

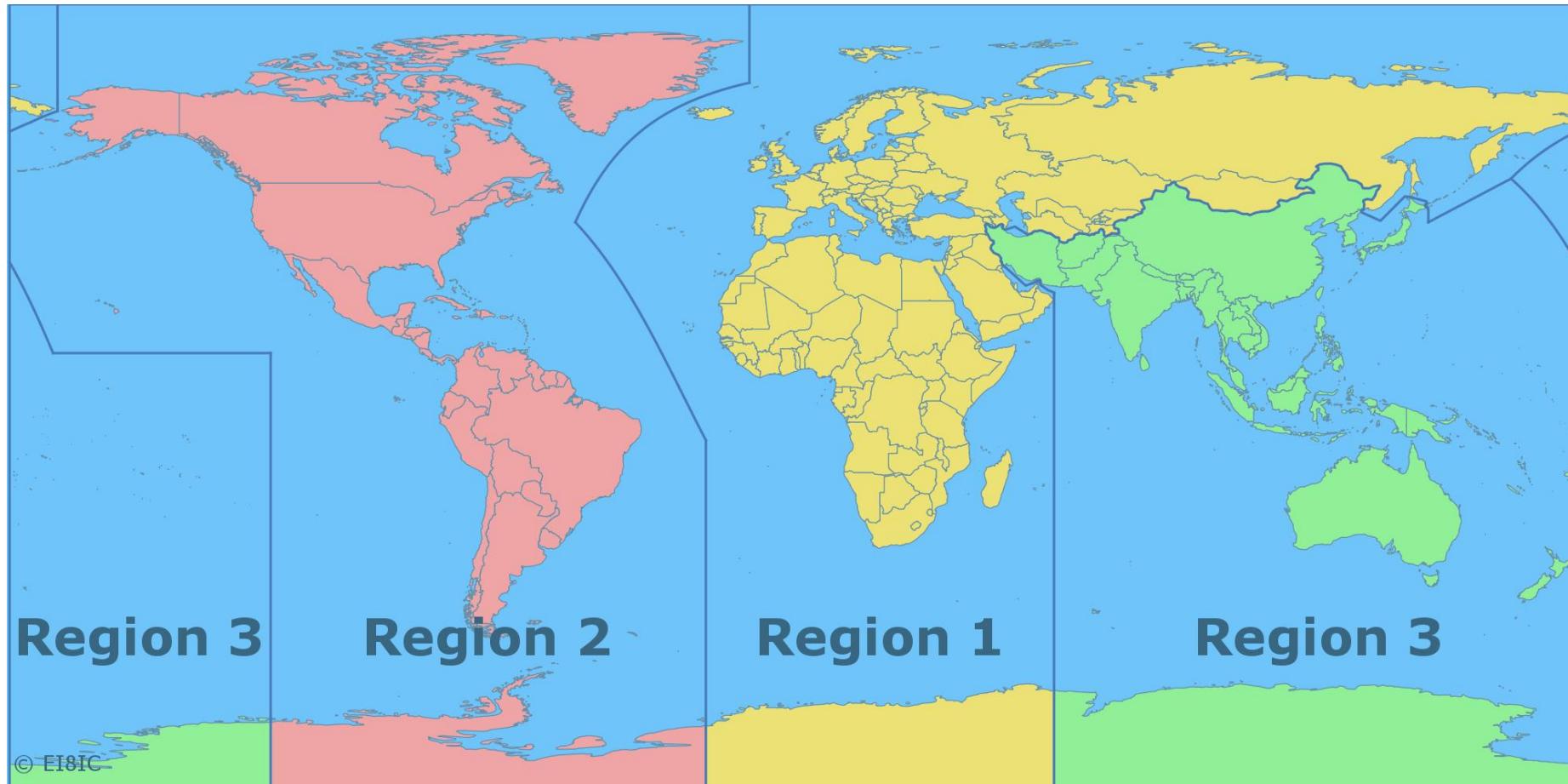
Network Technologies I. Mobile Networks

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ITU Regions

- The International Telecommunication Union (ITU) divides the world into **three ITU regions** for the purposes of managing the global radio spectrum.
- Each region has its own set of frequency allocations, the main reason for defining the regions.



Before cellular

Police testing early car phone in 1922 worked just above AM band.



Man testing mobile telephone service,
St. Louis, 1946

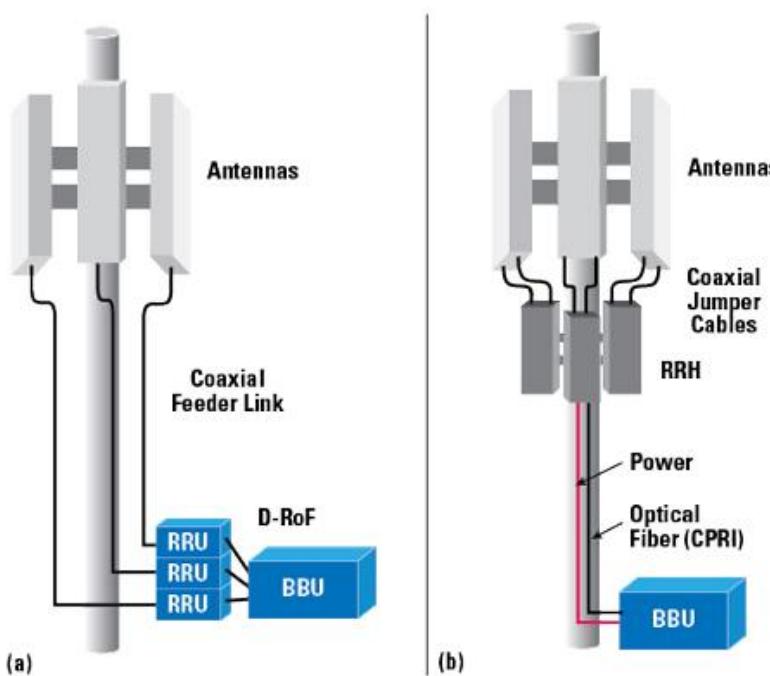
source: Keysight.com



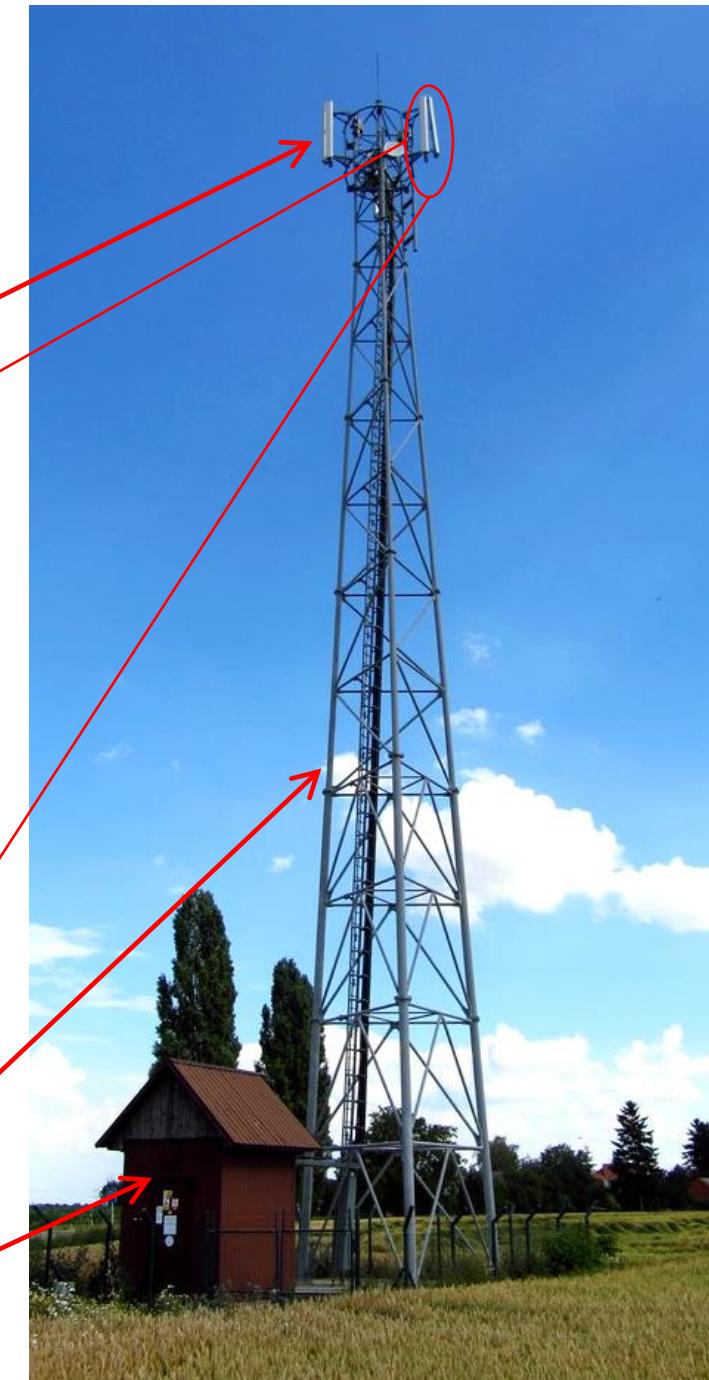
What is base station?

- equipment that facilitates wireless communication between user equipment (UE) and a network

antennas, remote units, microwave technology



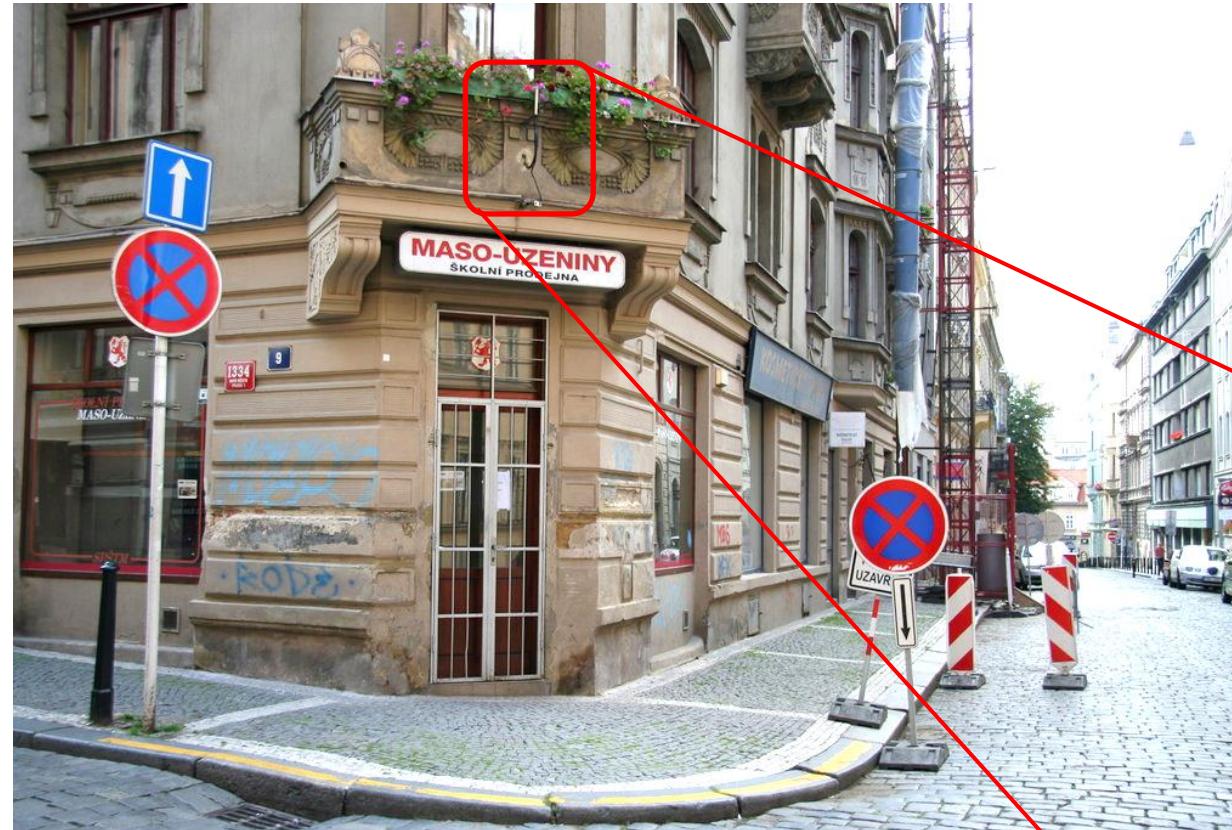
cabinet (baseband unit, power supply, batteries)



