

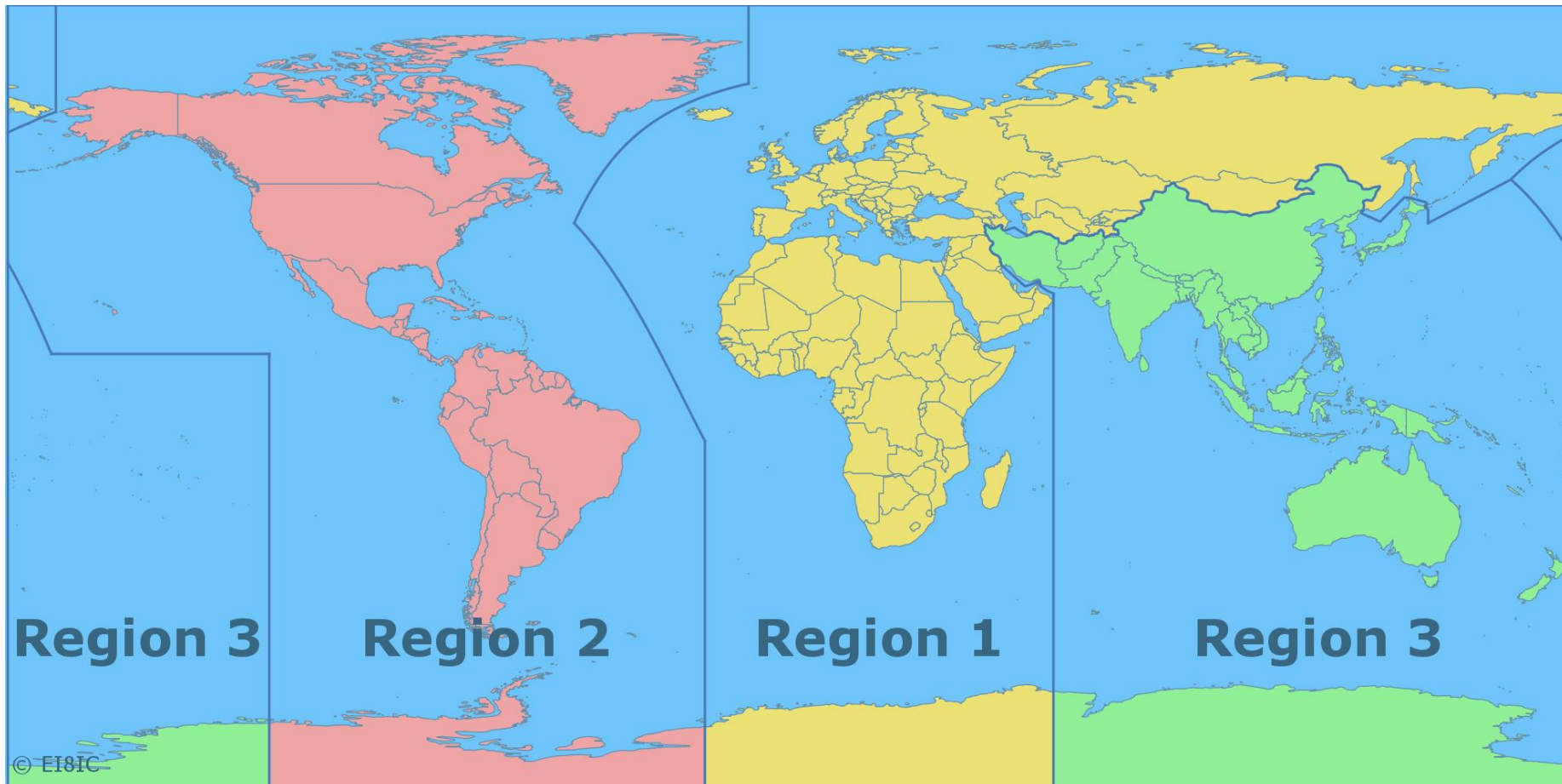
# Network Technologies I. **Mobile Networks**

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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

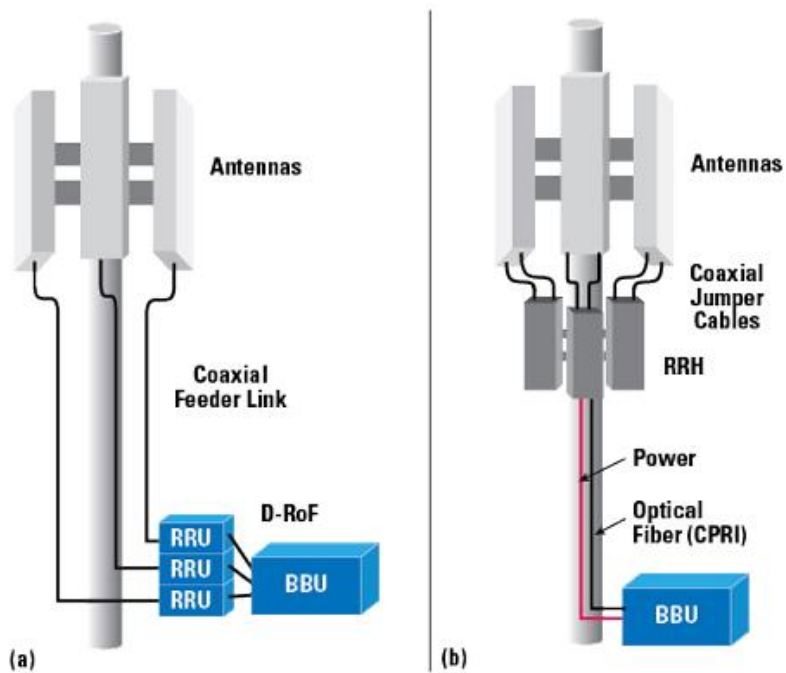
source: Keysight.com



## What is base station?

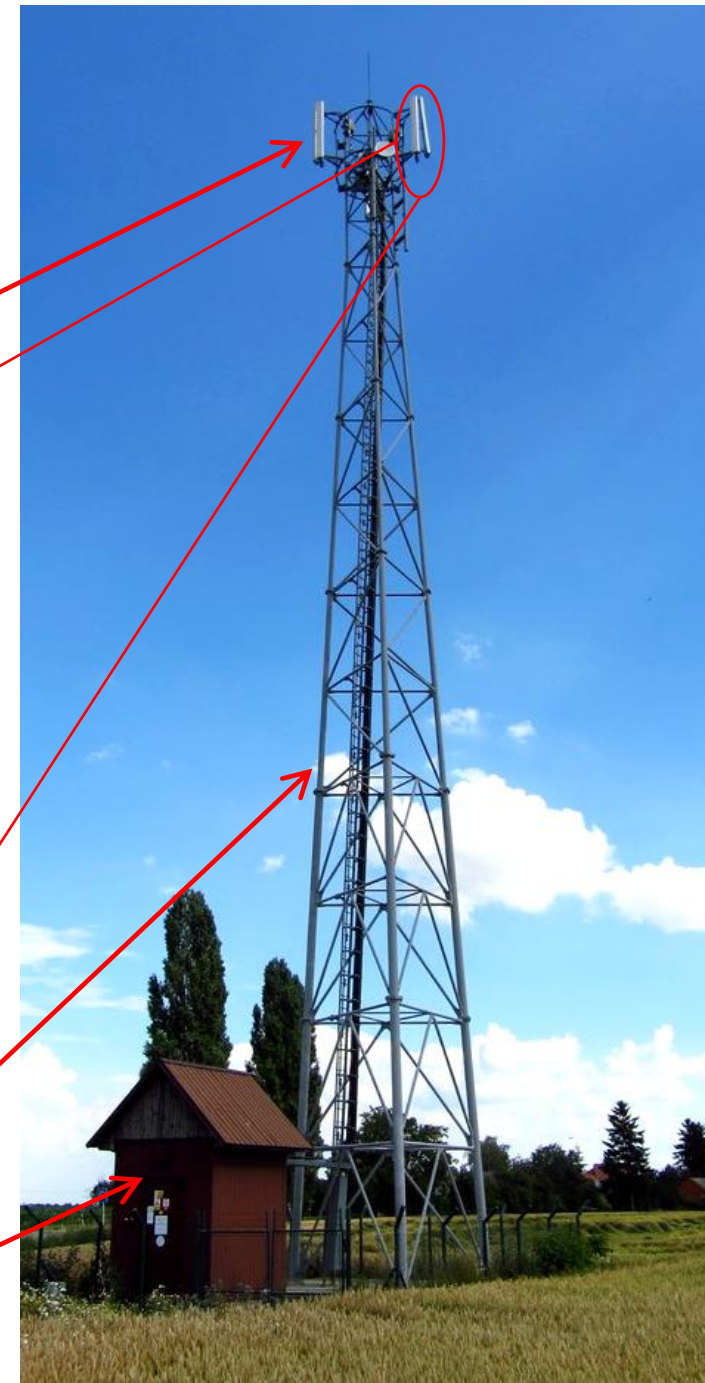
- equipment that facilitates **wireless** communication between **user equipment** (UE) and a network

