Mobile Networks

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of Telecommunications

Mobile fueled the last 30 years–interconnecting people

source: Qualcomm Technologies, Inc.

1st generation

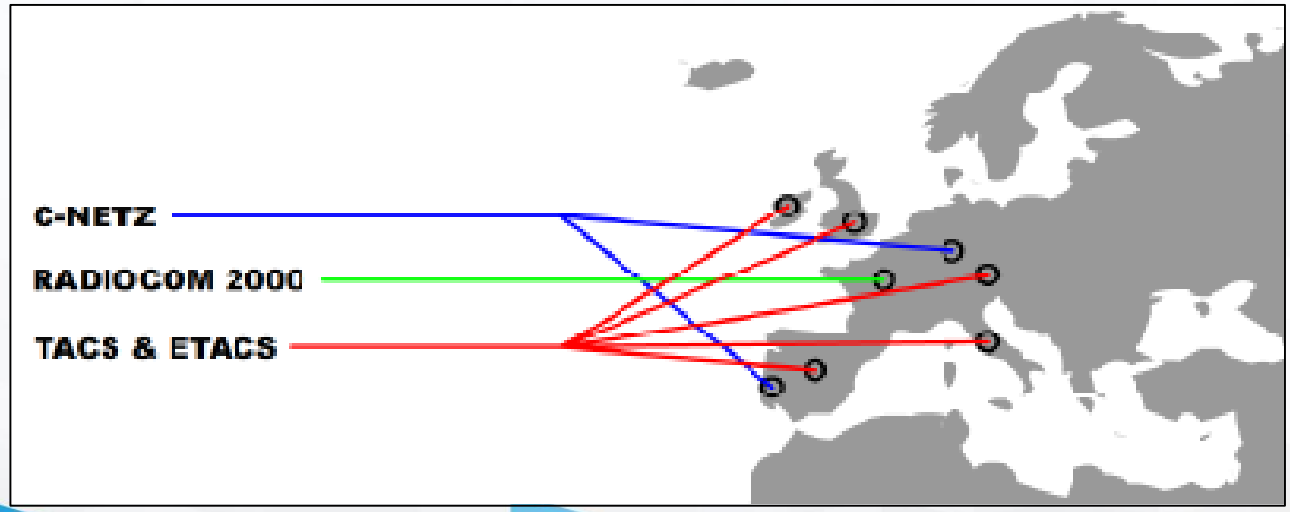
- using **analogue communications** and portable devices that were relatively large
- AMPS (Advanced Mobile Phone System)
  - the first cellular network standard
  - used primarily in the Americas, Russia and Asia
  - this first-generation analogue network had weak security mechanisms which allowed hacking of telephones lines
- TACS (Total Access Communication System)
  - is the European version of the AMPS
  - using the 900 MHz frequency band, this system was largely used in England, and then in Asia (Hong-Kong and Japan)
- NMT (Nordic Mobile Telephony)
  - common Nordic standard for analog mobile telephony as established by the telecommunications administrations in Sweden, Norway, Finland and Denmark in the early 1980s

NMT (Nordic Mobile Telephony)

- two variants: 450 MHz and 900 MHz
- cellular principle for covering the area
- cell diameter up to 30 km
- for full duplex FDD is used
- support pricing and roaming
- later also support security by scrambling
- transmission power of the base stations up to 20 W
- deployed in the Czech Republic (then Eurotel TiP, the system is shut down in 6/2006)
- in the Czech Republic was used
  - 451.31 to 455.73 MHz for the uplink
  - 461.31 to 465.73 MHz for the downlink
- channel bandwidth of 20 kHz → 222 frequency channels
- typical BTS served in peak up to 20 channels
- later supported CLIP / CLIR, SMS transmission
- frequency bands in the Czech Republic are now used by CDMA2000 EV-DO

Comparison of 1st generation of mobile networks

System	Downlink [MHz]	Uplink [MHz]	Channel Bandwidth [kHz]	Channels	Country
AMPS	869 - 894	824 - 849	30	180	America
NMT 450	463 - 467,5	453 - 457,5	25	832	Nordic, Spain, Italy, France
TACS	935 - 950	890 - 905	25	1000	Great Britain, Ireland, Austria

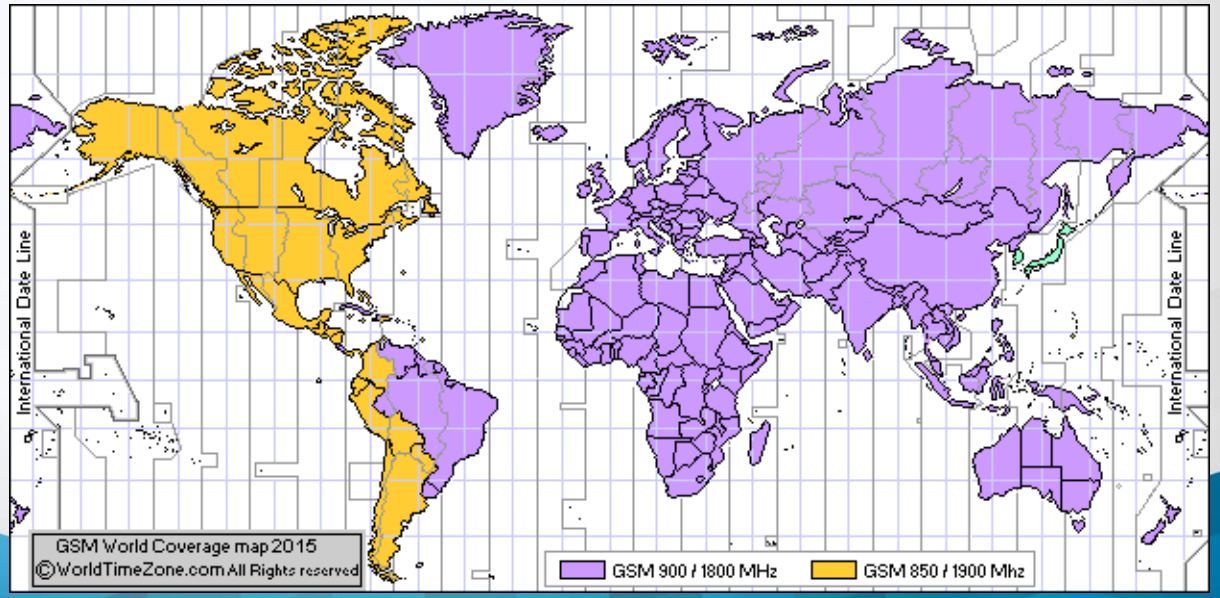


2nd generation

- variants
- **GSM**
  - based on TDMA standard used around the world, originally ETSI
  - worldwide
- **IS-95 (cdmaOne)**
  - based on the CDMA / FDMA is used for duplex FDD
  - North and South America, Asia
- **PDC (JDC)**
  - based on the TDMA / FDMA is used for duplex FDD
  - Japan
- **iDEN**
  - based on TDMA, developed by Motorola
  - USA, Canada
- **IS-136 (Digital AMPS)**
  - based on TDMA and FDMA is used for duplex FDD
  - uses the same frequency band as AMPS
  - 832 duplex channels
  - America

GSM (Global System for Mobile Communications)

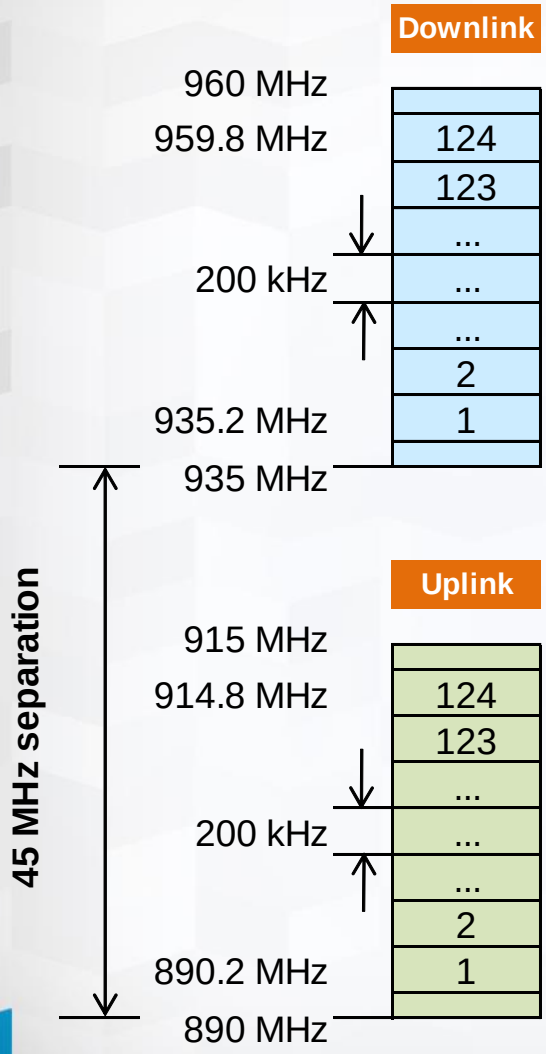
- Development started in the early eighties on the initiative of CEPT organization
- ETSI also participated on the development of this pan-European standard,
- 1991 - The first version of the recommendation - **GSM Phase 1** under ETSI
- quality connection in unfavorable radio conditions
- efficient use of the allocated frequency bands,interception is almost impossible
- transmission of signals in digital form allows considerably expand the range of services provided
- worldwide compatible

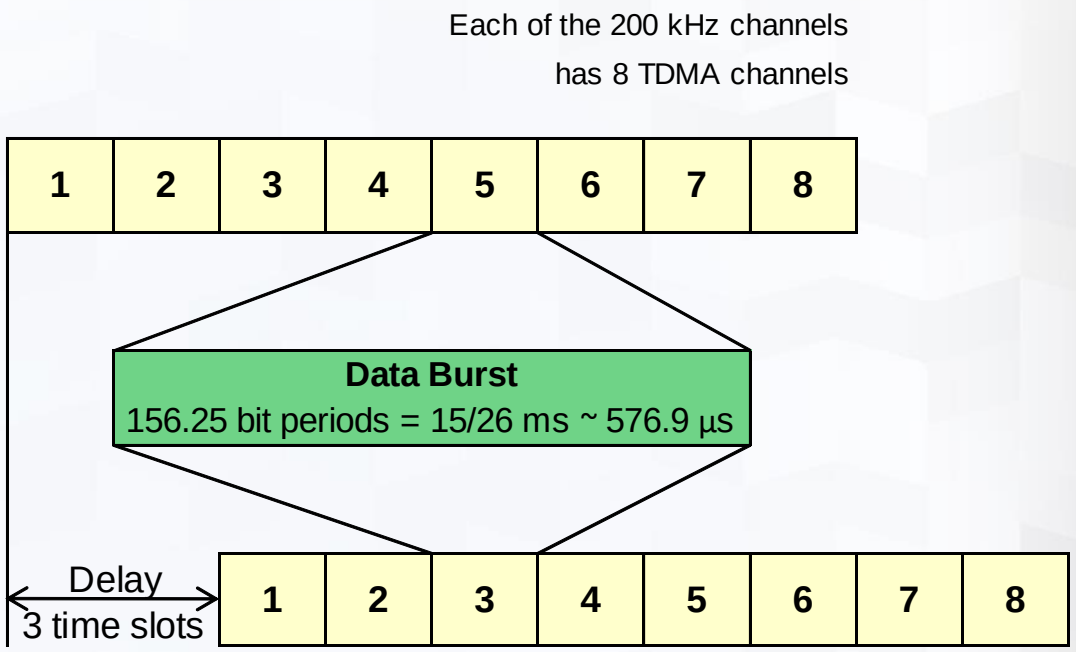


- the frequency band 890 MHz to 960 MHz is divided into two parts:
  - for connection from mobile station (MS) to Base Transceiver Station (BTS) so called uplink band is reserved from **890 MHz to 915 MHz**
  - for connection from BTS to MS, so called downlink band is reserved from **935 MHz to 960 MHz**
- spacing between uplink and downlink is **45 MHz**, we are talking here about the so-called P-GSM version
- a 124 radio channels is formed, each with a bandwidth of 200 kHz → FDMA and frequency duplex FDD is used
- **ARFCN** (Absolute Radio Frequency Channel Number) is the number of radio channel ***n***
- in the case of the GSM band - ARFCN 1 ... 124

$$f_{UPLINK}(n) = 890 + 0,2 \cdot n\,[MHz]$$
$$f_{DOWNLINK}(n) = f_{UPLINK}(n) + 45\,[MHz]$$

