Kiel University
Christian-Albrechts-Universität zu Kiel

Research Group
Distributed Systems

Internet of Things & Wireless Networks

Recap

Olaf Landsiedel

Summer Term 2020

Welcome to Recap

- Recap
  - Today
- AMA
  - Opens about two to three weeks before exam (check your emails)
  - Video about one week before exam
- Exam
  - Dates, times, room in Univis: seems we will be in the ”exam tent”
  - Register
  - Types of questions
- Course evaluations
  - They forgot us, check your email

Today: Recap

- A whole course in one lecture
  - Focus on key aspects
  - We cannot cover it all

- Note on the exam
  - Just because we cover it today:
    - it does not mean it will necessarily be part of the exam
  - Just because we do not cover it today:
    - it does not mean it will necessarily not be part of the exam

- Most of the things we discussed are also in the book

Course structure

Topic	Lectures
Introduction	1
Contiki	1
Wireless Transmissions	2
Media Access	1
WiFi etc.	3
Cellular	5

Internet of Things (IoT)

- What is the Internet of Things?

- Things

- Internet

Internet of Things

- Computing capabilities
- Interconnected
  - Usually: wireless communication
  - Usually: connected to the Internet
- Interact with the physical environment
  - Sensing
  - Control

Internet of Things

=

Computing + Networking + Sensors & Control

What components should a IoT device have?

Internet of Things

=

Computing + Networking + Sensors & Control

Some embedded MCU

Wireless communication:

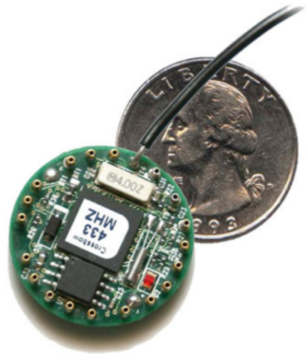
MAC: 802.15.4 (ZigBee) or Bluetooth or cellular…

Routing etc.

Sensors and actuators

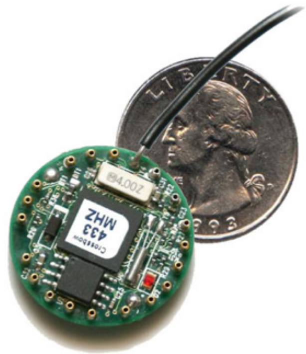
Platforms

- Embedded nodes
  - Limited computing capabilities
  - Low bandwidth communication
  - Usually: low cost
  - Often: Limited energy
- Sensing and actuation

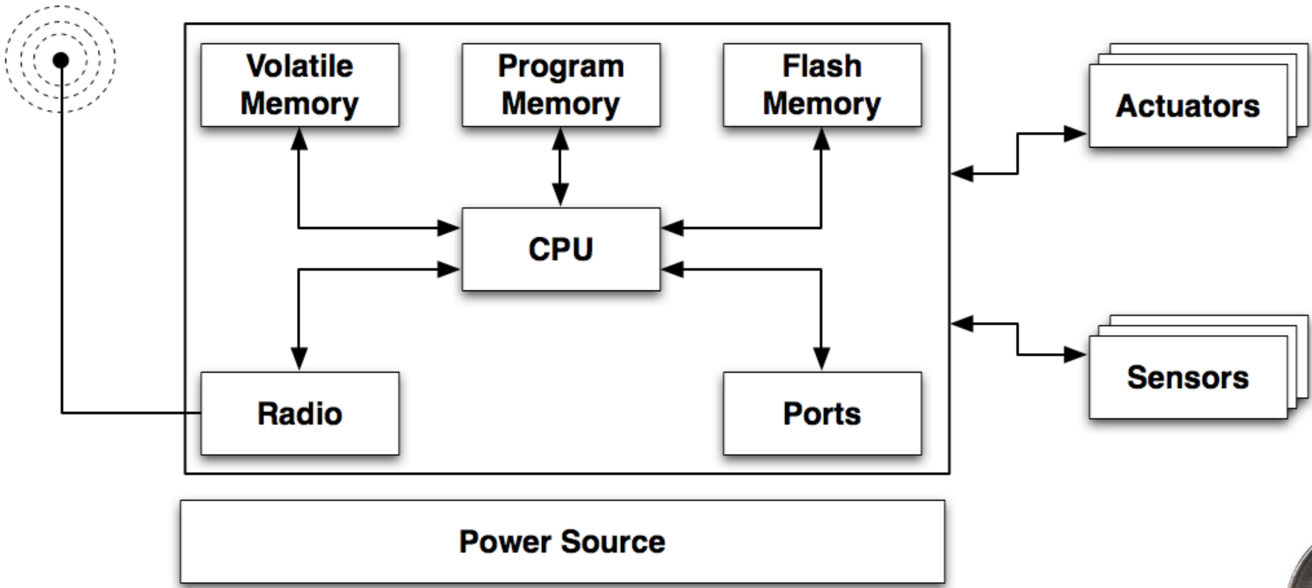


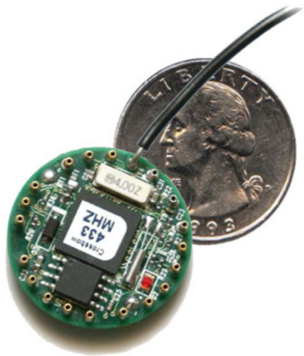
Platforms

- Computing: Microcontroller based
  - Commonly: no Memory Management Unit (MMU)
  - -> No segmentation faults
  - -> You can write to any memory address
    - Even into the interrupt information
  - You should know what you are doing when
    - Using pointers, casts, etc.
    - Bring C-Programming Skills

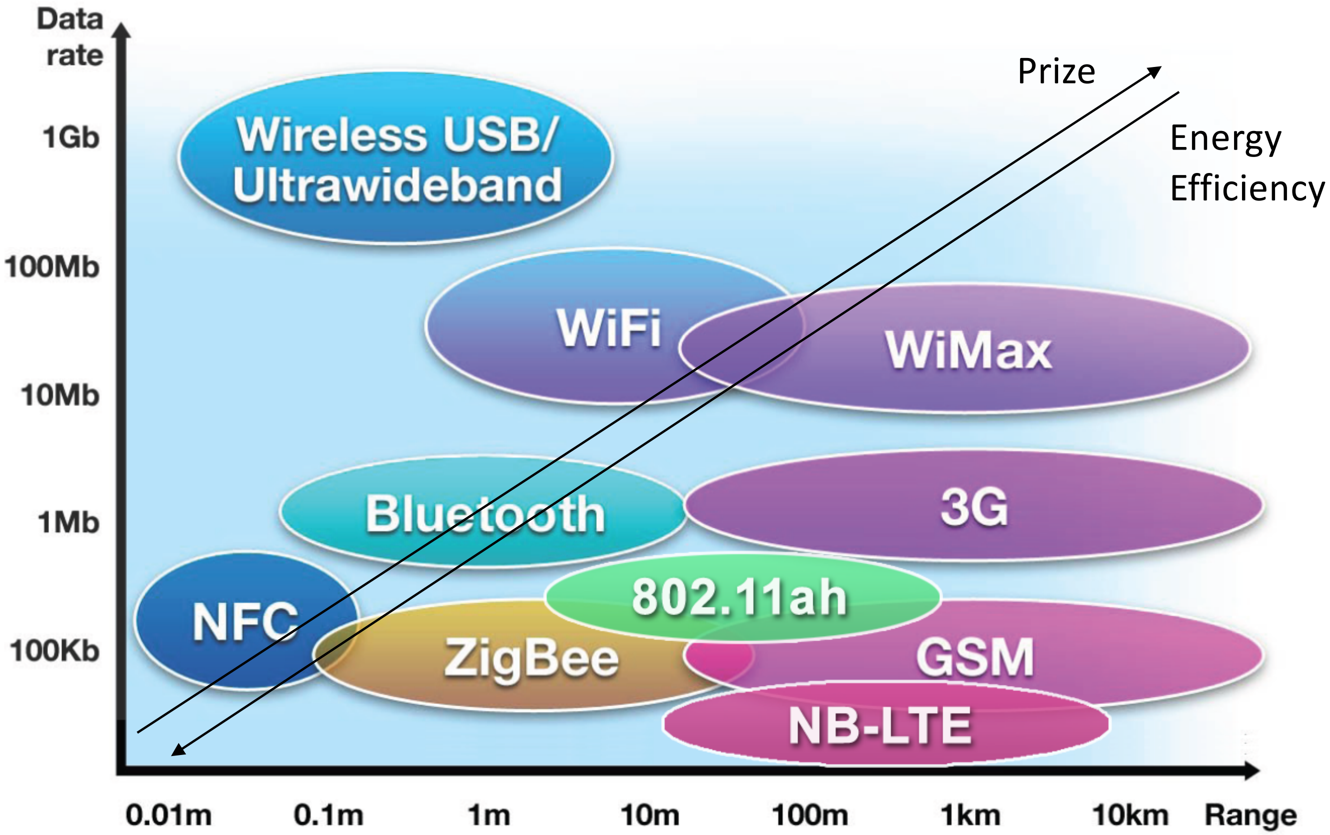


Example


Volatile Memory
Program Memory
Flash Memory
CPU
Radio
Ports
Actuators
Sensors
Power Source



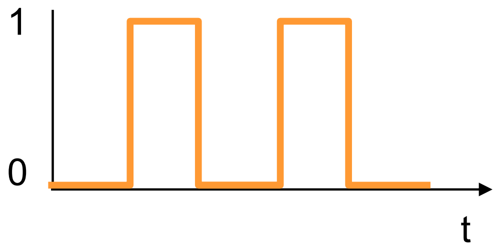
Connectivity



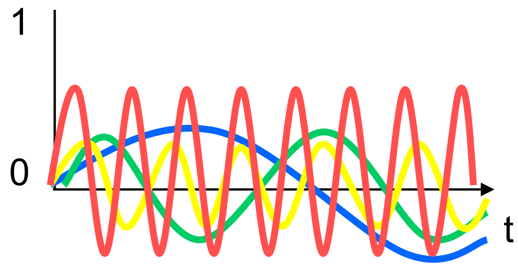
Wireless Transmissions

Fourier representation of periodic signals

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi n f t) + \sum_{n=1}^{\infty} b_n \cos(2\pi n f t)$$



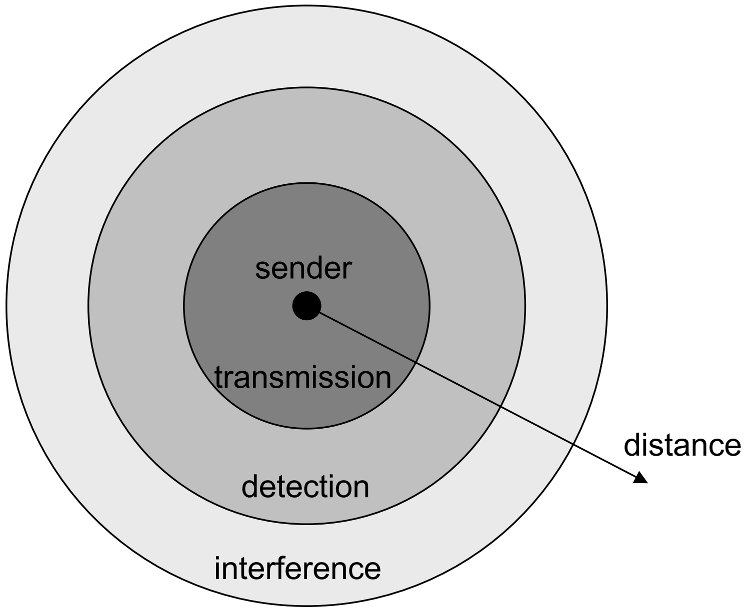
ideal periodic signal



real composition
(based on harmonics)

Signal propagation ranges

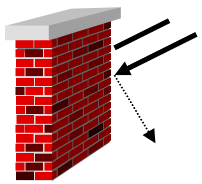
- Transmission range
  - communication possible
  - low error rate
- Detection range
  - detection of the signal possible
  - no communication possible
- Interference range
  - signal may not be detected
  - signal adds to the background noise



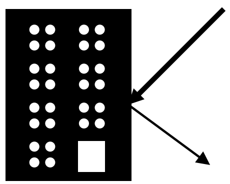
- Warning: figure misleading – bizarre shaped, time-varying ranges in reality!