antennas, remote units, microwave technology



antenna mast, cables

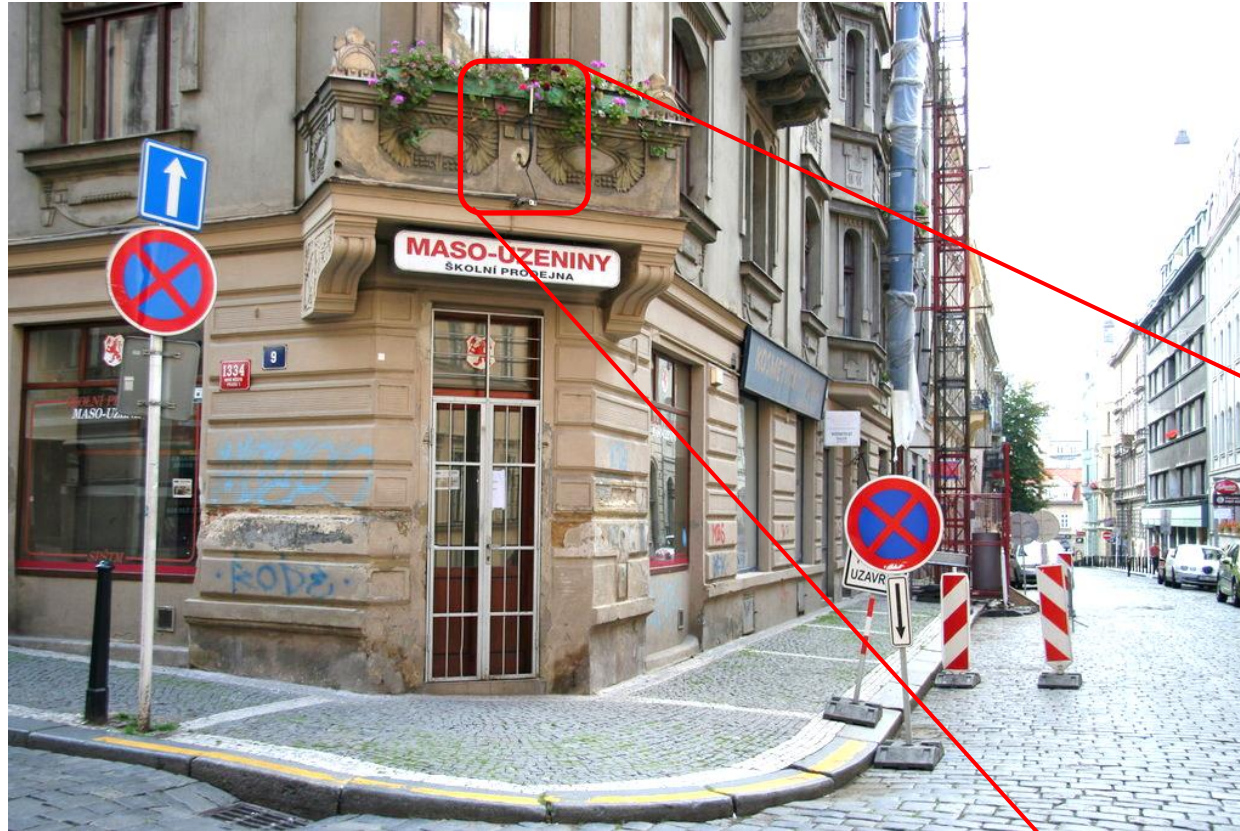
cabinet (baseband unit, power supply, batteries)



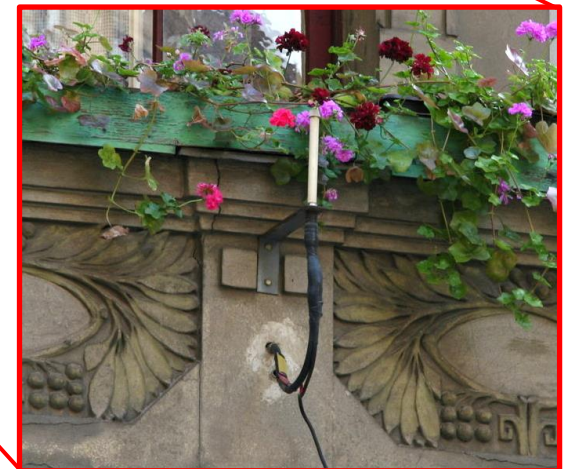
## Typical base stations



typical macro cell

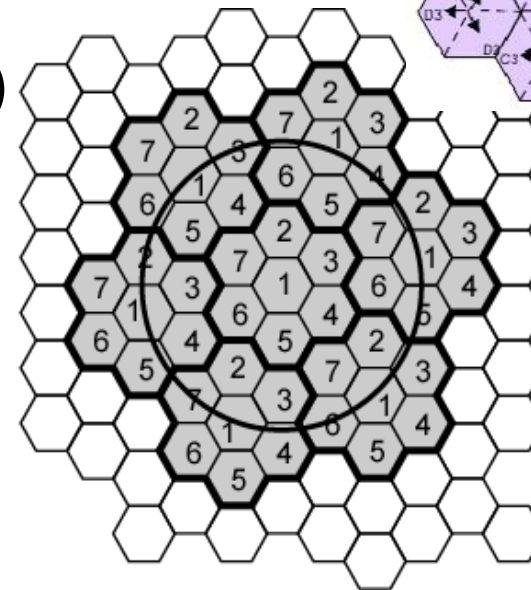
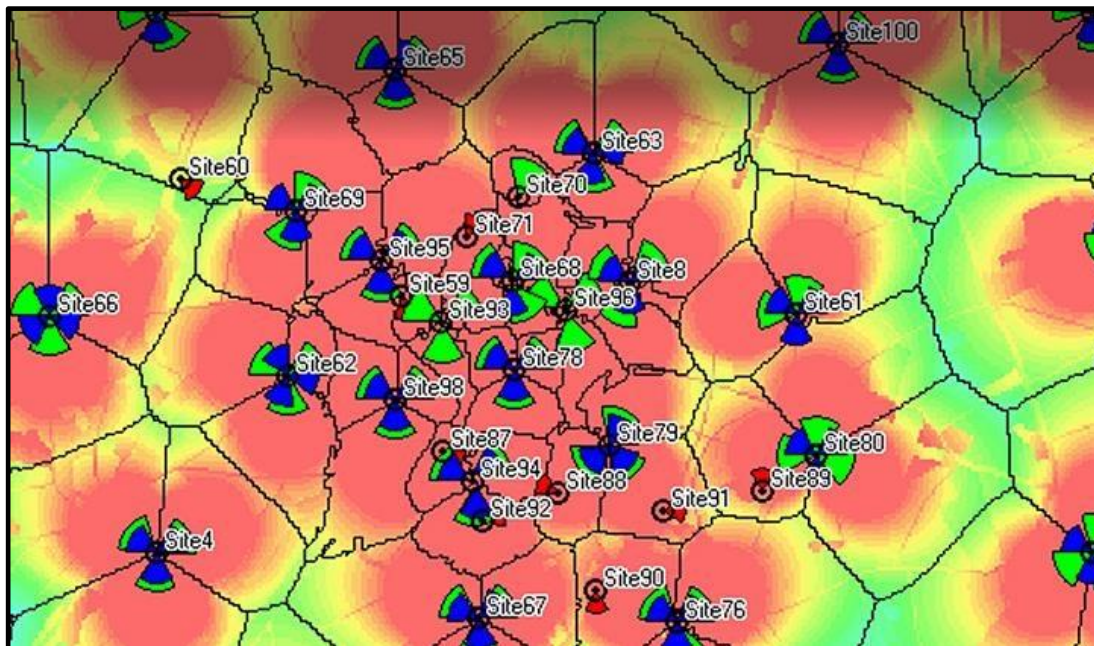


typical micro cell

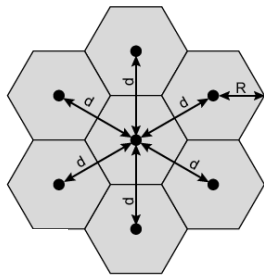
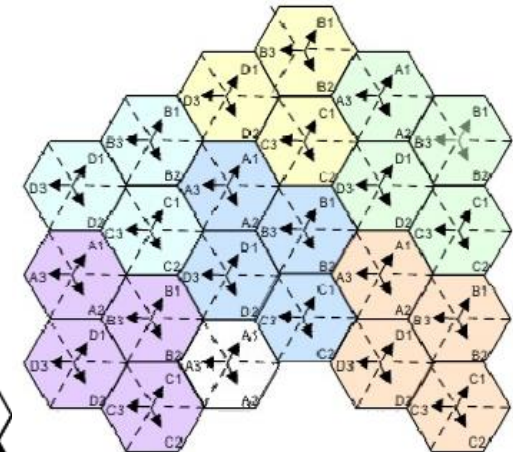


# Cellular Systems

- 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...)

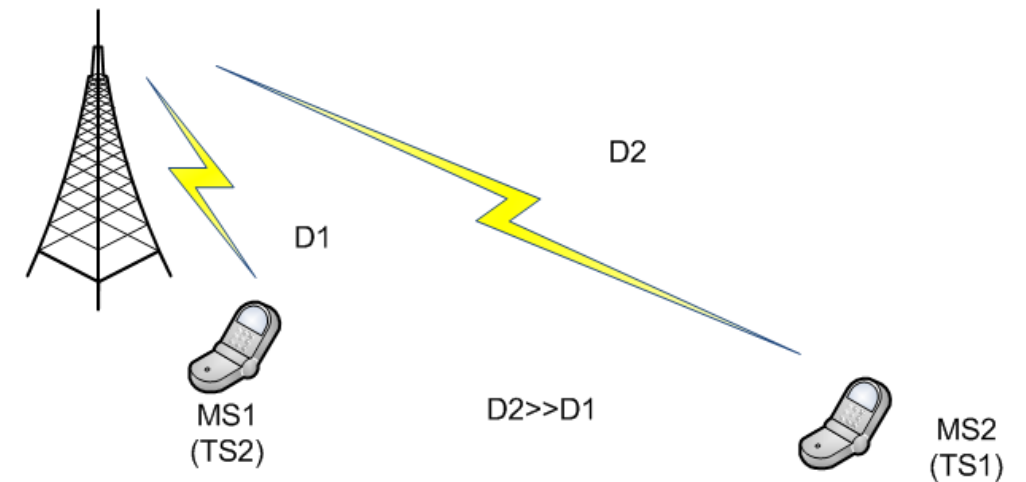
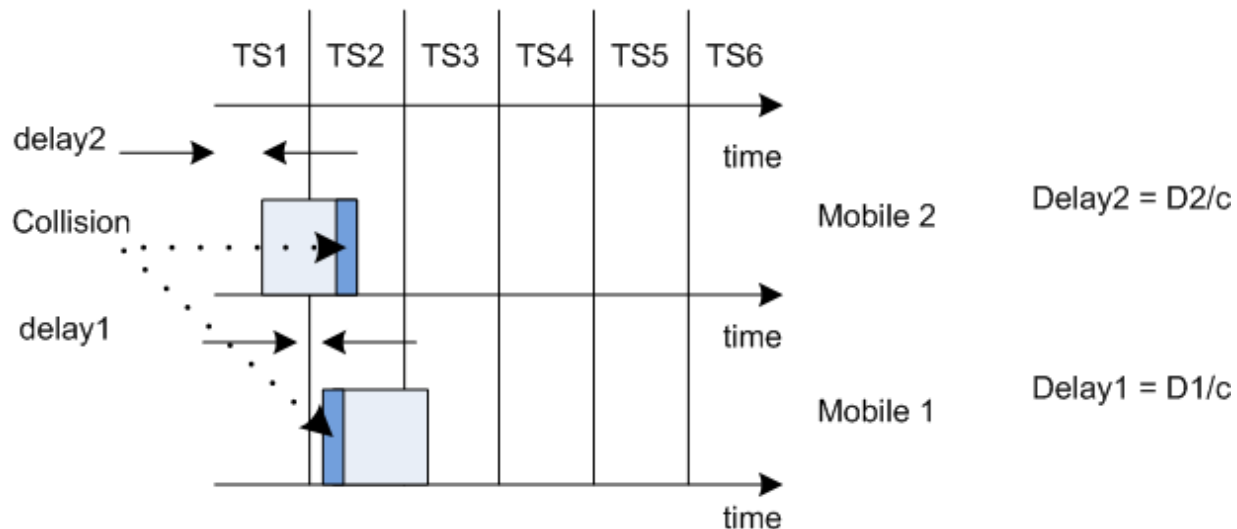