FDD and FDMA principle in GSM





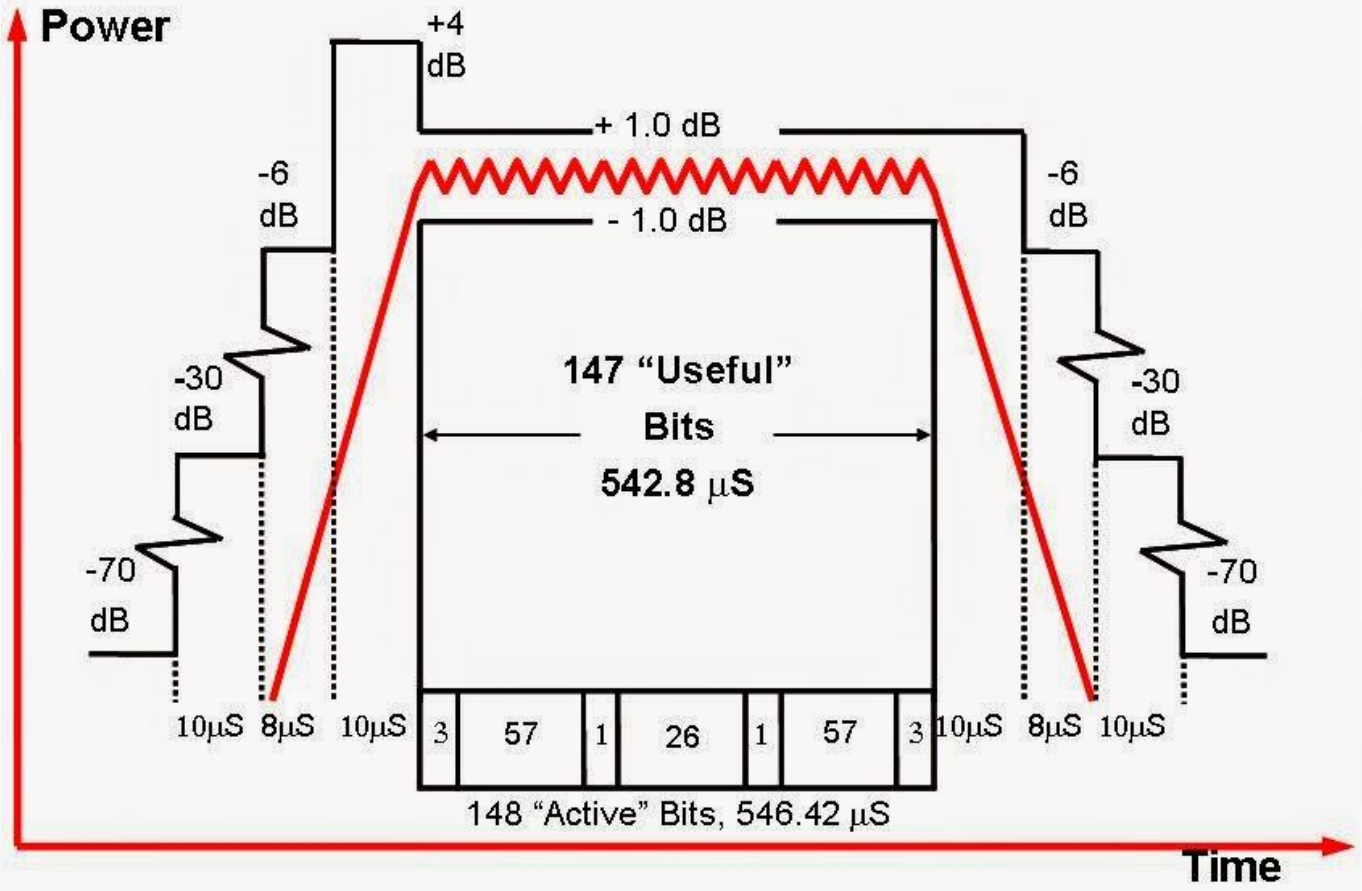
- each radio channel is formed by **eight TDMA time slots** and forming a **TDMA frame**
- one subscriber channel is inserted to each timeslot, i.e. the total number of subscribers when all frequencies are used = 124 x 8 = **992** (valid for **PGSM**)
- **EGSM system**
  - extension of the existing P-GSM for 10 MHz in each direction,
  - 880-915 MHz uplink, 925-960 MHz downlink
  - the total number of subscriber channels is 174 x 8 = 1392
  - ARFCN 1 ... 124, 975 ... 1023
- **DCS 1800 system**
  - **1710 MHz to 1785 MHz** for the uplink, **1805 MHz to 1880 MHz** for the downlink
  - 374 radio channels, each with a bandwidth of 200 kHz
  - the total number of subscriber channels is 374 x 8 = 2992
  - ARFCN 512 ... 810

- basic transmission unit of the GSM is **burst**
- burst is transmitted in each time slot of GSM frame
- in one frame of the GSM system may be **up to eight voice** subscribers
- burst contains a total of **156.25 bits** and its duration is **0.577 ms**
- frame duration is **4.615 ms**
- using TDMA transmission rate on one channel interval is

$$\frac{156,25}{4,615.10^{3}} = 33,85\,kb/s$$

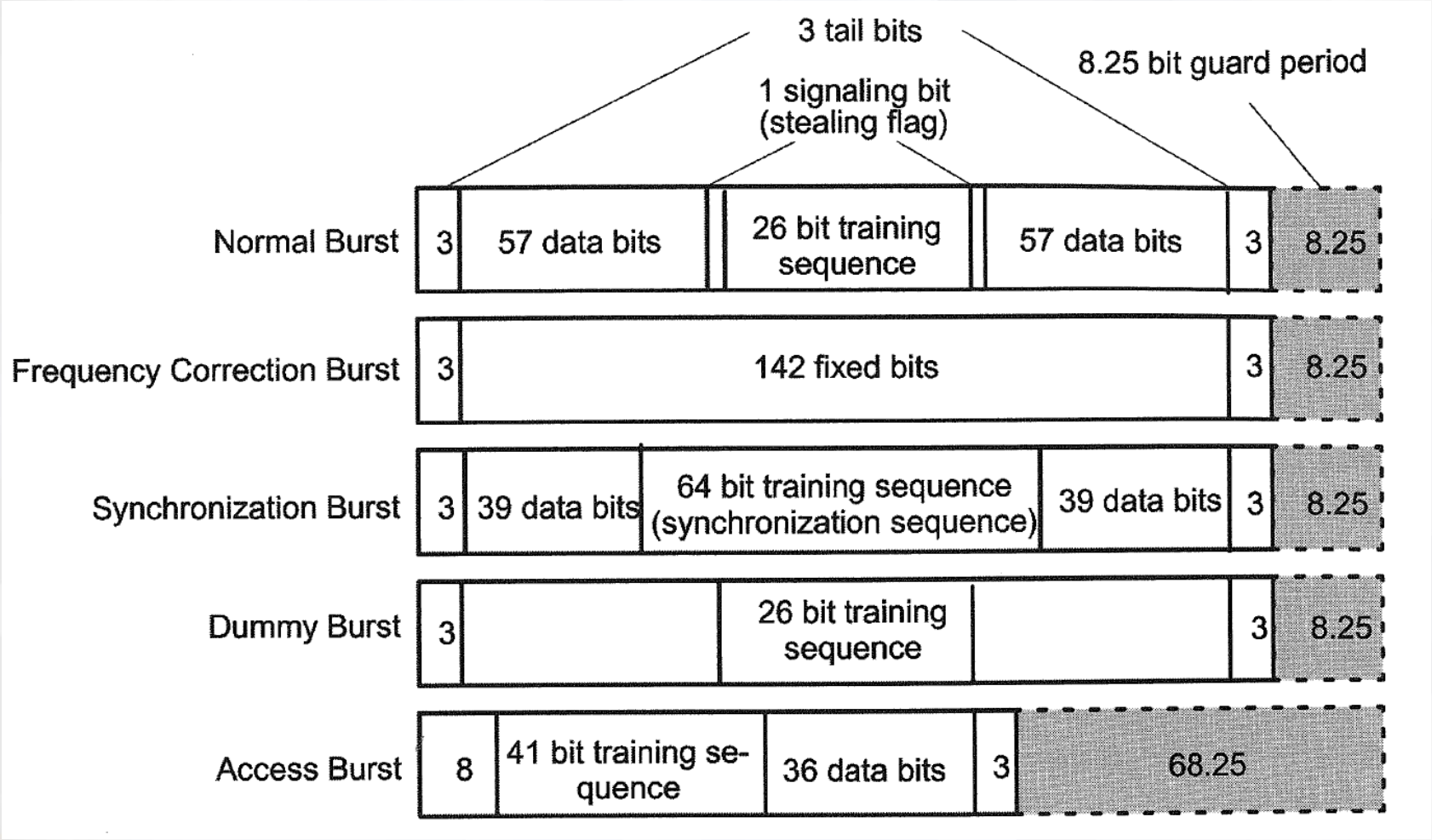
- guard bits at the end of the burst represent the so-called Guard Period in which a burst can move within a dedicated timeslot TS → this situation may occur as a result of signal delay while mobile station is moving during communication
- increase and decrease of transmitter power must keep strict criteria to signal not leaking into the adjacent timeslots and disturb neighboring subscriber channels → this describes the **Power-Time template**

Power-time template for GSM

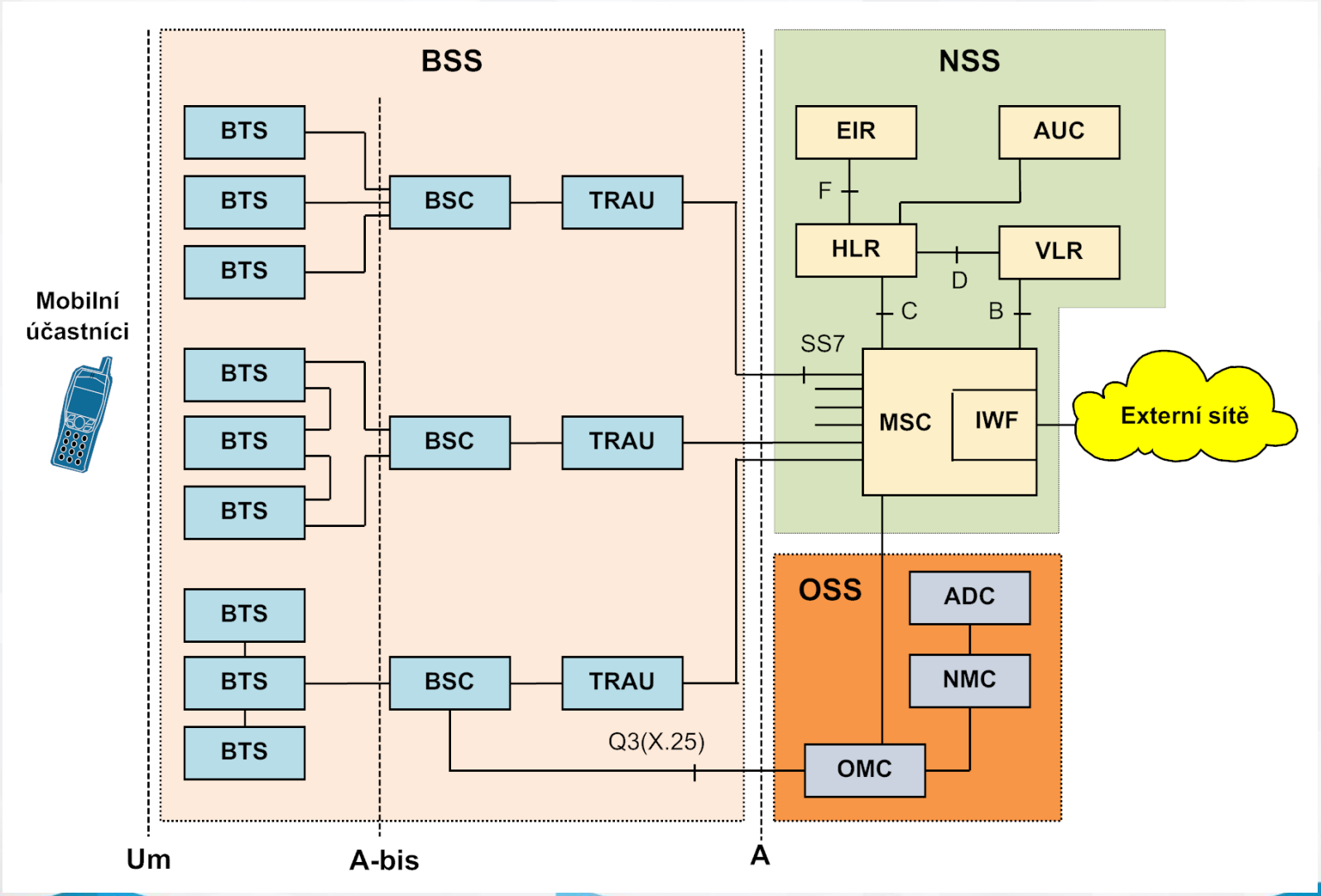


- in GSM there **are 5 types** of units burst:
  - **Normal Burst**
    - standard burst to transmit calls or data
  - **Frequency Correction Burst**
    - frequency correction burst for MS
  - **Synchronization Burst**
    - burst for time correction
    - the need for time correction due to the use of TDMA
  - **Dummy Burst**
    - if necessary, sent to MS, bears no information
  - **Access Burst**
    - random access of MS radio interface
    - has extended Guard Period

Types of bursts



GSM system architecture



- **the base station subsystem BSS**
  - radio subsystem, MS communicate directly with the mobile station MS through the radio interface **Um** contains:
  - **BTS** (Base Transceiver Station)
    - base radio station
    - function transmitter, receiver, signal processing
  - **BSC** (Base Station Controller)
    - cares about the allocation of radio channels, receives measurements from mobile phones, manages handover
- **network and switching subsystem NSS**
  - **MSC** (Mobile Switching Centre)
    - creates each connection in the mobile network and towards other networks

- **HLR** (Home Location Register)
  - database, which gathers information on all registered participants
- **VLR** (Visitor Location Register The)
  - This register temporarily stores information about the current mobile subscribers moving in the respective MSC, this is a temporary incomplete copy of the HLR
- **EIR** (Equipment Identity Register)
  - This database contains the identification number IMEI mobile phones
  - using the EIR can prevent unauthorized use of the mobile phone
- **AUC** (The Authentication Centre)
  - database containing keys for authentication of subscribers
  - verifies the identity of each participant before starting communication and guarantees protection against abuse of the GSM system

- **operational subsystem OSS** (Operation Support Subsystem)
  - is responsible for the operation and maintenance of the entire system, provides service and coordinates the function of the whole system
- **Mobile Station (MS)**
  - provides communication participant GSM network through radio environment

Cell Structure

- the coverage area of an operator is subdivided into hexagonal cells (radio zones)
- a cell is the area that one transmitter or a small collection of transmitters can cover
- the size of a cell is determined by the transmitter's power
- the concept of cellular systems is the use of low−power transmitters in order to enable the efficient reuse of the frequencies
- two neighboring cells must never use the same frequencies
- when a mobile station moves from one cell to another during an ongoing conversation, an automatic channel/frequency occurs (handover)
- the maximum size of a cell is approximately 35 km (radius)

