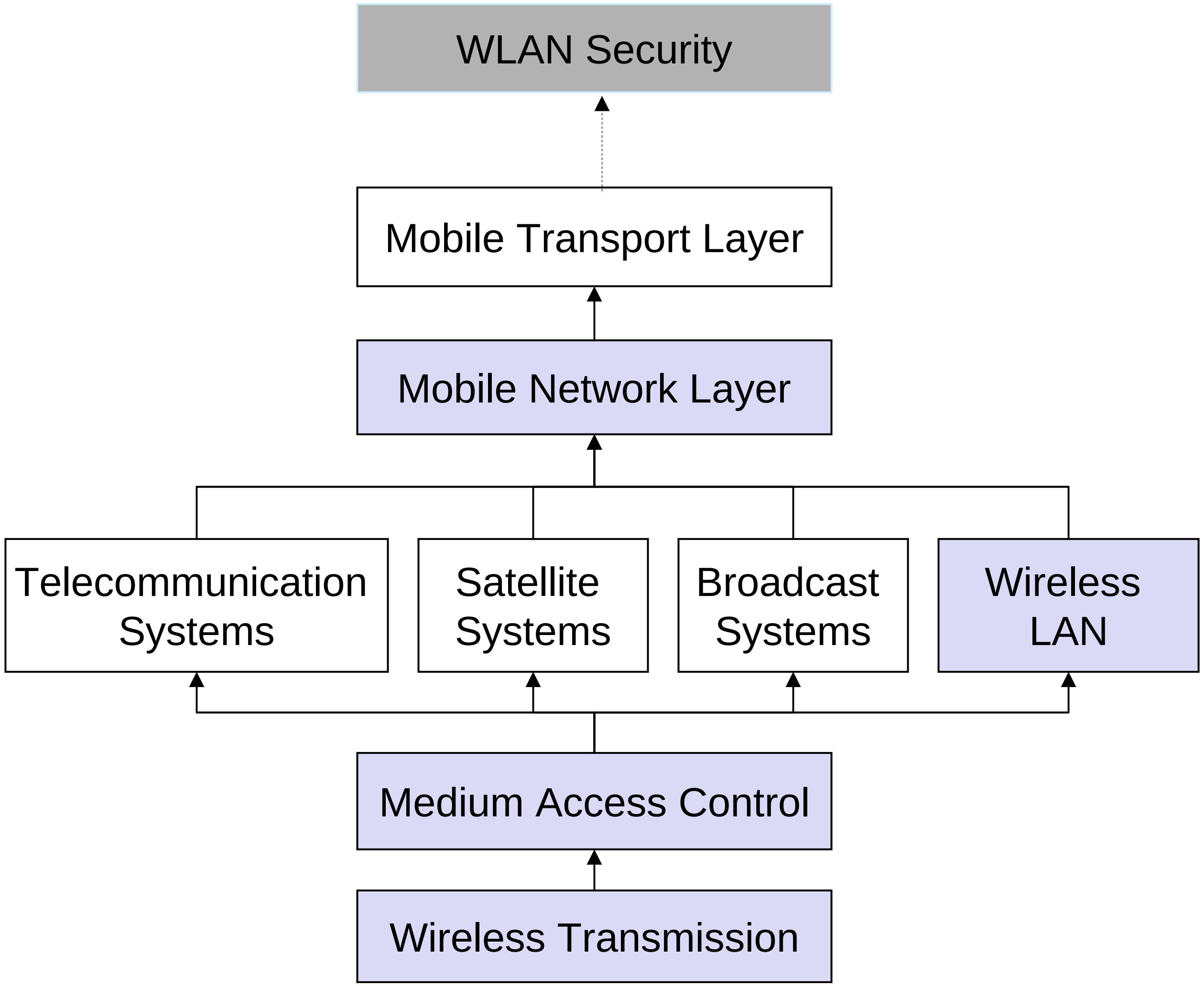
General Overview



Medium Access Control
(MAC Layer)

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
- Sense medium, send if the medium is free, listen into the medium if a collision occurs (original method in IEEE 802.3)
- Based on the fact, that every collision at a receiver also happens and therefore can be detected at the sender

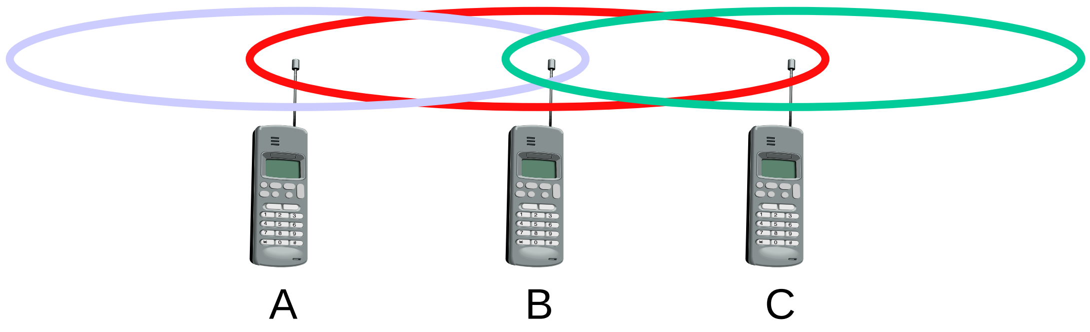
Problems in wireless networks

- Signal strength decreases in the best case (vacuum) proportional to the square of the distance
- ➔ Not all potential senders can “hear” each other
  - ➔ CS might not work
- ➔ Collisions do not happen everywhere
  - ➔ CD might not work

Problem: Hidden and exposed stations

Hidden station:

- 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 detect the collision (CD fails)
- A is “hidden” for C



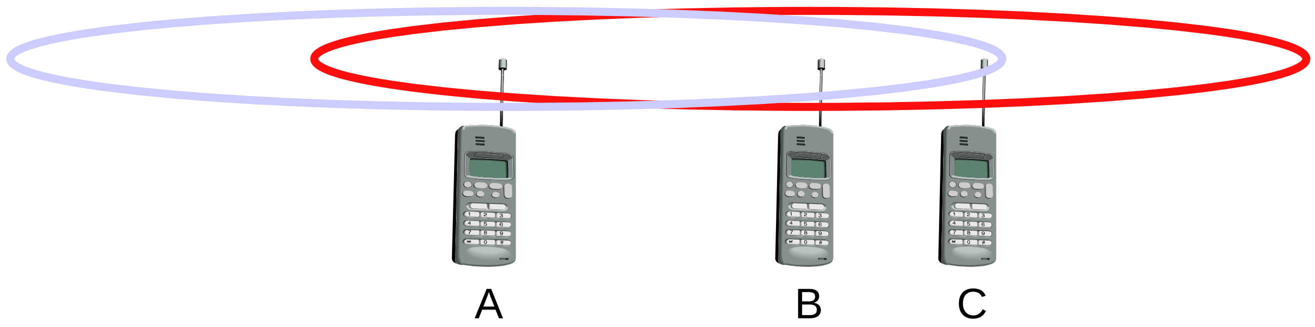
Exposed station:

