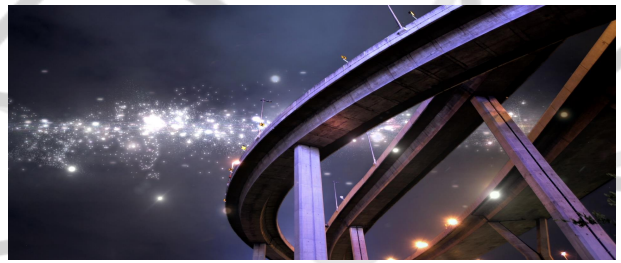
Communication Networks

VITMAB06

Mobile Networks 4G – 5G



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2024

TMiT

4G … 5G ON THE SUPERHIGHWAY

Based on slides of Paksy Patrik
Ericsson

2024

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- 4G/LTE – Data transmission
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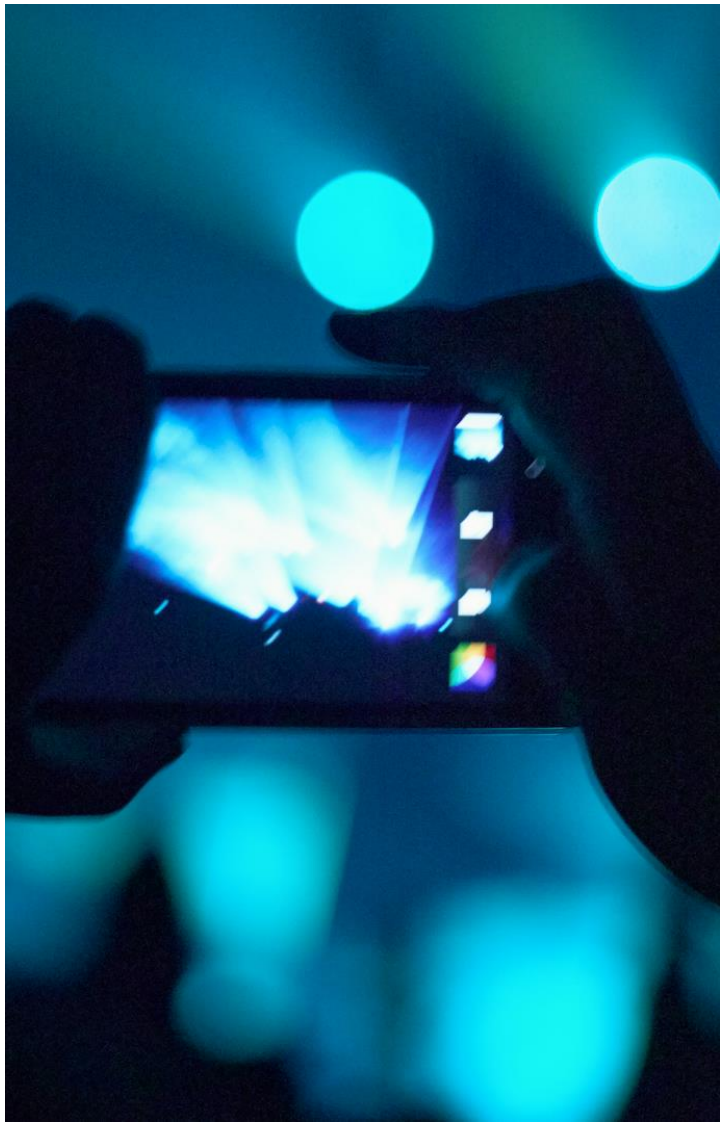
  - LTE/VoLTE carriers, QoS
  - “What happens when you turn on the phone? And when you make a call?
- VoWiFi – voice transmission over LTE with WiFi access
- Introduction to 5G - requirements, applications, architecture

Network evolution

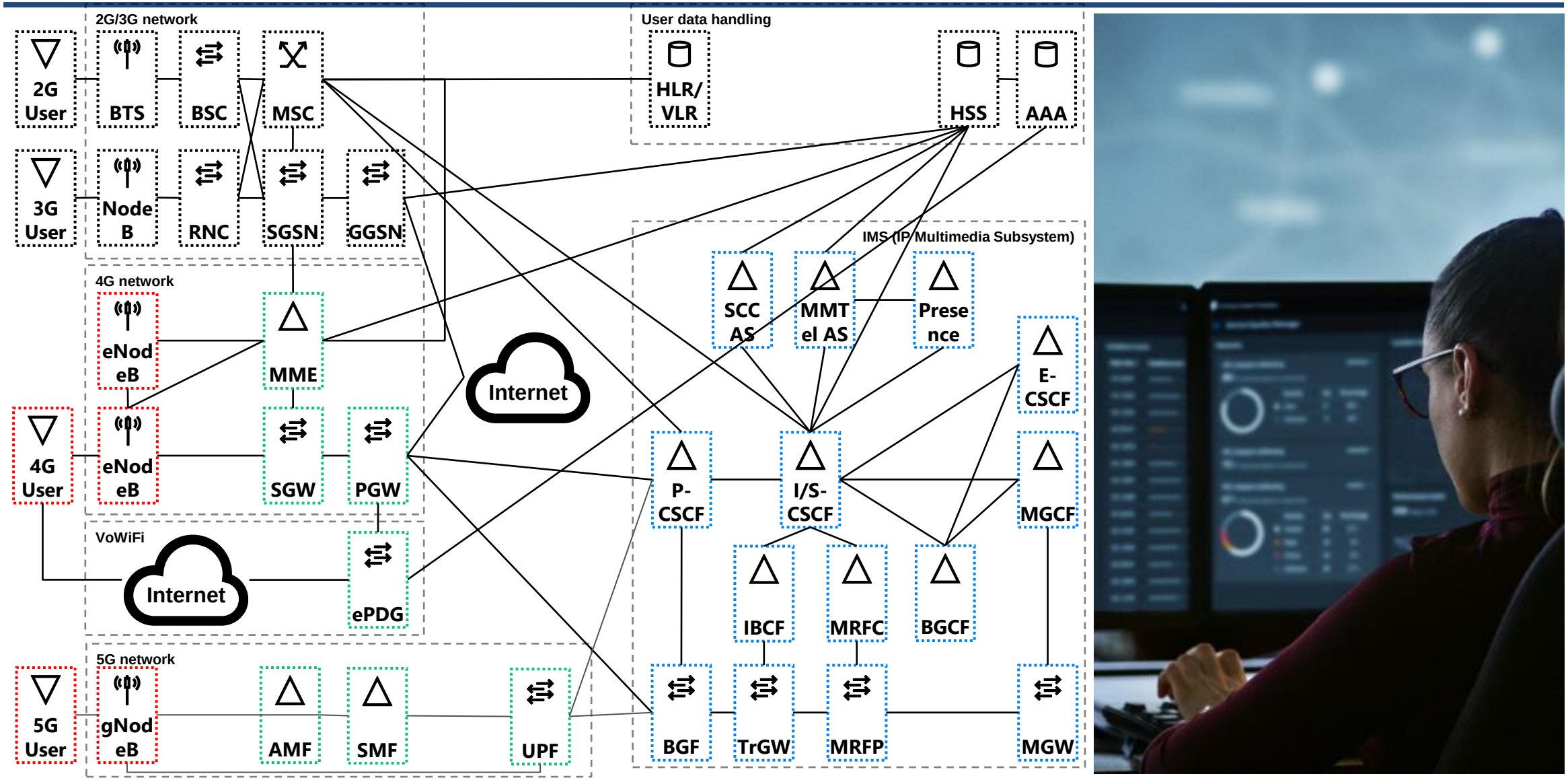
Just an overview, you only need to know the numbers in order of magnitude, and about the others only what is included in more details on other slides

Symbol	Standard	Full name	Theoretical max. download (DL)	Theoretical max. upload (UL)
2G	GSM	Global System for Mobile Communications	14.4 kbps	14.4 kbps
G	GPRS	General Packet Radio Service	53.6 kbps	26.8 kbps
E	EDGE	Enhanced Data Rates for GSM Evolution	217.6 kbps	108.8 kbps
3G	UMTS	Universal Mobile Telecommunications System	384 kbps	128 kbps
H	HSPA	High-Speed Packet Access	7.2 Mbps	3.6 Mbps
H+	HSPA+	HSPA Release 6	14.4 Mbps	5.76 Mbps
H+	HSPA+	HSPA Release 7	28 Mbps	11.5 Mbps
H+	HSPA+	HSPA Release 8	42.2 Mbps	11.5 Mbps
H+	HSPA+	HSPA Release 9	84.4 Mbps	11.5 Mbps
H+	HSPA+	HSPA Release 10	168.8 Mbps	23 Mbps
H+	HSPA+ Advanced	HSPA Release 11-12	336 Mbps	69 Mbps
4G	LTE	Long Term Evolution Release 8-9	100-300 Mbps	50-75 Mbps
4G+	LTE-A	LTE-Advanced Release 10	1 Gbps	500 Mbps
4G	WiMAX WiMAX 2	Worldwide Interoperability for Microwave Access	37 Mbps 350 Mbps	17 Mbps 200 Mbps
5G	5G	Release 15 <=	20 Gbps	10 Gbps



Complexity of the network

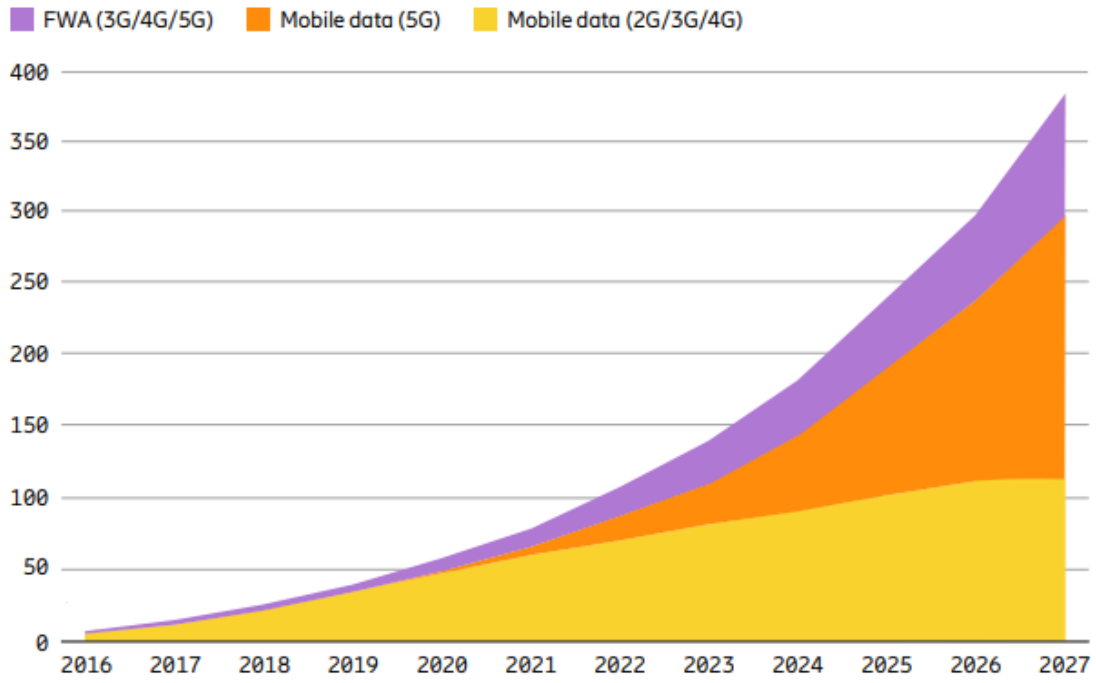
You need to know only what is on other slides is presented in details