Cellular System

- GSM uses to cover the area by signal so called **cellular** structure
- the coverage area of an operator is subdivided into hexagonal cells (radio zones)
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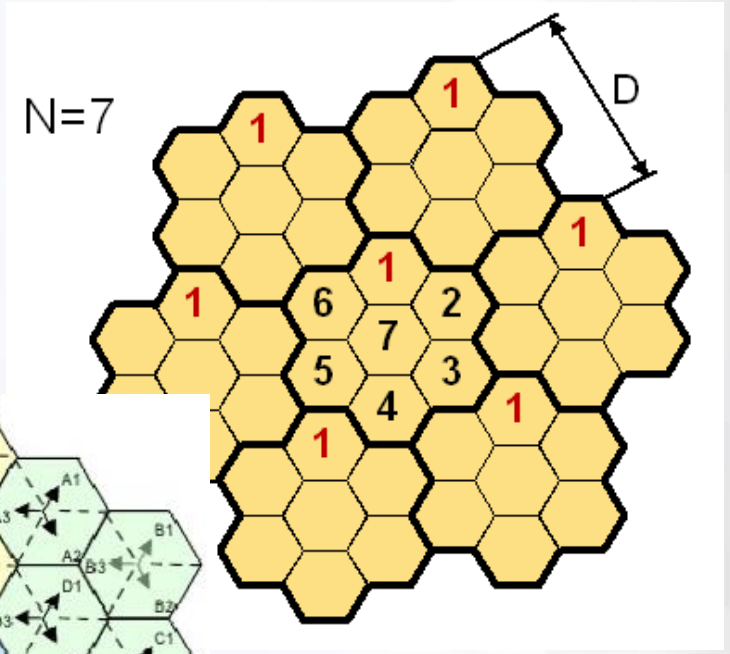
- when a mobile station moves from one cell to another during an ongoing conversation, an automatic channel/frequency occurs (handover)
- the maximum size of a cell is approximately 35 km (radius)
- by size of area which we want to cover, the cells are divided into:
  - micro / nano / pico / femto - cell
  - macro-cell
  - type umbrella

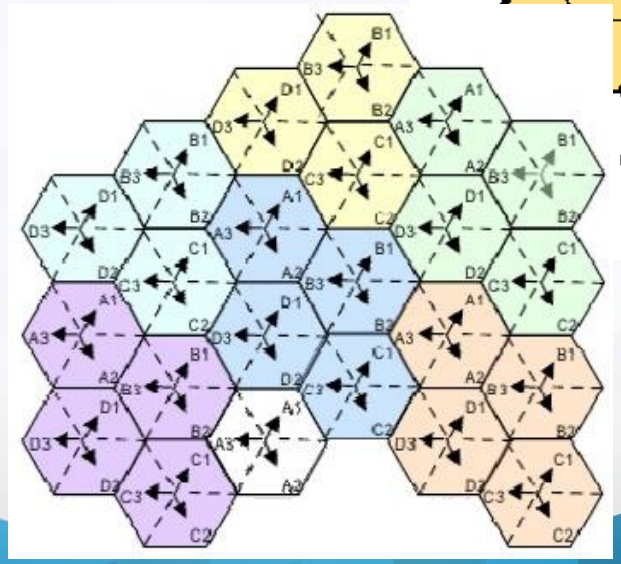
- a cluster can contain all the frequencies
- within a cluster, no frequency can be reused
- the larger a cluster, the larger the frequency reuse distance
- the larger values of *N*, the smaller the number of channels and the number of active subscribers per cell

$$D = R\sqrt{3N}$$

where

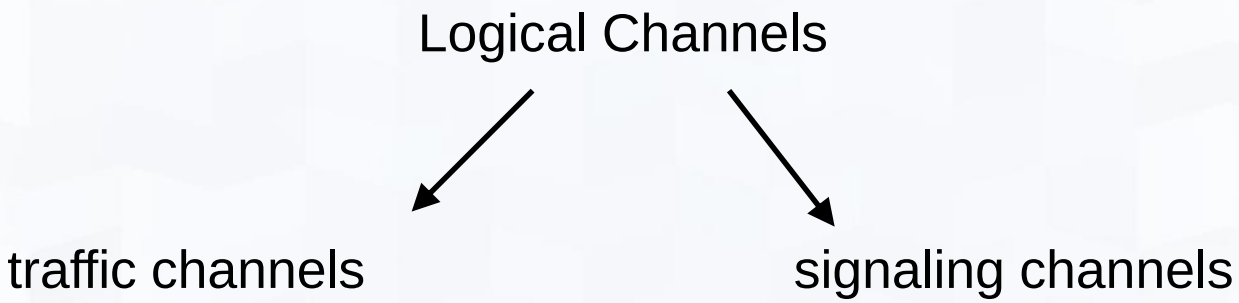
- D ... reuse distance
- R ... cell radius
- N ... number of cells





GSM Air Interface - Physical Layer

- logical channels
- physical channels



Traffic Channels (TCH)

- used for the transmission of user payload data (speech, data, fax)
- do not carry any control information of Layer 3
- communication over a TCH can be circuit switched or packet switched
- may be fully used (full rate) or be split into two half rate channels
- following ISDN technology, TCH are also designated as Bm channel (mobile B channel)
- 13 kbit/s of digitally coded speech

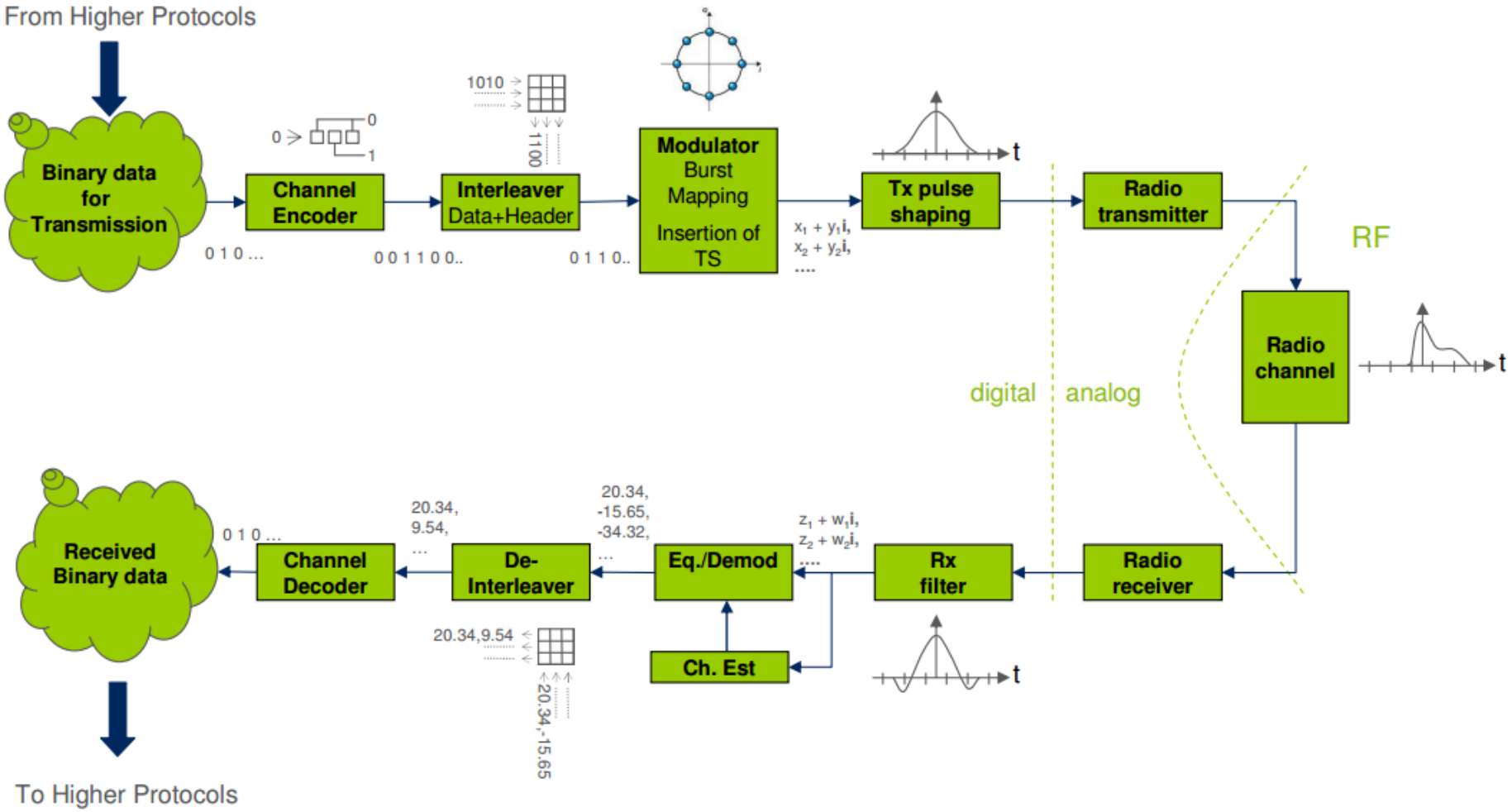
Signalling Channels

- to control and management of a cellular network demands
- are also called *Dm* channels (mobile D channels)
- are further divided into:
  - **Broadcast Channel** (BCH)
    - BCCH, FCCH, SCH
  - **Common Control Channel** (CCCH)
    - RACH, AGCH, PCH, NCH
  - **Dedicated Control Channel** (DCCH)
    - SDCCH, SACCH, FACCH

Physical Channels

- transport the logical channels via the air interface
- Gaussian Minimum Shift Keying (GMSK) modulation on the physical layer
- GSM uses **GMSK** or **8PSK** modulation which produces a 13/48 MHz (270.833 kHz or 270.833 K symbols/second) symbol rate

Transmission Chain



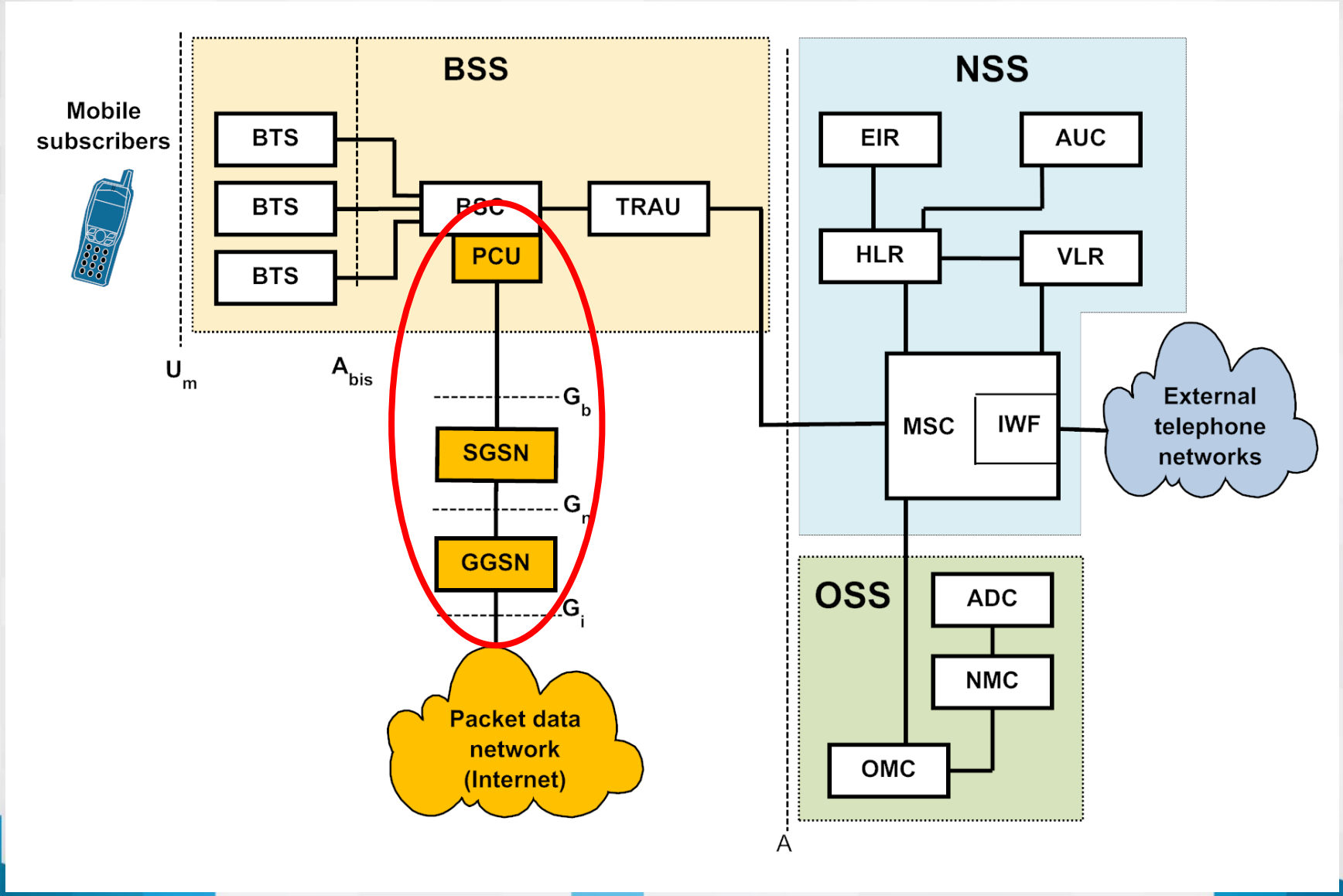
Data Communication over GSM

- **CSD**
  - Circuit Switched Data
  - uses a single radio time slot
  - 9,6 kbit/s
  - dial-up service for access to packet network (Internet)
  - single dedicated radio time slot is allocated between the phone and the base station - guaranteed bitrate
- **HSCSD**
  - High-Speed Circuit Switched Data
  - dedicated circuit-switched channels
  - uses multiple time slots to send data at the same time, thus increasing transmission capacity
  - maximum 4 time slots = 57,6 kbit/s