- B sends to A, C wants to send to another receiver (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
- B is “exposed” to C

Problem: Near and far stations

Stations A and B send, C receives

- signal strength decreases proportional to the square of the distance
- the signal of sender A may be drowned by B's signal
- C cannot receive A



A severe problem if CDM is used for medium access control where senders can transmit at the same time

➔ precise power control of the sender is needed such that all signals end up at the receiver with about the same signal strength

Access methods SDMA/FDMA/TDMA

SDMA (Space Division Multiple Access)

- cell structure, size of the cell determined by the range of it is base station
- MAC algorithm decides to which cell (base station) a terminal station is associated
- Still often several stations located within one cell ---> often used in combination with another access method

FDMA (Frequency Division Multiple Access)

- assign a certain frequency to a transmission channel between a sender and a receiver
- either permanent (e.g., radio broadcast), also called pure FDMA or
- combining FDMA and TDMA by assigning a sequence of frequencies (e.g FHSS)

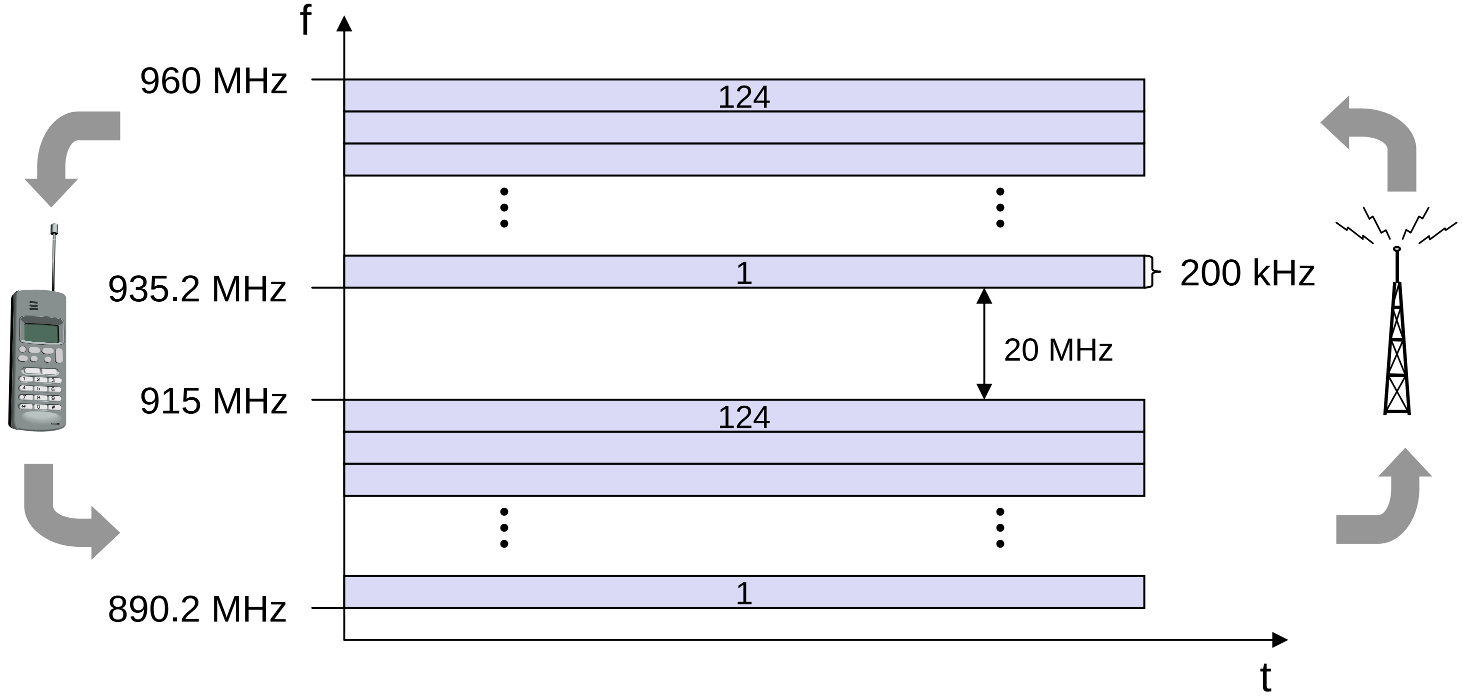
or

- to implement FDD (Frequency Division Duplex) in cell-based mobile radio networks

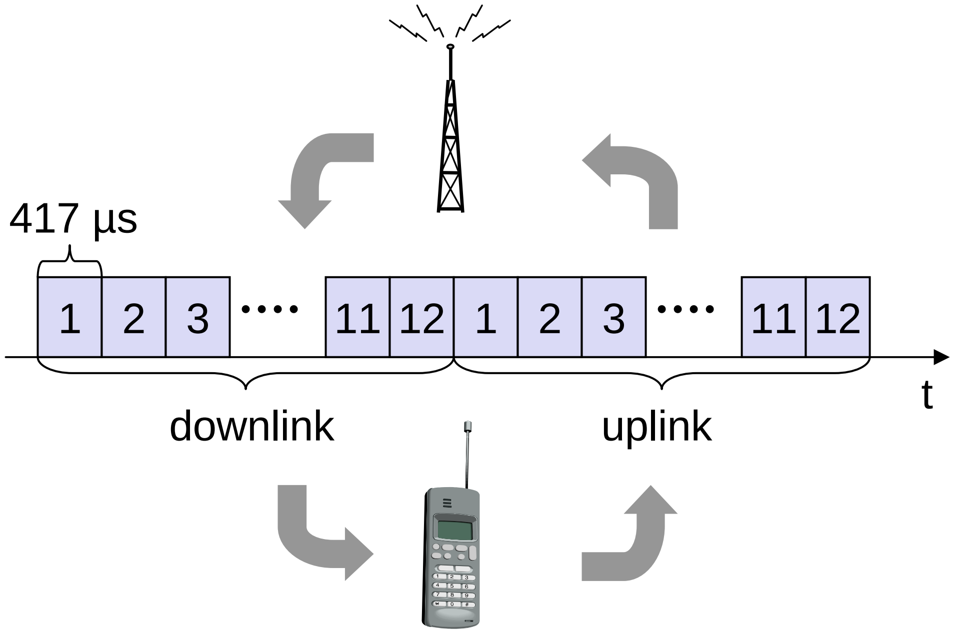
TDMA (Time Division Multiple Access)

- assign a transmission channel to each sender for a certain amount of time
- receivers can always listen on the same channel frequency
- physical layer not involved (only a matter of digital control software)
- very flexible ---> all MAC approaches in wired networks based on TDMA