Frequency  
reuse for  
 $N=7$



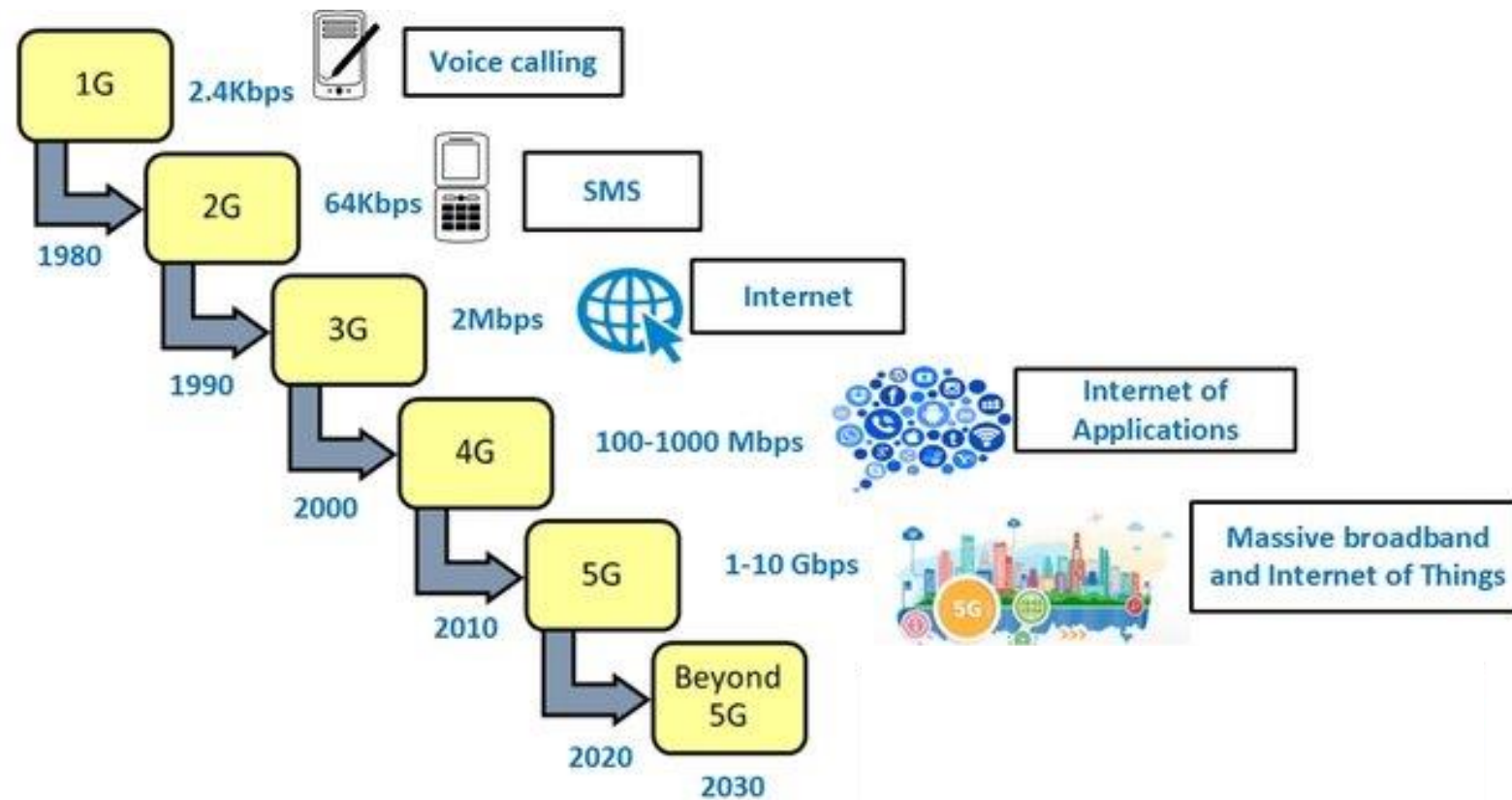
## Near-far problem in TDMA systems

- 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



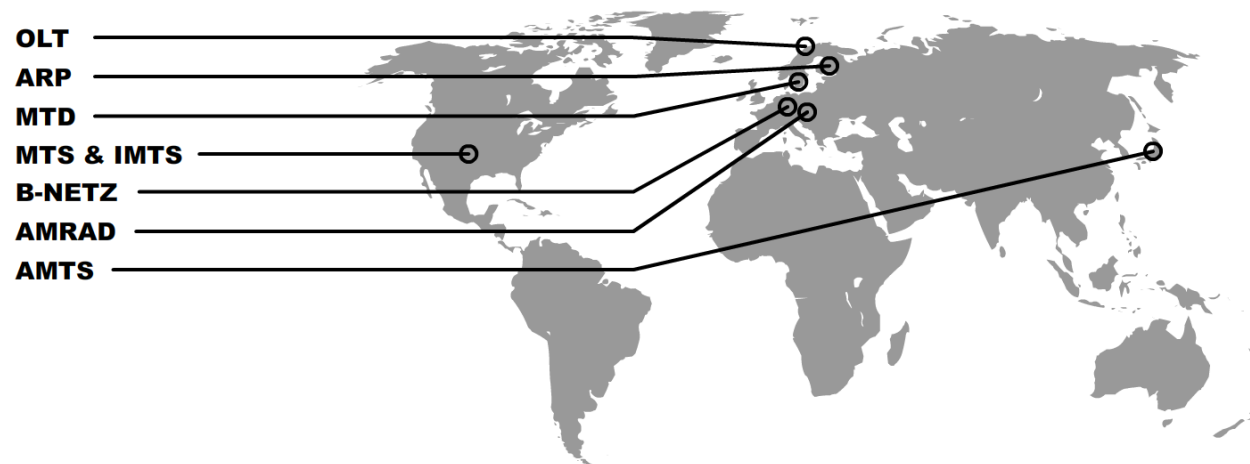
# Evolution of Mobile Radio Communications

