Technische Universität Darmstadt

Telecooperation Lab
Prof. Dr. Max Mühlhäuser

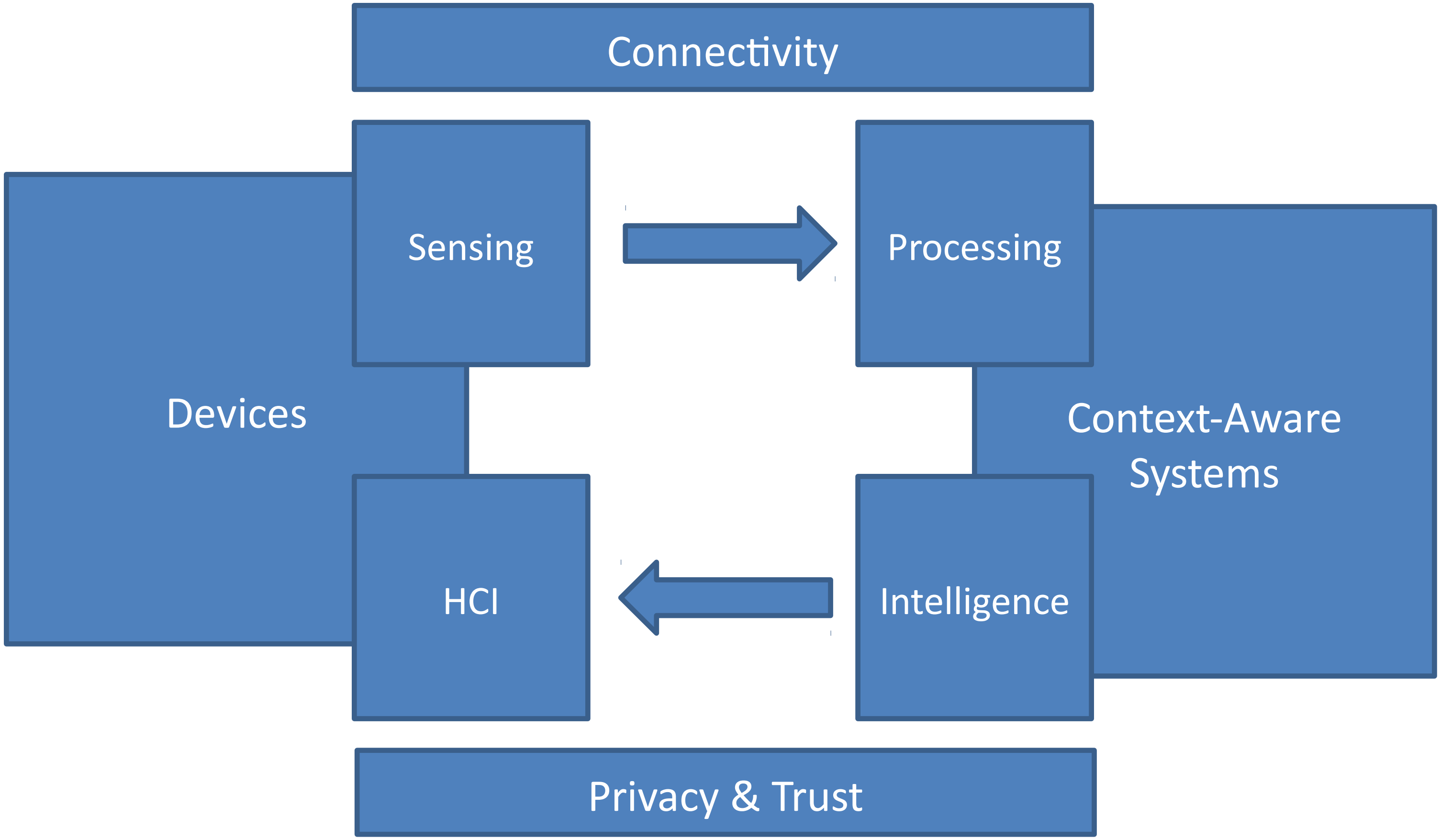
TK3: Ubiquitous Computing

Chapter 2: Infrastructure

Part 1: Connectivity

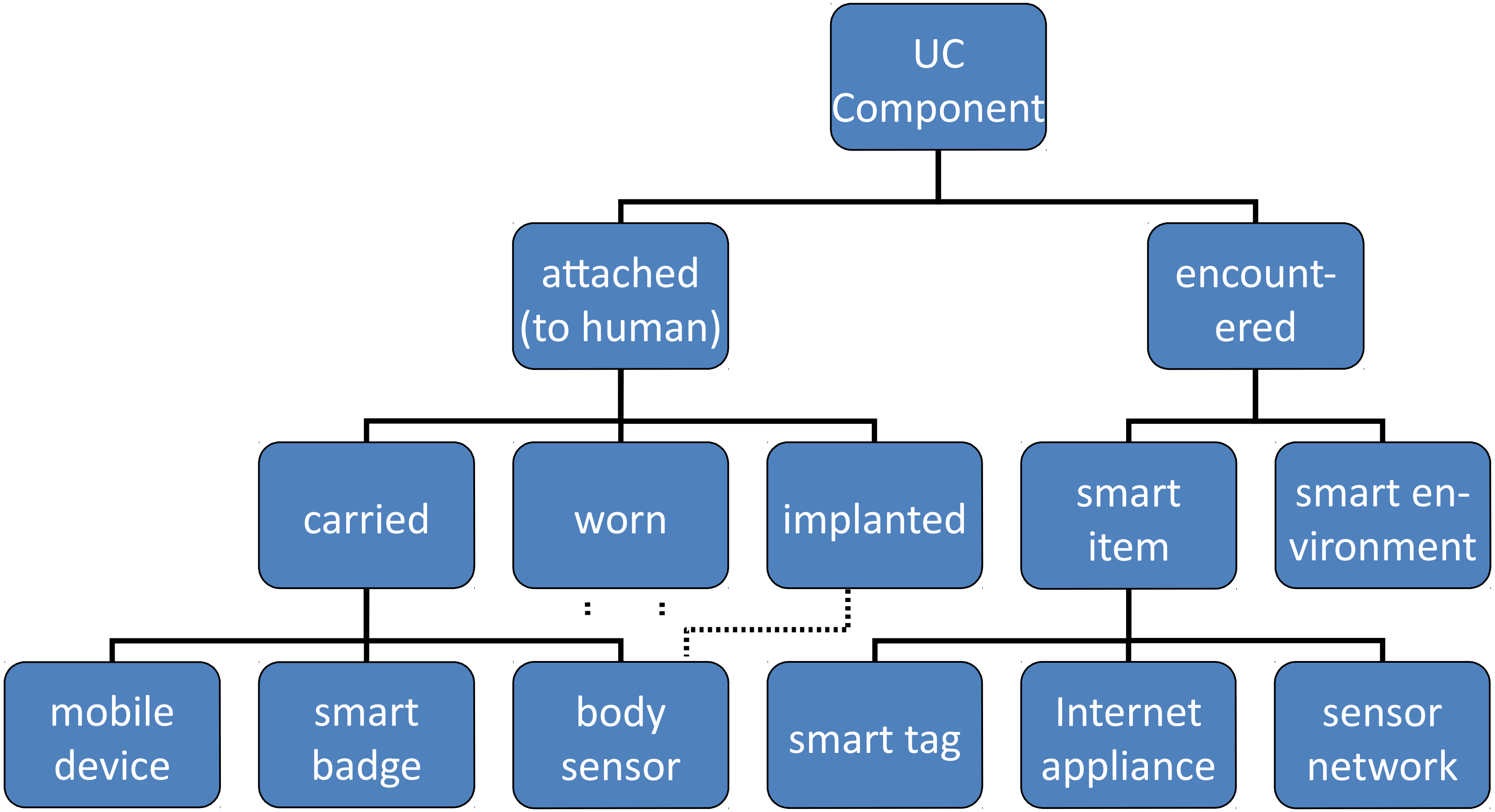
Lecturer: Dr. Immanuel Schweizer

Simple Architecture



Taxonomy: An Attempt

We may start to organize UC components in a real taxonomy:



Summary “Sensing”

- From tagging to people-centric sensing
  - **Mapping** the virtual and real-world
  - Measure and act on the **real-world**
  - Measure and act on **humans** and their **environment**
- Challenges
  - Energy
  - Communication
  - Data processing
  - Context-awareness
  - Interaction with humans
  - Privacy

Recap: Communication Interfaces

- Bluetooth - Desktop / Personal Area Net: few, „valued“ devices
- ZigBee – scales up to sensor networks („smart dust“) in terms of power, #of nodes, management …

Market Name Standard	**GPRS/UMTS (TDMA/CDMA)**	**Wi-Fi™ 802.11b**	**Bluetooth™ 802.15.1**	**ZigBee™ 802.15.4**
Application Focus	LongDist. Voice/Data	Web, Email, Video	Cable Replacement	Monitoring & Cntrl
System Resources	16MB+	1MB+	250KB+	4KB - 32KB
Battery Life (days)	1-7	.5 - 5	1 - 7	100 - 1,000+
Network Size	(1)	(32)	7	255 / 65,000
Bandwidth (kb/s)	14 - 2000	11,000+	720	20 - 250
Transmission Range (m)	1,000+	1 - 100	1 - 10+	1 - 100+
Success Metrics	Reach, Quality	Speed, Flexibility	Cost, Convenience	Reliab., Power, Cost

Recap: Communication Interfaces

- Close coupling systems
  - Use very small ranges (<= 1cm)
  - Transponder must be inserted into reader or positioned on surface
  - Greater amount of power can be provided

- Remote coupling systems
  - Read ranges of up to 1m
  - Almost always based on **Inductive Coupling**
  - Have 90% market share
- Long-range systems
  - Typical read ranges: 3m with passive tags, 15m with active tags
  - **Electromagnetic Backscatter Coupling** or **SAW-Transponders**

	LF	HF	UHF	Microwave
Freq. Range	125 - 134KHz	13.56 MHz	866 - 915MHz	2.45 - 5.8 GHz
Read Range	10 cm	1M	2-7 M	1M
Application	Smart Card, Ticketing, animal tagging, Access, Laundry	Small item management, supply chain, Anti-theft, library, transportation	Transportation vehicle ID, Access/Security, large item management, supply chain	Transportation vehicle ID (road toll), Access/ Security, large item management, supply chain