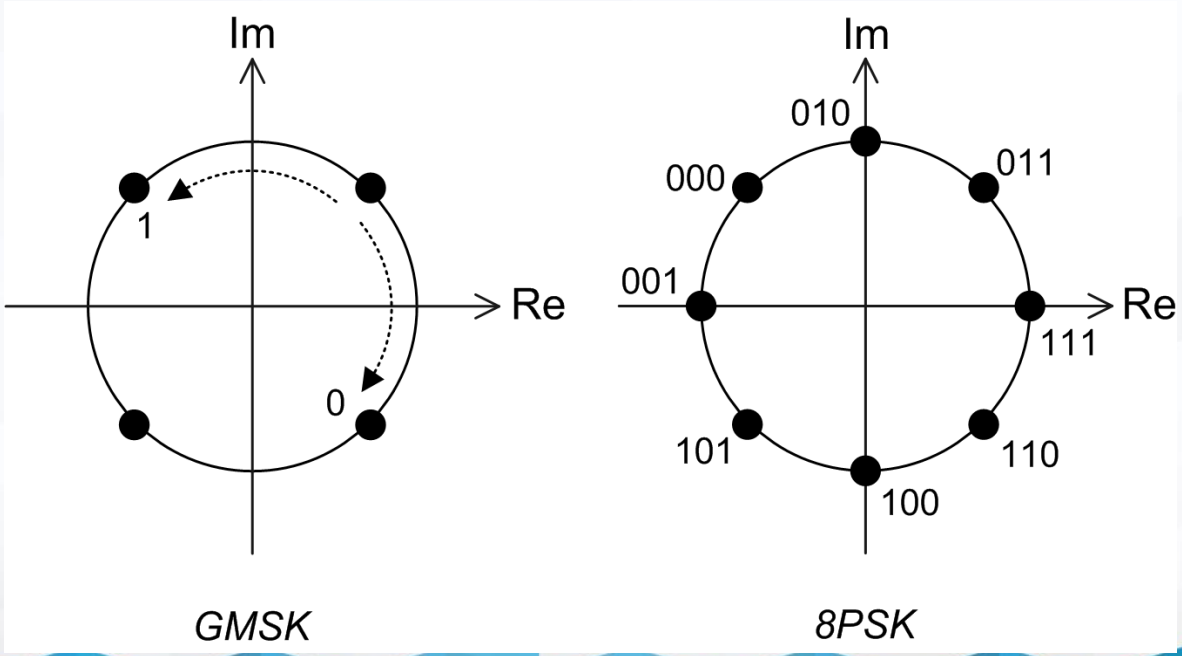
- **GPRS**
  - General Packet Radio Service
  - transmission of data packets over the radio interface - access to IP network (Internet)
  - higher efficiency of bandwidth
  - up to 171,2 kbit/s download
  - tarification according to the amount of data transferred, not counted by duration of connection
  - transfer rate depends on the number of allocated time slots, so-called GPRS multi-slot class
  - 4 coding schemes are defined:
    - CS-1, max. 9.05 kbit/s / 1 time slot
    - CS-2, max. 13.4 kbit/s / 1 time slot
    - CS-3, max. 15.6 kbit/s / 1 time slot
    - CS-4, max. 21.4 kbit/s / 1 time slot
  - Each scheme defines the level of protection against errors
    - CS-1 9.05 kbit/s, CS-2 13.4 kbit/s, CS-3, CS-4 21.4 kbit/s

- integration of GPRS into a GSM architecture requires the addition of new network nodes
  - **SGSN** (Serving GPRS Support Node)
    - switching and forwarding of data packets
  - **GGSN** (Gateway GPRS Support Node)
    - gateway interfaces with other data networks (the Internet)
    - responsible for providing an IP address to the mobile terminals throughout the duration of their connection

GSM/GPRS network architecture



- **EDGE**
  - Enhanced Data Rates for GSM Evolution
  - standardized by 3GPP as part of the GSM family
  - EDGE/EGPRS is a improvement to GPRS
  - base station subsystem needs to be upgraded to support EDGE
  - uses higher-order 8-PSK (Phase Shift Keying)
    - 3-bit word for every change in carrier phase
    - triples the gross data rate
  - theoretical maximum is 473.6 kbit/s for 8 timeslots



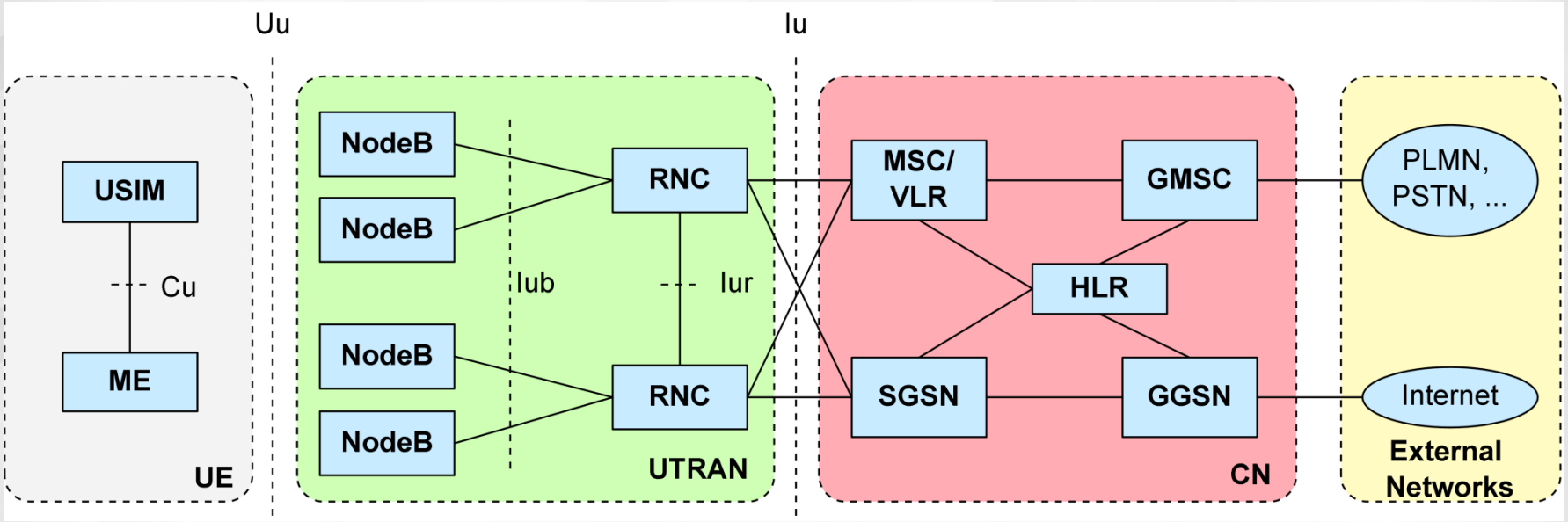
The evolution of mobile networks from the third generation ETSI / 3GPP standards

Release	Specification complete	Main feature of Release
Rel-99	March 2000	UMTS 3.84 Mcps (W-CDMA FDD & TDD)
Rel-4	March 2001	1.28 Mcps TDD (aka TD-SCDMA)
Rel-5	June 2002	HSDPA
Rel-6	March 2005	HSUPA (E-DCH)
Rel-7	Dec 2007	HSPA+ (64QAM DL, MIMO, 16QAM UL). LTE & SAE Feasibility Study, Edge Evolution
Rel-8	Dec 2008	LTE Work item – OFDMA air interface SAE Work item –New IP core network UMTS Femtocells, Dual Carrier HSDPA
Rel-9	Dec 2009	Multi-standard Radio (MSR), Dual Carrier HSUPA, Dual Band HSDPA, SON, LTE Femtocells (HeNB) LTE-Advanced feasibility study, MBSFN
Rel-10	March 2011	LTE-Advanced (4G) work item, CoMP Study Four carrier
Rel-11	Sept 2012	CoMP, eDL MIMO, eCA, MIMO OTA, HSUPA TxD & 64QAM MIMO, HSDPA 8C & 4x4 MIMO, MB MSR
Rel-12	March 2013 stage 1	New carrier type, LTE-Direct, Active Antenna Systems

3rd Generation

- based on the ITU IMT-2000 group, primarily focused on multimedia services and high-speed data transfers
- IMT-2000 defines the follow:
  - TDMA Single-Carrier (IMT-SC)
    - EDGE (UWC-136), worldwide
  - CDMA Multi-Carrier (IMT-MC)
    - CDMA2000, America, Asia
  - **CDMA Direct Spread (IMT-DS)**
    - **as UMTS**
    - **W-CDMA (worldwide), TD-CDMA (Europe), TD-SCDMA (China)**
  - FDMA/TDMA (IMT-FT)
    - as DECT (Europe, USA)
  - IP-OFDMA
    - IEEE 802.16 (WiMAX)
    - worldwide

Architecture



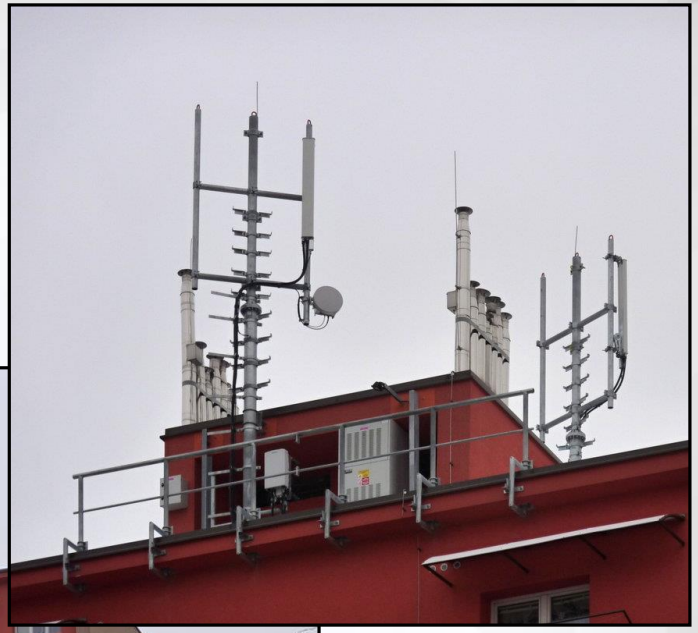
- **consist of:**
  - **UE** (User Equipment)
    - mobile phone

UTRAN (UMTS Terrestrial Radio Access Network)

- radio access network based on WCDMA
- consists of one or more radio network subsystems RNS (Radio Network Sub-system)
- performs two main functions:
  - **radio transmission,**
  - **management and allocation of radio resources**
- There are two defined network elements:
  - **Node B**
    - UMTS base station system (similar to BTS in GSM)
    - comprises a radio receiver, transmitter and antenna system serving one or more cells
    - basic functions of the Node-B units are modulation and demodulation, transmission and reception, coding physical channels protection against errors and transmit power control
  - **Radio Network Controller (RNC)**
    - radio network controller (similar to the GSM BSC)
    - controls the functionality of one or more base stations
    - allocation of radio resources (codes, performance), access control (security), encryption, management handover, transmit power control
    - RNS controls each unit of the RNC that is connected to the backbone network via the interface Ium, base stations are connected to the RNC through the Iub interface

- **CN** (Core Network)
  - provides switching functions (connecting subscribers, routing packets), and links to external networks (PSTN, Internet, etc.)

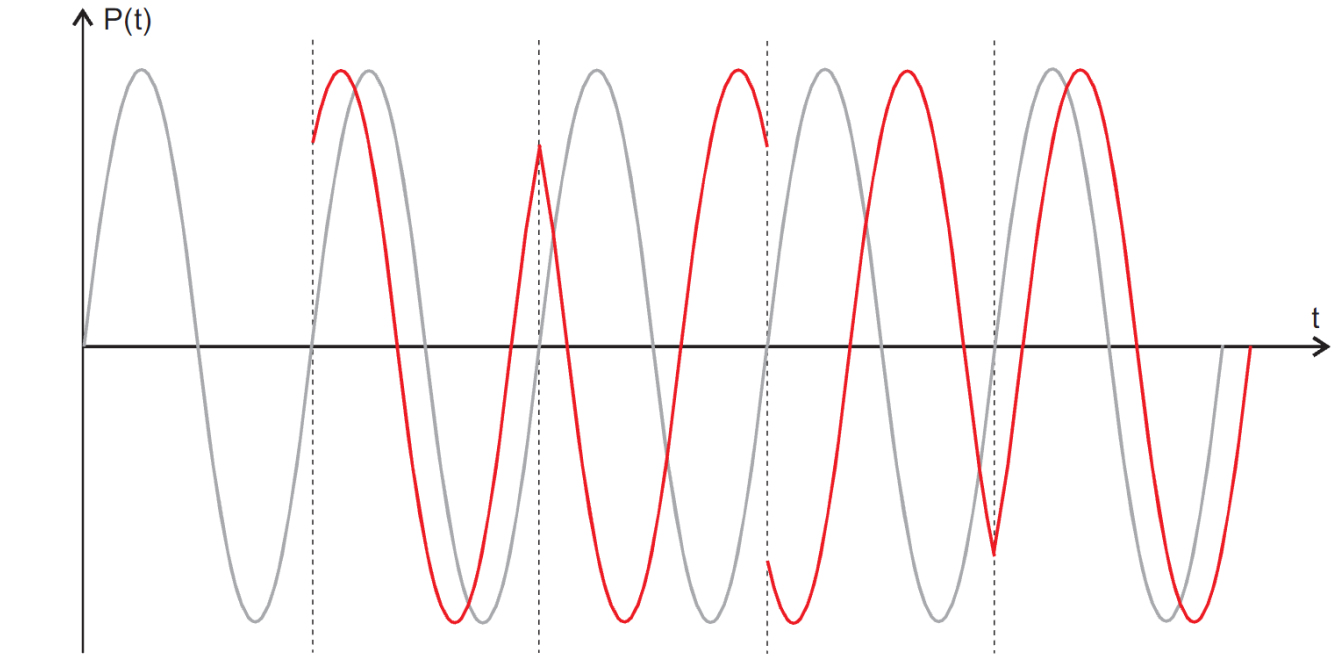
- **interfaces**
  - **Iu** between RNC a CN
  - **Uu** between Node B a UE
  - **Iub** between RNC a Node-B
  - **Iur** between two RNC