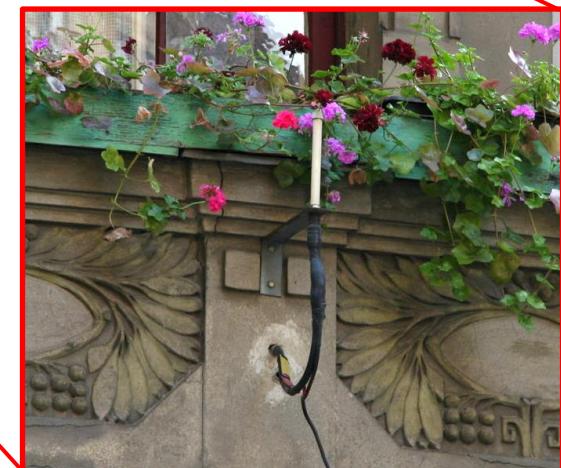
Typical base stations



typical macro cell

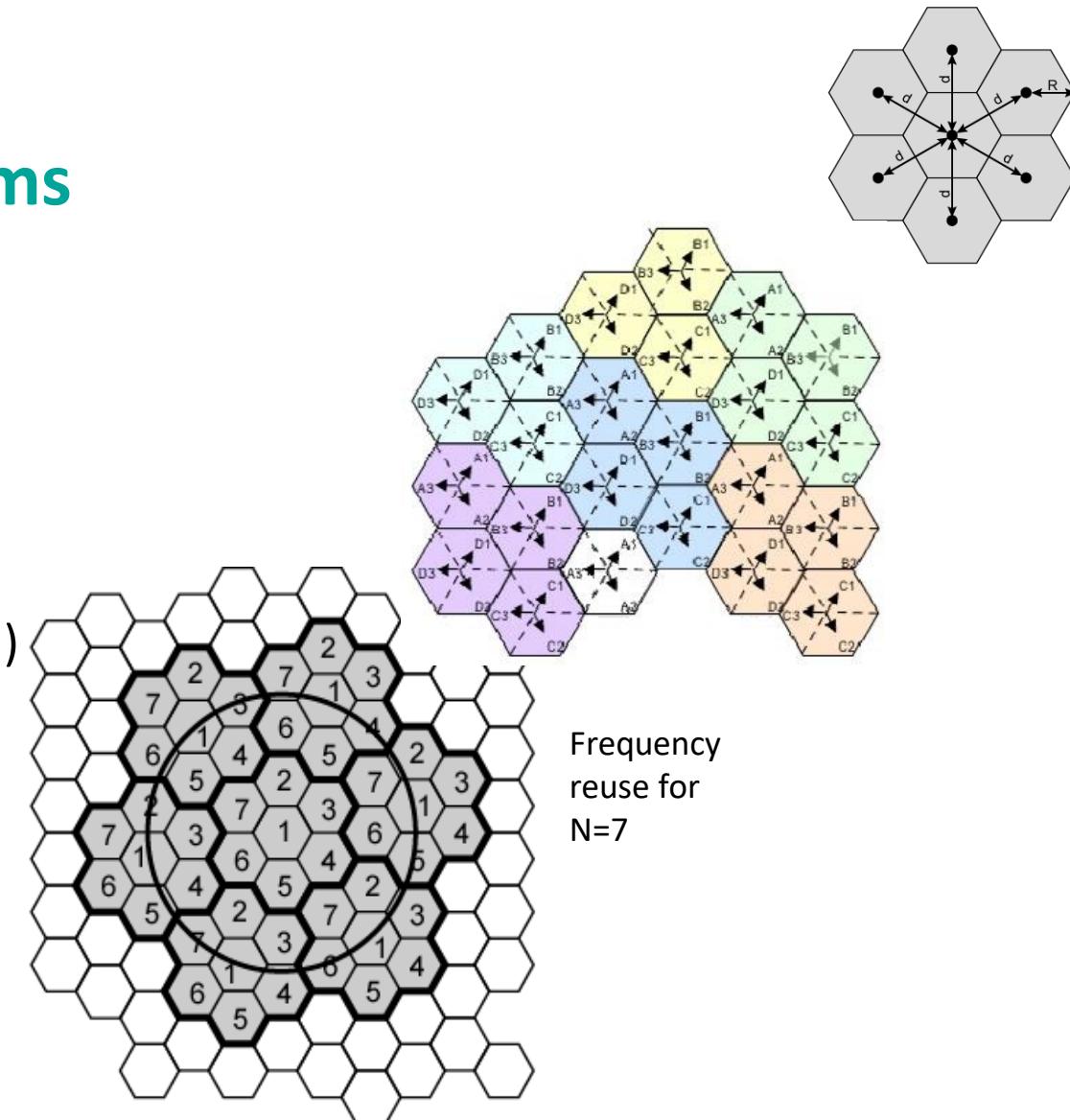
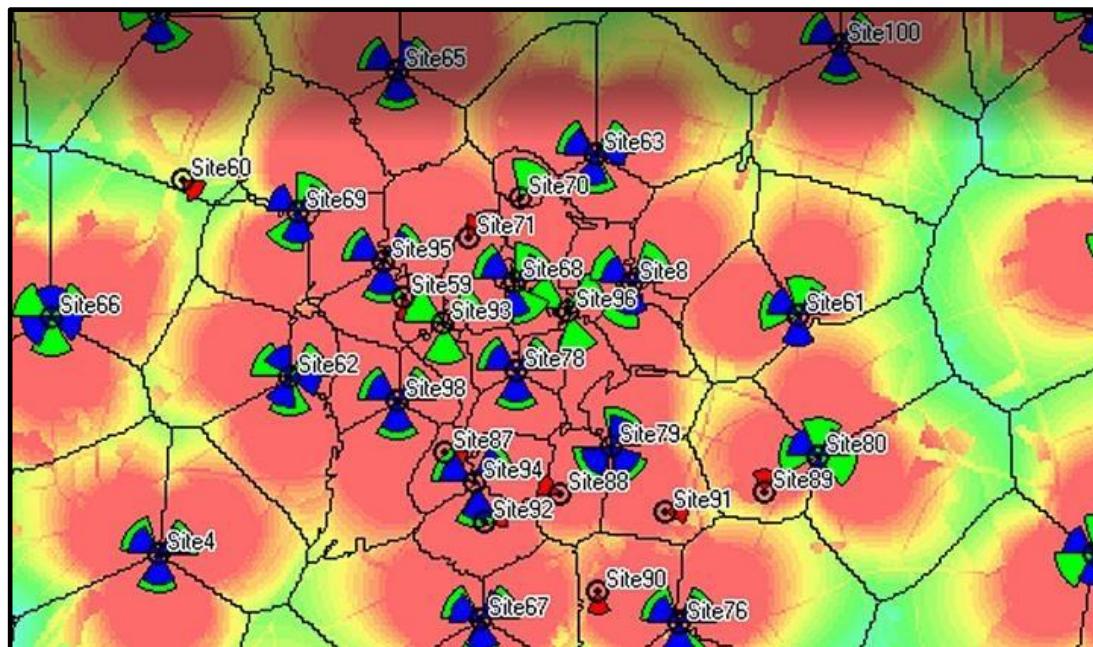


typical micro cell



Cellular Systems

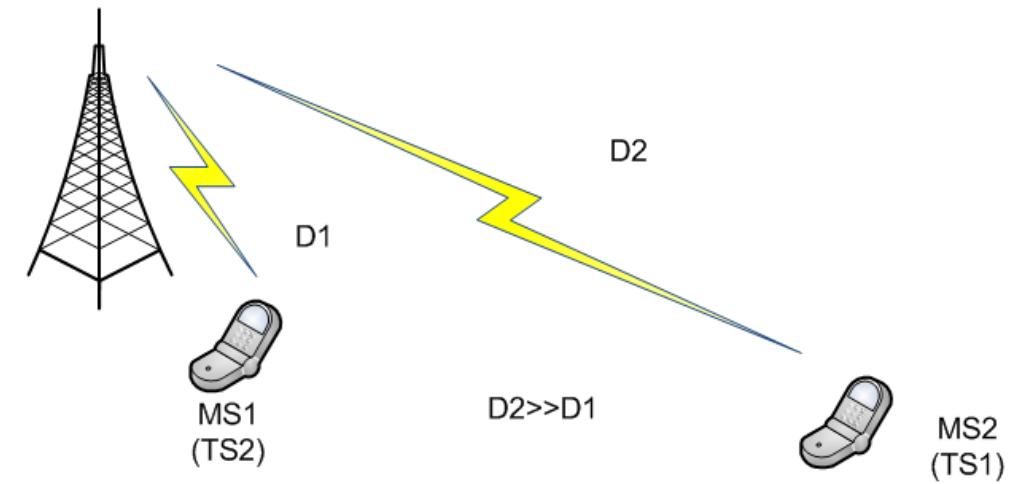
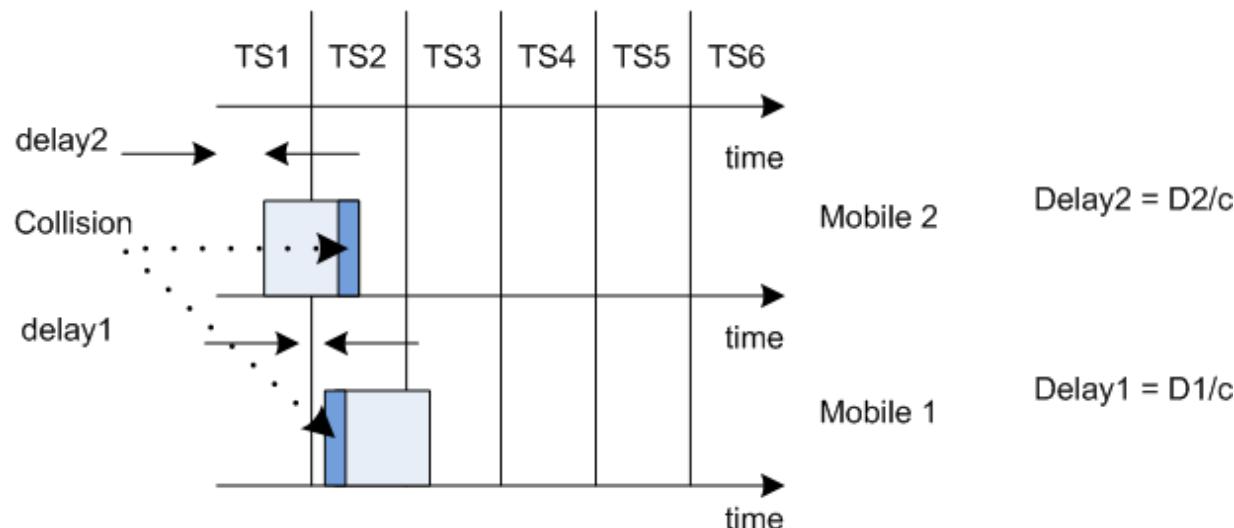
- Developed by Bell Labs, area divided into cells
- Each with own antenna served by base station
- Asset: Frequency reuse, increase system capacity
- Shape of cells is **hexagon** - provides equidistant antennas
- Not always **precise hexagons** (topographical limitations, local signal propagation conditions, location of antennas...)