Recap: Communication Interfaces

	NFC	RFID	IrDa	Bluetooth
Set –up time	<0.1ms	<0.1ms	~0.5s	~6 sec
Range	Up to 10cm	Up to 3m	Up to 5m	Up to 30m
Usability	Human centric Easy, intuitive, fast	Item centric Easy	Data centric Easy	Data centric Medium
Selectivity	High, given, security	Partly given	Line of sight	Who are you?
Use cases	Pay, get access, share, initiate service, easy set up	Item tracking	Control & exchange data	Network for data exchange, headset
Consumer experience	Touch, wave, simply connect	Get information	Easy	Configuration needed

http://www.oracle.com/technetwork/articles/javame/nfc-140183.html

Take-Away

- Connectivity mostly wireless
  - Easier installation and setup

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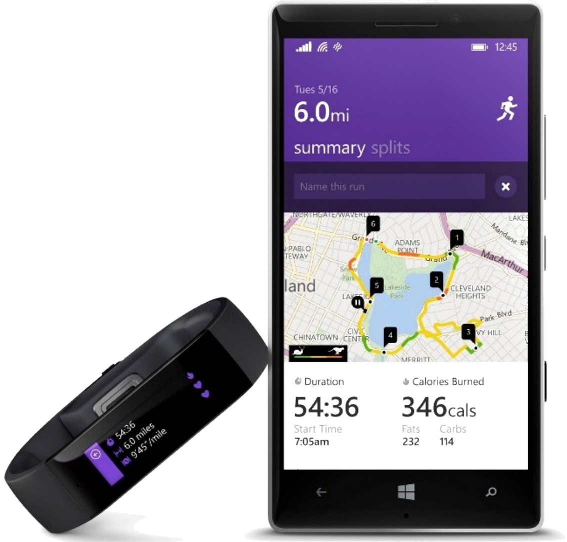
- No Wireless Band to rule them all

- Communication is crucial for UC

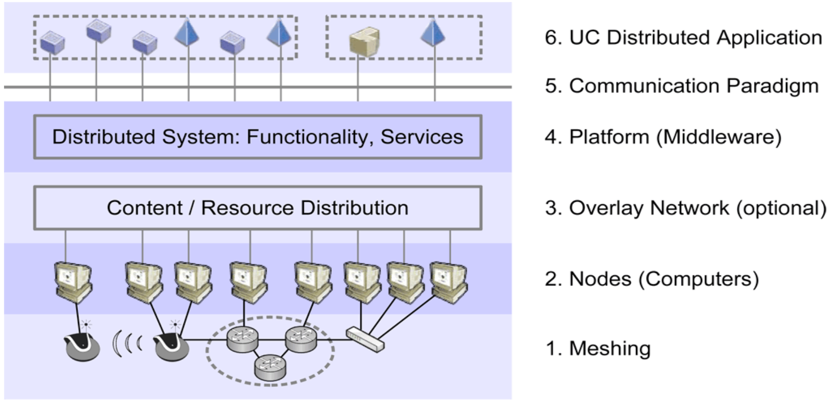
System Properties

1. Computers need to be networked, *distributed* and transparently accessible
2. Computer *Interaction* with Humans needs to be more *hidden*
3. Computers need to be *aware* of *environment context*
4. Computers can operate autonomously, without human intervention, be self-governed
5. Computers can handle a multiplicity of dynamic actions and interactions, governed by intelligent decision-making and intelligent organisational interaction. This entails some form of artificial intelligence.



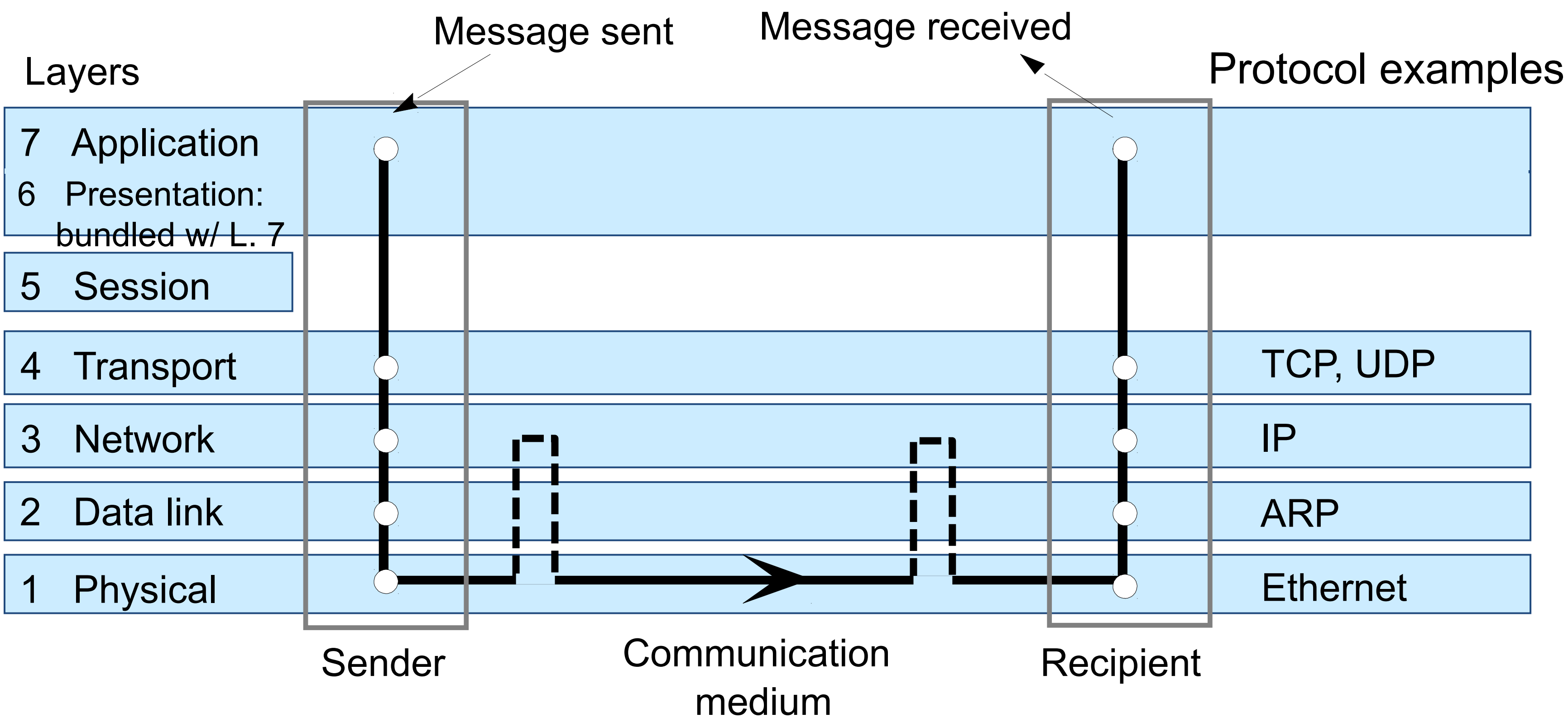
Introduction

- Background: Elaborate Disciplines of
  - Computer Networks: connect computers around the world
  - Distributed Systems: software infrastructure atop Computer Networks
  - Distinction? Not clearly defined, but Distributed Systems establish a level of transparency
    … of location, distribution, mobility, concurrency, …
- A rough layering of communication in UC:



Relation to IP stack is roughly: Layers 1+2 contain IP, layers 3+4 use IP

Internet Layer Architecture



Major Connectivity Approaches for UC

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1. **Meshing**: how to interconnect adjacent computers
   - Traditional networks: mostly wired, since ~1990: shared → switched media
   - UC: several wireless technologies - not all purposes served by a single one
     - increased importance of wireless networks
     - larger address space needed (cf. IPv6)
     - networks with Self-X capabilities: self-configuration, self-healing, …
     - mobility support, handovers, roaming (cf. Mobile IP)
2. **Nodes**: computers are resources added to system
   - Today: mostly considered homogeneous, except for client/server distinction; resources mostly under control of computer owner
   - UC: from general-purpose to special-purpose nodes
     - Resource heterogeneity will play a major role
     - Novel classes of nodes emerge, e.g.:
       - Federated computers: self-contained display + headset + PDA combined ad-hoc
       - „handles“: smart labels like RFIDs, pointing to the „digital shadow“ of everyday objects

Major Connectivity Approaches for UC

3. **Overlay Network**: adds an abstraction layer atop physical network
   - … to implement content-based addressing, caching/replication, fault tolerance, etc.
   - Today: used for special purposes, e.g., “content distribution”
   - UC: from “special case” to “standard case“
     - P2P networks: every participating computer is a “server” and adds resources to the system
     - Cloud Computing: users/enterprises rent fractions of datacenter → on-demand scalability

4. **Platform (Middleware):** everything that provides developers with a „powerful, easy-to-use“ distributed system
   - Today: bloated communication stacks (cf. Web Services), using solely TCP/IP
   - UC: several new challenges
     - Resource heterogeneity: super-lean platforms vs. rich functionality
     - Zero-effort deployment due to “zillions of nodes”
     - How to achieve interoperability in presence of many, competing middleware systems? (N platforms on my smoke detector?)
     - Novel common middleware services (industry-standard context server?)
     - Scalable support for communication abstractions, in particular: efficient event routing

Major Connectivity Approaches for UC

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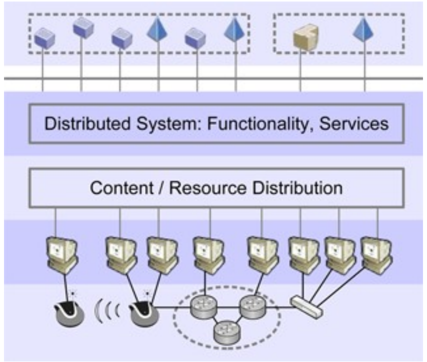
5. **Communication Paradigm**: abstraction crucial for programmers!
   - Today: mainly information pull, client/server paradigm
   - UC: evolution “pull -> push”
     - Scalable system architecture and scalable event routing algorithms
     - Standards for subscription languages? (use XQuery+XPath, SQL,...?)
     - Need for pull model remains – how to integrate?
6. **Distributed Applications** themselves
   - Today: rather “closed”, i.e., developed top-down by a team
   - UC: more open systems, service interoperability
     - further (exponential) growth in size, further diversification
     - How to better accommodate openness? (spontaneous integration of services provided by environment, service interoperability across multiple component vendors)
     - How to accommodate multimodal interaction?
     - „tapping into items“: reduce gap between real world state and enterprise information system (cf. RFID)
     - „tapping into humans“: reduce gap between humans (=subjects in a business process) and the information in the process engine (cf. order picking)

