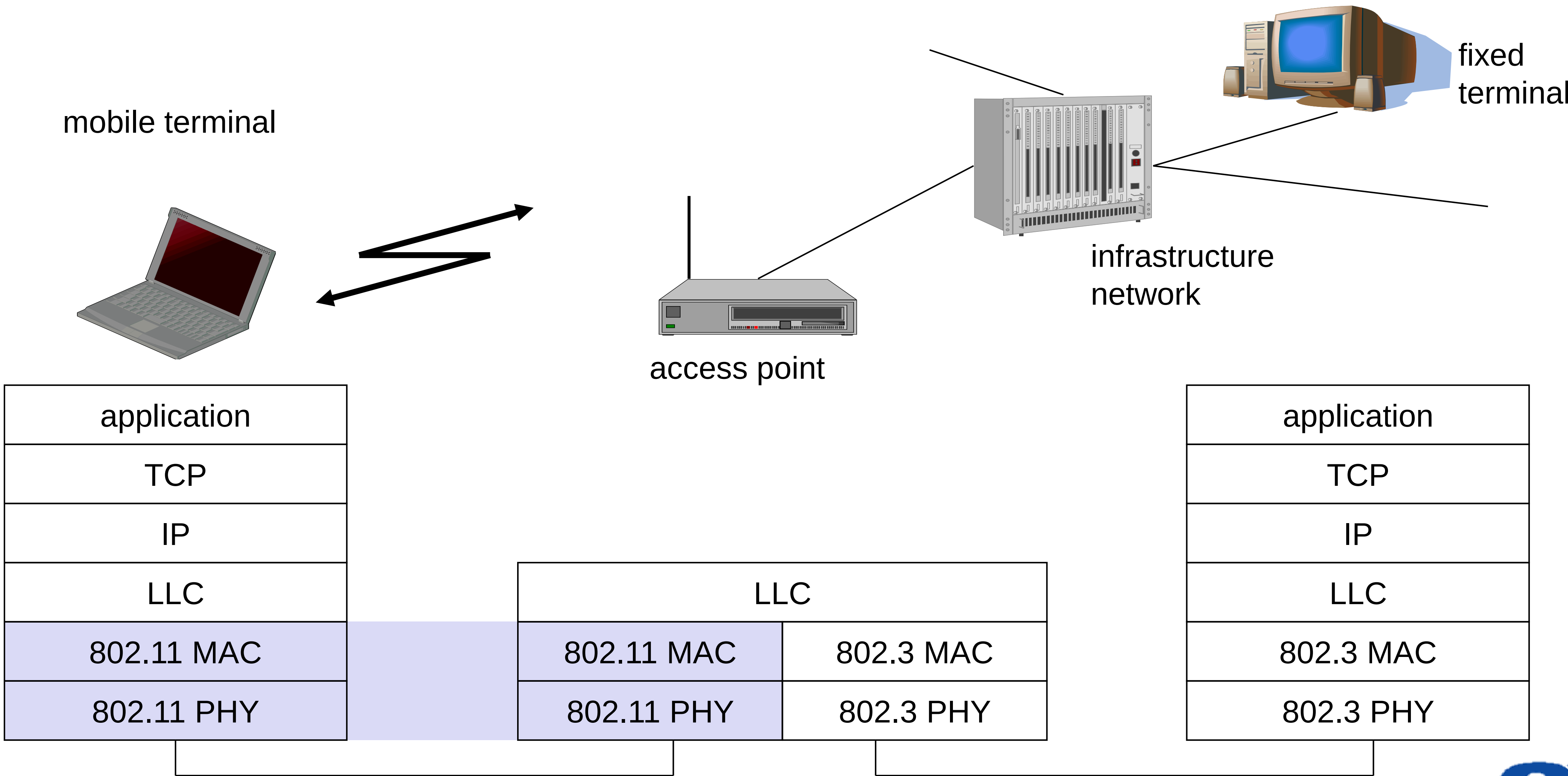
LEARNING OBJECTIVES

- To understand the about MAC protocols.

PURPOSE OF MAC PROTOCOLS

- The MAC sublayer provides
  - Addressing
  - channel access when multiple stations contend for the medium.
- Size of MAC Address??
- Mobile device MAC Address size???

PURPOSE OF MAC PROTOCOLS



PROPERTIES – MAC PROTOCOLS

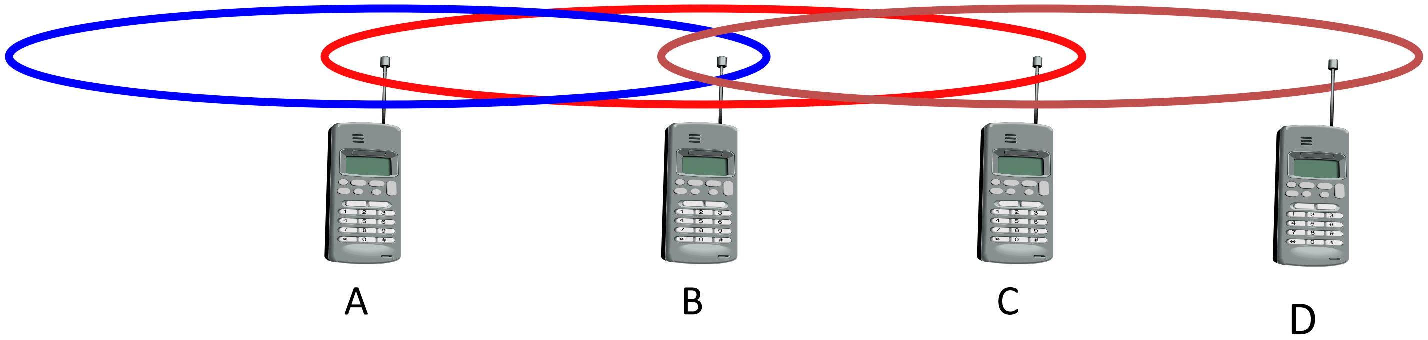
- Should implement some rules to enforce discipline when multiple nodes contend for a shared channel.
- Maximize the utilization of the channel.
- Fair Channel allocation
  - No discrimination for any node.
- Support different types of traffic with maximum and average bit rates.
- Robust incase of equipment failure and changing network conditions
- IEEE 802.11 (WLAN) – wifi hotspots.
- MANET- MACA

MOTIVATION FOR A SPECIALIZED MAC

- Difficult to implement a collision detection scheme, as collisions are hard to detect by the nodes.
- The main issues need to be addressed while designing a MAC protocol for ad hoc networks:
  - **Hidden and exposed terminal problems**:
  - Distributed Nature/Lack of Central Coordination
  - Mobility of Nodes: Nodes are mobile most of the time.

HIDDEN AND EXPOSED TERMINAL

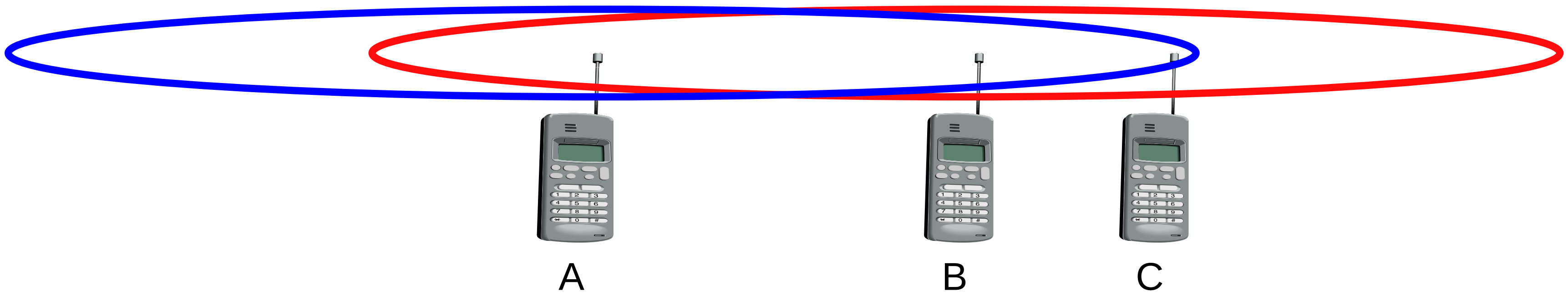
- Hidden terminals
  - A sends to B, C cannot receive A
  - C wants to send to B, C senses a “free” medium
  - collision at B, A cannot receive the collision
  - A is “hidden” for C