Physical Layer

- these IMT-A bands can be used for UMTS
  - 450 – 470 MHz
  - 698 – 960 MHz
  - **1710 – 2025 MHz**
  - **2110 – 2200 MHz**
  - 2300 – 2400 MHz
  - 2500 – 2690 MHz
  - 3400 – 3600 MHz
- in Czech Republic:
  - **UMTS FDD**
    - each provider has 20 MHz
    - uplink 1920 to 1980 MHz
    - downlink 2110 to 2170 MHz
  - **UMTS TDD**
    - **1910 - 1915 MHz**, 872 MHz
    - T-Mobile „4G“, network suspended in 6/2012

- the UMTS system uses advanced modulation technique - **QPSK** (Quadrature Phase Shift Keying)
- QPSK is described as four-states Phase Shift Keying where each state simultaneously transmits two bits (dibit)
- carrier has a constant amplitude and has one of four different states: 45 °; 135 °; 225 °; 315 °
- In the UMTS system, each phase shift codes two "**chips**"

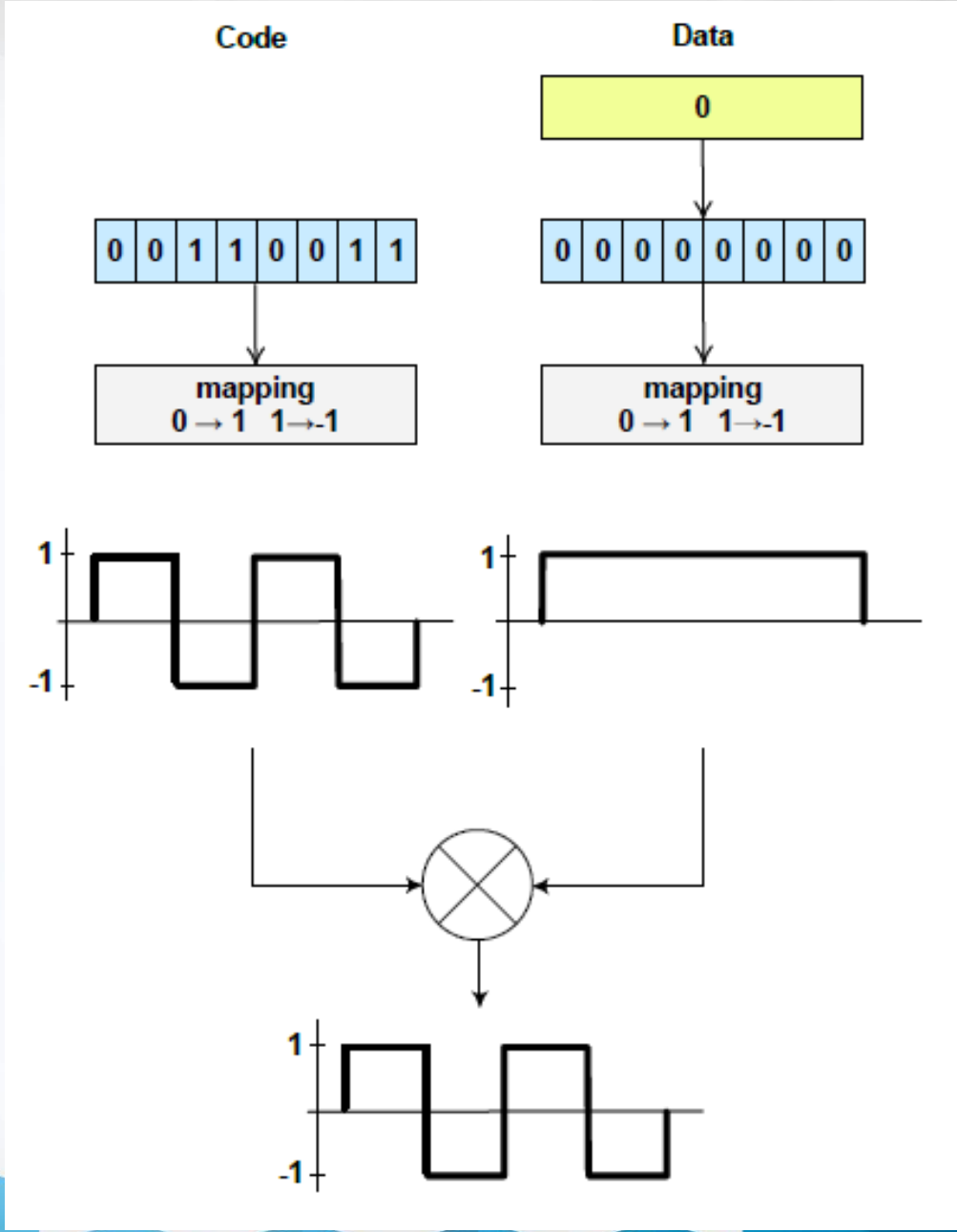


CDMA techniques in UMTS system

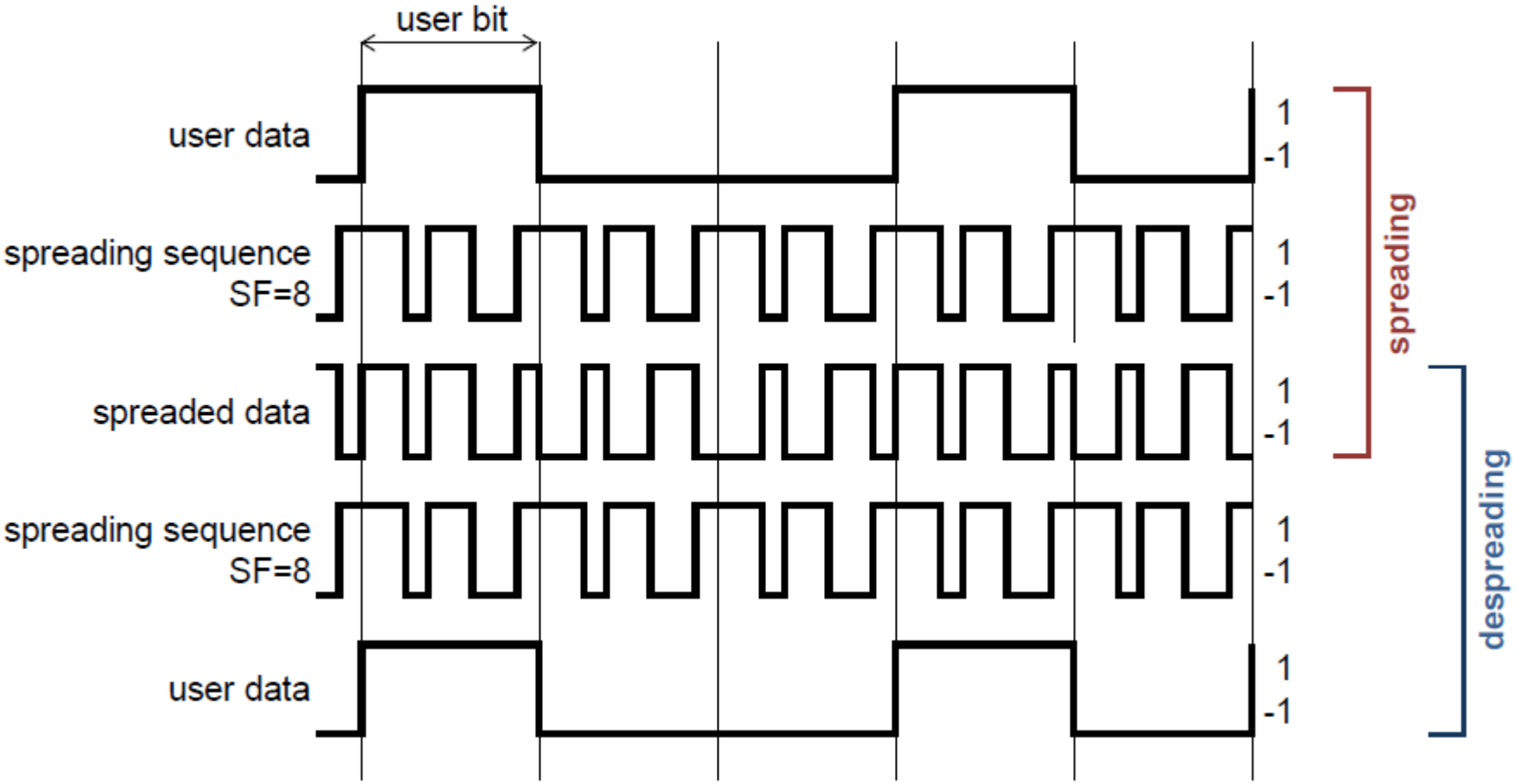
- To separate the direction of transmission / reception (uplink, downlink) and for increasing the spectral efficiency, the following duplex and multiplex techniques are used:
  - FDD / FDMA (Frequency Division Duplex / Frequency Division Multiple Access)
  - TDD / TDMA (Time Division Duplex / Time Division Multiple Access)
  - CDMA (Code Division Multiple Access)
- to separate individual users, different individual codes are them assigned
- with the fast pseudorandom sequences in the transmitter, signal is transformed in the form of broadband,
- this creates a spread spectrum signal, which is transmitted by the radio channel.

- WCDMA is a wideband CDMA system similar to direct spreading called DS-CDMA (Direct-Sequence CDMA)
- user's data are **spread** over the wideband channel, and so by multiplying with the sequence of random bits (chips)
- In WCDMA / UMTS systems is used the chip rate of **3.84 Mcps** which defines the channel width of **5 MHz**
- We distinguish:
  - **bit (element data sequence)**
  - **chip (element of spreading sequence).**

- Each pair of the transmitter / receiver is assigned a unique CDMA code, which consists of the sequence "chips" with the value +1 and -1
- User data are **spreaded** by **XOR** mathematical function, where each data bit is multiplied by ***n*** code bits (chips).
- This creates a wideband spread signal with n-multiplicatively increased frequency
- in this context, a **Spreading Factor** (SF) is defined

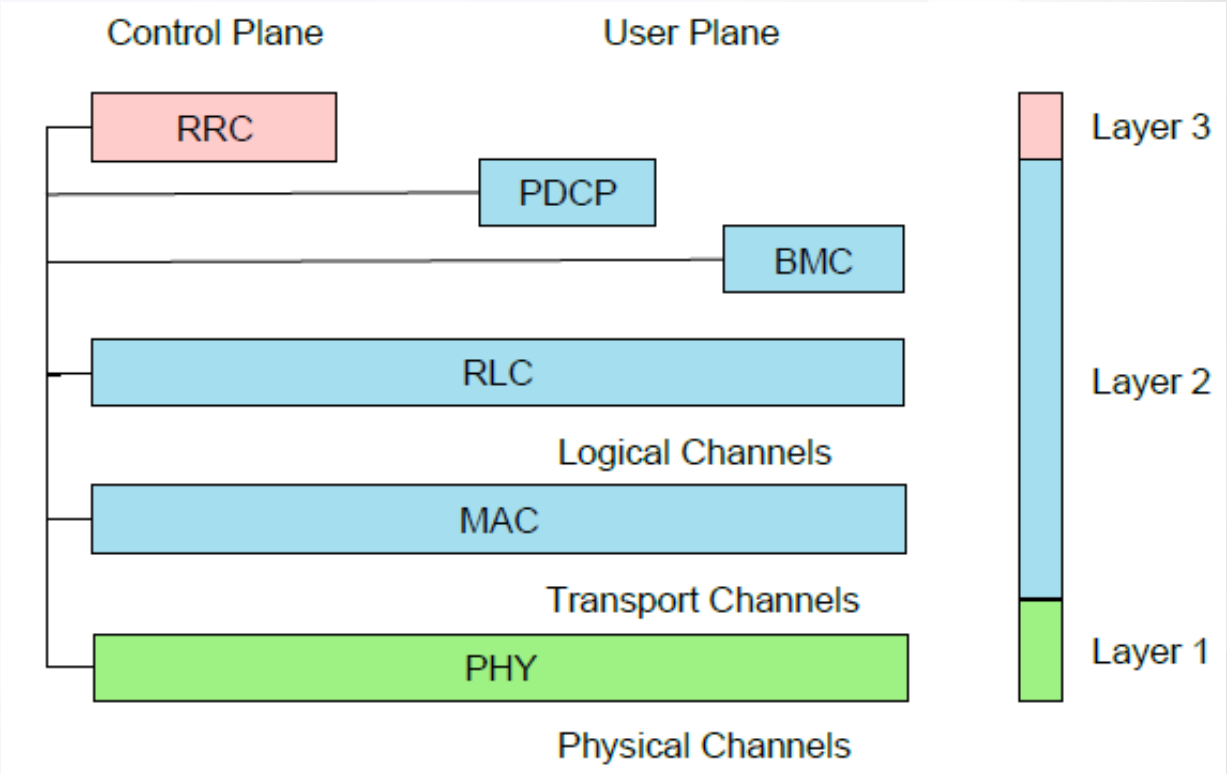


Example of spreading and despreading

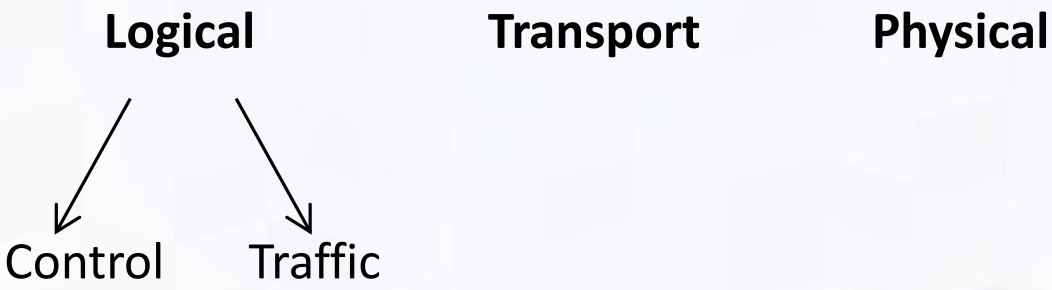


Protocol Stack

- Logical, transport and physical channels are described using a three layers UMTS protocol stack.
- Protocol architecture is divided into a control (Control Plane) and part of the user (User Plane).
- The data link layer is also divided into two sublayers:
  - RLC (Radio Link Control)
  - MAC (Media Access Control).