Meshing

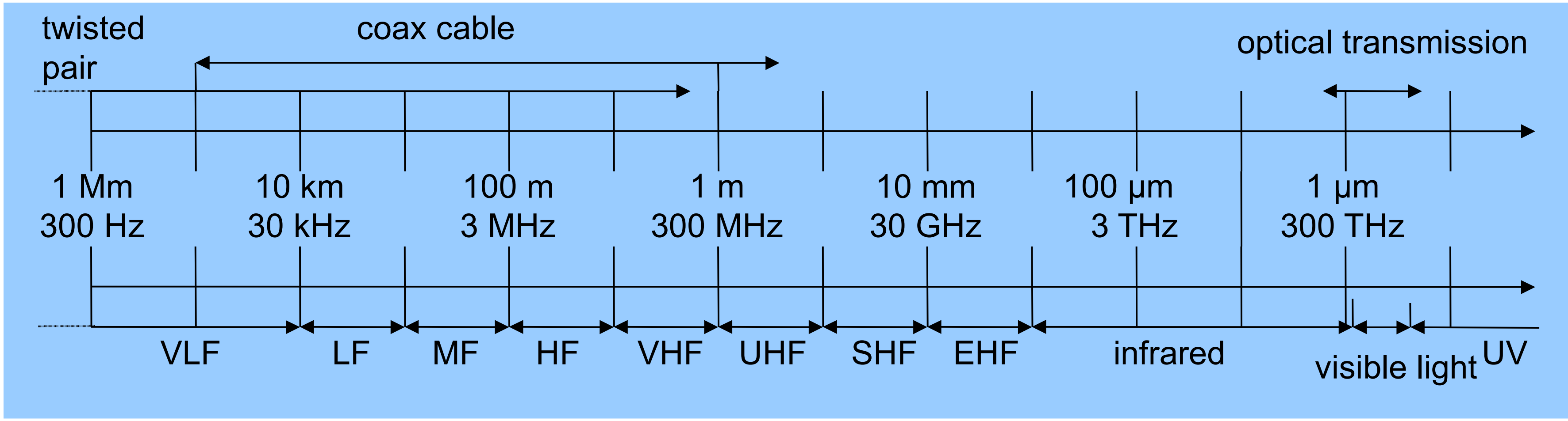


The basis of the basis: *wireless network technologies*

… and the basis thereof: some „physics“

(promise: understanding it will help a lot in understanding wireless technologies)

Electromagnetic Spectrum



- VLF = Very Low Frequency
- LF = Low Frequency
- MF = Medium Frequency
- HF = High Frequency
- VHF = Very High Frequency
- UHF = Ultra High Frequency
- SHF = Super High Frequency
- EHF = Extra High Frequency
- UV = Ultraviolet Light

$f * \lambda = c$
(c: speed of light, $3 * 10^8$ m/s)

note: above figure shows orders-of-magnitude (log)

rules-of-thumb (remember!):
1 MHz : 300 m
100 MHz : 3 m
10 GHz : 3 cm

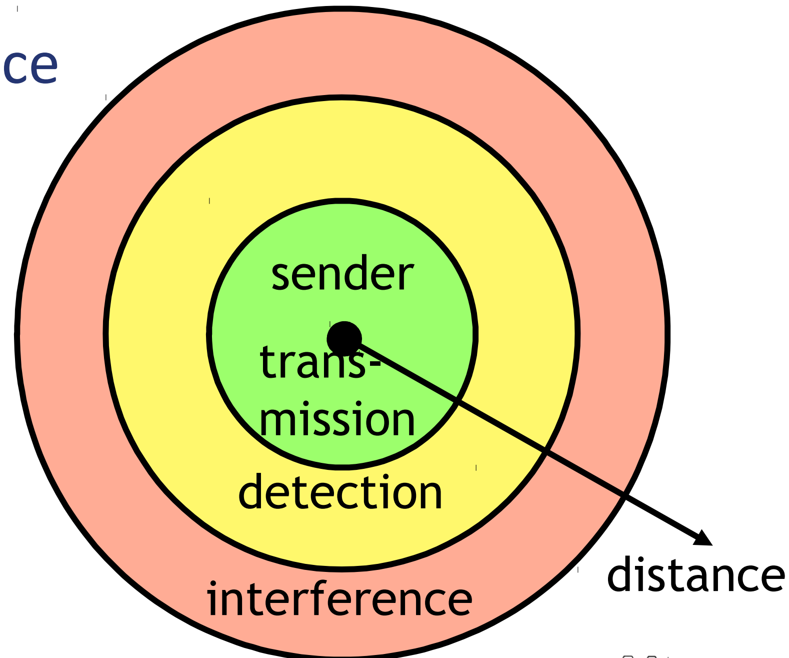
Data Transmission

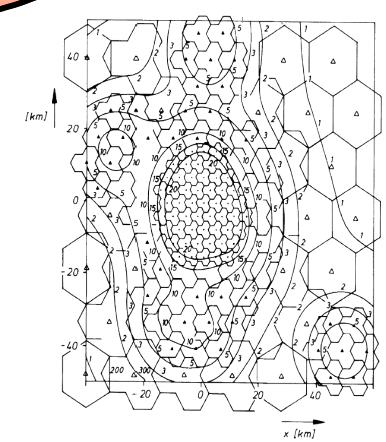
- Playground: Electromagnetic Spectrum
  - Above FM (e.g. FM-Radio, ~ **10^8** Hz)
  - Below visible light (~ **10^{15}** Hz) - in other words
    ~ microwaves 0.5 - 100 GHz or
    ~ infrared > 100 THz

- Rules-of-Thumb
  - higher carrier frequencies mean
  1. (-) needs higher energy, more difficult (expensive) electronics
  2. (+) fewer competing „networks“ (a mess up to 2 GHz, difficult up to 10)
  3. (+) larger bandwidths and/or # of channels
     –> higher data rates or more subscribers
  - **signal energy ~ data rate · reach**
    - related to: electrosmog, energy consumption, cost
  - **the higher the frequency, the more behavior resembles that of light**
    - very low frequencies: „surface waves“
    - medium freq: e.g., reflection at ionosphere ...
    - very high freq.: „line-of-sight“ (cf. shadowing, distortion...)

Wireless Transmission Effects

- Signal strength decreases with distance
  - Only in vacuum: signal strength ~ $1/d^2$ (Newton's inverse-square law)
- Signal propagation ranges
  - Transmission range
    - communication possible, low error rate
  - Detection range
    - signal detection possible, high error rate
  - Interference range
    - no signal detection, signal adds to noise
- Never circular shapes in real scenarios!
  - cf. cellular networks use higher cell density in city centers





Wireless Transmission Effects

Signal attenuation („path loss“) is crucial

- Function of distance d, landscape, obstacles (buildings, walls)
- Single most important difference to wired communications (most substantial effect on protocol design etc.)!

- A simple model for path loss (Friis transmission equation) (A: mean received signal power, related to transmitted power):
  - decreases w/ square of frequency
  - decreases w/ power-of-α of distance (α = 2 in free space, up to 5 in urban environment)

$$A = \frac{P_r}{P_s} = g \frac{1}{f^2 d^\alpha} \quad \text{(g: constant)}$$

A … amplification (1 / attenuation)

Basics: SNR, Decibel

„Design center“ of all networks (layer 1):

Signal-2-Noise-Ratio SNR (or S/R)

i.e., power of ‚signal of interest‘ related to power of ‚what disturbs‘

Decibel: unit used to express relative differences in signal strengths.

- Given: two signals with powers P1, P2
- → compute 10 * $\log_{10}$ (P1/P2)
- E.g.: P1 is 100 times P2:
  - P1/P2 = 100, $\log_{10}$ (100) = 2, ‚relation P1 : P2‘ is 20 dB
- ‚relation‘ may be: SNR; power sent vs. received (attenuation); ...
- E.g.: signal over 2 hops, no amplifier
  - attenuation is 20:1, then 7:1 → overall attenuation. is 140:1
  - or: 13.01 dB + 8.45 dB = 21.46 dB ($10 \cdot \log_{10} 20 + 10 \cdot \log_{10} 7 = 10 \cdot \log_{10} 140$)

(note: power is f(amplitude^2) → 20*$\log_{10}$ (A1/A2) yields same result

Wireless Transmission Effects

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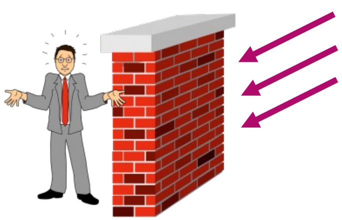
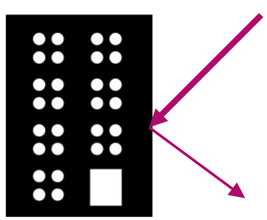
Signal path is crucial

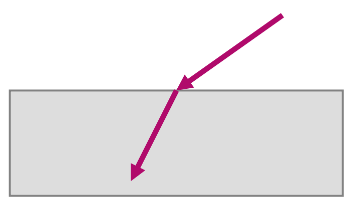
- Straight line only in open space (line-of-sight = LOS)
- Additional effects in real environments
    - Frequency dependent fading
        - Changes in signal power due to changing signal propagation paths
    - Shadowing (high frequency -> quasi-optical behavior)
    - Reflection at large obstacles
    - Refraction depending on medium density
    - Scattering at small obstacles
    - Diffraction at edges (relation wavelength : object size matters)



shadowing



reflection



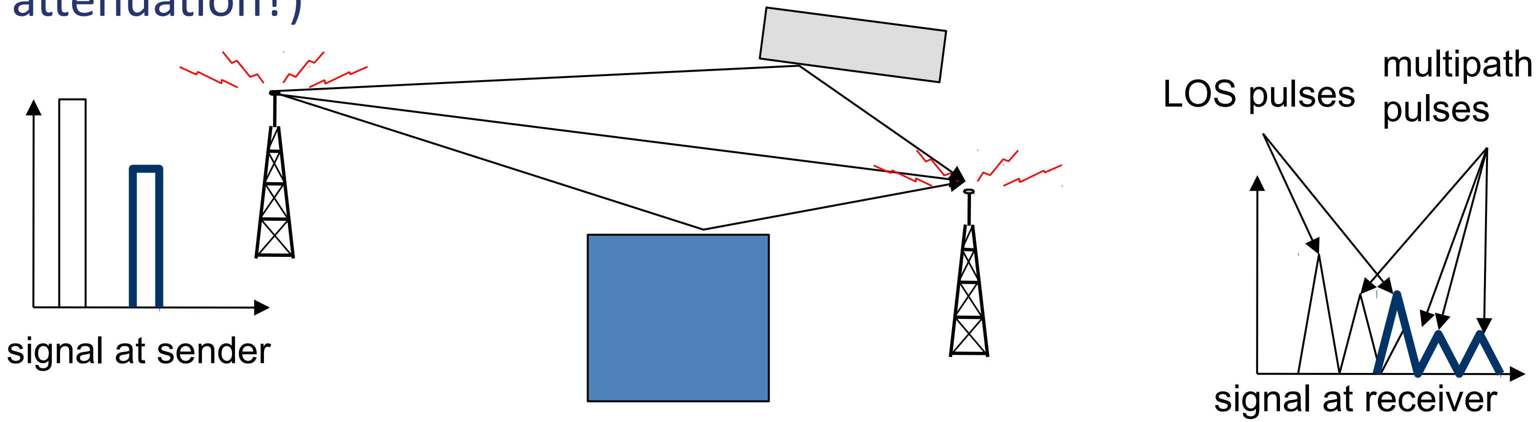
refraction

scattering

diffraction

Multipath propagation

- Due to multiple signal propagation effects, parts of a signal can travel along different paths → arrive at slightly different times
- Effect: **Inter-Symbol Interference (ISI)**
  - Different parts of different symbols may overlap
  - High data rate → reflections of symbol *n* interfere with symb. *n+i*
  - Consequence: **ISI limits data rate!**
- Considered big(gest) difference over wired Xmission (worse than attenuation?)