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



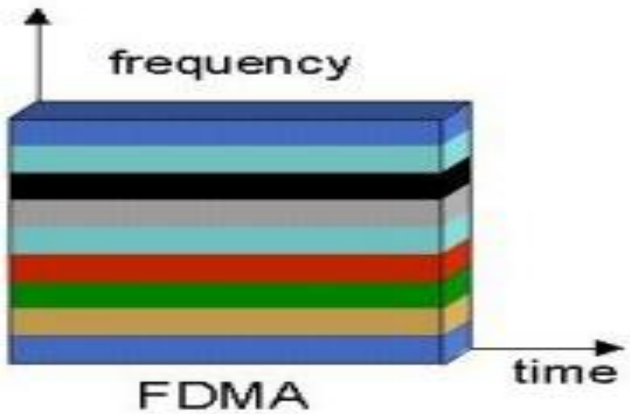
- If C for example was an arbiter for sending rights, terminal B would drown out terminal A already on the physical layer
- Also severe problem for CDMA-networks - precise power control needed!

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
- Code Division Multiple Access(CDMA)

FDMA

- Frequency division multiple access (FDMA) comprises all algorithms allocating frequencies to transmission channels according to the frequency division multiplexing (FDM)
- The existing bandwidth is divided into sub bands / channels



FDMA

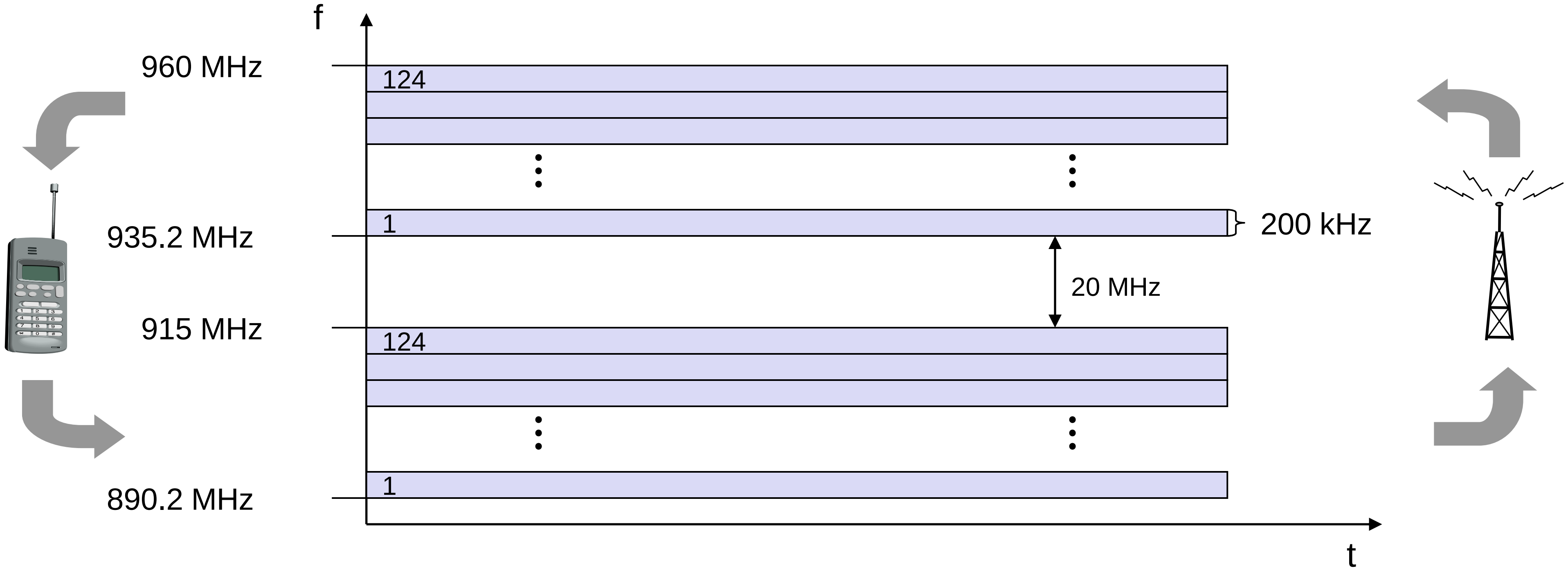
- Pure FDMA
  - Channels can be assigned to the same frequency at all times
- FDMA combined with TDMA
  - Channels can change frequencies according to a certain pattern
- For full duplex communication each user is allocated 2 unique frequency for transmitting and receiving signals during the call
  - Forward Link (Mobile to BS)
  - Reverse Channel (BS to Mobile)
- No other user can be allocated with same frequency to make a call.

FDMA

Frequency division duplex (FDD)

- The two directions, mobile station to base station and vice versa are separated using different frequencies.
- This scheme is called as frequency division duplex (FDD)
- Again, both partners have to know the frequencies in advance ; they cannot just listen into the medium.
- The two frequencies are also known as uplink and downlink

FDMA



FDMA

Uplink Frequency (For Transmission)

- From mobile station to base station or from ground control to satellite
- All uplinks use the band between 890.2 and 915

Downlink Frequency (Receiving information)

- From base station to mobile station or from satellite to ground control
- All downlinks use 935.2 to 960 MHz

FDMA

Allocation of uplink and downlink Frequency

- According to FDMA, the base station, allocates a certain frequency for up and downlink to establish a with a mobile phone
- Up and downlink have a fixed relation
- If the uplink frequency is $f_u = 890$ MHz $+ n \cdot 0.2$ MHz, the downlink frequency is $f_d = f_u + 45$ MHz, i.e., $f_d = 935$ MHz $+ n \cdot 0.2$ MHz for a certain channel n.
- The base station selects the channel. Each channel (uplink and downlink) has a bandwidth of 200 kHz
- This illustrates the use of FDM for multiple access (124 channels per direction are available at 900 MHz) and duplex according to a predetermined scheme.