- **RRC (Radio Resource Control)** layer provides an exchange of signaling messages with the UTRAN or CN
  - all signaling procedures such as maintain of connection, power control, handover are related to this layer
  - NodeB is transparent for the protocol entity.
- **PDCP (Packet Data Convergence Protocol)** is a protocol supporting L2, (eg. IPv4 and IPv6, respectively. TCP / IP and RTP / UDP / IP) with the RLC layer.
- BMC (Broadcast / Multicast Control Protocol) is a L2 protocol for the support of broadcast / multicast messages.
- Between the RLC layer, the MAC and PHY are defined several types of channels:

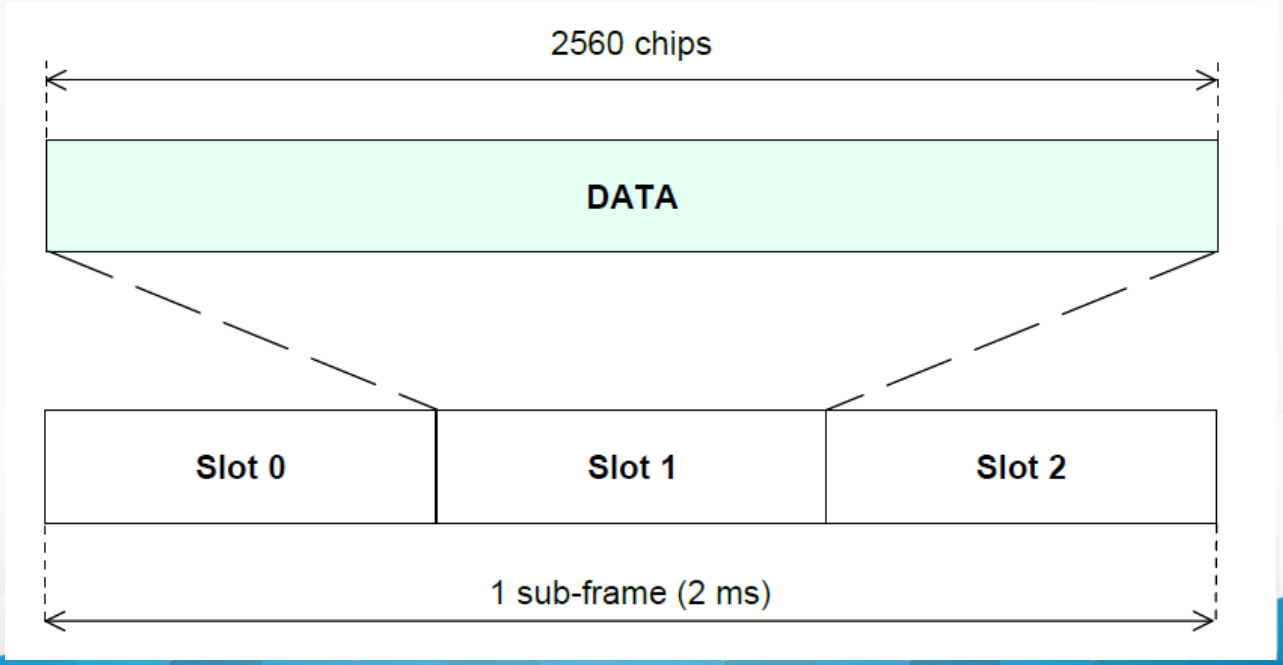


HSPA (High-Speed Packet Access)

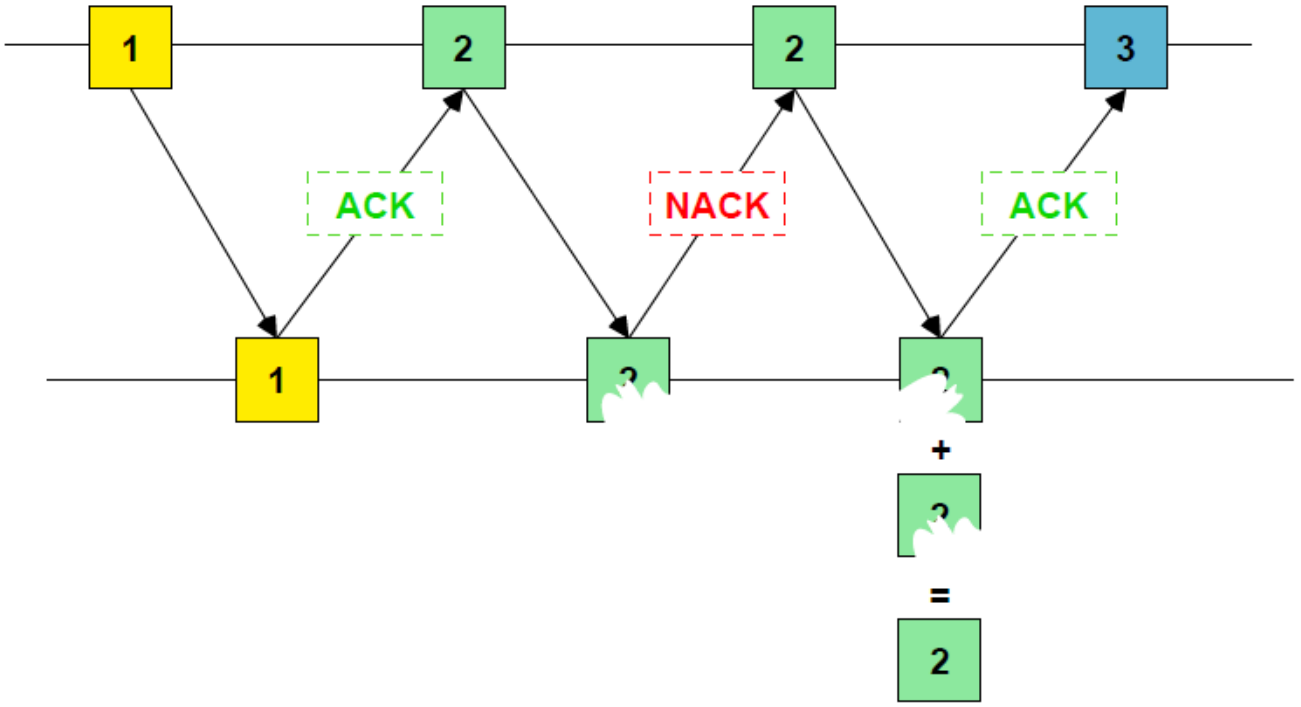
- HSPA is defined as:
  - **HSDPA** (High-speed Downlink Packet Access) defined in **Release 5**
  - **HSUPA** (High Speed Uplink Packet Access) defined in **Release 6**

HSDPA

- introduction of High-Speed Downlink Shared Channel (HS-DSCH)
- **main characteristics:**
  - 16QAM used
  - new **Adaptive Modulation and Coding** and **Code Multiplexing**
  - High-Speed Downlink Shared Channel (HS-DSCH) introduced
  - Transmission Time Interval (TTI) is reduced to 2ms (originally 10 ms), is transmitted through the **three** slots

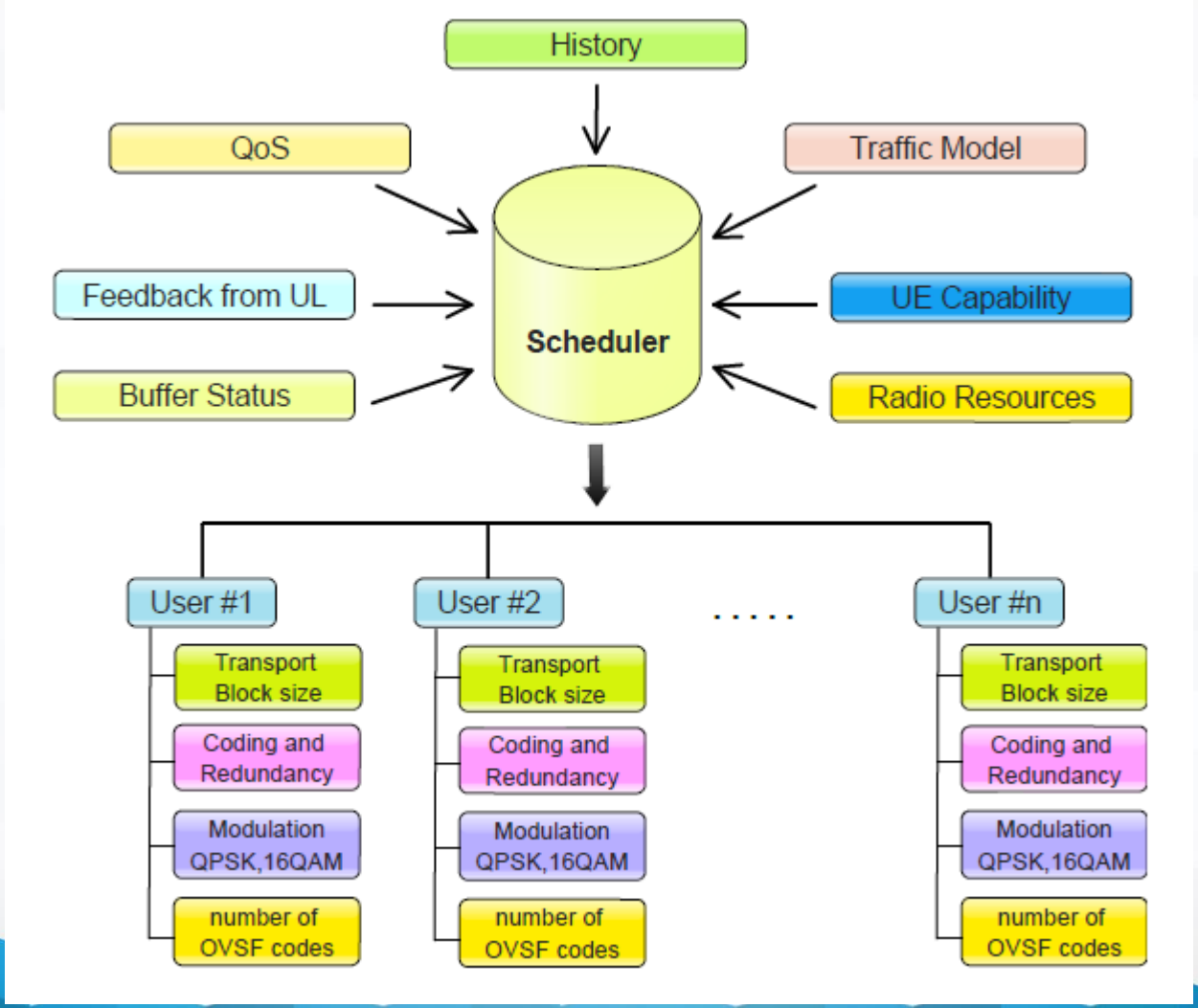


- **Hybrid automatic repeat-request (HARQ)**
  - If retransmission is needed, the user device saves the packet and later combines it with retransmitted packet to recover the error-free packet as efficiently as possible.



Fast packet scheduling

- downlink channel is shared between users using channel-dependent scheduling to make the best use of available radio conditions



HSUPA

- **aim:** adopt methods similar to those employed by HSDPA
- HSUPA uses an uplink enhanced dedicated channel (E-DCH)
- shorter Transmission Time Interval enabling faster link adaptation
- use of HARQ
- HSUPA uses a packet scheduler, but it operates on a request-grant principle where the UEs request a permission to send data and the scheduler decides when and how many

HSPA+

- Evolved High-Speed Packet Access
- **main characteristics**
  - back compatibility with UMTS release 99, Release 5 and Release 6,
  - reduction of latency below 50 ms,
  - 64 QAM for downlink,
  - 16 QAM for uplink,
  - use of MIMO (Multiple Input Multiple Output) technique,
  - carrier aggregation up to 40 MHz.

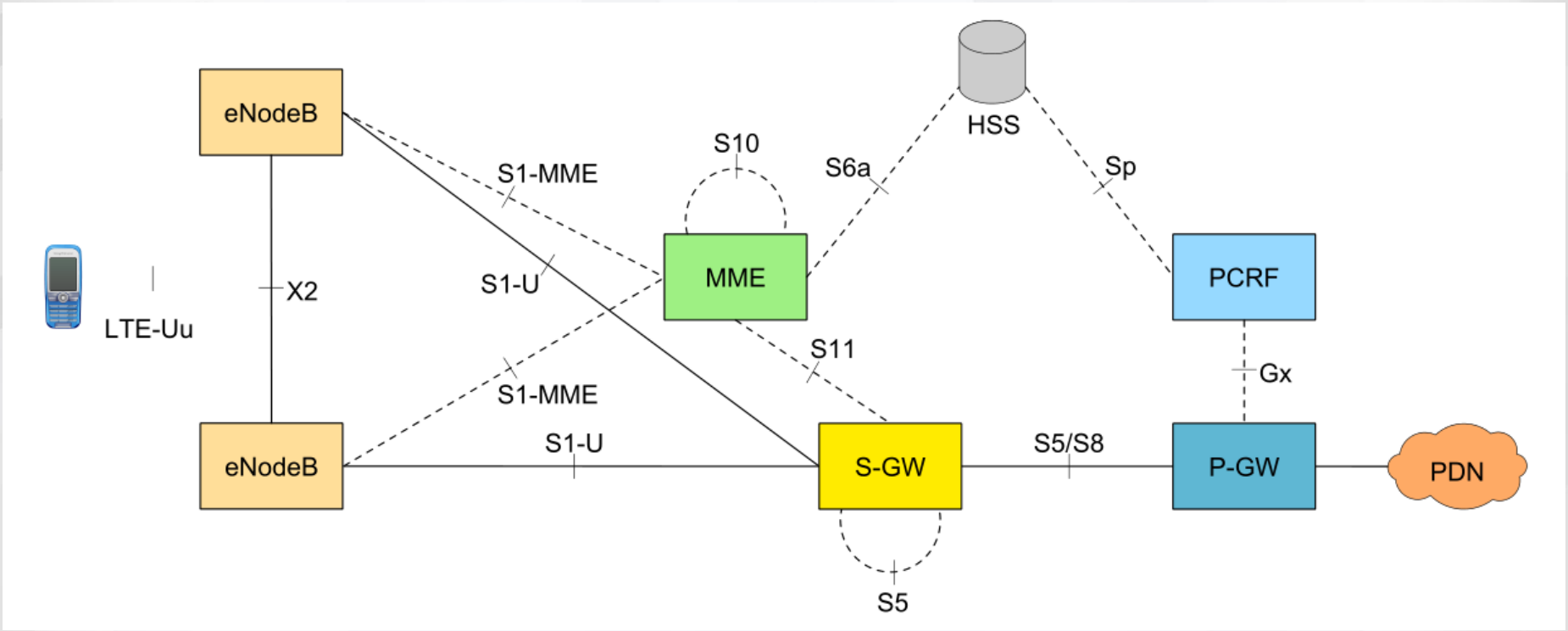
4th Generation

- **aims:**
  - support essentially only PS (Packet Switched) services incl. VoIP
  - much higher bit rate available for users – claims for data are still increasing
  - reduce latency
  - improved spectral efficiency (b/s/Hz)
  - spectral flexibility
  - simple migration from 3G
  - compared to 3G - reduction of interference between users
  - use of OFDM instead of WCDMA