Wireless Transmission Effects

1. Path Loss → no listen-while-talk (LWT)

- Given goal: uncoordinated access of N senders to 1 medium
- Problem: collisions → detect, resolve
- Wire (Ethernet): LWT possible
  - during Xmit: if signal-on-wire ≠ signal-sent: → collision
- Wireless: LWT impossible (received signal much too low-energy)

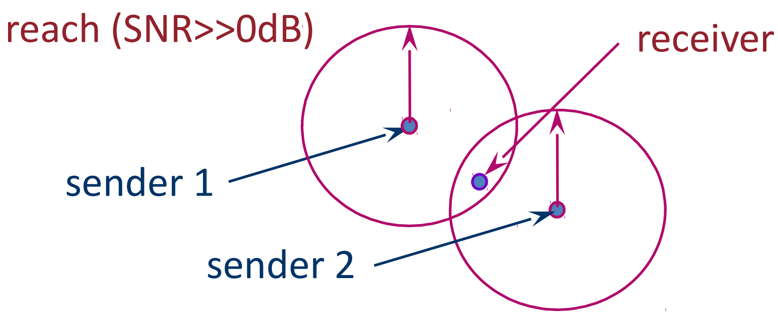
2. Path Loss → no full duplex traffic

- Wire: full duplex possible (2 peers use same wire)
- Wireless: needs two channels (= two carrier frequencies)
  - Mobile station MS → base (transceiver) station BTS: „uplink“
  - Base station → mobile station: „downlink“
  - (Satellite jargon)

Wireless Transmission Effects

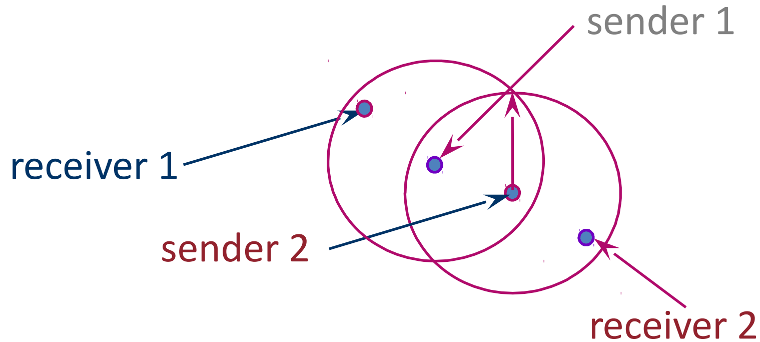
3. Hidden-Terminal Problem → listen-before-talk (LBT) may be too optimistic

- Given goal: uncoordinated access of N senders to 1 medium
- Problem: collisions → avoid by checking first if medium free
- In example:
  - S1 & S2 check: LBT o.k.
  - BUT: R experiences collision
    (S2 may also be in „shadow“ of S1)



4. Exposed-Terminal Problem → LBT may be too pessimistic

- In example:
  - Both S1 and S2 could send
  - But S2 senses S1 during LBT



Wireless Transmission Effects

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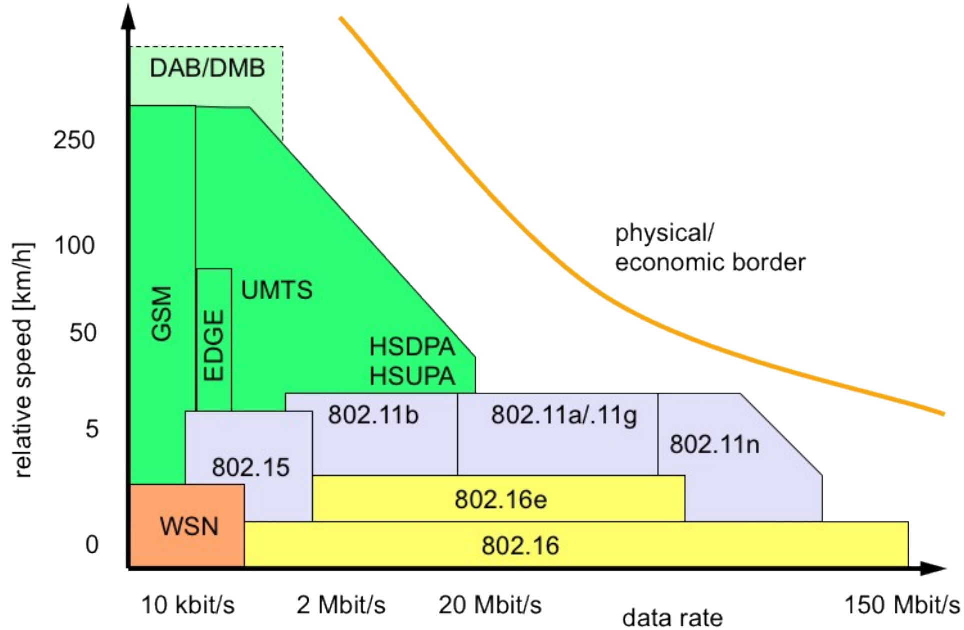
Doppler Effect

— speed

- Mobile sender stretches/quenches waves -> wireless technologies have a (mobility) speed limitation
  - Slow (walk): WLAN (Laptop), cordless phone
  - Medium (drive): cell phone < 250 km/h (high-speed trains need extension!)
  - Fast (fly): airplane phone system (uses satellites)



Wireless Transmission Effects

Signal Latency

- Often not an issue
  - In speed-of-light range: 2/3 c (air) ... 1/1 c (in space)
  - Depends (in range above) on altitude (air), frequency, ...
  - Example: GSM 9.6 kbps data or 10Mbps WiFi, 120B (SMS?) msg.:
    - GSM over 3km: 10^{-5} s latency, 0.1s transmission time – 4 orders of magnitude
    - WiFi over 30m: 10^{-7} s latency, 10^{-4} s transmission time – 3 orders of magnitude

- Often crucial (!)
  - Multipath → ISI (see above)
  - Timing, synchronization of stations, etc. (see later)
  - GPS etc.: calculation of distance, position
  - High tier antennas, in particular geostationary satellites:
    - 35.800 km orbit → up + down: some $7*10^7$ m, speed some $3*10^8$ m/s
      → ~ ¼ s delay
    - 1Mbps link: 120B „put on ether“ in only ~ 10^{-3} s

Multiple Access (xxMA)

Several stations (mobile stations MS, base transceiver stations BTS = cell towers) share ether

- Multiplex: Ether is „divided“, fractions (channels) are *assigned* to individual MS (xDM: x-division multiplex)
  - what is divided? frequency F (carrier/bands), time(-slots) T, etc. (below)
  - terms: frequency division multiplex FDM, time ... TDM, ...
- Multiple Access: (xxMA)
  - major issue is „how to assign fractions, how to share ...“
  - multiplex is *one* way, at link establishment (is there any?), (rather) fixed
    → each xDM is also called xDMA, synonymous
  - or: assignment is dynamic (on-the-fly, concurrent)
    - in many cases: methods (e.g., ALOHA) add distributed coordination to TDMA
- Multiple Access (xxMA) options:
  - *concurrent* (always decentralized): optimistic access („I think Ether is free“)
    - Collision? → “repair / retransmit”
  - *controlled-centralized:* BTS assigns „fractions“, informs MS
    - typical for cellular PLMN (GSM, UMTS, etc.)
    - but: how can MS tell „I am switched on“, „I am in your cell“?
    - usually, separate „channel“ for concurrent access
  - *controlled-decentralized:* for cases with no master (no BTS) → not for public mobile networks

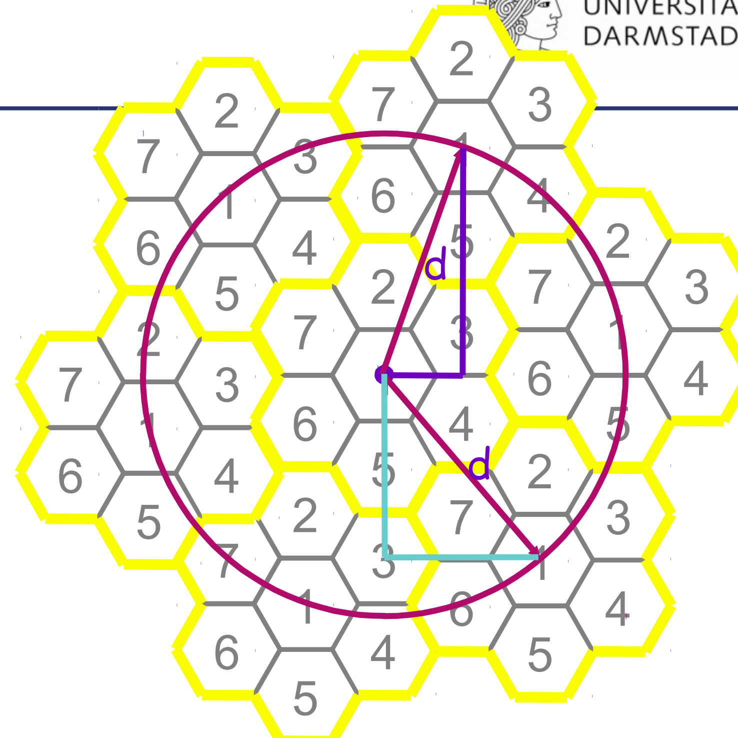
Multiplex / Multiple Access

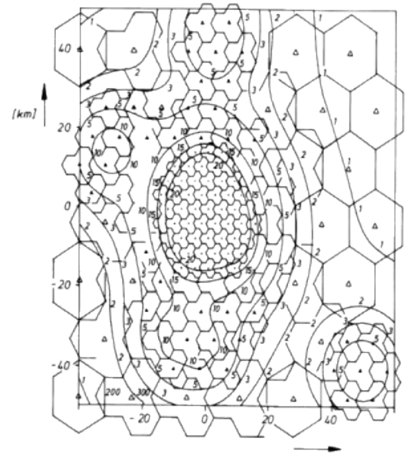
What is divided? ≥ four options (order ~ tech. complexity):

