Wireless Networks
5G Technologies

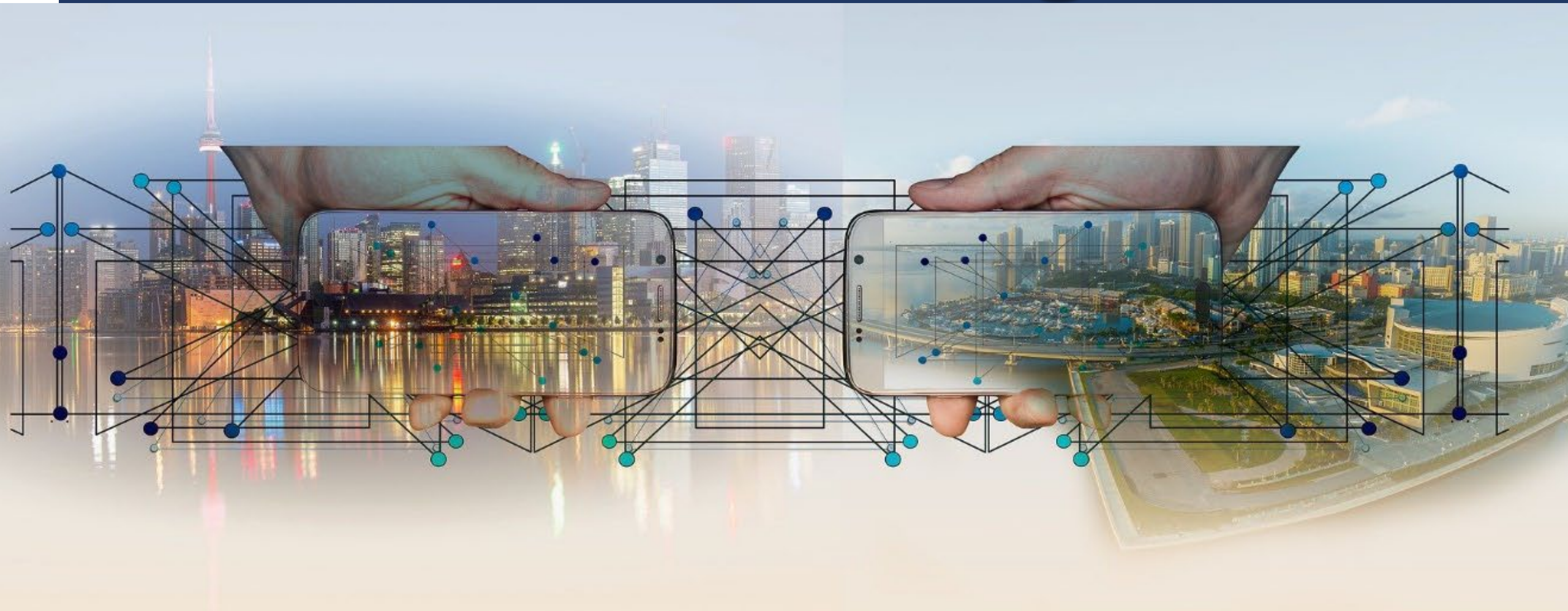


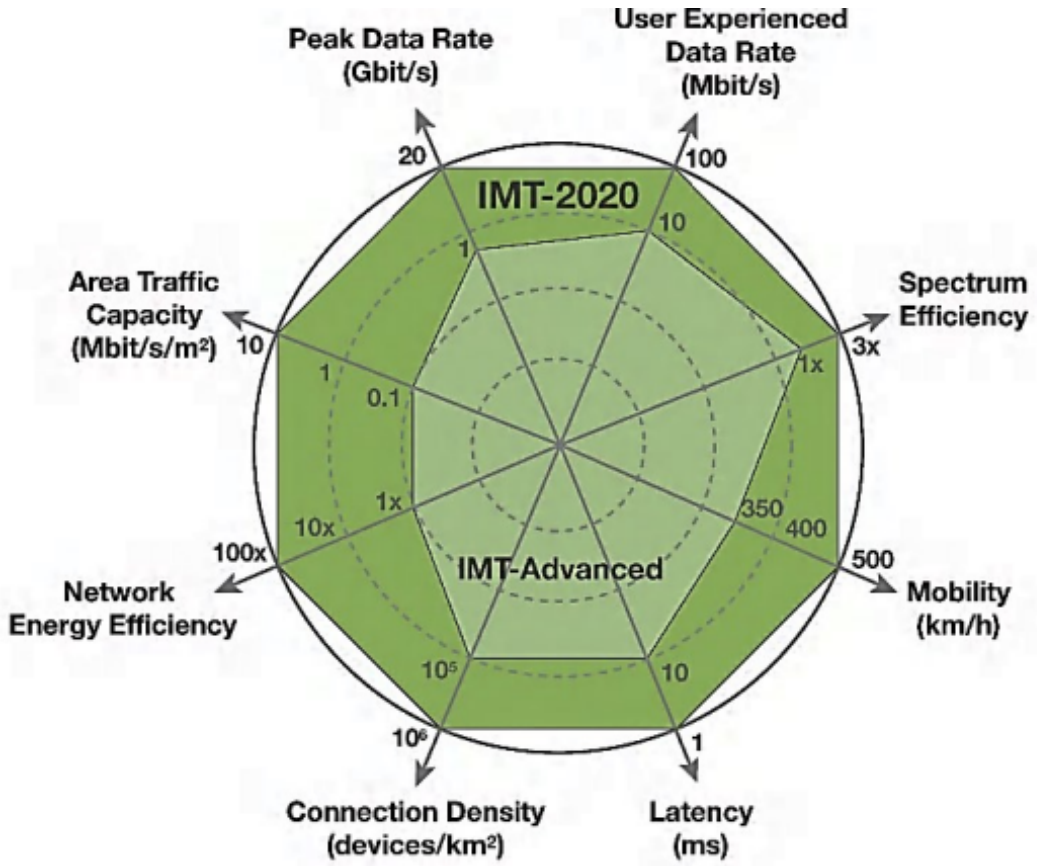
Table of Contents

Why 5G Communications?

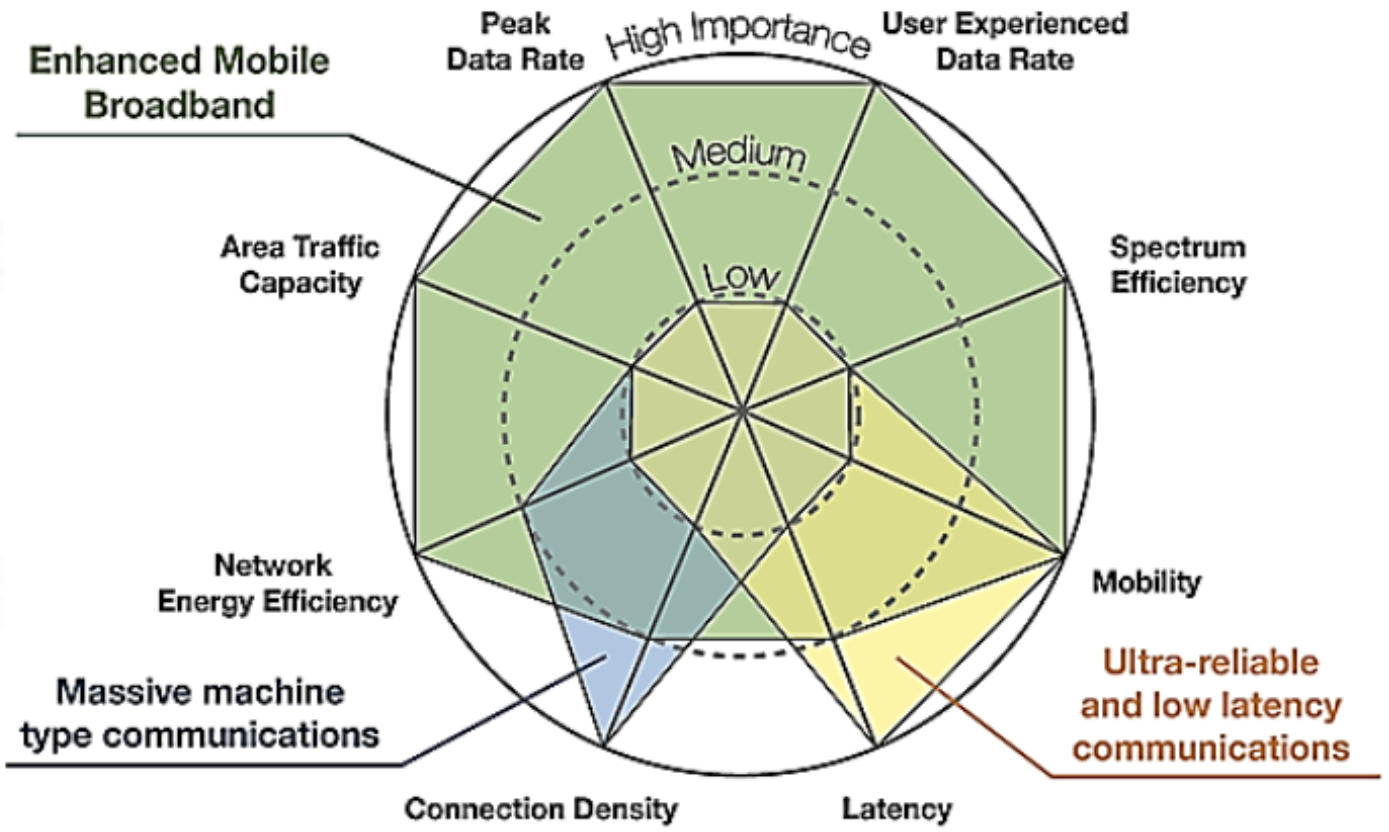
Why 5G Communications?