Trends – „Mobility report"

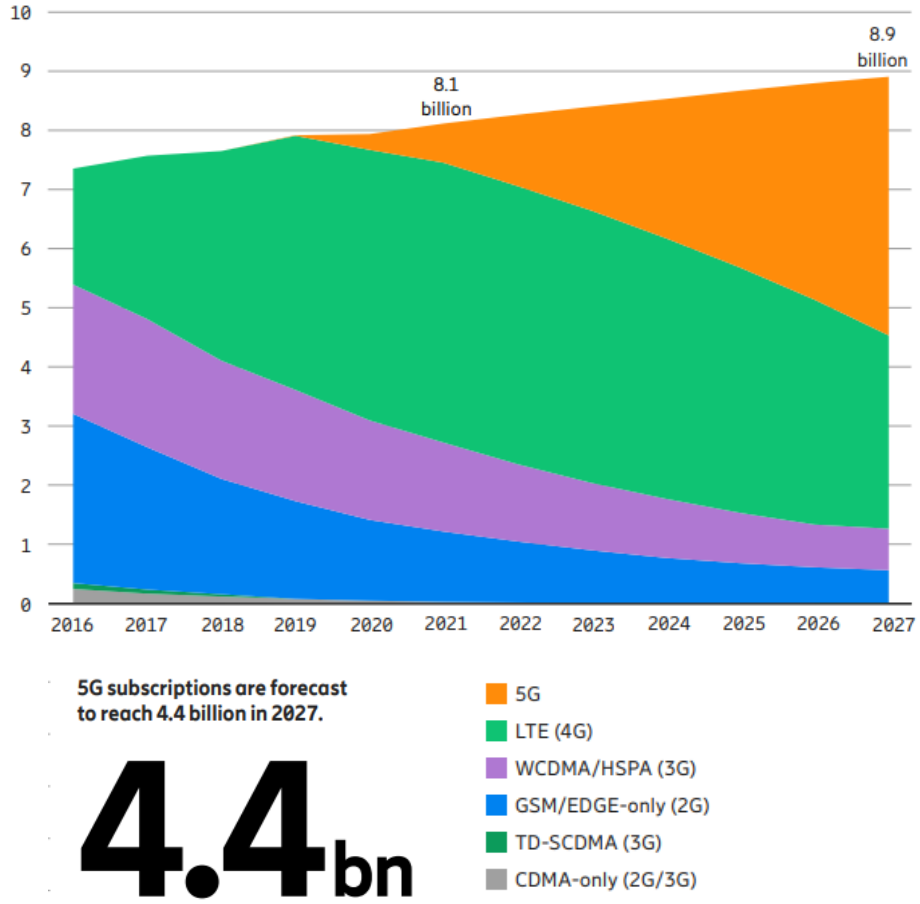
Not exam material

Figure 18: Global mobile network data traffic (EB per month)



1 EB (ExaByte) = 1000 PB = 1 000 000 TB

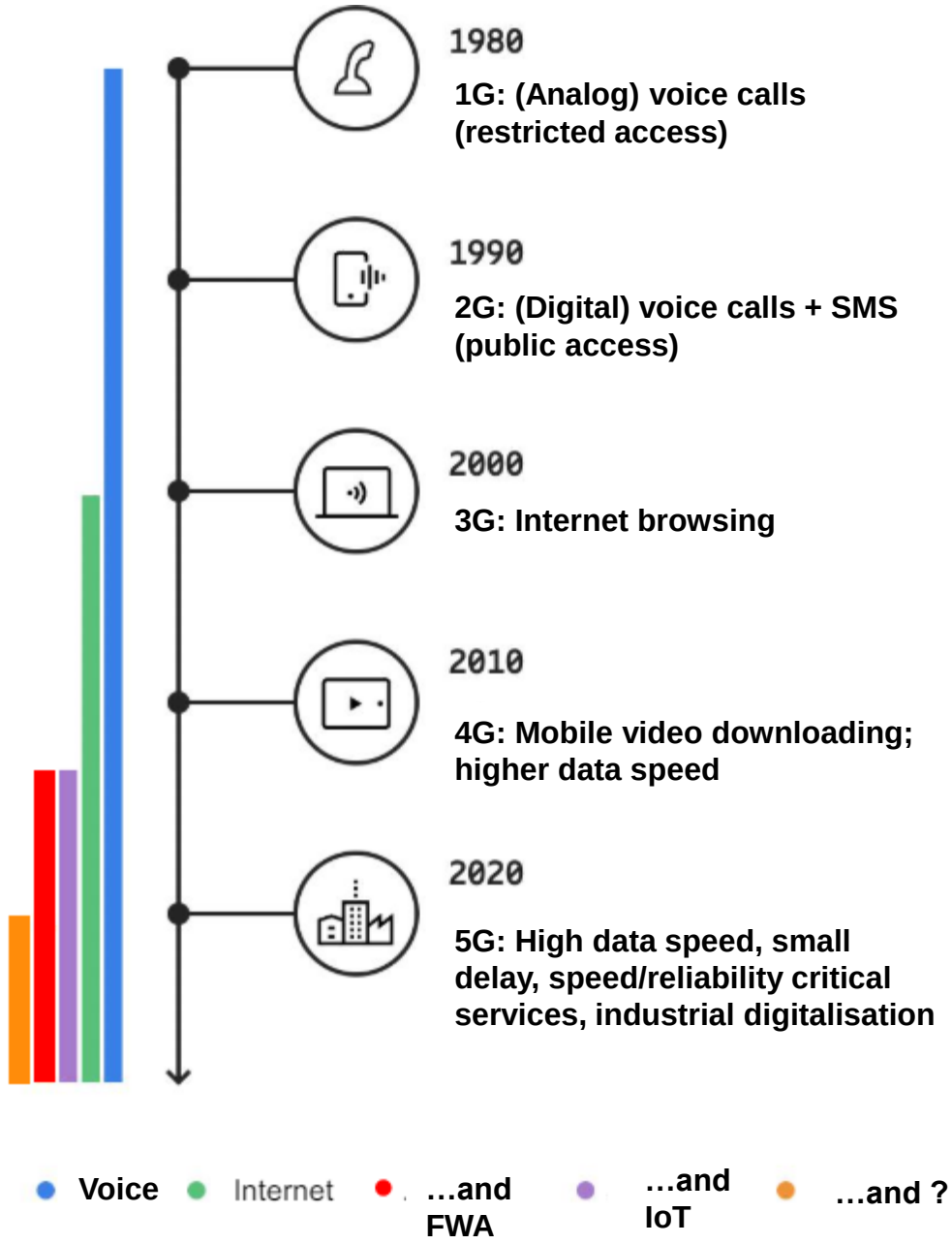
Figure 3: Mobile subscriptions by technology (billion)



https://www.ericsson.com/en/mobility-report/reports

4G – Motivation, demands

- Motivation
  - User demand
    - Faster mobile internet
    - Multimedia content, video download
  - Operators demand
    - New services (IoT – Internet of Things, FWA - Fixed Wireless Access)
    - Better service quality, serving more subscribers
    - More economical network operation
  - Manufacturers' demand: sale of new devices and services
- How to continue after 3G?
  - 3G network development
    - Minor changes, compatible
  - **New radio interface**
    - With what requirements?
    - LTE – Long Term Evolution (4G Internet service)
    - Voice transmission only later - VoLTE



4G / LTE requirements

- LTE = Long Term Evolution
  - For Internet only, voice transmission requires VoLTE (appearing later)
- ITU IMT (International Mobile Telecommunications) Advanced Standards - LTE requirements
  - "All-IP" packet-switched network (NO circuit switched subnetwork)
  - 100 Mbps for fast moving / 1 Gbps for non-moving users
  - 5-20 MHz scalable bandwidth
  - Spectral efficiency: 15 bit/s/Hz (DL) | 6.75 bit/s/Hz (UL)
  - Compatibility with previous (2G/3G) systems
- Basic properties
  - *Radio delay*: 5-10 ms
  - *Cells*: 1-5 km cell radius (1800-2500 MHz)
  - *Duplexity*: FDD LTE is more common, but TDD is also possible (mainly in Asia)
  - Used frequencies: 800, 1800, 2600 MHz

Let's count a bit:

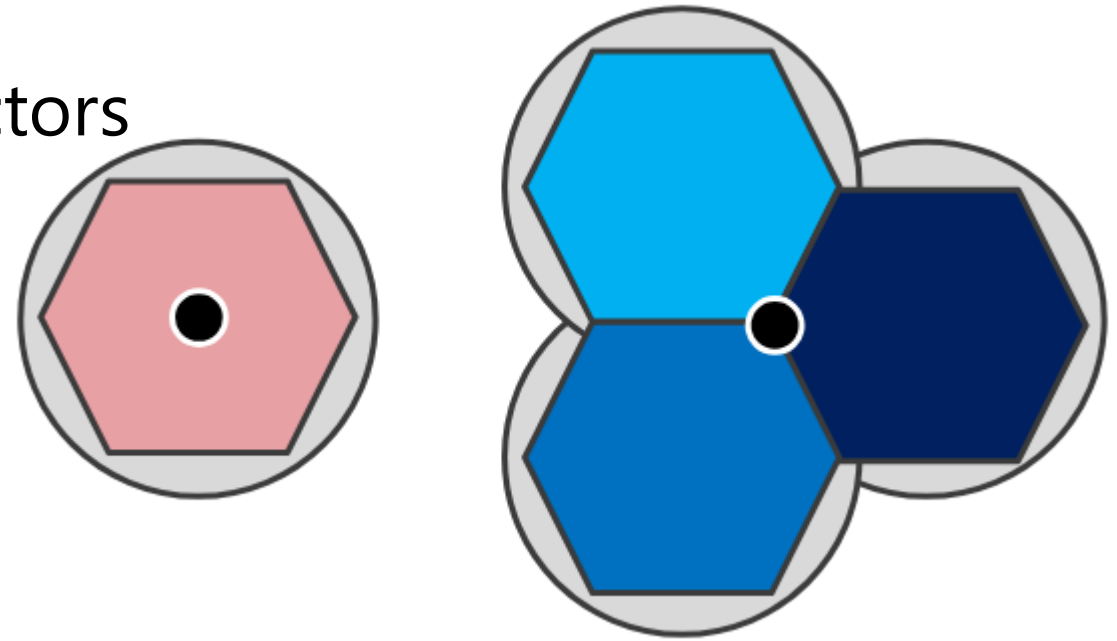
Max. bandwidth: 20 MHz
Required spectral efficiency: 15 bps/Hz

20 000 000 * 15 = 300 000 000 bps = 300 Mbps

How will it be 1Gbps???