1. Space (SDM / SDMA):
   - „bands“ are re-used at a certain distance (remote cell)
   - attenuation → remote re-use won‘t interfere (much) with local cell
2. Frequency (FDM / FDMA):
   - different MS use different carrier frequencies
   - allocated frequency band divided into subbands
   - GSM900: 124*200kHz, GSM1800: 374*200kHz
3. Time (TDM / TDMA):
   - different MS use different time-slots
   - often: revolving frames, MS knows „its“ pos. (slot) in frame
4. Code (CDM / CDMA):
   - different MS use different „characteristic“ codes
   - receiver tunes to this code

Multiple Access: SDMA

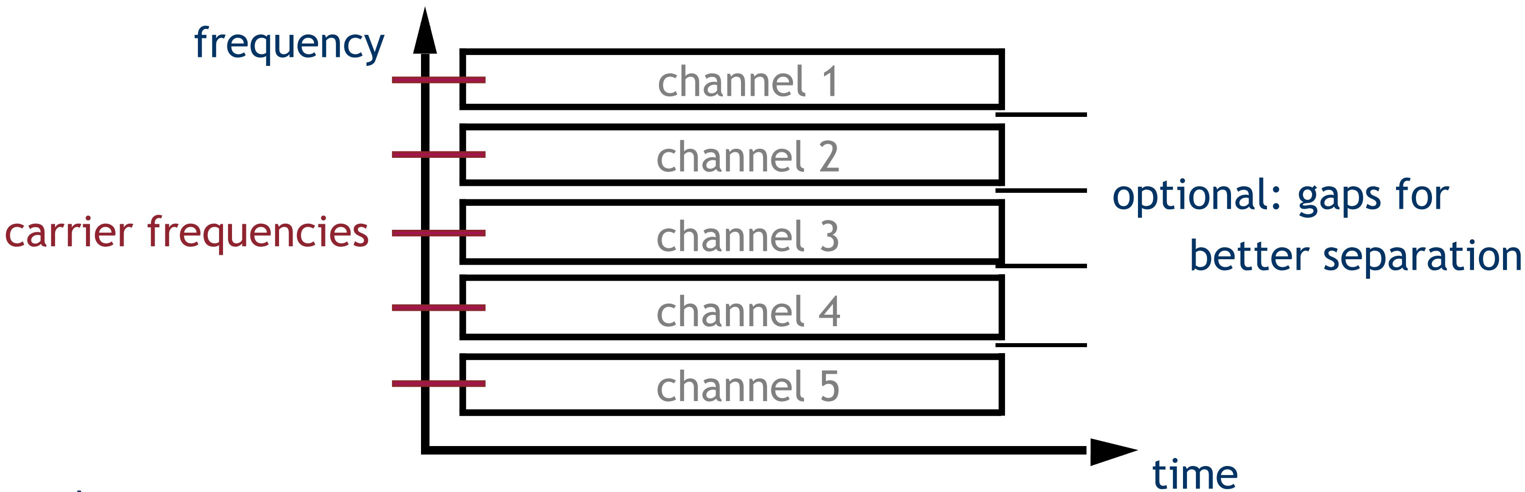
- SDMA (SDM): frequency bands re-used in remote cells
- Different re-use patterns possible: (repeated) clusters of cells
  - N = 3, 4, 7 (shown), 12, ... cells per cluster
  - Each band used only once per cluster
- Design parameters:
  - Reuse distance d=f(r,pattern)
  - Cell radius r (coverage)
- For different N (cluster sizes, patterns):
  - Different d/r ratios → different SNR induced by remote cells of same band
  - Tradeoff: 1/N of all bands usable per cell
- Again, remember realistic example (from Book by B. Walke):





Multiple Access: FDMA

Channels = subbands, distributed over available bandwidth



Example GSM900:

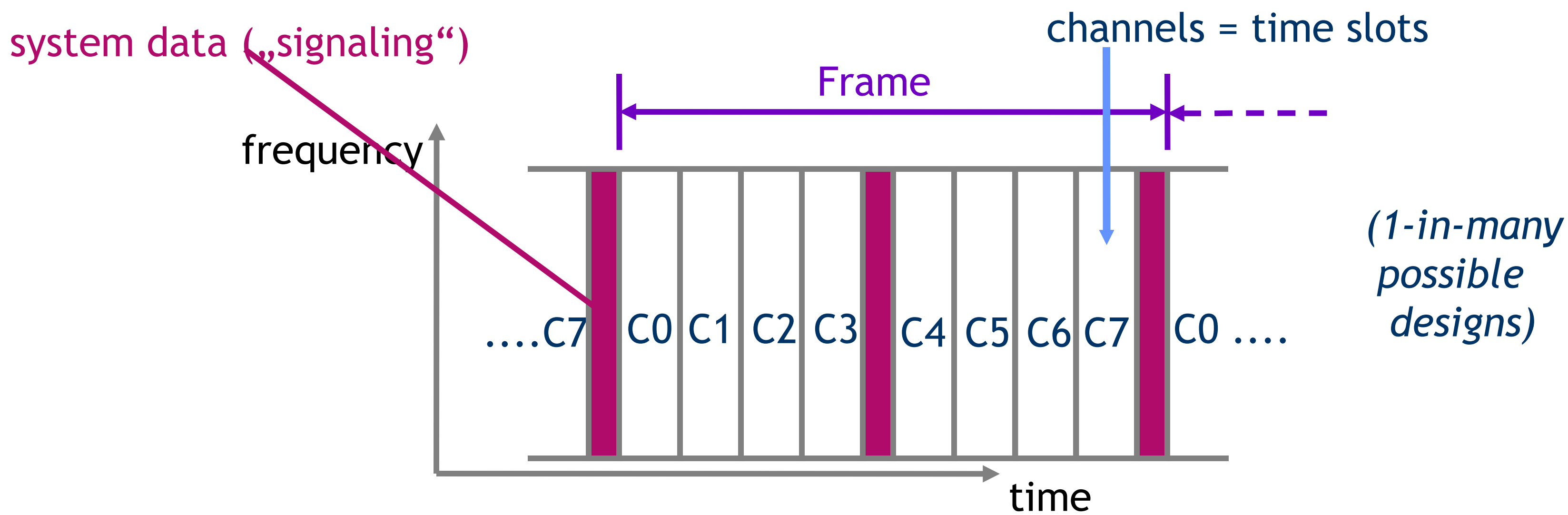
- Carrier frequency of uplink/downlink F_u/F_d:
  - $F_u(n) = 890.2$ MHz + (n-1) * 0.2 MHz, n=1 … 124
  - $F_d(n) = F_u(n) + 45$ MHz

Note: high-speed (wLAN, wATM etc.) → increasing use of OFDM:

Overlapping bands, orthogonal frequencies (harmonic distances of subcarriers, equals carrier distance) dyn. bandwidth assignment ...

Multiple Access: TDMA

- Entire frequency dedicated to single sender-receiver pair, but only for a short period of time (time slot, slice)
- Not applicable in analog transmission systems (old telephone net)
- E.g., 9.6 kbps per channel → > 80 kbps on ether for 8 channels
- GSM: 8 slots (TDMA+FDMA!)
- Practical systems: TDMA always w/ FDMA
- CON: Need for time synchronization



Multiple Access: CDMA

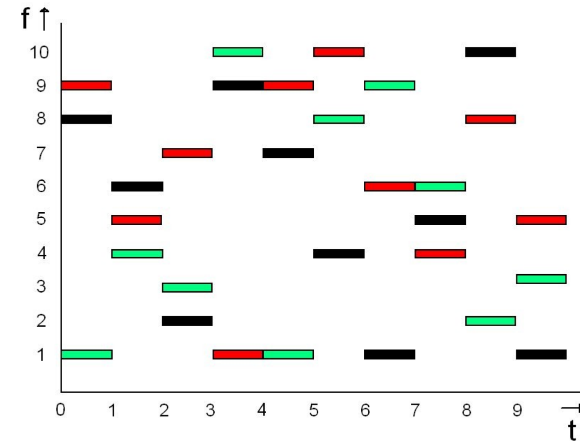
CDMA, also called „spread spectrum“ SS

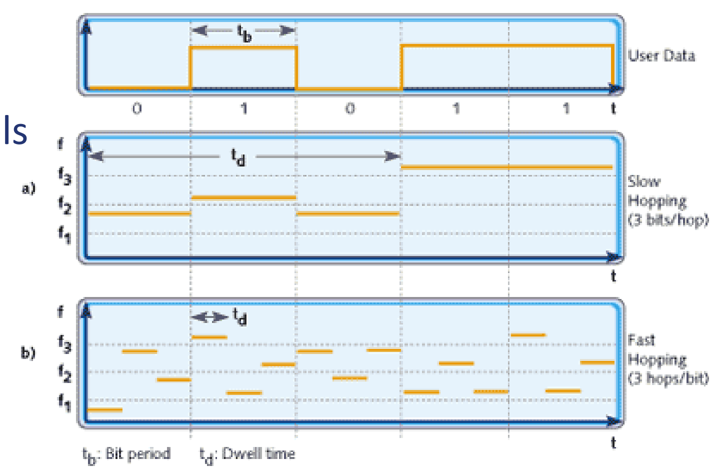
- Versions: FH (FHSS), DS (DSSS) (chaotic crosstalk, but not ‚concurrent‘!)
- Each sender uses “entire” bandwidth & time, „spreads“ code
- Wideband (W-CDMA): plus FDMA, but huge subbands (~5MHz)
    - Narrow (N-CDMA): smaller (~1MHz), but still >> FDMA+TDMA-subbands
- Receiver knows coding rules of sender:
    - Autocorrelations → transforms signal back (to lo-bandwidth/hi-power)
    - All other signals appear as noise (→ # of senders limited, cf. TDM,FDM)
- No channel assignment → simpler plus better spectrum utilization
  → used in wireless LANs, increasingly in PLMN
- No synchronization needed (each code is self-synchronizing)
- Problem: needs fine-grained transmission power control
    - E.g., MSes must adjust such that all signals reach BTS w/ ~same power
    - But: signal loss may change very fast (as MS moves)
    - IS-95 (USA Qualcomm): 1kbps „adjustment channel“ per MS

Multiple Access: CDMA-FH

Frequency-Hopping FH:

- Sender+receiver constantly change (hop-2-new) frequency
  - Basis: pseudo-random sequence, initial value agreed
  - Origin: military networks (sequence unknown→ secret comm.)
- „Hope“: few collisions → high probability of correction
- Fast-FH: several / many hops per bit
  - „a few“ collisions per bit don‘t harm
- Slow-FH: several bits per hop
  - GSM: optional (deterministic) slow-FH
    - Reason: distribute errors in „noisy“ bands over all channels
    - Hope: corrected by forward-error-correction FEC



