Telecooperation Lab
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TK3: Ubiquitous Computing

Chapter 2: Infrastructure

Part 2: Communication Technology

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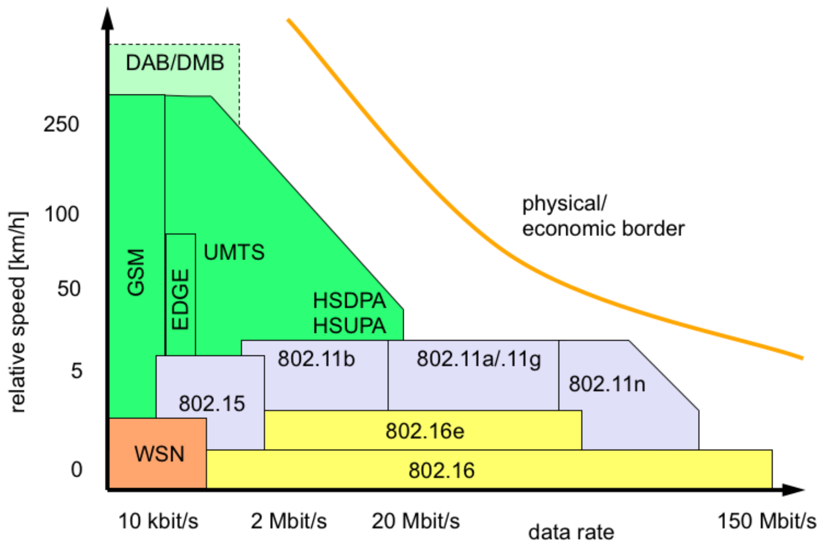
Wireless Classification

- 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), NFC
  - Wireless Sensor Networks (WSN)
    - ZigBee



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

Wireless Wide Area Networks

- Development from 2G to 4G (user data rates)
  - GSM (2G): 9.6/14.4 kbit/s
    - GSM+GPRS (2.5G): 53 kbit/s (downlink)
    - GSM+EDGE (2.5G): up to 384 kbit/s
  - UMTS (UTRA FDD/W-CDMA, 3G): up to 384 kbit/s
  - UMTS+HSDPA (3.5G): up to 1.8 Mbit/s first, meanwhile 3.6 and 7.2
  - LTE (3GPP) (marketed as 4G, not according to IMT standards):
    Peak Upload: 75 Mbit/s Peak Download: 300 Mbit/s
  - LTE Advanced (4G): Peak Upload: 500Mbit/s Peak Download: 1Gbit/s
- Data rates depend very much on
  - Mobility, direction (uplink/downlink), signal strength, cell load, error rate
- Other systems
  - cdmaOne (2G), cdma2000 1X (2.5G), cdma2000 1X EV-DO (3G)
  - Unidirectional (broadcast) systems – as an addition: DVB (-T, -H), DMB

Basics: Cellular Networks

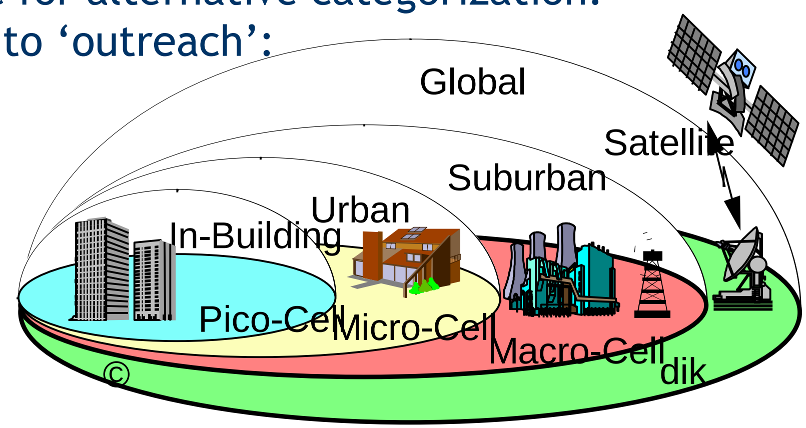
For our lecture: a) cell sizes (roughly) categorized according to radius, e.g.:

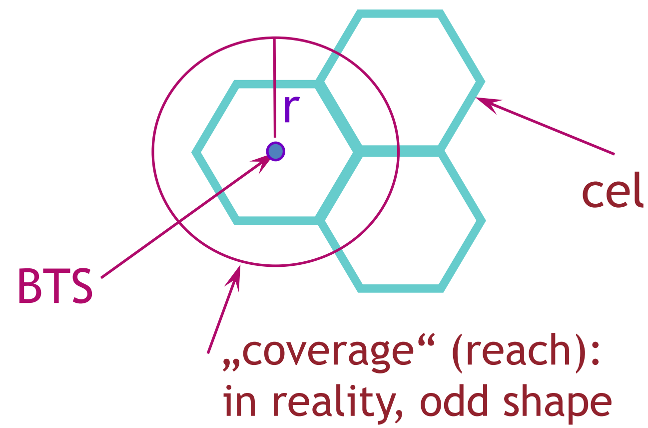
▪ pico:	r = 50 m	private (home, office)	PicoNet
▪ micro	r = 500 m	inner city (many users)	WLAN, PLMN
▪ macro	r = 10 km	‚standard GSM‘; city, road	PLMN
▪ hyper	r = 30 km	rural area	PLMN, HALO
▪ overlay	r = 200 km	high tier antenna coverage	HALO, LEO

- PLMN: Public Land Mobile Network; LEO: Low Earth Orbit (Satellite)
- HALO: High Altitude Long Operations; flying/floating platforms

Many categorizations of “cell sizes” exist: LTE “femto cell” is privately operated BTS i.e. “pico” above

b) one example for alternative categorization:
according to ‘outreach’:





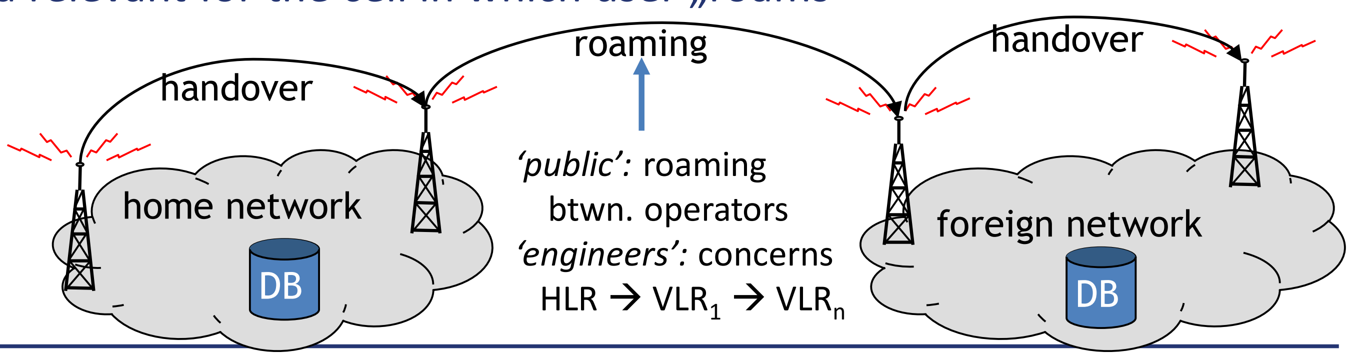
Basics: Cellular Networks

Roaming (option in cellular networks, some degree always supported):
- MS may move freely between cells, even (!) switched-off
- MS are "found", identified upon switch-on (cf. incoming calls)