Frequency
reuse for
 $N=7$

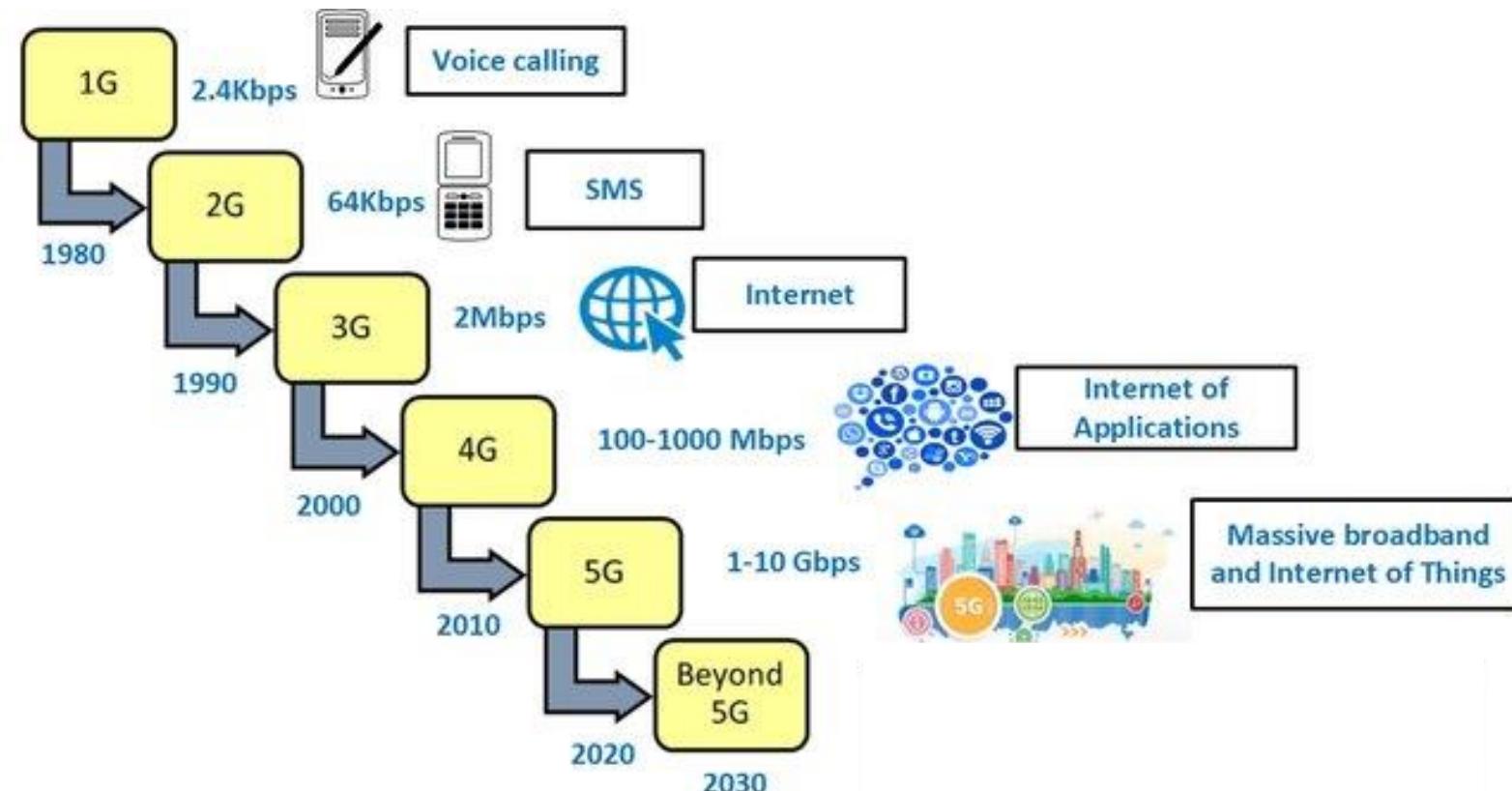
Near-far problem in TDMA systems

- In TDMA synchronization between users is necessary
- Delay of the timeslot for the further mobiles is larger
- Due to different delays – timeslot may collide
- To remedy the problem - mobiles advance their transmission
- The amount of time advancement is determined by base station and communicated to the mobiles



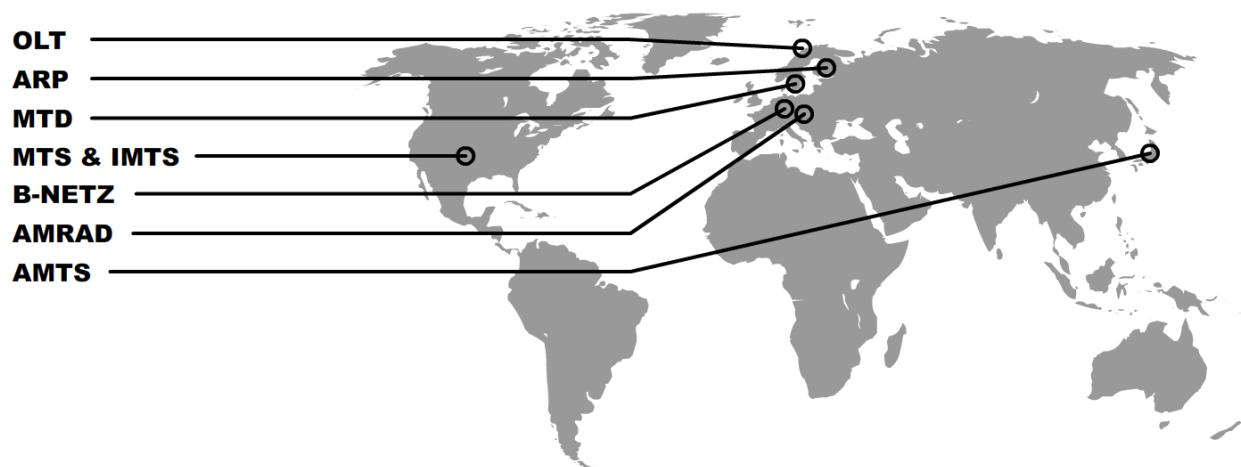
Evolution of Mobile Radio Communications

- 1934 - Police Radio uses conventional AM mobile communication system.
- 1946 - First public mobile telephone service - push-to-talk
- **1960 - Bell Lab introduce the concept of Cellular mobile system**
- 1983 - Advanced Mobile Phone System (AMPS), FDMA, FM
- **1991 - Global System for Mobile (GSM)**
- **1999 – Universal Mobile Telecommunication System (UMTS)**
- **2005 – Long Term Evolution (LTE)**
- **2019 – 5G**
- **2024 – 5G Advanced**
- **2028 – 6G**

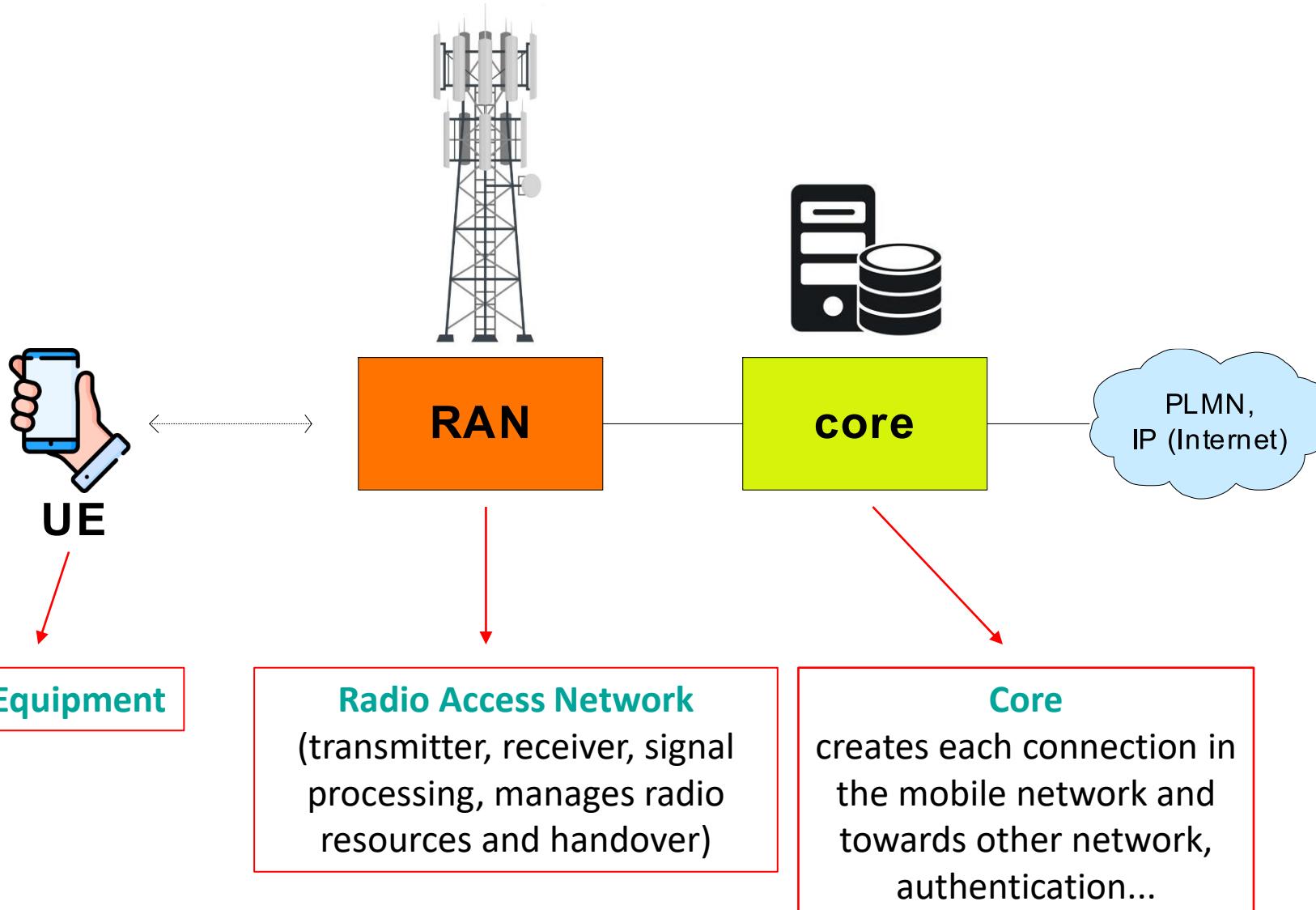


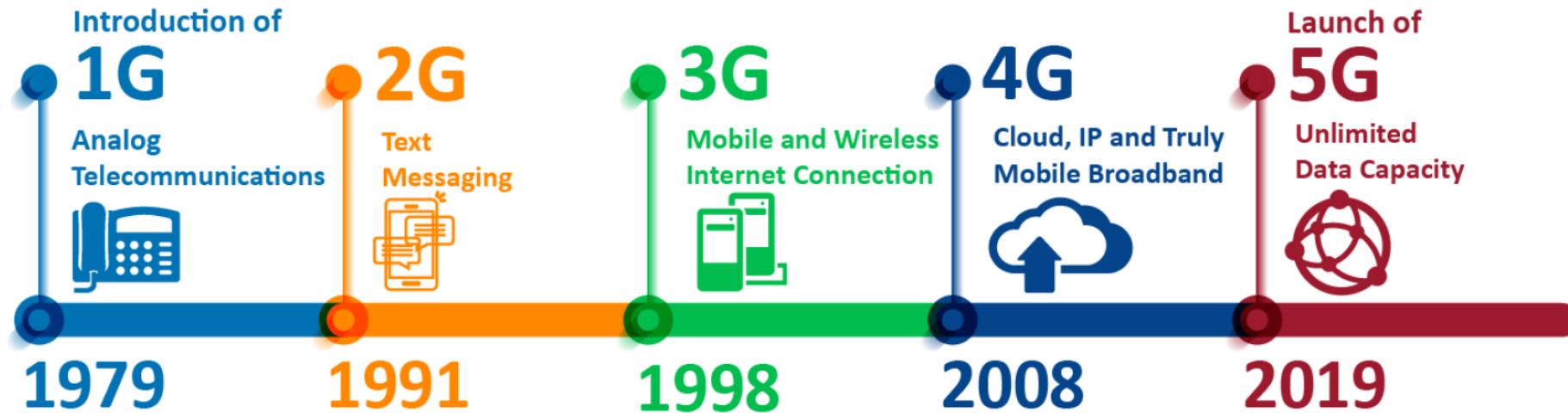
0. Generation of Mobile Networks

- **B-Netz** - 1972-1994, 150 MHz, Germany
- **MTS** (Mobile Telephone System) - 1946-1980, 35 MHz, 150 and 455 MHz, America
- **IMTS** (Improved Mobile Telephone Service) - extension of MTS, America
- **AMTS** (Advanced Mobile Telephone System) - 1979, 900 MHz, Japan
- **AMRAD** (Automated City Radiotelephone) - 1983, approx. 160 MHz, Czech Republic
- **OLT** (Offentlig Landmobil Telefoni) - 1966, 160 MHz, Norway
- **MTD** (Mobiltelefonisystem D) - 1971, 450 MHz, Sweden, later Norway and Denmark, the possibility of international roaming



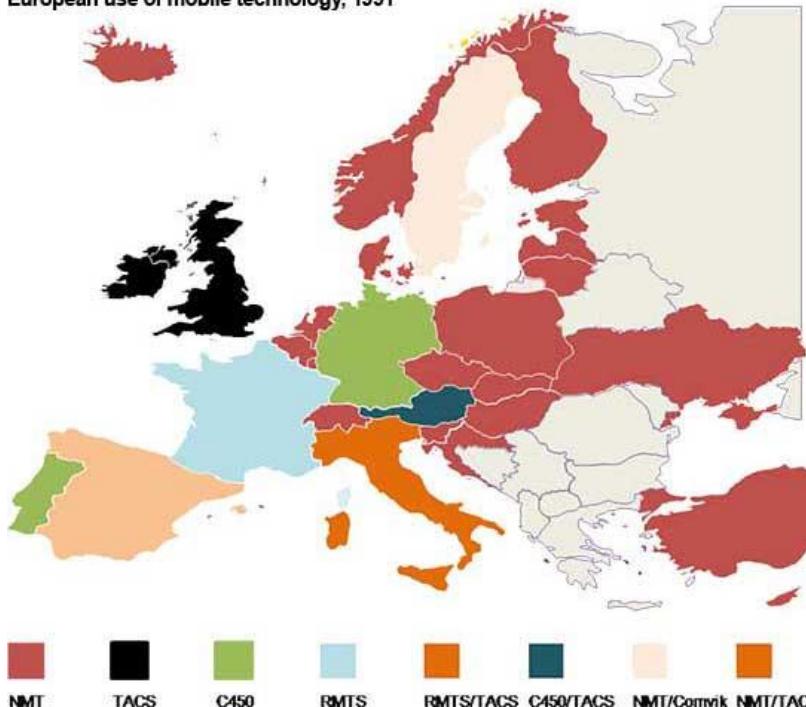
Mobile Network – Basic System Architecture