Terminology

- **LTE** (Long Term Evolution)
  - sometimes as **eUTRAN** (evolved UTRAN) - new type of access technology for mobile network
- **SAE** (System Architecture Evolution)
  - 3GPP technology study, which defines **EPC** (Evolved Packet Core), which is Core Network
- **EPS** (Evolved Packet System) → **EPS = LTE + SAE + terminal**

System Architecture



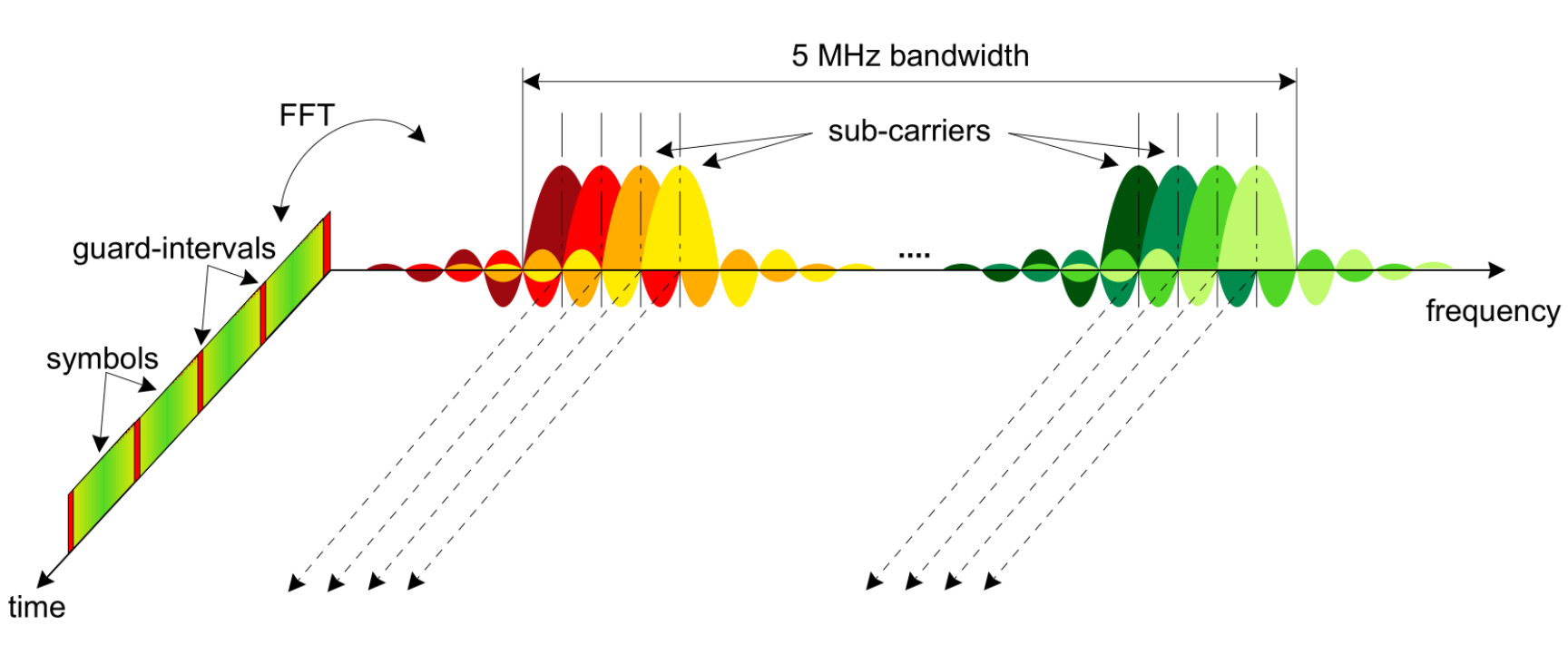
- The high-level network architecture of LTE is comprised of following three main components
  - **The User Equipment** (UE).
  - **The Evolved UMTS Terrestrial Radio Access Network** (E-UTRAN).
  - **The Evolved Packet Core** (EPC).

- **HSS** (Home Subscriber Server) - a central database that contains information about all subscribers
- **PDN** (The Packet Data Network) Gateway (P-GW) - termination point of the packet data interface towards the Packet Data Network
- **S-GW (**Serving Gateway) - acts as a router, and forwards data between the base station and the PDN gateway.
- **MME** (Mmobility Management Entity) – Control plane functions related to subscriber and session management such as end-user authentication, initiation and negotiation of ciphering and integrity protection algorithms,
- **PCRF** (The Policy Control and Charging Rules Function) - provides policy control and flow based charging control decisions

Physical Layer

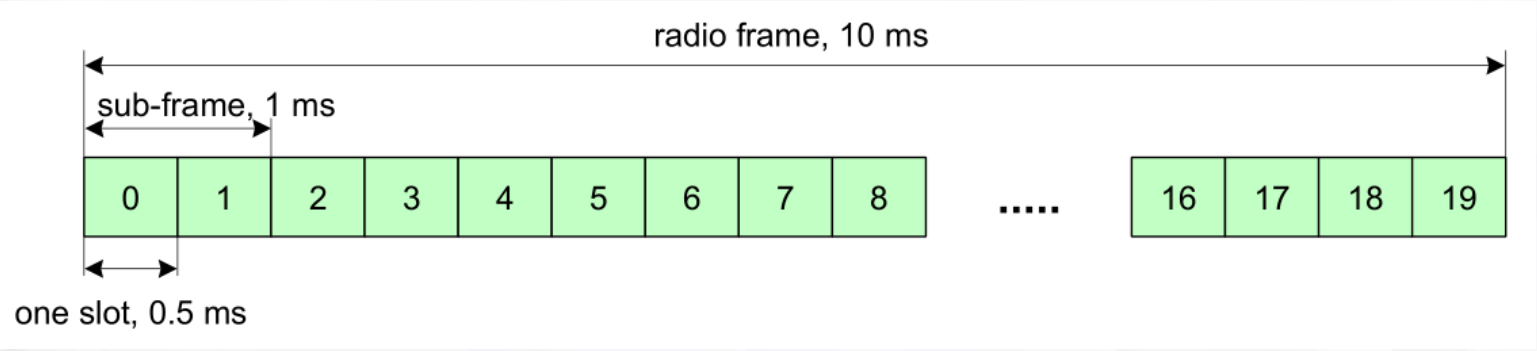
- 32 frequency bands supported according to ETSI TS 136 101
- **most used in EU:**
  - **band I** (1920 – 1980 MHz, 2110 – 2170 MHz)
  - **band 3** (1710 – 1785 MHz, 1805 – 1880 MHz)
  - **band 7** (2500 – 2570 MHz, 2620 – 2690 MHz)
  - **band 8** (880 – 915 MHz, 925 – 960 MHz)
  - **band 20** (832 – 862 MHz, 791 – 821 MHz)

- **OFDM** (Orthogonal Frequency-Division Multiplexing) used
  - OFDM uses a large number of narrow sub-carriers for multi-carrier transmission to carry data.
  - Orthogonal frequency-division multiplexing (OFDM), is a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method.

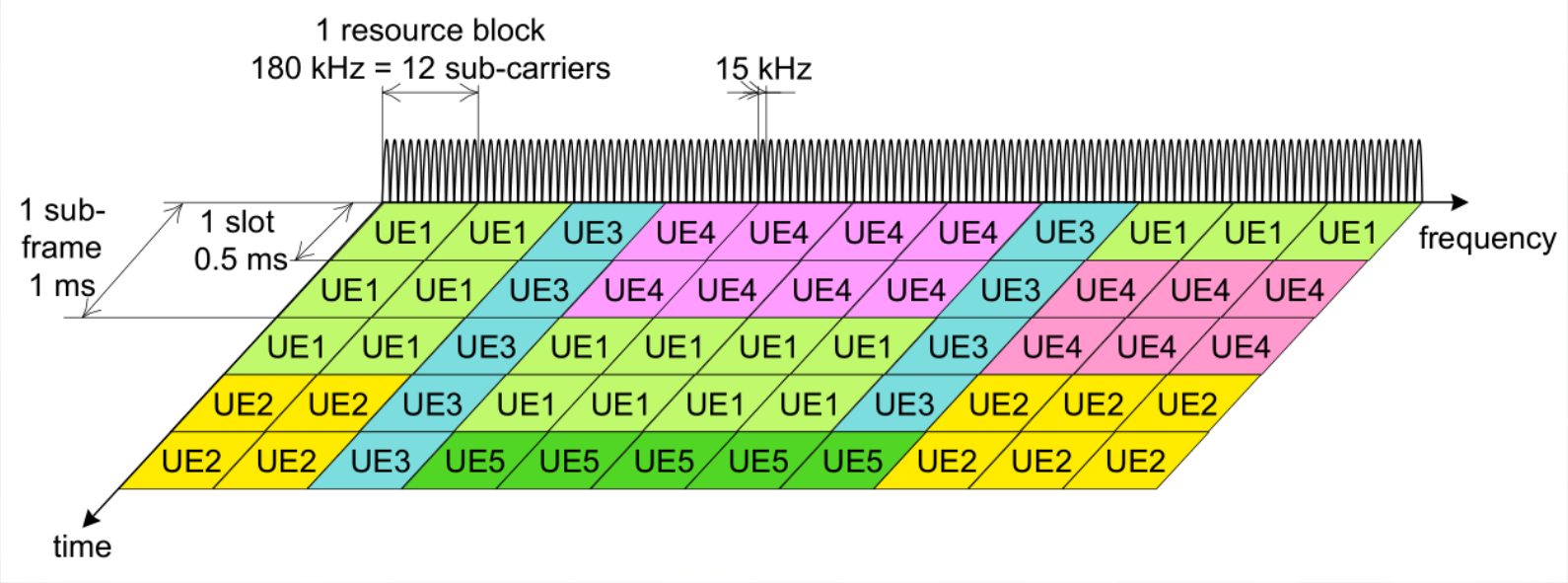


- Within the OFDM signal it is possible to choose between three types of modulation:
  - **QPSK -** 2 bits per symbol
  - **16QAM** - 4 bits per symbol
  - **64QAM -** 6 bits per symbol
- The channel bandwidths that have been chosen for LTE are:
  - 1.4 MHz
  - 3 MHz
  - 5 MHz
  - 10 MHz
  - 15 MHz
  - 20 MHz

- LTE frames are 10 ms in duration
  - They are divided into 10 subframes, each subframe being 1.0 msec long.
  - Each subframe is further divided into two slots, each of 0.5 msec duration. Slots consist of either 6 or 7 ODFM symbols, depending on whether the normal or extended cyclic prefix is employed.
  - Each user is allocated a number of so-called resource blocks in the time-frequency grid.
  - The more resource blocks a user gets, and the higher the modulation used in the resource elements, the higher the bit-rate.
  - Which resource blocks and how many the user gets at a given point in time depend on advanced scheduling mechanisms in the frequency and time dimensions.