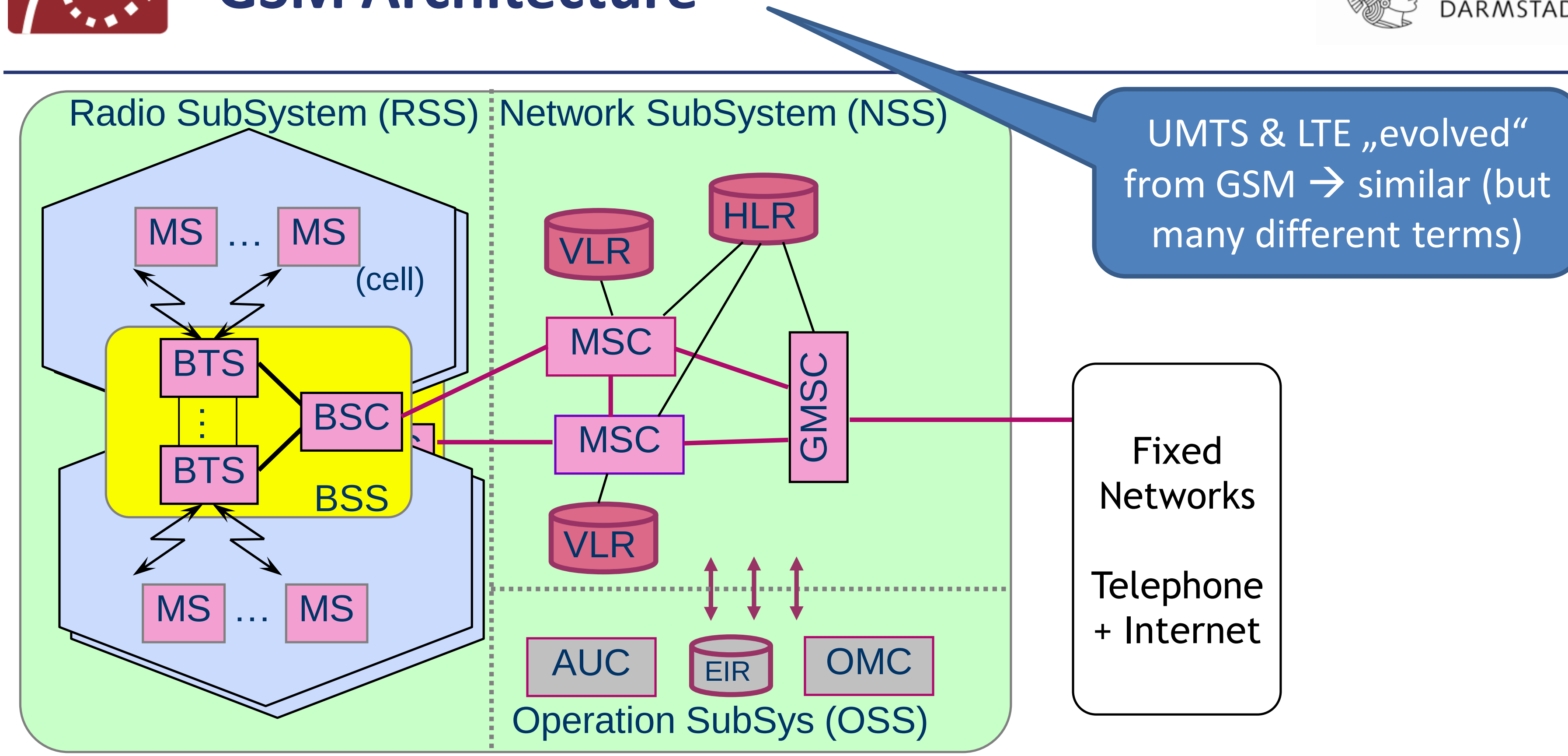
Handover (option in cellular networks):
- cross cell boundaries during **existing connection** (mobile phone: active phone call)
- connection „handed off" to new cell …
- … w/o interruption & noticeable effect to user(s) [*might be* between operators, too]

Home location register **HLR**:
- each operator (T-Mobile, O2, ...) has at least one HLR
- holds all subscriber data: contract data, current location, ...
- holds pointer to current VLR

Visitor location register **VLR**:
- holds all admin. data relevant for the cell in which user „roams"



GSM Architecture



MS: Mobile Station

BTS: Base Transceiver Station

BSC/BSS: Base Station Controller / Subsystem

MSC: Mobile Service Switching Center

GMSC: Gateway MSC

VLR: Visitor Location Register

HLR: Home Location Register

AUC: AUthentication Center

EIR: Equipment Identity Register

OMC: Operation & Maintenance Center

GSM Overview

Origin: Intl. Telecom. Union ITU → Eur. branch CEPT → groupe spéciale mobile

Today: a) European standards rather by ETSI (telecoms + vendors +...)

b) name change: Global System for Mobile communication

- Frequencies: ⇧890-915MHz; ⇩935-960 (1710-85/1805-80; US: 19xx)
- Per frequency channel: 200kHz, 256kbps raw symbols + slot guard time
  - 8 slots → phys. channel: pair (freq. channel no. C_n; timeslot no. t_m), t_m=0..7
  - 32kbps raw symbols per channel; 24,7 kbps raw bits per channel
  - multiframes within (C_n, t_m): 26 (or 51) slots; x-in26/51: logical channels
  - Full rate channel: 24 of 26 slots → **22,8 kbps**
  - Half rate channel: 12 of 26 slots → 11,4 kbps
  - Full rate speech: 13kbps voice + 9,8 kbps FEC (forward error correction)
  - Full rate data: 2,4 / 4,6 / 9,6 kbps plus CRC plus FEC
    (CRC: cyclic redundancy check: checksum)

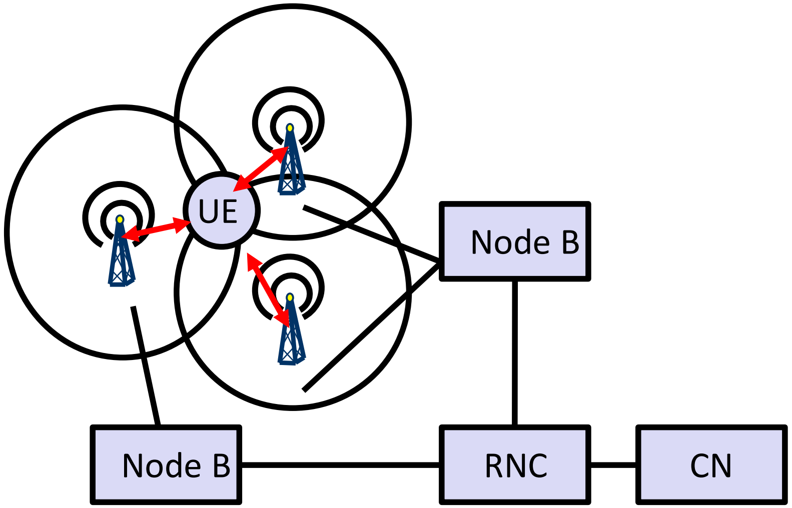
Data services in GSM

- CSD (Circuit Switched Data)
  - Data transmission standardized with only 9.6 kbit/s
  - Advanced coding allows 14,4 kbit/s
  - Not enough for Internet and multimedia applications
- HSCSD (High-Speed Circuit Switched Data)
  - Bundling of several time-slots to get higher AIUR
    (Air Interface User Rate), e.g., 57.6 kbit/s using 4 slots, 14.4 each
  - Advantage was: ready to use, constant quality, simple
  - Disadvantage: channels blocked (no voice transmission; cost!)
  - Disadv.: equipment not ready for simultaneous xmit/rcv → ≤4 (2?) slots
- GPRS (General Packet Radio Service)
  - Packet switching
  - Using free slots only if data packets ready to send
    (e.g., 115 kbps using 8 slots temporarily: 8*14.4)
  - Standardization 1998, introduction 2000