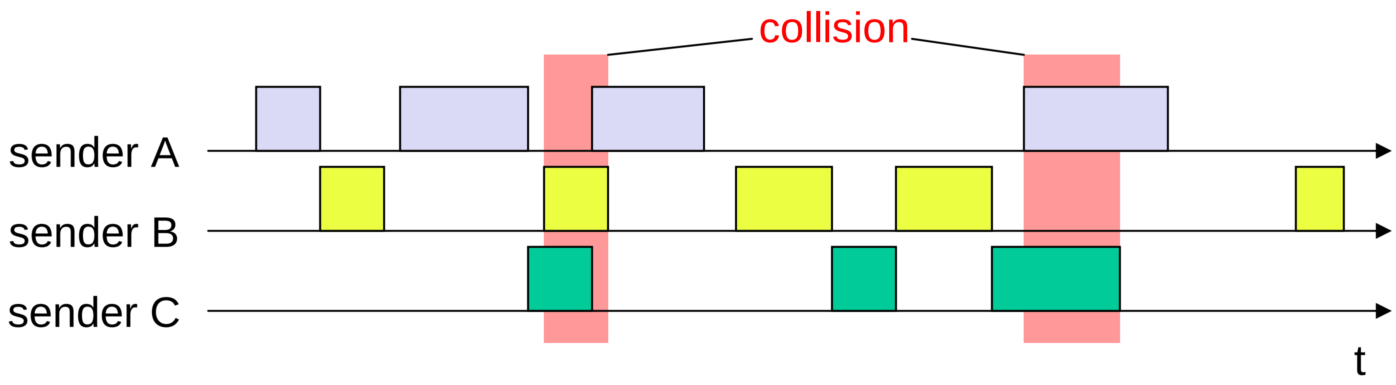
GSM- example for combination of FDM and FDD



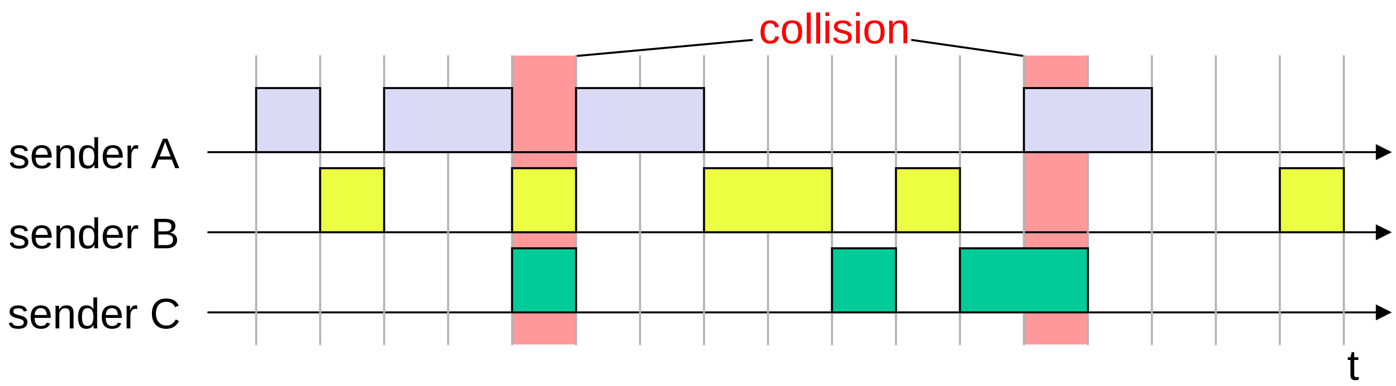
DECT - example for static TDMA + TDD



Aloha



Slotted Aloha



A priori reservation combined with static TDMA

Maximum throughput per frame time (at low load) only 18% (Aloha), 36% (Slotted Aloha) (assuming Poisson distribution for packet arrival)

Reservation can increase throughput up to 80% due to less collisions

- a sender *reserves* a future time-slot during a reservation phase
- sending within this reserved time-slot is possible without collision
- reservation also causes higher delays
- typical scheme for satellite links

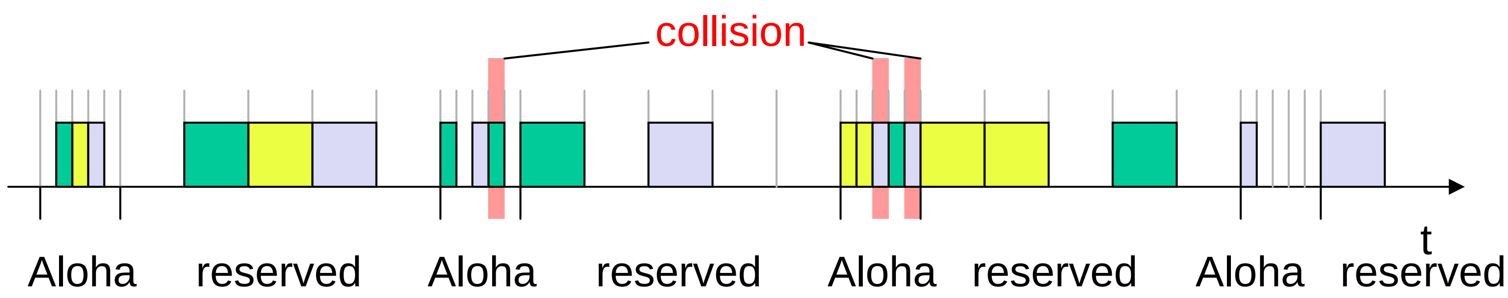
Examples for reservation algorithms:

- *Explicit Reservation (DAMA (Reservation-ALOHA))*
- *Implicit Reservation (PRMA)*
- *Reservation combined with dynamic TDMA*

DAMA - Demand Assigned Multiple Access

Explicit Reservation (Reservation Aloha):