- eMBB (Enhanced Mobile Broadband)
  - Faster Throughput and Bandwidth
- URLLC (Ultra-reliable and Low Latency Communication)
  - 4G is not enough for real-time response.
  - Uninterrupted Services
- mMTC (massive Machine Type Communication)
  - Exponentially Increasing # of Users/Devices
- More Flexible Architecture
- Intelligent Network
- Energy Efficiency
- More Secure than 4G

5G Capability Perspectives
from the ITU-R IMT-2020 Vision Recommendation



Enhancement of key capabilities from IMT-Advanced to IMT-2020



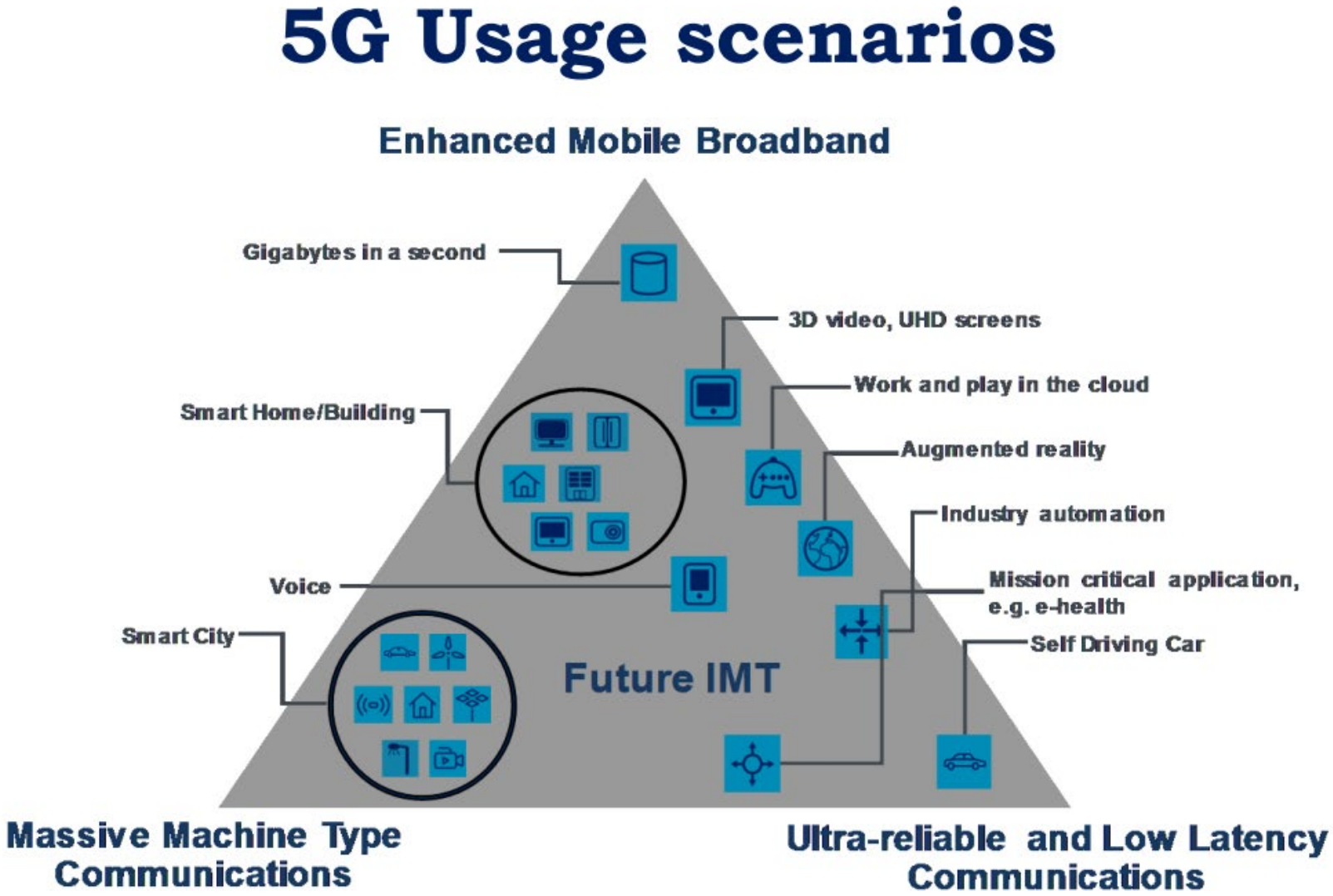
The importance of key capabilities in different usage scenarios

The values in the figures above are targets for research and investigation for IMT-2020 and may be revised in the light of future studies. Further information is available in the IMT-2020 Vision Recommendation (Recommendation ITU-R M.2083)

Emerging Trends in 5G/IMT2020, ITU, https://www.itu.int/en/membership/documents/missions/gva-mission-briefing-5g-28sept2016.pdf

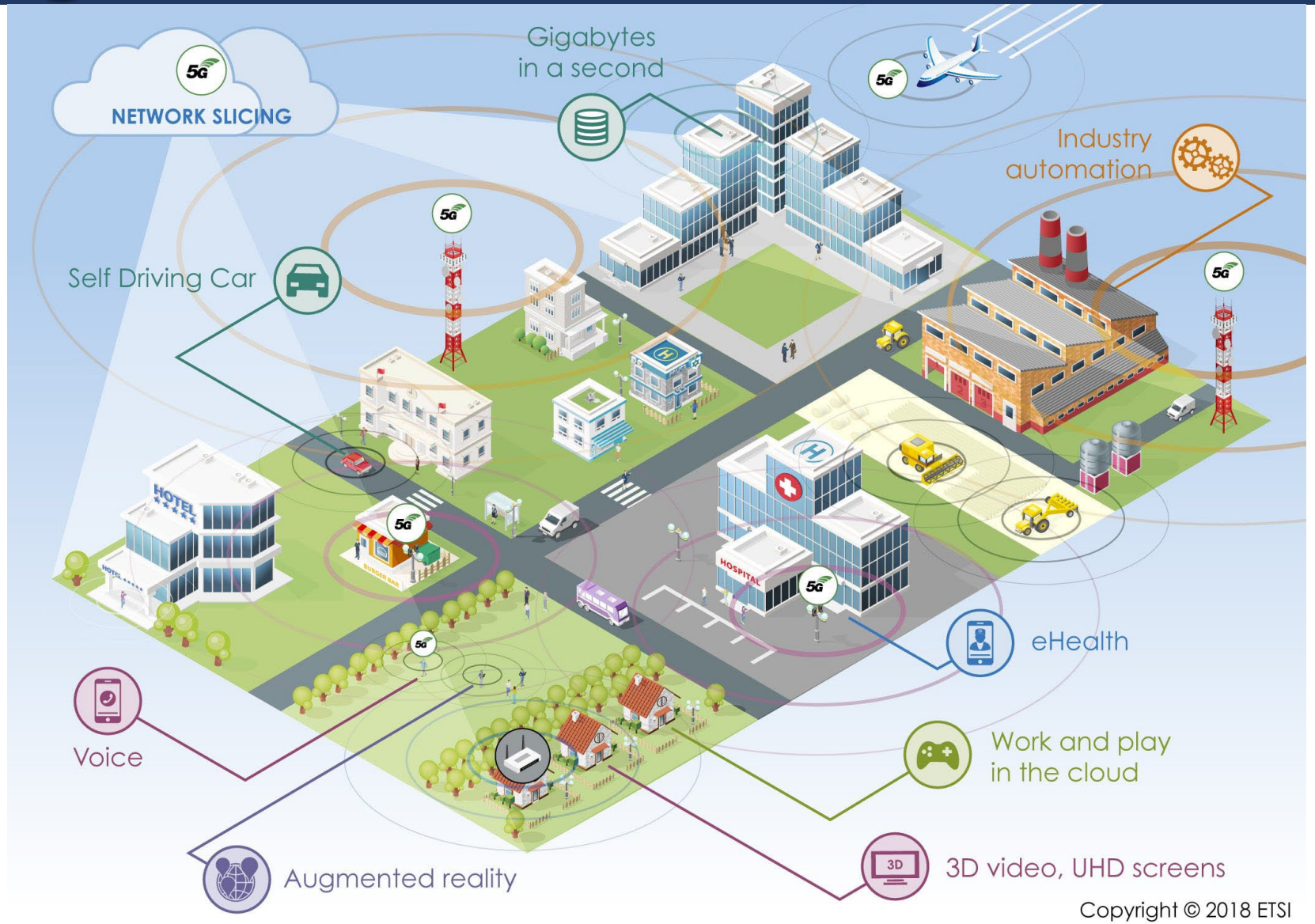
Possible Applications using 5G

5G Usage Scenarios (1)



Emerging Trends in 5G/IMT2020, ITU, https://www.itu.int/en/membership/documents/missions/gva-mission-briefing-5g-28sept2016.pdf

5G Usage Scenarios (2)



European Telecommunications Standards Institute (ESTI), https://www.etsi.org/technologies/5G

Network Fundamentals

What is Computer Networks?

- A collection of autonomous computers interconnected by a single or multiple technologies
  - Interconnected via:
    - Copper wire
    - Fiber optics
    - Microwaves
    - Infrared
    - Communication satellites, etc.

What is a protocol?

- Communications between computers requires very specific unambiguous rules
- A protocol is a set of rules that governs how two or more communicating parties are to interact
  - Internet Protocol (IP)
  - Transmission Control Protocol (TCP)
  - HyperText Transfer Protocol (HTTP)
  - Simple Mail Transfer Protocol (SMTP)

What is a communication network?

- The equipment (hardware & software) and facilities that provide the basic communication service
- Virtually invisible to the user; Usually represented by a cloud

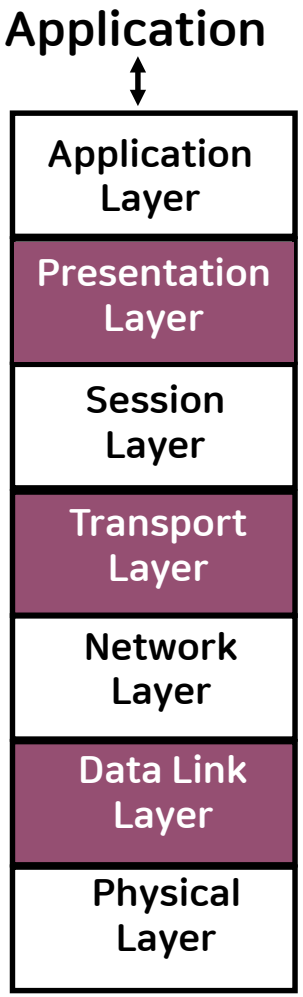
- Equipment
  - Routers, servers, switches, multiplexers, hubs, modems, …
- Facilities
  - Copper wires, coaxial cables, optical fiber
  - Ducts, conduits, telephone poles …

How are communication networks designed and operated?

