

Business Informatics 2 (PWIN)
WS 2023/24

Communication Systems II
Wired and Wireless Communication

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- **Wired Communication**
 - Basic Cable Types and Topologies
 - Types of Wired Communication
 - Ethernet, Digital Subscriber Line (xDSL), Fiber to the x (FTTx)
 - Connecting Computer Peripherals

- **Wireless Communication**
 - GSM
 - UMTS
 - LTE
 - 5G
 - Wireless LAN (Wi-Fi)
 - WiMax
 - Bluetooth
 - Near Field Communication (NFC)
 - Starlink

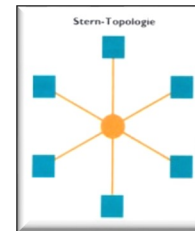
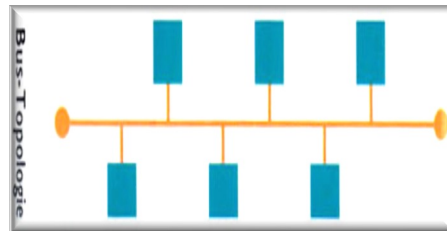
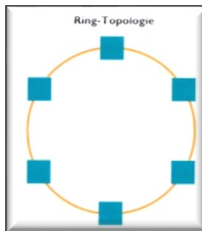
- Wired communication denotes data transmission using physical wires, e.g. for
 - Telephone networks
 - Cable television/Internet access
 - Fiber-optic networks
- Main challenges in wired communication
 - Coping with the distance between two endpoints
 - Provision of the appropriate bandwidth

- Wired networks

- Use different types of conductors to build a network
 - Coaxial cable, twisted pair wire, optical fibre, ...



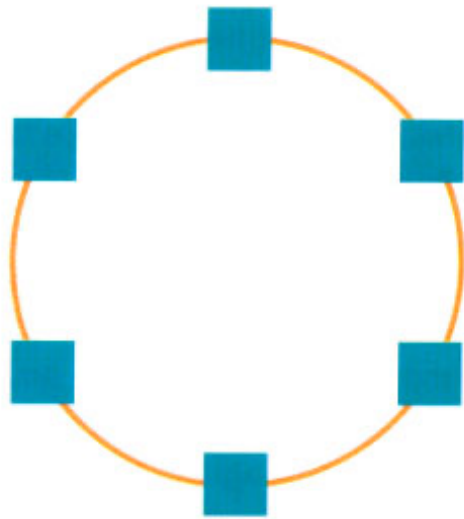
- Make use of different topologies
 - E.g. ring, bus, star topology



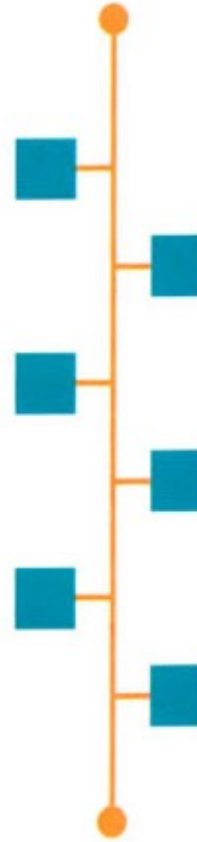
- Provide different transfer rates
 - 10 / 100 / 1000 Mbit / 1 Gbit / 10 Gbit and more...

Wired Network Topologies

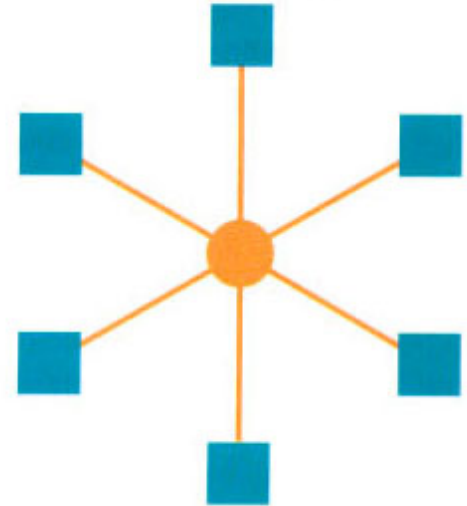
Ring Topology



Bus Topology



Star Topology



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- Definition of wiring and signalling standards for local area networks (LAN)
- Developed in the beginning of the 1970s by Xerox and from 1980 continued by DEC, Intel and Xerox (DIX group)
- Implementation of an access method called Carrier Sense Multiple Access/Collision Detection (CSMA/CD), an enhancement of the Aloha concept, which was previously developed at the University of Hawaii
- Thus, Ethernet is a product name by Xerox, DEC and Intel, in which the product itself had not been compatible to the IEEE specification 802.3 for years.

Ethernet Transfer Rate Evolution

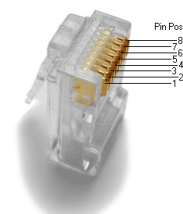
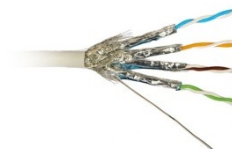
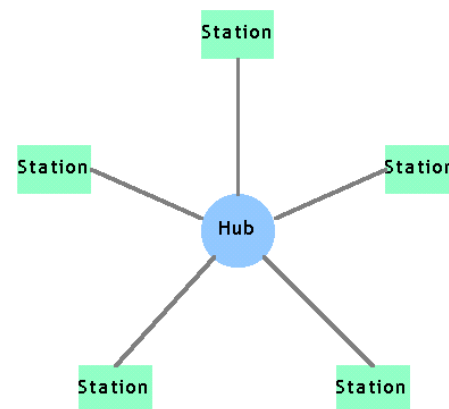
1990

1999

2006

2016

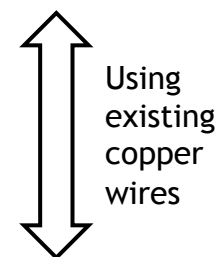
- 10Base-T (10 Mbit/s transfer rate)
 - This version of Ethernet was the first to permit **structured cabling** in buildings using copper cables (multiple twisted pairs).
 - Topology: Star
 - Uses 2 twisted pairs in a **Category 5** cable
- 100Base-TX (100 Mbit/s transfer rate)
- 1000Base-T (1 Gbit/s transfer rate)
 - 5 twisted pairs in a **Category 5e** cable
- 10GBase-T (10 Gbit/s transfer rate)
 - Requires **Category 6a** cable
- 25GBase-T (25 Gbit/s transfer rate)
 - 4 twisted pairs in a **Category 8** cable
- 40GBase-T (40 Gbit/s transfer rate)
 - 4 twisted pairs in a **Category 8** cable
- 100GBase-x (100 Gbit/s transfer rate)
- 200GBase-x and above forthcoming



Source: Tanenbaum, A. (2006), IEEE (2016)

Digital Subscriber Line (xDSL)