Signal propagation

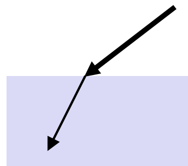
- Propagation in free space always like light (straight line)
- Receiving power proportional to $1/d^2$ in vacuum – much more attenuation in real environments, e.g., $d^{3.5}$…d^4 (d = distance between sender and receiver)
- Receiving power additionally influenced by
  - fading (frequency dependent)
  - shadowing
  - reflection at large obstacles
  - refraction depending on the density of a medium
  - scattering at small obstacles
  - diffraction at edges



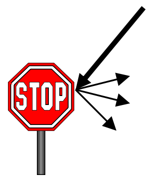
shadowing



reflection



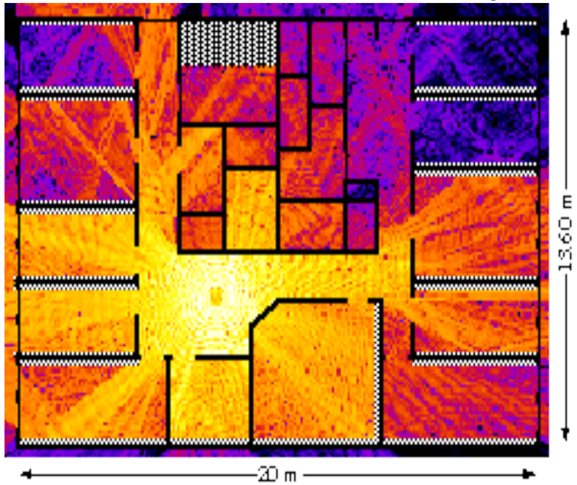
refraction

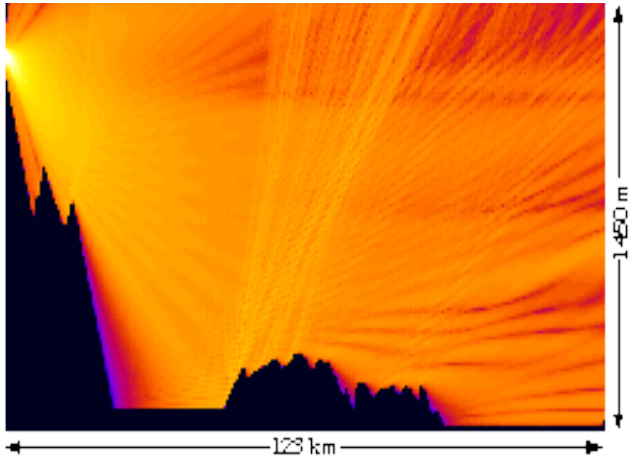


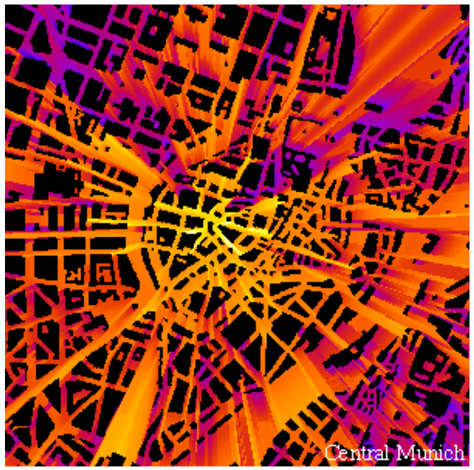
scattering

diffraction

Real world examples







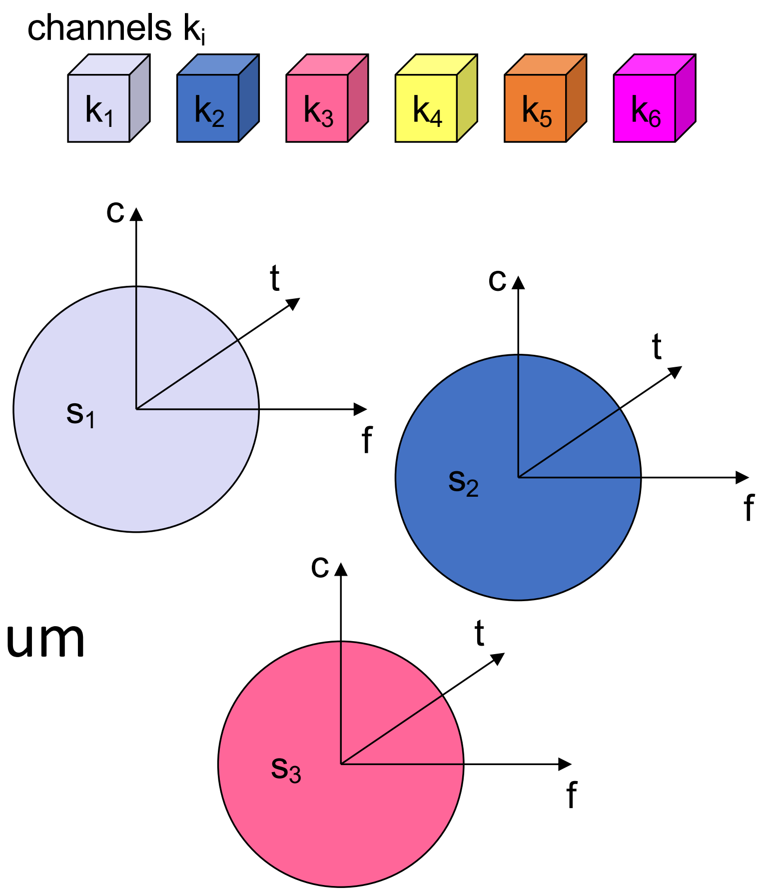
www.ihe.kit.edu/index.php

Multiplexing

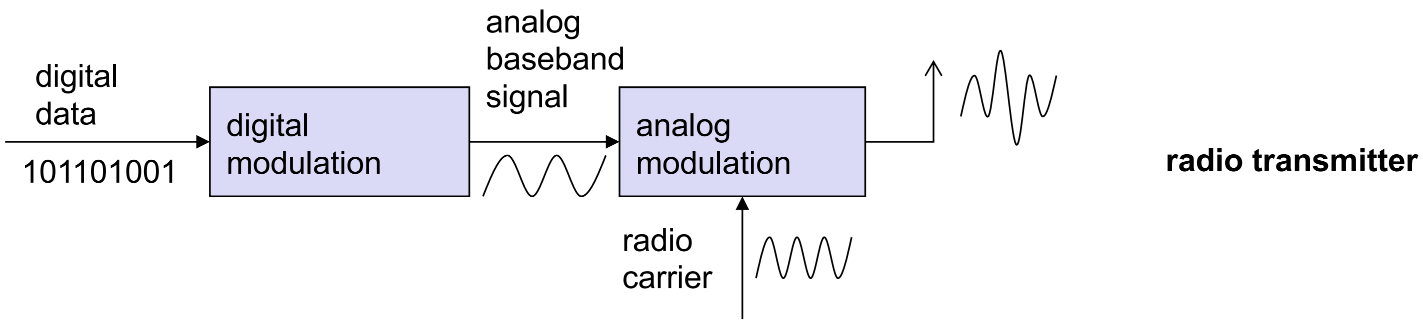
- Multiplexing in 4 dimensions
  - space (si)
  - time (t)
  - frequency (f)
  - code (c)

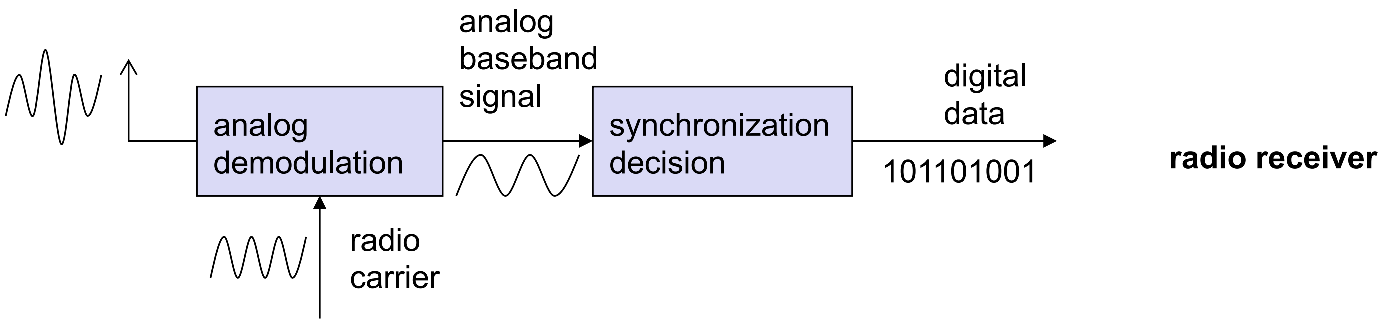
- Goal: multiple use of a shared medium

- Important: guard spaces needed!

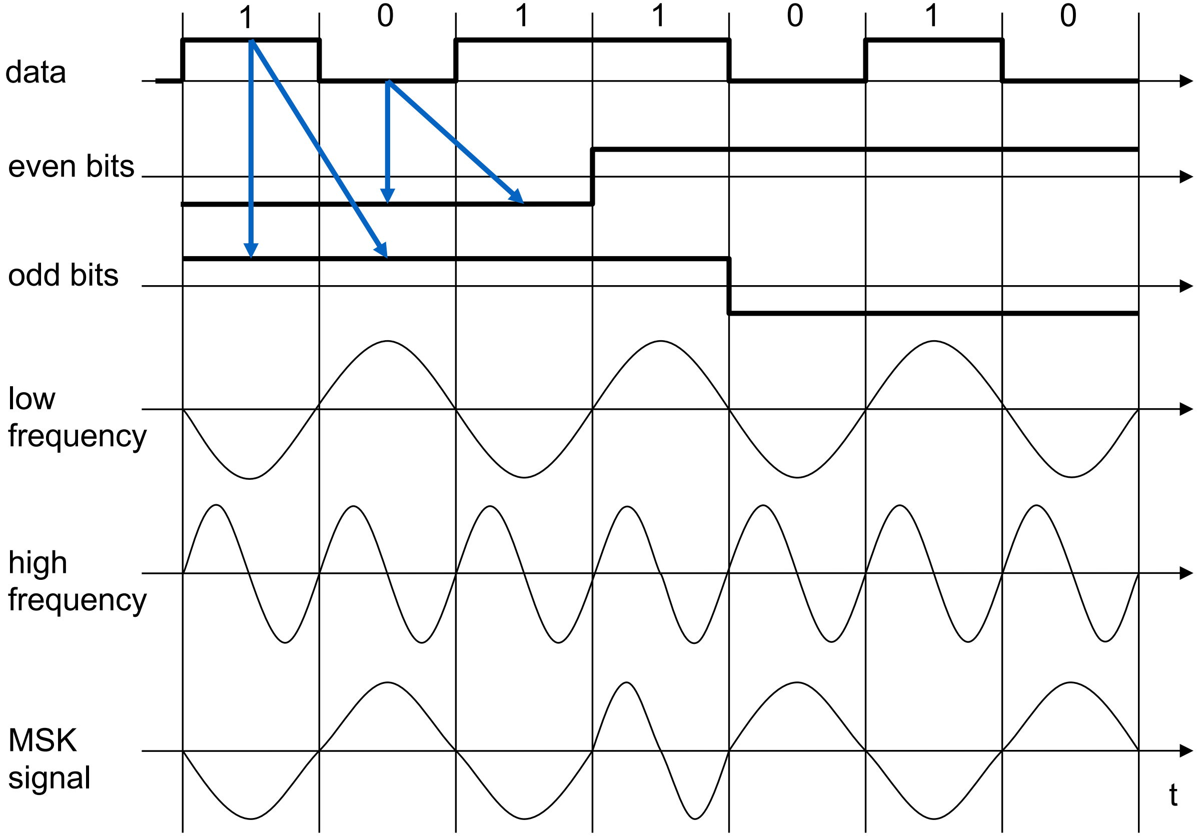


Modulation and demodulation





Example of MSK



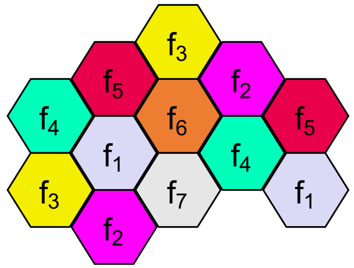
bit	
even	0 1 0 1
odd	0 0 1 1
signal	h n n h
value	- - + +

h: high frequency
n: low frequency
+: original signal
-: inverted signal

No phase shifts!