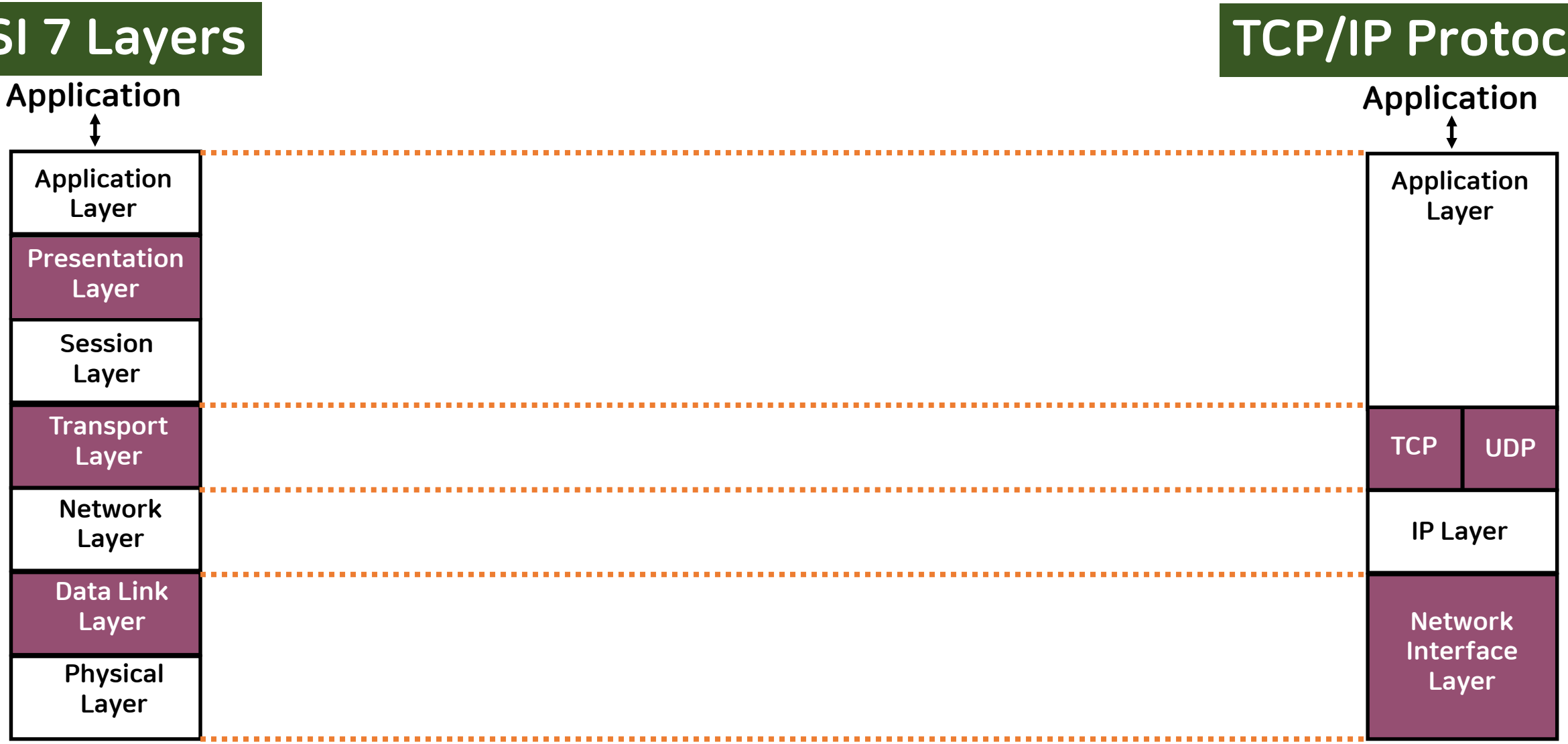
Communication Network Architecture

- *Network architecture*: the plan that specifies how the network is built and operated
- Architecture is driven by the network services
- Overall communication process is complex
- Network architecture partitions overall communication process into separate functional areas called *layers*

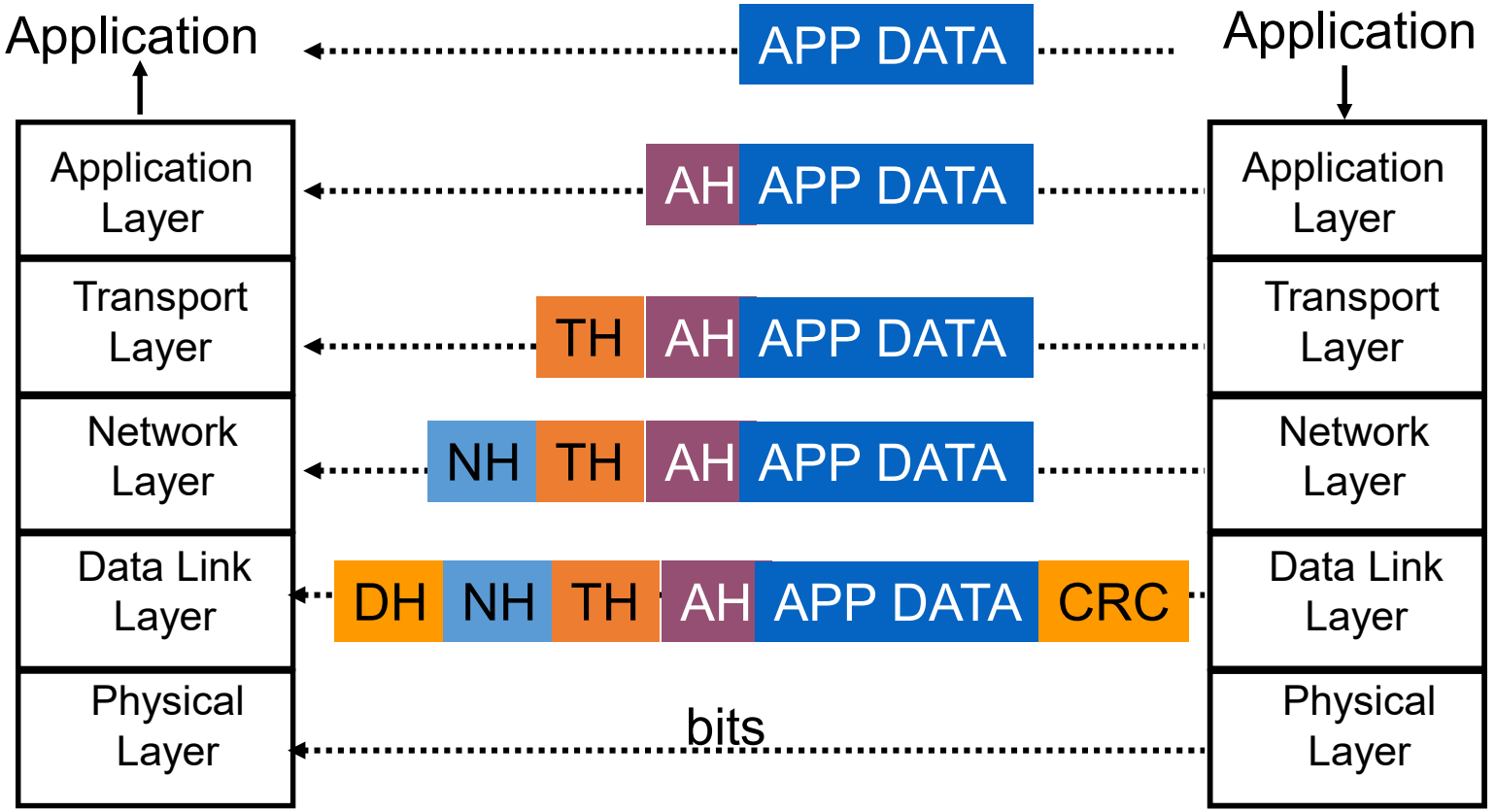
OSI Reference Model



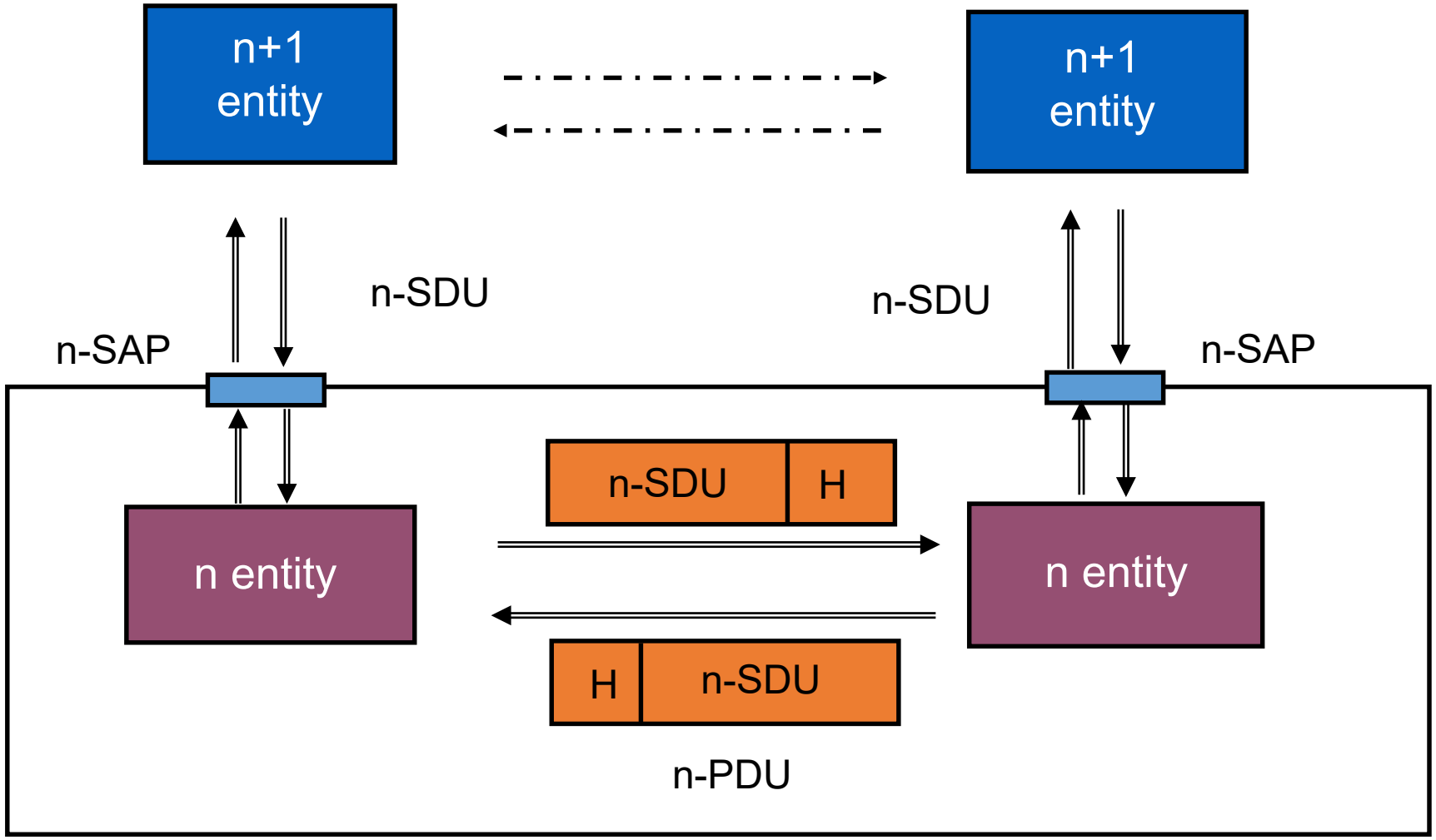
OSI Reference Model & TCP/IP Protocol Stack



Headers & Trailers



Layers, Services & Protocols



Connectionless & Connection-Oriented Services

Connection-Oriented

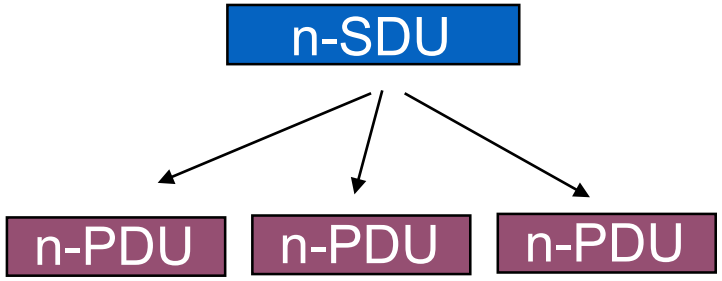
- Three-phases:
  1. Connection setup between two SAPs to initialize state information
  2. SDU transfer
  3. Connection release
- e.g. TCP, ATM