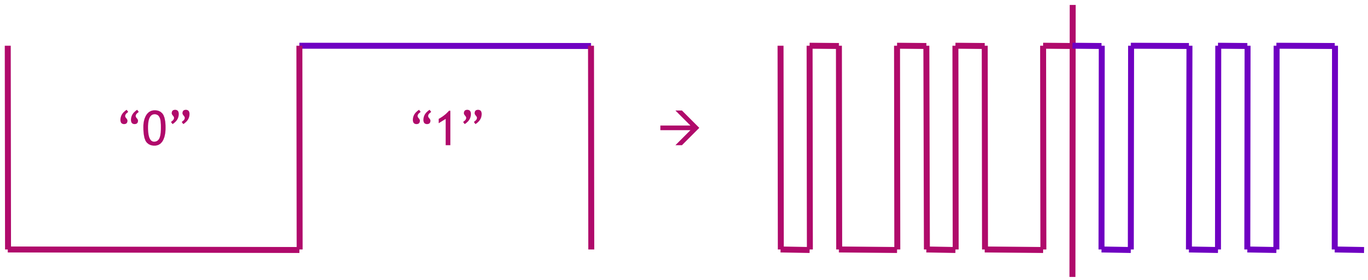


Hedy Lamarr (Hedwig Kiesler), US Pat. 1942 w/ George Antheil

Multiple Access: CDMA-DS

Direct Sequence (by far most commonly used today):

- Each bit mapped onto sequence of mini-bits (“chips”)
- 10 chips / needs 10 times higher data rate (reality: up to ~1000)
- Bit „1“ → chip-sequence, Bit „0“ → inverse sequence
- Receiver autocorrelates → reconstructs original signal
  - Again: secrecy is by-product (IFF chip-seq. per station is random) SNR near 0 → not even existence of communication detectable
  - Again: much more dynamic than FDM, TDM
  - Plus: no (‚expensive‘) synchronous frequency-hopping needed!

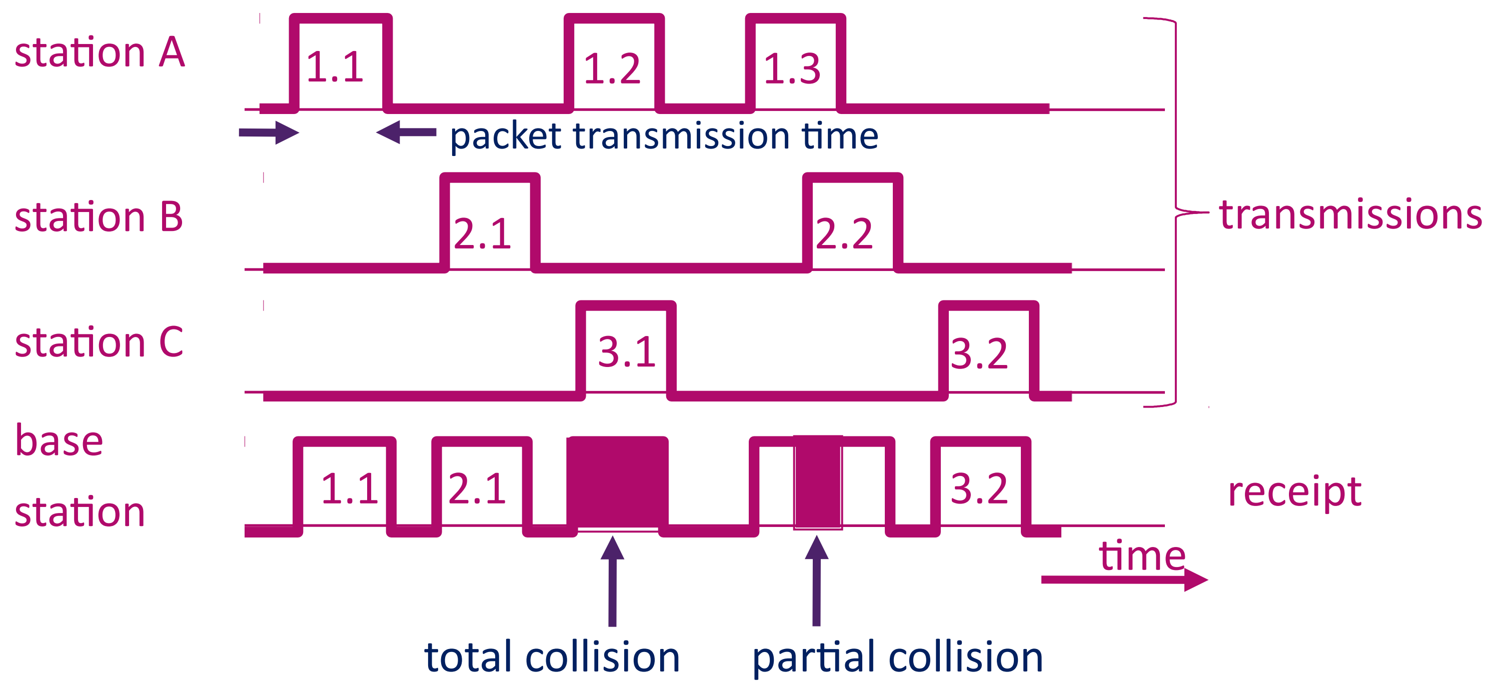


Concurrent Access: ALOHA

- Concurrent Access is mostly about 'coordinating' medium access over *time*
- Developed at U Hawaii (islands, hills!) since 1970:
  - Wireless net connects terminals(/hubs) ⇔ host system
  - Compares well to: MS ⇔ BTS
  - ‚grand father' of concurrent access schemes (wireless *and* Ethernet)
- Channels: 407,350 MHz uplink, 413,475 downlink
  - Concurrent access (ALOHA) on uplink only
  - Downlink: packets + acknowledgements (ACK) for uplink packets
- MS send whenever packet ready
- BTS sends corresponding ACK on downlink
- If 2-or-more MS send with time overlap → collision
  → BTS ignores „jam" received → no ACK
- MSes: timeout (no ACK received) → send again
  → collision repeated?
  No: since random „backoff" (waiting time)

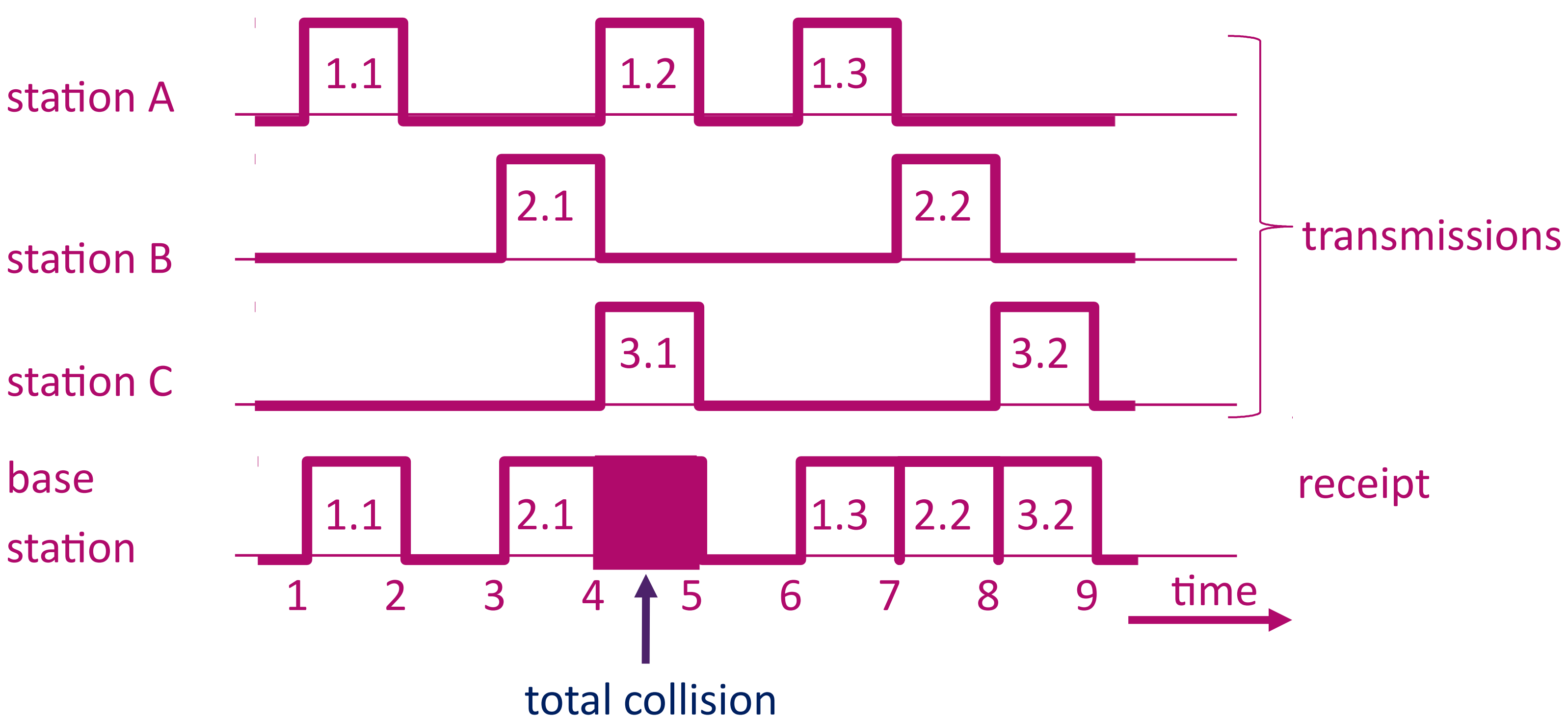
Concurrent Access: Pure ALOHA

- packets 1.1 (station A), 2.1 (B), 3.2 (C) transmitted ok
- packets 1.2/3.1 collide, 1.3/2.2 too (partial as bad as total!)