Wireless Wide Area Networks

- UMTS (Universal Mobile Telecommunications System)
  - One out of several 3G standards, but the most successful
  - Builds directly on GSM+GPRS infrastructure

- Components
  - Node B = BTS
    - Controls several antennas
  - RNC: Radio Network Controller
    - Controls several Node Bs
  - UE: User Equipment
  - CN: Core Network



UMTS vs. GSM

- Introduces CDMA (+)
  - Allows higher data rates
- Soft handover (+)
  - GSM: MS is only connected to a single BS (hard handover)
  - UMTS: MS can be connected to 3 BSes (soft handover)
- More intelligent and dynamic SDMA (+)
  - All cells can use the same frequencies
  - Multipath propagation treated similarly to receiving signal from different senders
- Requires tight power control (-)
  - Signals from different MSes must arrive with roughly same power at BS (requirement of CDMA correlation-based detection)
  - 1500 power control cycles/s
- Cell Breathing (-)
  - Sending with high data rate increases noise for other MSes
  - Other MSes must also increase power -> more noise
  - Devices at the edge reach max. power limit -> cell virtually shrinks

Data services in UMTS

- **HSDPA** (High Speed Downlink Packet Access)
  - uses 16-QAM instead of QPSK and multicode transmission
  - HS-DSCH (High Speed Downlink Shared Channel)
    - shared by all HSDPA users connected to the NodeB
    - dynamically shared between users
    - supports adaptive coding and modulation
      - 16-QAM and 5 codes -> ~ 3,6 Mbit/s (category 6)
      - 16-QAM and 10 codes -> ~ 7,2 Mbit/s (category 8)
      - more is hardly achievable under real conditions, but defined up to 84,4 Mbit/s (category 28)
- **HSUPA** (High Speed Uplink Packet Access)
  - uses 16-QAM instead of QPSK and multicode transmission
  - cannot use as many codes as in HSDPA, because more interference on the uplink channel
    - 16-QAM and 2 codes -> ~ 1,4 Mbit/s (category 3)

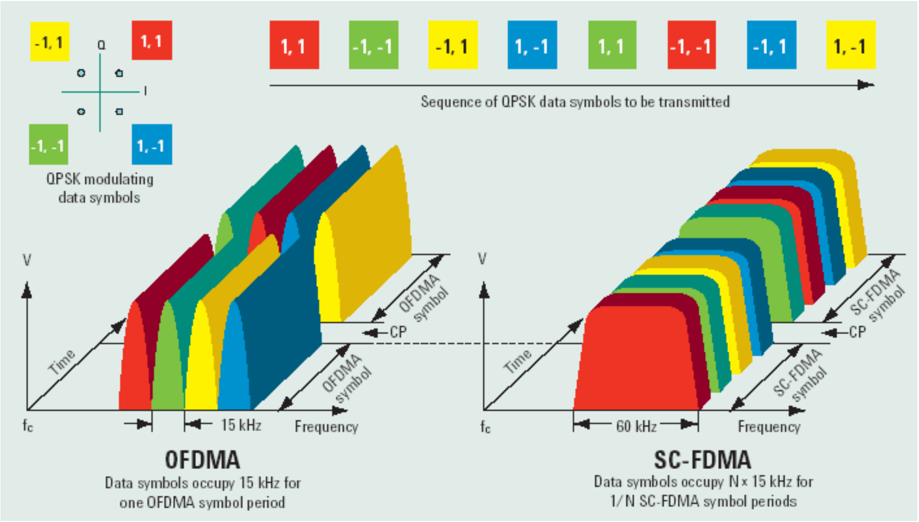
LTE

- Long Term Evolution (LTE): 3.9G, frozen with ‘release 9’ (2010)
  - *LTE-Advanced* starts with ‚release 10‘ (2011)
  - LTE builds on UMTS → aims to be a Wireless Wide Area Network
  - Many components of the 3G architecture can be reused
  - Uses different radio interface: CDMA → OFDMA & SC-FMDA
- LTE is an all IP network
  - Supports both IPv4 and IPv6
  - No basic provision for voice → use VoIP, or:
    - Several ‚evolutionary‘ substandards: combine 3G-for-voice w/ LTE-for-data
- LTE has lower latency: RoundTrip Time (RTT) ~ 10ms (HSPA: ~ 100ms)
- Includes/supports „almost everything“: FDD and TDD and …:
  - Broadcast (mobile TV) – not always implemented
  - Flexible allocation (blocks of subframes for limited time → fast bandwidth variation)
  - Large # of bands (from ~700 to ~3600 MHz), different bandwidths (1.4, 3, N*5MHz)
  - Various speeds (up to 500 km/h), cell sizes: ~100m … 100 km → rural „last mile“
  - LTE-Advanced (4G): largely asymmetric transmission up-/downlink

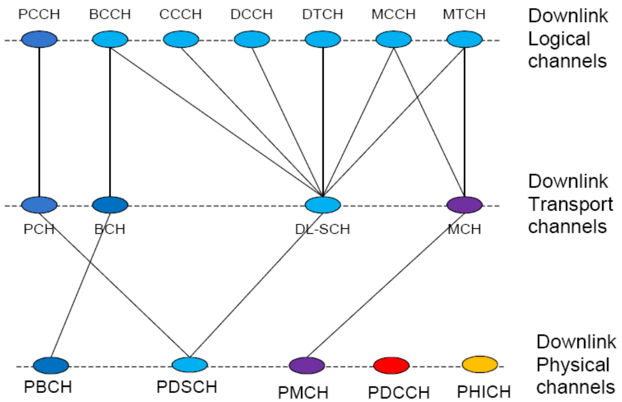
LTE (2)

- Downlink: OFDMA (OFDM multiple access)
  - peak downlink speeds using 64QAM [Mbit/s]: 100 (SISO), 172 (2x2 MIMO), 326 (4x4 MIMO)
- Uplink: SC-FDMA (Single carrier FDMA)
  - Reduced peak to average power ratio
  - Peak uplink speeds, in Mbit/s
    50 (QPSK), 57 (16QAM), 86 (64QAM)

(3-4x better spectral efficiency than HSDPA/HSUPA)