Connectionless

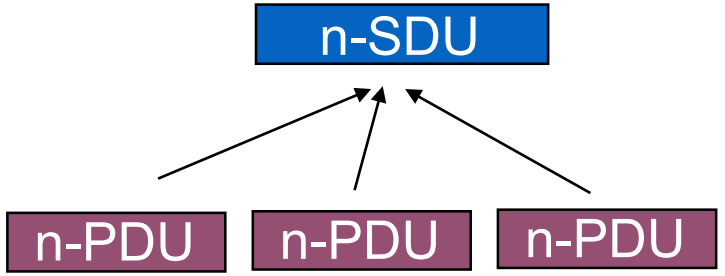
- Immediate SDU transfer
- No connection setup
- e.g. UDP, IP

Segmentation & Reassembly

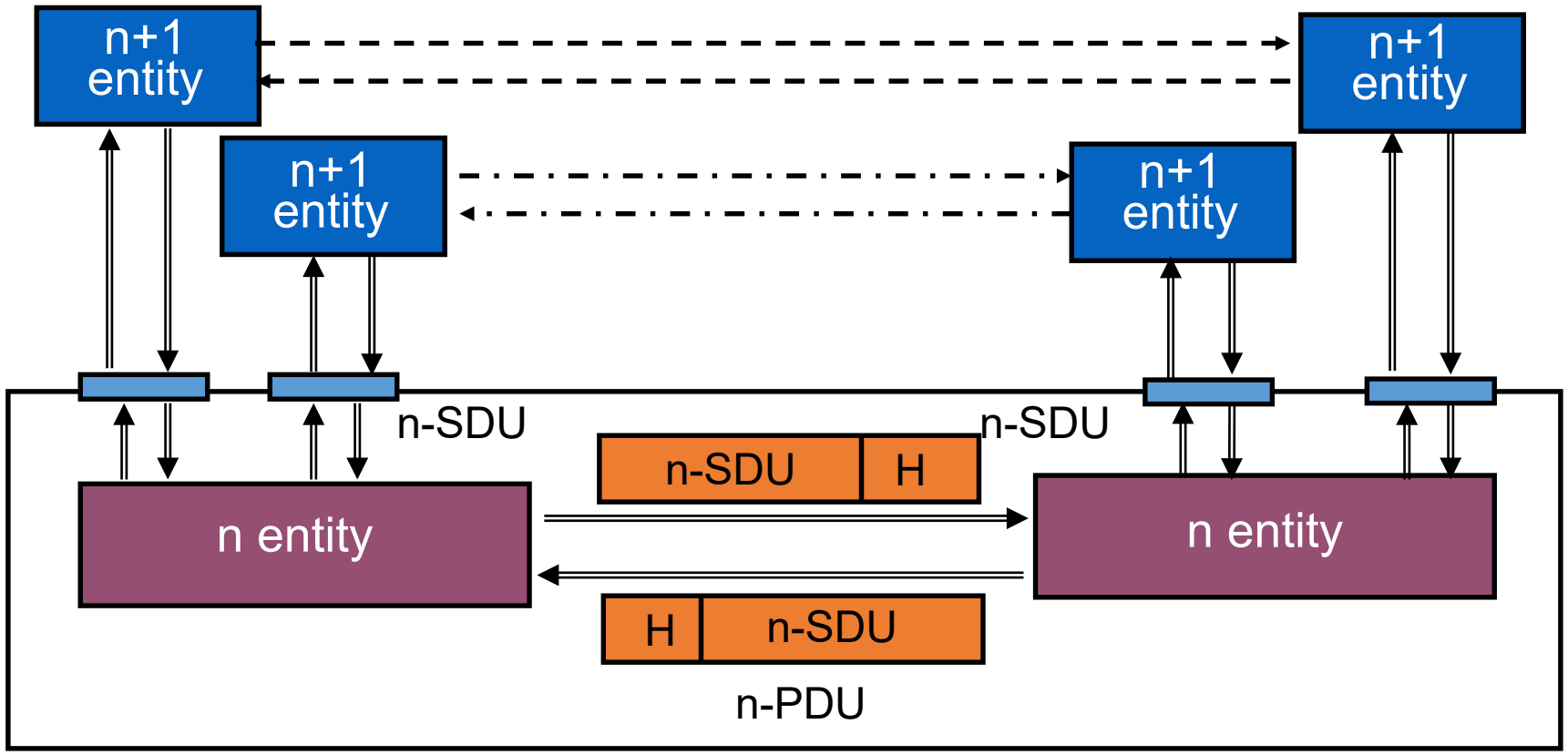
Segmentation



Reassembly



Multiplexing



Multiplexing

- FDM (Frequency Division Multiplexing)

- TDM (Time Division Multiplexing)

Before 5G Communications

Before 5G Communications

Image Source: https://www.cengn.ca/information-centre/innovation/timeline-from-1g-to-5g-a-brief-history-on-cell-phones/

Before 5G Communications

Commsbrief	1G				2G			3G		4G		5G
Technology standard	AMPS	NMT	TACS	C-Netz	GSM	D-AMPS	IS-95 A	UMTS	CDMA2000	LTE		NR
Digital or not?	Analogue				Digital			Digital		Digital		Digital
Launch year (approx.)	~1980				~1990			~2000		~2010		~2020
Enhancements	Commsbrief				GPRS		IS-95 B	HSPA	EVDO Rev. 0	LTE-Advanced		
					EDGE			HSPA+	EVDO Rev. A	LTE-Pro	Commsbrief	
									EVDO Rev. B			
Services	Voice only				Voice + SMS + Data (Mobile Internet)							
Peak download speeds	-				GPRS	171.2 kbps		UMTS	2 Mbps	LTE	300 Mbps	10 Gbps
								HSPA	14.4 Mbps			
					EDGE	384 kbps		HSPA+	42 Mbps	LTE-A	1 Gbps	
					IS-95 A	14.4 kbps		CDMA2000	153 kbps			
					IS-95 B	115 kbps		EVDO 0	2.4 Mbps	LTE-Pro	3Gbps	
								EVDO A	3.1 Mbps			
								EVDO B	14.7 Mbps			

Summary of 1G, 2G, 3G, 4G and 5G network technologies

Adnan Ghayas, "What do the terms 1G, 2G, 3G, 4G and 5G really mean?," COMMSBRIEF, March 3, 2020
https://commsbrief.com/what-do-the-terms-1g-2g-3g-4g-and-5g-really-mean/#:~:text=1G%2C%202G%2C%203G%2C%204G%20and%205G%20are%20the%20five,Stands%20for

5G Communications

5G Standard and Specification

International Telecommunication Union (ITU)
Overall Concepts

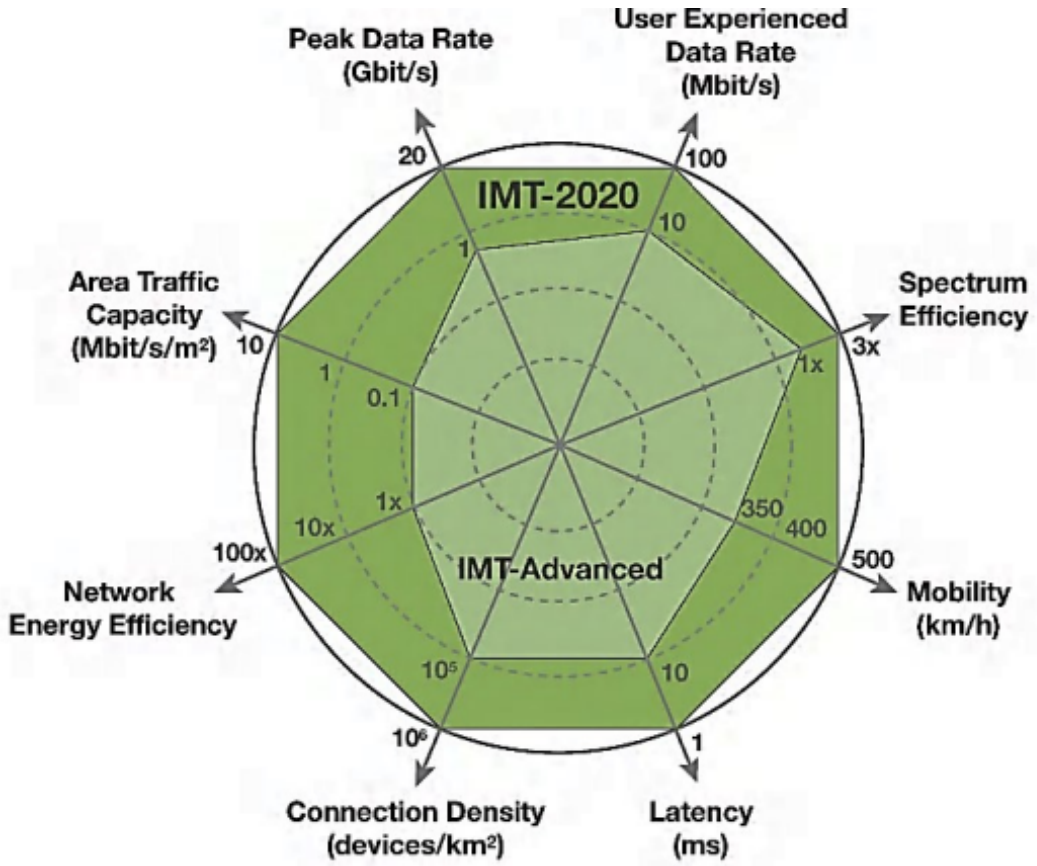
The 3rd Generation Partnership (3GPP)
Specifications

Region	Organization	Specifications	Time line
FC	FCC : FEDERAL COMMUNICATIONS COMMISSION	Code of Federal Regulations(CFR) Title 47 Part 2, Part 22, Part24, Part27 (FR1) Title 47 Part 2, Part30 (FR2)	Available
	ARIB : Association of Radio Industries and Businesses	Technical Regulations Conformity Certification(TRCC) Article 2-1-11-30 (FR1) Article 2-1-11-32 (FR2)	Available
CE	ETSI : European Telecommunications Standards Institute	Radio Equipment Directive(RED) ETSI EN 301 908-25 (FR1, FR2) (Publication Target Feb. 2021)	Publication Target Feb. 2021
CTA	CTA : China Type Approval Network Access License	Test requirements follow 3GPP TS 38.521-1/3GPP TS 38.521-3, but test with specific channel. Focus on "Transmitter" and "Receiver" part.	under approval (*1)
	RRA : National Radio Research Agency	KS X 3270:2019 (FR1) KS X 3271:2019 (FR2)	Available (*1)