1st Generation

European use of mobile technology, 1991



2nd Generation

- initiative of CEPT organization, ETSI standard
- 1991 first version of the recommendation, voice only
- quality connection in unfavorable radio conditions compared to 1G
- worldwide compatible
- 1999 - GPRS and EDGE for packet data transmission



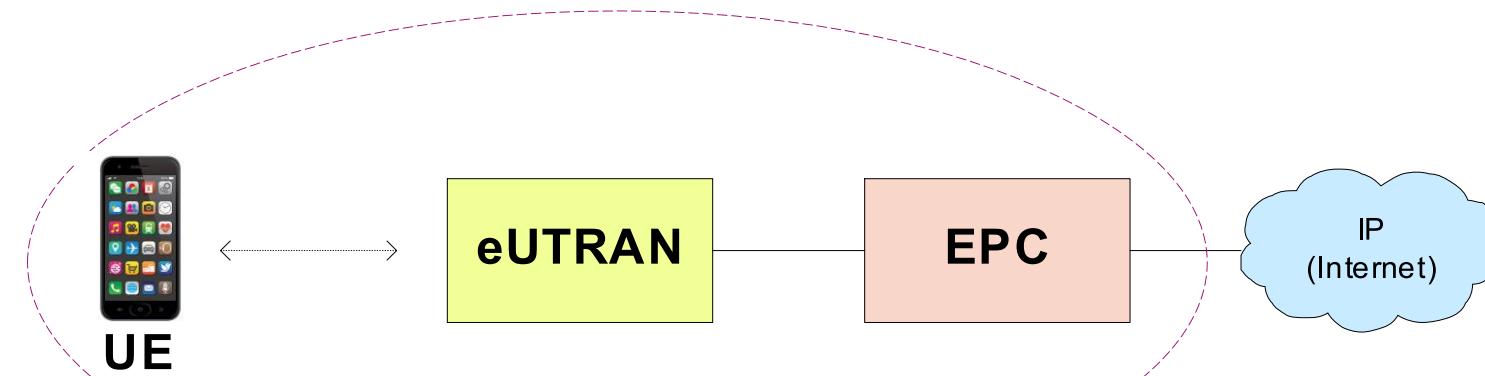
3rd Generation

- Phenomenal growth of 2G - **lack of capacity**
- Voice is becoming a commodity service
- 3G is designed to address the deficiencies of 2G
- 1998 - 3GPP was formed to build the technical specification work for 3G **UMTS** (Universal Mobile Telecommunication System)

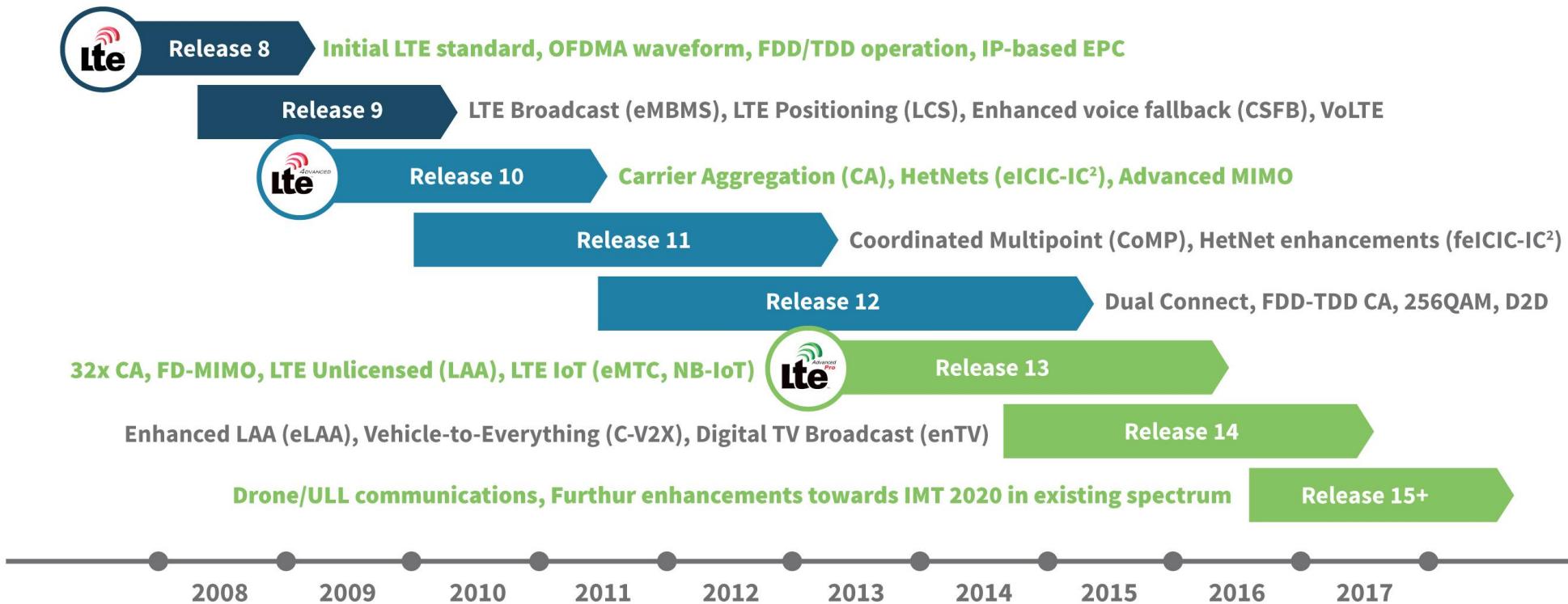
4th Generation of Mobile Networks

- Under 3GPP (3rd Generation Partnership Project)
- High-speed wireless communication with increased capacity and reduced latency
- LTE operates on multiple bands specific to regions and carriers, up to 3.8 GHz
- Frequency Division Duplex (FDD) and Time Division Duplex (TDD)
- Fully IP-based (for both voice and data)

EPS (Evolved Packet System)



LTE - timeline



source: 3gpp.org

LTE Physical Layer

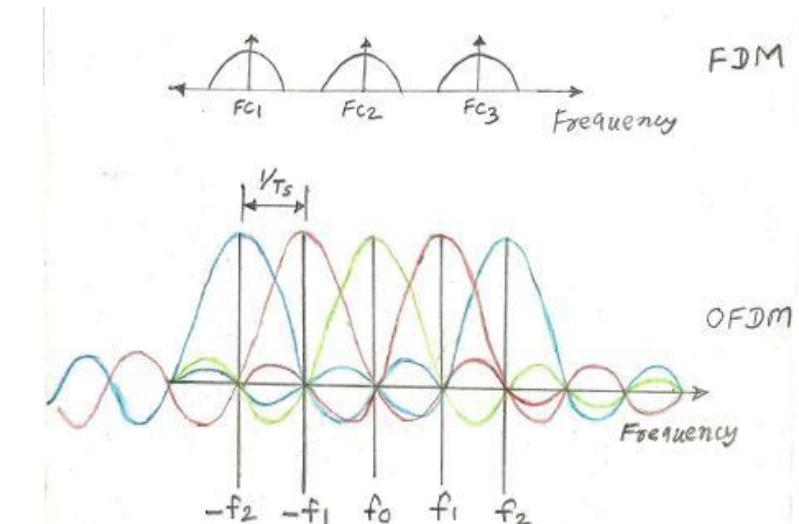
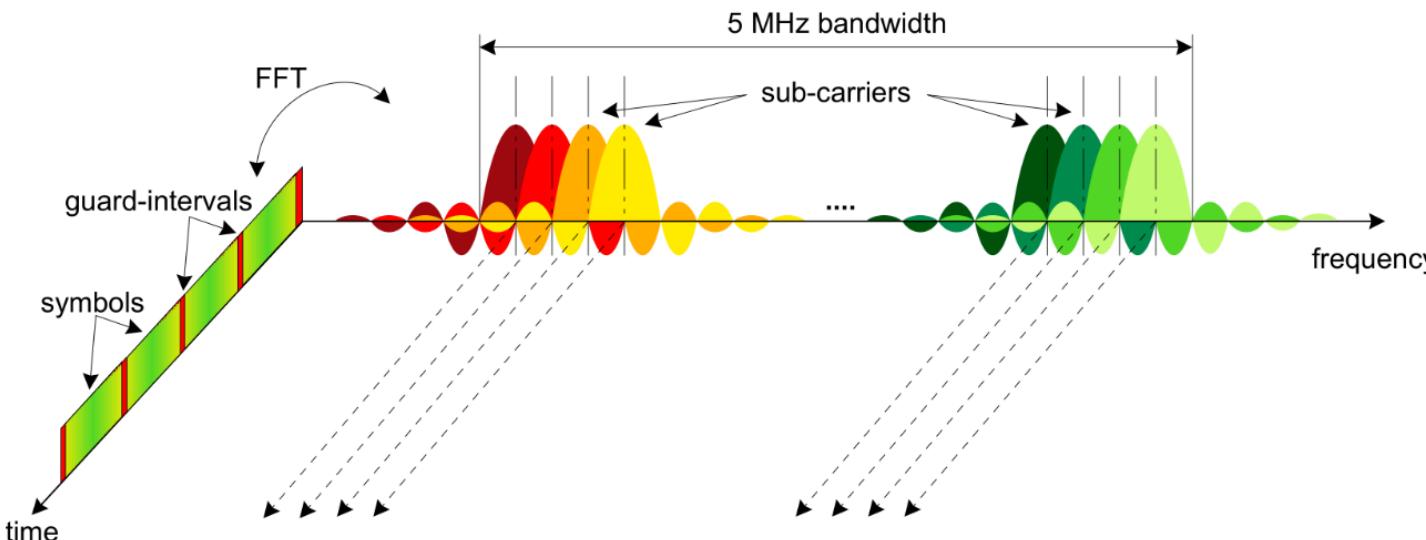
- Time Division Duplexed (TDD) or Frequency Division Duplex (FDD)
- different channel bandwidths: 1.4, 3, 5, 10, 15 or 20 MHz in a signal channel
- frequencies from 450MHz to 3.8GHz
- LTE-A supports carrier aggregation - multiple channels may be aggregated in data delivery
- more than 40 frequency bands supported according to [3GPP 36.101](#)
- not all bands are available in all geographical regions

| FDD | | |
|----------------|--------------|----------------|
| | uplink [MHz] | downlink [MHz] |
| band 1 | 1920 – 1980 | 2110 - 2170 |
| band 3 | 1710 - 1785 | 1805 - 1880 |
| band 7 | 2500 - 2570 | 2620 - 2690 |
| band 8 | 880 - 915 | 925 - 960 |
| band 20 | 832 - 862 | 791 - 821 |

| TDD | |
|----------------|-----------------------|
| | uplink/downlink [MHz] |
| band 38 | 2570 - 2620 |
| band 43 | 3600 - 3800 |