- 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**

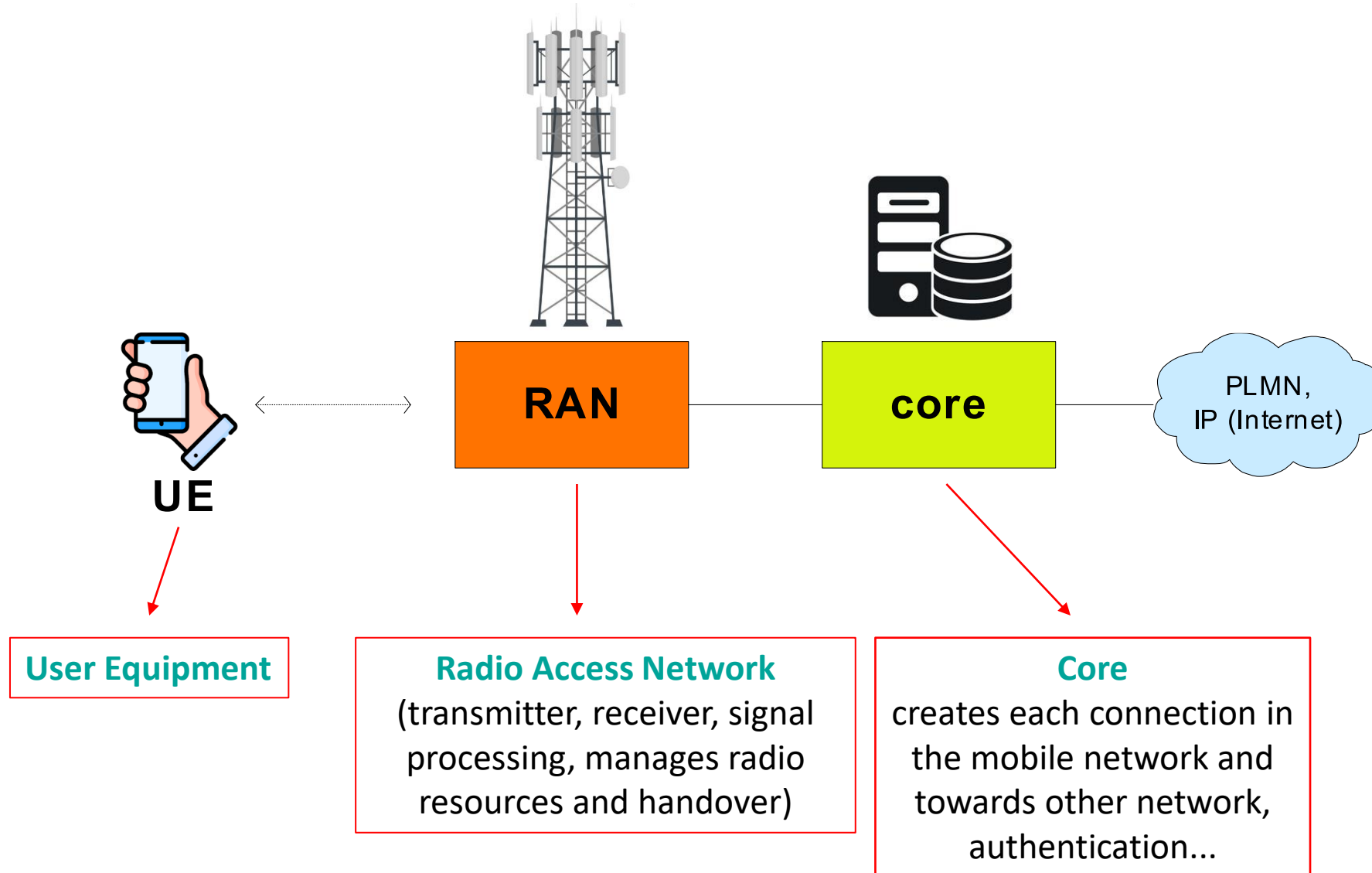


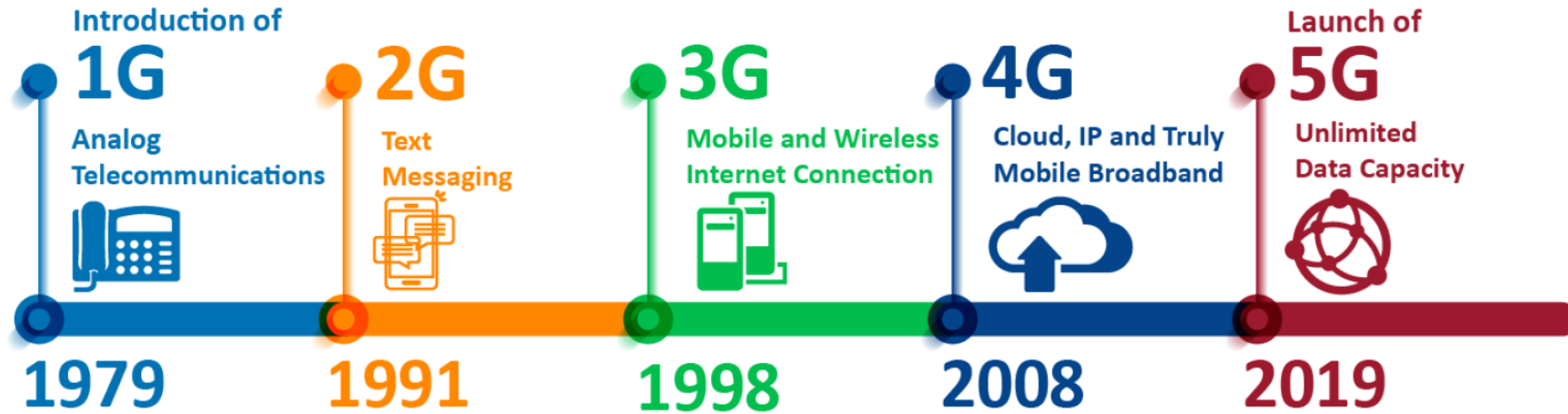
## 0. Generation of Mobile Networks

- **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



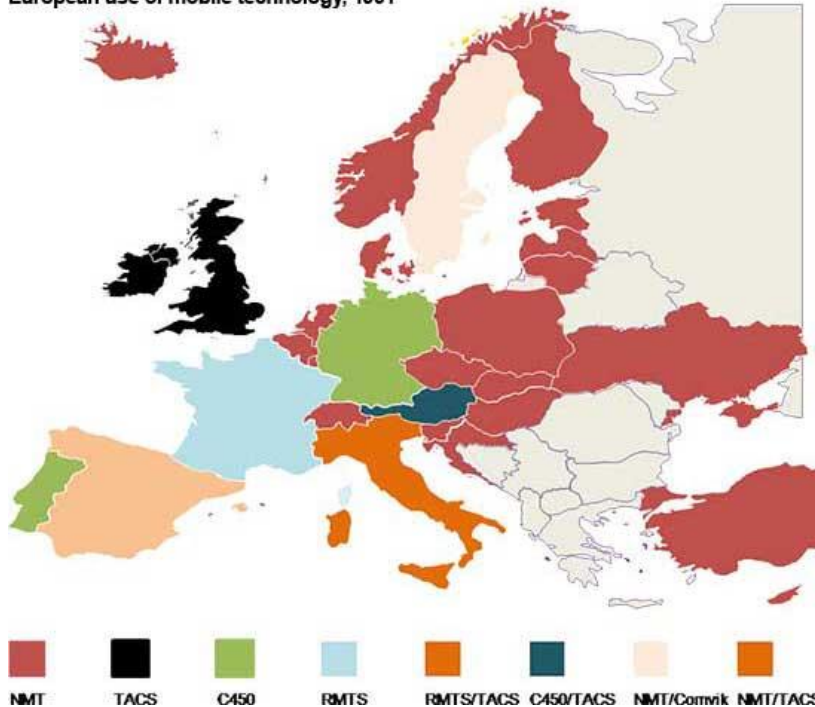
## Mobile Network – Basic System Architecture





## 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

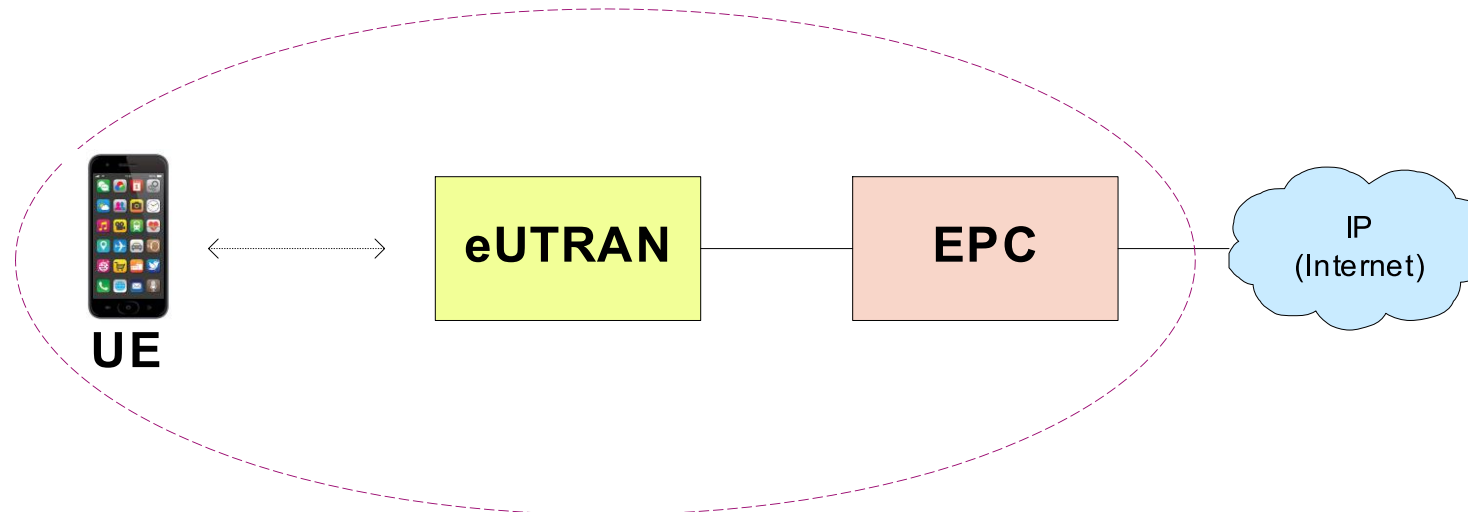
- Phenomenal growth of 2G - **lack of capacity**
- Voice is becoming a commodity service
- 3G is designed to address the deficiencies of 2G
- 1998 - 3GPP was formed to build the technical specification work for 3G **UMTS** (Universal Mobile Telecommunication System)