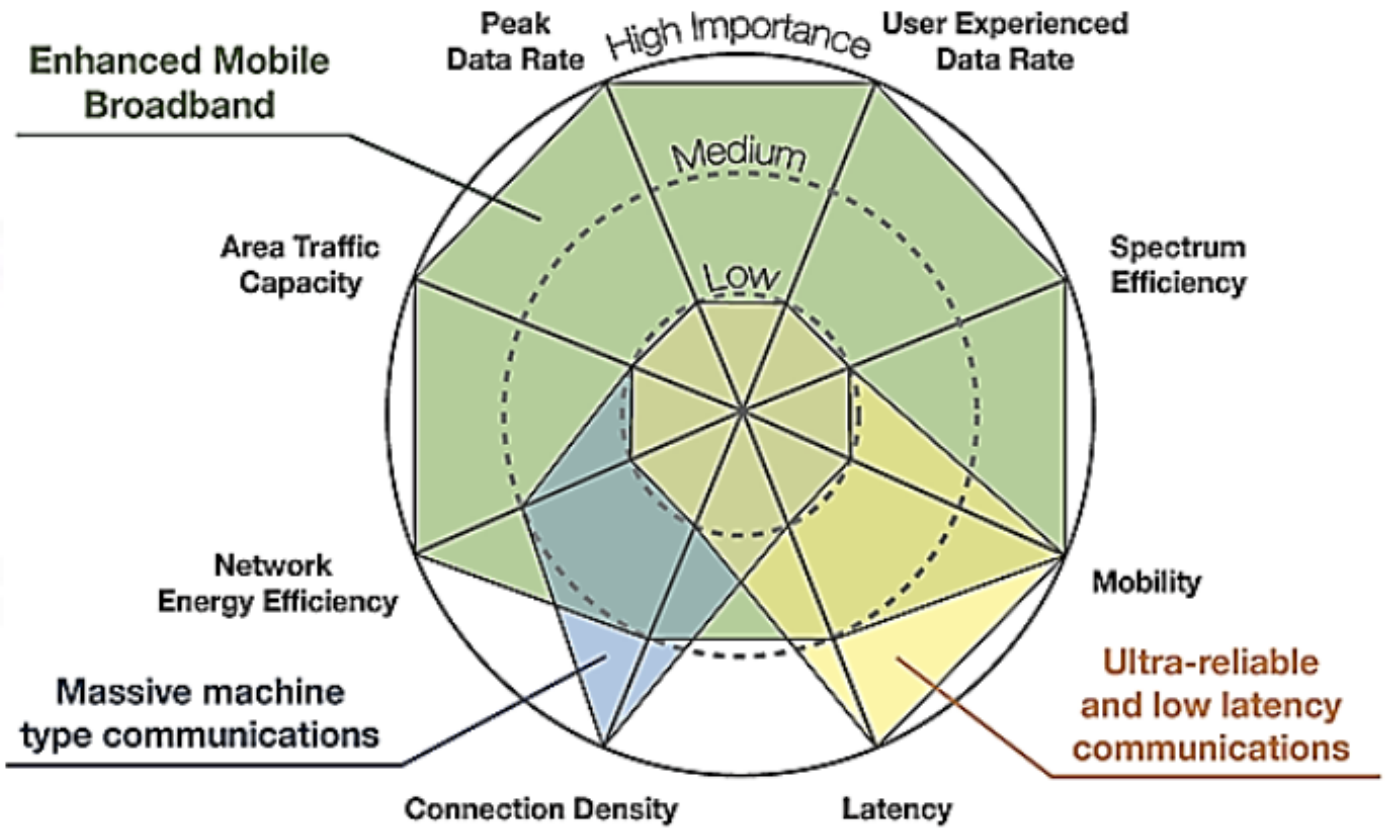
2G	Phases 1, 2, 2+, Releases 97, 98
3G	Releases 99, Release 4, 5, 6, 7
4G	Releases 8, 9, 10, 11, 12, 13, 14
5G	Releases 15, 16, 17, 18, 19

https://www.5gtechnologyworld.com/5g-radios-increase-emphasis-on-compliance-testing/

5G Capability Perspectives
from the ITU-R IMT-2020 Vision Recommendation



Enhancement of key capabilities from IMT-Advanced to IMT-2020



The importance of key capabilities in different usage scenarios

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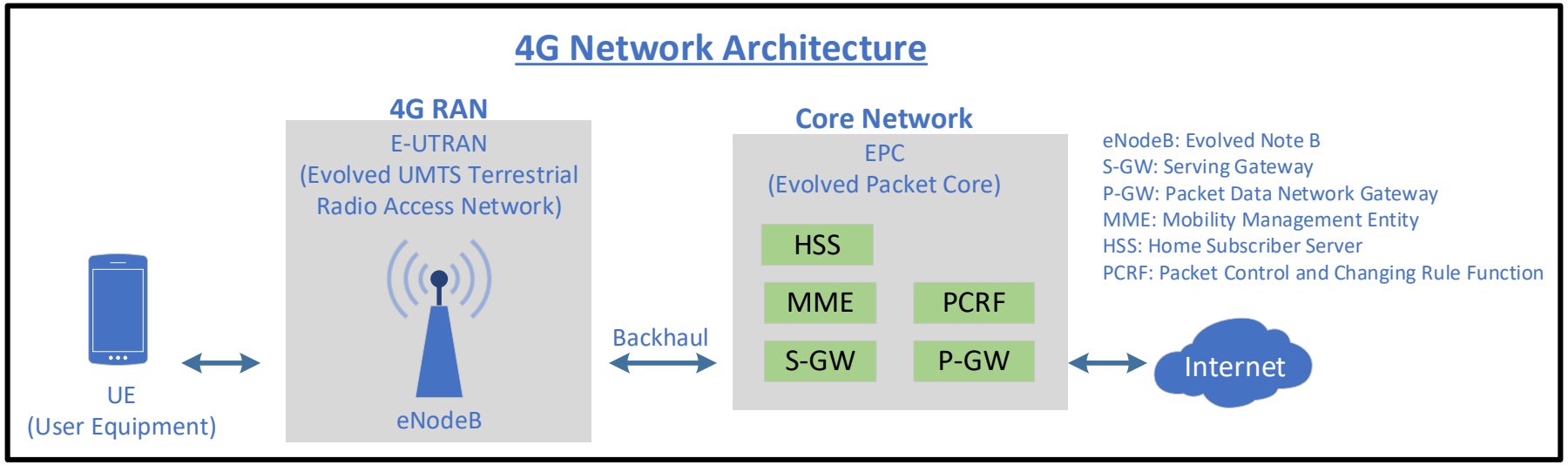
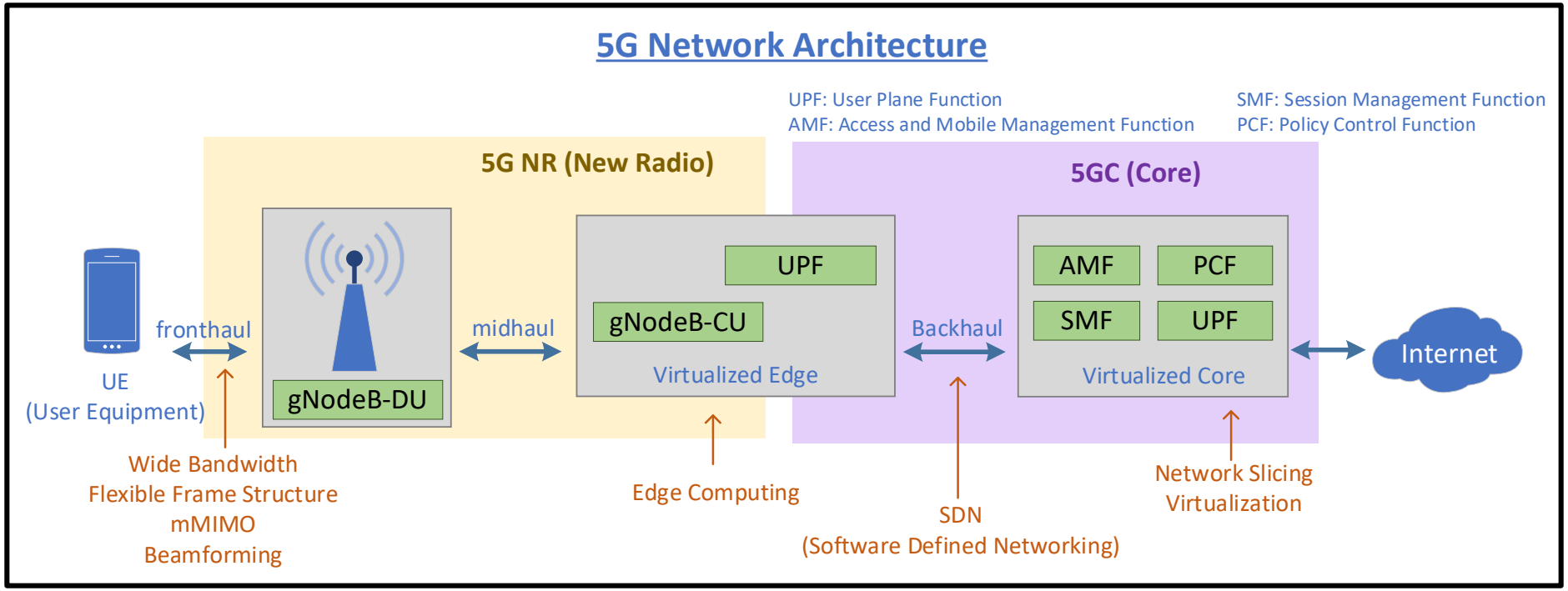
Emerging Trends in 5G/IMT2020, ITU, https://www.itu.int/en/membership/documents/missions/gva-mission-briefing-5g-28sept2016.pdf