Concurrent Access: Slotted ALOHA

- Fixed (maximum) packet size, equals time slots
- common clock for slots (xmitted at downlink → latency was rel. low)
- start xmit w/ slot only (end ≤ slot end) → all collisions are total
- ‚surprise': mean throughput increased by factor of 2!
  - why? xmission slightly later, but ‚just hit'-overlaps avoided



Concurrent Access: CSMA

Idea: stations ‚sense' channel before sending

- CS = carrier sense („cs = on" means: channel busy)
- CS also called LBT = listen-before-talk

- Advantage: channel busy → somebody sends –> don't disturb
- Total avoidance of collisions? NO
  - MS_1 ready2send, MS_2 *just* started (signal has not arrived yet)
    –> MS_1: CS=off (no ‚busy' sensed) –> collision
- Collision probability high at end of a transmission:
  - several MS want to send, sense channel during CS=on
    - all MS realize CS=off → immediate xmit
  - CSMA variants therefore wrt. „when/how to start xmit"

Concurrent Access: CSMA variants

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Major distinction: procedure applied when station is ready2send

1. non-persistent:

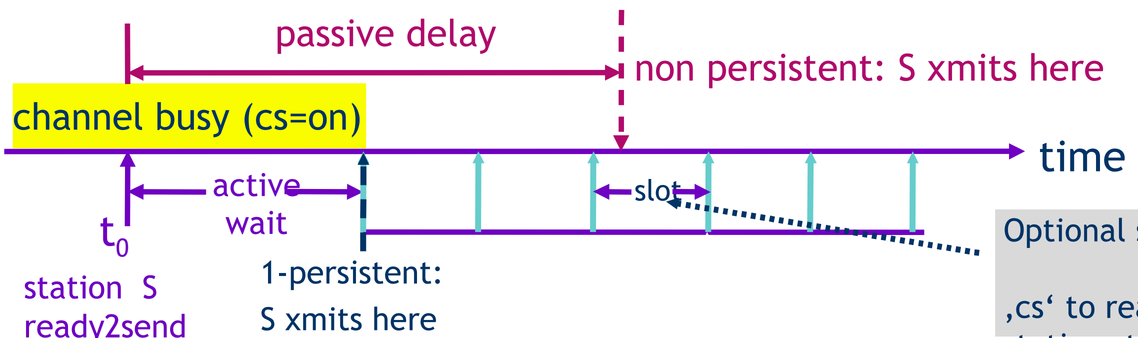
```
snd:  while <cs=on> DO < delay (t)> ;      /** t constant or random
      <send>;      /** no polling, no danger after end of Xmit
```

2. p-persistent:

```
snd:  WHILE <cs=on> DO <active wait>;      /** usually: cs=off→ interrupt
      IF <random-bool(p)> THEN <send>  /** true with probability p < 1
      ELSE { <delay t>; GOTO  snd }       /** t may be random # of ‚slots‘
  /** lower p reduces probability of ‚competition‘ after end of xmission
```

3. 1-persistent: (the one used for 'wired' Ethernet = CSMA/CD – LWT is possible there!)

```
snd:  WHILE <cs=on> DO <active wait>;      /** as above
      <send>;      /** high competition → backoff algo.
  IF <collision> THEN  {  /** here: binary exponential backoff
      IF <subsequent-collision> THEN T:=T*T ELSE T:=Tstart;
      <delay (random(0,T)>; GOTO  snd  } /** heavy traffic: interval grows exp
```

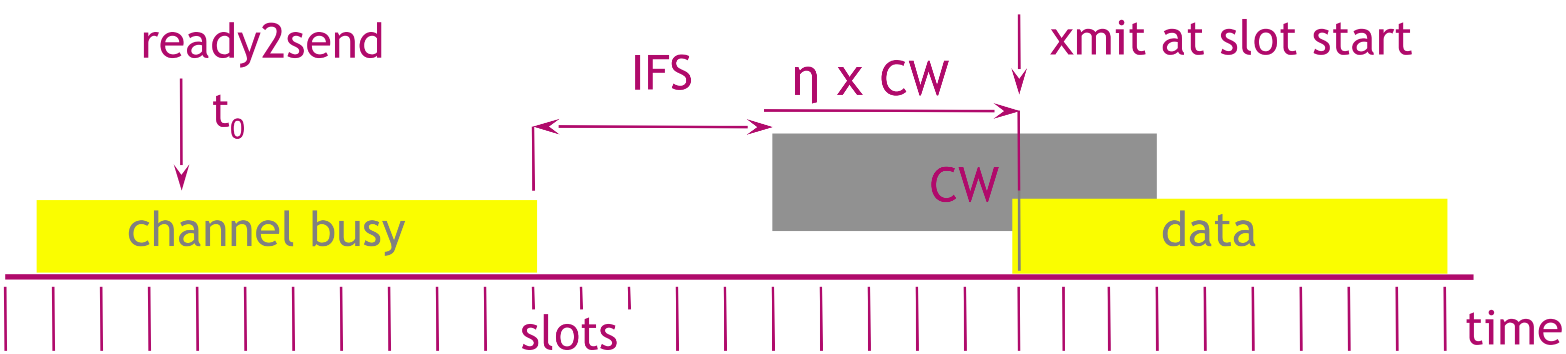


Optional slotting; *Reason:* slots large enough for ‚cs‘ to reach all stations → no collision if other station starts earlier (successful as CSMA/CA)

Concurrent Access: CSMA/CA

- CA = collision avoidance; several minor variants
  as described here: ≈ slotted variant of p-persistent CSMA with p=0
- Contention window CW = time interval considered collision intensive
- After active wait; cs=off → delay during IFS (interframe spacing)
  - minimum IFS determined by wireless signal latency
  - 3 different IFSs (signal/priority/data: SIFS, PIFS, DIFS): priorities
- Then:
  - draw random $\eta \in [0,1)$
  - wait for slot that ‚contains' time $\eta \cdot$ CW (active wait: maybe cs→on)

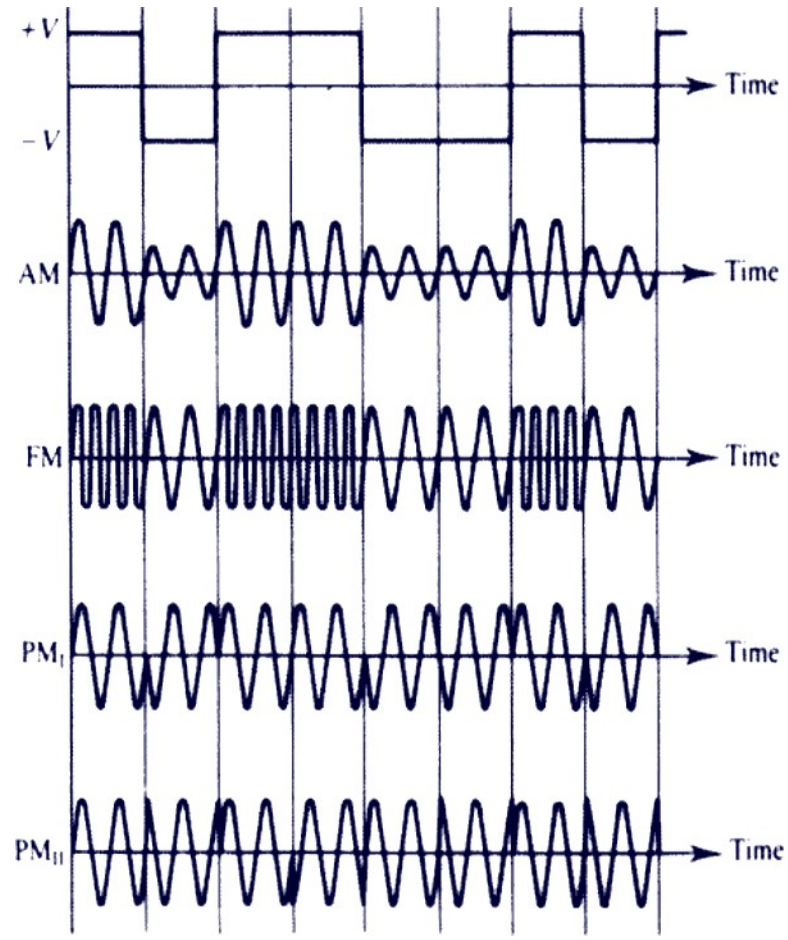
    η → risk of collision ‚spread' over CW
  - if still collision → increase CW exponentially (up to maximum)
- Fairness: if preceded by other station, # of slots waited count next time



Modulation

Low bandwidth → needs
highly efficient modulation

- Known: carrier frequency:
  - s(t) = A·sin (2πf · t + φ)
  - bits modulate amplitude A, frequency F, phase φ (P)
  - A/F/P-„modulation“ AM, FM ...
  - also: shift keying ASK, FSK, PSK
  - A→F→P: better, more complex



Data Rate vs. Signaling Rate

Signaling rate:

:= number of times per time unit (second) the signal parameter may change (usually isochronous)

v_S, measured in **bauds** (1/s), symbols/second

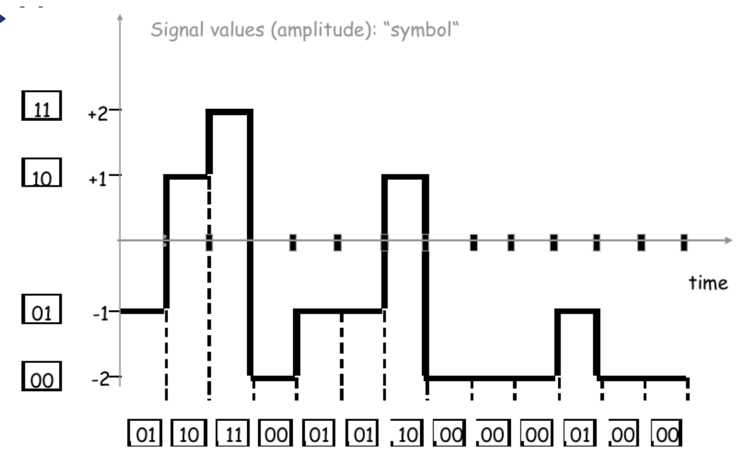
Data rate:

:= number of bits transmitted per time unit (second)

v_B, measured in **bits per second** (bit/s)

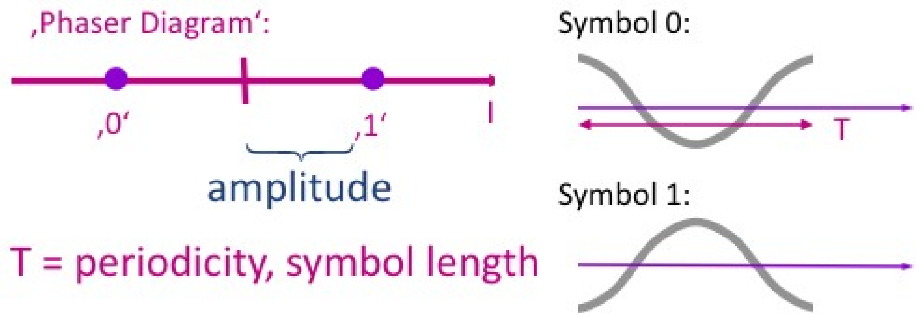
Question: how many **bits** per **symbol**, i.e. $v_S \leftrightarrow$

1. binary signal: $v_B = v_S$
2. synchronization, clock, redundancy part of encoding: $v_B < v_S$
3. one symbol carries several bits (eg.: 00, 01, 10, 11): $v_B > v_S$
   - for symbol with n values: $v_B = v_S \, \mathrm{ld}\,(n)$
   - n = 2 (binary), 4 (quarternary / **DIBIT**), ...