- Digital Subscriber Lines (xDSL) use **existing copper wires** of a telephone network
- DSL communication is enabled by a connection between **DSL modem (user)** and a **Digital Subscriber Line Access Multiplexer (DSLAM)** (provider).
- DSL download bandwidth typically higher than upload (asymmetric DSL)
- Bandwidth also depends on distance between DSL modem and DSLAM
- Most widely used DSL types
 - Asymmetric DSL (ADSL/ADSL2)
 - ADSL max. Downstream 12 MBit/s ADSL, max. Upstream 1.8 MBit/s
 - ADSL2+ max. Downstream 24 MBit/s, max. Upstream 1.3 MBit/s
 - Very High Speed DSL (VDSL and VDSL2)
 - 55 and 300 MBit/s Downstream, 3 and 100 MBit/s Upstream
 - Symmetric DSL (SDSL), often named Single-Pair High-Speed DSL (SHDSL)
 - 2.36 Mbit bi-directional (Downstream, Upstream)



Fiber to the x (FTTx)

- In telecommunications, “fiber to the x“ denotes a generic term for any broadband network architecture that uses optical fiber for the so-called “last mile”.
- Optical fiber has significant advantages over existing copper wire in long distances and for high-demand applications.
- However, optical fiber systems are complex and expensive compared to their copper equivalent.
- Reasonable solution is a combination of optical fiber and copper wires, e.g.
 - **FTTN - Fiber-to-the-node** - fiber is terminated in a street cabinet up to several kilometers away from the customer premises, final connection is typically established via copper.
 - **FTTB - Fiber-to-the-building** - fiber reaches the boundary of the building, final connection is typically established via copper.
 - **FTTH - Fiber-to-the-home** - fiber reaches the boundary of the living space.

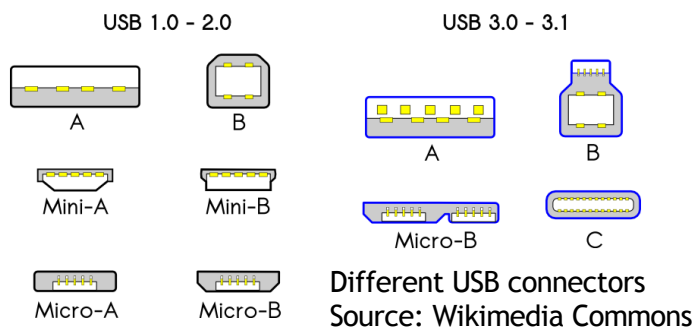


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Connecting Computer Peripherals: Universal Serial Bus (USB)

- **Universal Serial Bus (USB)** specifies communication between devices and host controllers (e.g. PCs)
- Developed and invented by Ajay Bhatt at Intel
- Different types of connectors specified, e.g. Standard-A, Standard-B, Micro-B, Mini-B 8-pin, Mini-B 5-pin, Standard-C etc.
- Supports transfer speeds up to 40 GBit/s (USB 4)



- **Other technologies:**
 - FireWire (0.8, 1.6, and 3.2 GBit/s)
 - Ethernet (see previous slides)
 - eSATA (PC bus interface for storage devices, max. 1.5, 3.0, 6.0 GBit/s)
 - Thunderbolt 3 (expansion bus for devices including displays, max. 40 GBit/s)



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- Unlike wired networks, wireless networks use „air“ as transmission medium.
- Progress depends on availability of processors (chips) that can handle frequency issues with demanding too much power.
- Nine selected types of wireless communication:
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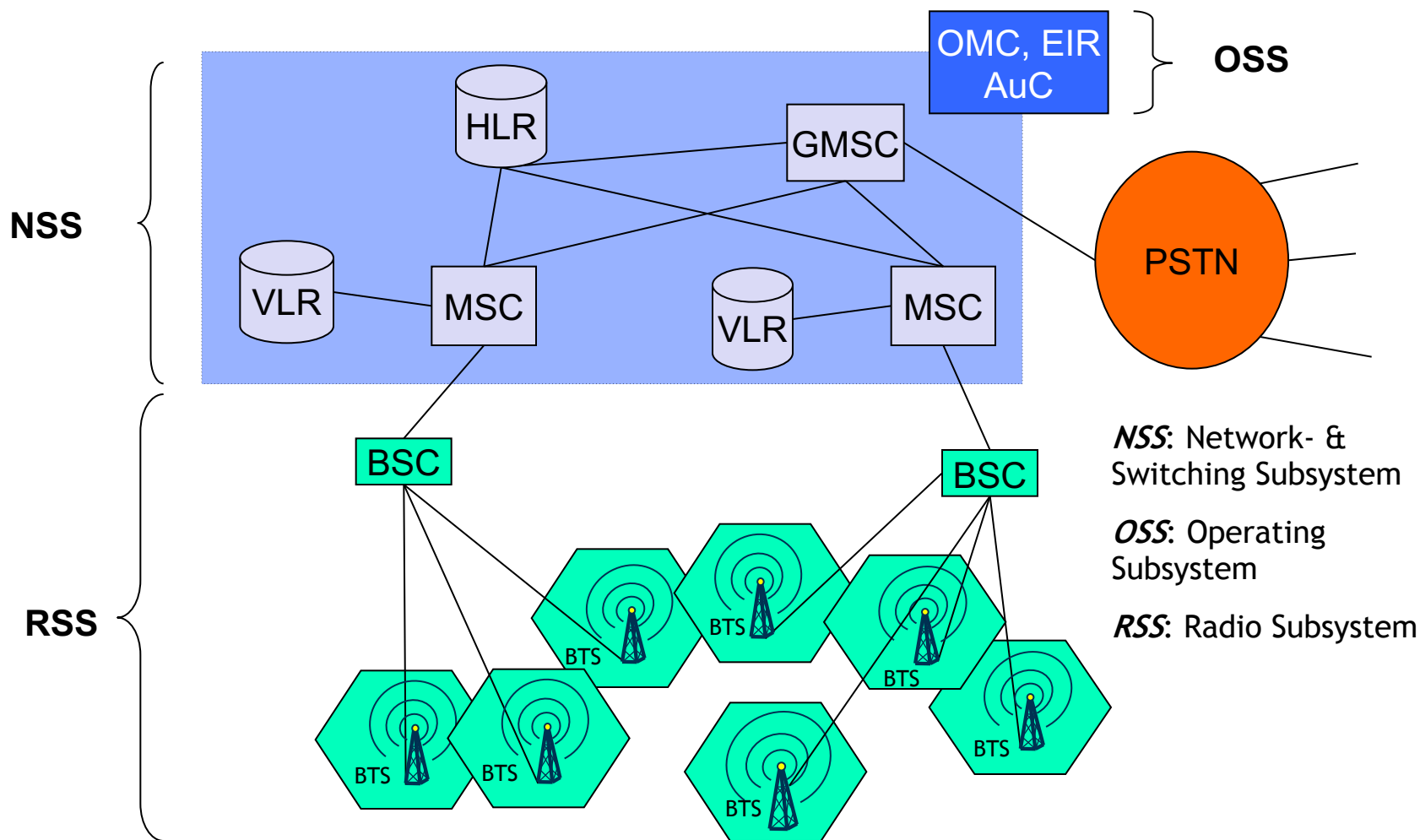
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- Global *S*ystem for *M*obile Communications (GSM)
- Originally 1982 driven by “*Groupe Spéciale Mobile*” in order to create a cross national standard contrary to national analogue standards
- European standard by *ETSI* (European Telecommunications Standardisation Institute)
- Worldwide adoption of the standard in more than *212 countries and territories* (most successful mobile radio system up to now)
- Thus, worldwide roaming among different mobile network operators became possible.