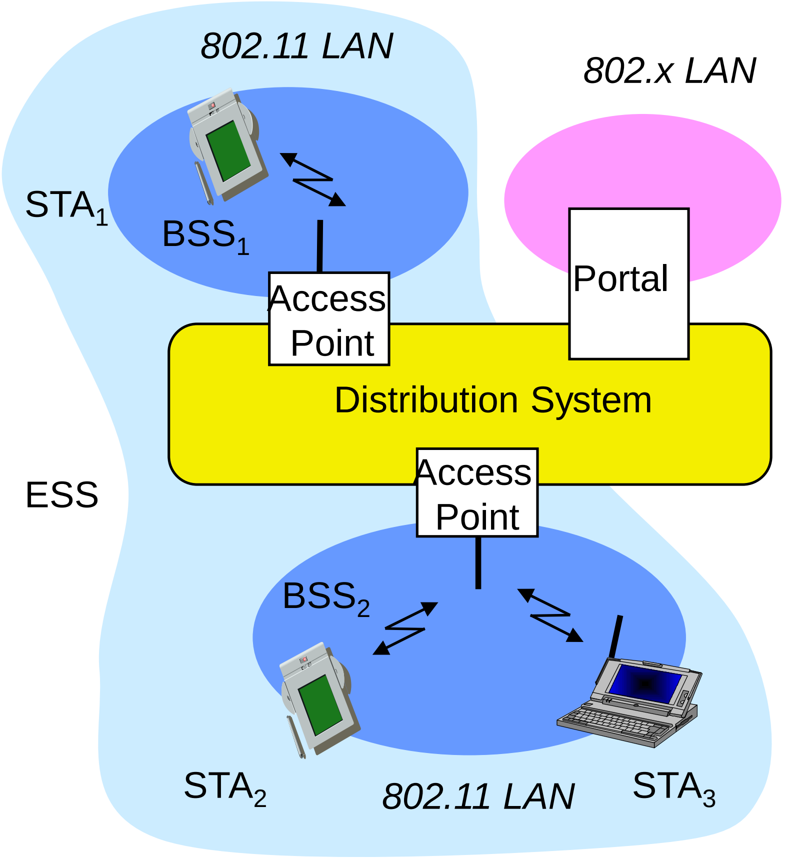


- 3-Layer Channel Multiplexing
  - Here, a glimpse at the downlink channels → →
- LTE-Advanced:
  - Coordinated beamforming, multi-carrier (spectrum aggregation), relay support, and more …



Wireless Local Area Networks (WLAN)

- IEEE 802.11 family of WLAN standards
  - supports "Infrastructure Networks" and "AdHoc Networks"
  - supports "WLAN cells" -> roaming
  - operates in unlicensed ISM bands (industry, science, med.)
  - Typically only best effort MAC, no service guarantee
- Infrastructure Network Architecture
  - Station (STA)
  - Basic Service Set (BSS)
    - group of stations using same radio freq.
  - Access Point
    - station integrated into WLAN and distribution system
  - Portal
    - bridge to other (wired) networks
  - Distribution System
    - interconnection net; one logical net = ESS: Extended Service Set based on several BSS



802.11: Standards

Standard	802.11a	802.11b	802.11g	802.11n
Year	1999	1999	2003	2009
RF Band (GHz)	5	2,4	2,4	2,4 or 5
Max. raw data rate (Mbps)	54	11	54	600
Modulation	OFDM	DSSS or CCK	DSSS, CCK or OFDM	DSSS, CCK or OFDM
# of spatial streams	1	1	1	1-4

802.11 ac: 2012+, 5GHz (2.4 for 11n compat.), >1Gbps, up to 8 spatial streams

- Modulations (FH was used in 'legacy' 802.11-1997, even Infrared was defined):
  - DSSS (Direct Sequence Spread Spectrum)
  - CCK (Complementary Code Keying) – DSSS variant, see later
  - OFDM (Orthogonal Frequency Division Multiplex)

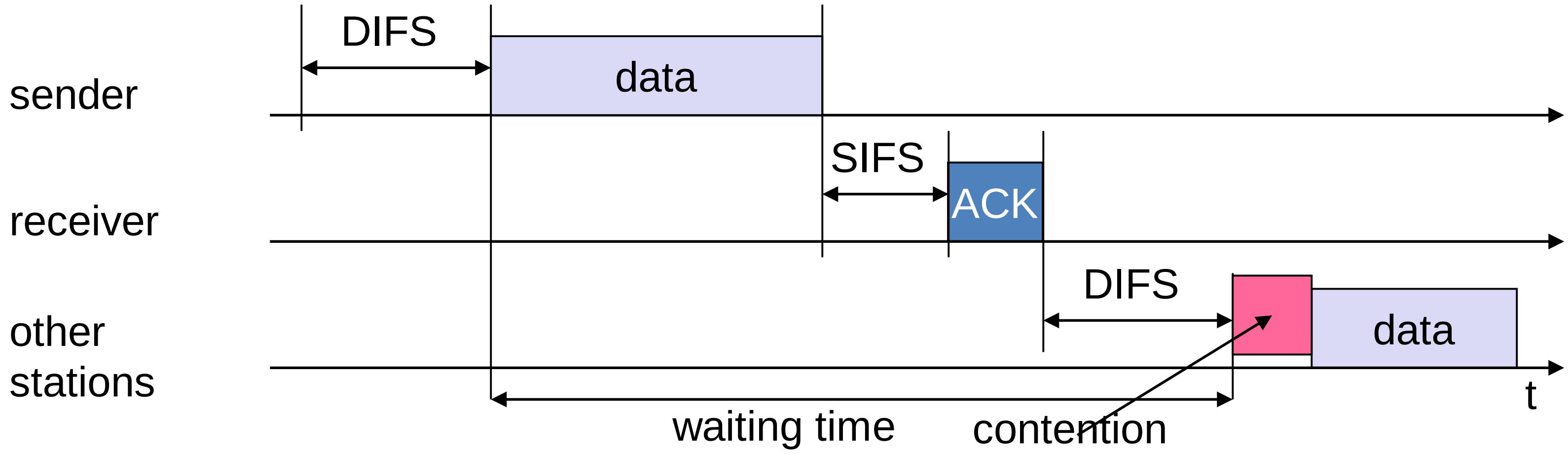
802.11 - MAC Layer

- Traffic services
  - Asynchronous Data Service (mandatory)
    - exchange of data packets based on “best-effort”
    - support of broadcast and multicast
  - Time-Bounded Service (optional)
    - implemented using PCF (Point Coordination Function)

- Access methods: DFWMAC = Distributed Foundation Wireless MAC (distributed „D“ or polling based „P“ access ctrl. functions DCF/PCF)
  - DFWMAC-DCF CSMA/CA (mandatory)
    - collision avoidance via randomized „back-off“ mechanism
    - minimum distance between consecutive packets
    - ACK packet for acknowledgements (not for broadcasts)
  - DFWMAC-DCF w/ RTS/CTS (optional)
    - avoids hidden terminal problem
  - DFWMAC- PCF (optional)
    - access point polls terminals according to a list