FDMA

- 3^{rd} channel uplink and downlink frequency

- fu= 890 MHz + n*0.2 MHz

  = 890 MHz + 3*0.2 MHz

  = 890.6 MHz

- fd= fu+ 45 MHz

  = 890.6 MHz + 45 MHz

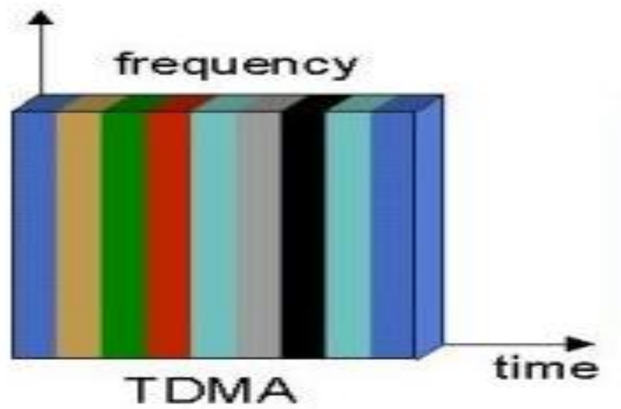
  = 935.6 MHz

FDMA

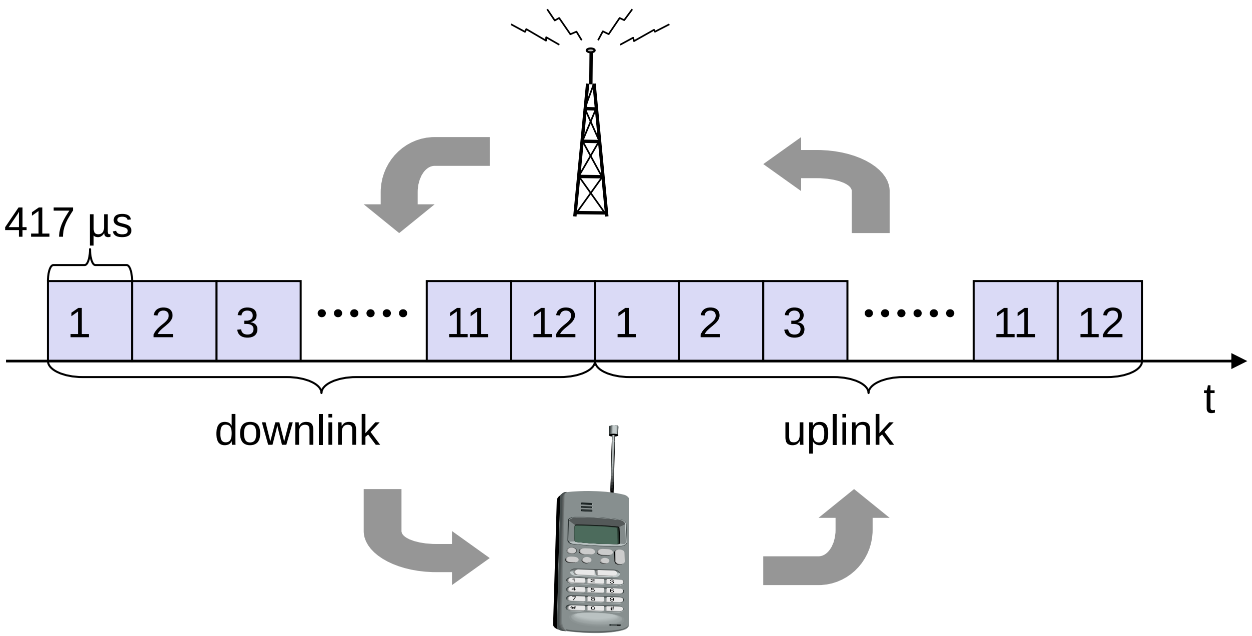
- Drawback
  - When allocated user paused between transmission –unused transmission
  - No user is allocated, the band goes idle.
  - Does not achieve high channel utilization

TDMA

- Time division multiple access (TDMA) allocate certain time slots for communication, i.e., controlling TDM.
- The timeline is divided into fixed time slots.
- Time slots are allocated in round robin manner.



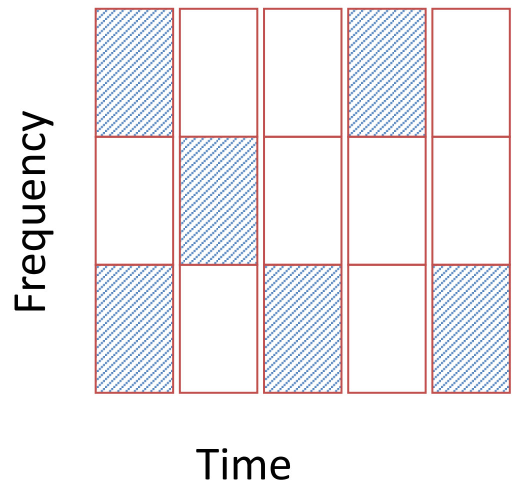
Time Division Duplex (TDD)



TDMA

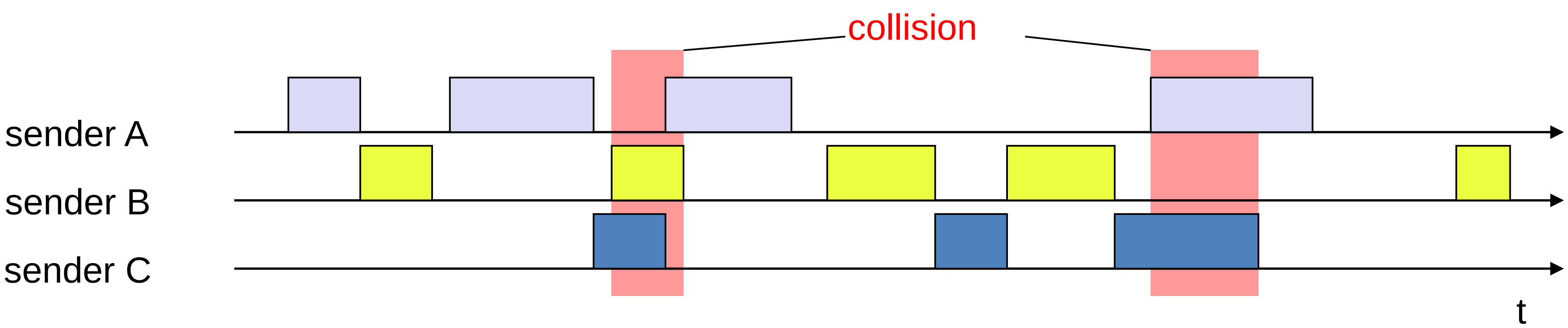
- Only one frequency is used.
- Each partner must be able to access the medium for a time slot at the right moment.
- The base station uses 12 slots for downlink and the mobile uses other 12 slots for uplink.
- Up to 12 different mobile stations can use the same frequency.
- Every 10ms = 417μs*24 a mobile station can access the medium.
- Very inefficient for bursty data
- Unused Time slots go idle , leading to low channel Utilization

HYBRID FDMA/TDMA



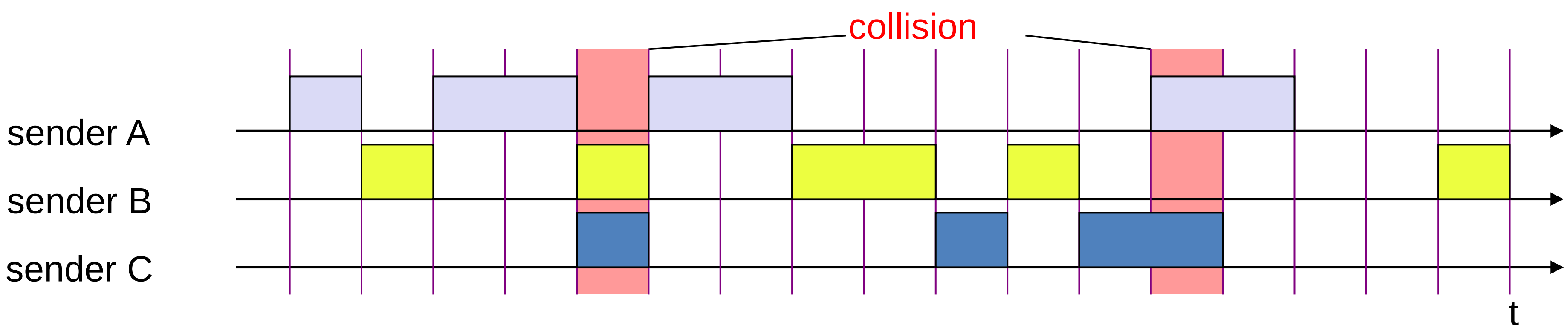
ALOHA

- Mechanism
  - random, distributed (no central arbiter), time-multiplex
- Free for all
- Any station has a frame to transmit, it transmits.
- Collision occurs when more than one station transmits.



SLOTTED ALOHA

- Mechanism
  - Slotted Aloha additionally uses time-slots, sending must always start at slot boundaries
- Slot size is equal.
- Therefore fixed time for frame transmission.
- Beacon signal – to notify start of time slot
- If a station is ready with a frame, it waits until start of next transmission time.
- Collision occurs at time slots.



CSMA

- Carrier Sense Multiple Access.
- Before transmitting the data listens the medium
- If medium is idle then transmit else wait and try again.
- How to identify collision occurs?
- 2 stations senses and transmit at time t.
- No ack for some amount of time.
- Assume collision and retransmit.