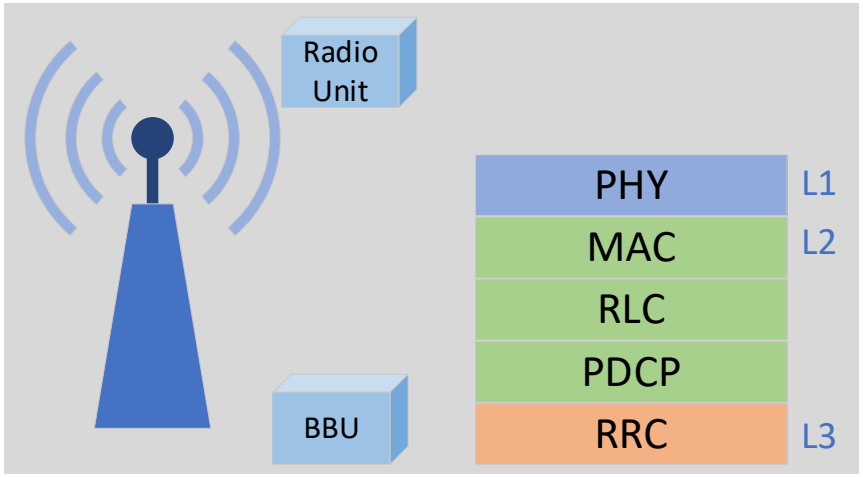
5G Network Architecture



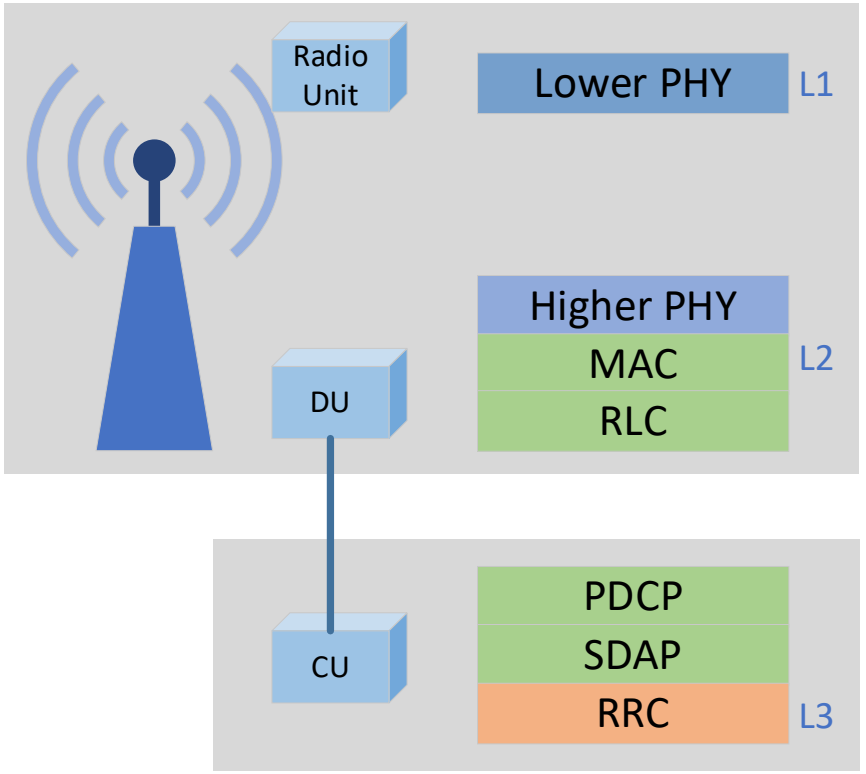


5G NR (New Radio) Architecture

4G RAN



5G RAN



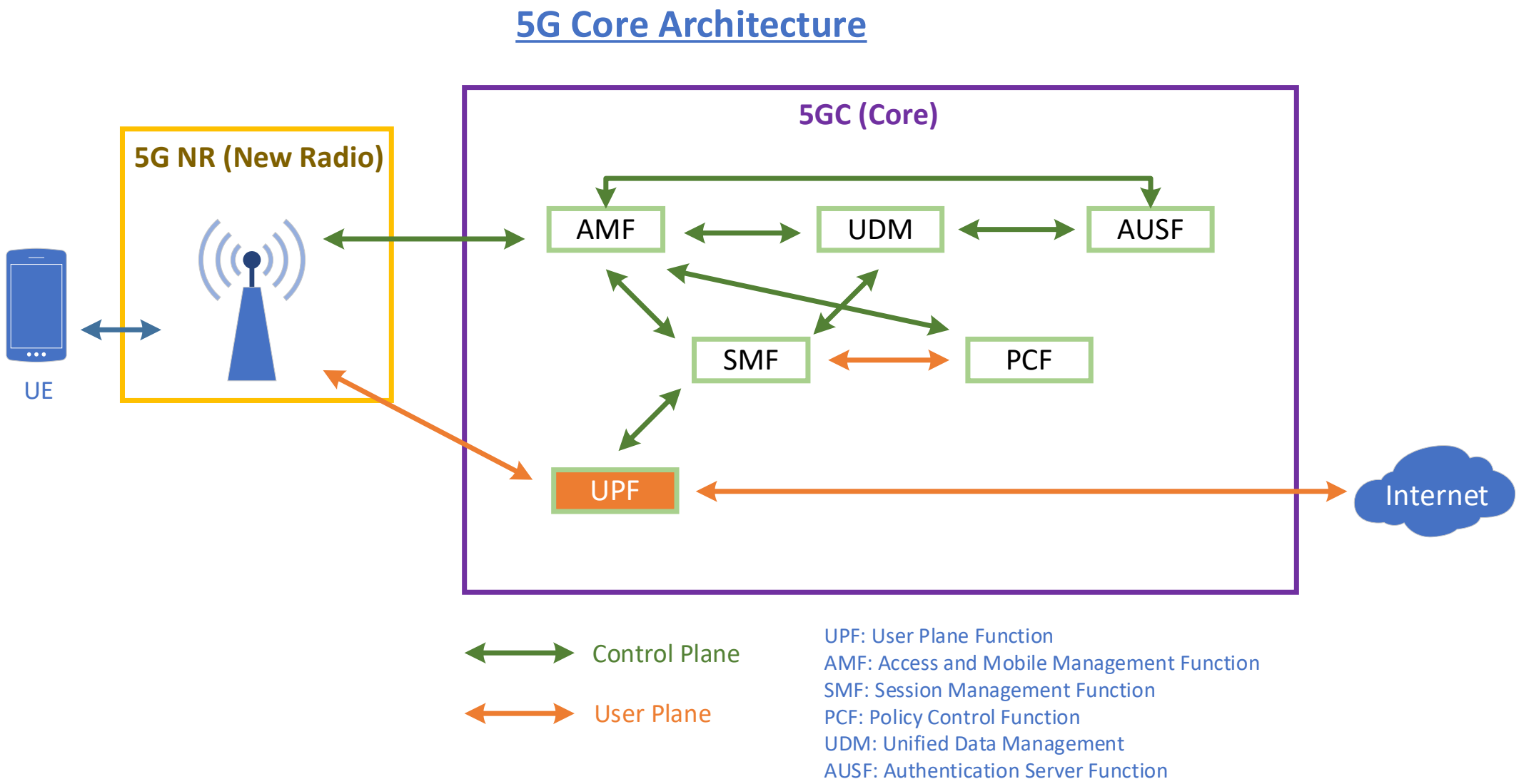
BBU: Baseband Unit
DU: Distributed Unit
CU: Central Unit

PHY: Physical Layer
MAC: Medium Access Control Layer
PDCP: Packet Data Convergence Protocol
RRC: Radio Resource Control

Radio Unit	Lower PHY	L1	Analog to Digital / Digital to Analog
Distributed Unit	Higher PHY		Modulation, Coding and Rate Matching
	MAC	L2	Scheduling, HARQ (Hybrid Automatic Repeat Request), Multiplexing/Demultiplexing
	RLC		ARQ, Segmentation
Central Unit	PDCP		Robust Header Compression (RoHC), Security
	SDAP		QoS Flow Handling
	RRC	L3	Public Land Mobile Network (PLMN) ID selection, SIB, Mobility, 5GC Connect

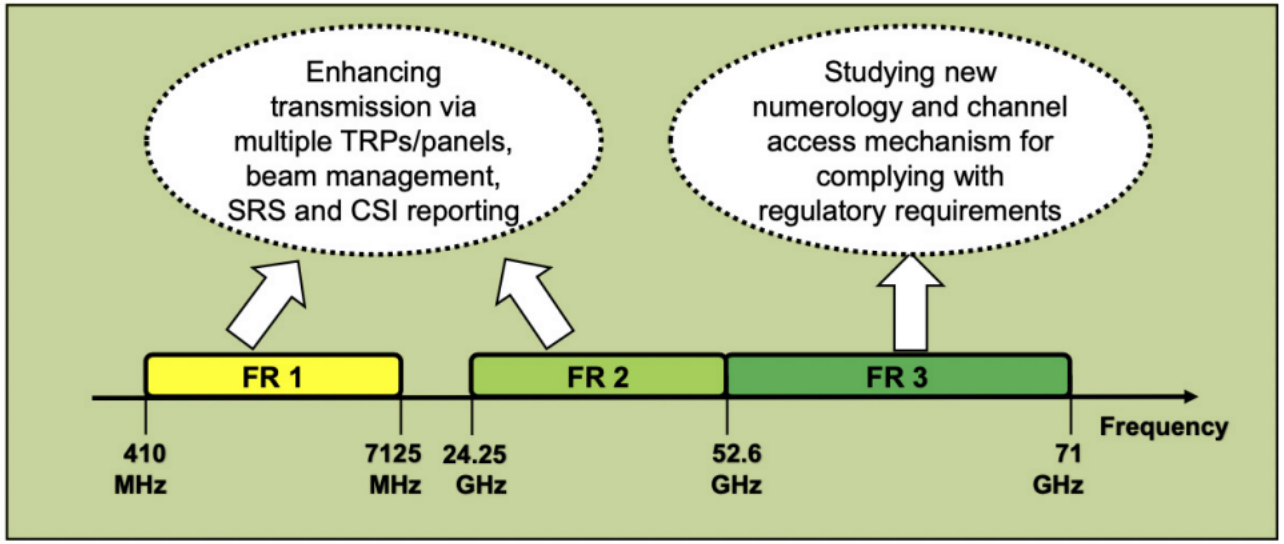
PHY: Physical Layer
MAC: Medium Access Control Layer
PDCP: Packet Data Convergence Protocol
RRC: Radio Resource Control