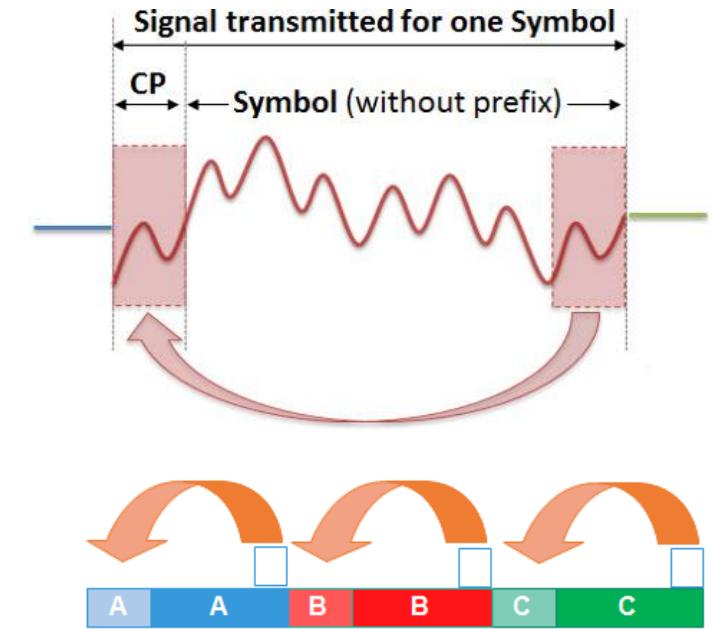
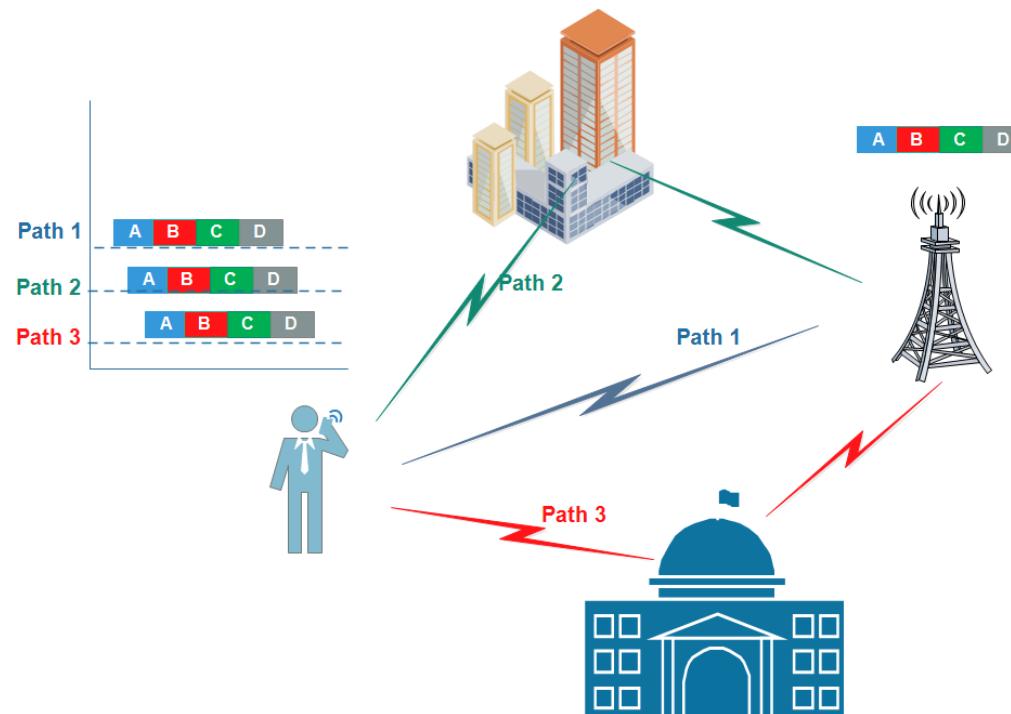
LTE and OFDM (Orthogonal Frequency-Division Multiplexing)

- 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.
- OFDMA minimizes separation between carriers
- Carriers are selected so that they are *orthogonal* over symbol interval
- Carrier orthogonality leads to frequency domain spacing $\Delta f = 1/T$, where T is the symbol time
- In LTE carrier spacing is 15kHz and useful part of the symbol is 66.7 μs



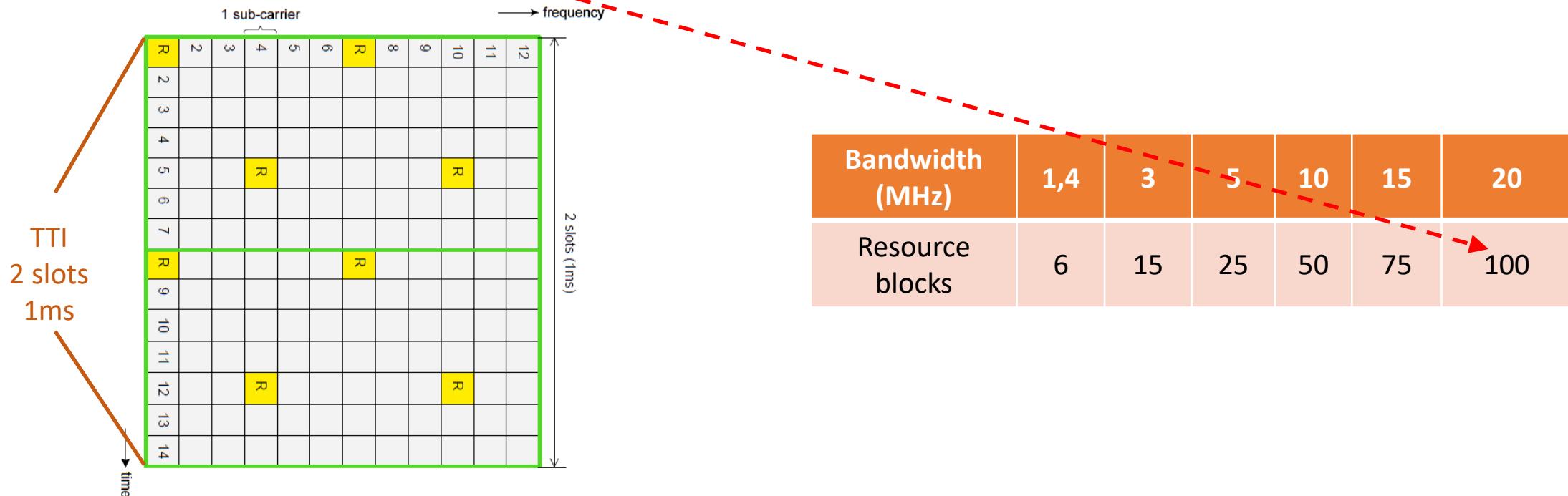
ISI (Inter Symbol Interference) in LTE

- in a real scenario the transmitted signals are affected in different ways, for example, according to the propagation environment
- all these multipath components are summed and the practical result is that we have multiple symbols being received simultaneously - this is **the intersymbol interference (ISI)**
- to overcome ISI, portion of the signal is copied and added to the beginning of the signal as **Cyclic Prefix**

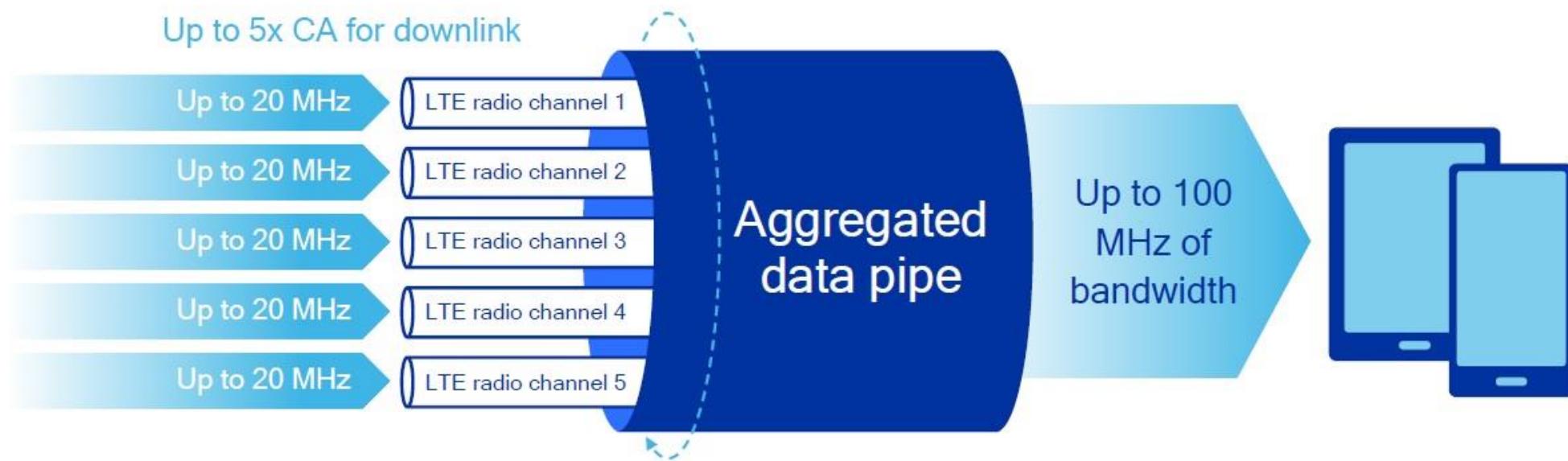


What is the PHY rate for 20MHz band in LTE?

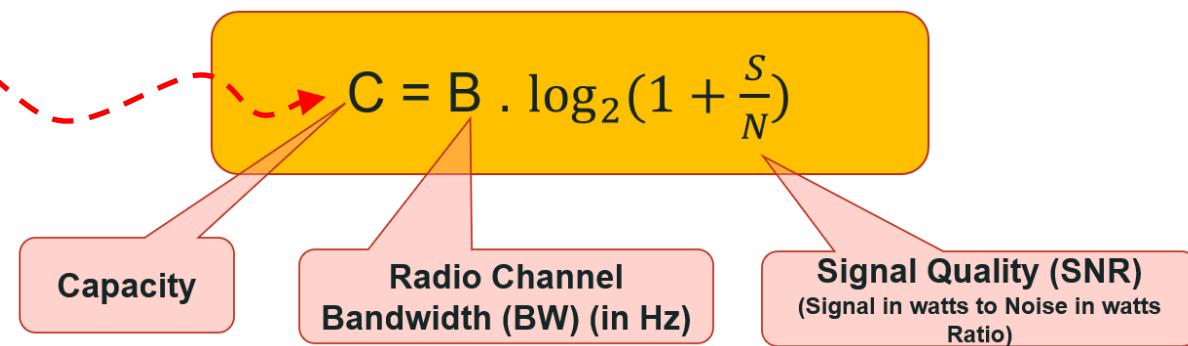
- 1 TTI : 12 carriers x 14 OFDM symbols = 168 resource elements
- Each resource element carries one modulation symbol
- For 64 QAM: 1 symbol = 6 bits
- Number of bits per subframe = $168 \times 6 = 1008$ bits/subframe (1ms)
- Raw PHY data rate = $1008/1\text{ms} = 1.008.000$ bits/sec/resource block (180kHz)
- For 20MHz, Raw PHY data rate = 100 x resource blocks x $1.008.000$ bits/sec/RB = **100.8 Mbps**



LTE – Advanced – Carrier Aggregation



Why Carrier Aggregation?



A yellow box contains the formula $C = B \cdot \log_2(1 + \frac{S}{N})$, where C is capacity, B is bandwidth, and S/N is Signal-to-Noise Ratio. Three pink callout boxes point to the terms: "Capacity", "Radio Channel Bandwidth (BW) (in Hz)", and "Signal Quality (SNR) (Signal in watts to Noise in watts Ratio)".

$$C = B \cdot \log_2\left(1 + \frac{S}{N}\right)$$

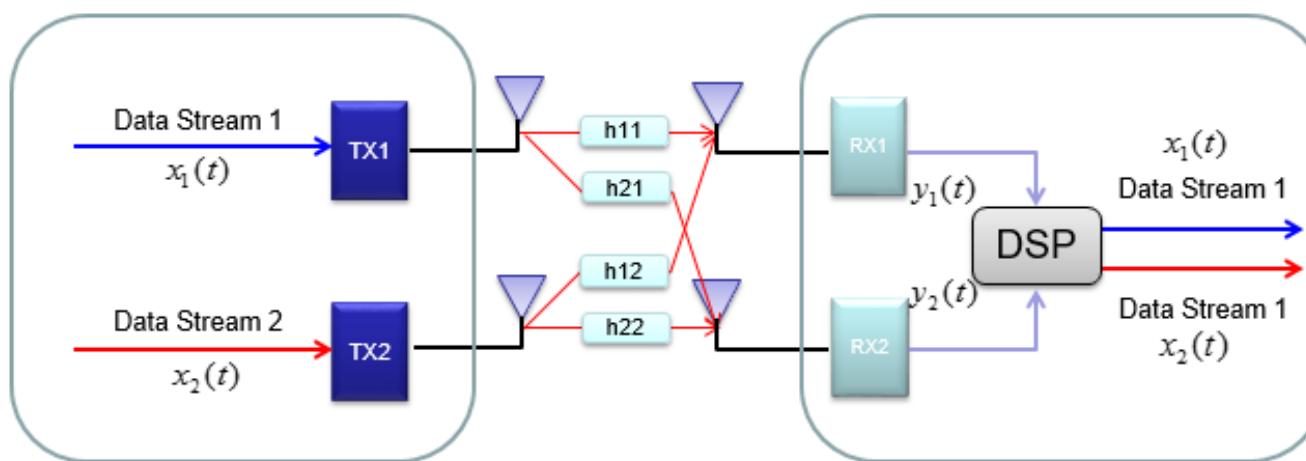
Capacity

Radio Channel Bandwidth (BW) (in Hz)

Signal Quality (SNR)
(Signal in watts to Noise in watts Ratio)

MIMO (Multiple Input Multiple Output)

- MIMO is effectively a radio antenna technology as it uses multiple antennas at the transmitter and receiver to enable a variety of signal paths to carry the data, choosing separate paths for each antenna to enable multiple signal paths to be used.
- MIMO uses **spatial multiplexing** - multiple data streams are transmitted at the same time. They are transmitted on the same channel, but by different antenna. They are recombined at the receiver using MIMO signal processing.