CSMA/CD

- CSMA wastes bandwidth
- Some mechanism is needed to detect collision
- Listen the medium continuously when the medium is transmitting
  - If idle transmit
  - If collision stop transmission
    - Then transmit jamming signal.
  - Wait a random time and then try to transmit again. (exponential backoff algorithm)
- Improves performance by terminating transmission ie avoiding collision

EXPONENTIAL BACKOFF ALG.

- The retransmission is delayed by an amount of time derived from the slot time and the number of attempts to retransmit.
- After *c* collisions, a random number of slot times between 0 and $2^c - 1$ is chosen.
- For the first collision, each sender will wait 0 or 1 slot times.
- After the second collision, the senders will wait anywhere from 0 to 3 slot times inclusive.

EXPONENTIAL BACKOFF ALG.

- After the third collision, the senders will wait anywhere from 0 to 7 slot times (inclusive), and so forth.
- As the number of retransmission attempts increases, the number of possibilities for delay increases exponentially.
- The 'truncated' simply means that after a certain number of increases, the exponentiation stops; i.e. the retransmission timeout reaches a ceiling, and thereafter does not increase any further.
- For example, if the ceiling is set at i = 10 then the maximum delay is 1023 slot times.

CSMA/CD

- In wireless network CSMA/CD does not work well.
- Carrier sense → NAV (Network Allocation Vector)
  - Virtual carrier-sensing mechanism used with wireless network protocols such as IEEE 802.11
  - The MAC layer frame headers contain a *duration* field that specifies the transmission time required for the frame, in which time the medium will be busy.
  - The other stations listening on the wireless medium read the *Duration* field and set their NAV, which is an indicator for a station on how long it must defer from accessing the medium
  - The NAV may be thought of as a counter, which counts down to zero at a uniform rate
  - Counter → 0 → Medium is idle
  - Counter → non zero → Medium is busy

CSMA/CD

- Wired network → Collision Detection is simple.
  - No voltage → Medium idle
  - Current flows → some station is transmitting
  - Voltage for each bit → 18-20 mA
  - When collision each bit is > 24mA
- Wireless network → very difficult.
  - When the signal is weak, it can easily be masked by noise.
  - The destination notices this while performing checksum.
  - Leads to retransmission, wastage of bandwidth.
  - Therefore collision detection does not work well with wireless networks

CSMA/CA

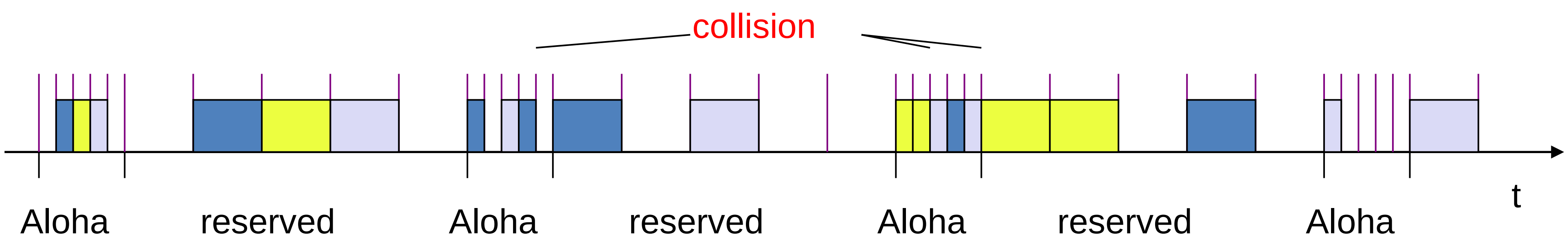
- A node wishing to transmit data has to first listen to the channel for a predetermined amount of time to determine whether or not another node is transmitting on the channel within the wireless range.
- If the channel is sensed "idle," then the node is permitted to begin the transmission process.
- If the channel is sensed as "busy," the node defers its transmission for a random period of time.
- Collision avoidance is used to improve CSMA performance by not allowing wireless transmission of a node if another node is transmitting, thus reducing the probability of collision due to the use of a random waiting time.

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*

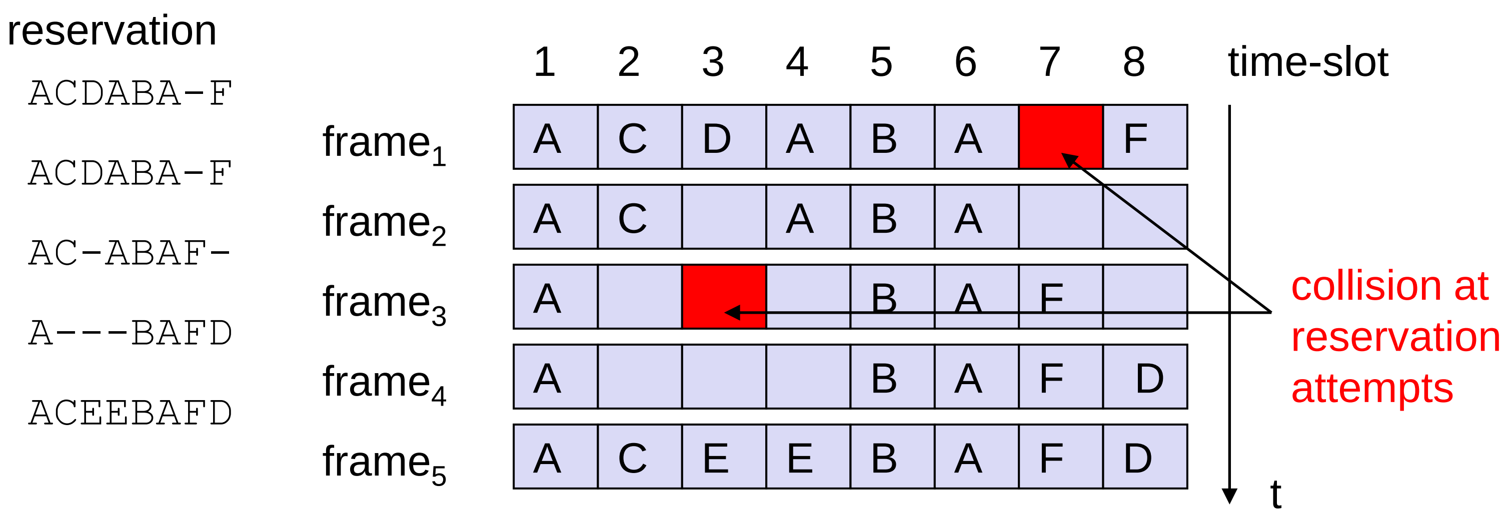
ACCESS METHOD DAMA: EXPLICIT RESERVATION

- Explicit Reservation (Reservation Aloha)(satellite transmission)
  - 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



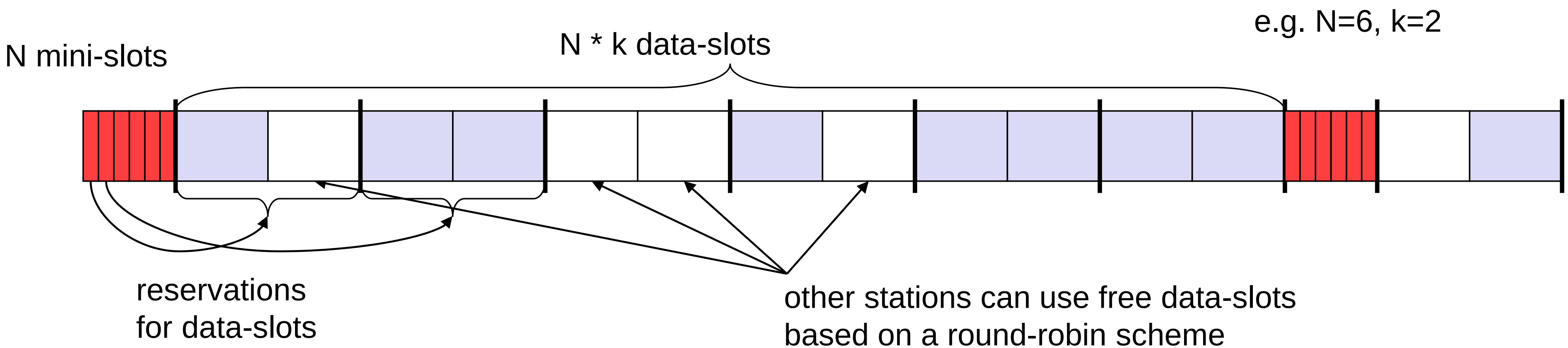
ACCESS METHOD DAMA: PRMA

- 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)