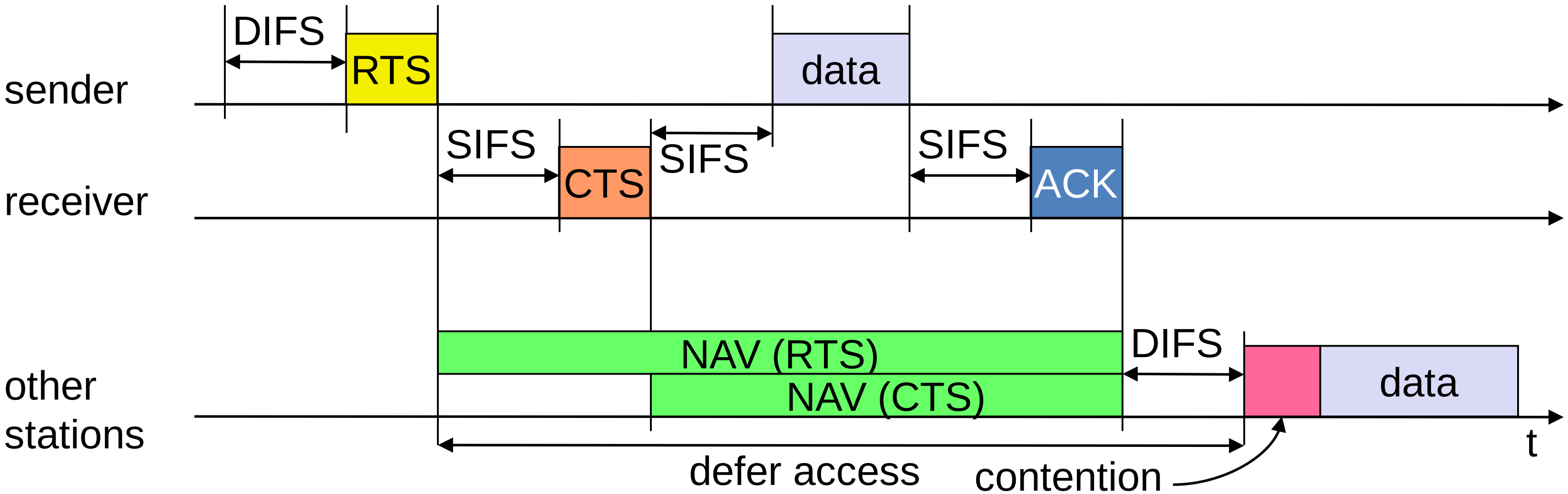
802.11 - CSMA/CA detail

- Remember: CSMA/CA
  - DIFS = Data Inter-Frame Spacing, SIFS = Signal Inter-Frame Spacing
- Here: acknowledging unicast packets
  - Station has to wait for DIFS before sending data
  - Receivers acknowledge at once (after waiting for SIFS) if the packet was received correctly (CRC)
  - Automatic retransmission of data packets in case of transmission errors



802.11 – DFWMAC w/ RTS/CTS

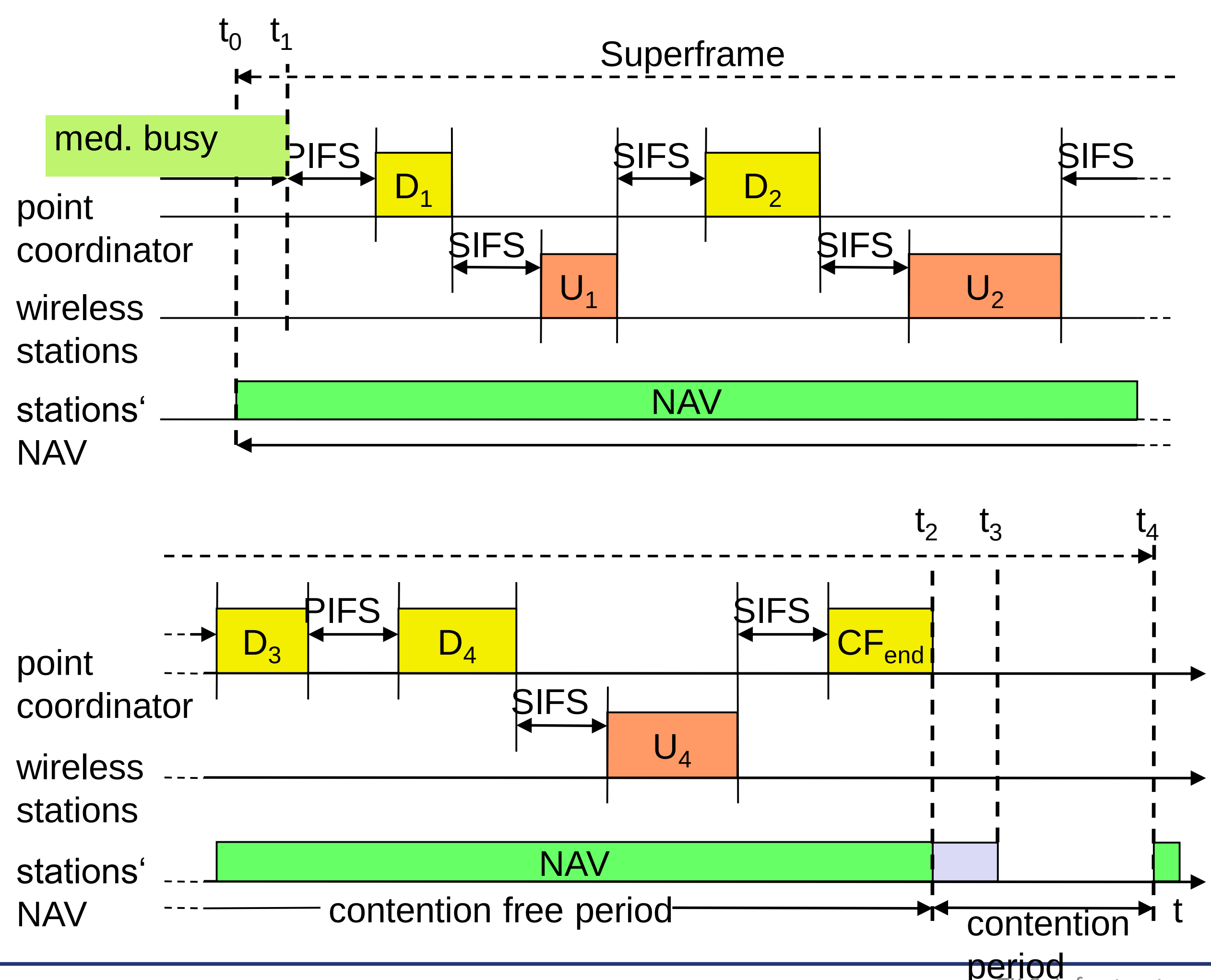
- Sending unicast packets
  - Station can send RTS with reservation parameter after waiting for DIFS (reservation determines amount of time the data packet needs medium)
  - Acknowledgement via CTS after SIFS by receiver (if ready to receive)
  - Sender can now send data at once, acknowledgement via ACK
  - Other stations store medium reservations distributed via RTS and CTS
  - Optional fragmentation (data fragmented → reduced error probability)



NAV: Net allocation vector (min. forbidden time for other stations)

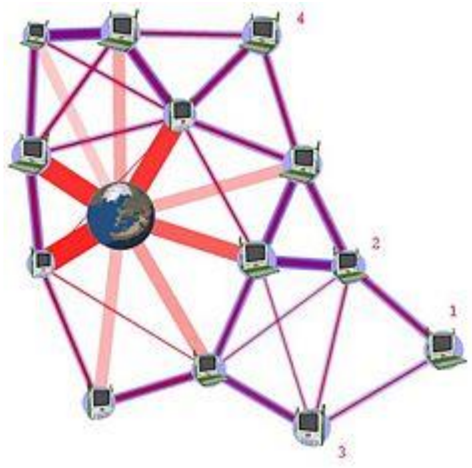
802.11 - DFWMAC w/ PCF

point coordinator determines access (down/up link); polling & contention phases may alter