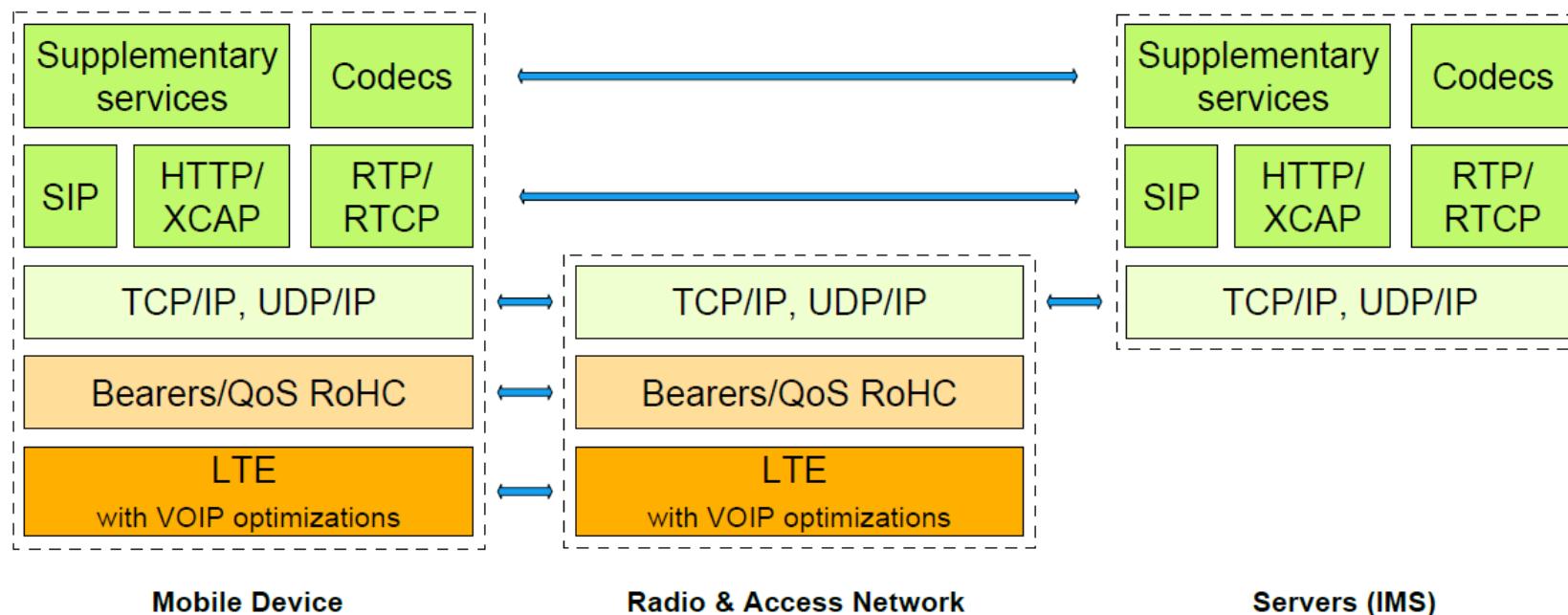
$$\begin{aligned}y_1 &= h_{11}x_1 + h_{12}x_2 \\y_2 &= h_{21}x_1 + h_{22}x_2\end{aligned}$$

Channel Information Matrix

$$\mathbf{y} = \mathbf{H}\mathbf{x}$$
$$\mathbf{y} = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix}, \quad \mathbf{H} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}, \quad \mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$
$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

VoLTE (Voice over LTE)

- based on IP Multimedia Subsystem (IMS)
- initiative of GSMA (GSM Association) under [IR.92](#)
- codec: AMR-WB G.722 (7 kHz, 23.85 kbit/s), Enhanced Voice Services (20 kHz, 128 kbit/s)
- Voice Codecs Comparison: <https://youtu.be/LNMfDrTka3c>



5th Generation of Mobile Networks

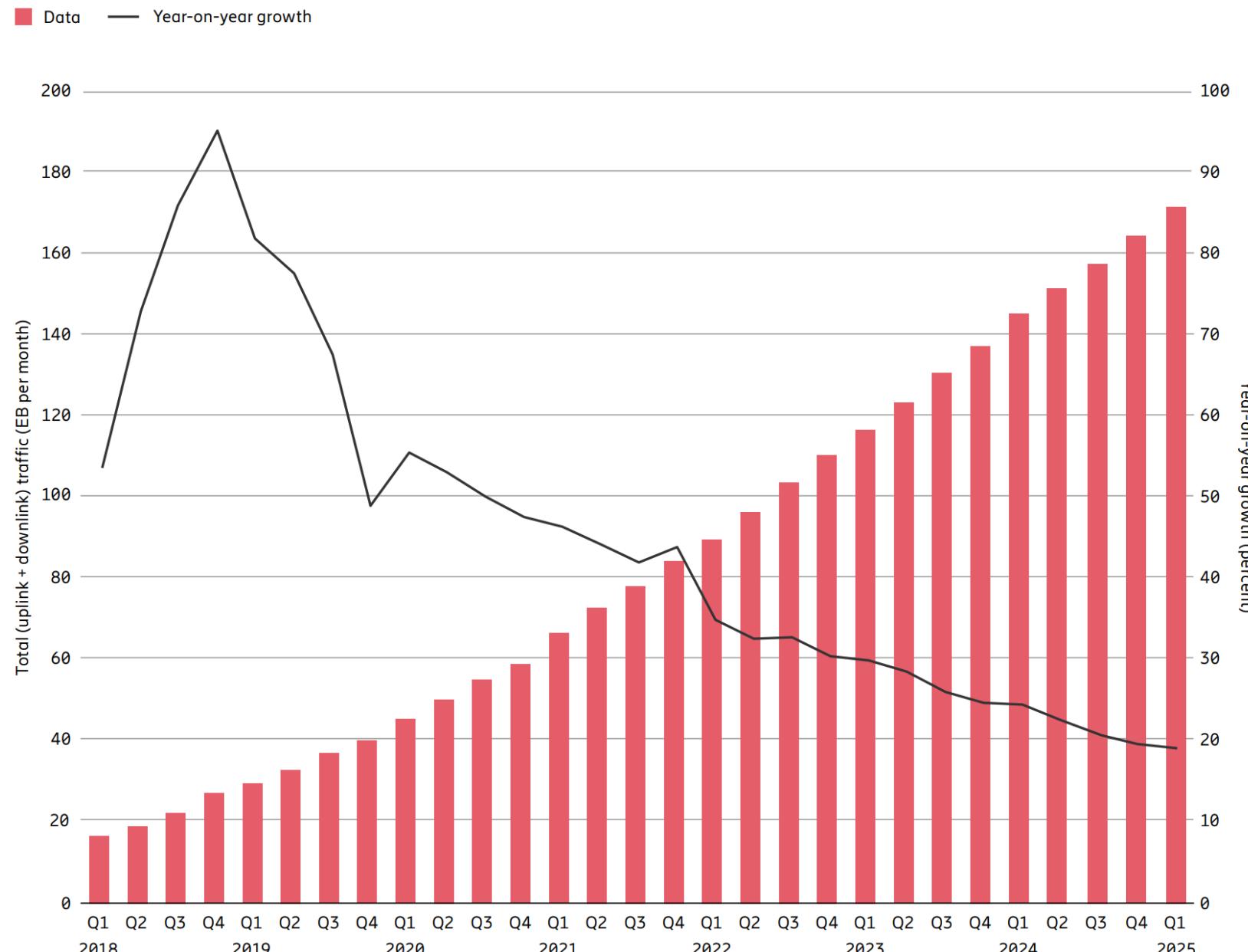
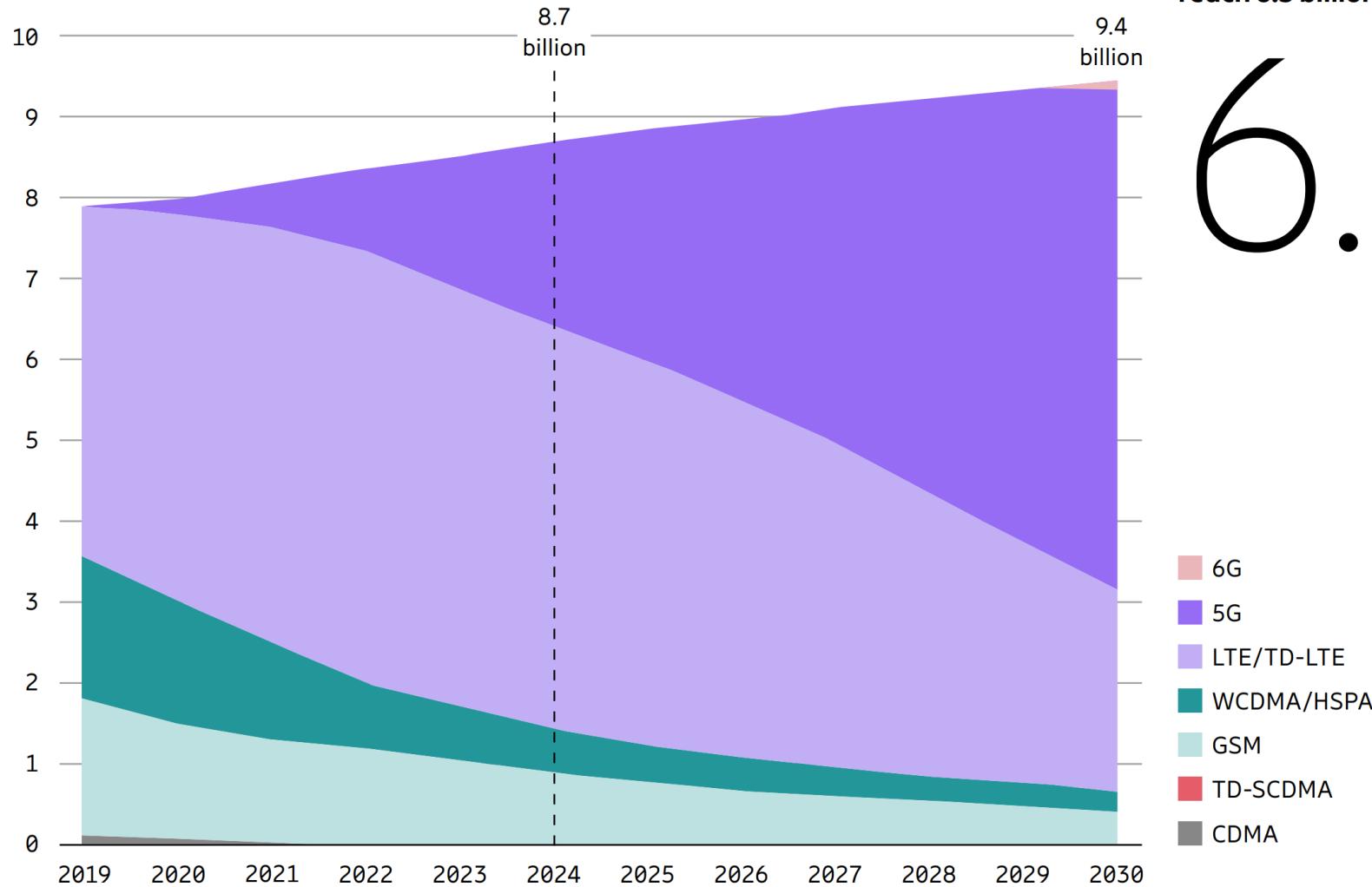


Figure 1: Mobile subscriptions by technology (billion)

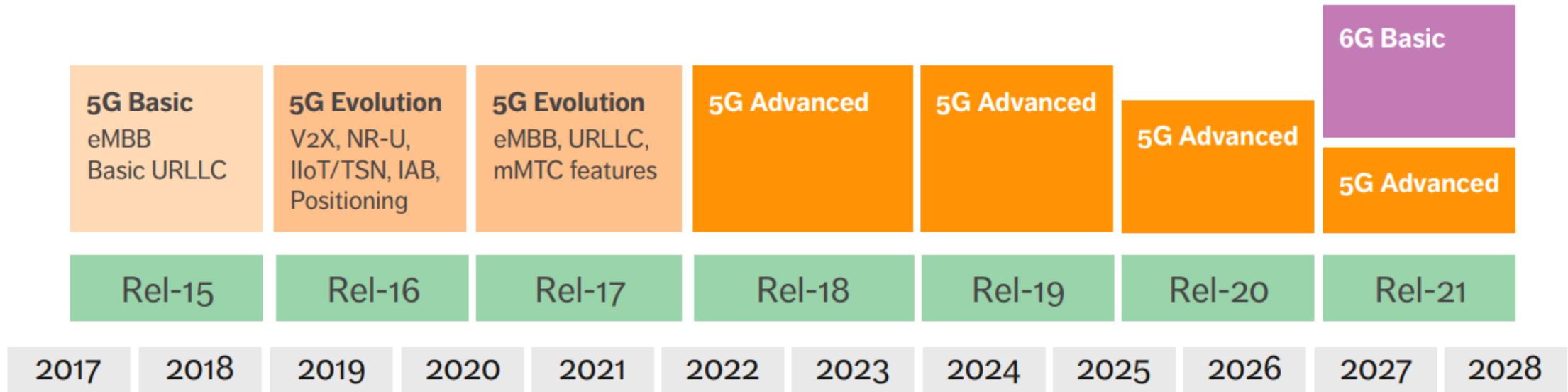


5G subscriptions are forecast to reach 6.3 billion by the end of 2030.