Evolution of cellular principle

- Cell: area covered by one base station
- Sector: area covered by one antenna
  - Directed antennas
  - Typically, 1 base station 3-6 sectors
  - 3-6x increased capacity
  - More complicated frequency allocation design

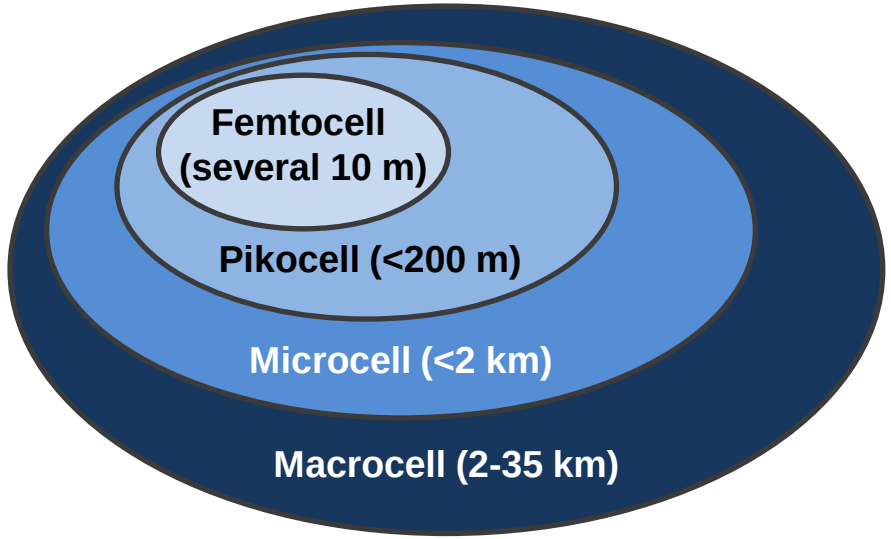


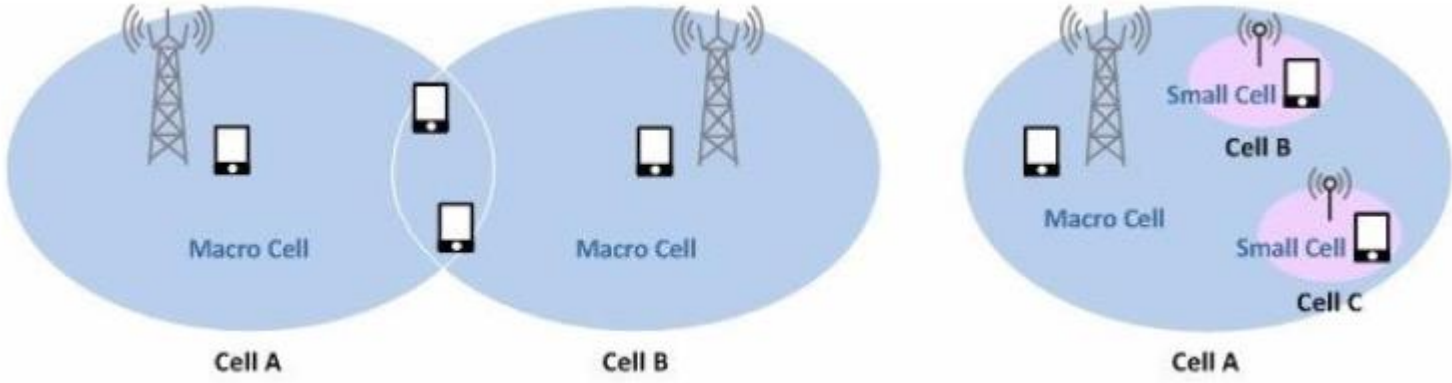
Circular (360º) radiation

Directed antennas (3 sectors 120º each)

Evolution of cellular principle

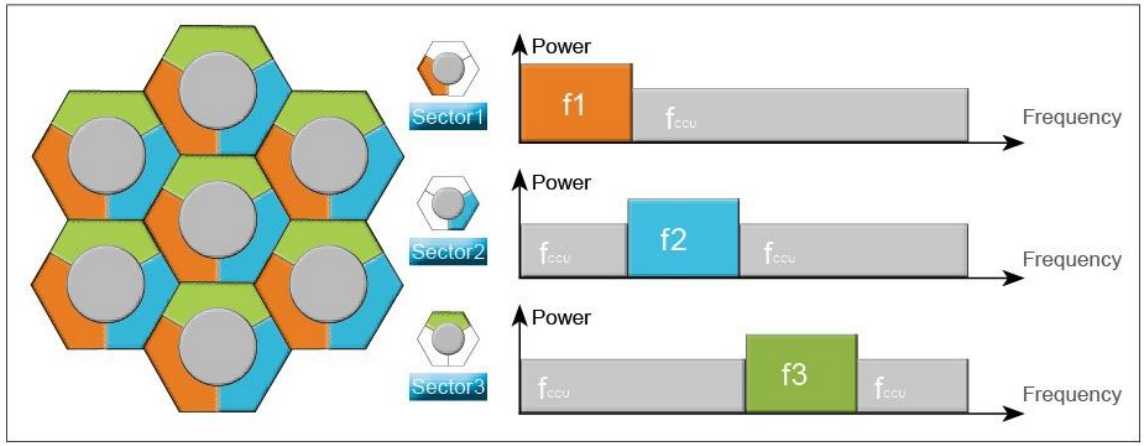
- „Small Cells"
  - Combining several different cell types
  - Overlapping cells / "cell in a cell" – interference may happen
  - Goal: better coverage, greater data speed
- Interference is more important
  - Smaller, denser cells
  - Cell in a cell
  - Larger data speed (smaller loss allowed)





Evolution of cellular principle

- Solutions for handling the interference
  - Different frequencies in different cells – 2G
    - Only a part of the frequency range can be used in a cell
  - ICIC: Inter-Cell Interference Coordination
    - Coordinated control of power and frequency
    - Whole bandwidth can be used in every cell
    - Close to base station with limited power
    - Cell boundaries are critical: here only a part of the spectrum – different than in the neighbours
  - eICIC: enhanced ICIC
    - Also time division in overlapping cells
    - Internal small cells and the container large cell can transmit in different time slots

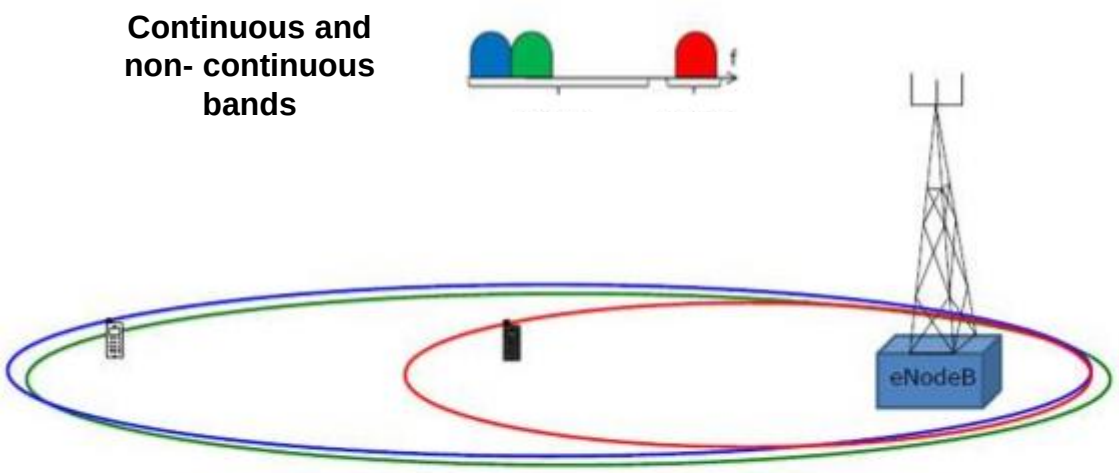


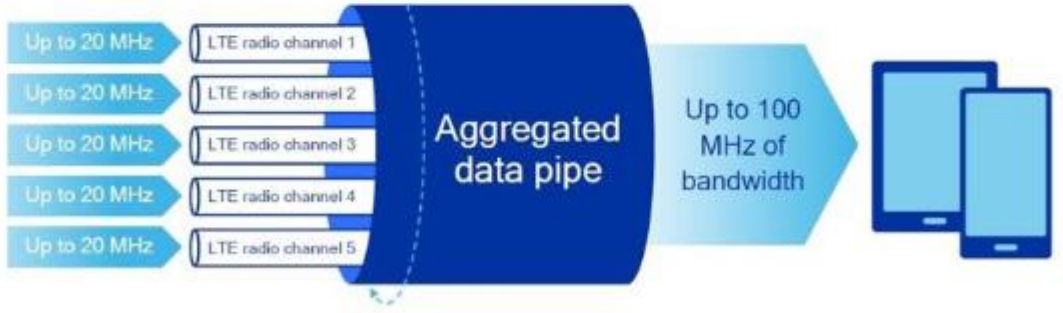
LTE – How can it be faster?

- Increase the efficiency of the modulation
  - Non-binary symbols
- Increase the bandwidth
  - But it's limited
  - Carrier Aggregation (CA)
- Transmit more data streams in parallel
  - More antennas
  - MIMO (Multiple In – Multiple Out) antennas

Carrier Aggregation (CA)

- Carrier: given frequency block or bandwidth on which data is transferred
- Aggregation: we transfer data at the same time on several carriers / frequency bands
- Prerequisite: subscriber is located in an area, where several cells of the same base station provide coverage with different frequency bands
  - e.g. 20+20 MHz from the 800 and 1800 bands
  - Max 32*20 = 640 MHz aggregate bandwidth
  - Can be continuous or non-continuous frequency aggregation of bands
  - Marked as 4G+





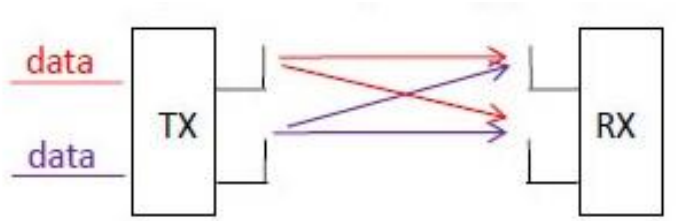
Carrier Aggregation example 5*20MHz bands

https://www.youtube.com/watch?v=SCbN1DgF60g

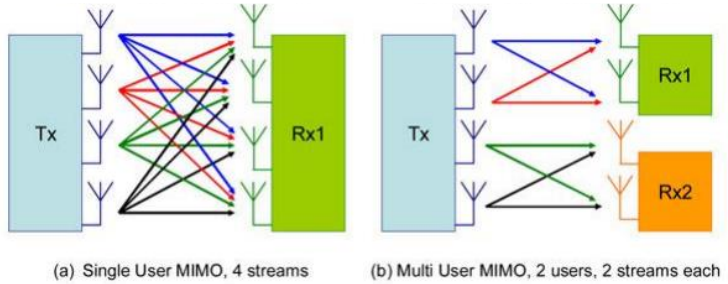
LTE – radio techniques

Used also at HSPA

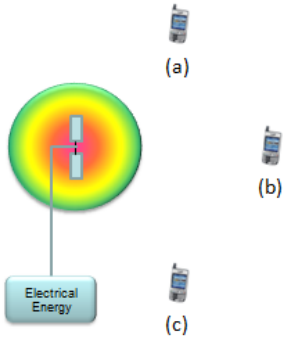
- **MIMO**: Multiple In, Multiple Out
  - More antennas in the base station and in the user devices as well
  - Purposes of use
    - Increasing **robustness** (transmission quality): same data stream on more antennas (spatial diversity)
    - Increasing **data speed**: different data streams in the same frequency and time (spatial multiplexing)
  - Massive MIMO: more than 8 antennas
  - MU-MIMO (Multi User MIMO): it serves more than one client at a time
- **Beamforming**: spatial multiplexing
  - A mobile client communicates its location to the base station, which broadcasts to it in a directed manner, controlling the phase and amplitude/signal level of the signal
    - Better signal level, better bandwidth utilization, greater range