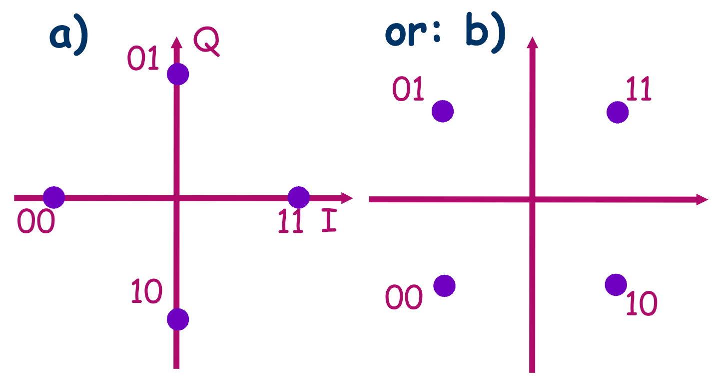


Modulation: PSK

- **Binary PSK** (BPSK; = old PSK):
  - phase change 0° or 180°
  - this is the simplest method;
    last 30 years: move to
    very sophisticated PSK!!

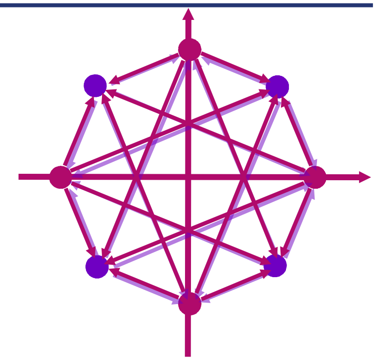


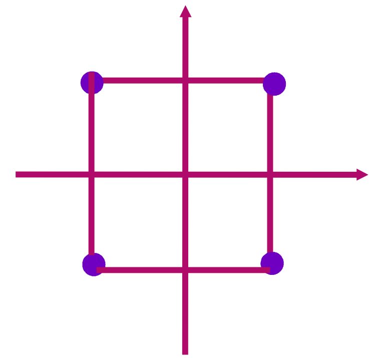
- **QPSK** (Q=quadrature):
  - 4 phases: 0°, 90°, 180°, 270° (a)
  - only phase changes, same amplitude
  - 2 bits per symbol (dibit)
  - Problem: 180° phase change
    -> zero crossing
    -> decoding at receiver problematic,
    because temporarily no carrier



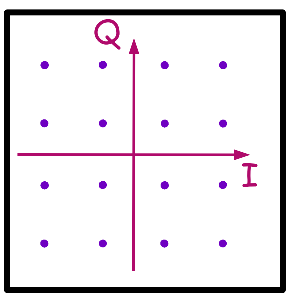
Modulation: PSK

- **π/4-QPSK**
  - add 45° phase jump after each symbol, independent of data
  - carrier signal always present
- **OQPSK**: Offset-QPSK
  - change of real part/imaginary part delayed by half symbol time
  - max. phase change reduced to 90°





- **QAM**: quadrature amplitude modulation
  = PSK + ASK
  - e.g., 16 values, 4 bits: I/Q-diagram for 4-QAM (‚optimal' I/Q-diag on 2 amplitude ‚rings'? or else?)
  - wired-modem 4-QAM example (9600 baud): 12 phases, 4 phases w/ 2 amplitudes
  - 16QAM and 64QAM exist (need good SNR)

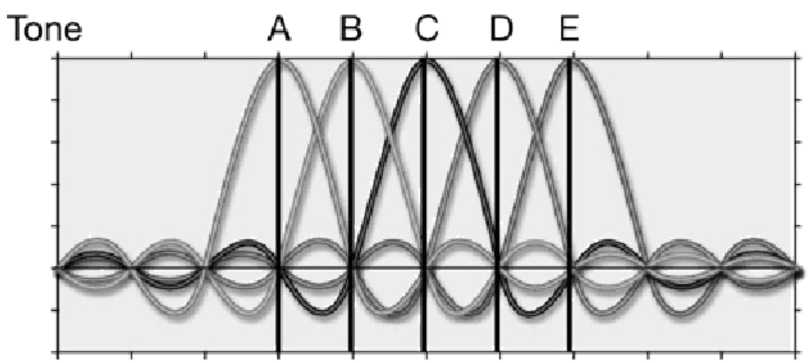


Modulation: OFDM

- **Orthogonal FDM** (OFDM) --- called OFDMA if used to multiplex multiple channels
  - Large number of closely-spaced, orthogonal sub-carriers used for transmission
  - Minimizes crosstalk between carriers
  - When A is at peak, B, C, D, E are all zero
  - Sub-carriers use "conventional modulation" (e.g., 16QAM)
  - N slowly-modulated narrowband signals instead of 1 rapidly-modul. broadband signal
  - For a single fast bit stream: serial-to-N*parallel, then each of N slower signals controls one carrier frequency → IFFT applied → „integrated" signal transmitted
  - Condition for orthogonality:

$$\boxed{\Delta f = \frac{1}{T_S}} \approx \frac{B}{N}$$

Δf … sub-carrier spacing
T_S … symbol length (time)
B … bandwidth
N … number of sub-carriers



When A is at the peak, B, C, D and E are all zero.

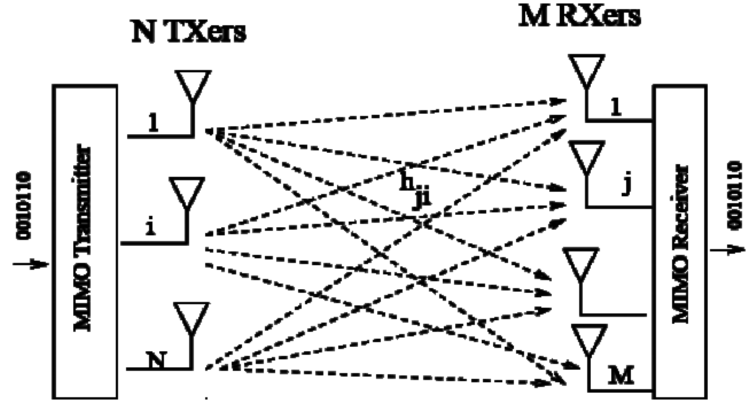
Modulation: OFDM

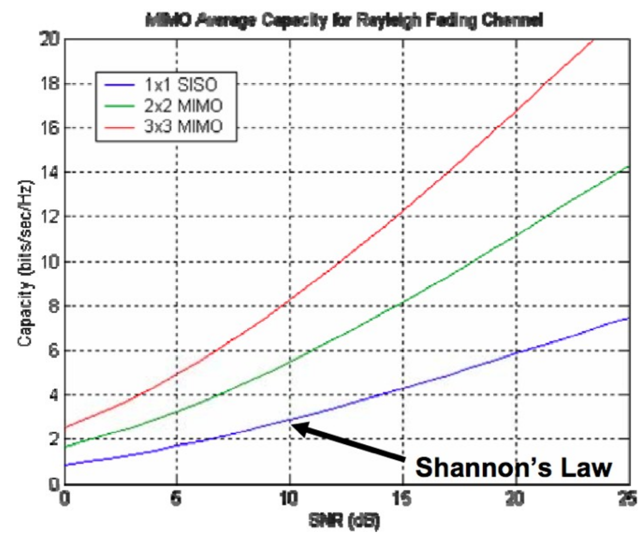
- Primary advantage of OFDM: ability to cope with severe channel conditions

	single rapidly-modulated broadband signal	**OFDM: many slowly-modulated narrowband signals**
intersymbol interference	inevitable for reasonable bitrates	can be reduced or eliminated
narrowband interference	destroys whole signal	sub-carriers can be selectively disabled
frequency-selective fading	requires complex channel equalization	equalization simple, because sub-carriers are narrowband and separated
spectral efficiency	space multiplex = „waste of spectrum“ (cf. SDMA reuse patterns)	Single Frequency Networks
complexity of RF electronics	low...medium (depends on modulation)	computationally very complex (-> energy!)

MIMO

- Multiple Input Multiple Output (MIMO)
  - „Multipath is not enemy, but ally“
  - Uses multiple antennas at transmitter and receiver -> N x M signal paths
  - Variety of paths is a result of objects in the environment
  - Moving antennas even a small distance -> paths will change
- MIMO channel matrix H
  - h_{ij} are complex numbers (amplitude + phase)
  - Number of spatial streams: rank(H) ≤ min(M, N)
  - Line of sight? -> rank(H) ~ 1 !
    -> **MIMO requires multipath to work!**
  - Estimation of H is difficult; ‚multipath resilient‘ modulation helps -> combine MIMO with OFDM
- MIMO capacity
  - Capacity improves linearly w/ antenna pairs
  - Same data is coded & transmitted through different antennas
    → multiplies power in the channel
    → improves SNR





Wireless Classification

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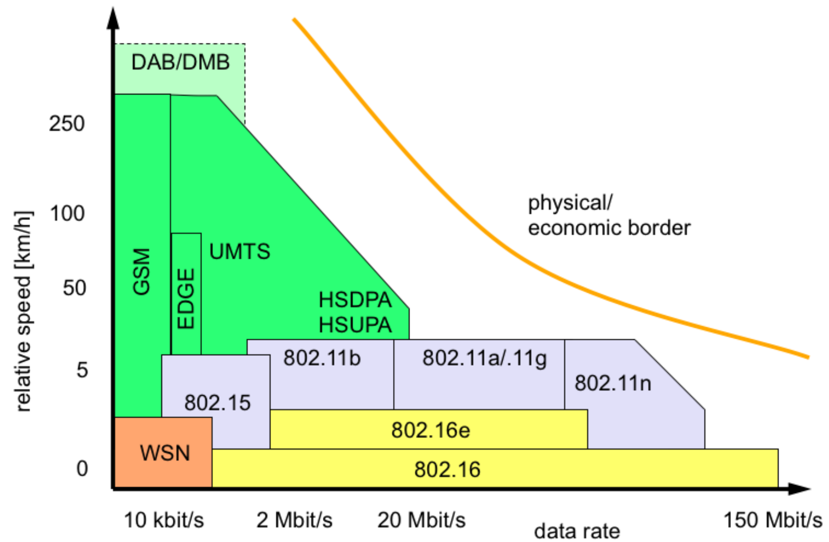
- Five major most relevant classes of wireless (non broadcast) networks:
  - Wireless Wide Area Networks
    - GSM, UMTS, LTE
  - Wireless Distribution Networks
    - WiMAX, LTE
  - Wireless Local Area Networks (WLAN)
    - 802.11
  - Wireless Personal Area Networks (WPAN)
    - Bluetooth, (ZigBee)
  - Wireless Sensor Networks (WSN)
    - ZigBee
  - Near Field Communication (NFC)
    - RFID enhanced(introduced in chapter 2)



- Note: we use this classification here;
  - in general: „acronym / classification Babylon reigns!“
  - „4G convergence“ → maybe this looks different in 5-10 years