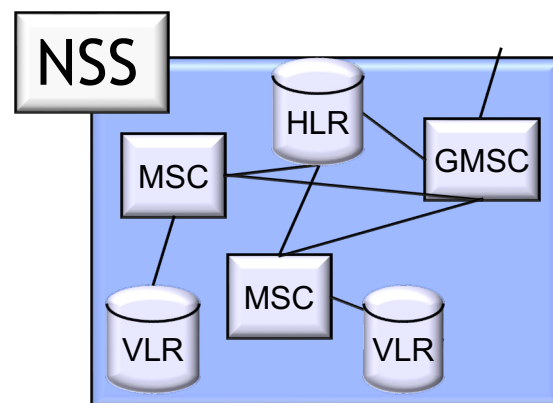
- Carrier services
 - Services to transfer signals over the GSM network:
 - The focus of GSM standardisation was on voice services.
- Telecommunications services
 - Telecommunication services (mainly voice) support the mobile communications among users:
 - Telecommunication services play a central role in the GSM standard.
- Supplementary services
 - GSM provides a number of supplementary services (specific to network operators), such as
 - Caller ID
 - Call redirect
 - Closed user groups (e.g. company-internal network or GSM-R)
 - Teleconferences (up to seven participants).



Based on [Schiller2003]

- **Network & Switching Subsystem (NSS)**

- Connects radio network with conventional networks
- Locates subscribers and monitors change of location



- **Components:**

- **Mobile Switching Centre (MSC):** Switching center for initiation, termination and handover of connections
- **Home Location Register (HLR):** Central database with subscribers' data (telephone numbers, keys, locations)
- **Visitor Location Register (VLR):** Database assigned to every MSC with subscribers' data (HLR fraction copy) of active subscribers in the MSC's range
- **Gateway Mobile Switching Center (GMSC):** Terminates the PSTN (Public Switched Telephone Network) signaling and traffic formats and converts this to protocols employed in mobile networks

- **Operation Subsystem (OSS)**

- Supervises operation and maintenance of the whole GSM network

OSS

OMC, EIR
AuC

- **Components:**

- **Operation and Maintenance Centre (OMC):** Supervises each network component and creates status reports
- **Authentication Centre (AuC):** Protects identity of participants & data transmission, administrates keys
- **Equipment Identity Register (EIR):** Database with identification list for devices, e.g. stolen terminals (whitelist, greylist, blacklist)

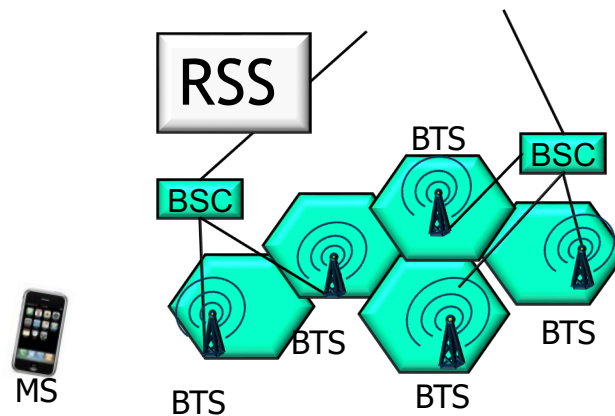
GSM - Radio Subsystem (RSS)

- **Radio Subsystem (RSS)**

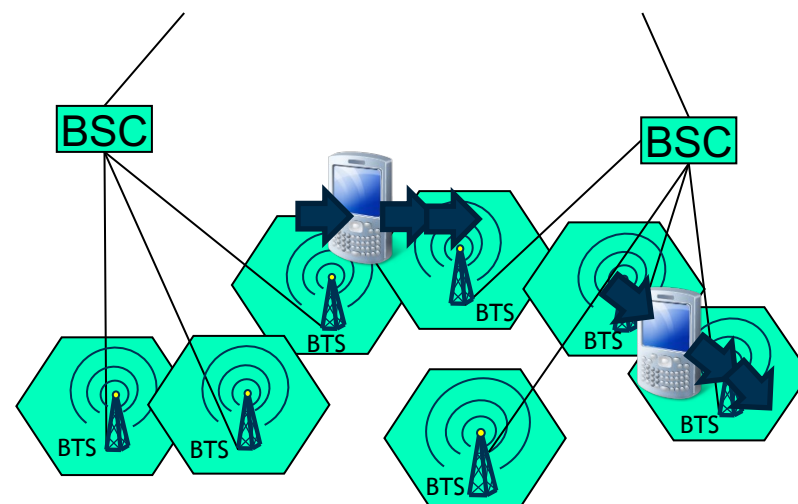
- System consisting of radio
- Specific components