Frequency planning I

- Frequency reuse only with a certain distance between the base stations
- Standard model using 7 frequencies:



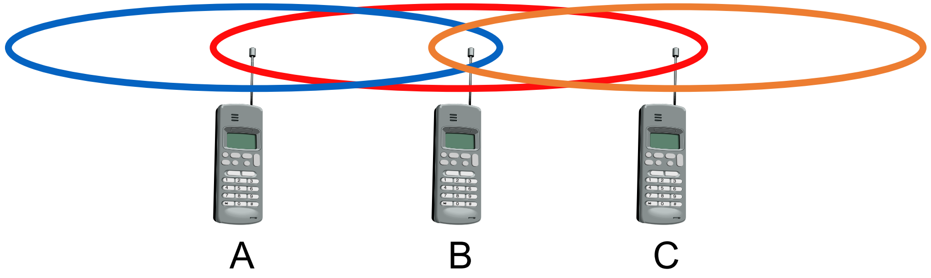
- Fixed frequency assignment:
  - certain frequencies are assigned to a certain cell
  - problem: different traffic load in different cells

- Dynamic frequency assignment:
  - base station chooses frequencies depending on the frequencies already used in neighbor cells
  - more capacity in cells with more traffic
  - assignment can also be based on interference measurements

Media Access

Motivation - hidden and exposed terminals

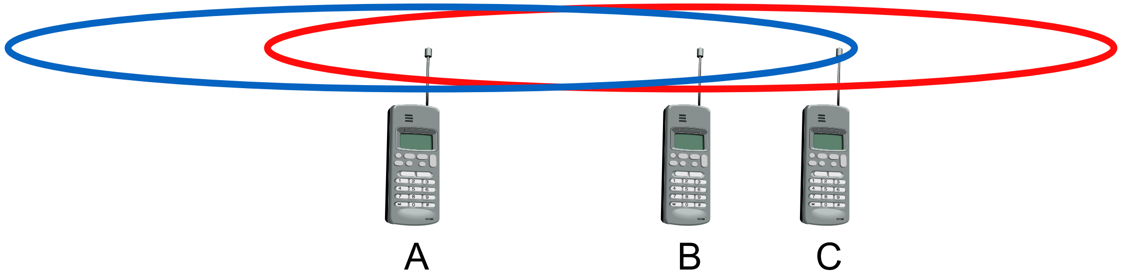
- Hidden terminals
  - A sends to B, C cannot receive A
  - C wants to send to B, C senses a “free” medium (CS fails)
  - collision at B, A cannot receive the collision (CD fails)
  - A is “hidden” for C



- 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

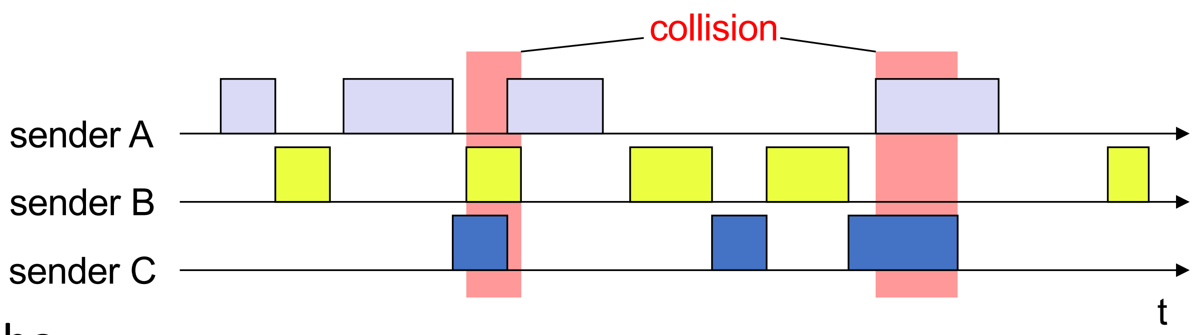


- If C for example was an arbiter for sending rights, terminal B would drown out terminal A already on the physical layer

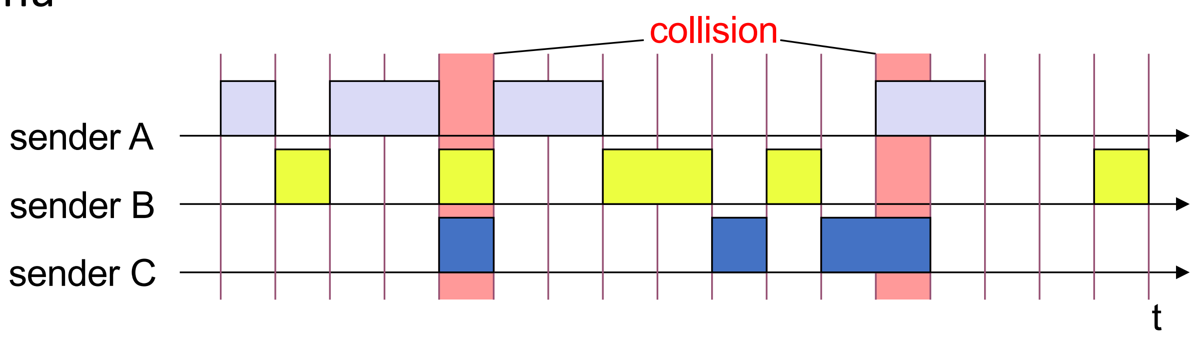
- Also severe problem for CDMA-networks - precise power control needed!

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

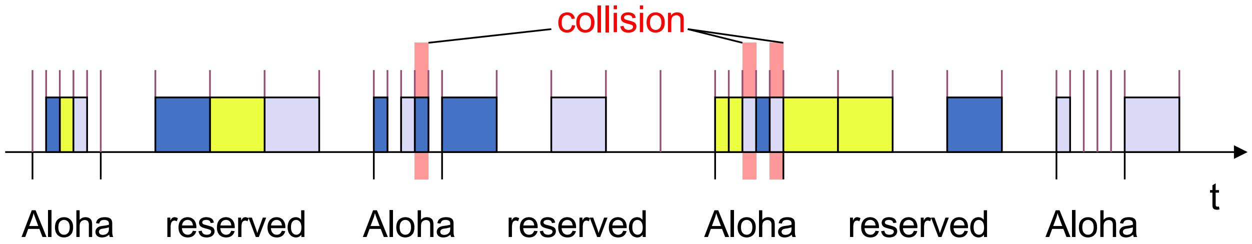
- Channel efficiency only 18% for Aloha, 36% for Slotted Aloha
  - assuming Poisson distribution for packet arrival and packet length

- 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*

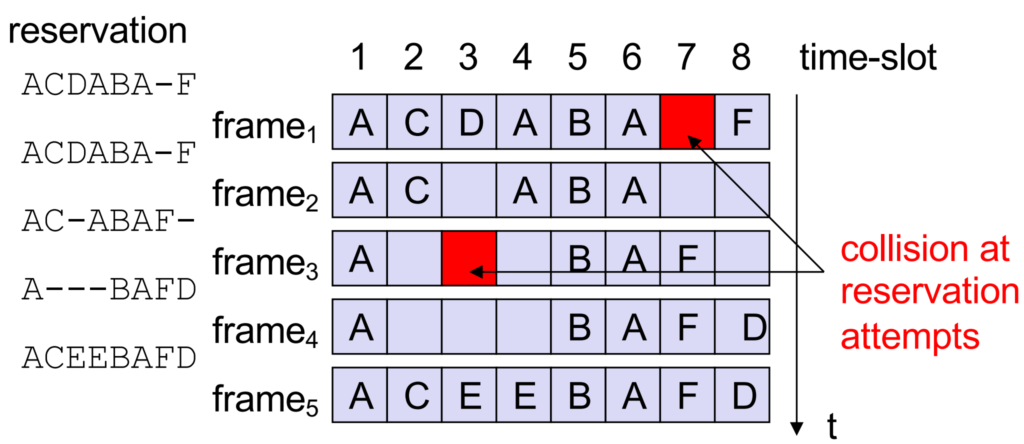
Access method DAMA: Explicit Reservation

- 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



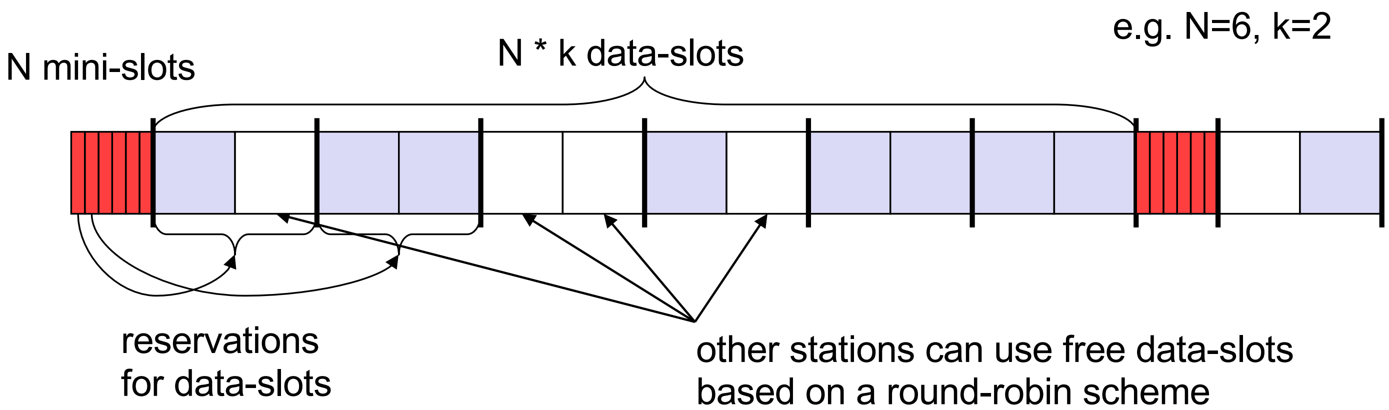
Access method DAMA: PRMA

- 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)

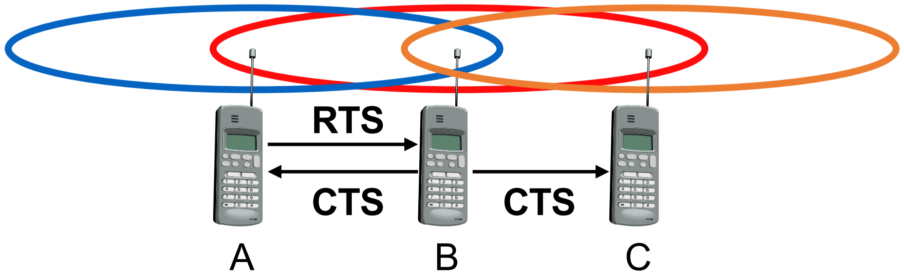


MACA - collision avoidance

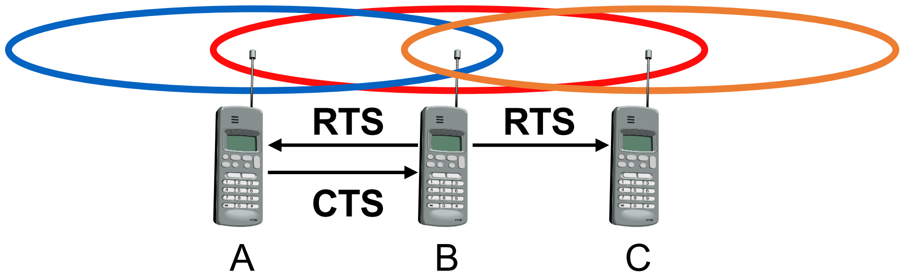
- MACA (Multiple Access with Collision Avoidance) uses short signaling packets for collision avoidance
  - RTS (request to send): a sender request the right to send from a receiver with a short RTS packet before it sends a data packet
  - CTS (clear to send): the receiver grants the right to send as 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



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

WiFi (and related technologies)

Mobile Communication Technology according to IEEE (examples)

WiFi

Local wireless networks
WLAN 802.11

- 802.11a → 802.11h
- 802.11i/e/…/n/…/z/az/ba/bb…
- 802.11b → 802.11g

ZigBee

Personal wireless nw
WPAN 802.15

- 802.15.4 → 802.15.4a/b/c/d/e/f/g…q/r/s
- 802.15.5, .6 (WBAN), …
- 802.15.3 → 802.15.3b/c…e
- 802.15.2
- 802.15.1