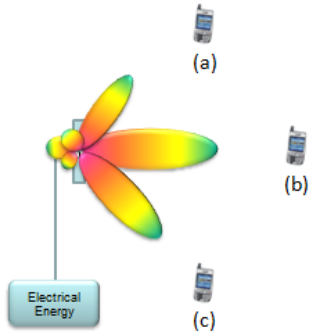
2x2 MIMO



(a) Single User MIMO, 4 streams (b) Multi User MIMO, 2 users, 2 streams each



< Case 1 >



< Case 2 >

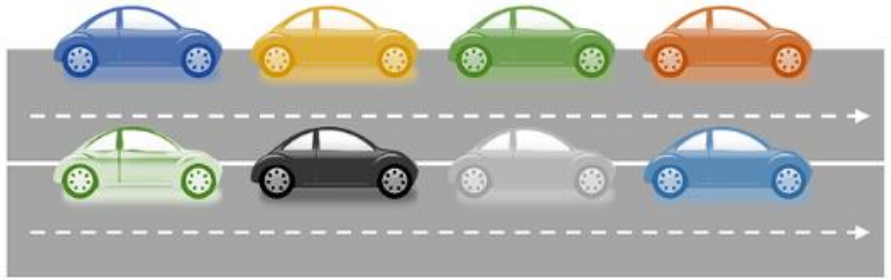
https://www.youtube.com/watch?v=xGkyZw98Tug

Carrier Aggregation and MIMO – simply

Single Lane with Standard Cars

Carrier Aggregation

Adding more lanes (Using more frequency bands)



MIMO

No space for new lanes (no more frequency band) -> build new lanes above the others

Goal of CA and MIMO is the same:
Carry different data streams in parallel, achieving larger speed

BUT the main difference:
CA: different frequencies, different cells,
MIMO same frequency, same cell

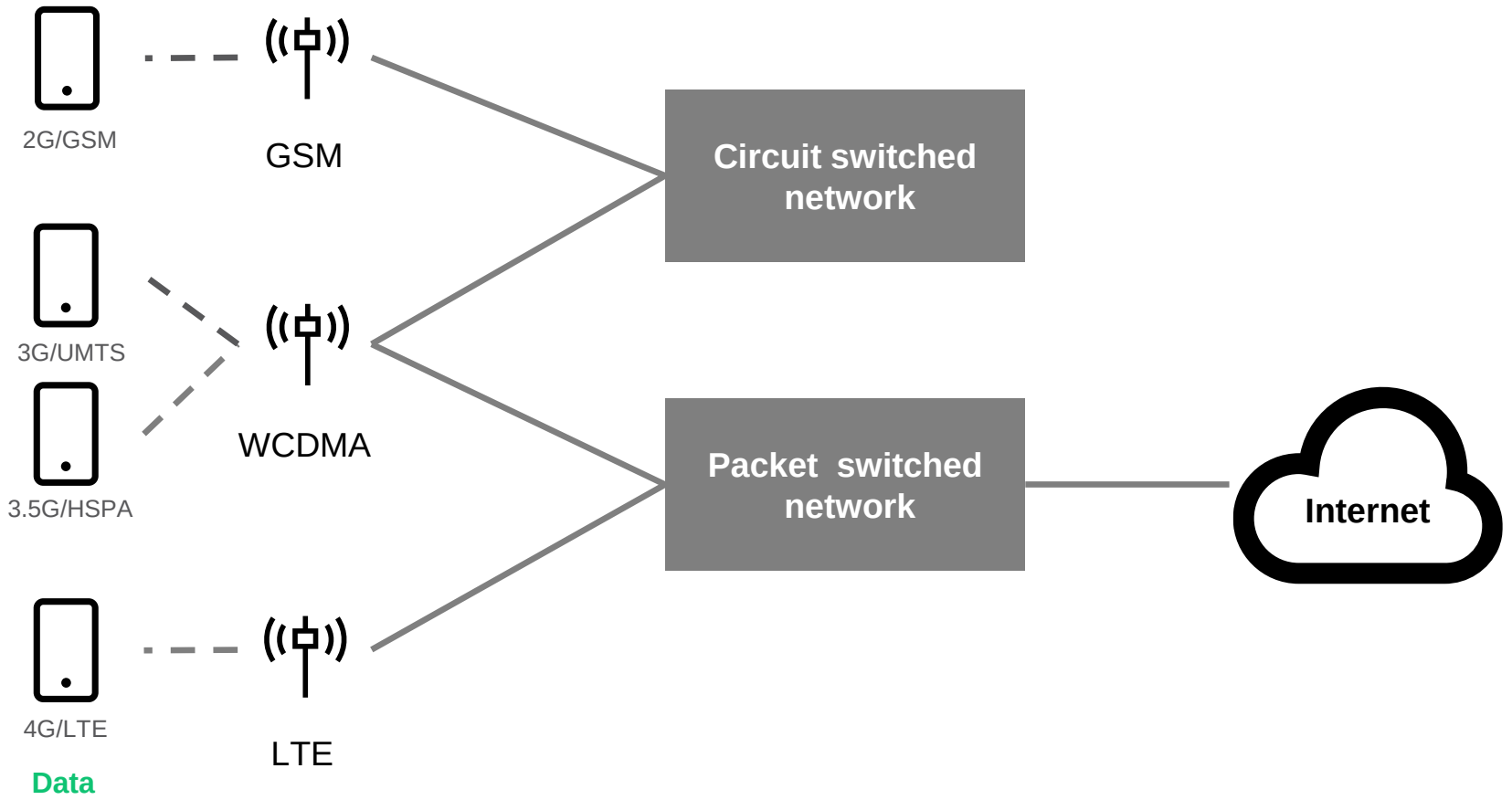
LTE evolution

Only the order of magnitude for data speed shall be known

3 main standards	LTE Release 8-9 2008-2009	LTE Advanced Release 10-12 2010-2014	LTE Advanced Pro Release 13 2016	Advantages
Max. dataspeed	DL 100-300 Mbps UL 50-75 Mbps	DL 1-3 Gbps UL 0.5-1.5 Gbps	DL 3 Gbps UL 1.5 Gbps	
MIMO & beamforming	4x4 MIMO + Beamforming	DL 8x8 MIMO UL 4x4 MIMO	Full-Dimension (3D) beamforming	Greater data speed Effective communication
Carrier aggregation	No (20 MHz)	Max 5 carriers (5*20 MHz)	Max 32 carriers (32*20 MHz)	Higher data speed Lower delay
Cells	Femtocell	SmallCells		Better coverage
Connections		VoWiFi		Less traffic on radio

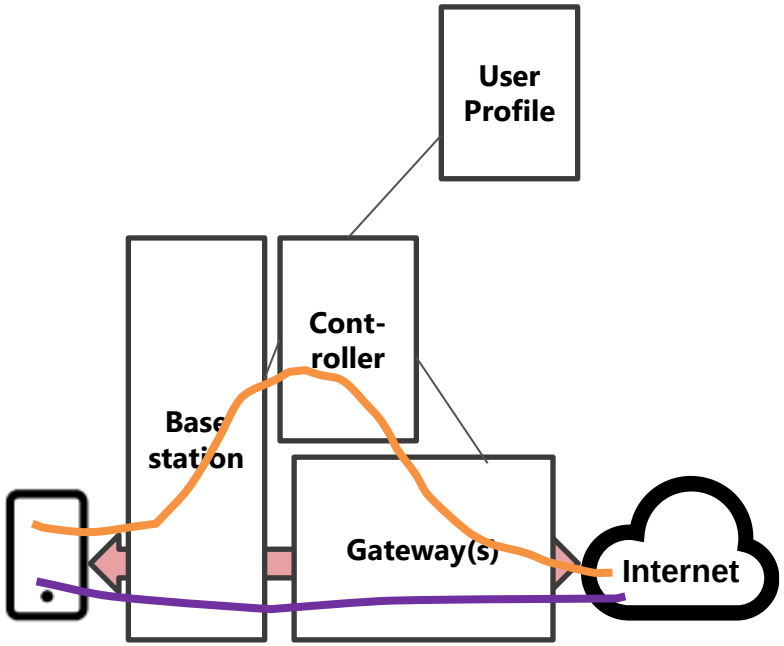
Other techniques also help to achieve higher data rates: 64-QAM modulation, variable bandwidth spectrum allocation
LTE Advanced is the first standard that fulfills all the previously mentioned requirements

LTE – architecture



LTE – architecture

- Functional units
- Control (signaling) flow
- Data flow



LTE – architecture

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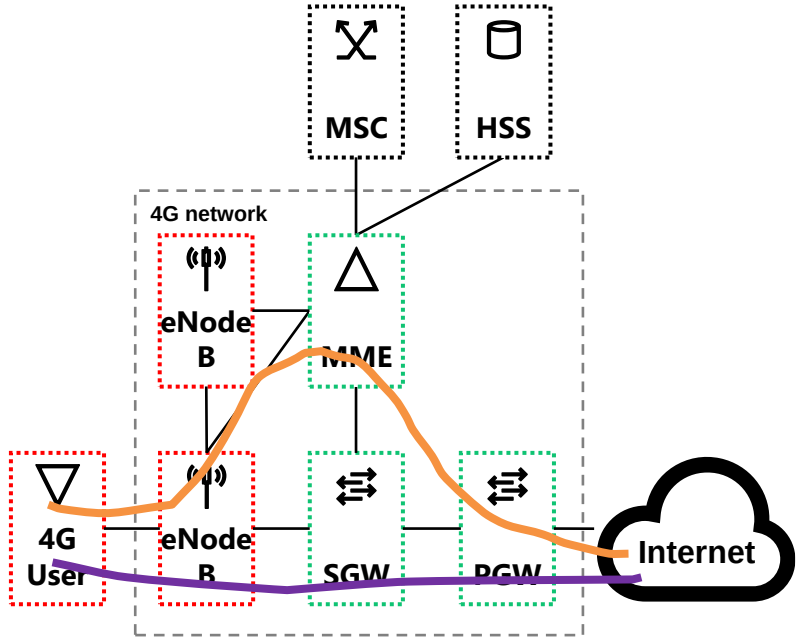
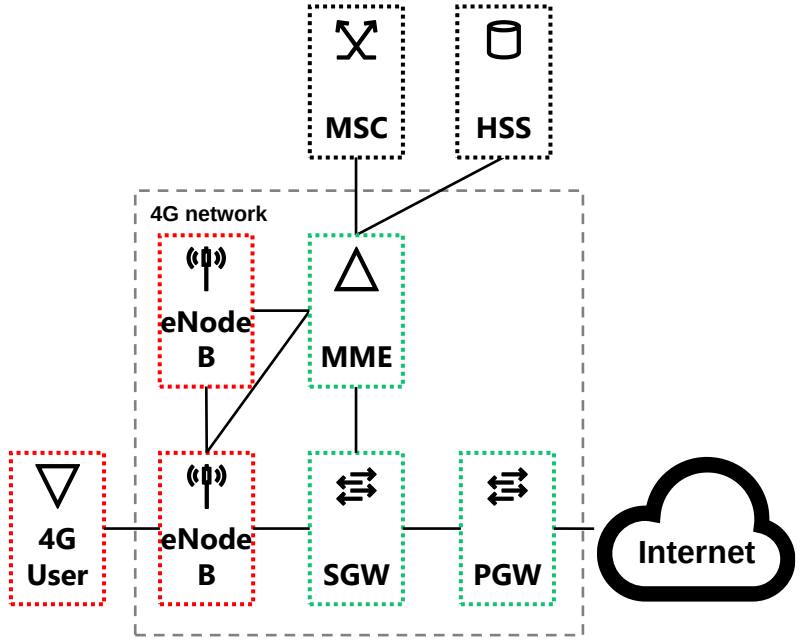