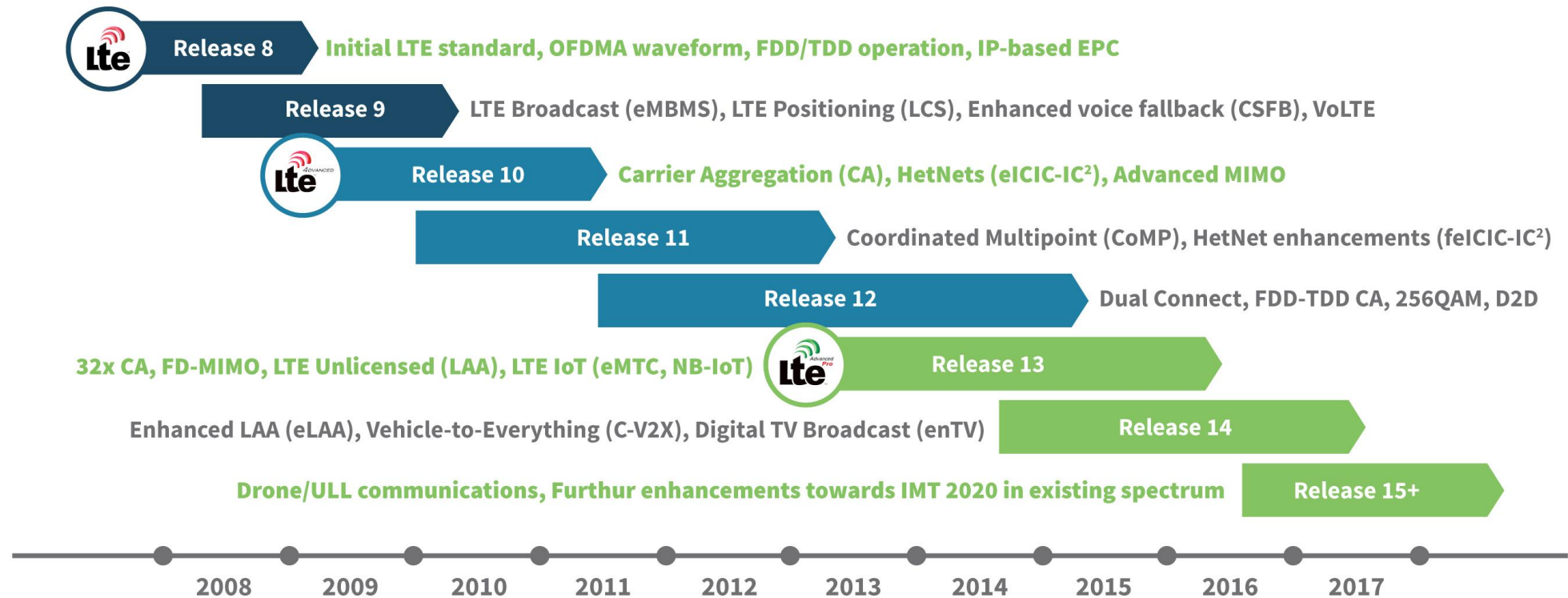
## 4th Generation of Mobile Networks

- 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

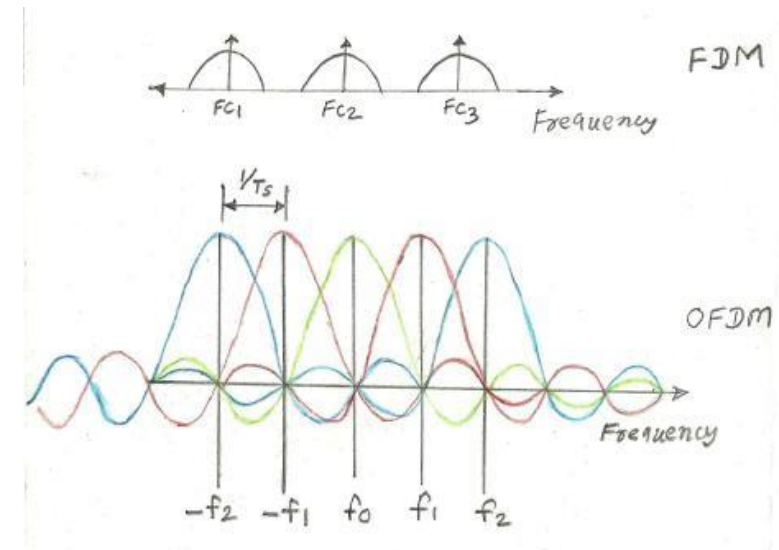
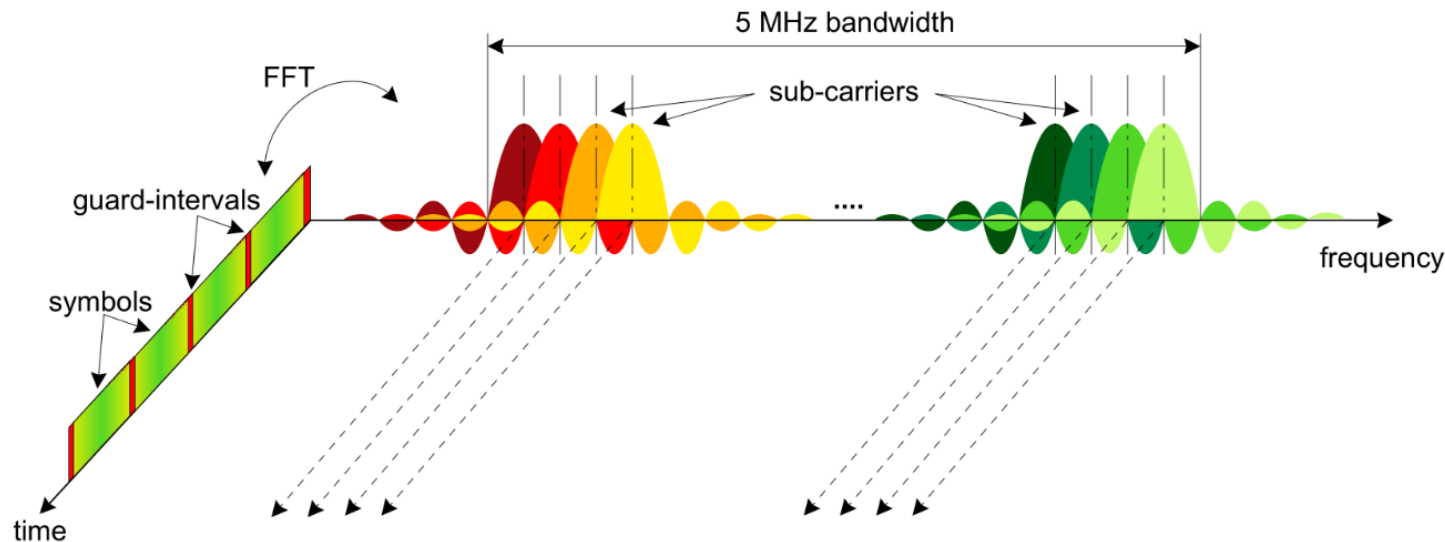
## LTE Physical Layer

- 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]
<b>band 1</b>	1920 – 1980	2110 - 2170
<b>band 3</b>	1710 - 1785	1805 - 1880
<b>band 7</b>	2500 - 2570	2620 - 2690
<b>band 8</b>	880 - 915	925 - 960
<b>band 20</b>	832 - 862	791 - 821
TDD		
	uplink/downlink [MHz]	
<b>band 38</b>	2570 - 2620	
<b>band 43</b>	3600 - 3800	

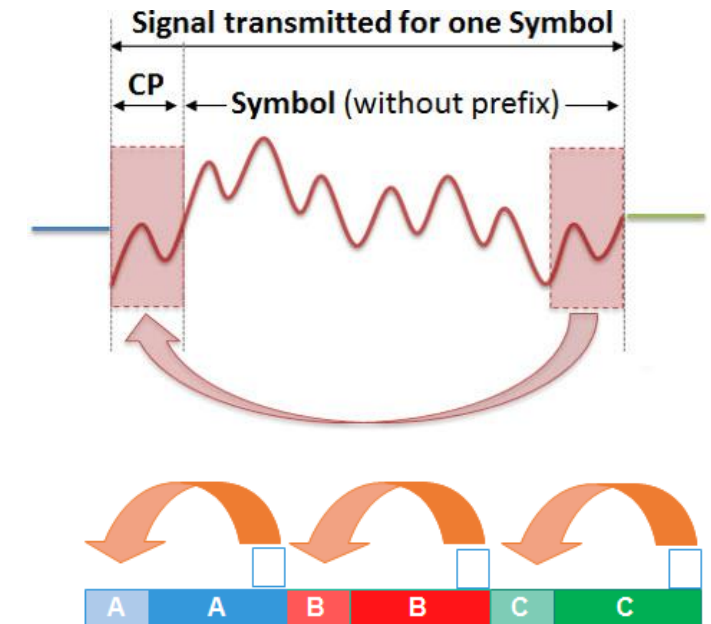
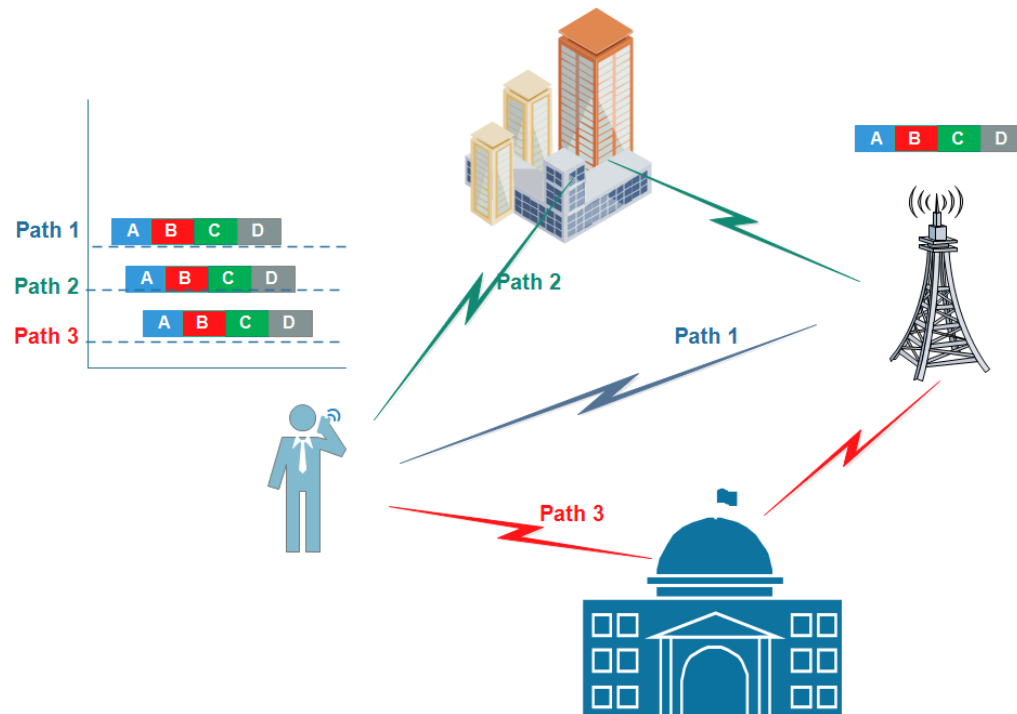
## LTE and OFDM (Orthogonal Frequency-Division Multiplexing)

- 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  $\mu s$



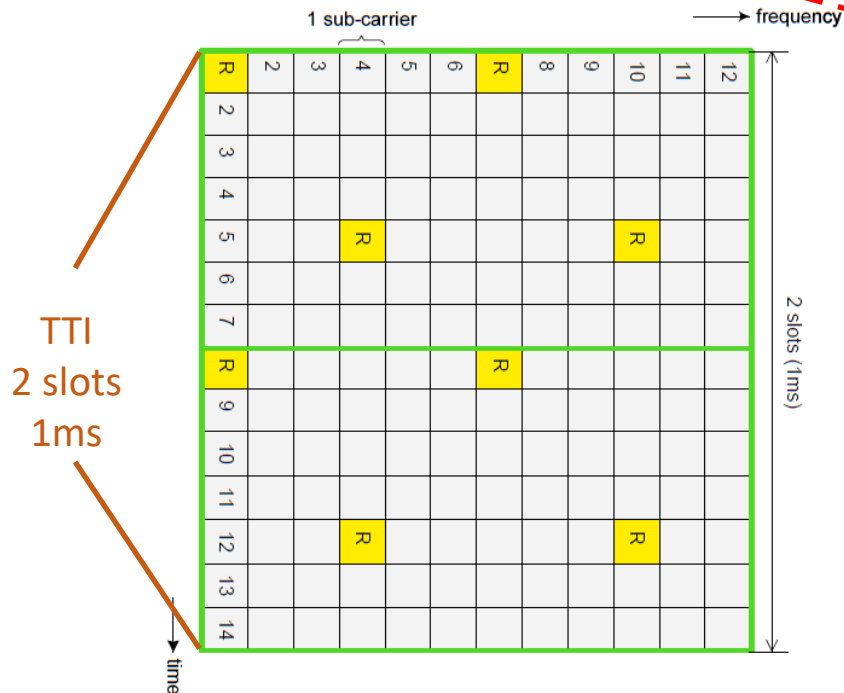
## ISI (Inter Symbol Interference) in LTE

- 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**



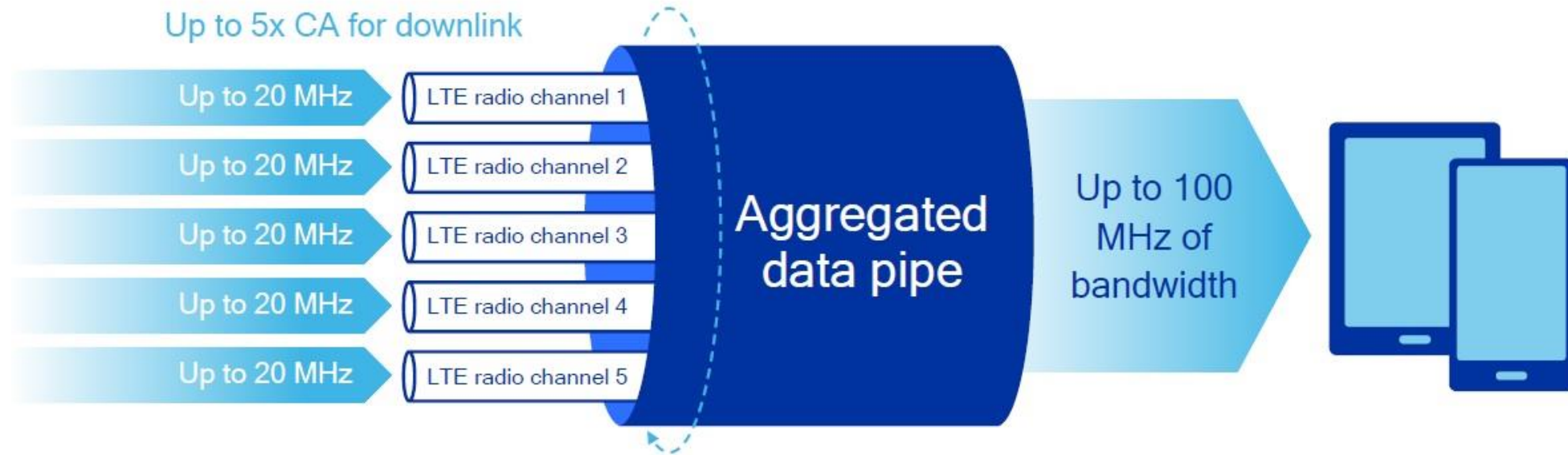
## What is the PHY rate for 20MHz band in LTE?