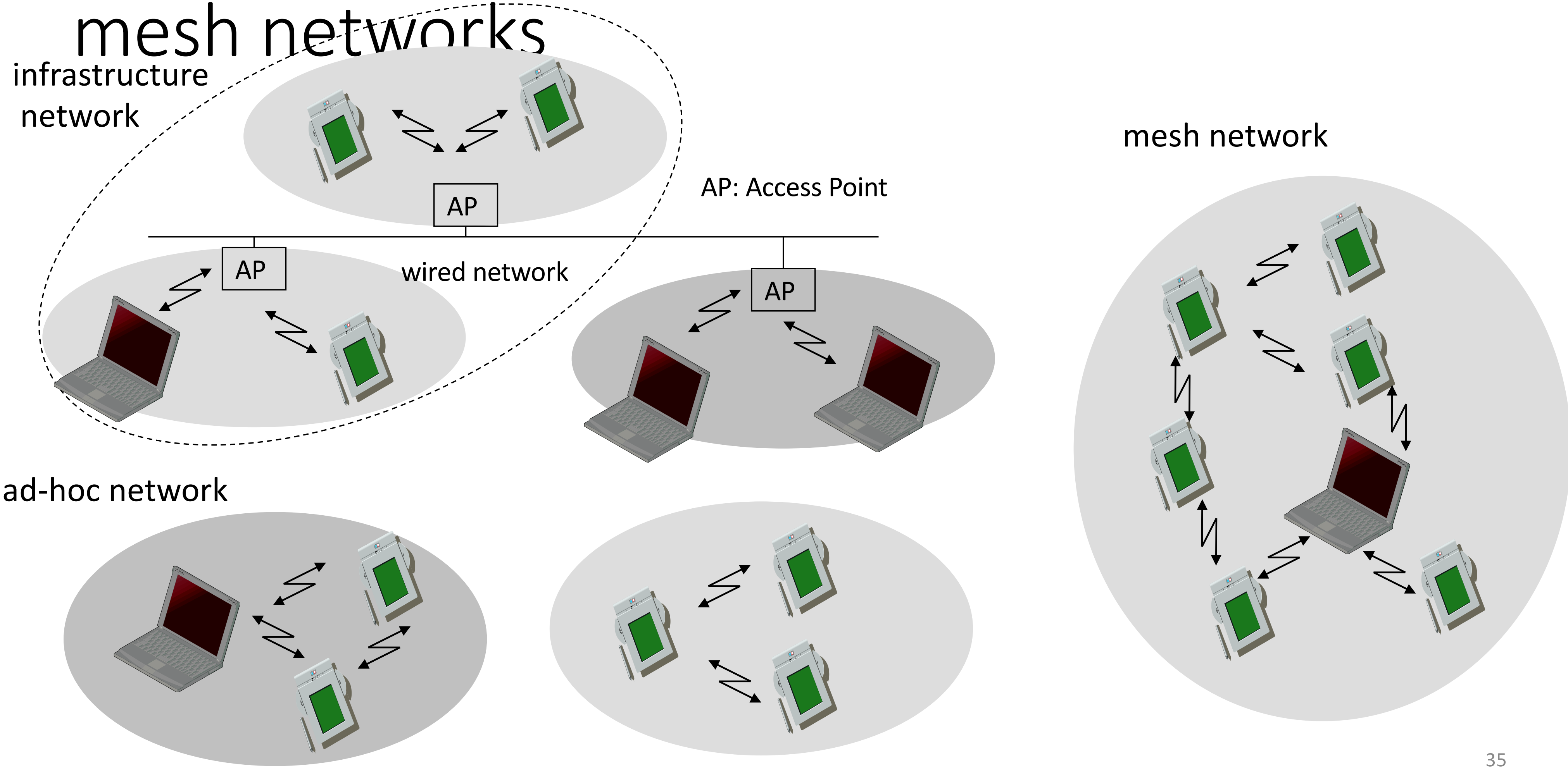
Bluetooth

Wireless distribution networks
WMAN 802.16 (Broadband Wireless Access)

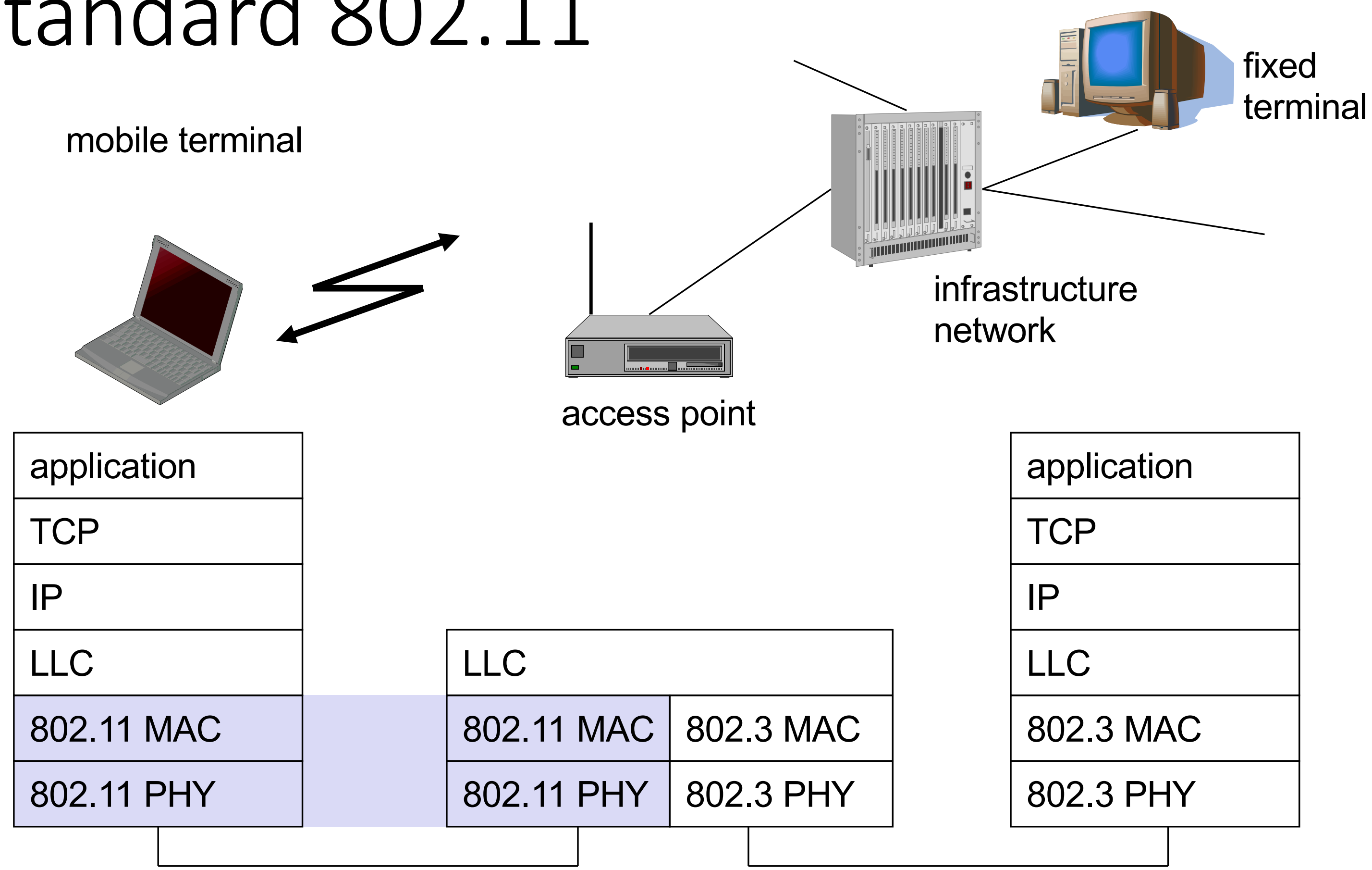
WiMAX

+ Mobility
[hist.: 802.20 (Mobile Broadband Wireless Access)]
802.16e (addition to .16 for mobile devices)

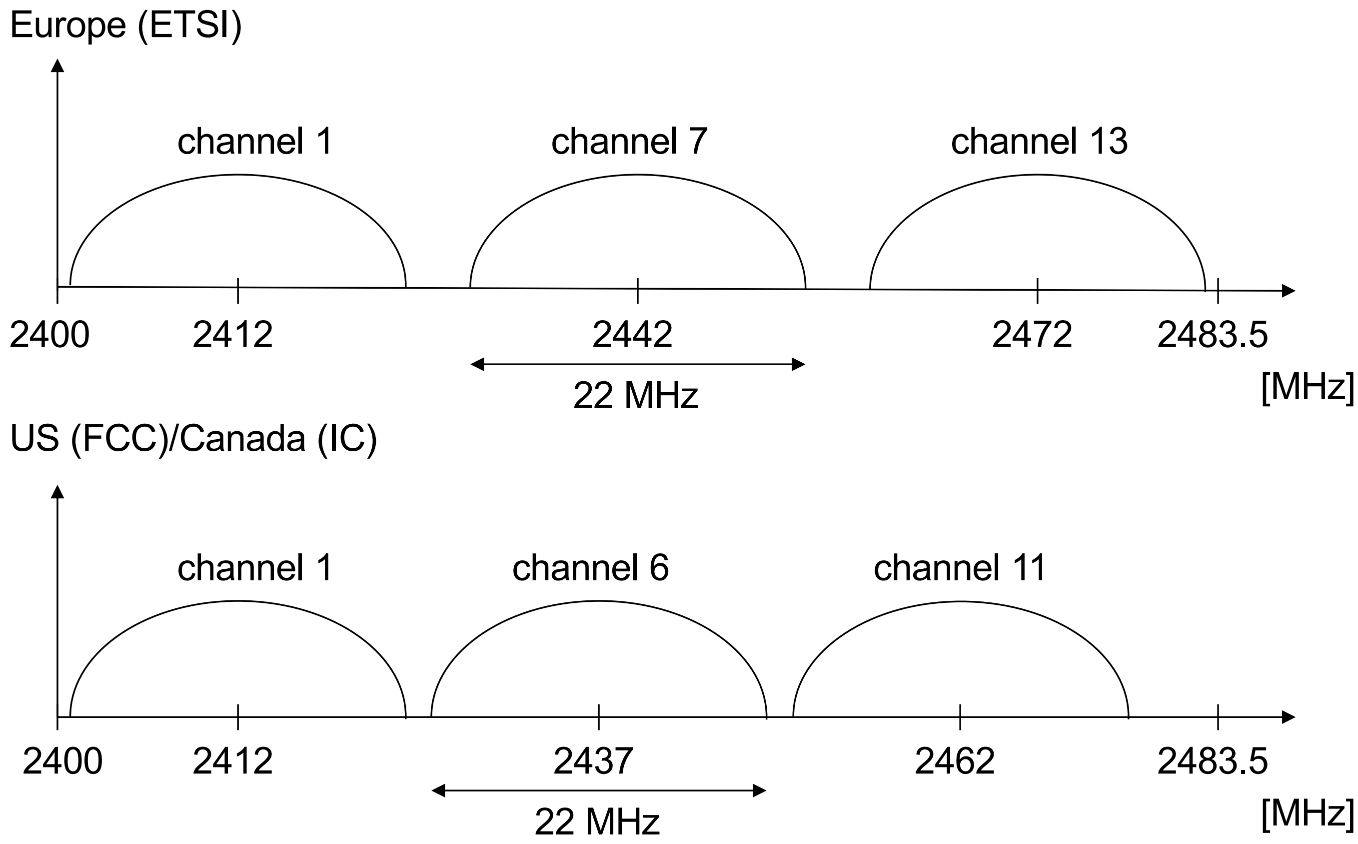
Comparison: infrastructure vs. ad-hoc vs. mesh networks