- **Components:**

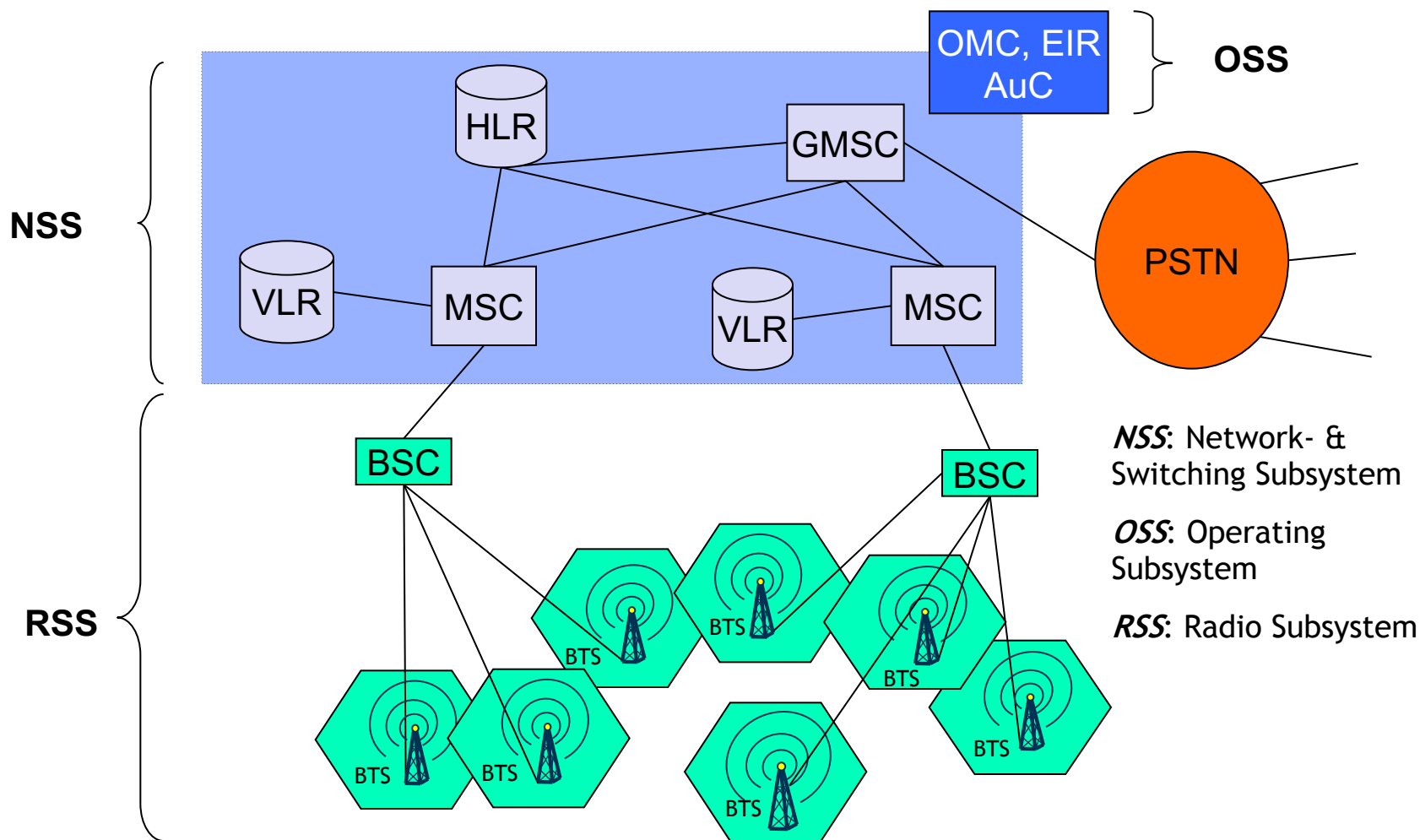
- **Mobile Station (MS):** System of mobile terminal & SIM
- **Base Transceiver Station (BTS):** Radio facility for signal transfer. A BTS serves one GSM cell (~100m to ~30km radius).
- **Base Station Controller (BSC):** Administrates affiliated BTS and supervises e.g. frequency allocation and connection handover between cells.



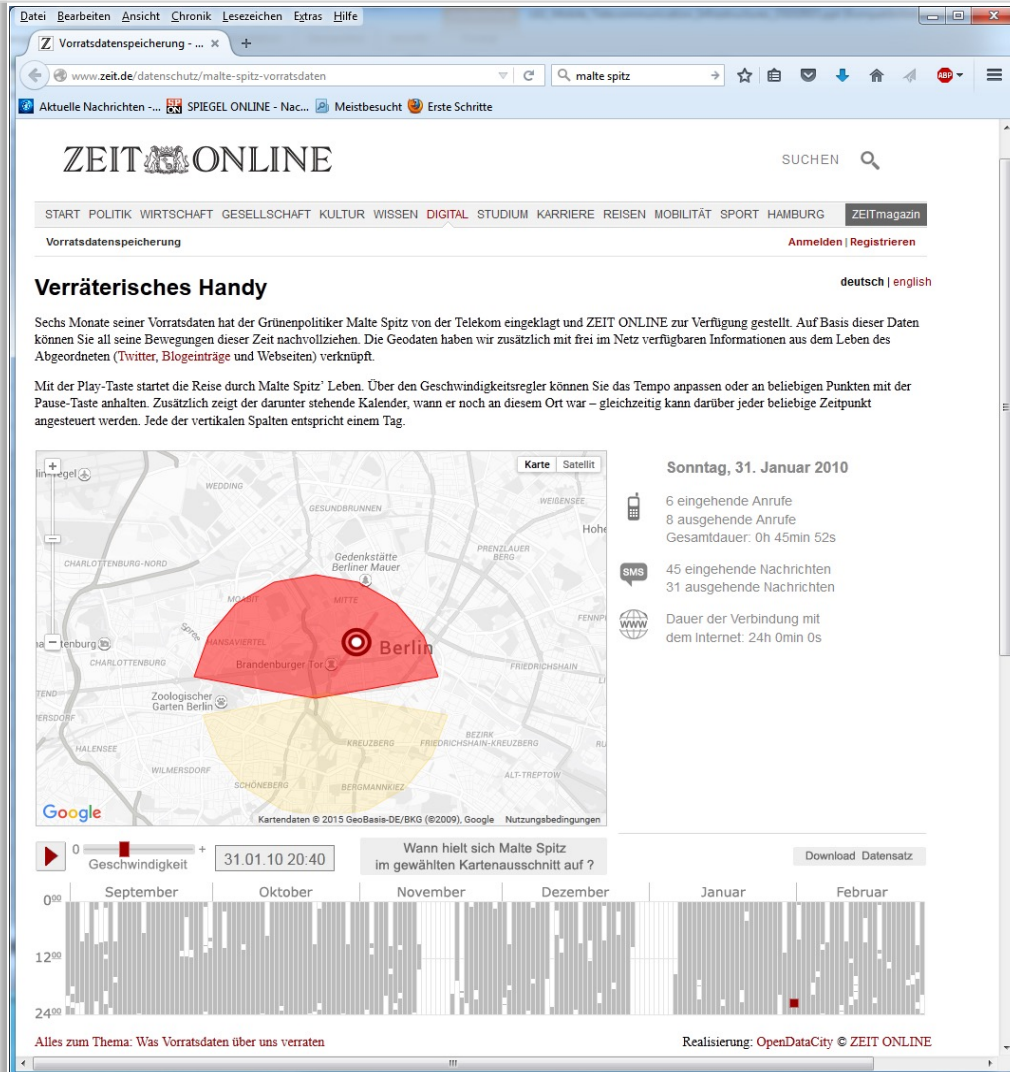
- Transfer of calls or data sessions from one transmitting station (in GSM: Base Transceiver Station, BTS) to another.