- 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 x 6 = 1008 bits/subframe (1ms)
- Raw PHY data rate = 1008/1ms = 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**

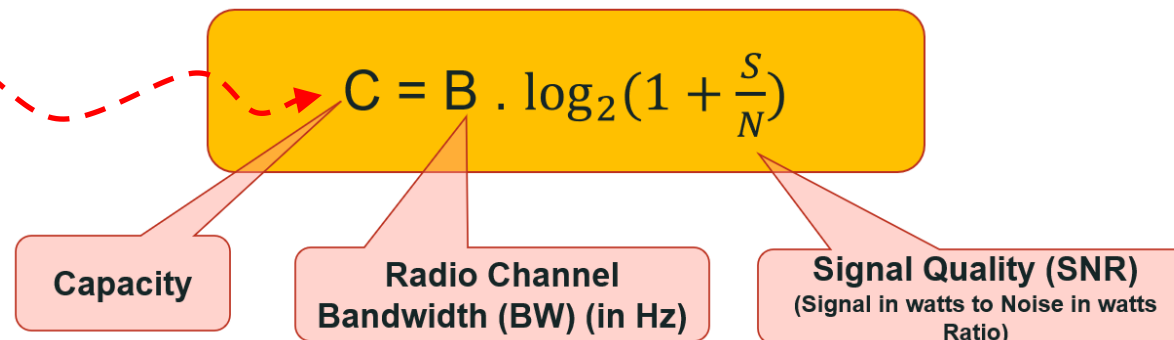


Bandwidth (MHz)	1,4	3	5	10	15	20
Resource blocks	6	15	25	50	75	100

## LTE – Advanced – Carrier Agregation

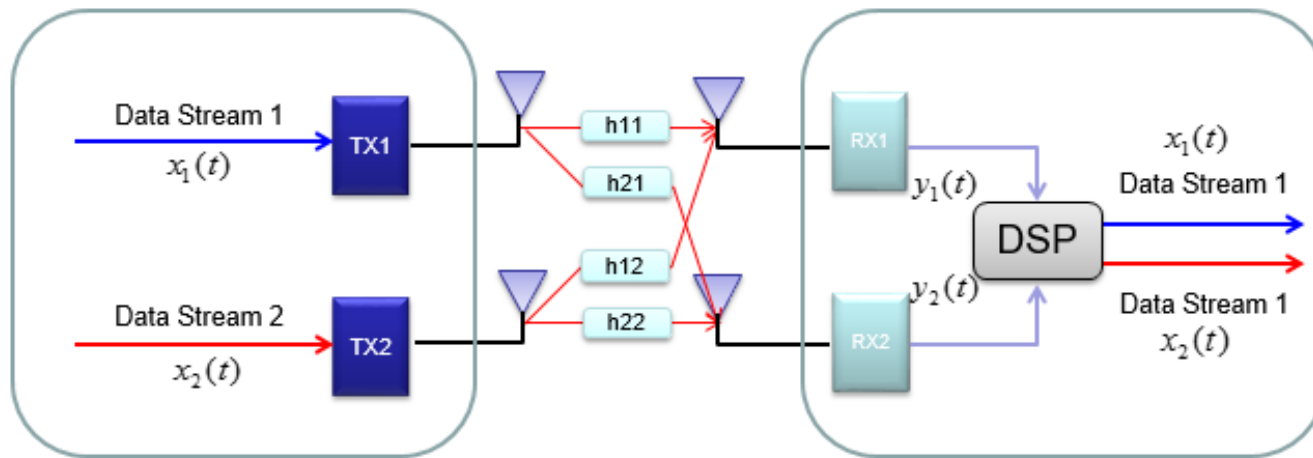


Why Carrier Agregation?



## 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

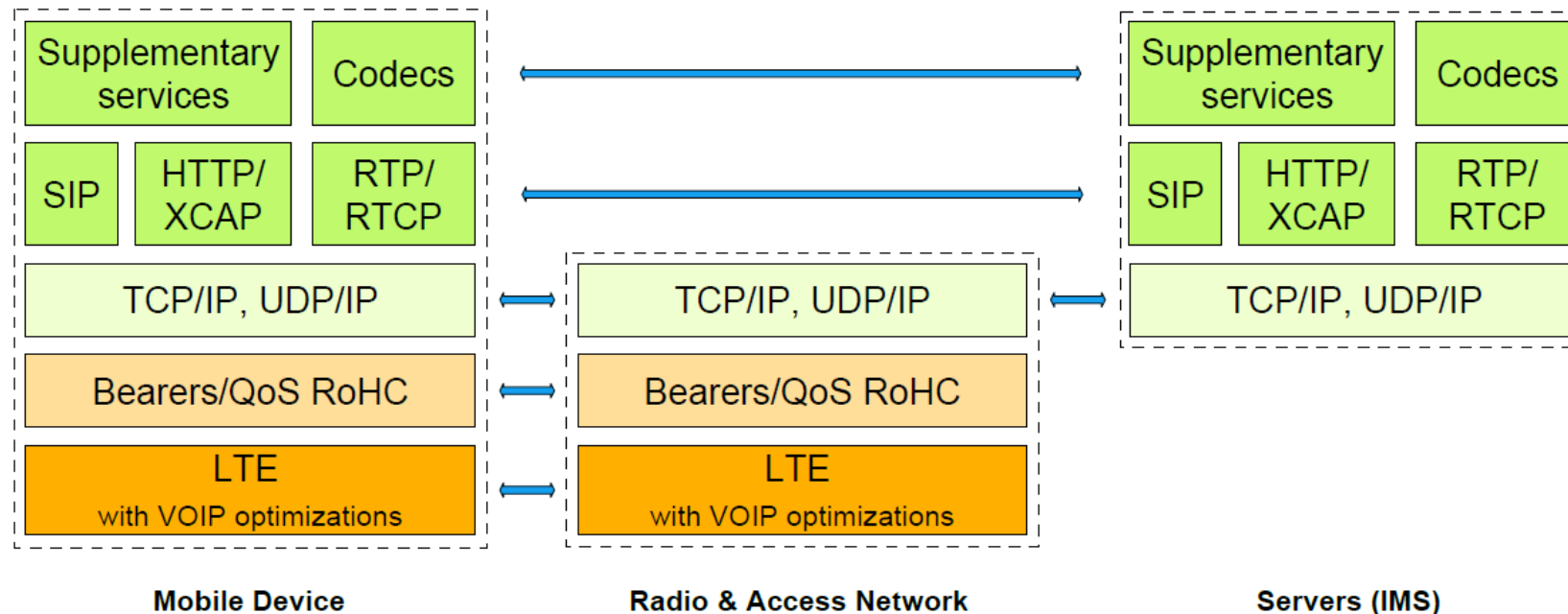
Received data  $\mathbf{y}$  =  $\mathbf{H}\mathbf{x}$  Transmitted data  $\mathbf{x}$