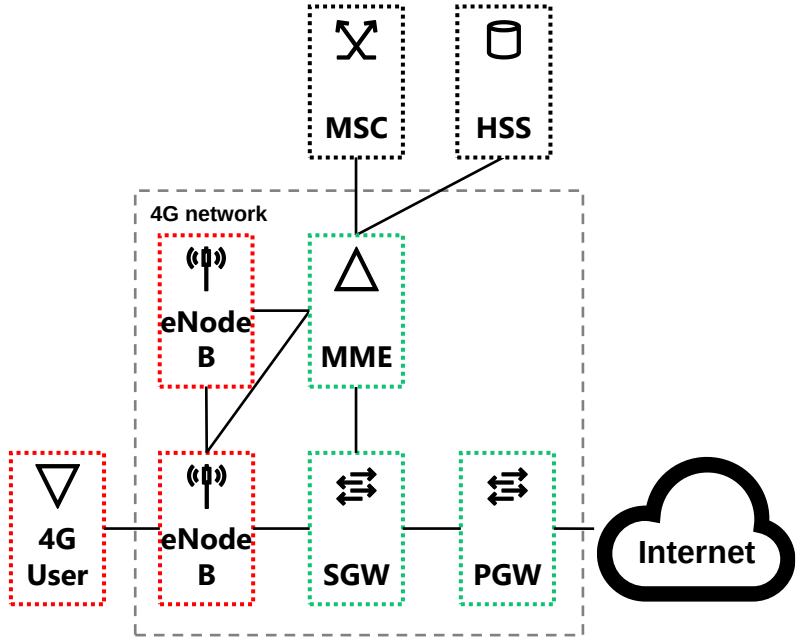
LTE – architecture

- **4G UE** – User Equipment
  - Transmits/Receives Data
    - **LTE is ONLY for Data Transmission!**
  - Radio communication
    - Searches cell
    - Connects to base station(s)
    - Establishes radio connection(s), etc.
- **eNodeB** – LTE base station
  - Evolved NodeB
  - No standalone Controller
    (In 2G/3G dedicated controllers: BSC/RNC)
    - Part of eNodeB → smaller delay
- **MME** (Mobility Management Entity)
  - User tracking and paging (waking up UE from "idle" mode)
  - It only handles control messages, a central control function in LTE
  - Mobility management
  - Bearer activation
  - SGW choice
  - Authentication handling (HSS)

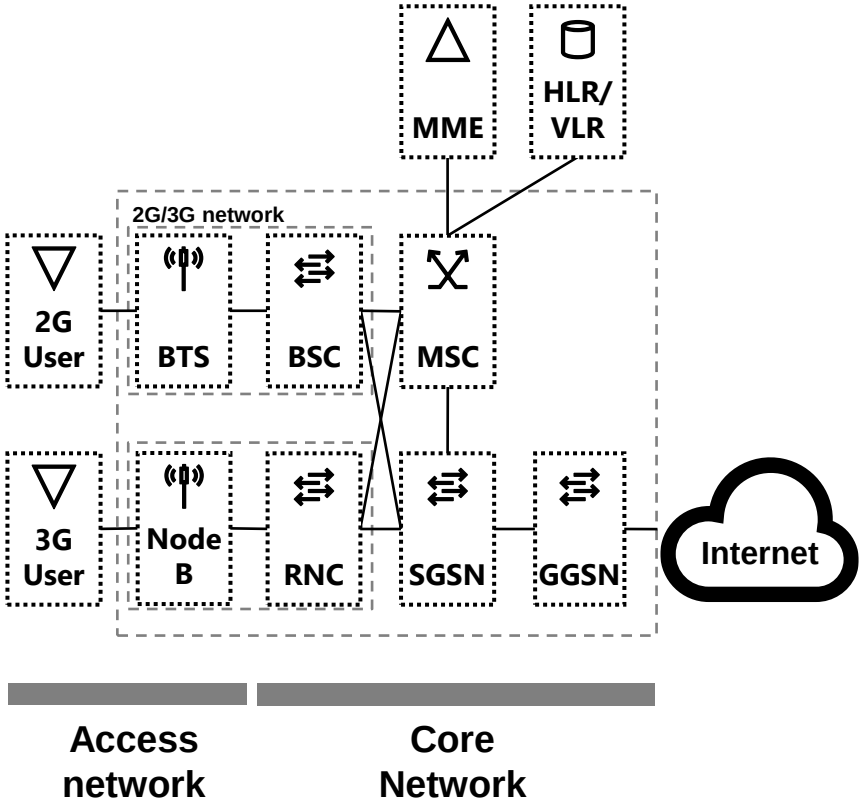


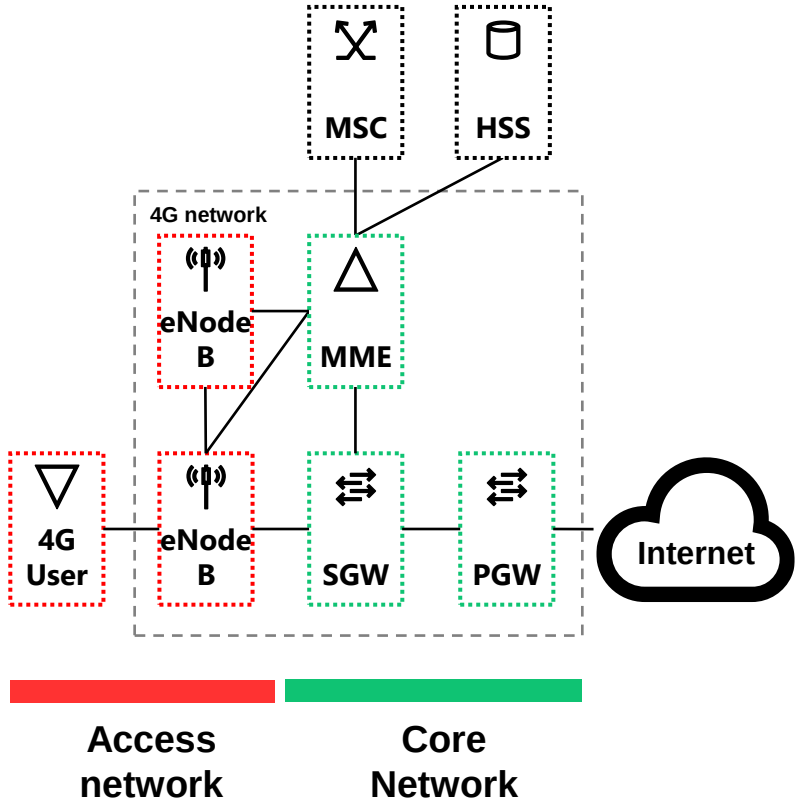
LTE – architecture

- **HSS** (Home Subscriber Server)
  - User data (identifiers, services, limits, authentication data)
  - HLR + AuC
- **SGW** (Serving Gateway)
  - IP data transmission between user (eNodeB) and PGW (external data network)
  - Have role also in mobility management and roaming
- **PGW** (Packet Gateway)
  - Gateway to external PDNs
  - IP address allocation
  - Policy application/packet filtering
  - Supports pricing
  - Deep packet inspection (lawful interception)



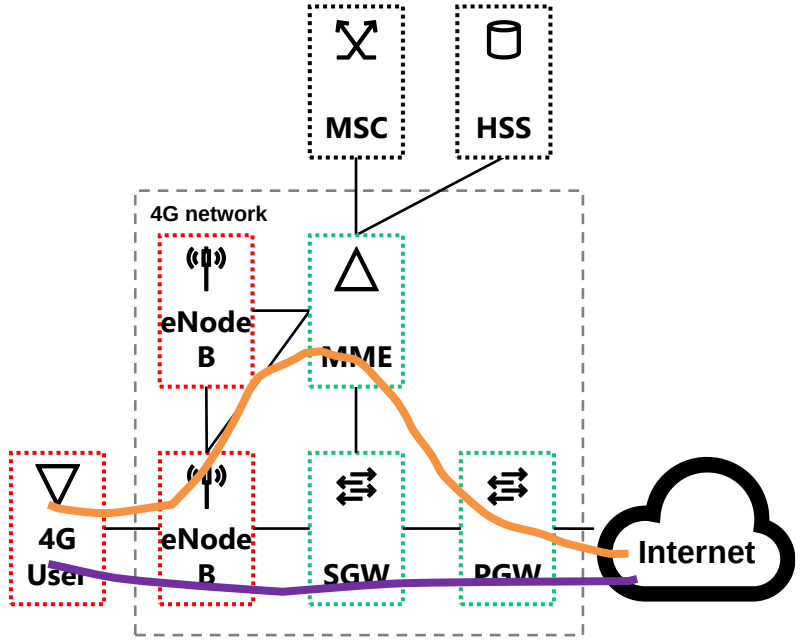
2G/3G vs. 4G architecture





LTE – Control Plane / User plane

- Control Plane
  - Route of message exchange: 4G User – eNodeB – MME – SGW – PGW
  - Orange path
- User (Data) Plane
  - Route of message exchange: 4G User – eNodeB – SGW – PGW – External data network (e.g. Internet)
  - Purple path

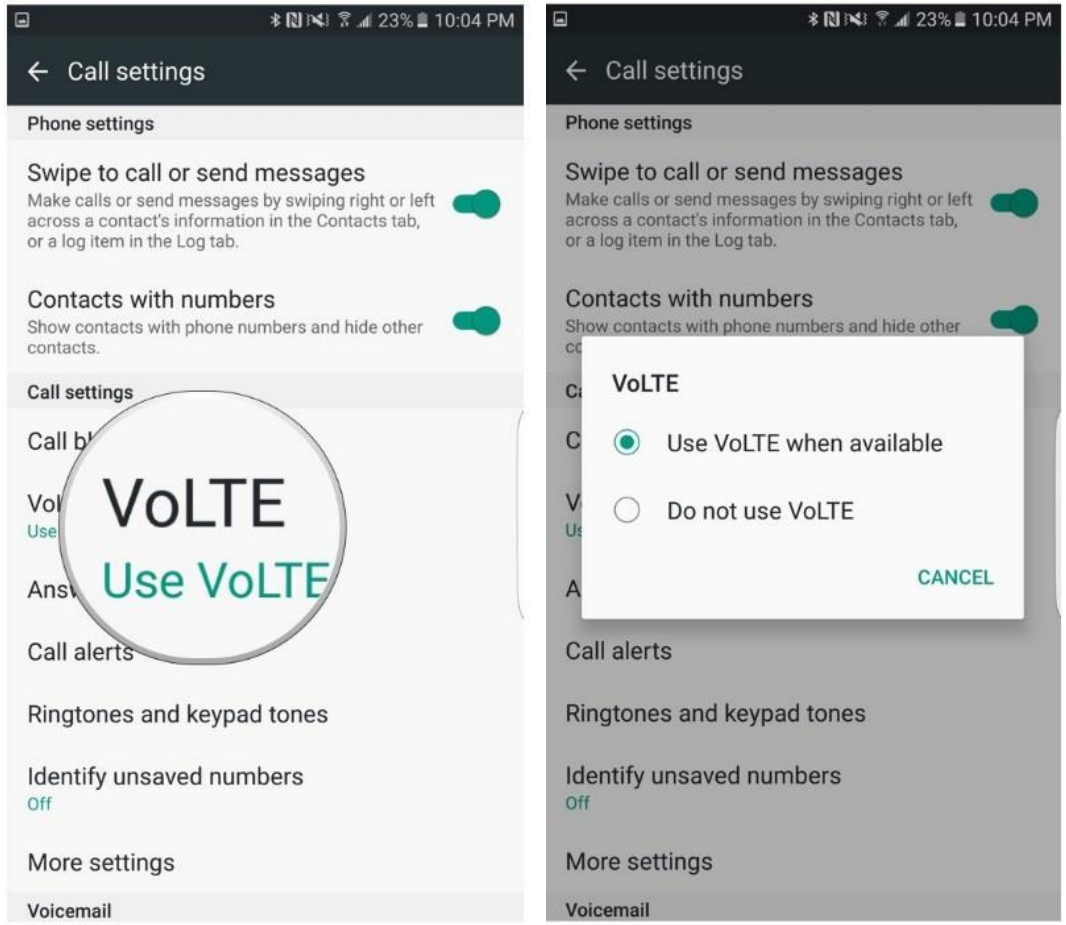


VoLTE – Voice over LTE

- Operators' demand
  - Possibility of voice calls in 4G
    - Voice calls still represent a large share of revenue
- Voice over LTE (VoLTE)
  - Goals:
    - Better quality voice transmission
      - HD Voice (AMR-WB), smaller delay,
      - Voice and internet at the same time
        - » Without VoLTE in LTE if you wanted to make a voice call, fallback to 2G/3G
    - Energy efficiency, better capacity utilization
    - More economical network operation
      - New operators may consider an LTE-based solution only
- VoIP vs VoLTE
  - VoLTE = VoIP?
    - IP based voice transmission, but with guaranteed quality!