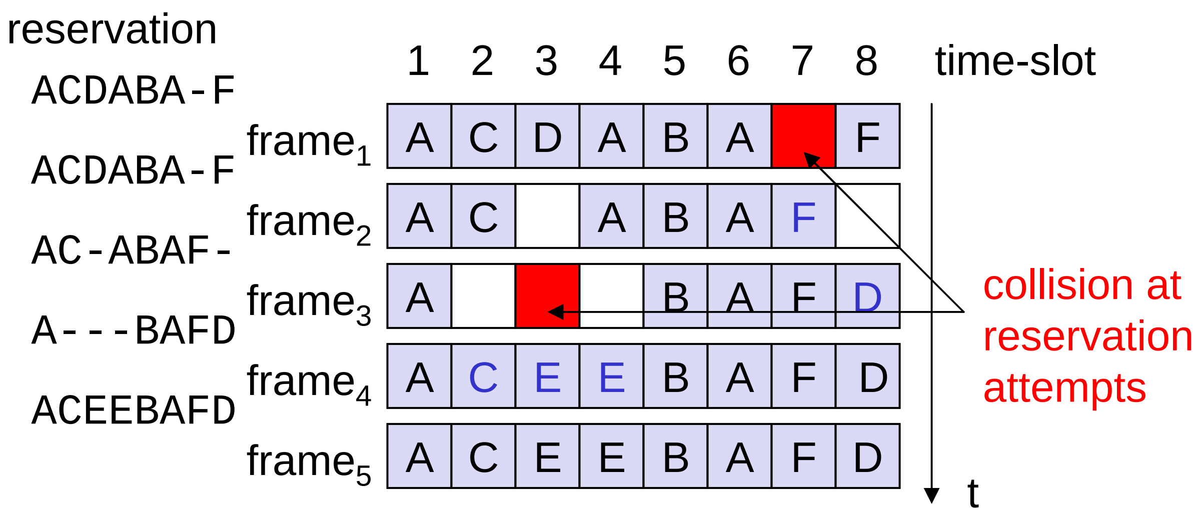
- two modes:
  - *ALOHA mode* for reservation:
    competition for small reservation slots, collisions possible
  - *reserved mode* for data transmission within successful reserved slots (no collisions possible)
- it is important for all stations to keep the reservation list consistent at any point in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



PRMA: Packet Reservation Multiple Access

Implicit reservation :

- a certain number of slots form a packet, packets 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 packets 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 packet

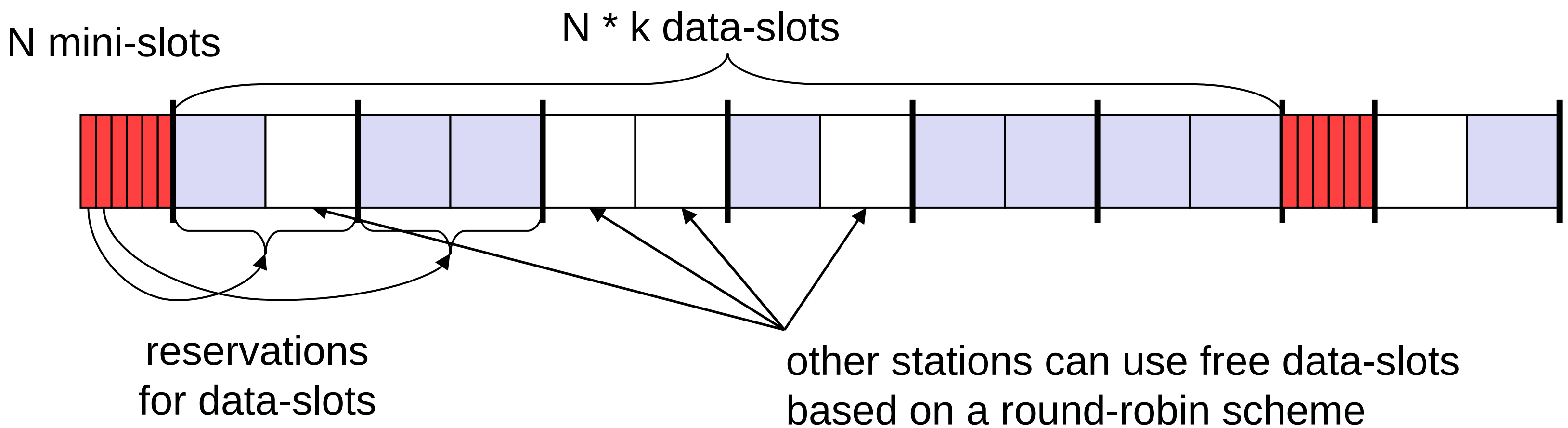


DAMA combined with dynamic TDMA

Reservation without collision for a fixed number of N stations:

- each frame consists of N reservation slots and x = N * k data-slots
- each station has its own mini-slot and can reserve up to k data-slots (guaranteed)
- all other stations can send data in not reserved data-slots according to some method, e.g. ALOHA (random) or round-robin (fixed) sending scheme (best-effort)

Example: N=6, k=2



CSMA - Carrier Sense Multiple Access

Types of CSMA protocols:

1-persistent

When a station has data to send, it transmits with a probability of 1 whenever it finds the channel idle. If the channel is busy, the station waits until it becomes idle (greedy approach).

nonpersistent

It differs from 1-persistent w.r.t. the case where the channel is busy.Then, the station deliberately waits a random period of time before sensing the channel again.

p-persistent (applies to slotted channels)

When a station has data to send, it transmits with a probability of p whenever it finds the channel idle. With a probability of q = 1- p it defers until the next slot and the same procedure iterates. If the channel has become busy meanwhile, the station waits a random time and starts again. If the channel is busy when first sensing it, the station waits until the next slot and repeats the procedure.

MACA - solving the problem of hidden stations

MACA (Multiple Access with Collision Avoidance) uses short signaling (control) 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:

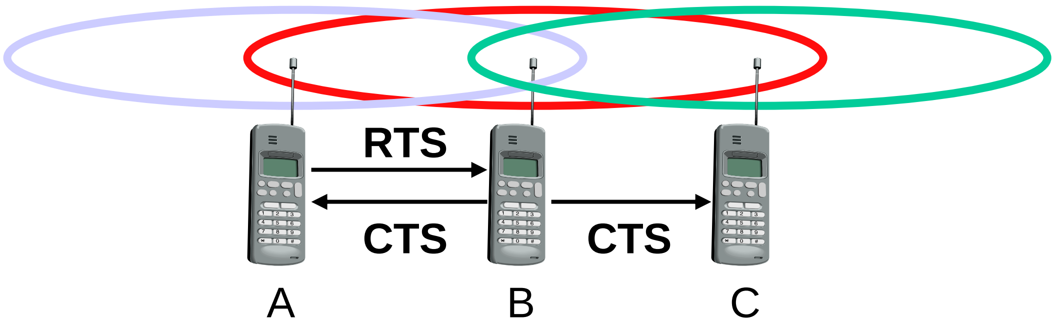
- sender address
- receiver address
- packet size (from which the transmission time can be derived)

Variants of this method can be found in IEEE802.11

Examples of MACA

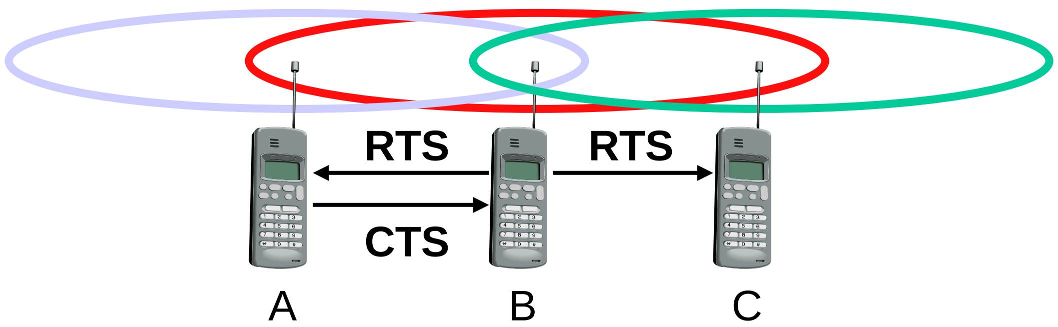
MACA avoids the problem of hidden stations