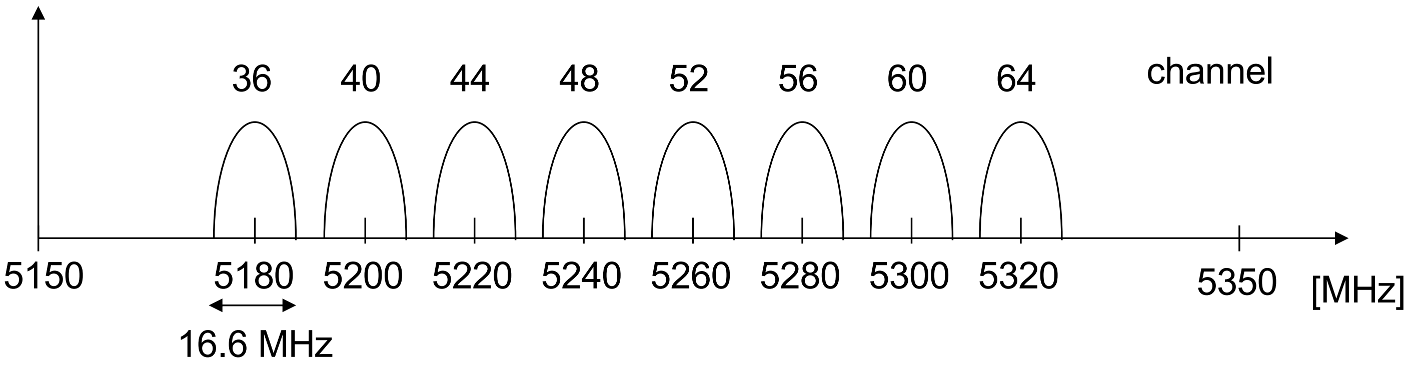
IEEE standard 802.11

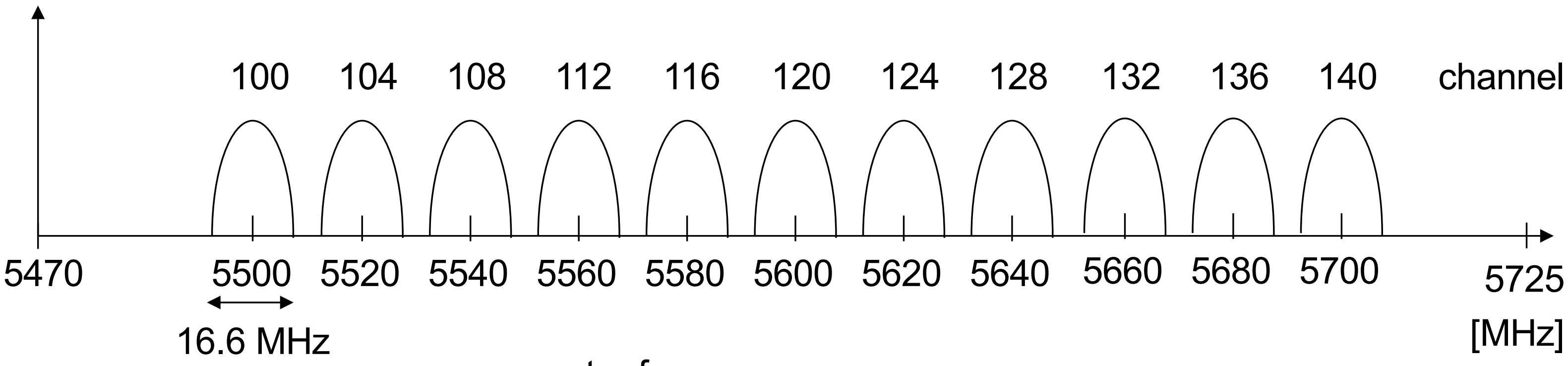


2.4 GHz: Channel selection (non-overlapping)



5 GHz: Operating channels of 802.11a in Europe

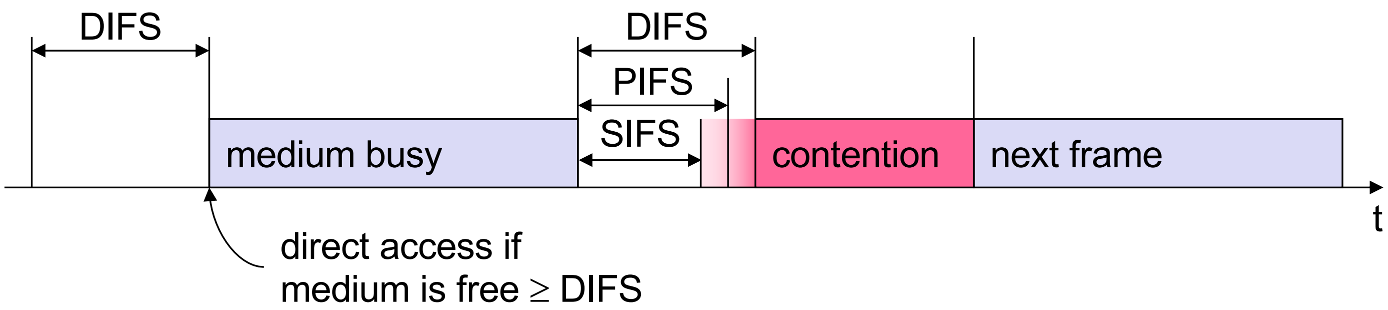




center frequency =
5000 + 5*channel number [MHz]

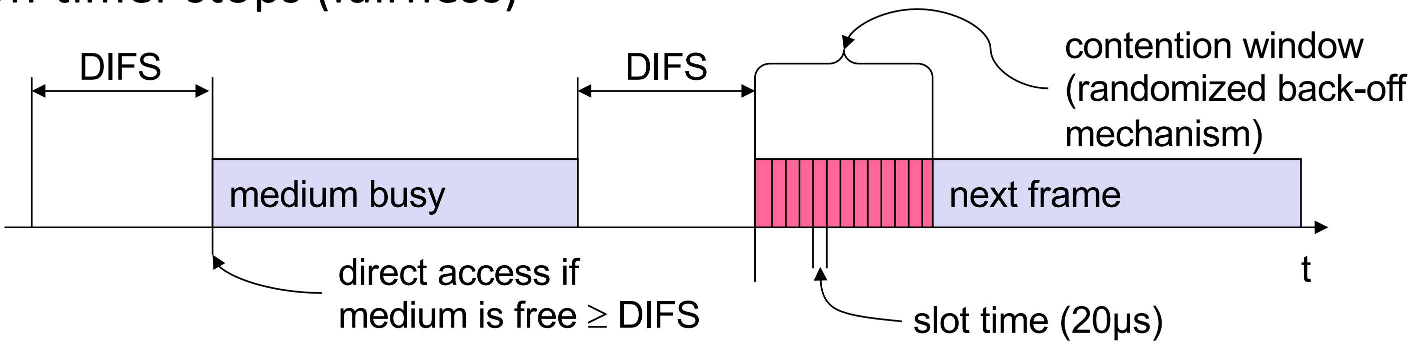
802.11 - MAC Inter Frame Space

- Priorities of packets defined through different inter frame spaces (not always guaranteed)
  - RIFS (Reduced IFS)
    - shortest IFS, reduced overhead, only if no SIFS expected, for higher throughput
  - SIFS (Short IFS)
    - for ACK, CTS, polling response
  - PIFS (PCF IFS)
    - for time-bounded service using PCF
  - DIFS (DCF IFS)
    - for “normal” asynchronous data service
  - AIFS (Arbitration IFS)
    - Variable depending on QoS
  - EIFS (Extended IFS)
    - IFS e.g. after an incorrect FCS

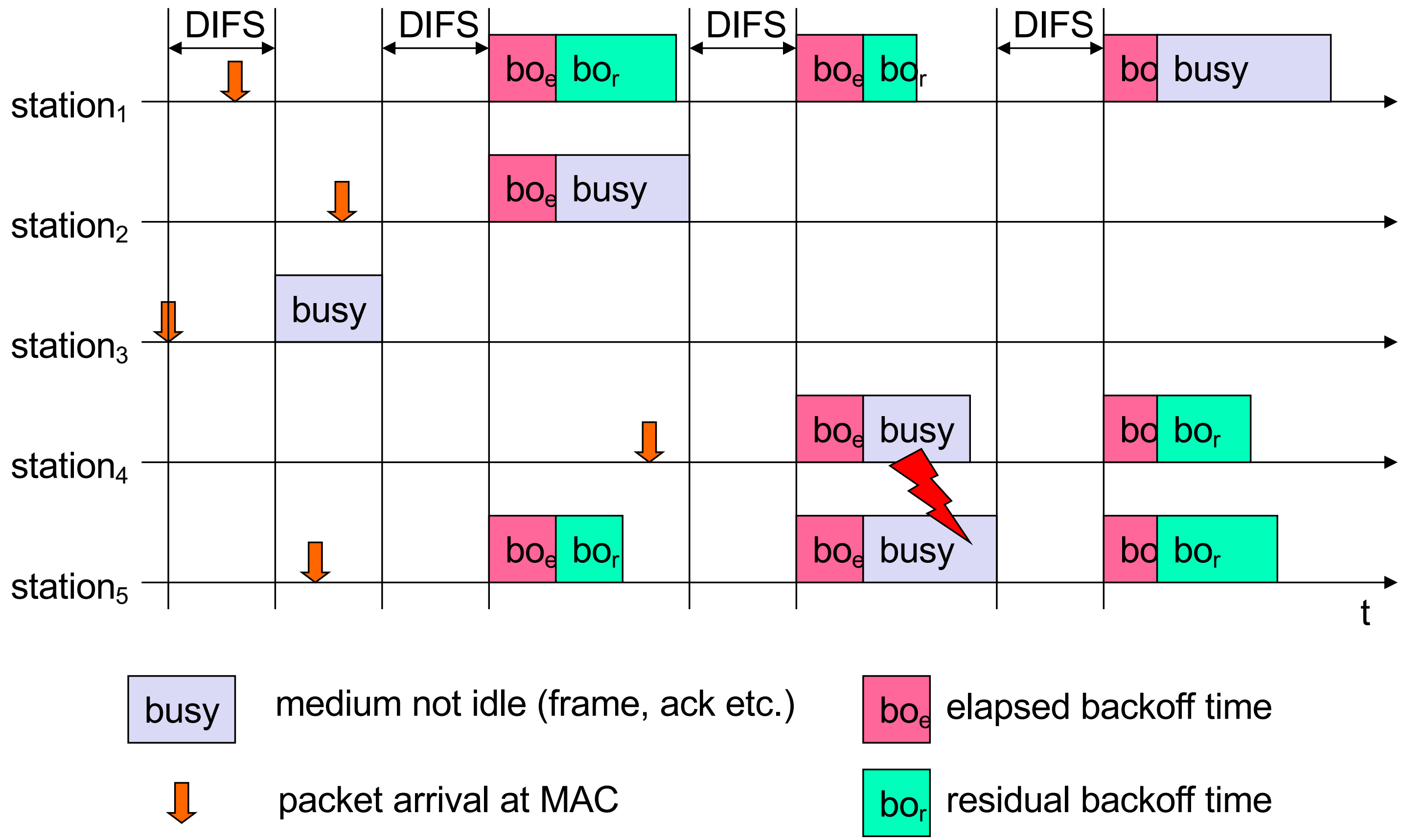


802.11 - CSMA/CA access method I

- station ready to send starts sensing the medium (Carrier Sense based on CCA, Clear Channel Assessment)
- if the medium is free for the duration of an Inter-Frame Space (IFS), the station can start sending (IFS depends on service type)
- if the medium is busy, the station has to wait for a free IFS, then the station must additionally wait a random back-off time (collision avoidance, multiple of slot-time)
- if another station occupies the medium during the back-off time of the station, the back-off timer stops (fairness)

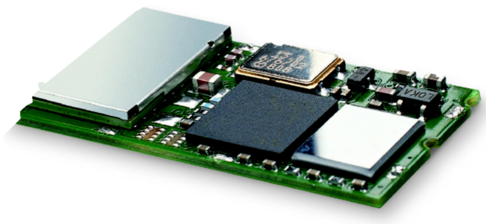


802.11 - Competing stations - simple version

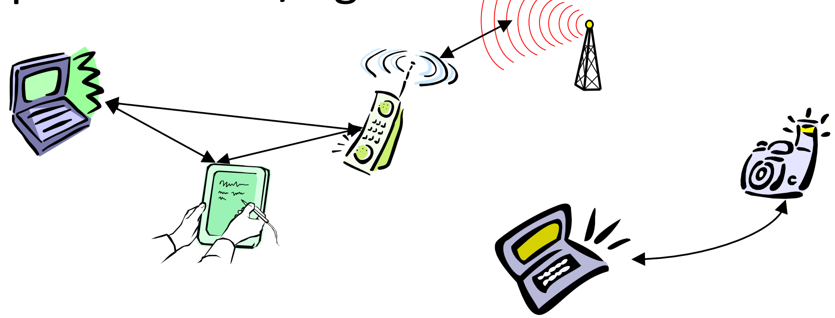


Bluetooth

- Basic idea
  - Universal radio interface for ad-hoc wireless connectivity
  - Interconnecting computer and peripherals, handheld devices, PDAs, cell phones – replacement of IrDA
  - Embedded in other devices, goal: 5€/device (already < 1€)
  - Short range (10 m), low power consumption, license-free 2.45 GHz ISM
  - Voice and data transmission, approx. 1 Mbit/s gross data rate