5G Core Architecture



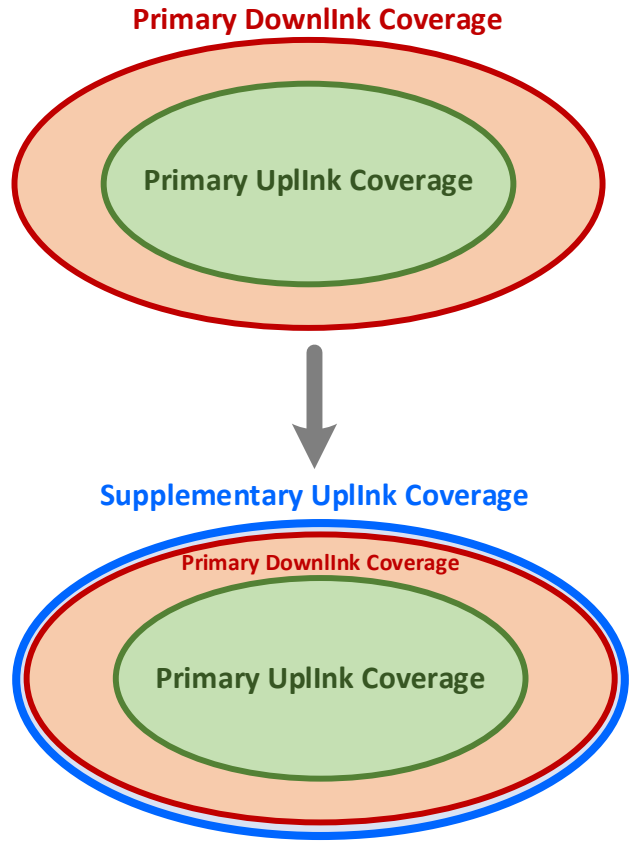
Frequency Bands & SUL Coverage

Frequency Bands



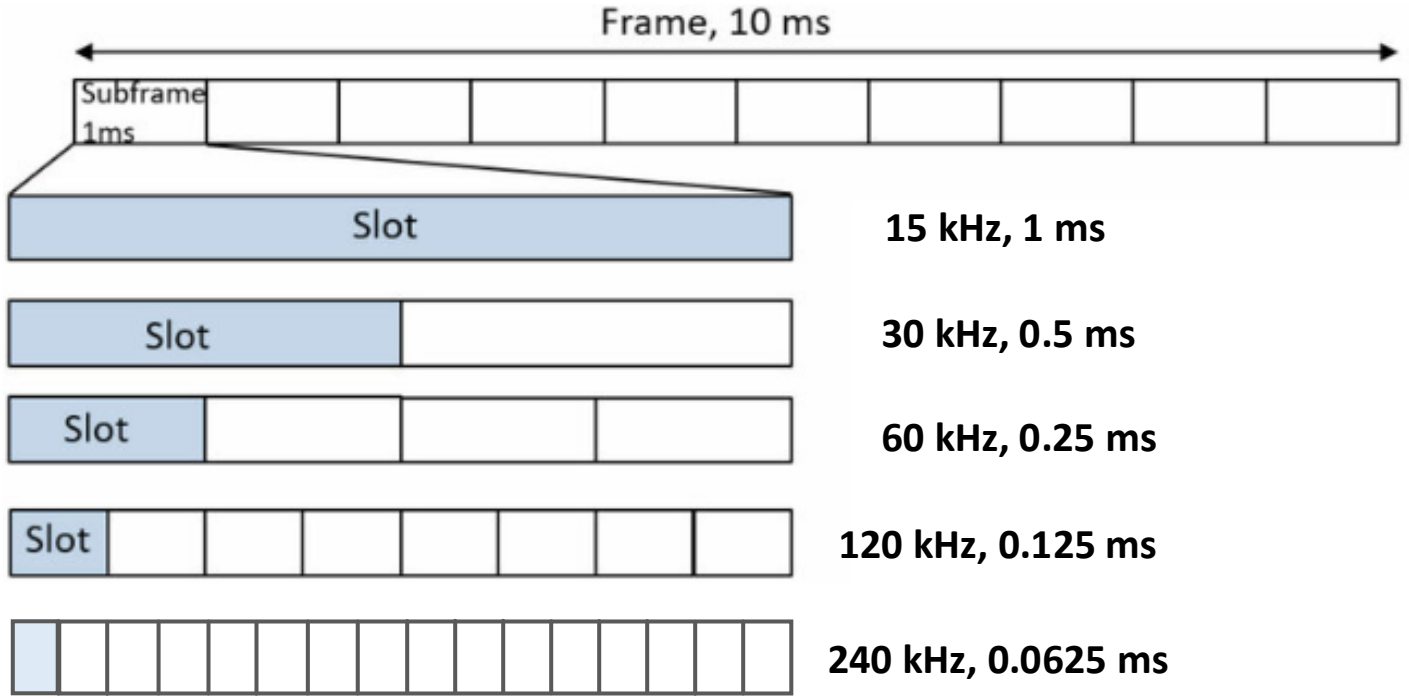
Hua Shou, "New Features in the Next Release of 5G New Radio,"
https://ofinno.com/wp-content/uploads/2020/08/OFNO_White_Sheet_082120.pdf

SUL (supplementary Uplink) Coverage



Numerology: Subcarrier Spacing (SPS)

5G NR frame structure with multiple numerology parameters



15 kHz, 1 ms

30 kHz, 0.5 ms

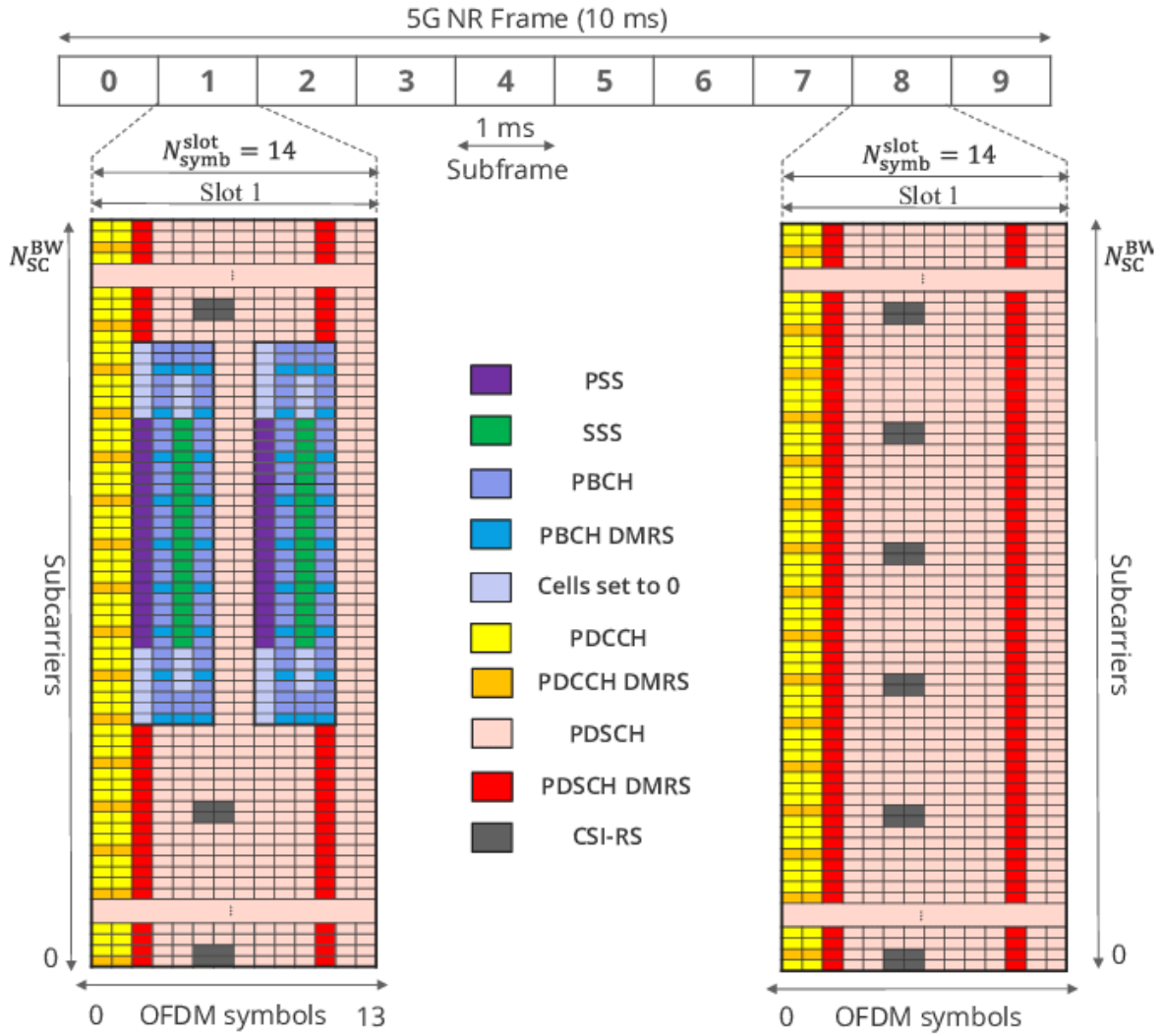
60 kHz, 0.25 ms

120 kHz, 0.125 ms

240 kHz, 0.0625 ms

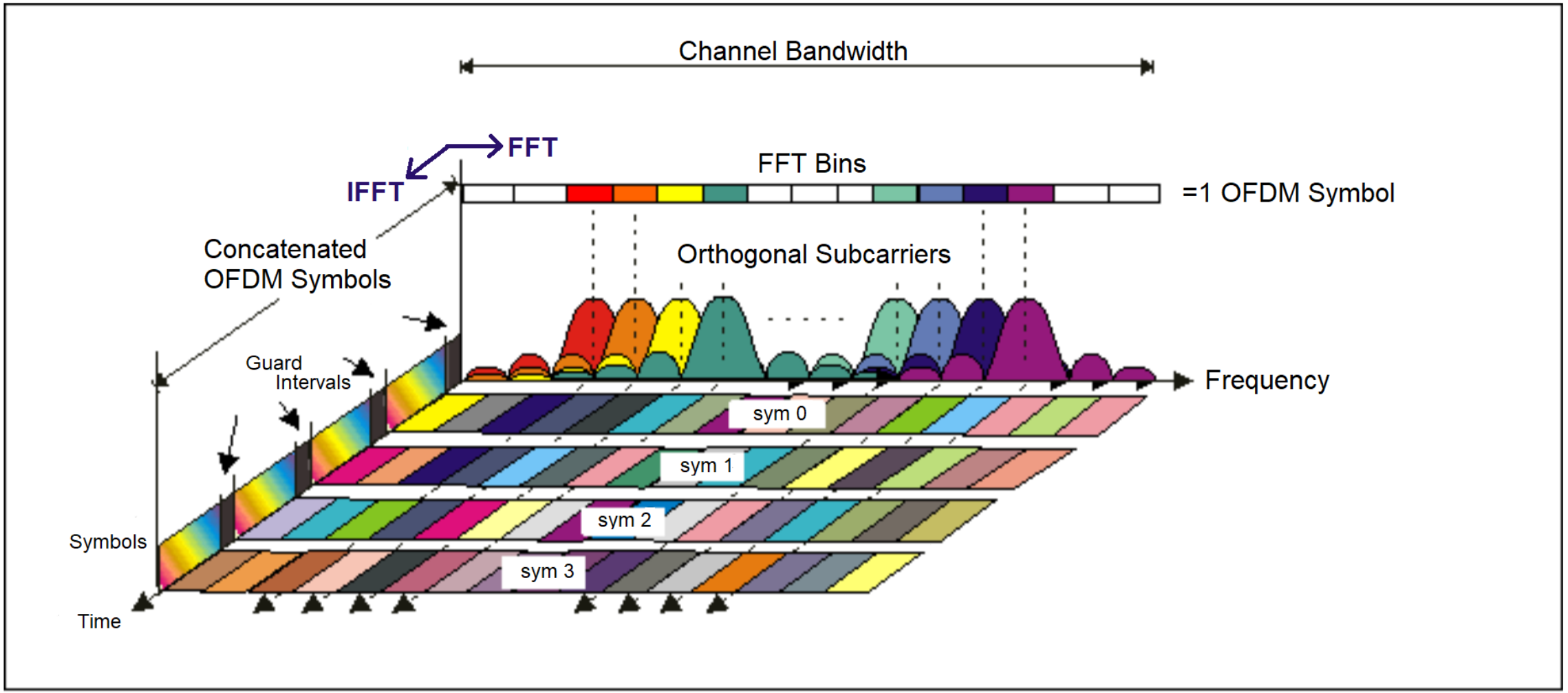
Supported Transmission Numerology

μ	$\Delta f = 2^{\mu} \cdot 15[\text{kHz}]$	Cyclic prefix	Supported for data	Supported for synch
0	15	Normal	Yes	Yes
1	30	Normal	Yes	Yes
2	60	Normal, Extended	Yes	No
3	120	Normal	Yes	Yes
4	240	Normal	No	Yes