6.3 bn



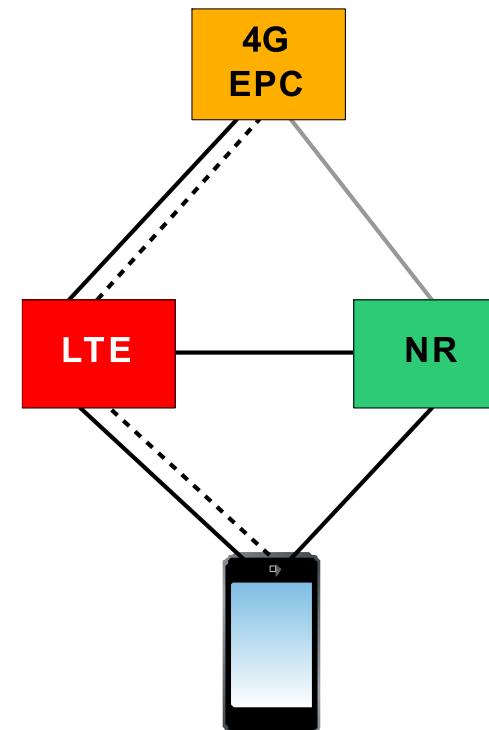
5G Roadmap



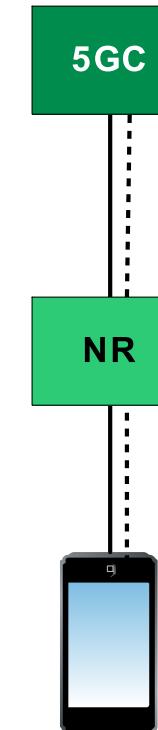
source: Ericsson.com: An overview of 3GPP releases 17 and 18.

5G NR Deployment Options

Option 3 (NSA)
Non Standalone



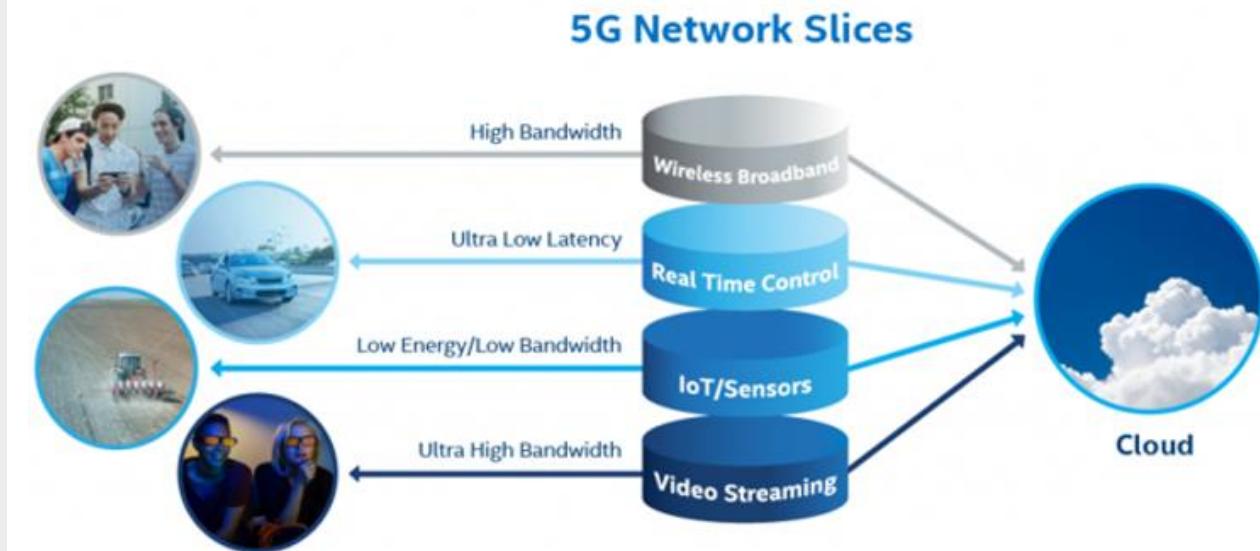
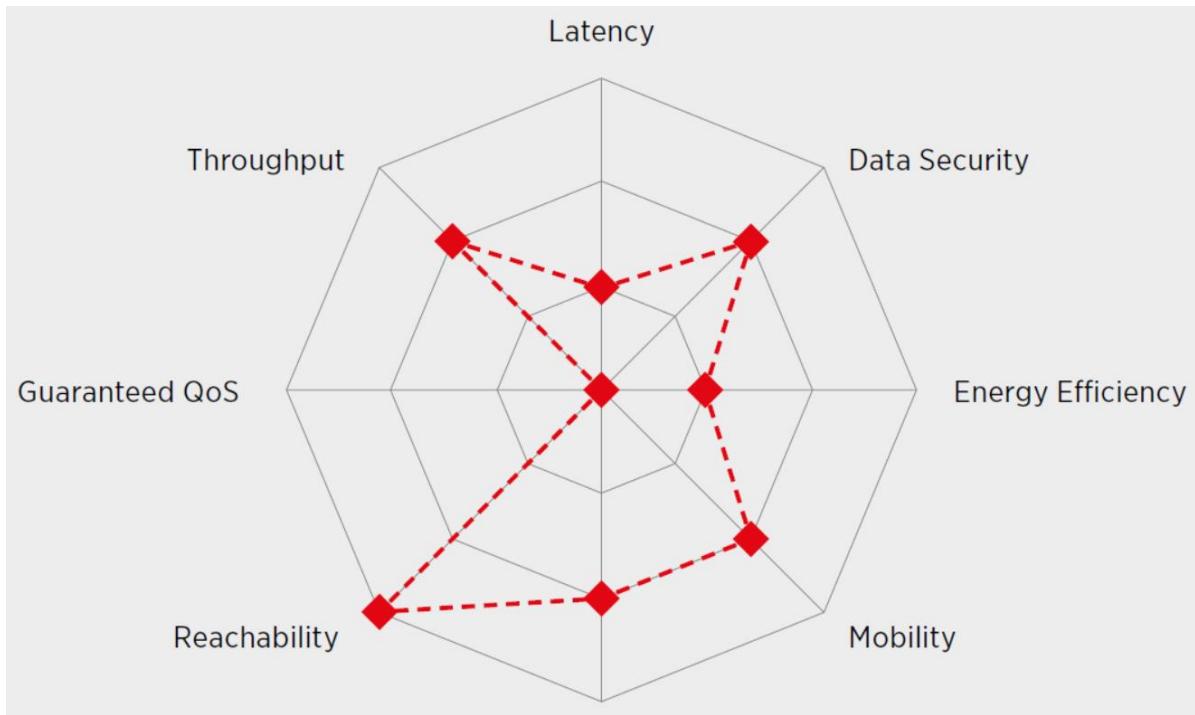
Option 2 (SA)
Standalone



— User Plane
- - - Control Plane
— Option

5G - Network Slicing

- technology that allows a single physical 5G network to be divided into multiple virtual networks
- each "slice" operates as an independent network, with its own resources and performance characteristics



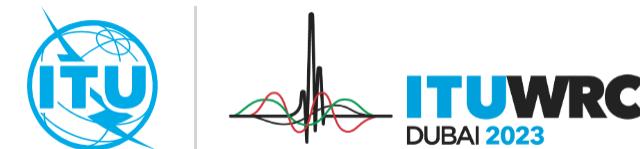
5G NR Bands in Czech Republic

| Band n28 (700 MHz) FDD | downlink | uplink |
|------------------------------|-------------|-------------|
| O2 Czech Republic a.s. | 758-768 MHz | 703-713 MHz |
| T-Mobile Czech Republic a.s. | 768-778 MHz | 713-723 MHz |
| Vodafone Czech Republic a.s. | 778-788 MHz | 723-733 MHz |

| Band n78 (3,5 GHz) TDD | uplink / downlink |
|--|-------------------|
| T-Mobile Czech Republic a.s. | 3400–3480 MHz |
| | 3480–3540 MHz |
| Vodafone Czech Republic a.s. | 3540–3600 MHz |
| | 3600–3640 MHz |
| O2 Czech Republic a.s. / Nordic Telecom 5G a.s. | 3640–3700 MHz |
| | 3700–3800 MHz |

ITU World Radiocommunication Conference

- Revision of the Radiocommunication Regulations
- Allocation of frequencies to radio communication services and coordination between states and regions
- The WRC is usually held every 4 years and its decisions have a long-term impact on development of telecommunications and radio communication technologies at the international level.
- WRC-19: globally harmonized bands for mobile networks: **24.25-27.5 GHz**, 37-43.5 GHz, 45.5-47 GHz, 47.2-48.2 and 66-71 GHz
- WRC-23: band 6425-7125 MHz for mobile networks
- WRC-27 IMT bands under consideration:



| Region 1 |
|-----------------|
| 4 400-4 800 MHz |
| 7 125-7 250 MHz |
| 7 750-8 400 MHz |
| 14.8-15.35 GHz |

| |
|---|
| Direct to Device |
| Mobile satellite in IMT bands between 694/698 MHz and 2.7 GHz |

| |
|---|
| New Mobile Satellite |
| 1 427-1 432 MHz 1 645.5-1 646.5 MHz 1 880-1 920 MHz 2 010-2 025 MHz 2 120-2 170 MHz |

5G NR Frequency Bands

- **Frequency Range 1 (FR1):** includes sub-6GHz frequency bands
 - [3GPP TS 38.104](#)
 - over 100 bands
 - channel bandwidth from 5 to 100 MHz
- **Frequency Range 2 (FR2):** includes frequency bands from 26500 MHz – 71000 MHz
 - [3GPP TS 38.104](#)
 - total 7 bands
 - channel bandwidth from 50 to 2000 MHz
- NR Absolute Radio Frequency Channel Number (NR-ARFCN): range [0...3279165]

| Frequency range [MHz] | ΔF_{Global} [kHz] | $F_{\text{REF-Offs}}$ [MHz] | $N_{\text{REF-Offs}}$ | Range of N_{REF} |
|-----------------------|----------------------------------|-----------------------------|-----------------------|---------------------------|
| 0 – 3000 | 5 | 0 | 0 | 0 – 599999 |
| 3000 – 24250 | 15 | 3000 | 600000 | 600000 – 2016666 |
| 24250 – 100000 | 60 | 24250.08 | 2016667 | 2016667 – 3279165 |