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

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

## 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

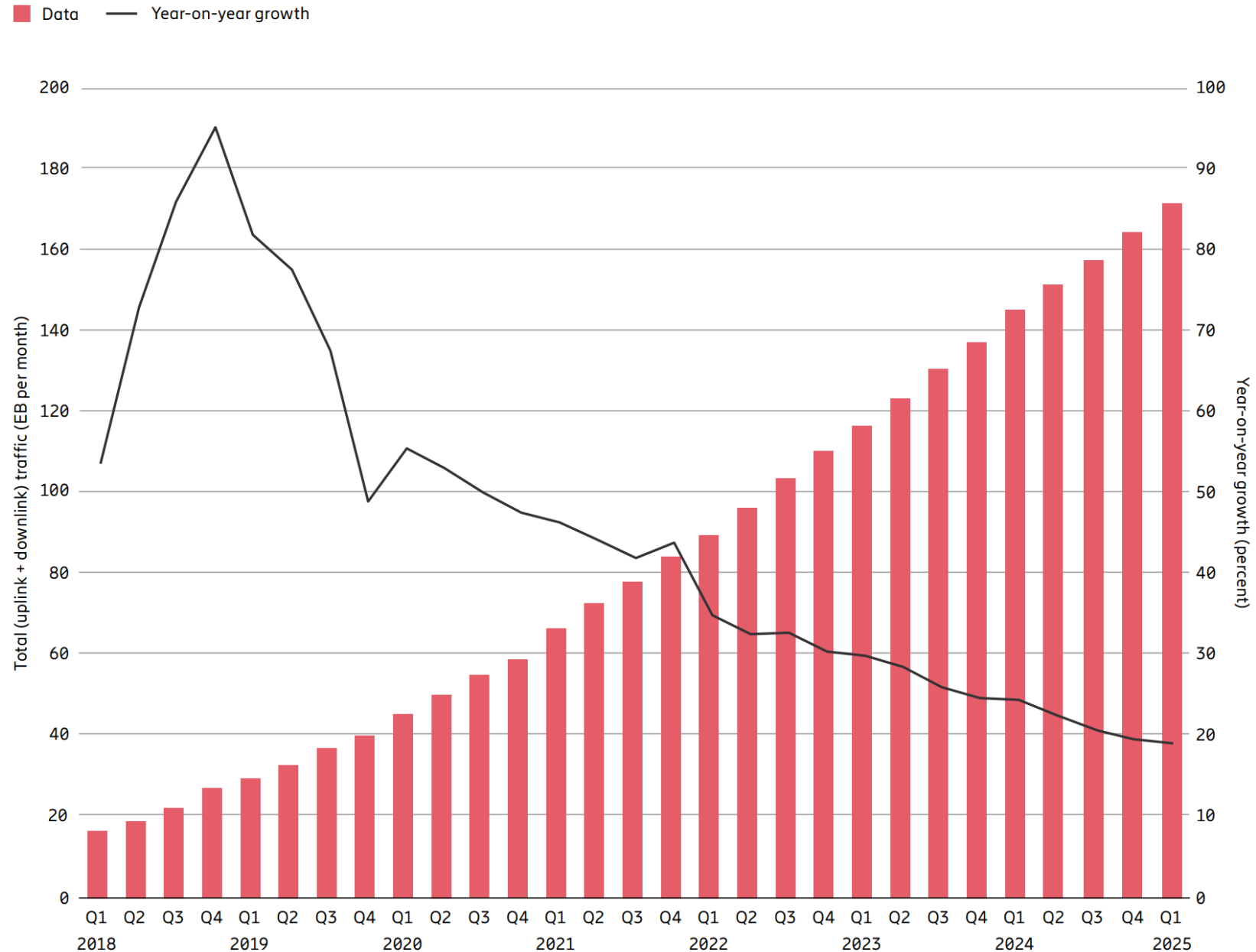
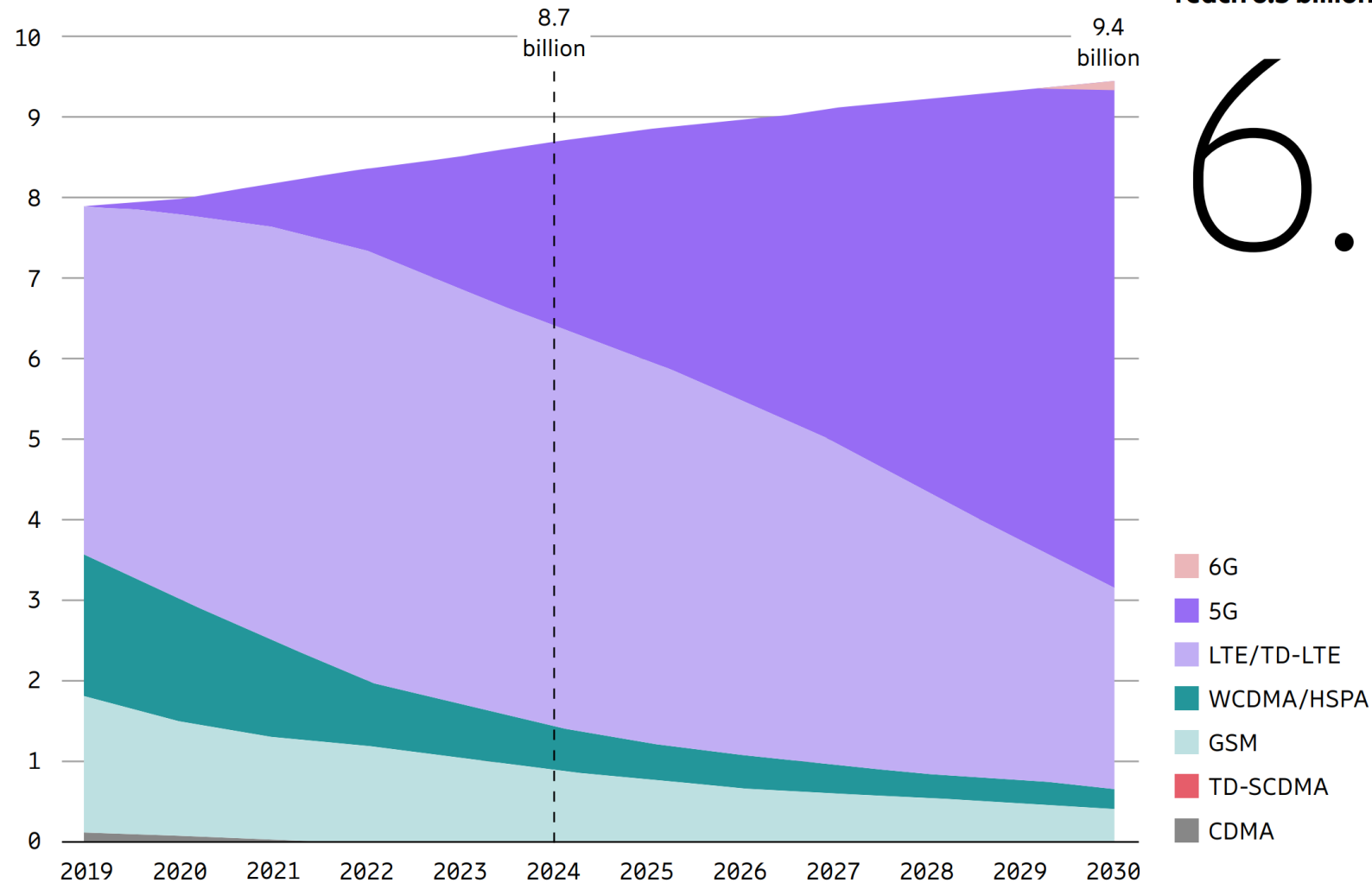


Figure 1: Mobile subscriptions by technology (billion)

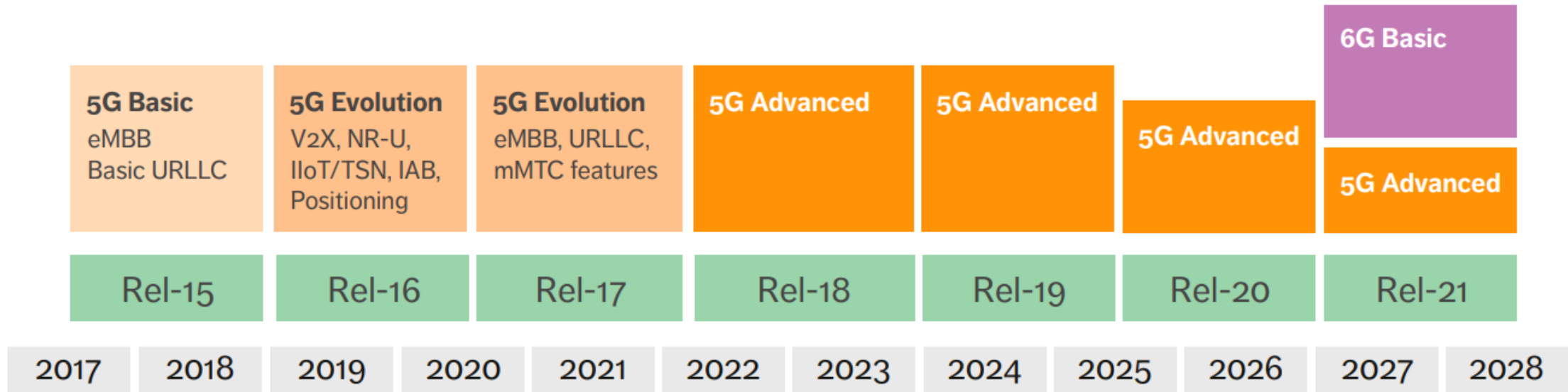


5G subscriptions are forecast to reach 6.3 billion by the end of 2030.

6.3bn



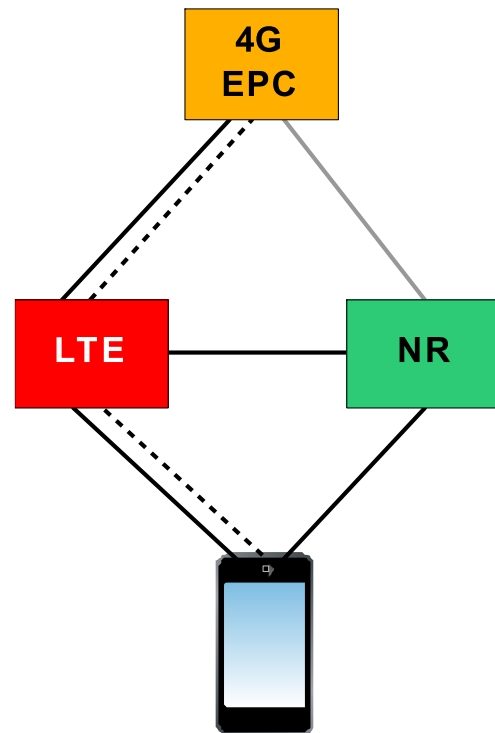
## 5G Roadmap



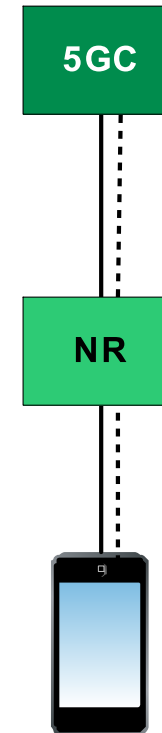
source: Ericsson.com: An overview of 3GPP releases 17 and 18.