VoLTE – prerequisites for use

- Network support
- Special device, chipset
  - Maintaining 2 connections (internet + IMS)
  - Support of media codec
- Availability of VoLTE function
  - SW upgrade
    (e.g.: Samsung Galaxy S5 – June 2014)
  - OS: Android 5+, iOS 8+
- Phone settings

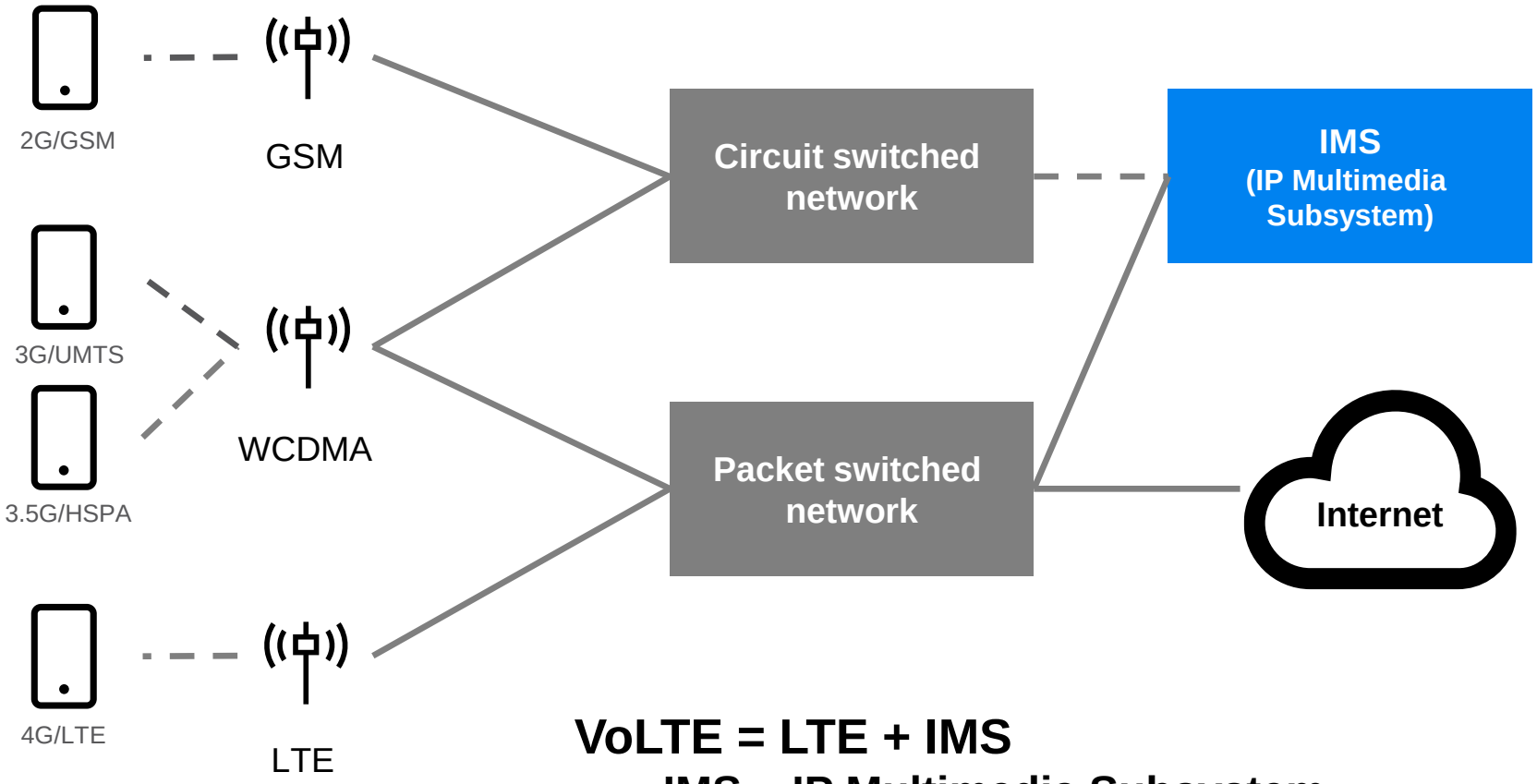


VoLTE – milestones

Not an exam material!

- 2009: IMS-based VoLTE solution proposal (OneVoice – 12 companies)
- 2010 Feb – Sept: GSMA standardisation
- 8 Feb 2011: The world's first VoLTE call (Verizon)
- 2012: first commercial network (SK Telecom)
- In Hungary
  - Testing since first half of 2016: Telenor, then Telekom
  - Introduction
    - Apr 2017 – Telekom
    - Jan 2019 – Telenor
    - Apr 2019 – Vodafone
    - June 2019 - Digi

VoLTE – architecture



VoLTE = LTE + IMS

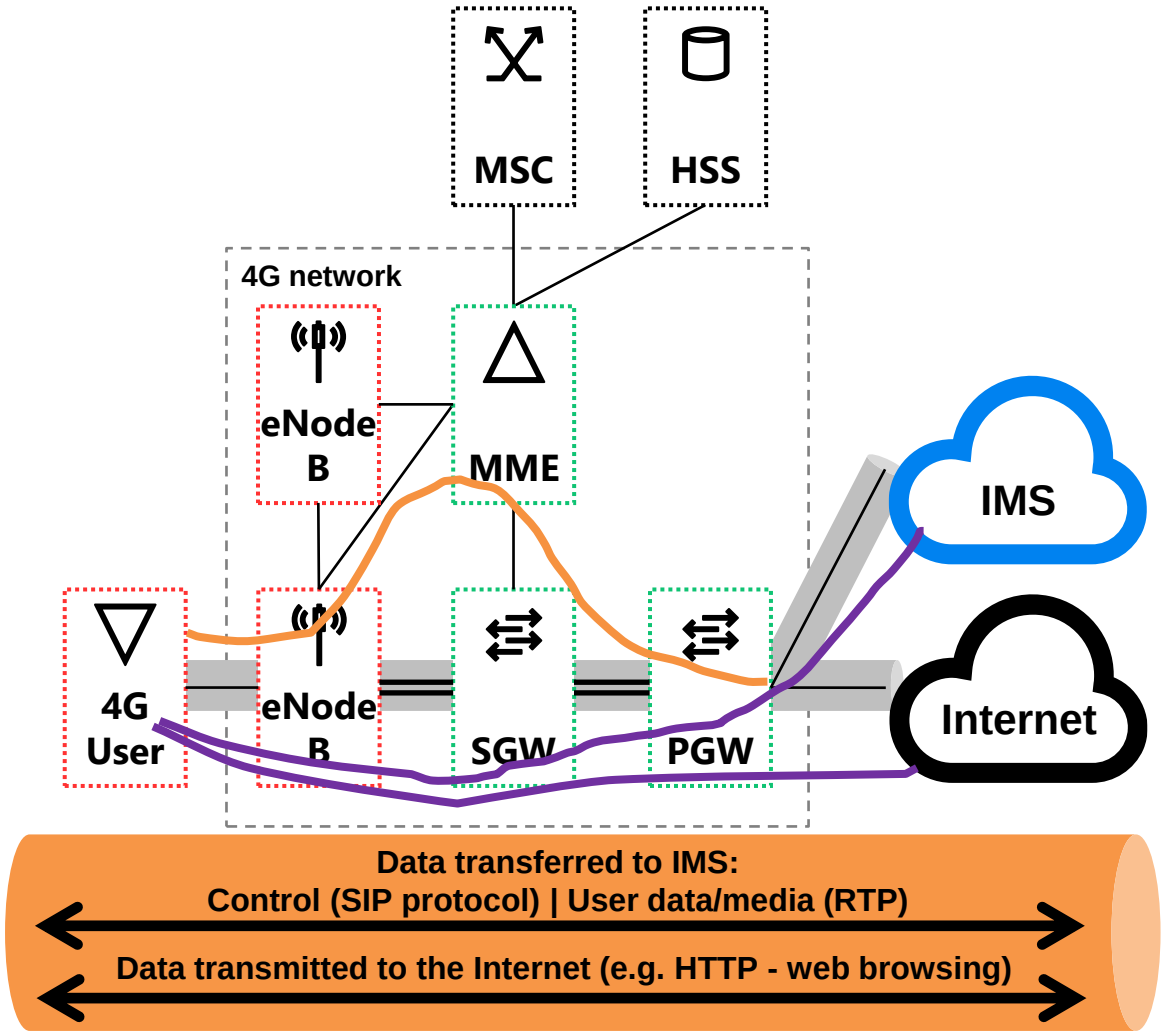
IMS = IP Multimedia Subsystem

Application and connection controller / set of media servers (network functions)

IMS – the only standard multimedia service for LTE

VoLTE – architecture

- Connections to different endpoints (Internet/IMS)
  - Must be told to which
  - APN: Access Point Name (e.g. Internet, IMS, etc.)
- The core network only terminates and transmits data transparently