- A and later C want to send to B
- A sends RTS first
- C waits after receiving CTS from B



MACA avoids the problem of exposed stations

- B wants to send to A, C to another station
- now C does not have to wait because it cannot receive CTS from A



Polling

If one station can be heard by all others, this master station (e.g. satellite, base station) can poll all other slave stations according to a certain scheme

Example: Randomly Addressed Polling

- master signals readiness to all (mobile) slaves
- slaves 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)
- master now chooses one address for polling from the list of all random numbers (collision if two slaves choose the same address)
- master acknowledges correct packets and continues polling the next slaves
- this cycle starts again after all slaves have been polled

Access method CDMA

CDMA (Code Division Multiple Access)

- all stations 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
- forward error correction and encryption can be easily integrated

Simple example how CDMA basically works

Sender A

- sends A_d = 1, code 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, code 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 senders A and B

- apply code A_k bitwise (inner product)
  - A_e = (-2, 0, 0, -2, +2, 0) • A_k = 2 + 0 + 0 + 2 + 2 + 0 = 6
  - result much 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
  - result much lesser than 0, therefore, original bit was „0"

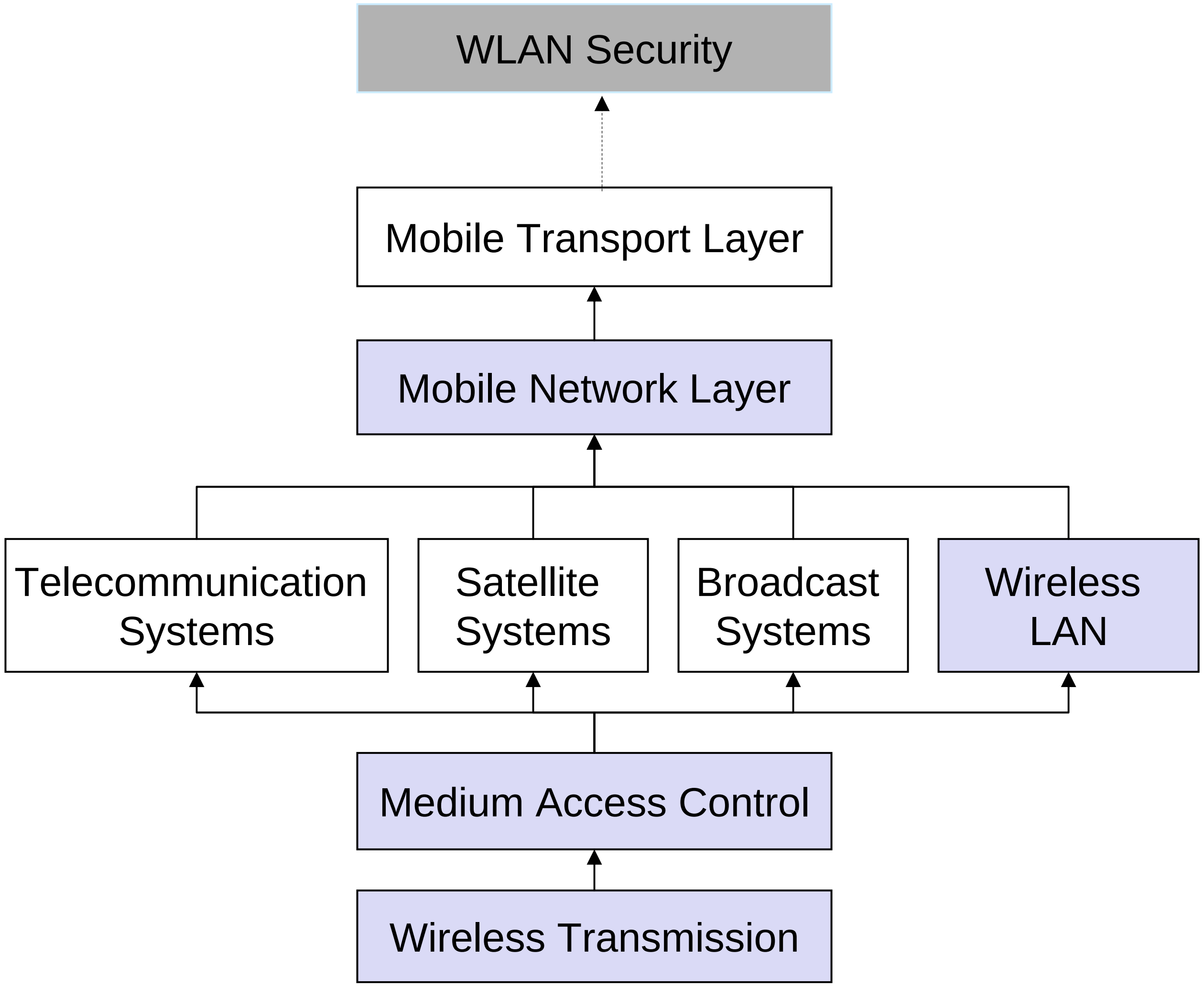
Real systems use much longer codes resulting in a larger distance between single code words

➔ Higher probability that the receiver reconstructs (decodes) the original data (signal) sent since the integrator results in higher positive or negative values

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_	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

General Overview



Wireless LANs

Characteristics of Wireless LANs

Advantages (flexibility, mobility, robustness, cost efficiency)

- very flexible including mobility within the reception area
- Ad-hoc (mobile) networks without previous planning possible
- (almost) no wiring difficulties (e.g. historic buildings, firewalls)
- more robust against disasters like, e.g., earthquakes, fire - or users pulling a plug...

Disadvantages

- typically very low bandwidth compared to wired networks (1-10 Mbit/s) due to shared medium
- compared to classical (wired) LANs very low Quality of Service (QoS)
- standards, especially for higher bit-rates (bandwidth) and QoS, take their time (e.g. IEEE 802.11a,g and 802.1x)

Ultimate goal: Be as good as LAN's

Major Drawbacks

Less to no Quality of Service (QoS) regarding the most important parameters

- Bandwidth
  - much lower in general (1-10 Mbit/sec vs 100 - 1000Mbit/sec) (**performance aspect)**
  - difficult to predict (**real-time aspect)**
- Transmission errors
  - tremendously higher loss rates (on average 10^{-4} versus 10^{-12}) **(reliability aspect)**
- Latencies
  - much higher (**performance aspect)**
  - less predictable **(real-time aspect)**

Additional safety and security problems may arise

- Radio communication may affect other electronic devices and radio communication
- Communication medium (air) difficult to shield against unauthorized individuals

Conclusion:

Depending on

- **standard, architecture, and size**

of the network, wireless communication in computing networks is quite a challenge!