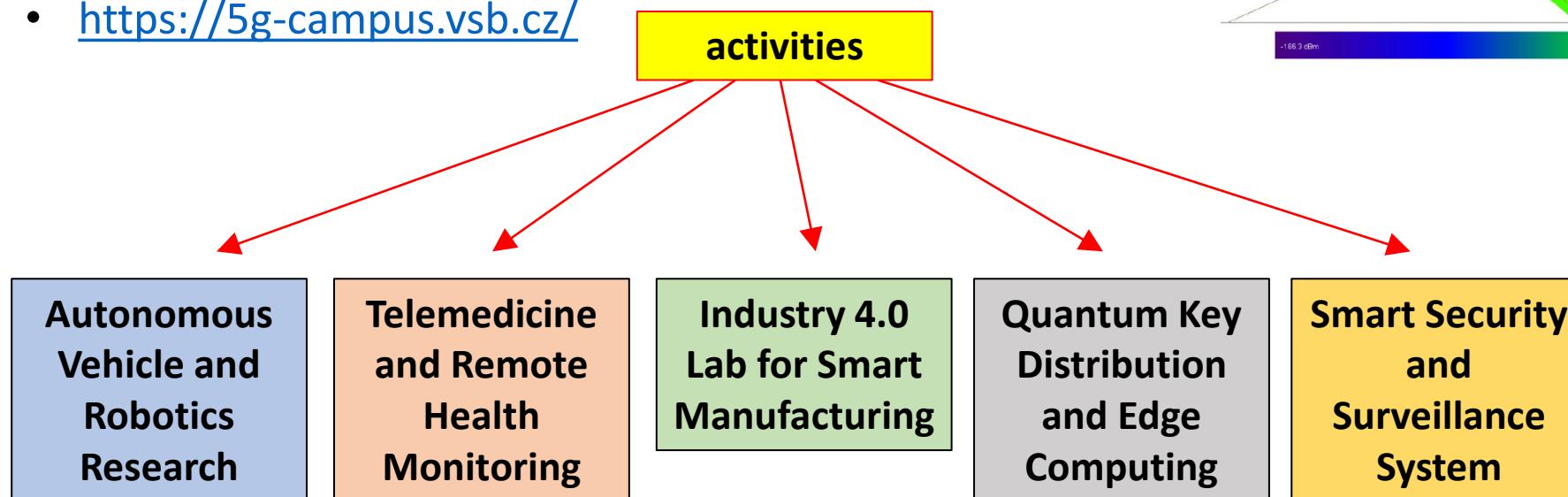
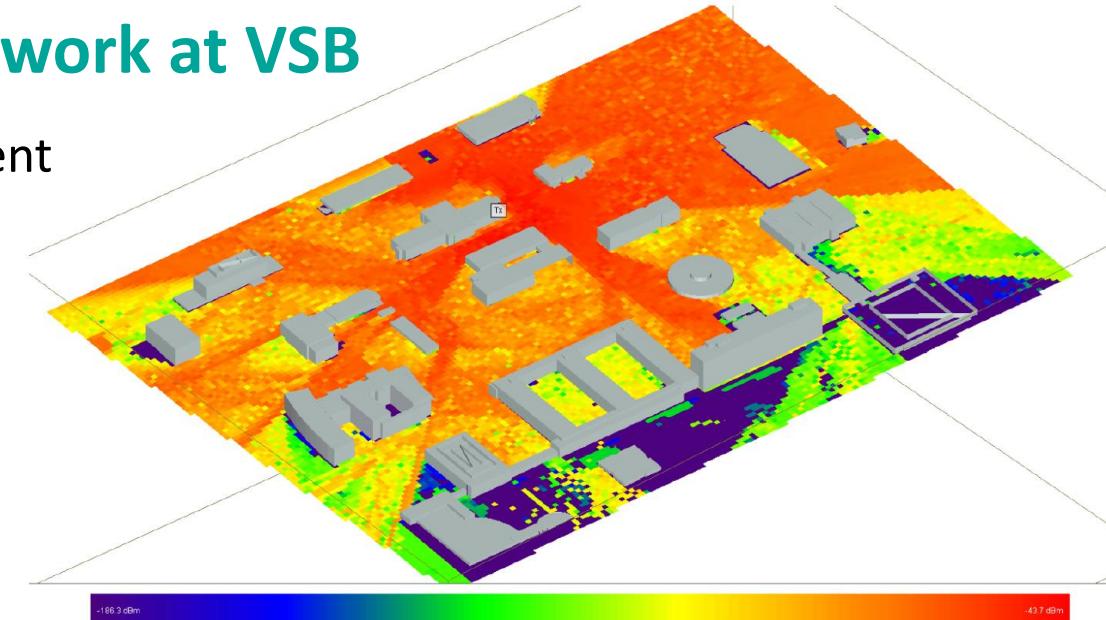
$$F_{\text{REF}} = F_{\text{REF-Offs}} + \Delta F_{\text{Global}} (N_{\text{REF}} - N_{\text{REF-Offs}})$$

NR-ARFCN

<https://5g-tools.com/5g-nr-arfcn-calculator/>

5G Campus Private Network at VSB

- Campus Network (CN) is built as a separate and independent mobile network infrastructure
- 5G SA (Stand Alone architecture)
- 3.5 GHz band + mmWave (26.5 GHz) band
- Use for education within lectures
- Bachelor/Master degree thesis, R&D projects
- <https://5g-campus.vsb.cz/>



Legislation for Mobile Networks in Czech Republic

- ▶ Zákon č. 267/2015 Sb. o ochraně veřejného zdraví a o změně některých souvisejících zákonů.
 - stanovuje v § 35 „Neionizující záření“ provozovatelů BTS mj. **povinnost vypracovat dokumentaci**, ve které bude doloženo výpočtem nebo měřením dodržení nejvyšších přípustných hodnot neionizujícího záření z hlediska možné expozice fyzických osob, a předložit tuto dokumentaci příslušnému orgánu ochrany veřejného zdraví.
- ▶ Nařízení Vlády č. 291/2015 Sb. o ochraně zdraví před neionizujícím zářením.
 - Limity jsou rozdílné pro **zaměstnance** - osoby seznámené s riziky vystavující se EMP při práci, a pro **ostatní osoby** - všechny fyzické osoby). Limitními hodnotami jsou určeny:
 - měrný výkon absorbovaný v tkáni těla **SAR** (Specific Absorption Rate)
 - hustota zářivého toku **S**

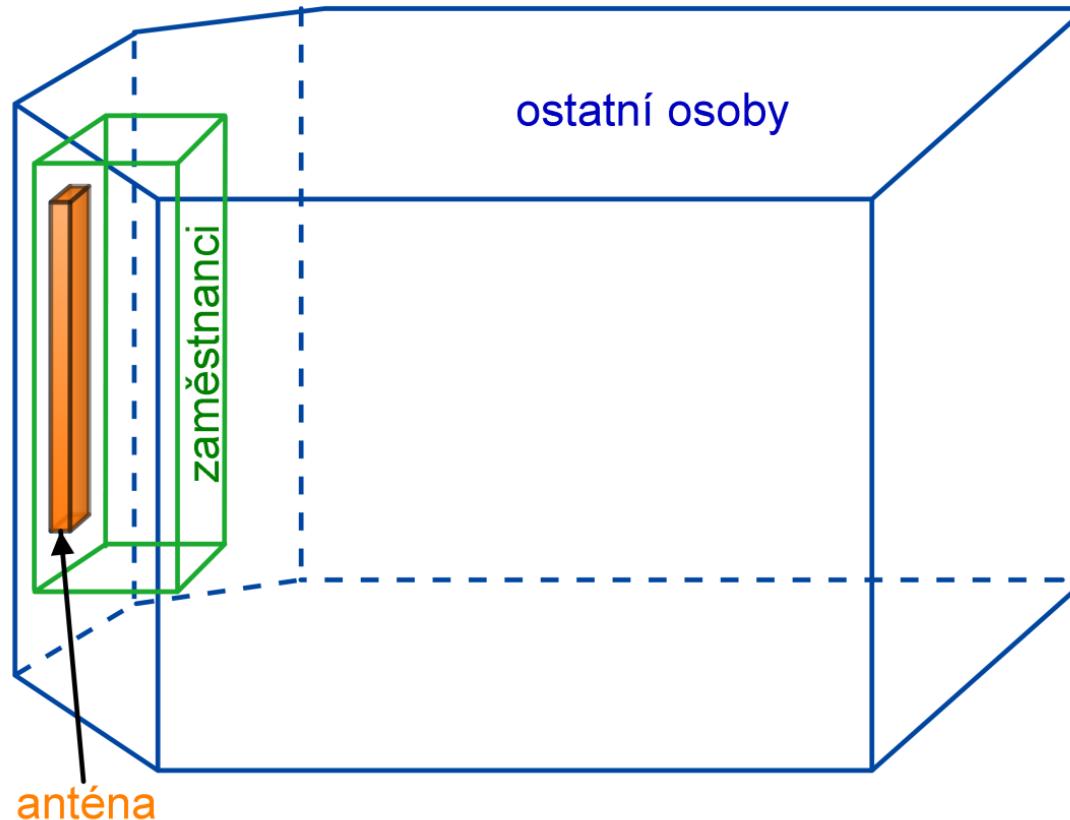
| Intenzita elektrického pole E^{limit} [V/m] | | |
|--|---|-------------------------------------|
| Frekvence (f) | Fyzické osoby v kom.prostředí | Zaměstnanci |
| 10 MHz - 400 MHz | $E = 28$ | $E = 61$ |
| 400 MHz - 2 GHz | $E = 1,375 \cdot 10^{-3} \cdot f^{0,5}$ | $E = 3 \cdot 10^{-3} \cdot f^{0,5}$ |
| 2 GHz - 300 GHz | $E = 61$ | $E = 137$ |

| Platí pro frekvence od 100 kHz - 6 GHz | | SAR [W/kg] |
|--|--|------------|
| zaměstnanci | | 0,4 |
| ostatní osoby | | 0,08 |
| Platí pro frekvence od 6 GHz - 300 GHz | | |
| zaměstnanci | | 50 |
| ostatní osoby | | 10 |

- ▶ Metodický návod MZ ČR ke sjednocení postupu orgánů a zařízení ochrany veřejného zdraví při kontrole dodržování opatření uložených fyzickým a právnickým osobám v ochraně před neionizujícím zářením

Legislation for Mobile Networks in Czech Republic

- ▶ Determine **the dimensions of the zones** with possible exceeding of the reference values for the movement of persons near the antennas.



Comparison of the effects for individual frequencies



Campus 5G network - electromagnetic field calculation

| označení antény | označení sloupu | souřadnice X(m) | souřadnice Y(m) | operátor | pásma (MHz) | výkon (W) | azimut antény (°) | výška nad terénem (m) | tilt mechanický (°) | tilt elektrický (°) | zisk antény (dBi) | délka antény (m) | horizontální šířka svazku 3dB (°) | vertikální šířka svazku 3dB (°) | Multiband anténa | typ antény |
|-----------------|-----------------|-----------------|-----------------|----------|-------------|-----------|-------------------|-----------------------|---------------------|---------------------|-------------------|------------------|-----------------------------------|---------------------------------|------------------|---------------------|
| L_316859_40° | S1 | 0 | 0 | TM | 2600 | 40 | 40 | 15,1 | 0 | 12 | 18 | 1,4 | 65 | 5,8 | | H-A264518R0v06 |
| L_316859_185° | S1 | 0,38 | -0,92 | TM | 2600 | 40 | 185 | 15,1 | 0 | 12 | 18 | 1,4 | 65 | 5,8 | | H-A264518R0v06 |
| L_316859_360° | 1 | 0 | 0 | TM | 2600 | 0,1 | omni | 0 | 0 | 0 | 17 | 0,2 | 360 | 14 | | E-Radio Dot RD 2243 |
| L_316859_360° | 2 | 0 | 0 | TM | 2600 | 0,1 | omni | 0 | 0 | 0 | 17 | 0,2 | 360 | 14 | | E-Radio Dot RD 2243 |
| L_316859_360° | 3 | 0 | 0 | TM | 2600 | 0,1 | omni | 0 | 0 | 0 | 17 | 0,2 | 360 | 14 | | E-Radio Dot RD 2243 |
| L_316859_360° | 4 | 0 | 0 | TM | 2600 | 0,1 | omni | 0 | 0 | 0 | 17 | 0,2 | 360 | 14 | | E-Radio Dot RD 2243 |
| L_316859_360° | 5 | 0 | 0 | TM | 2600 | 0,1 | omni | 0 | 0 | 0 | 17 | 0,2 | 360 | 14 | | E-Radio Dot RD 2243 |
| L_316859_360° | 6 | 0 | 0 | TM | 2600 | 0,1 | omni | 0 | 0 | 0 | 17 | 0,2 | 360 | 14 | | E-Radio Dot RD 2243 |

Rozměry zón shody (výpočet zahrnuje expozice od všech antén)

| Označení antény | Sloupek | D čelní [m] | D šířka [m] | D pod [m] | D zadní [m] | R [m] | Multiband / typ |
|-----------------|---------|-------------|-------------|-----------|-------------|--------|---------------------|
| L_316859_40° | S1 | 2,52 m | 1,35 m | 0,35 m | 0,10 m | 0,50 m | H-A264518R0v06 |
| L_316859_185° | S1 | 2,52 m | 1,35 m | 0,35 m | 0,10 m | 0,50 m | H-A264518R0v06 |
| L_316859_360° | 1 | 0,49 m | --- | 0,35 m | --- | 0,22 m | E-Radio Dot RD 2243 |
| L_316859_360° | 2 | 0,49 m | --- | 0,35 m | --- | 0,22 m | E-Radio Dot RD 2243 |
| L_316859_360° | 3 | 0,49 m | --- | 0,35 m | --- | 0,22 m | E-Radio Dot RD 2243 |
| L_316859_360° | 4 | 0,49 m | --- | 0,35 m | --- | 0,22 m | E-Radio Dot RD 2243 |
| L_316859_360° | 5 | 0,49 m | --- | 0,35 m | --- | 0,22 m | E-Radio Dot RD 2243 |
| L_316859_360° | 6 | 0,49 m | --- | 0,35 m | --- | 0,22 m | E-Radio Dot RD 2243 |