# 5G NR Deployment Options

Option 3 (NSA)  
Non Standalone



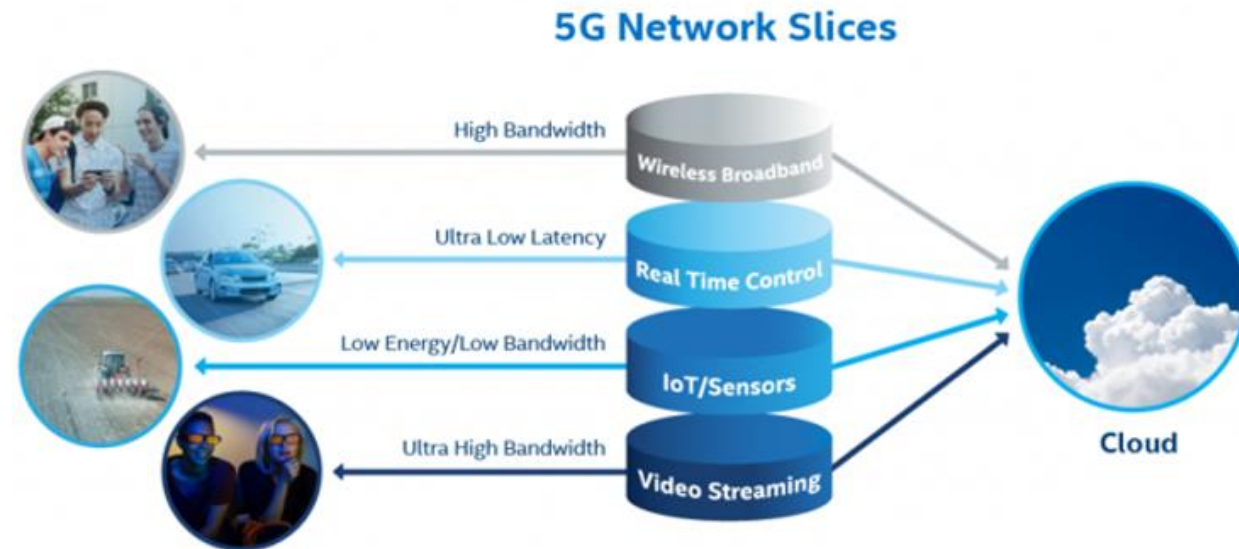
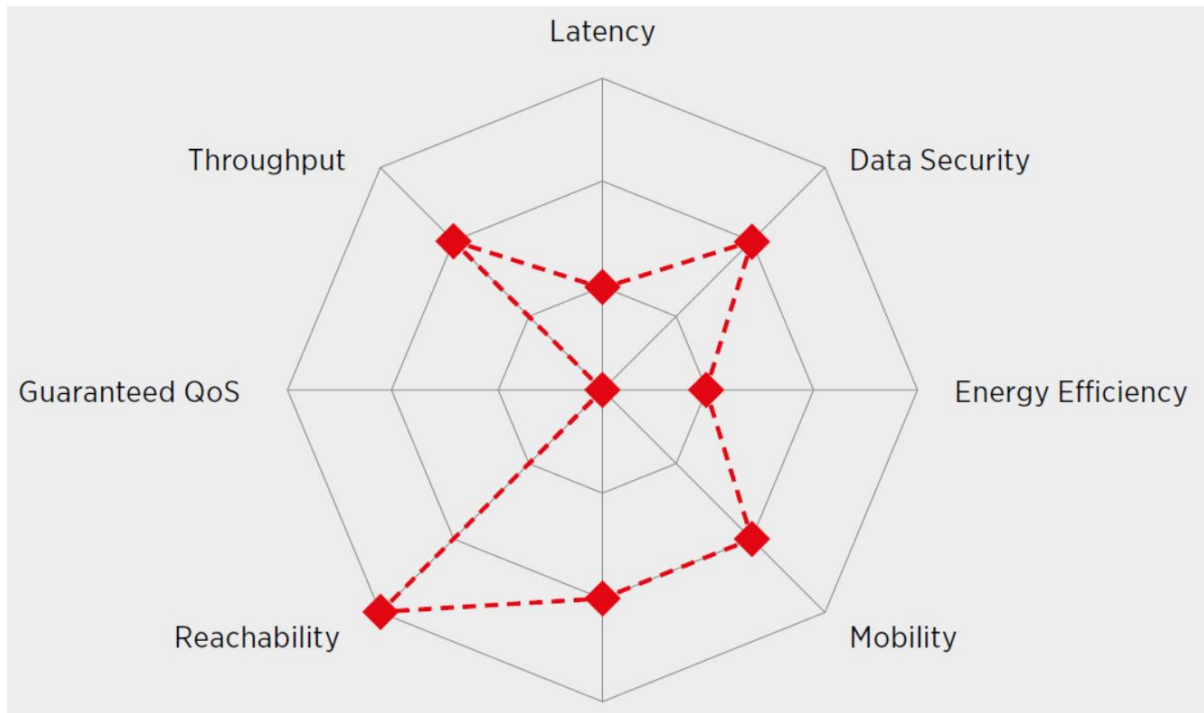
Option 2 (SA)  
Standalone



— 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



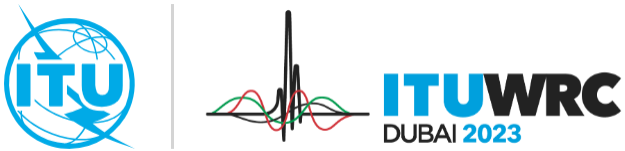
## 5G NR Bands in Czech Republic



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	 Direct to Device	 New Mobile Satellite
7 125-7 250 MHz		
7 750-8 400 MHz		
14.8-15.35 GHz		
	Mobile satellite in IMT bands between <b>694/698 MHz and 2.7 GHz</b>	<b>1 427-1 432 MHz</b> 1 645.5-1 646.5 MHz <b>1 880-1 920 MHz</b> 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]	$\Delta F_{\text{Global}}$ [kHz]	$F_{\text{REF-Offs}}$ [MHz]	$N_{\text{REF-Offs}}$	Range of $N_{\text{REF}}$
0 – 3000	5	0	0	0 – 599999
3000 – 24250	15	3000	600000	600000 – 2016666
24250 – 100000	60	24250.08	2016667	2016667 – 3279165

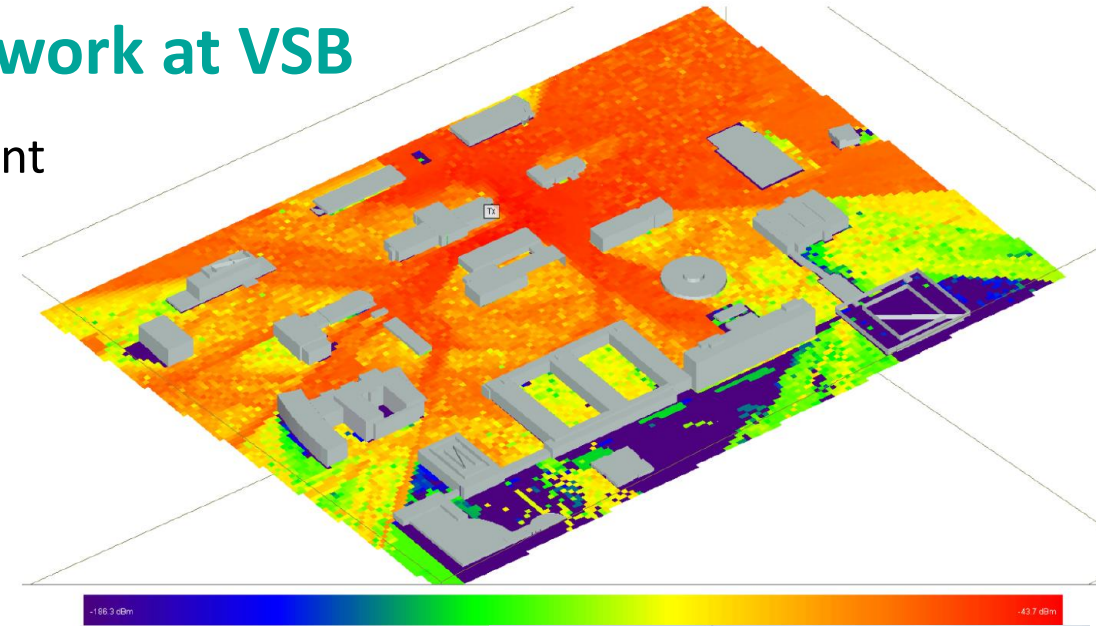
$$F_{\text{REF}} = F_{\text{REF-Offs}} + \Delta F_{\text{Global}} (N_{\text{REF}} - N_{\text{REF-Offs}})$$

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/>



activities

Autonomous  
Vehicle and  
Robotics  
Research

Telemedicine  
and Remote  
Health  
Monitoring

Industry 4.0  
Lab for Smart  
Manufacturing

Quantum Key  
Distribution  
and Edge  
Computing

Smart Security  
and  
Surveillance  
System



# 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“ provozovateli 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**

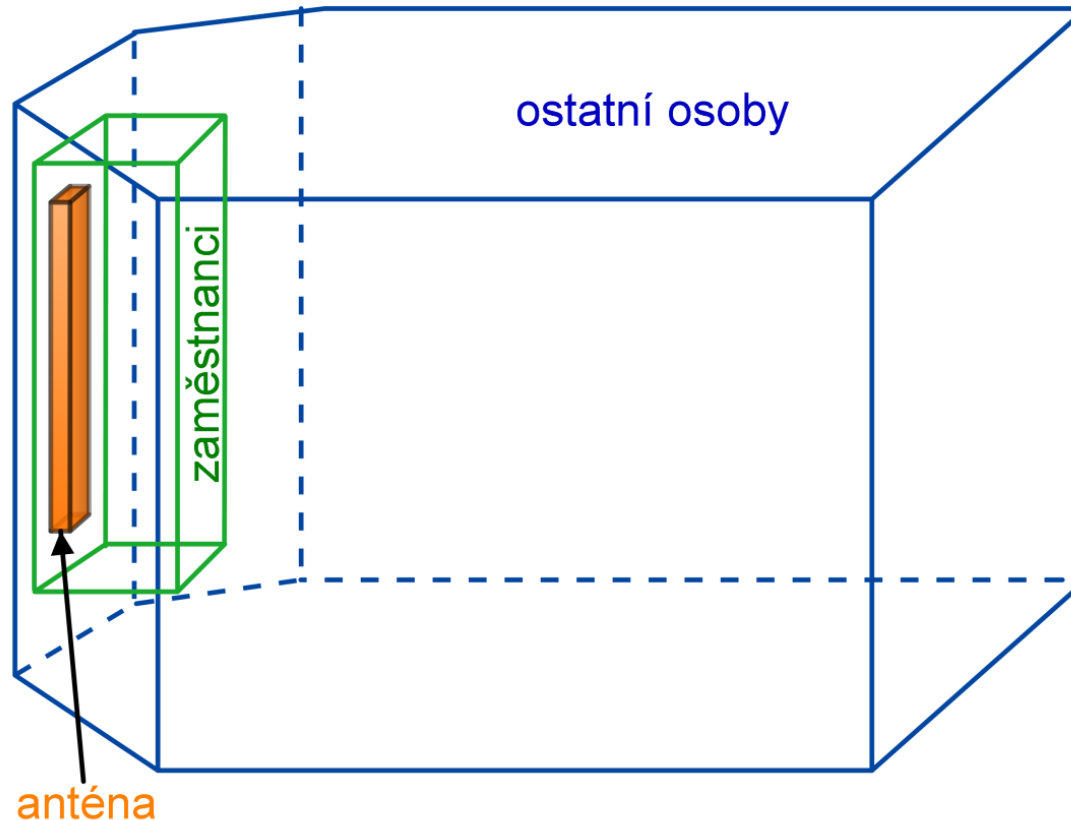
Intenzita elektrického pole $E^{\text{limit}}$ [V/m]		
Frekvence (f)	Fyzické osoby v kom.prostředí	Zaměstnanci
10 MHz - 400 MHz	$E = 28$	$E = 61$
400 MHz - 2 GHz	$E = 1,375 \cdot 10^{-3} \cdot f^{0,5}$	$E = 3 \cdot 10^{-3} \cdot f^{0,5}$
2 GHz - 300 GHz	$E = 61$	$E = 137$

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		S [W.m <sup>-2</sup> ]
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 sloupku	souřadnice X(m)	souřadnice Y(m)	operátor	pásmo (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 (°)	Multi-band 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



Thank you for your attention.