802.11s

- Adding Mesh Networking
  - No access point needed; Multihop wireless network enabled



- Addition on top of 802.11
  - Peer Link Management protocol for neighbor discovery
    - Nodes transmit beacons
    - Link formed upon receiving neighbor beacons
  - Hybrid Wireless Mesh Protocol (HWMP);
    - uses MAC addresses for „routing“ thus called path selection
    - Proactive protocol; Modification of AODV

802.11s

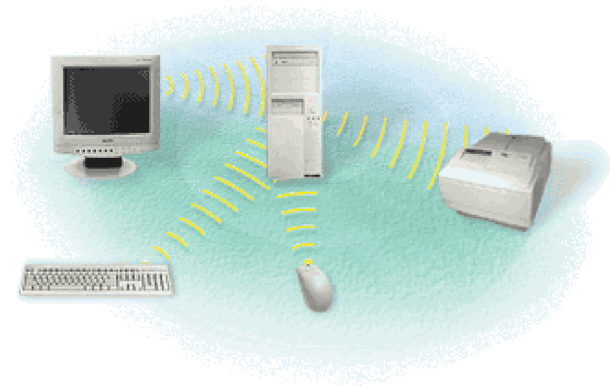
- 3 types of nodes; each can forward frames
  - Mesh Point (MP)
    - Supports Peer Link Management and HWMP
  - Mesh Access Point (MAP)
    - A normal Access Point augmented with mesh functionality
  - Mesh Portal (MPP)
    - A MP with Internet access acting as Gateway

- Applications
  - One Laptop per Child using pre-802.11s
  - Part of the Linux kernel (>=2.6.26)
  - What about smartphones? Good idea, but not yet implemented!

Wireless Personal Area Networks

Bluetooth: Goals

- Provide small, inexpensive, power-conscious radio system
- Personal short-range (~10m) networks
- „Cable replacement“ - not really intended as WLAN technology
- Embedded in many devices: mobile phones, laptops, PDAs, cameras



1.The cordless desktop
(headset, loudspeaker... → audio!)

2.Object Exchange (OBEX) Push
(send images from phone to PC)

3.Tethering
(Internet access from PC via GSM phone)

Profiles: define functionality for connection of “logically matching” devices (e.g., headset profile, handsfree profile, …)

- Origin of technology:
  - Five founders: Nokia, Ericsson, Intel, IBM, Toshiba) → 1000+ !!
  - Idea: advance „wireless car key“ chip („1$-world“) to appliances
- Origin of name:
  - Danish king Bluetooth (940-981), unified (!) Danemark & Norway

Bluetooth: Basics

Bluetooth Versions:

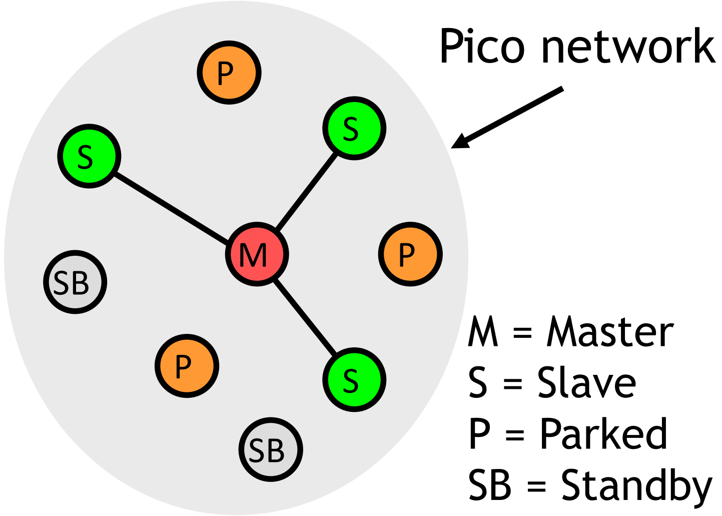
- 1.1, 1.2: speed, HW functionality → better communication, audio, …
- 2.0: Enhanced Data Rate (EDR): up to 2.1 Mbps, more profiles
- 3.0: Ultra WideBand (UWB)
- 4.0: Bluetooth low energy (BLE)

Piconet:

- Each piconet has one master and $\leq$ 7 slaves
- Master controls medium access (strict polling scheme)
- Master determines hopping sequence
    - Different networks use different hopping sequences (low probability of collision)
- Master role can be switched (optional)
- Several low-power modes
- Security model requires pairing
    - almost always: manual, requires user interaction

Scatternet:

- multiple piconets can form a scatternet
- node is slave in one piconet and master in another



Bluetooth Baseband

"Radio" Layer:

- Frequency: 2.4 – 2.4835 GHz (most of Europe, USA)
- 79 (.fr, .jp, .es: 23) channels ("hop carriers")

CDMA-FH:

- CDMA-FH: 1.600 hops/s -> slot is 625µs, 1 Mbps
- Frequency usually hops after each slot
- TDD: all even-numbered slots are reserved for the master
- Multi-slot packets: occupy 3 or 5 slots, frequency not changed