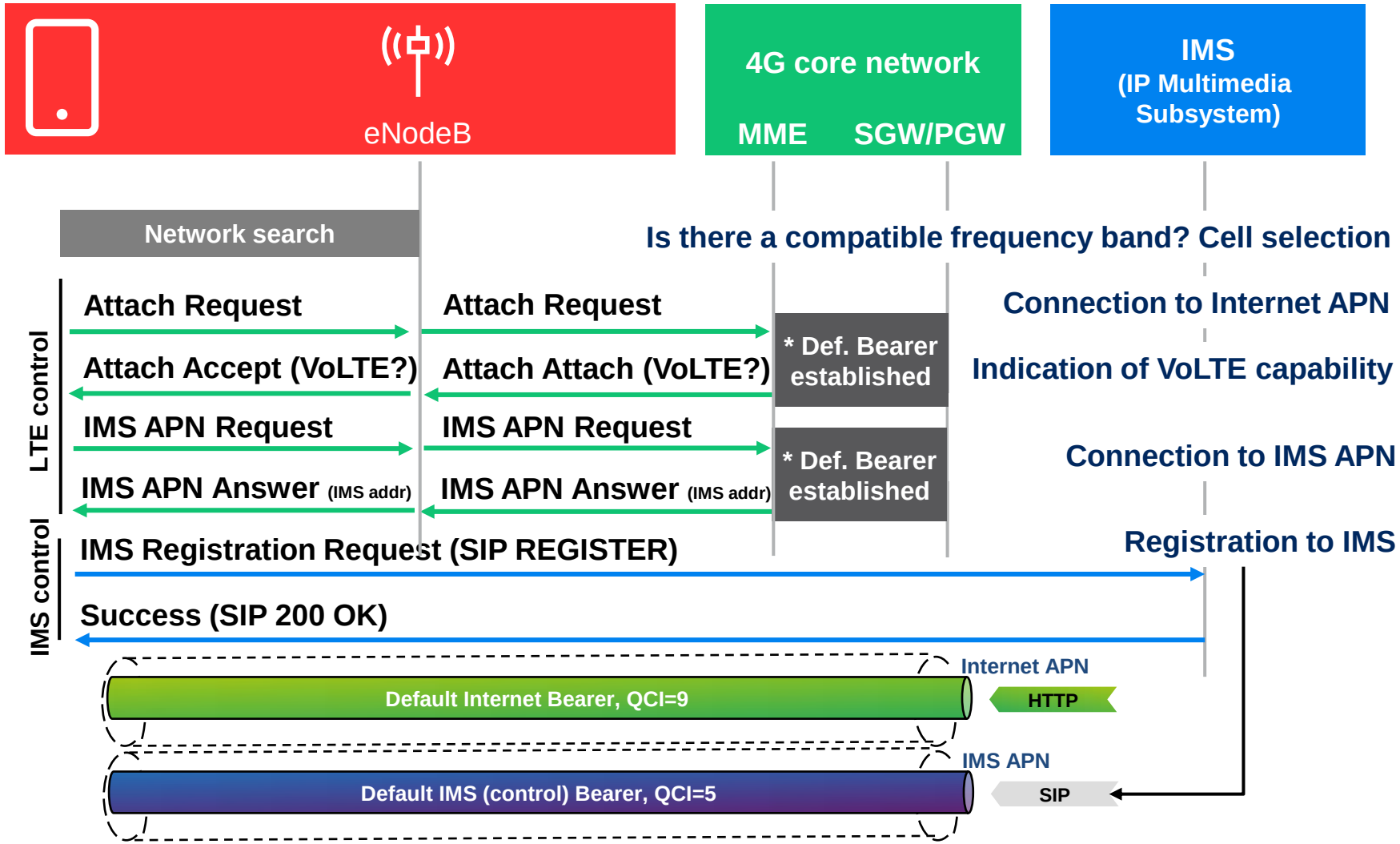
VoLTE – LTE bearers

- How does a packet get from the user to the external (Internet/IMS) network?
  - Radio interface + resources reserved in core network → a so-called bearer is reserved
- Bearer
  - User (Data) plane connection between a user equipment (UE) and PGW
  - Toward a given endpoint / service
    - APN: Access Point Name
- QoS
  - Different services require very different type of bearers (resources)
    - 9 QoS classes defined with given parameters (packet loss, delay)
      - QCI = QoS Class Identifier: 1-9

VoLTE – LTE bearers

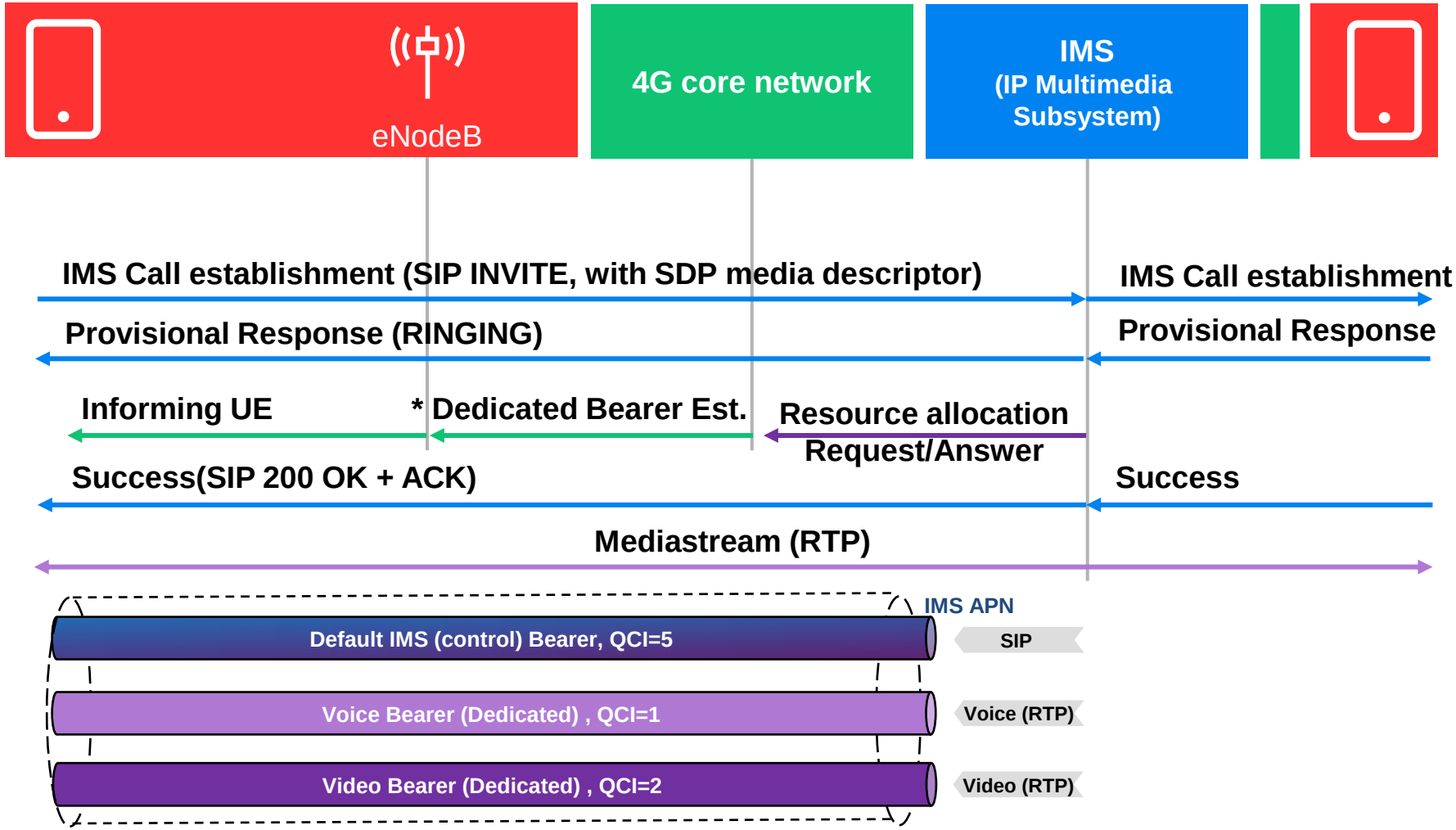
- 2 Bearer types
  - Default – QoS not guaranteed – "best effort" (QCI 5-9)
    - Established during the connection to the network (Attach procedure)
    - Maintained till disconnecting from the network (Detach procedure)
    - Several can be created for different services
      - In LTE: one default bearer to Internet APN
        - » For browsing it is enough
      - In VoLTE: one default bearer to Internet APN and another to IMS (for control – SIP)
  - Dedicated – guaranteed QoS (QCI 1-4)
    - Established temporarily e.g. to an audio or video call
      - Will be released at the end of a call
    - Always connected to a Default Bearer
      - E.g. Dedicated default bearer to the IMS APN for a VoLTE call
- UE and PGW enforce QoS
  - Prioritization, bandwidth/traffic control
    - In case of congestion dropping packets
    - Based on Source/Destination IP address and port + protocol
    - First from "best effort" services

VoLTE – Connecting to the network



* Reminder: Bearer: Between UE-PGW, Radio + User Plane connection

VoLTE – Call establishment



* Reminder: Bearer: Between UE-PGW, Radio + User Plane connection

VoWiFi

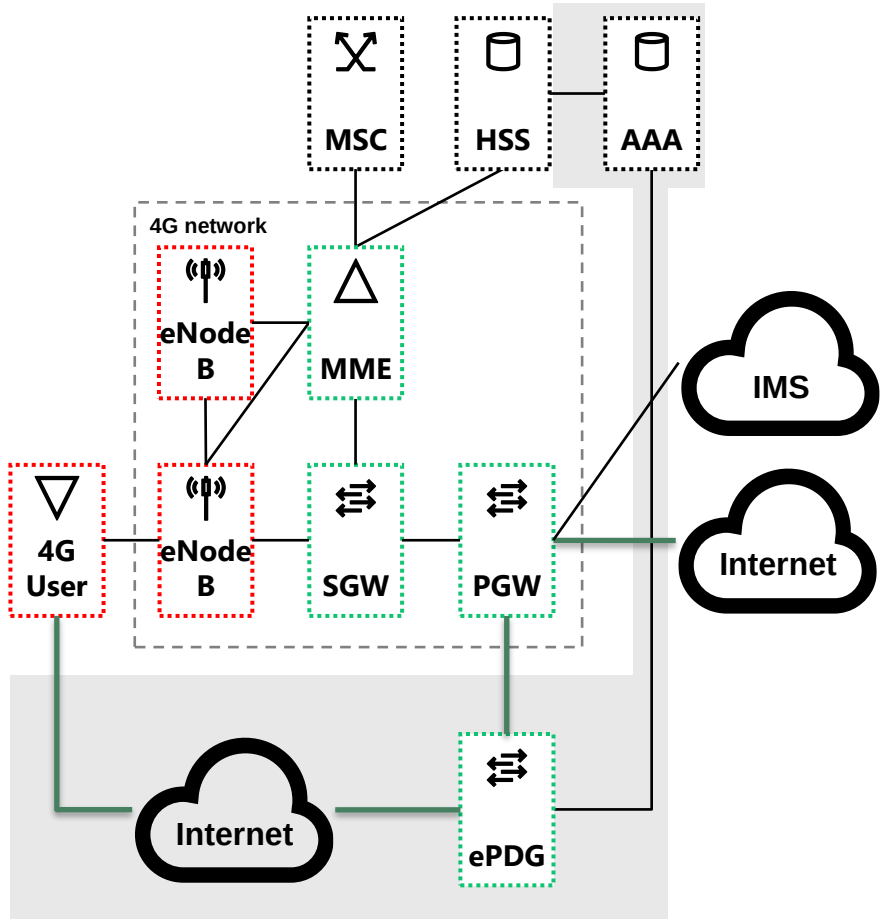
- Motivation
  - Indoor coverage at home – VoLTE call may be problematic → coverage extension
  - **Reduce the usage of 4G cells and frequencies**
- VoWiFi (Voice over WiFi)
  - Mobile voice service via WiFi access
    - Existing infrastructure (WiFi devices)
  - Prerequisites:
    - Network shall support it – but roaming is not always supported
    - Phone shall support it, SW upgrade may be needed, service shall be switched on
  - Introduced as an additional service to VoLTE

VoWiFi

- Advantages
  - No additional application is required
  - Using the existing phone number
  - Call origination
    - 2G/3G/VoLTE/WiFi the same – user cannot even recognize
  - During the call
    - Call continuity – LTE-WiFi or WiFi-WiFi handover
  - Billing is the same as in VoLTE
    - Access-independent service
  - No roaming fee (if roaming supported)
- Trusted / Untrusted
  - Trusted: the same operator provides mobile and WiFi services
    - No separate identification is required, similar to the 3GPP network
  - Untrusted: usage of any WiFi access point
    - Plus authentication and a secure connection are required