- Term **handover** common in British English
 - In international and Europe based organisations, e.g. ITU-T, IETF, ETSI and 3GPP
- Equivalent term **handoff** in American English
 - In IEEE and ANSI publications



Based on [Schiller2003]



[\[www.zeit.de/datenschutz/malte-spitz-vorratsdaten\]](http://www.zeit.de/datenschutz/malte-spitz-vorratsdaten)

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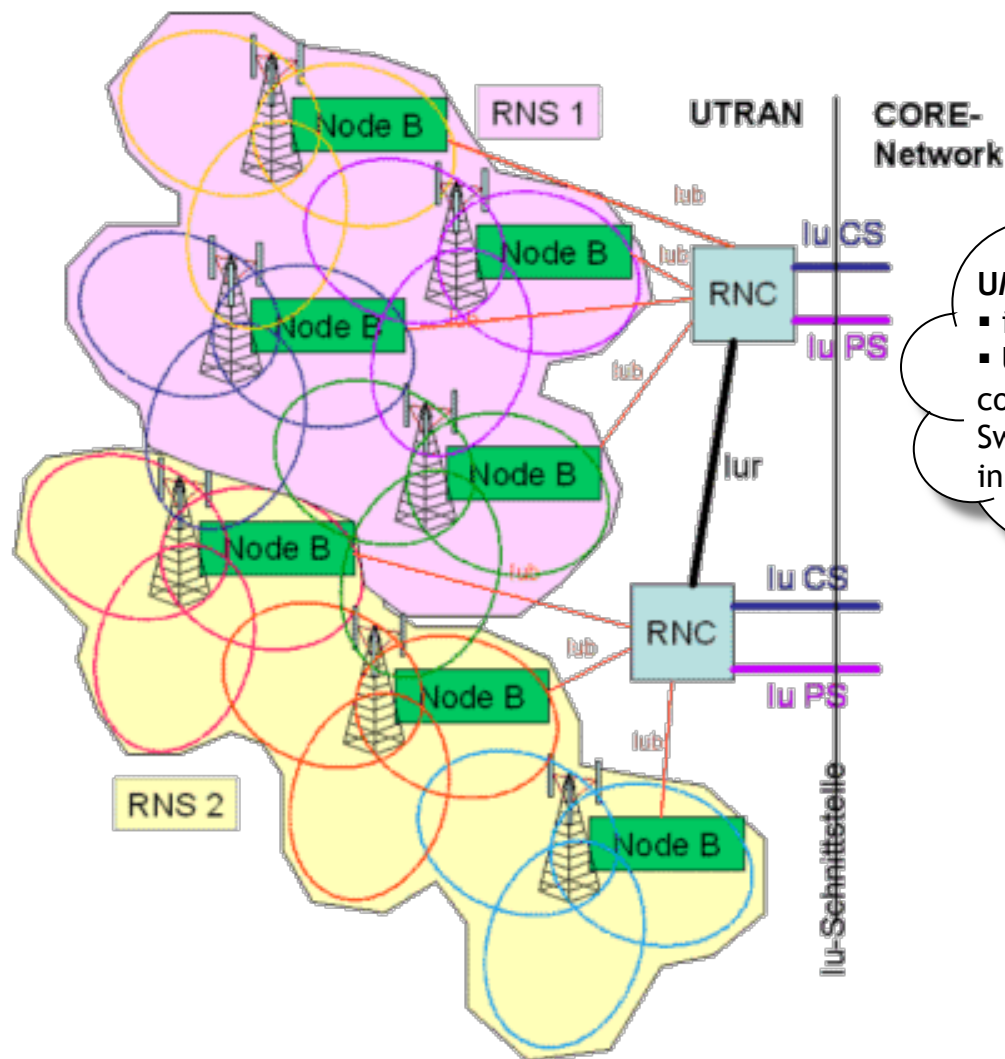
- Universal Mobile Telecommunications System (UMTS):
 - **Status of 2G-Networks:** Different standards in some different continents inhibit worldwide roaming.
 - **Demand for 3G-Networks:** Globally uniform standard

➔ Voting of regional & national regulation offices (e.g. ETSI, ARIB, ANSI) via the International Telecommunication Union (ITU)



UMTS (3G) System Architecture

- **UTRAN:**
UMTS Terrestrial Radio Access Network
- **RNS:** Radio Network Subsystem
- **RNC:** Radio Network Controller (controls the Node Bs)
- **Node B:** UMTS base stations (equivalent to base transceiver stations (BTS) in GSM)



UMTS Core network

- is not shown here in detail
- UMTS Core network corresponds to Network- & Switching Subsystem (NSS) in GSM

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Next Generation Networks (4G) and Long Term Evolution (LTE)

4th Generation Networks

- 4G networks integrate a wide range of different wireless technologies, including technologies from existing 3G networks
- **Long Term Evolution (3.9G, “4G”)** standard allows for 300 Mbit/s downlink and 75 Mbit/s uplink speeds
 - First commercial LTE network launched in Scandinavia in December 2009
 - LTE was originally not named a “4G network” due to stricter naming requirements *)
 - The technology can be named either 3.9G or 4G network today.
- **LTE Advanced (4G)** makes use of the frequency spectrum more efficiently, resulting in higher data rates (towards 1 Gbit/s) and lower latency. It remains backward compatible with LTE, uses same frequency bands.



*) A 4G service was originally defined as meeting the *IMT-Advanced* requirements issued by the ITU-R. For more information see [Parkvall2008].

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5th Generation Networks (5G) Concept & Requirements

- Two initial views of 5G:
 - View 1 - The hyper-connected vision
 - View 2 - Next-generation radio access technology
- Standardisation process ongoing (3GPP, ITU)
- Commercial availability started in 2020 in Germany
- 5G technology requirements
 - 1 millisecond end-to-end round trip delay (latency)
 - 1-10 Gbps connections to end points in the field (i.e. not theoretical maximum)
 - 1000 x bandwidth per unit area
 - 100 billion connected devices worldwide
 - 99.999 % availability
 - 90 % reduction in network energy usage
 - Network slicing: multiple logical networks created on top of a common shared physical infrastructure
- "We should consider 5G rather as a business model than a technology" - Börje Ekholm, CEO Ericsson



- Autonomous driving/Connected cars
- Machine-to-machine connectivity (M2M)
 - vehicle telemetric systems (a field which overlaps with Connected cars above)
 - ‘connected home’ systems (e.g. smart meters, smart thermostats, smoke detectors)
 - consumer electronics and healthcare monitoring.
- Virtual Reality/Augmented Reality/Immersive or Tactile Internet
- Wireless cloud-based office / Multi-person videoconferencing

- Identification of new services, market segments and business models to unlock the 5G opportunity and to optimise cost of network investment
- Pro-investment and pro-innovation regulatory framework required given high network expenses
- Spectrum availability (sub 1 GHz, 1-6 GHz, above 6 GHz) will influence the business case behind 5G.
- Technological breakthroughs needed for e.g. spectral efficiency, low latency and network design
- Successful standardisation to minimise industry fragmentation in spectra, technologies, and operator services

Mobile Telecommunication Infrastructures

- *1st Generation (1G) - Analogue networks*
- *2nd Generation (2G) - GSM networks*
Global System for Mobile Communications
- *3rd Generation (3G/3.5G) - UMTS/HSPA/HSPA+*
Universal Mobile Telecommunications System
High Speed Packet Access / Evolved HSPA = HSPA+
- *3.9G or 4G - LTE*
Long Term Evolution
- *4th Generation (4G) - LTE Advanced*
- *5th Generation (5G) - Mobile broadband*
- *6th Generation (6G) - Ubiquitous wireless intelligence [Latva19]*

Evolution of mobile telecommunication infrastructures



2G – GSM

3.9G/4G – LTE

5G

1G

3G – UMTS

4G – LTE Advanced

6G

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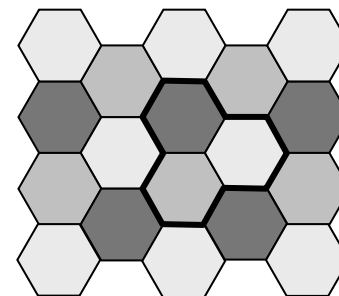
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Wireless Local Area Network (Wi-Fi) Basics

- Short-range wireless communication technology with cell-based architecture
- Possible extension to a wired Local Area Network (LAN)
- One Wi-Fi cell serves a circular area in which PCs, laptops, and other connected devices can move freely.