IEEE 802.11 (WLAN)

Characteristics:

- Worldwide mostly used, available in most products used for wireless communication
- Member of the IEEE 802.x family for LANs like Ethernet (802.3) and Token Ring (802.5)
- Like the others specifies the Physical Layer and the MAC layer of the TCP/IP reference model
- Supports two different kinds of architectures

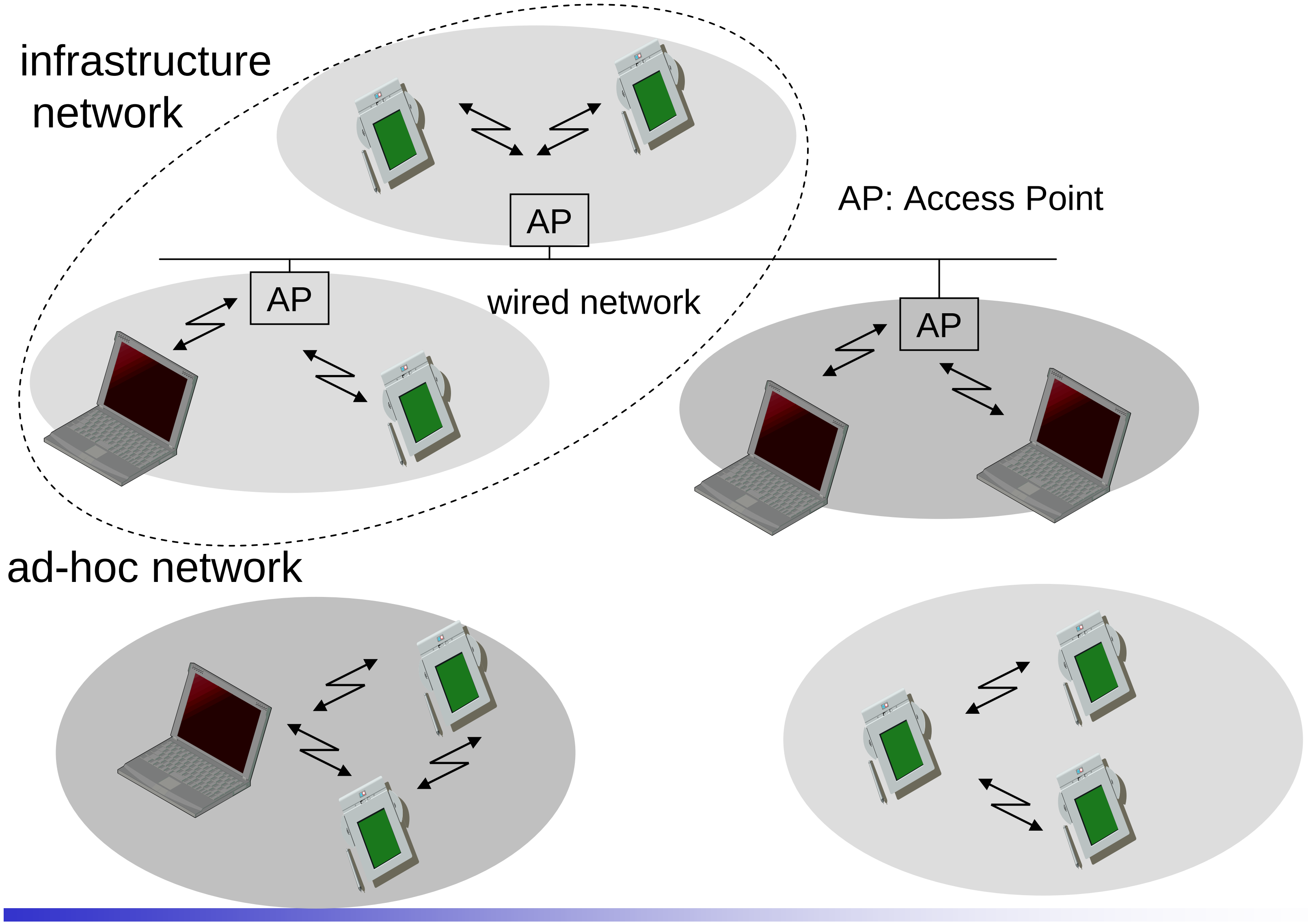
Primary goal:

- Specifying a simple and robust LAN providing time-bounded and asynchronous data service
- Still, services above the MAC layer are considered to be of best-effort character.

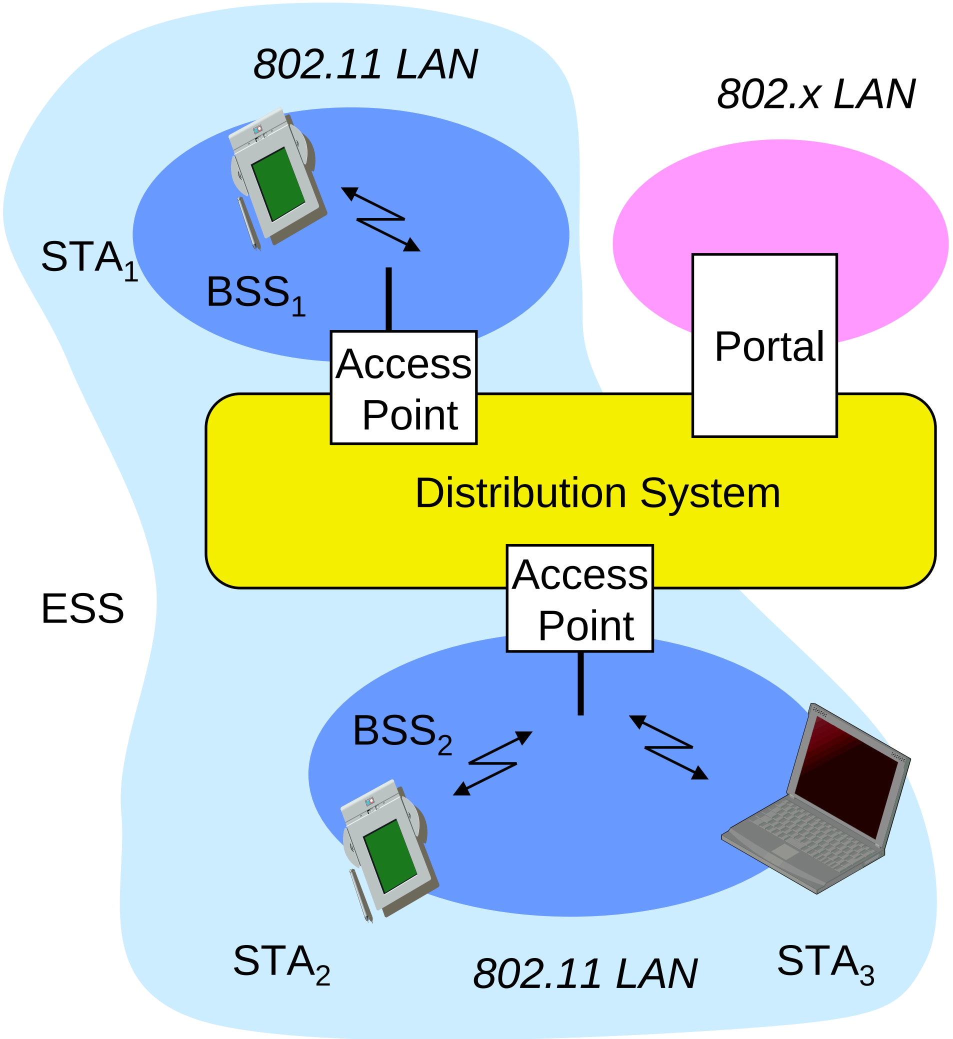
Other standards:

- HIPERLAN
  - European Standard (ETSI), improved QoS specifications, never reached product status (but several mechanisms have been adopted by other standards (e.g. 802.11a and g))
- Bluetooth
  - Industry standard for WPAN (adopted in 802.15)

Comparison: infrastructure vs. ad-hoc networks



802.11 - Architecture of an infrastructure network



Station (STA)

- terminal with access mechanisms to the wireless medium and radio contact to the associated access point (AP)

Basic Service Set (BSS)

- group of stations being in the same transmission range as the associated AP + the AP itself

Access Point

- station integrated into the wireless LAN and the distribution system

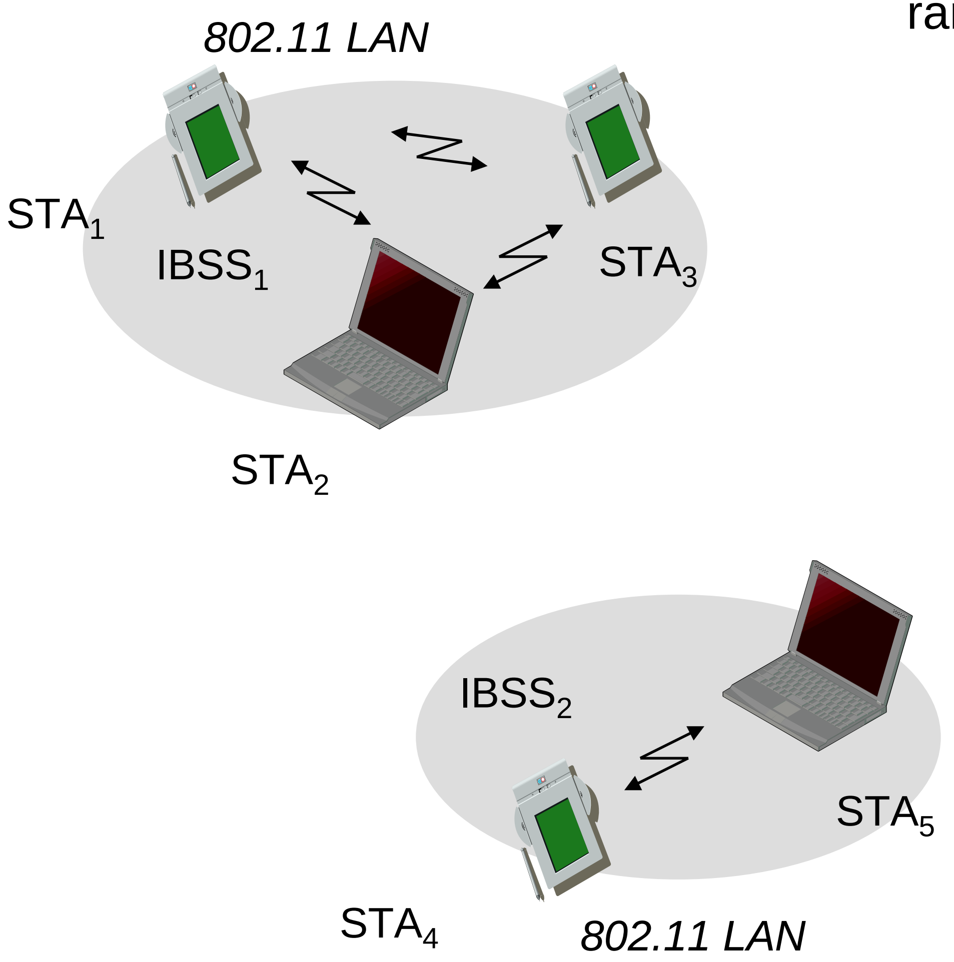
Distribution System

- interconnection network to form one logical network (ESS: Extended Service Set) based on several BSS