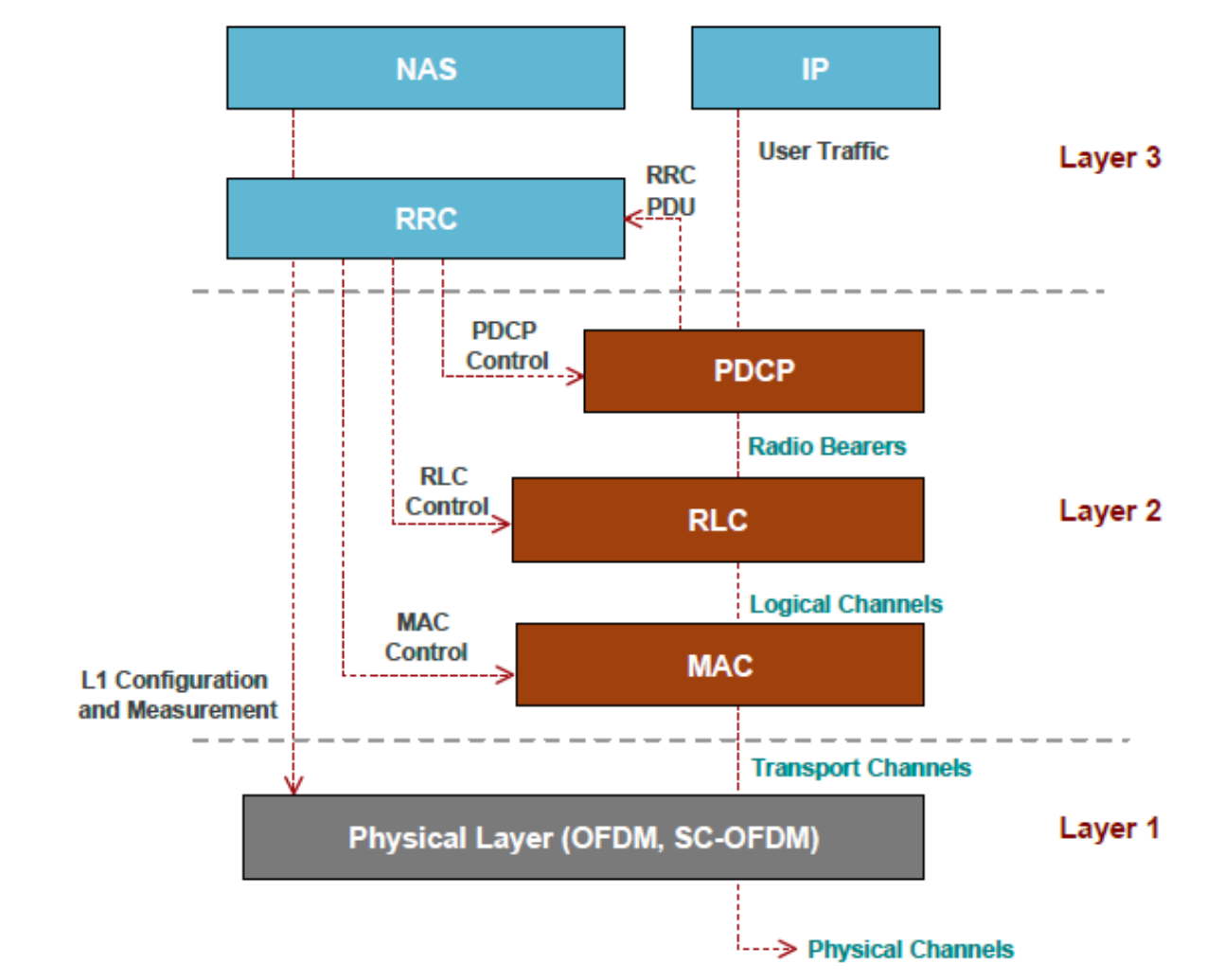


- OFDM symbols are grouped into resource blocks. The resource blocks have a total size of 180kHz in the frequency domain and 0.5ms in the time domain. Each 1ms Transmission Time Interval (TTI) consists of two slots



- The Cyclic Prefix represents a guard period at the start of each OFDMA symbol which provides protection against multi-path delay spread. The cyclic prefix also represents an overhead which should be minimised.
- LTE specifies both normal and extended cyclic prefix lengths. The normal cyclic prefix is intended to be sufficient for the majority of scenarios, while the extended cyclic prefix is intended for scenarios with particularly high delay spread.

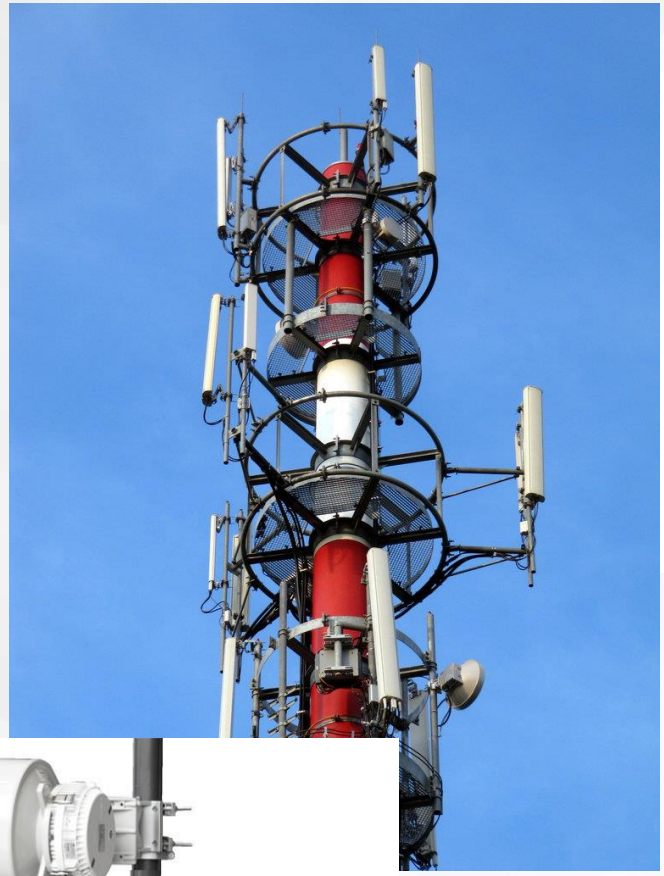
Protocol Architecture



Future of LTE

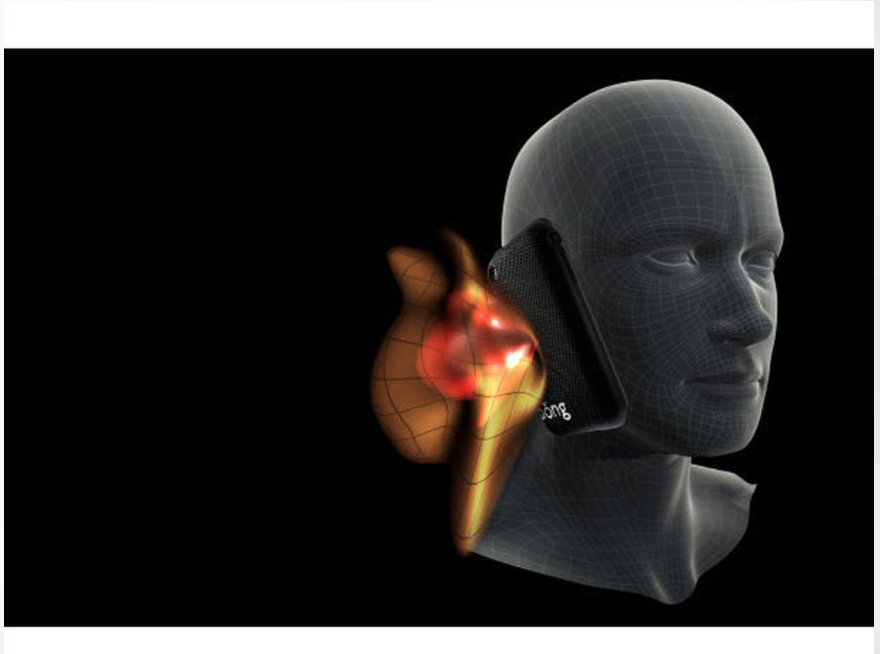
- **LTE-A**
  - as 3GPP Release 10
  - main improvements:
    - Carrier Aggregation up to 100 MHz
    - MIMO (Multiple Input Multiple Output)
- World Radiocommunication Conference 2015 (WRC-15)
  - new frequency band allocations
  - **band 68** 698-728 MHz, 753-783 → conflict with TV BAND ch 49-59
  - World Radiocommunication Conferences (WRC) are held every three to four years.
  - It is the job of WRC to review, and, if necessary, revise the Radio Regulations, the international treaty governing the use of the radio-frequency spectrum and the geostationary-satellite and non-geostationary-satellite orbits.

Technology for base stations

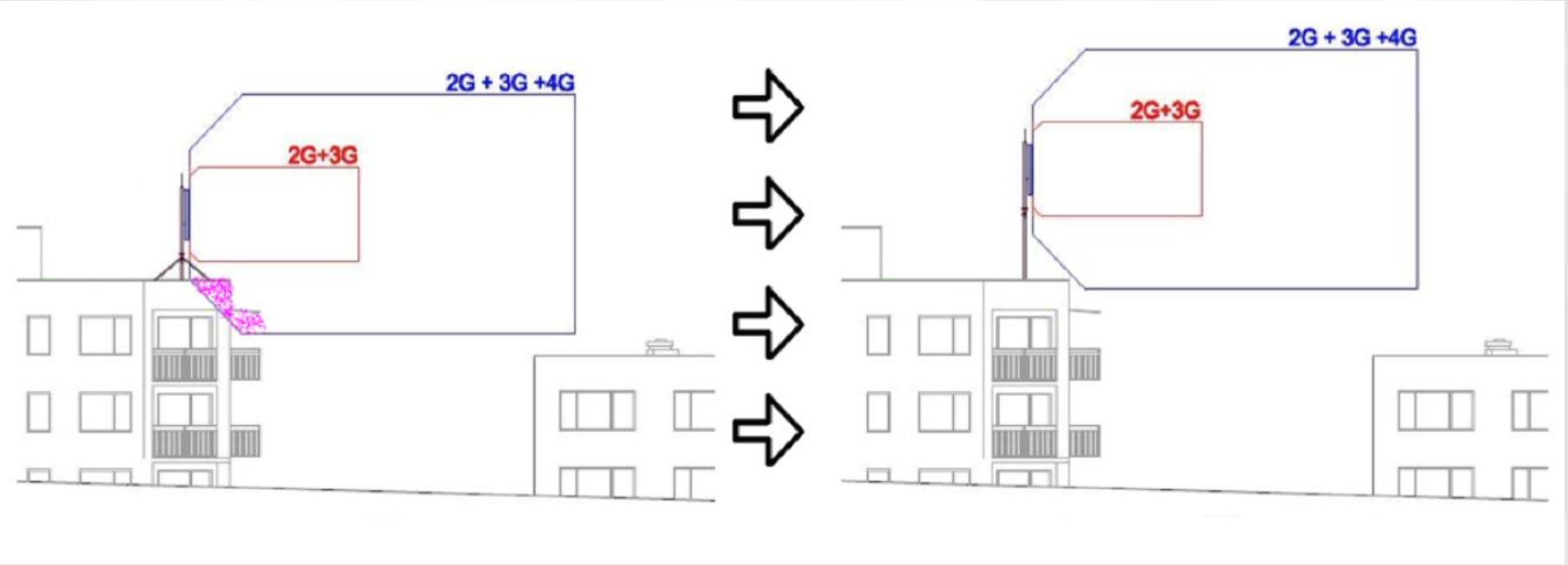


Legislation and limits for GSM, UMTS and LTE systems

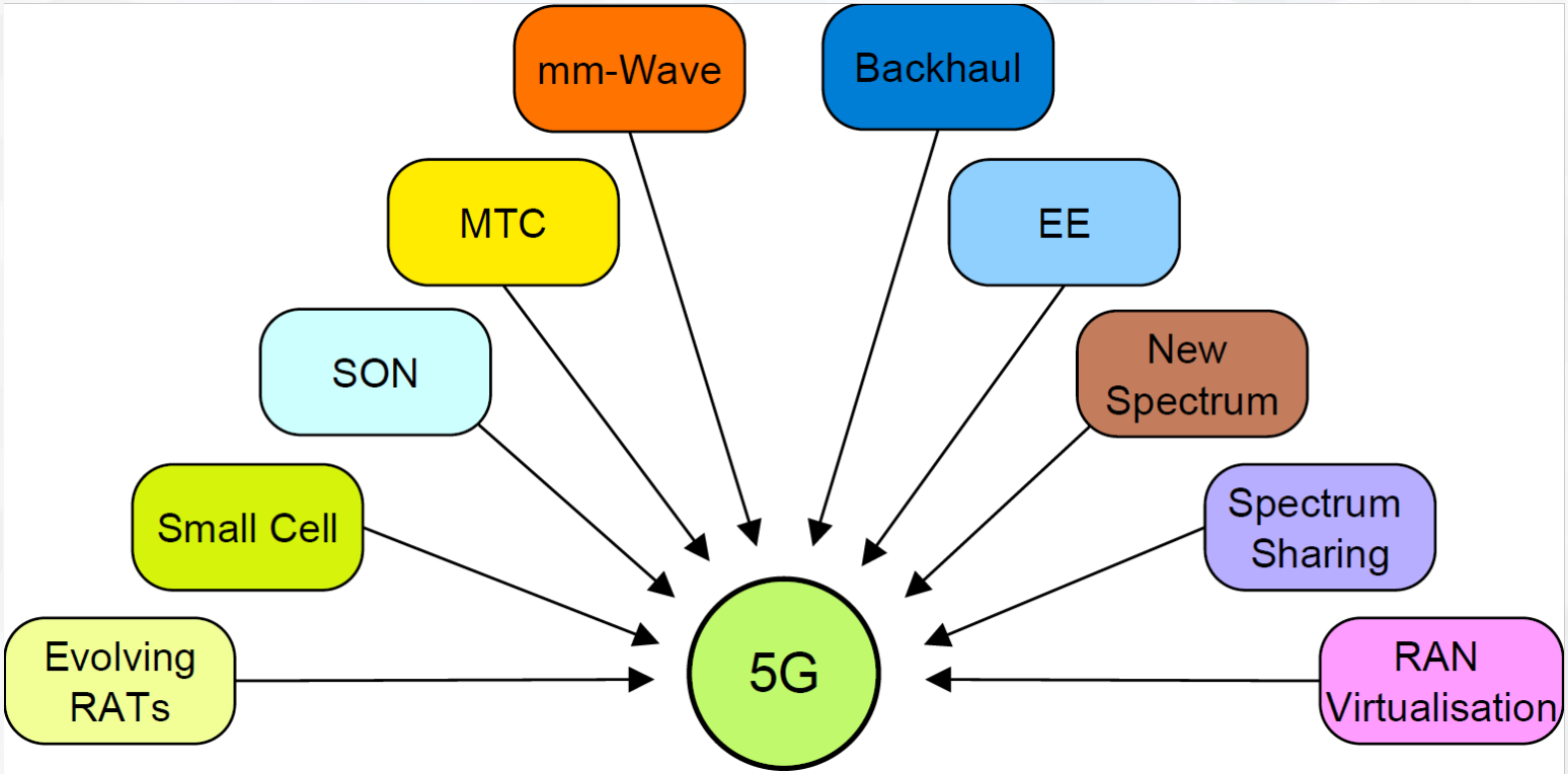
- Laws that define limits for:
  - Specific absorption rate (SAR) - it is defined as the power absorbed per mass of tissue and has units of watts per kilogram (W/kg)
  - power density S (W/m^2)



- Optimisation of antenna system depending on the impact of EMF



10 pillars of 5G



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