- The basic module of a wireless LAN is a radio cell.
- A radio cell covers a circular area that PCs or laptops and other connected devices are able to use.



Wireless LAN (Wi-Fi) Components

- Components (802.11b)
 - Access Point (AP)
Sender and receiver station that allows the connecting of multiple receiving stations
 - Stations
End-systems that establish a wireless connection for instance by using an access point (e.g. a notebook with built-in wireless LAN)



- **Beacon Frame (SSID)**
 - The access point is transferring a periodical beacon. A beacon communicates the service set identifier (SSID) and other important operational parameters (channel, ...).
 - A wireless LAN client sends a probe request. The access point answers with a probe response. If there is an agreement, the wireless LAN client starts the communication over the access point.
 - A more detailed description of beacon frames can be found in Sauter (2008).

Wireless LAN (Wi-Fi)

Standard IEEE 802.11 – Examples

Standard	Description
802.11	Protocol for transmission methods for wireless networks, defined in 1997 for 2 MBit/s at 2,4 GHz
802.11a	Wireless LAN up to 54 MBit/s at 5 GHz
802.11b	Wireless LAN up to 11 MBit/s at 2,4 GHz
802.11f	Roaming between access points of different manufacturers (published in 2003 and withdrawn by IEEE in 2006) [IEEE2010]
802.11g	Wireless LAN up to 54 MBit/s at 2,4 GHz
802.11i	Extended security features: AES, 802.1x, TKIP
802.11n	Wireless LAN up to 450 MBit/s when using 3 spatial streams (3x 150 Mbit/s) at 2,4 GHz or 5 GHz *)
802.11r	Fast Roaming/Fast BSS Transition
802.11ac	Wireless LAN using 3 spatial streams at 5 GHz: Up to 1.3 GBit/s (3x 433 Mbit/s) or even up to 2.6 GBit/s (3x 867 Mbit/s, part of 802.11ac Wave2) *) **)
802.11ad	Wireless LAN at 60 GHz: Up to 7 GBit/s
802.11ah	Wi-Fi HaLow for Smart Home and connected devices (900 MHz, increased distance, ~1km)
802.11aj	A rebanding of 802.11ad for use in the 45 GHz unlicensed spectrum in some regions of the world (specifically China)
802.11ax	New Standard operating in the existing 2.4 GHz and 5 GHz spectrums but incorporating additional bands between 1 and 7 GHz. Achieved 4x increase to user throughput.
802.11ay	Upcoming Standard extending 802.11ad by defining a new physical layer for 802.11 networks to operate in the 60 GHz spectrum
802.11ba	Amendment of IEEE 802.11 enabling energy efficient operation for data reception without increasing latency
802.11be	Potential next amendment likely be designated Wi-Fi 7 building upon 802.11ax

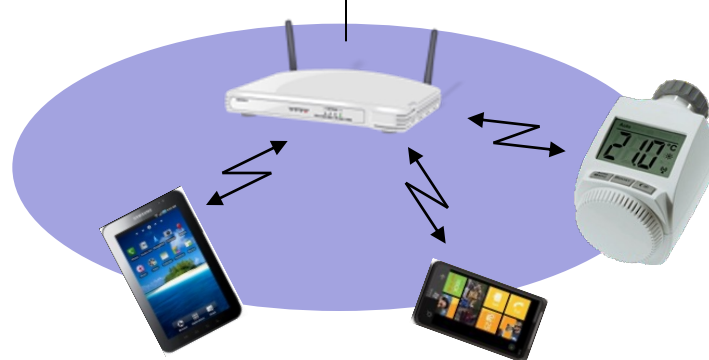
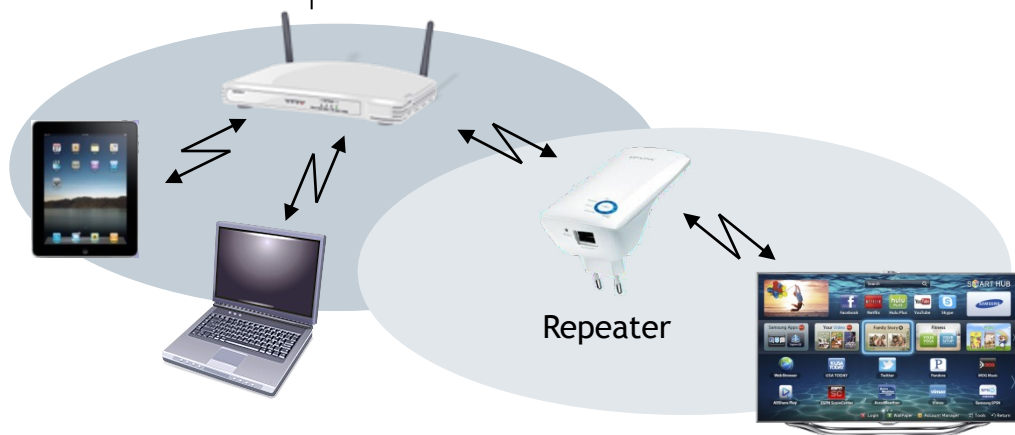
*) 802.11n and 802.11ac data rates depend on the number of antennas and spatial streams ("parallele räumliche Inhaltsströme") supported by the hardware. 802.11ac devices often support 3 streams at most. 802.11n specifies a maximum of 4 streams, 802.11ac a maximum of 8 streams. **) 802.11ac is a 5 GHz-only standard, so dual-band access points and clients will probably continue to use 802.11n at 2.4 GHz in parallel.

Wireless LAN Infrastructures

Infrastructure Network



Existing cable based Network



Ad hoc Networks



Based on [Sauter 2008]

- The usage of wireless LANs is one of the grey areas of Internet related legislation. The border between legal and illegal is not clearly defined. Most cases the courts decide are precedents.
- What is important?
 - § 202a Strafgesetzbuch
Spying on data (Ausspähen von Daten)
 - § 88 Telekommunikationsgesetz
Secrecy of telecommunications (Fernmeldegeheimnis)
 - § 89 Telekommunikationsgesetz
Ban on eavesdropping (Abhörverbot), receiver operator's confidentiality duty (Geheimhaltungspflicht der Betreiber von Empfangsanlagen)

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- **WiMAX** (Worldwide Interoperability for Microwave Access)
- IEEE standard 802.16
- Establishes mobile (broadband) Internet access of up to 40 Mbit/s downlink.
- Services once available e.g. in the USA, Japan, Korea, Taiwan, Russia, Mexico, Middle East, Africa
- In May 2014 a majority of the IEEE 802.11 Working Group agreed to close the IEEE 802.16 WG due to the missing market penetration of the WiMAX standard.
- In 2015 Sprint Corporation began closing its WiMAX network.
- Since 2015: WiMAX Networks phased out in favour of LTE in Nigeria
- LTE has replaced WiMAX in most countries. However, due to the simplicity and cost-effectiveness of WiMAX, it will likely persist as a niche alternative in some countries.