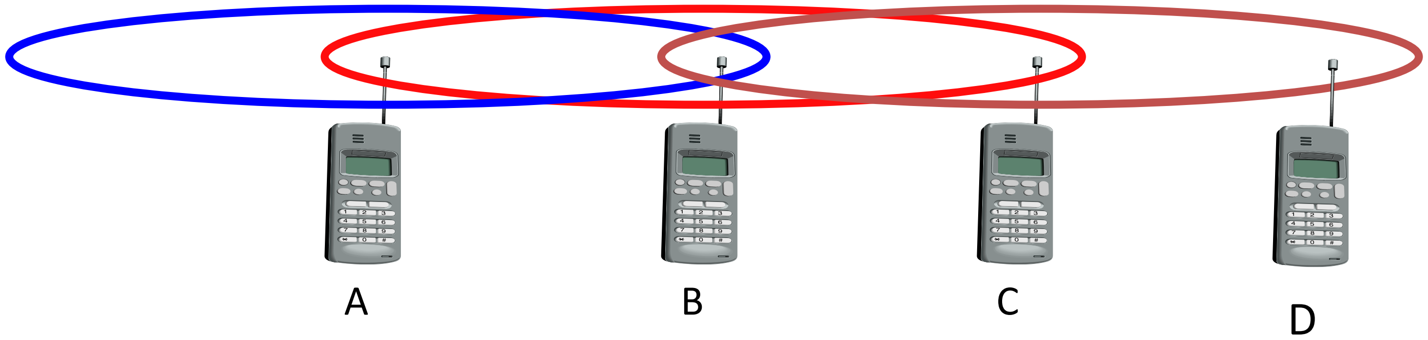


MULTIPLE ACCESS WITH COLLISION AVOIDANCE

- This is done by RTS/CTS
- 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

HIDDEN AND EXPOSED TERMINAL

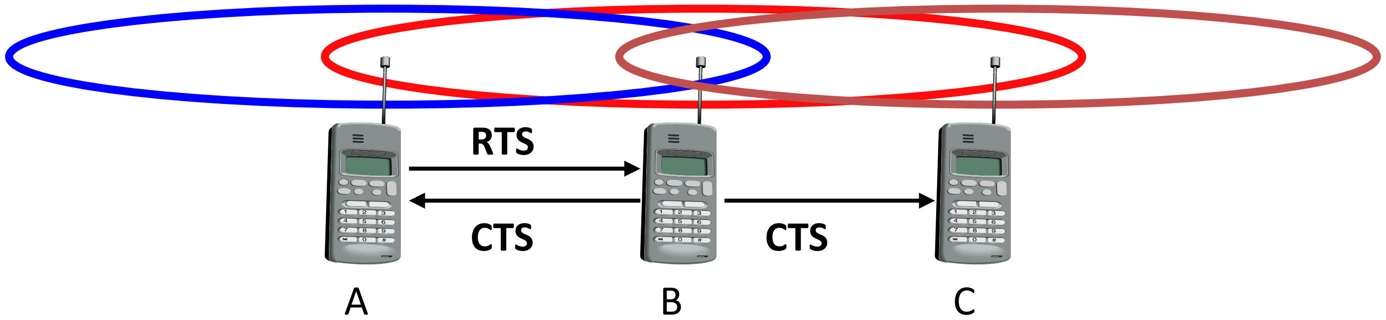
- Hidden terminals
  - A sends to B, C cannot receive A
  - C wants to send to B, C senses a “free” medium
  - collision at B, A cannot receive the collision
  - A is “hidden” for C



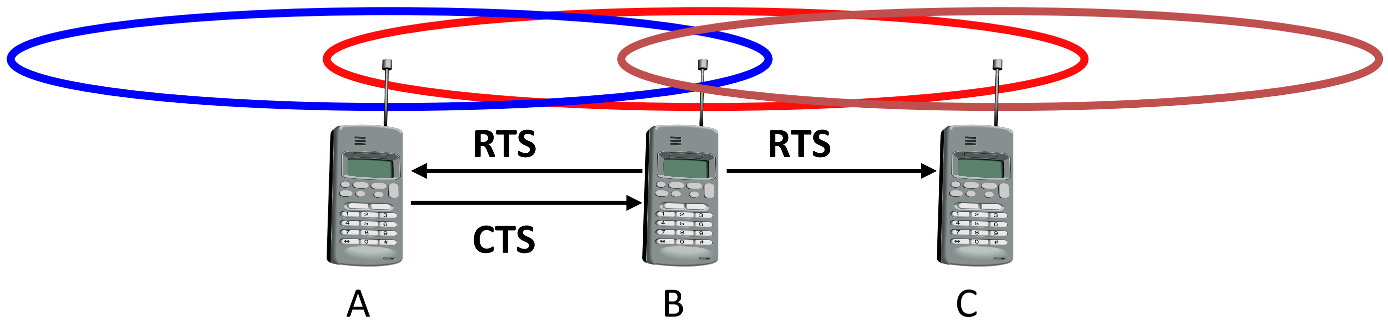
- Exposed terminals
  - B sends to A, C wants to send to another terminal (not A or B)
  - C has to wait, C senses the medium in use
  - but A is outside the radio range of C, therefore waiting is not necessary
  - C is “exposed” to B

MULTIPLE ACCESS WITH COLLISION AVOIDANC

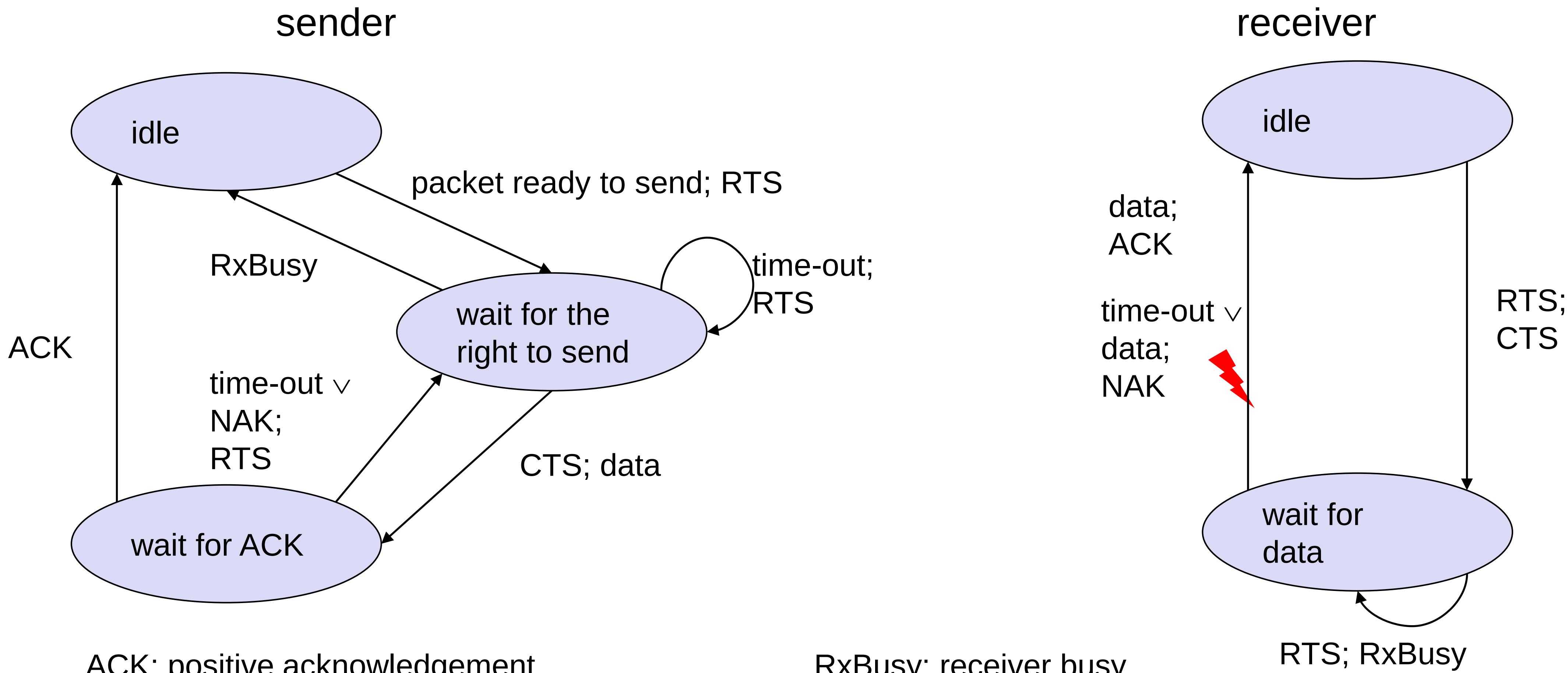
- MACA avoids the problem of hidden terminals
  - A and C want to send to B
  - A sends RTS first
  - C waits after receiving CTS from B