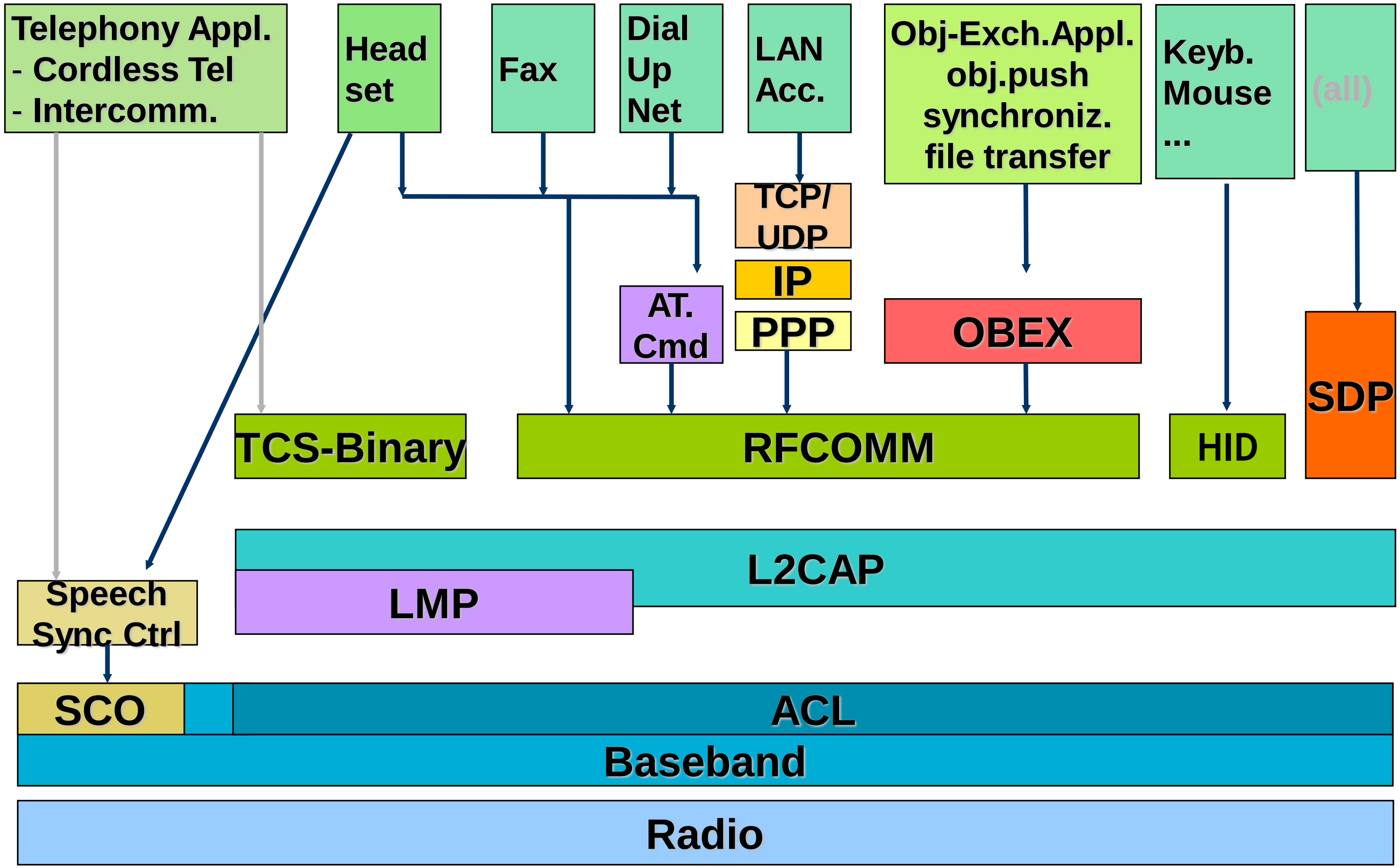
Connection types / Packet types

- SCO (synchronous connection-oriented) link, telephony: „reserve each *n*-th slot"
    - HV1/2/3: HiFi voice, all 1-slot, reserves every 2nd/ 4th /6th slot, use FEC1/3, 2/3, and none
- ACL (asynchronous connectionless) links for everything else
    - DM1/3/5: data medium, 3 & 5 are multislot, 2/3 FEC
    - DH1/3/5: data high, 3 & 5 are multislot, no FEC

Error correction schemes: none, „1/3" or „2/3"

- 1/3: each bit individually repeated 3 times
- 2/3: groups of ten bits are expanded to 15 bits (5 parity bits)

Bluetooth Protocol Stack



Bluetooth Protocol Stack

Bluetooth Protocol Stack

- Link Manager Protocol LMP responsible for SCO/ACL link mgmt.
- L2CAP: logical link control & adaptation protocol: general API
- TCS-bin (telephony control protocol specification binary) common management for telephony applications
- RFCOMM emulates serial link „cable" (up to 60 logical links)
- AT command emulation for modem compatibility
- SDP (service discovery protocol) in later chapter
- OBEX (object exchange) is compatible w/ IrDA: send biz card, photo
- HID (human interface device) is compatible w/ USB

Bluetooth Profiles

- A profile specifies all details needed to use, connect, control, ... a device
    - parts of the Bluetooth stack used
    - options, parameters, SDP record
- >30 profiles are defined
- Example: Headset Profile specifies
    - audio is transported via SCO, audio encoding, ...
    - device is controlled via a RFCOMM connection using AT commands
    - AT command set

Wireless Sensor Networks

- Key characteristics
  - Network is embedded in the environment
  - Nodes measure and influence the environment
  - Nodes process information and communicate it wirelessly
  - Network is self-organizing and energy efficient
  - Potentially high number of nodes at very low cost per node
- Differences to WLAN, WPAN, classical ad-hoc networks
  - WSN is much more application specific, application driven
  - Device power in WSNs is rather limited, lower data rates, embedded
  - WSNs can be large scale with thousands of nodes
  - WSNs are data centric, individual node may be dispensable
  - Much lower cost per node

Wireless Sensor Networks

- Machine and vehicle monitoring
  - Sensor nodes in moveable parts
  - Monitoring of temperatures, fluid levels, …
  - Calculation of maintenance intervals
- Smart Cities
  - Intelligent buildings, building monitoring
  - Intrusion detection, mechanical stress detection
  - Smart heating, ventilating, air conditioning
- Health & medicine
  - Long-term monitoring of patients with minimal restrictions
  - Assisted Living
- Environmental monitoring, person tracking
  - Monitoring of wildlife and national parks
  - Cheap and (almost) invisible person monitoring
  - Monitoring demilitarized zones, ...
- Logistics
  - Dataloggers: Temperature, Humidity, Acceleration/Shock
- … and many more

ZigBee

- 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

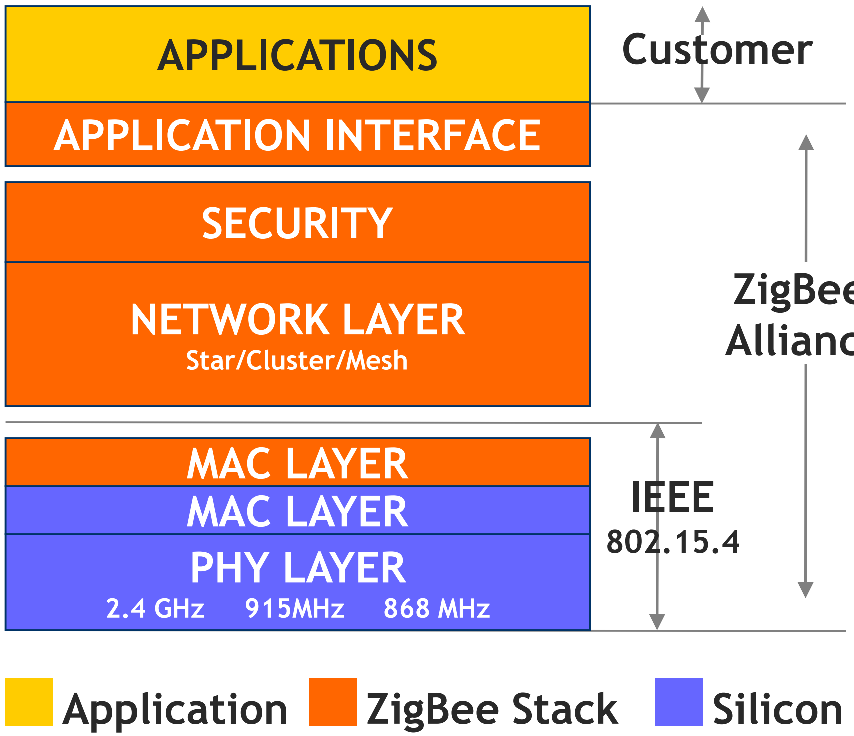
ZigBee Node Types, Protocol Stack

a) FFN vs. RFN: Full Function Nodes– Reduced Function Nodes

b) Coordinator vs. Router vs. EndNode

Only EndNode may (!) be RFN

- Microcontroller utilized
- FFN protocol stack <32 k
- RFN protocol stack ~4k
- Coordinators: extra RAM
  (DBs f. nodes/transactions/pairing)
- PHY: OQPSK (2.4GHz); CDMA
- MAC: CSMA/CA



ZigBee Net can be replaced w/ IEEE802 MAC + IP

Summary

- Key thesis
  - One size does not fit all!
  - Many different wireless systems already exist and there will be more in the future
  - You can‘t beat physics … thus different systems are needed
    - Different ranges, data rates, robustness, power consumption …
  - Performance fluctuations, interrupts, lack of resources etc. have to be taken into account by applications
- Convergence will come, but …
  - Applications will have to run on many different networks, thus adaptivity is important
  - Convergence on the network layer, but still many open issues
    - Security, reliability, maintenance, charging models, quality-of-service…