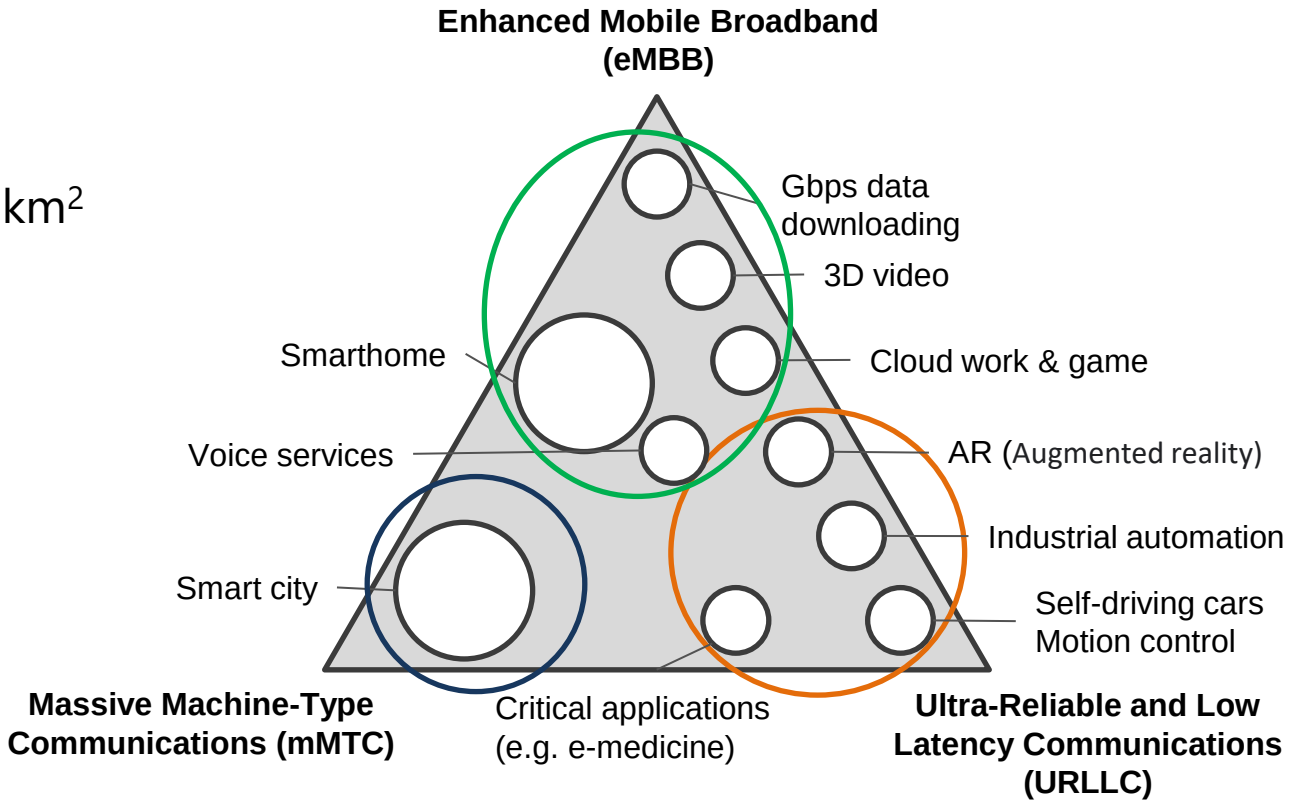
VoWiFi – architecture („untrusted")

- Why is there no roaming fee?
  - We connect via the Internet to our home operator's gateway (ePDG), which in turn connects to the LTE core network (PGW)
- ePDG
  - Evolved Packet Data Gateway
  - Establishing a secure connection (IPSec)
    - VPN connection to mobile network
  - SGW-like functionality
  - PGW selection
  - Mobility management
  - In Trusted version TWAG (Trusted Wireless Access Gateway) instead of ePDG
- AAA
  - Authentication, Authorization, Accounting
  - User authentication based on authentication data obtained from HSS



5G ITU requirements

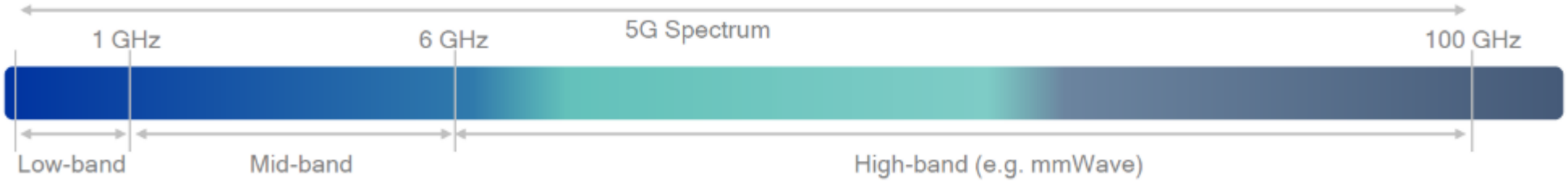
- Max. speed (DL/UL): 20/10 Gbps
- Radio delay on User Plane: 1-4 ms
- Delay on Control Plane: 20 ms
- * Spectral efficiency (DL): 30 bit/s/Hz
- Speed of mobile device: 0-500 km/h
- Connection density: 1 Million device / km^2
- 3 main application areas
  - eMBB
  - mMTC ~massive IoT
  - URLLC



5G overview: https://www.ericsson.com/en/reports-and-papers/white-papers/5g-wireless-access-an-overview
5G applications: https://www.ericsson.com/assets/local/5g/5g-use-cases-ericsson.pdf

5G network

- Access Network
  - Improved solutions already used in LTE
    - MIMO, Carrier Aggregation, Beamforming
    - Flexible spectrum allocation
    - Heterogenous networks / SmallCells
  - Frequency
    - mmWave: In the 24-100 GHz range (peak speed with high sensitivity and short distance) – festival, stadium
    - 3.4-3.8 MHz (high capacity) + 700 MHz (large cells) ranges



- Core Network
  - SBA – Service Based Architecture
    - Independent services are accessed via HTTP2 APIs
  - NFV – Network Function Virtualization (cloud)
    - Software - hardware independence, flexibility, scaling
    - Infrastructure sharing in central data centers → cost reduction
  - SDN – Software Defined Networking
    - Complementing NFV with the possibility of dynamic, programmable configuration of the topology
    - Automation, self-correcting networks („closed loop", „zero touch automation")
  - Network slicing
    - Several different (e.g. eMBB / IoT / Industry) virtual networks with different quality requirements according to application needs

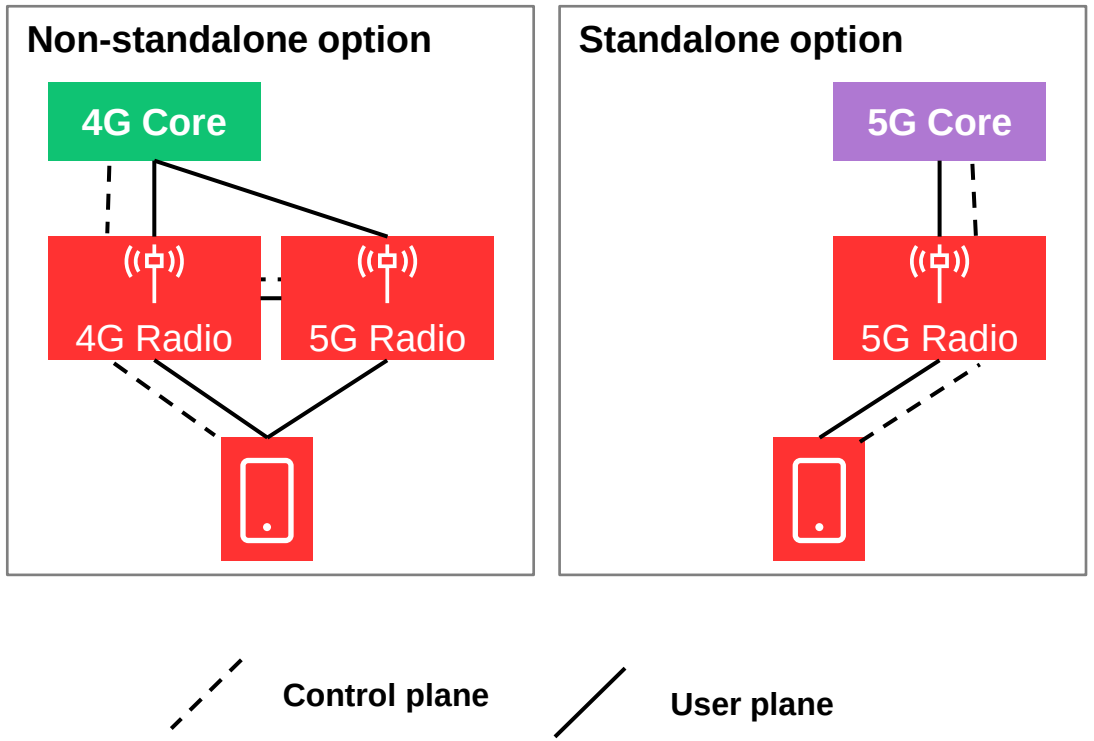
5G overview

Not an exam material!

- 2016/2017 – 5G test
  - 800MHz bandwidth at 15 GHz (SK Telekom & Ericsson)
    - 1 Gbps End-to-End (E2E) speed
    - 4 ms delay
  - Handover test at very high speed (KDDI & Samsung)
  - Telekom + Ericsson: first 5G connection (22Gbps)
- Standardisation in progress (3GPP)
  - Release 15 (2018) – 5G radio, 5G Non-Standalone, 5G Standalone architecture, eMBB
  - Release 16 (2020) – Network slicing, private 5G networks, V2X (vehicle-to-everything)
  - Release 17 (2022) – improvement of rel.15/16 functions, satellite 5G access
- Initial introduction in 2019
  - In Hungary: Vodafone (2019), Telekom (2020), Telenor/Yettel (2021)
    - Measurements in Budapest: up to 5-700 Mbps (DL) at good coverage, with a nearby base station

5G deployment

- More options defined for 4G → 5G transition
- 2 most important
  - Non-standalone option: a typical initial step for those having a 4G network
    - Introduction of 5G radio, but the core is still 4G
    - Higher data speeds are available, but services requiring "5G Core" (e.g. URLLC applications) are not yet available
  - Standalone option : standalone 5G network
    - This does not mean that the operator cannot also have a 4G network
- Similar to 4G: data service initially, voice later (IMS will be here as well)



Abbreviations

Basic notions
- DL = downlink
- UL = uplink

Technologies
- LTE / LTE-A = Long Term Evolution Advanced
- VoLTE = Voice over LTE
- VoWiFi = Voice over WiFi

Technical solutions
- FDD / TDD = Frequency/Time Division Duplexing
- * OFDMA = Orthogonal Frequency Division Multiple Access
- * SISO = Single In, Single Out
- (MU-)MIMO = (Multi-User) Multiple In, Multiple Out
- * CoMP = Coordinated Multi Point Operation
- * LTE-U = LTE-Unlicensed
- ICIC: Inter-Cell Interference Coordination

2G/3G compatibility
- ICS (IMS Centralized Services)
- CSFB (Circuit Switched Fall Back)
- SRVCC (Single Radio Voice Call Continuity)

Network elements
- eNodeB = evolved NodeB, (base station)
- SGW = Serving Gateway
- PGW = Packet Gateway
- MME = Mobility Management Entity
- HSS = Home Subscriber Server
- IMS = IP Multimedia Subsystem
- ePDG = Evolved Packet Data Gateway
- AAA = Authentication, Authorization, Accounting

Bearers, Quality
- APN = Access Point Name
- QoS = Quality of Service
- QCI = QoS Class Identifier

5G
- * CUPS = Control and User Plane Separation
- * SBA = Service Based Architecture
- * NFV = Network Function Virtualization
- * SDN = Software Defined Networking