- 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 – STATE DIAGRAM



ACK: positive acknowledgement
NAK: negative acknowledgement

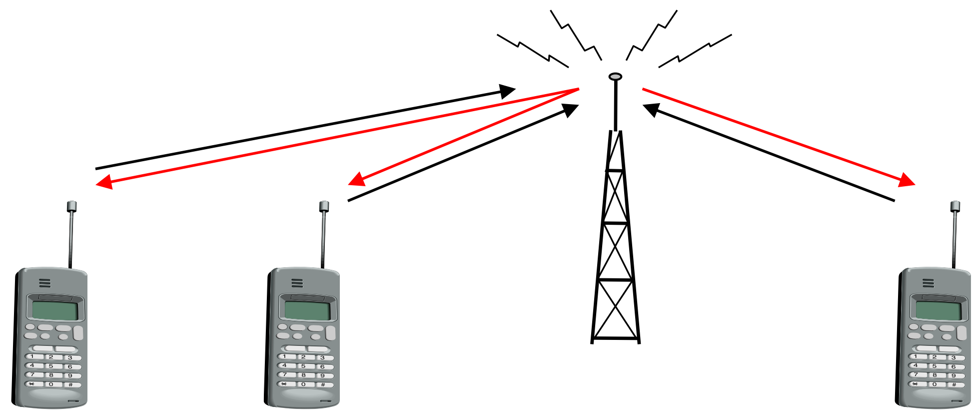
RxBusy: receiver busy

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
  - 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

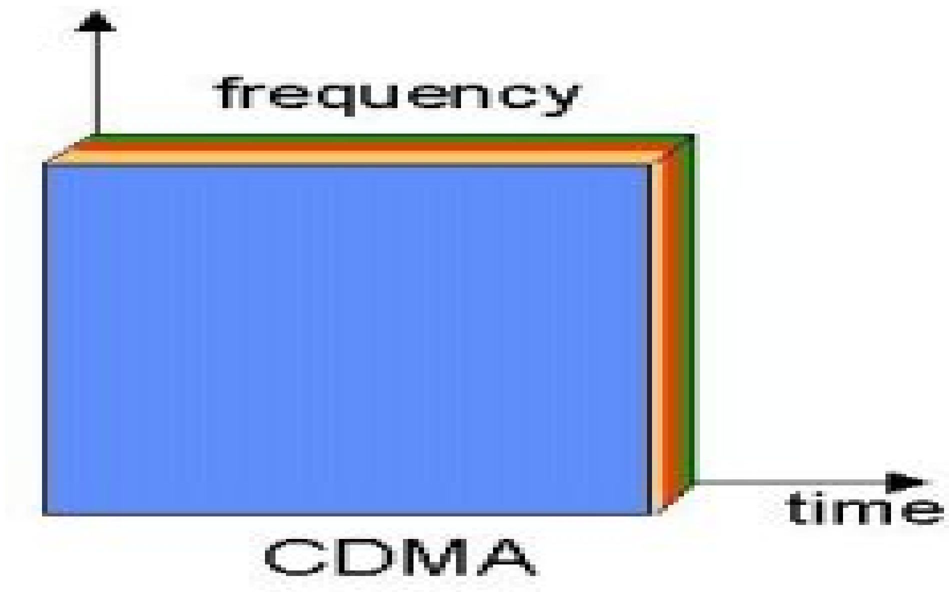
ISMA (INHIBIT SENSE MULTIPLE ACCESS)

- 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)



CDMA

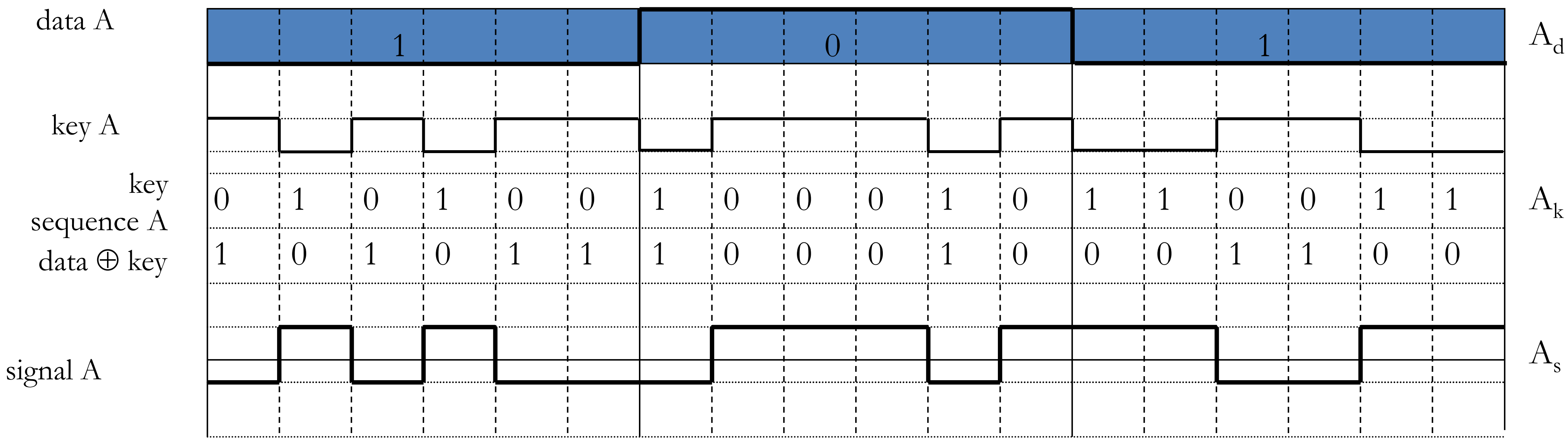
- All terminals send on the same frequency probably at the same time and can use the whole bandwidth of the transmission channel
- Each sender has a unique random number, the sender XORs the signal with this random number
- The receiver can "tune" into this signal if it knows the pseudo random number,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