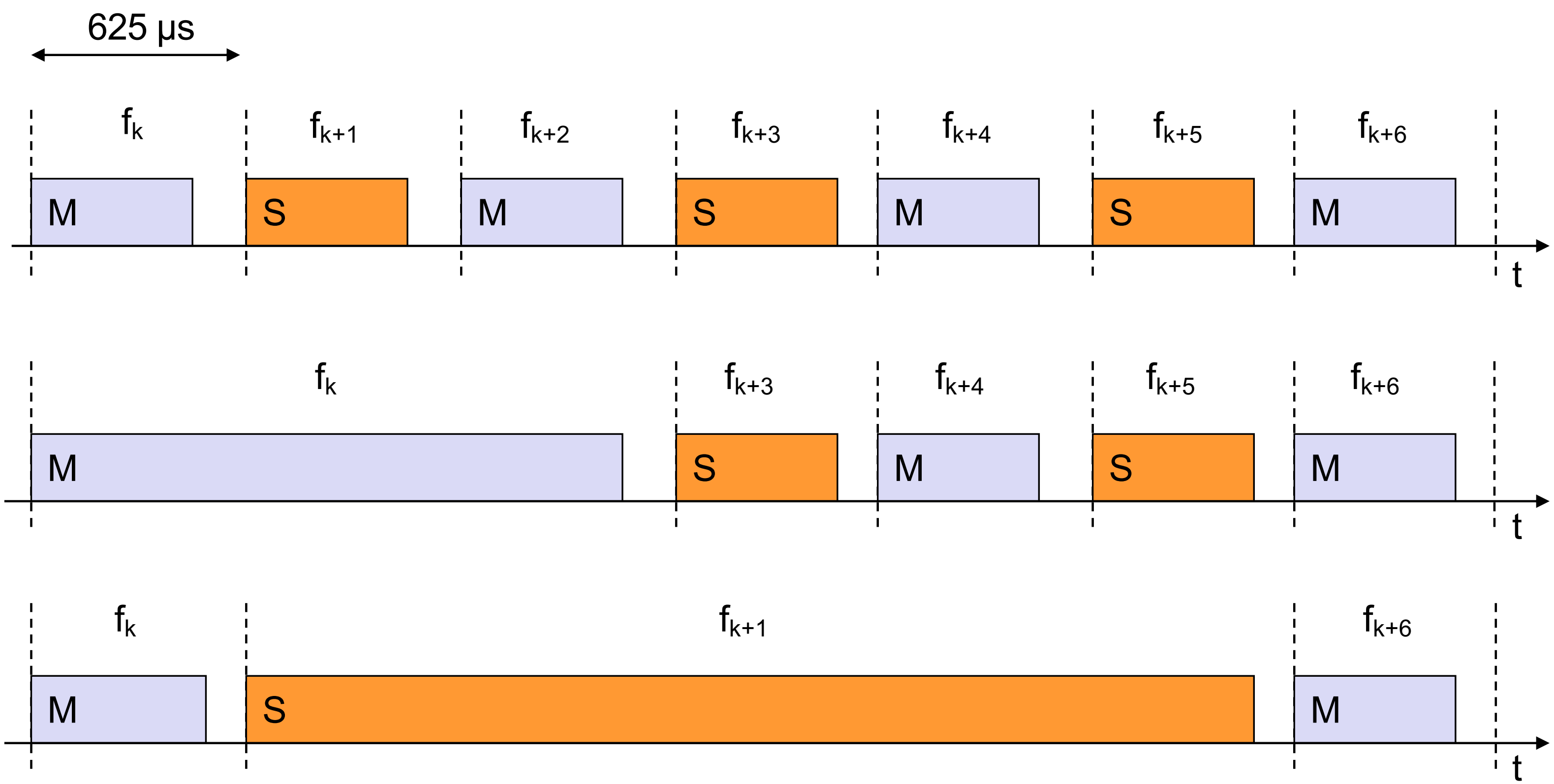
One of the first modules (Ericsson).



Characteristics of the classical system

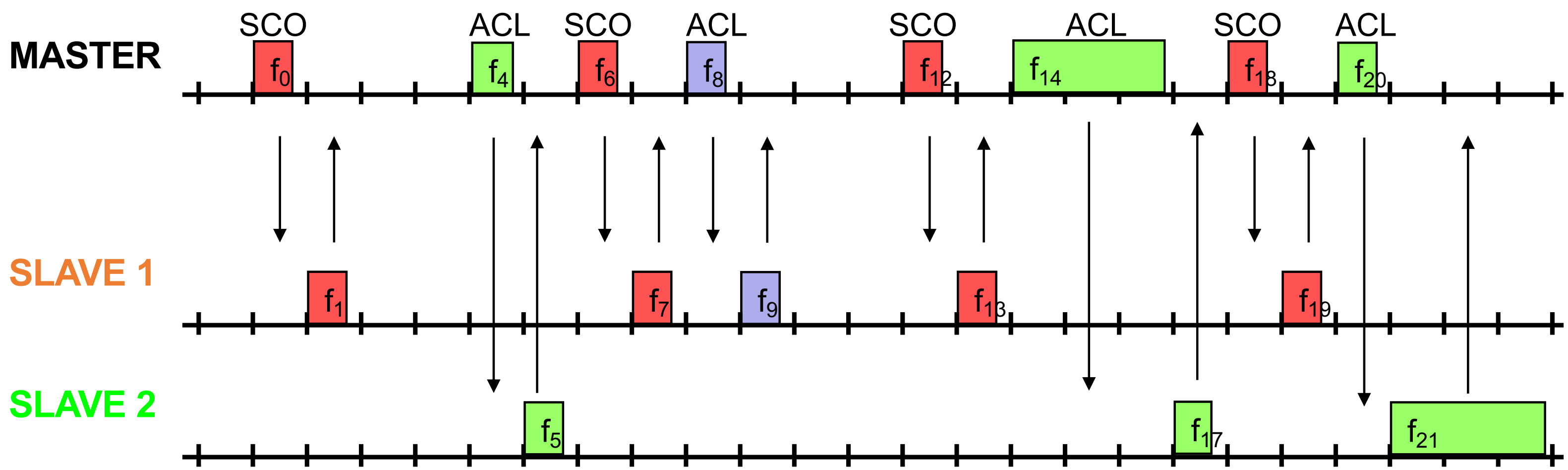
- 2.4 GHz ISM band, 79 (23) RF channels, 1 MHz carrier spacing
  - Channel 0: 2402 MHz … channel 78: 2480 MHz
  - G-FSK modulation, 1-100 mW transmit power
- FHSS and TDD
  - Frequency hopping with 1600 hops/s
  - Hopping sequence in a pseudo random fashion, determined by a master
  - Time division duplex for send/receive separation
- Voice link – SCO (Synchronous Connection Oriented)
  - FEC (forward error correction), no retransmission, 64 kbit/s duplex, point-to-point, circuit switched
- Data link – ACL (Asynchronous ConnectionLess)
  - Asynchronous, fast acknowledge, point-to-multipoint, up to 433.9 kbit/s symmetric or 723.2/57.6 kbit/s asymmetric, packet switched
- Topology
  - Overlapping piconets (stars) forming a scatternet

Frequency selection during data transmission



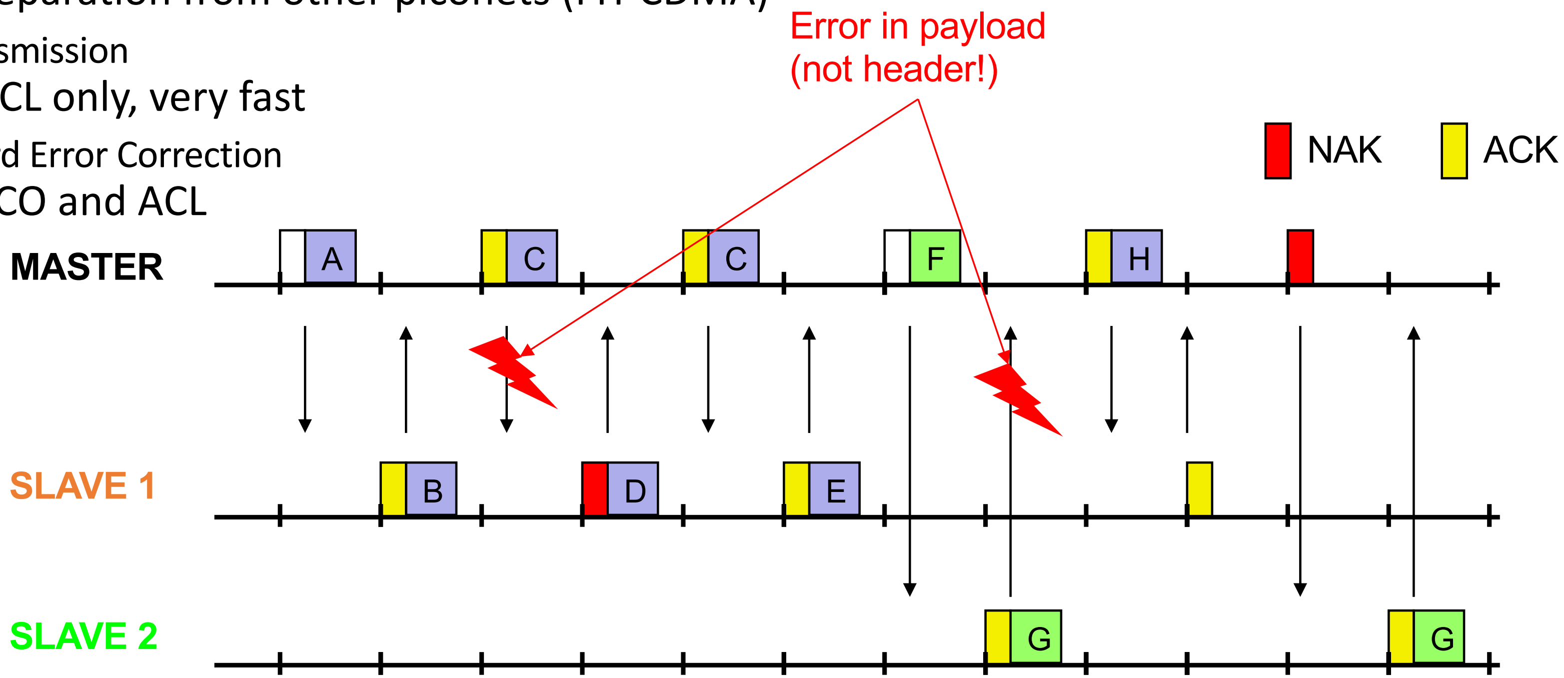
Baseband link types

- Polling-based TDD packet transmission
  - 625µs slots, master polls slaves
- SCO (Synchronous Connection Oriented) – Voice
  - Periodic single slot packet assignment, 64 kbit/s full-duplex, point-to-point
- ACL (Asynchronous ConnectionLess) – Data
  - Variable packet size (1, 3, 5 slots), asymmetric bandwidth, point-to-multipoint



Robustness

- Slow frequency hopping with hopping patterns determined by a master
    - Protection from interference on certain frequencies
    - Separation from other piconets (FH-CDMA)
- Retransmission
    - ACL only, very fast
- Forward Error Correction
    - SCO and ACL