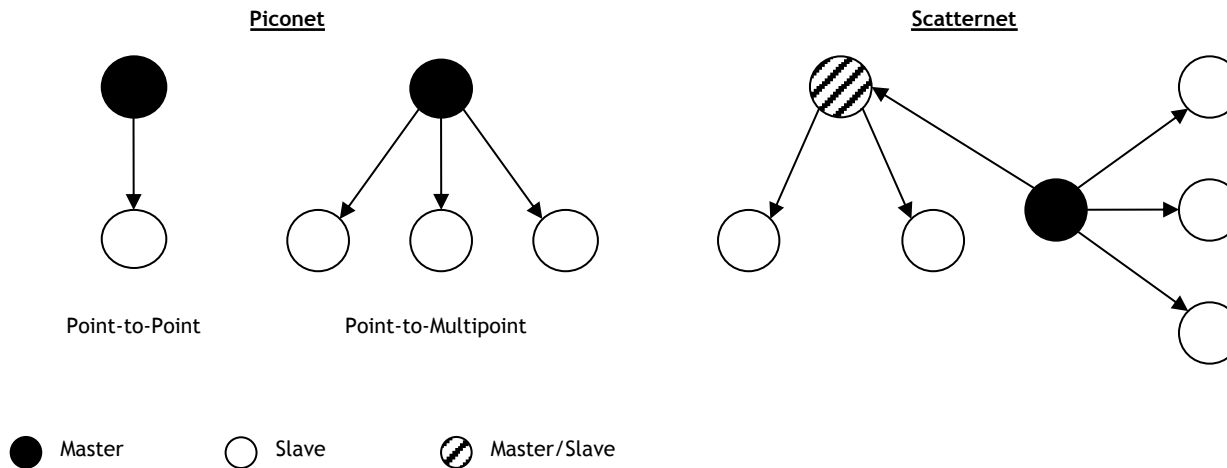
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- Bluetooth is a wireless technology standard for data exchange using small ad-hoc networks called “personal area networks” (PANs)
 - Devices such as laptops, mobile phones, printers, headsets and other periphery-devices can establish a connection.
 - Simple and cheap possibility to set up ad-hoc networks of limited range (up to 10 meters) for spontaneous data exchange
 - Technical specifications for Bluetooth were developed by the Bluetooth Special Interest Group (SIG).
 - Findings were added to the IEEE 802.15 standard.

- There are different types of Bluetooth networks

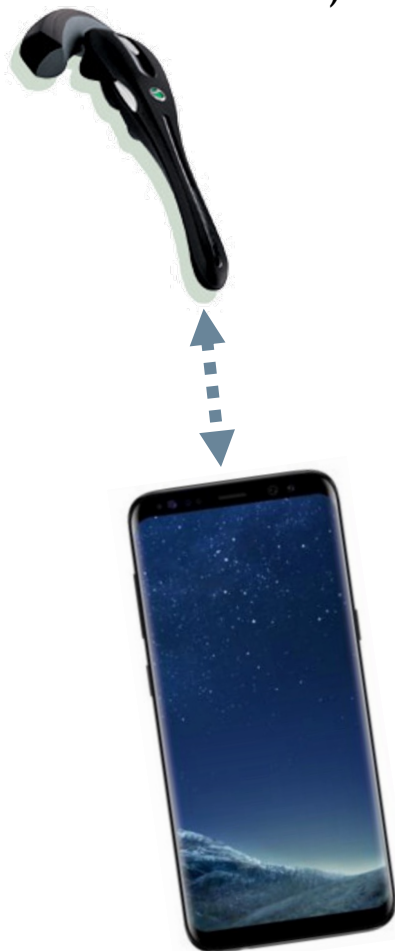


- A piconet is a connection of one device with another device (point-to-point) or multiple devices (point-to-multipoint).
- A scatternet is the combination (connection) of two or more piconets.

Bluetooth Popular Applications

Wireless connections between devices
(Bluetooth-headset)

Sound transmission (to earphones,
headphones or Hi-Fi equipment)

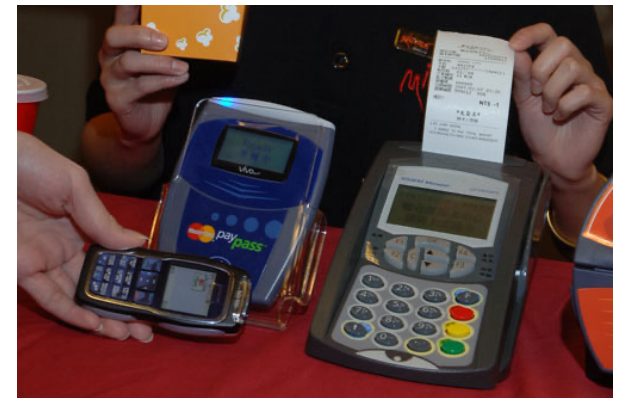


- **Wired Communication**
 - Basic Cable Types and Topologies
 - Types of Wired Communication
 - Ethernet, Digital Subscriber Line (xDSL), Fiber to the x (FTTx)
 - Connecting Computer Peripherals

- **Wireless Communication**
 - GSM
 - UMTS
 - LTE
 - 5G
 - Wireless LAN (Wi-Fi)
 - WiMax
 - Bluetooth
 - Near Field Communication (NFC)
 - Starlink

Near Field Communication (NFC)

- NFC is a short-range (< 4 cm) wireless technology
 - Communication mode of a device can be active or passive
 - Magnetic induction between two loop antennas
 - Application domains
 - Mobile payment / mobile wallet
 - Mobile marketing (e.g. redemption of digital coupons)
 - Mobile ticketing
 - Access control (e.g. e-Key)
 - Mobile data user exchange
 - ...