Summary: WWAN

- Wireless Wide Area Networks
  - Mobile voice comm. has become a „ubiquitous demand“ anyway
  - Mobile data services / mobile Internet use growing
- GSM (2G)
  - Wide area cellular network
  - Circuit-switched, designed for voice comm. only
- EDGE (2.5G)
  - adds packet-switching extension for free slots
- UMTS (3G)
  - CDMA vs. FDMA+TDMA: better spectrum utilization and robustness
    - no guard bands / guard times necessary
    - frequencies can be reused in adjacent cells
    - channel assignment much more flexible:
      silence (speech) -> no data to send -> less noise for other comm.
    - spreading -> more robust against narrowband interference
- HSDPA / HSUPA (3.5G)
  - OFDM instead of CDMA
  - better spectrum utilization, higher data rates
  - less interference between cells (even SFNs for downlink)
- LTE („3.99G“)
  - less latency, packet switching only, All-IP networks

Summary: WLAN

- Today: 802.11 family is the ubiquitous standard
    - competitors have disappeared, e.g., HiperLAN
- Substandards
    - 802.11b: 2.4 GHz, DSSS (2 Mbit/s), CCK (11 Mbit/s)
    - 802.11a: 5 GHz, OFDM (54 Mbit/s)
    - 802.11g: 2.4 GHz, OFDM (54 Mbit/s)
    - 802.11n: 2.4/5 GHz, OFDM (150...600 Mbit/s)

- Wireless Distribution Networks
    - 802.16 / WiMAX
    - Directed connections, enable DSL connectivity for rural areas
    - Terminal mobility requires 802.16e
    - Directly competed with HSDPA/HSUPA and LTE
        - WiMAX is an „extended LAN technology“ - does not have the infrastructure components of WWANs
        - WiMAX does not integrate in existing GSM/UMTS infrastructure
        - In the US Sprint has started with WiMAX is now switching to LTE!

Summary: WPAN, etc.

- Which one is best for my Ubicomp application?
  A discussion of: Bluetooth, ZigBee & WLAN

- Bluetooth
  - „designed to connect a headset wirelessly to a cellphone“
    - most other things turn out to be a hack (see HIDs below)
  - Pros:
    - easy to implement, because of simple modulation and MAC
    - relatively low power
  - Cons:
    - not much more than „cable replacement“
      - pairing procedure unsuitable for WSNs or ad-hoc networks
    - strict master/slave polling scheme
      - nonsense for HID devices
      - sensors could not push data to the master
      - high latency
    - IP data connections are „circuit switched“
      - IP traffic tunneled using PPP through an RFCOMM link
      - broadcast functionality of wireless network lost
    - only 7 slaves

Summary: WPAN, etc.

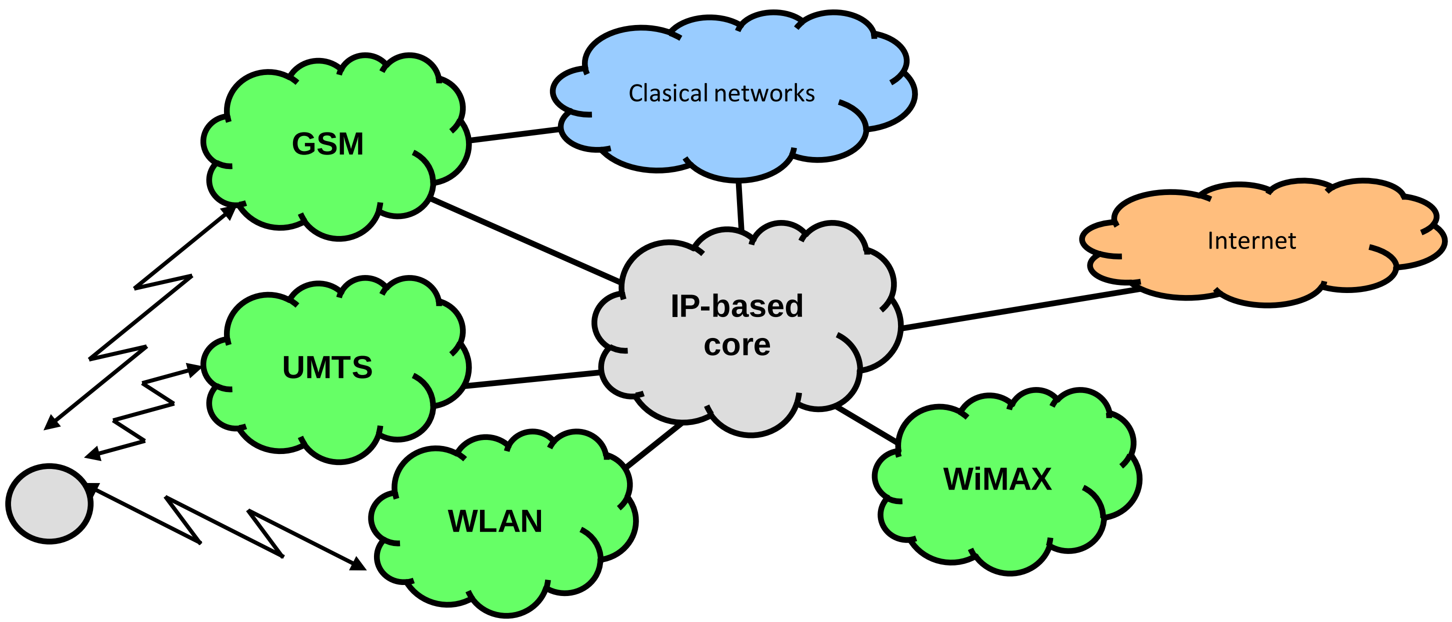
- ZigBee
  - designed for sensor networks, where typically
    - many nodes are interconnected
    - nodes sleep most of the time
    - nodes occasionally send small amounts of data
  - Pros:
    - very low power
    - software stack kept simple (smaller than Bluetooth)
    - flexible radio layer: 10m - 1.5km range
    - flexible MAC: non-beacon networks, beacon-enabled networks
    - supports large networks
    - supports different network topologies (star, mesh, hybrid)
  - Cons:
    - low data rate

Summary: WPAN, etc.

- WLAN
  - complex radio, signal processing, and software stack
  - requires high power
    - general rule: energy needed to decode a signal is proportional to data rate
- Convergence? (WPAN,WLAN,WSN)
  - possible solution: use two radios
    - MAC radio: simple modulation, low bandwidth, low power
    - data radio: modulation selectable based on demand
  - research prototypes exist, but currently there is no real business case
  - related: Cognitive Radio: „fully reconfigurable radio that automatically changes its communication variables in response to network and user demands"
- Cognitive Radio - Goals
  - Spectrum Sensing: detecting unused spectrum
  - Spectrum Management: select spectrum that best meets user reqs.
  - Spectrum Mobility: adapt to changes
  - Spectrum Sharing: similar to MAC

Convergence – the 4th Generation

- Trends
  - Key idea: Always Best Connected (ABC)
  - Many different wireless & mobile systems will co-exist due to physics, applications, limitations, key properties
  - Big mobile operators will also operate WLAN, etc.



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