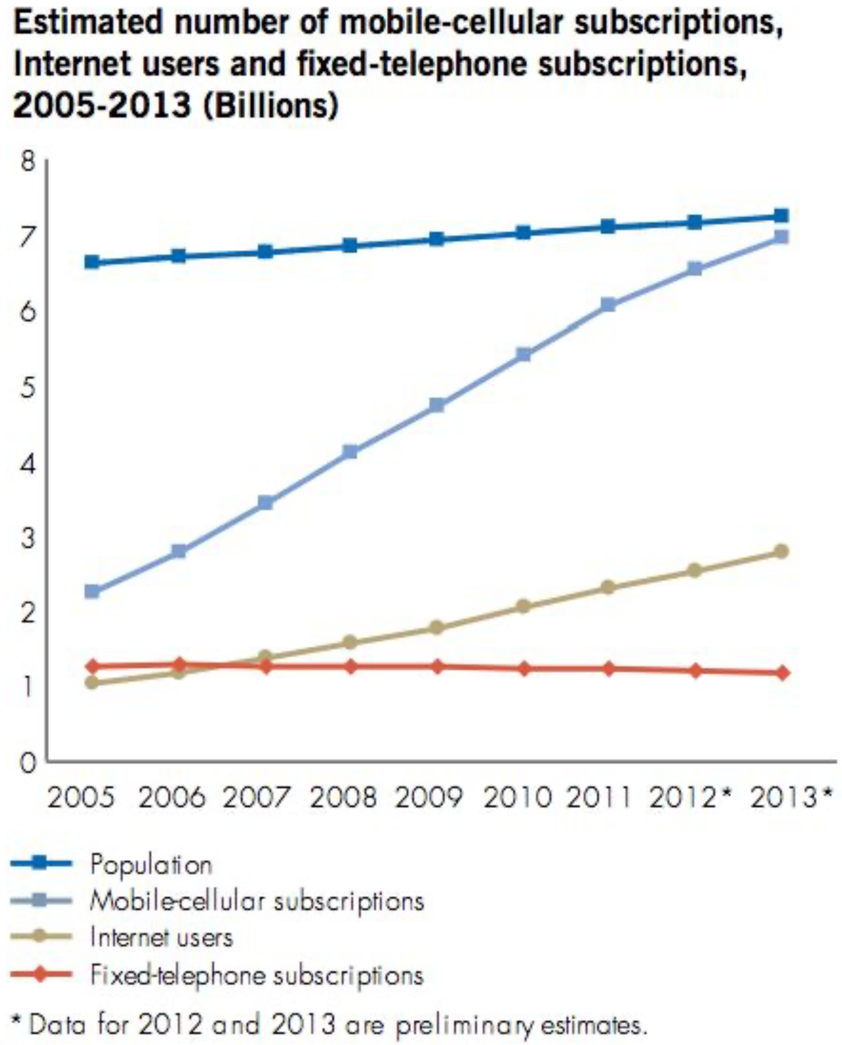


ZigBee

- Relation to 802.15.4 similar to Bluetooth / 802.15.1
- Pushed by Chipcon (now TI), ember, freescale (Motorola), Honeywell, Mitsubishi, Motorola, Philips, Samsung…
- More than 260 members – see www.zigbee.org
  - about 11 promoters, 160 participants, 240 adopters
  - must be member to commercially use ZigBee spec
- ZigBee platforms comprise
  - IEEE 802.15.4 for layers 1 and 2
  - ZigBee protocol stack up to the applications

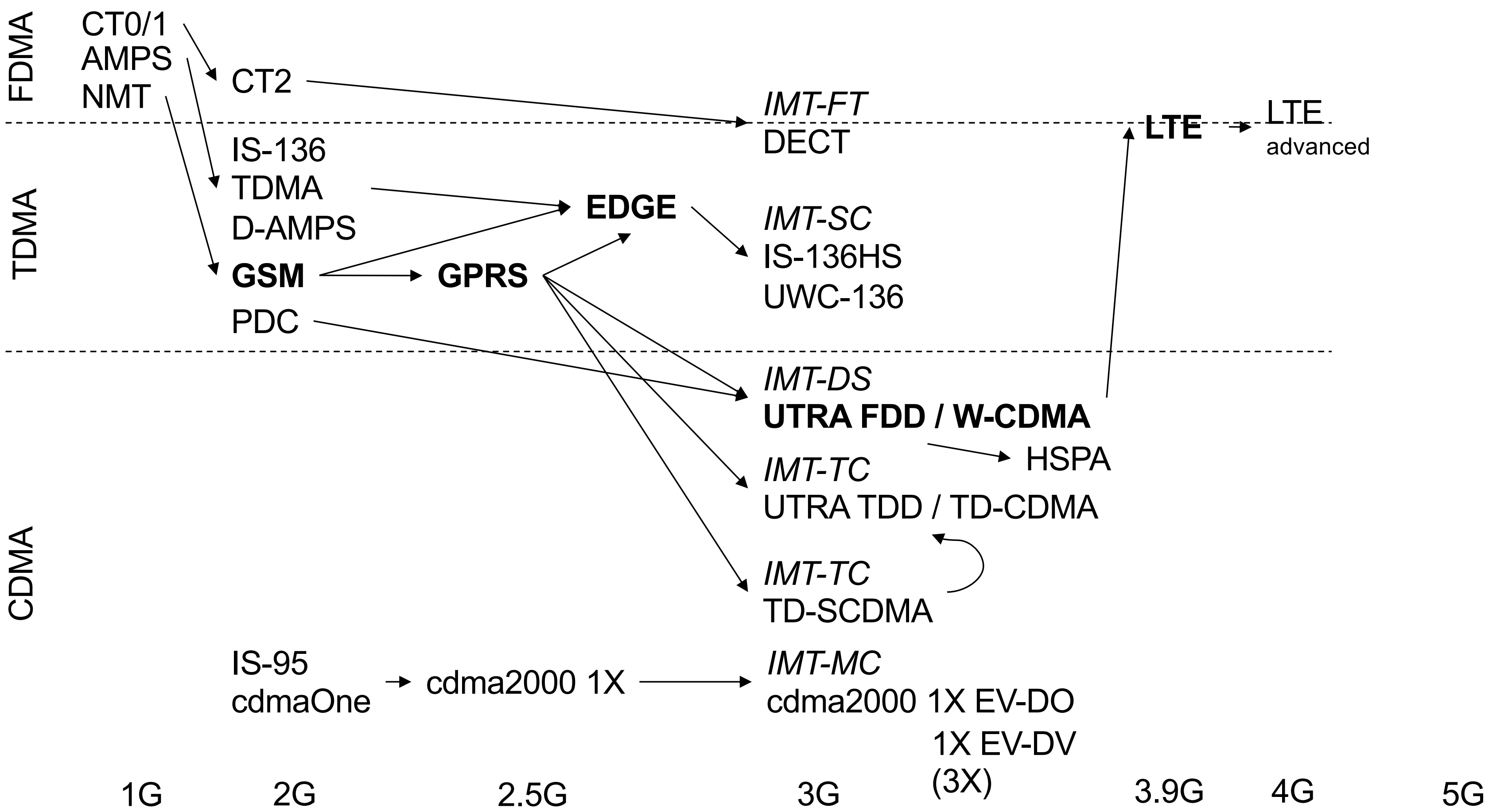
Cellular

Cellular

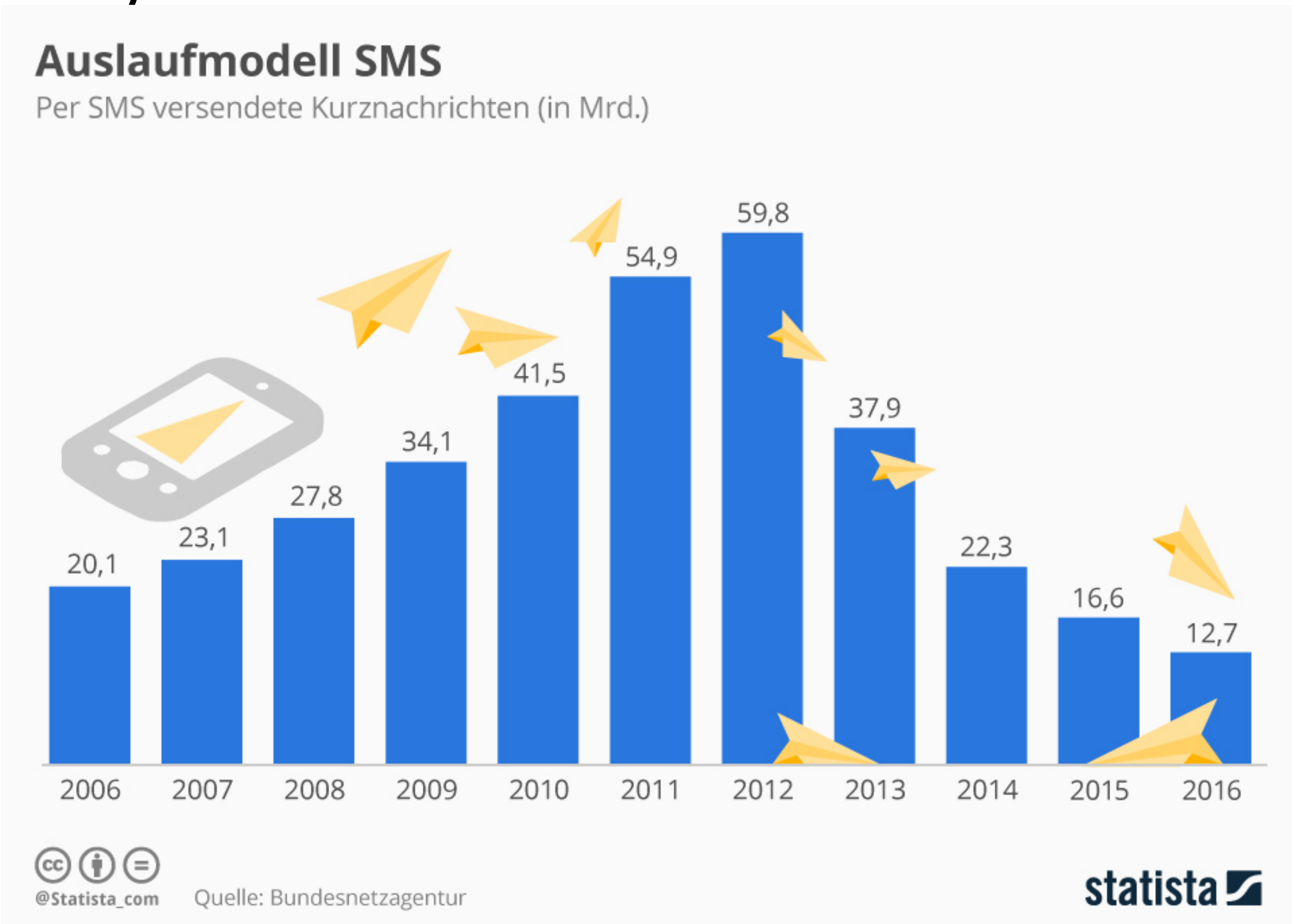


- Nearly one mobile phone per person
- Landline connections on the decline

Development of mobile telecommunication systems



Good bye SMS!?



Auslaufmodell SMS
Per SMS versendete Kurznachrichten (in Mrd.)
20,1
23,1
27,8
34,1
41,5
54,9
59,8
37,9
22,3
16,6
12,7
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
@Statista_com
Quelle: Bundesnetzagentur
statista

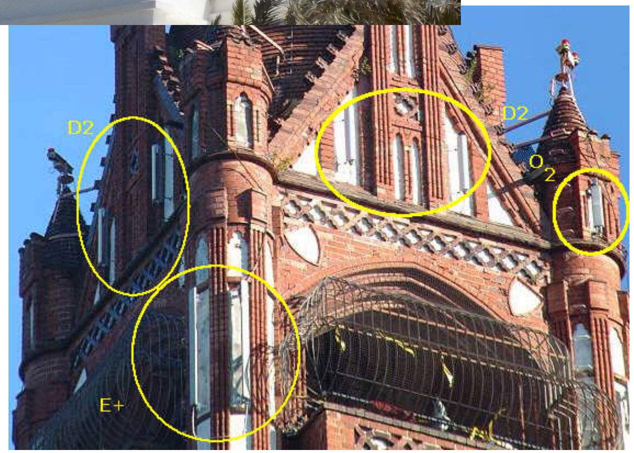
Bearer Services

- Telecommunication services to transfer data between access points
- Specification of services up to the terminal interface (OSI layers 1-3)
- Different data rates for voice and data (original standard)
  - data service (circuit switched)
    - synchronous: 2.4, 4.8 or 9.6 kbit/s
    - asynchronous: 300 - 1200 bit/s
  - data service (packet switched)
    - synchronous: 2.4, 4.8 or 9.6 kbit/s
    - asynchronous: 300 - 9600 bit/s
- Today (classical GSM!): data rates of approx. 50 kbit/s possible – will be covered later! (far more with new modulation)

Ingredients 1: Mobile Phones, PDAs & Co.

The visible but smallest part of the network!