Source: techtickerblog.com (2011)

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- Satellite constellation operated by SpaceX offering satellite internet access
 - Available in 62 countries as of September 2023
 - Provided by over 5,000 satellites, to be expanded to 12,000
 - Monthly costs of 65€ plus a one-time 450€ payment for hardware as of September 2023
 - Mobile phone service planned to start in 2023



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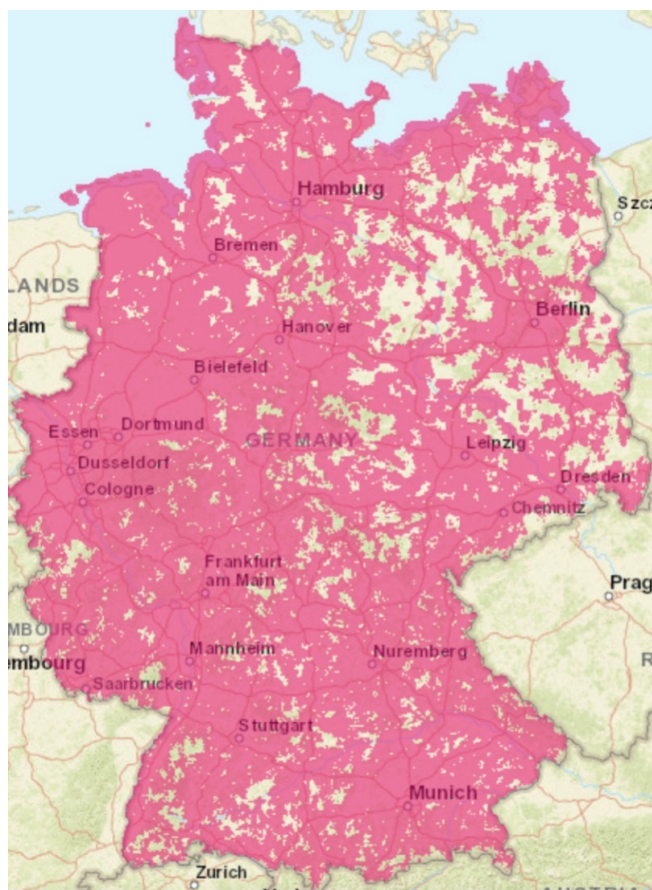


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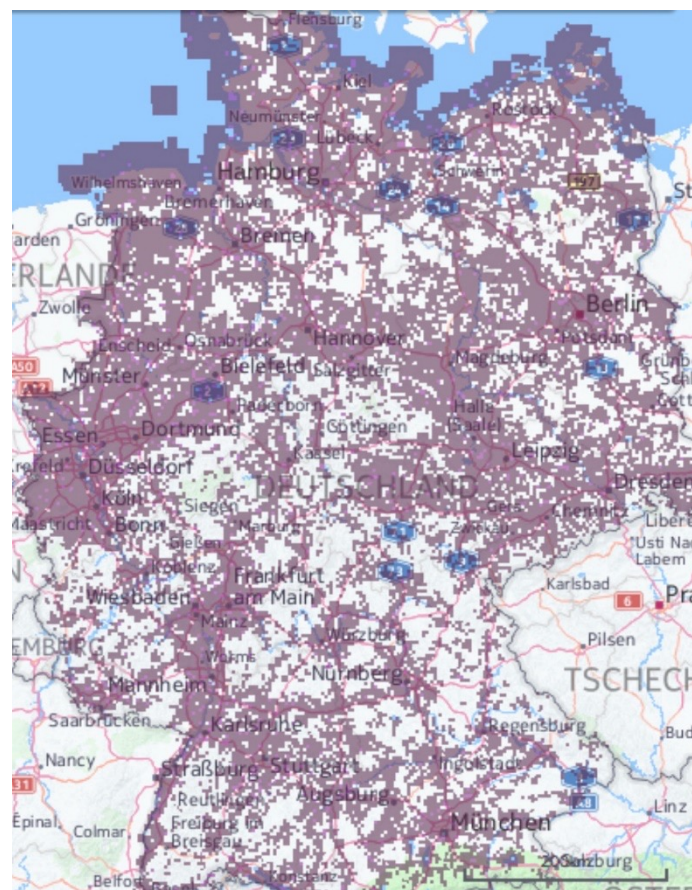


- The UMTS standard includes the following features:
 - Multilateral Security (with regard to authentication)
 - High Speed Downlink Packet Access (HSDPA)
 - ...
- 3G UMTS/HSPA/HSPA+ bandwidths
 - **UMTS**: up to 384 kbit/s downlink/uplink
 - **High Speed Packet Access (HSPA)** provides up to 14.2 MBit/s downlink speed and up to 5.7 MBit/s uplink speed.
 - **HSPA+** provides up to 56 MBit/s and up to 11.5 Mbit/s uplink speed.
- But: Available bandwidth per user decreases if terminal is moving or if there are many participants in one radio cell.

T-Mobile



Vodafone



Source: T-Mobile & Vodafone (2017)

T-Mobile



Vodafone



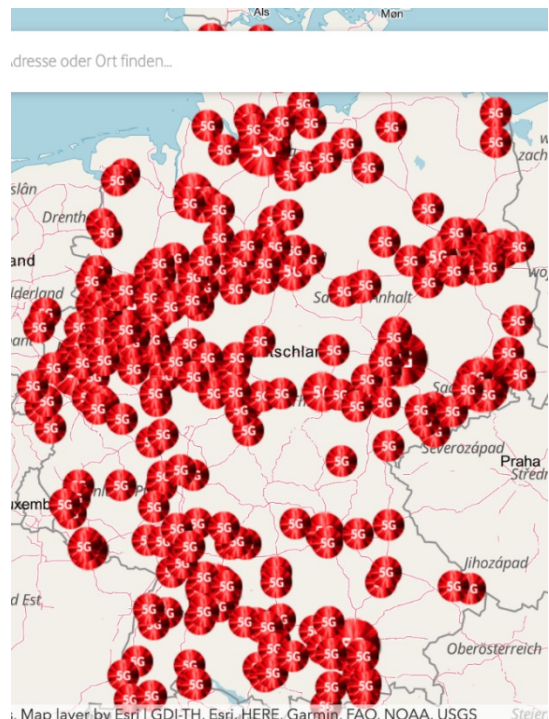
Source: T-Mobile & Vodafone (2017)

Mobile Telecommunication 5G - Status of Rollout

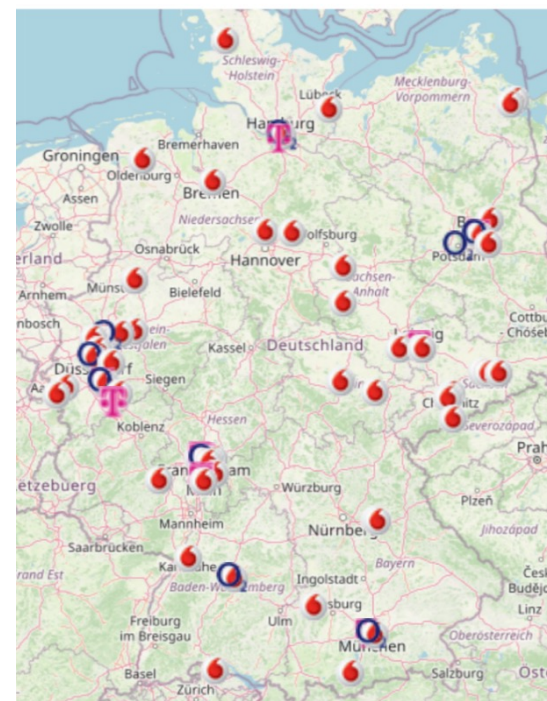
Telekom



Vodafone



Neutral homepage



→ No similar representation of the current network coverage across Telcos