CDMA

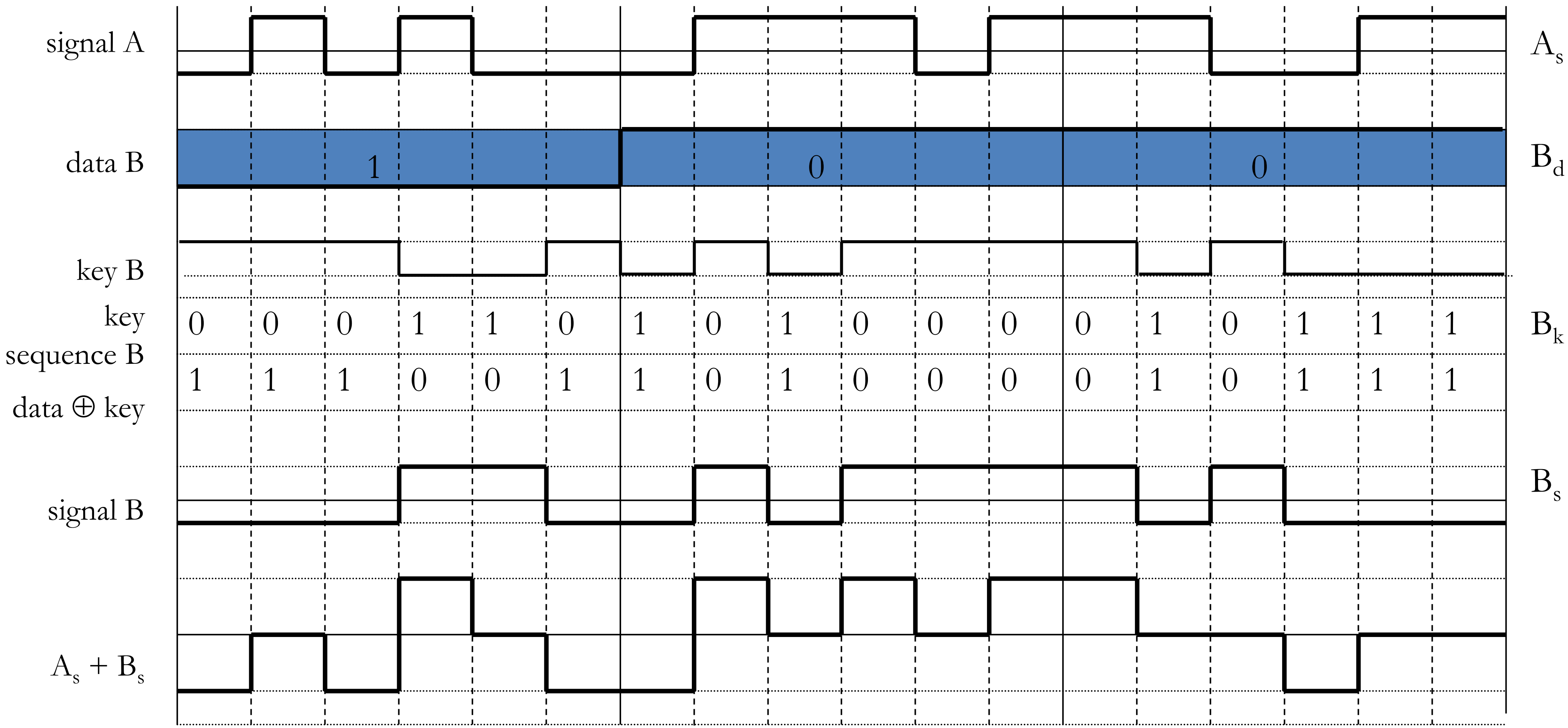
- Sender A
  - sends $A_d = 1$, key $A_k = 010011$ (assign: "0"= -1, "1"= +1)
  - sending signal $A_s = A_d * A_k = (-1, +1, -1, -1, +1, +1)$
- Sender B
  - sends $B_d = 0$, key $B_k = 110101$ (assign: "0"= -1, "1"= +1)
  - sending signal $B_s = B_d * B_k = (-1, -1, +1, -1, +1, -1)$
- Both signals superimpose 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



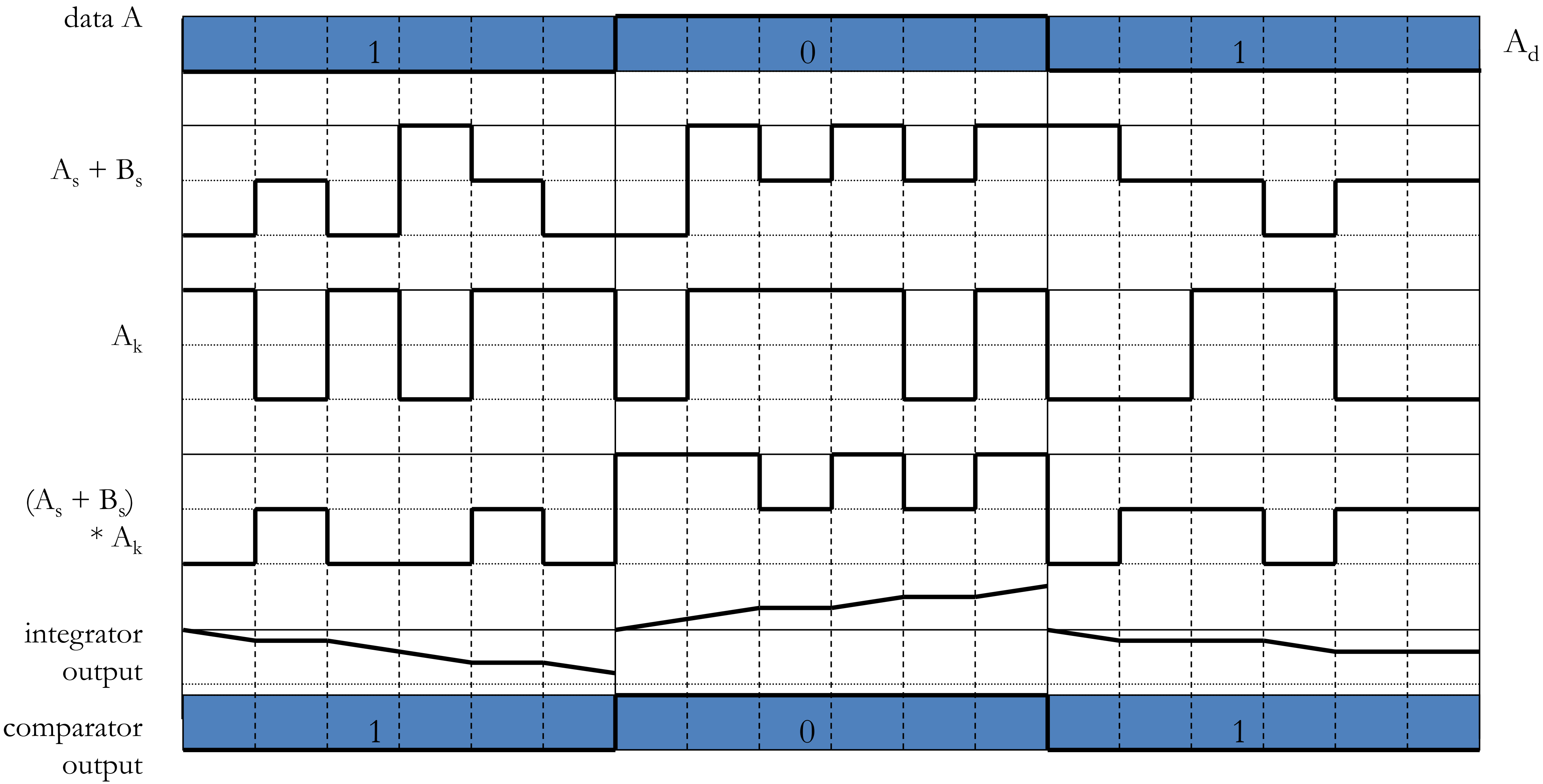
Real systems use much longer keys resulting in a larger distance between single code words in code space.