Ingredients 2: Antennas

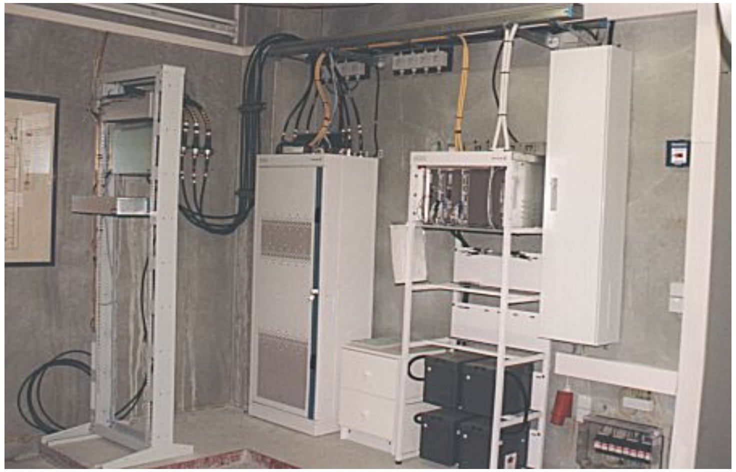


Still visible – cause many discussions…

Ingredients 3: Infrastructure 1

Base Stations

Cabling



Microwave links

Ingredients 3: Infrastructure 2

Not „visible“, but comprise the major part of the network (also from an investment point of view…)

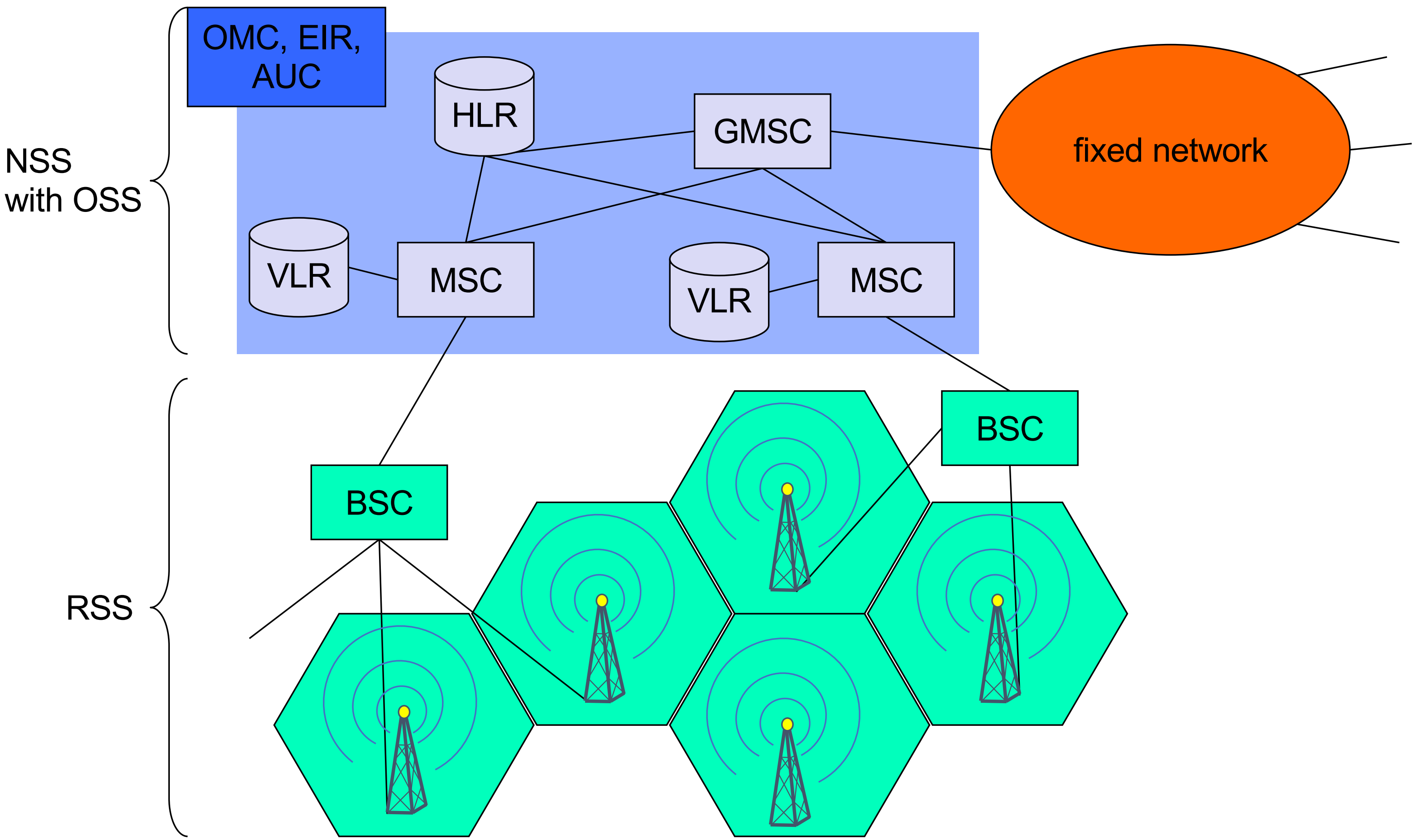
Switching units

Management

Data bases

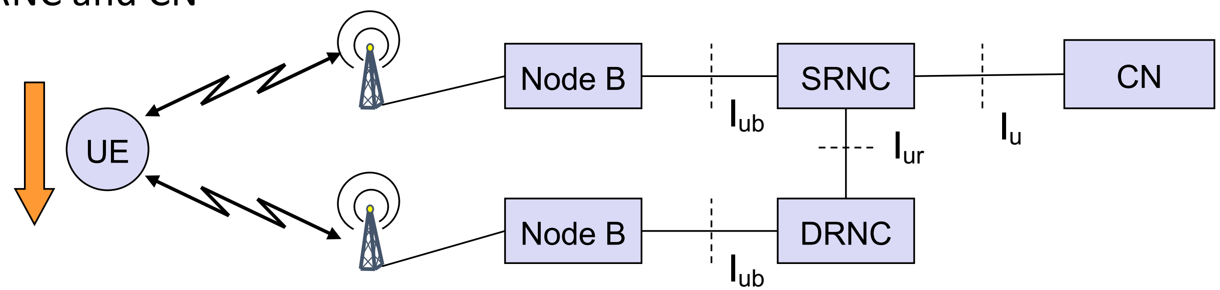
Monitoring

GSM: overview

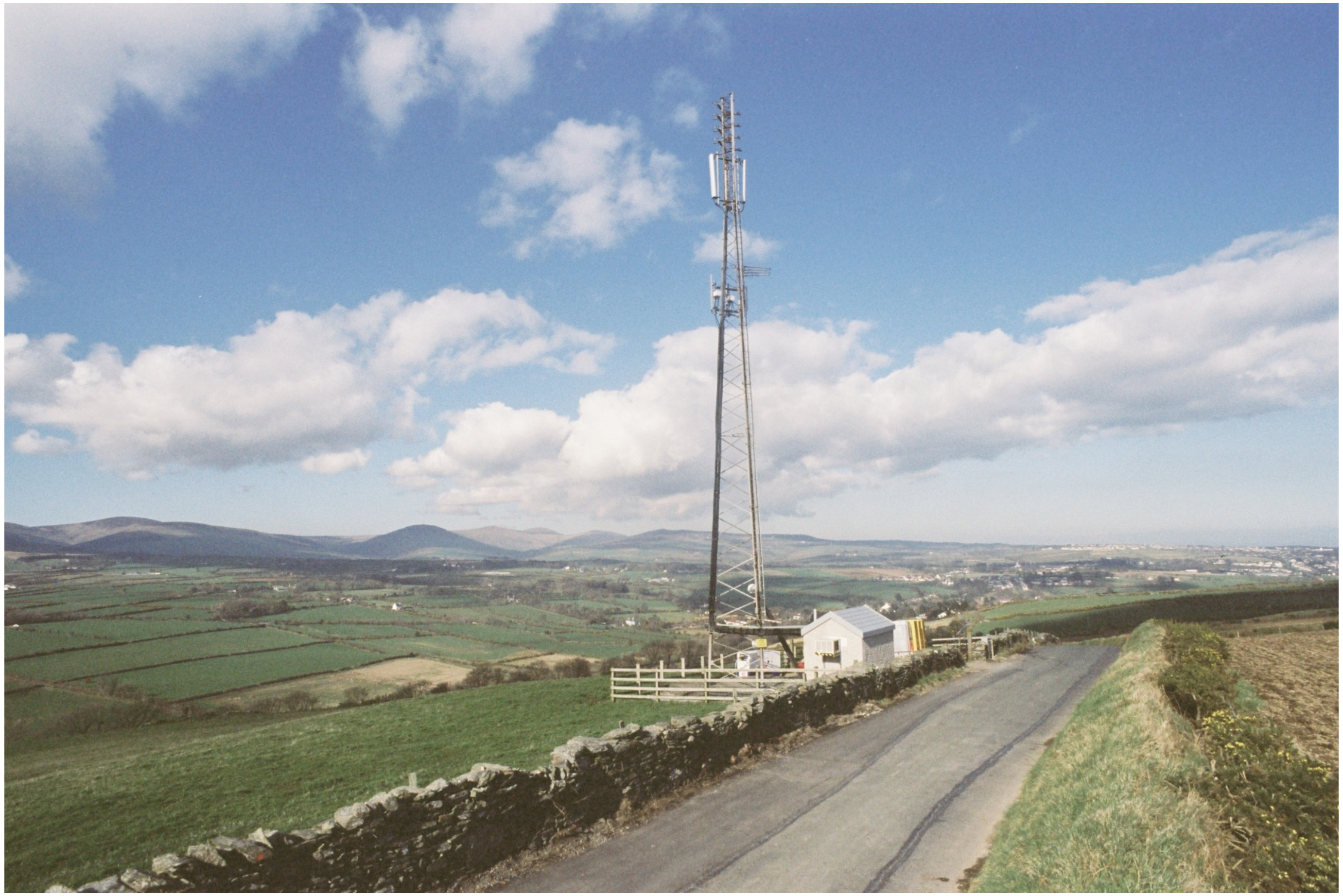


Support of mobility: handover

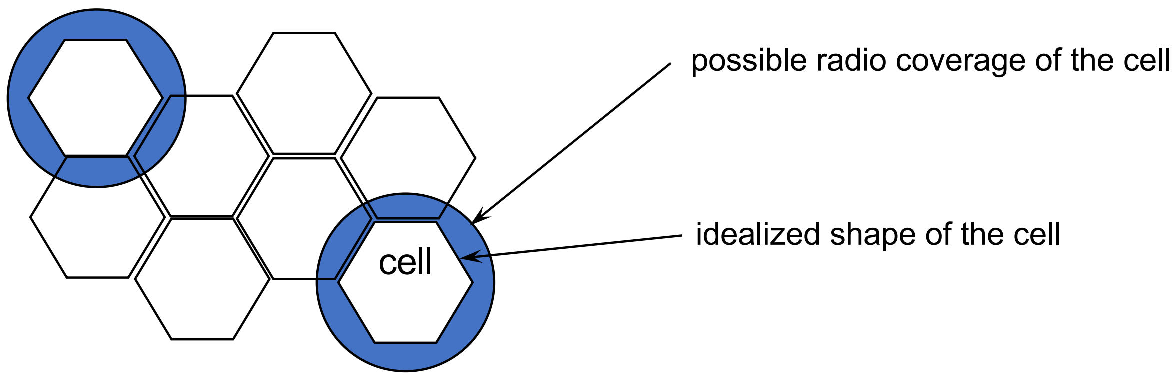
- From and to other systems (e.g., UMTS to GSM)
  - This is a must as UMTS coverage is/was poor in the beginning
- RNS controlling the connection is called SRNS (Serving RNS)
- RNS offering additional resources (e.g., for soft handover) is called Drift RNS (DRNS)
- End-to-end connections between UE and CN only via Iu at the SRNS
  - Change of SRNS requires change of Iu
  - Initiated by the SRNS
  - Controlled by the RNC and CN



Isle of Man – Start of UMTS in Europe as Test



GSM: cellular network



segmentation of the area into cells

- use of several carrier frequencies
- not the same frequency in adjoining cells
- cell sizes vary from some 100 m up to 35 km depending on user density, geography, transceiver power etc.
- hexagonal shape of cells is idealized (cells overlap, shapes depend on geography)
- if a mobile user changes cells handover of the connection to the neighbor cell

Key LTE features

- Simplified network architecture compared to GSM/UMTS
  - Flat IP-based network replacing the GPRS core, optimized for the IP-Multimedia Subsystem (IMS), no more circuit switching
- Network should be in parts self-organizing
- Scheme for soft frequency reuse between cells
  - Inner part uses all subbands with less power
  - Outer part uses pre-served subbands with higher power
- Much higher data throughput supported by multiple antennas
- Much higher flexibility in terms of spectrum, bandwidth, data rates
- Much lower RTT – good for interactive traffic and gaming
- Smooth transition from W-CDMA/HSPA, TD-SCDMA and cdma2000 1x EV-DO – but completely different radio!
- Large step towards 4G – IMT advanced

- See www.3gpp.org for all specs, tables, figures etc.!

Next time(s)

- Friday: Optional Project Q&A
- Friday after that: Project Presentations
- AMA
  - Open two to three before the exam
  - Video will be out about one week before the exam
- Exam!

Questions?

Please stay safe and healthy!