Portal

- Bridge from one ESS to other (wired) networks

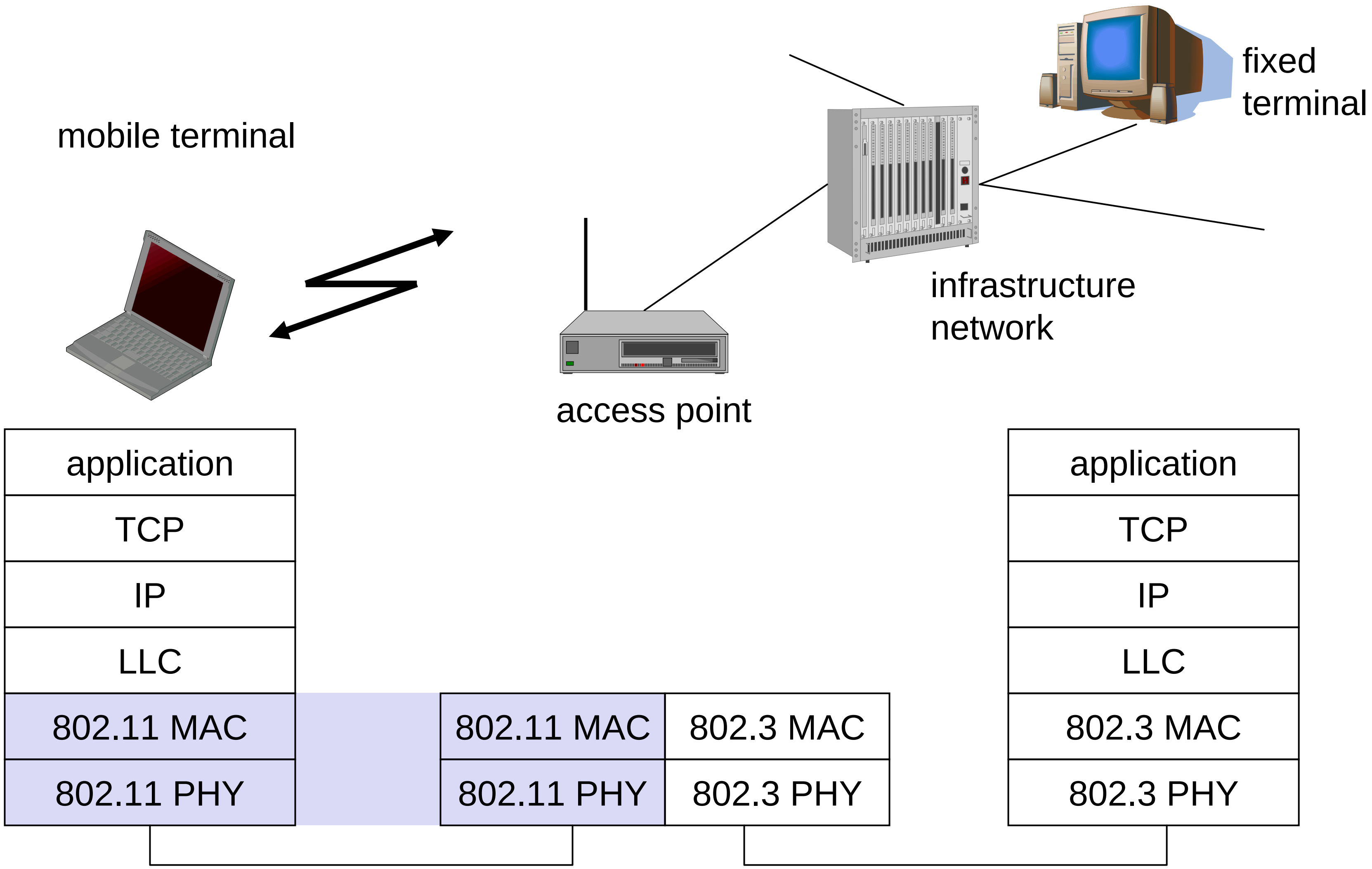
802.11 - Architecture of an ad-hoc network



Direct communication within a limited range

- Station (STA):
  terminal with access mechanisms to the wireless medium
- Independent Basic Service Set (IBSS):
  group of stations using the same radio frequency being within the same transmission range

802.11 - Protocol architecture (infrastructure embedded)



802.11 - Physical layer (classical)

3 versions: 2 radio (typ. 2.4 GHz), 1 IR
- data rates 1 or 2 Mbit/s
- Offer CCA-signal allowing carrier sense on the MAC layer

Infrared
- wave length ca.850-950 μm (ca. 300 GHz)
- range about 10m if conditions are very good

FHSS (Frequency Hopping Spread Spectrum)
- Separation of nets due to different hoping sequences
- Individual channels have a bandwidth of about 1MHz each

DSSS (Direct Sequence Spread Spectrum)
- chipping sequence: +1, -1, +1, +1, -1, +1, +1, +1, -1, -1, -1 (Barker code)
- Individual channels have a bandwidth of about 22 MHz each

802.11 versus 802.3

802.3 MAC Sublayer:

- implements CSMA/CD
- CD works because the medium takes care that every collision at the receiver of a message also happens at the sender

  --> CD in 802.3 relies on the fact that the sender detects the collision at his site and concludes from that the collision at the receiver

Problem:

This does no longer hold if radio communication is applied --> CD does not work in 802.11

- signal strength decreases proportional to the square of the distance

  ---> radio range is restricted
- collisions at the sender do no longer compare to collisions at the receiver

  ---> hidden station problem

  ---> exposed station problem

802.11 - MAC layer

Traffic services

- Asynchronous Data Service implementing CSMA/CA (mandatory)
  - exchange of data packets based on “best-effort”
  - support of broadcast and multicast
- Time-Bounded Service (optional)
  - needs a central coordinator (master)

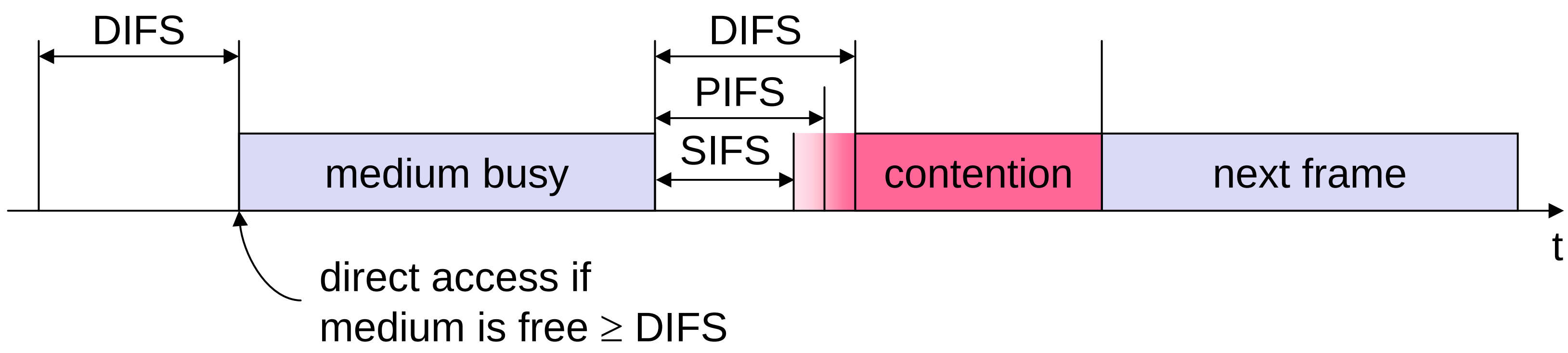
Access methods

- Distributed Coordination Function (DCF) -simple version- (mandatory)
  - collision avoidance via randomized „back-off“ mechanism
  - ACK packet for acknowledgements (not for broadcasts)
- Distributed Coordination Function (DCF) -enhanced version- (optional)
  - avoids hidden station problem by adopting the MACA approach (providing additional RTS/CTS control frames)
- Point Coordination Function (PCF) (optional)
  - instead of doing CS, access point polls stations and ensures CA by assigning exclusive time slots to the potential senders (TDMA approach)
  - requires an infrastructure network

General approach to CSMA/CA

Priorities

- defined through Inter Frame Spaces (IFS)
- no guaranteed, hard priorities
- SIFS (Short Inter Frame Spacing)
  - highest priority used for control messages like ACK, CTS, polling response
- PIFS (P(CF) IFS)
  - medium priority, for time-bounded service using PCF
- DIFS (D(CF) IFS)
  - lowest priority, for asynchronous data service



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