CDMA

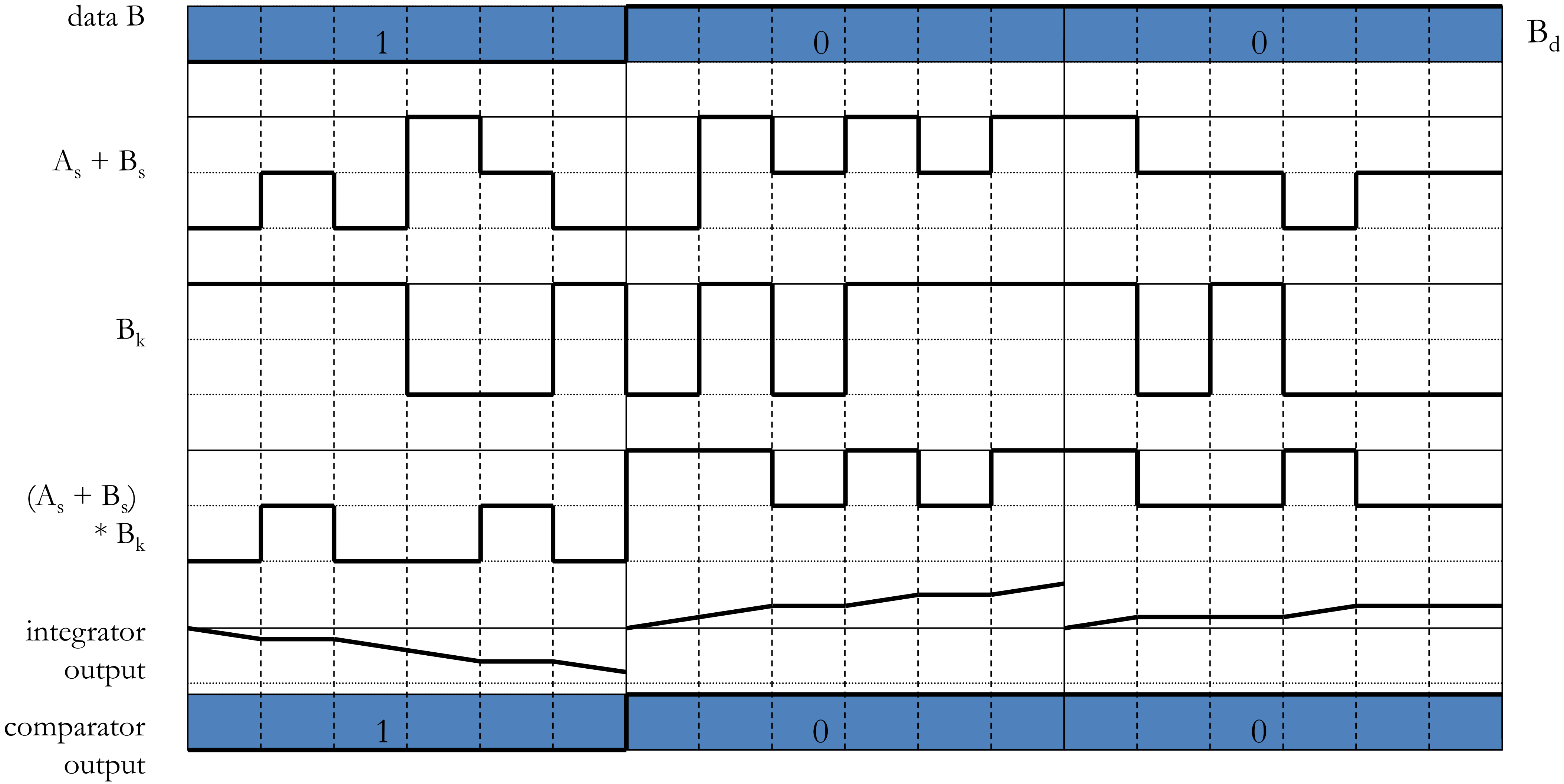


signal A
A_s
data B
1
0
0
B_d
key B
key sequence B
0 0 0 1 1 0 1 0 1 0 0 0 0 1 0 1 1 1
B_k
1 1 1 0 0 1 1 0 1 0 0 0 0 1 0 1 1 1
data ⊕ key
signal B
B_s
$A_s + B_s$

CDMA


data A
1
0
1
A_d
$A_s + B_s$
A_k
$(A_s + B_s) * A_k$
integrator output
comparator output
1
0
1

CDMA



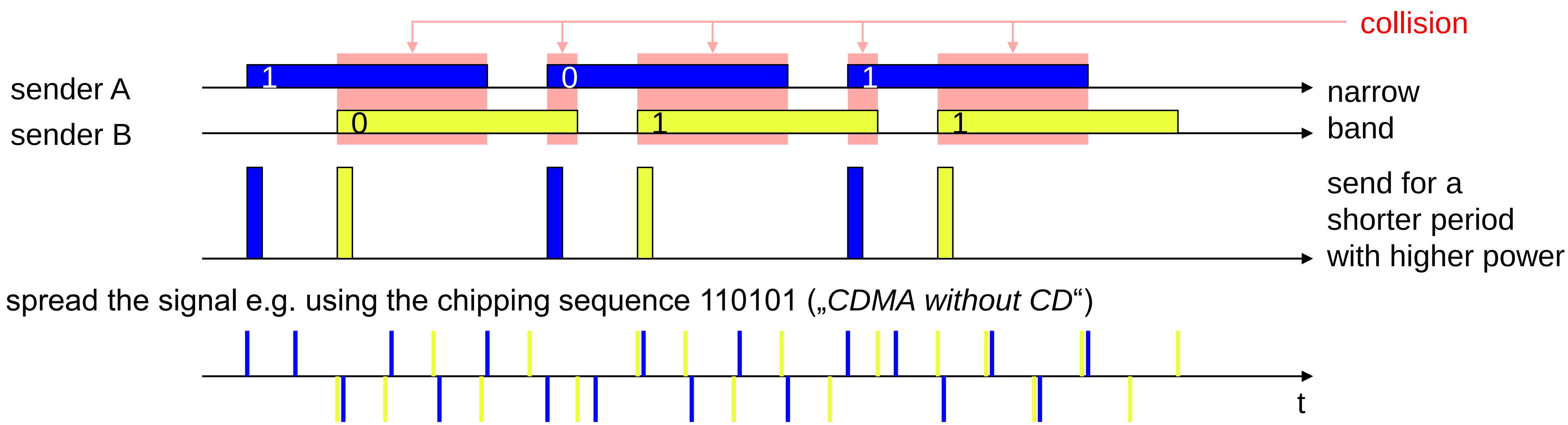
data B
1
0
0
B_d
$A_s + B_s$
B_k
$(A_s + B_s)$
$* B_k$
integrator
output
comparator
output
1
0
0

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

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

SUMMARY

- MAC Protocols
  - Properties, Issues
  - Different Categories of MAC

TEST YOUR KNOWLEDGE

- Switches are capable of reading the MAC address field from each frame that comes to them. So we can say they work on the ____________ layer from the TCP/IP model.
  - Physical
  - Network
  - Data Link

- In IEEE 802.11, a ___ is made of stationary or mobile wireless stations and an optional central base station, known as the access point (AP)
  - ESS
  - BSS
  - CSS

TEST YOUR KNOWLEDGE

- 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?

- Who performs the MAC algorithm for SDMA? What could be possible roles of mobile stations, base stations, and planning from the network provider?

TEST YOUR KNOWLEDGE

- A BSS without an AP is called an __________.
  - an ad hoc architecture
  - an infrastructure network

- communication between two stations in two different BSSs usually occurs via two _________.
  - BSSs
  - ESSs
  - APs

TEST YOUR KNOWLEDGE

- When a frame is going from one station to another in the same BSS without passing through the distribution system, the address flag is ______
  - 00
  - 01
  - 10
- When a frame is going from a station to an AP, the address flag is ______.
  - 01
  - 10
  - 11

REFERENCES

- Jochen H. Schller, “Mobile Communications”, Second Edition, Pearson Education, New Delhi, 2007.
- Behrouz A. Forouzan, “Data communication and Networking”, Fourth Edition,Tata McGraw – Hill, 2011.