Jose Luis Carcel, Belkacem Mouhouche, Manuel Fuentes, and Edurado Garro, "IMT-2020 Key Performance Indicators: Evaluation and Extension Towards 5G New Radio Point-to-Multipoint," IEEE International Symposium on Broadband Multimedia Systems and Broadcasting, 2019, DOI:10.1109/BMSB47279.2019.8971948

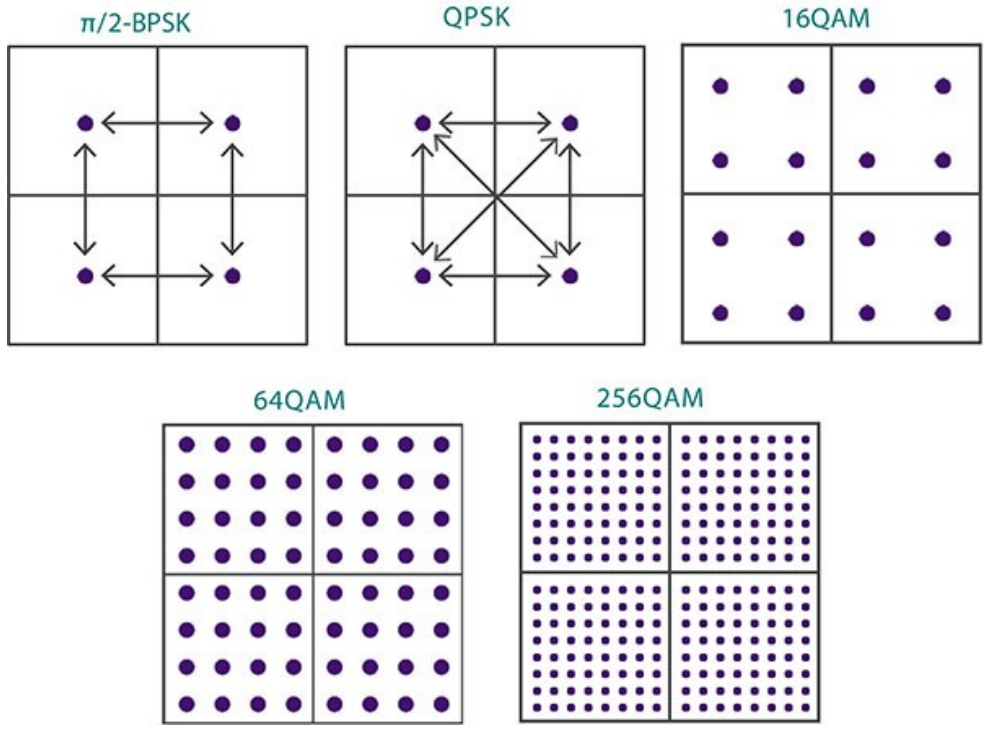
OFDMA
(Orthogonal Frequency Division Multiple Access)



Frequency-Time Representative of an OFDM signal

Combined time/frequency domain view of OFDM signal. (Image: Keysight Technologies)
https://www.5gtechnologyworld.com/the-basics-of-5gs-modulation-ofdm/

Modulation



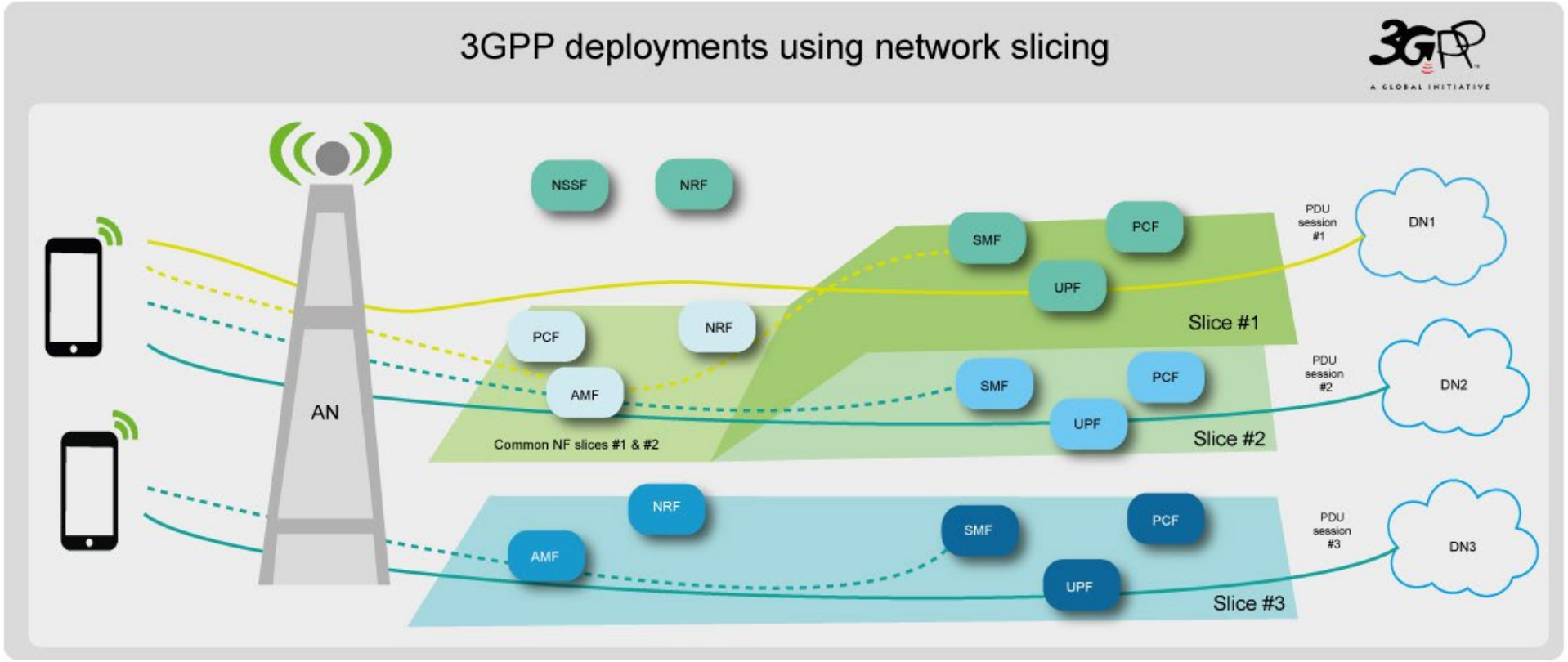
Modulation scheme	Bits/symbol	DL	UL	
		CP-OFDM	CP-OFDM	DFT-S-OFDM
π/2-BPSK	1			Y
QPSK	2	Y	Y	Y
16QAM	4	Y	Y	Y
64QAM	6	Y	Y	Y
256QAM	8	Y	Y	Y

Houman Sadeghi Kaji, “Understanding 5G, A Practical Guide to Deploying and Operating 5G Networks, 5G New Radio,”Sept 1, 2021
https://www.linkedin.com/pulse/understanding-5g-practical-guide-deploying-operating-new-houman

Duplex Schemes

- TDD
  - Uplink and downlink transmission use the same carrier frequency and are separated in different time slices
- FDD
  - Uplink and downlink transmission use the different frequencies simultaneously

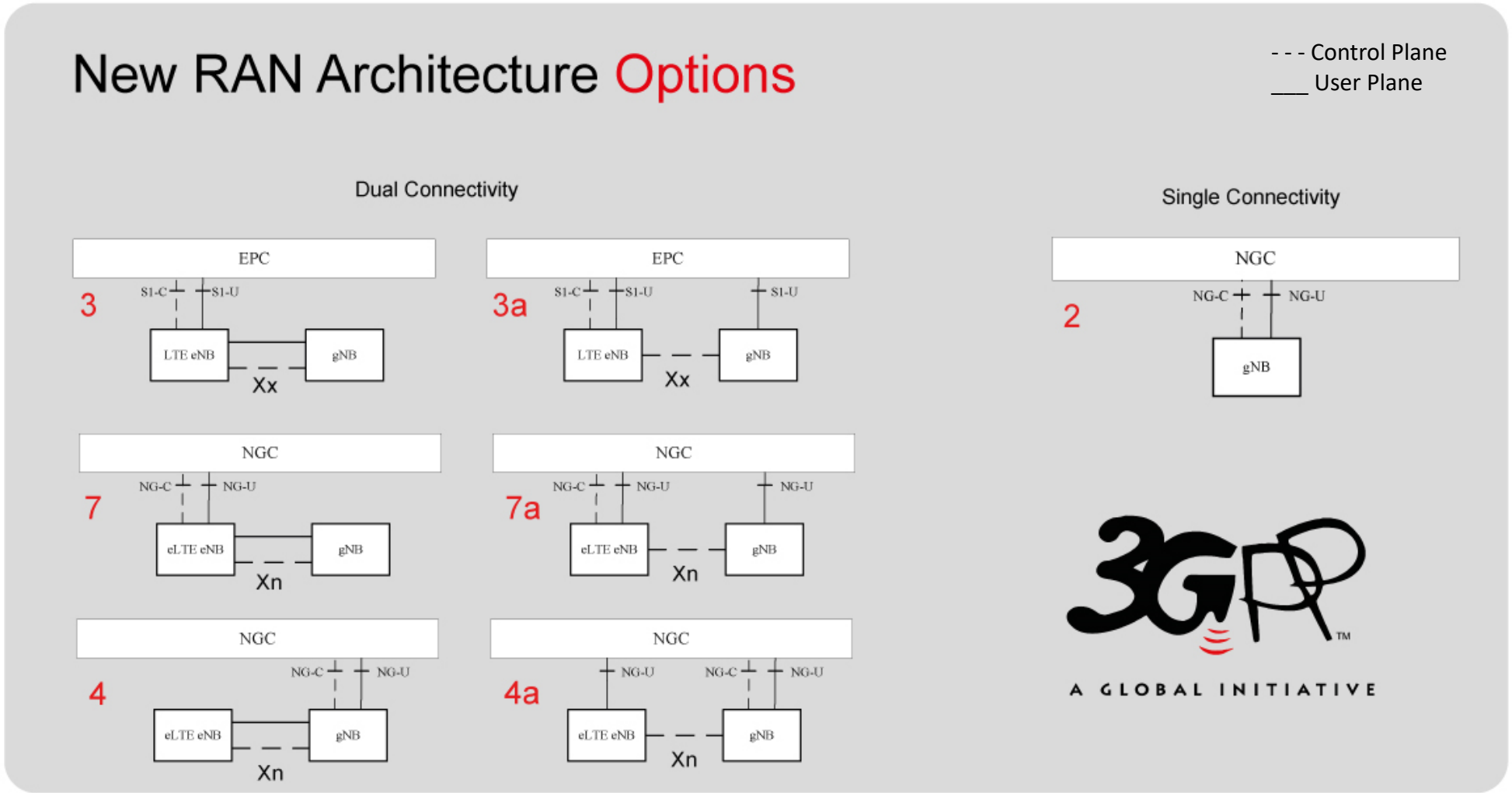
Network Slicing



https://www.3gpp.org/news-events/3gpp-news/sys-architecture

Deployment Options:

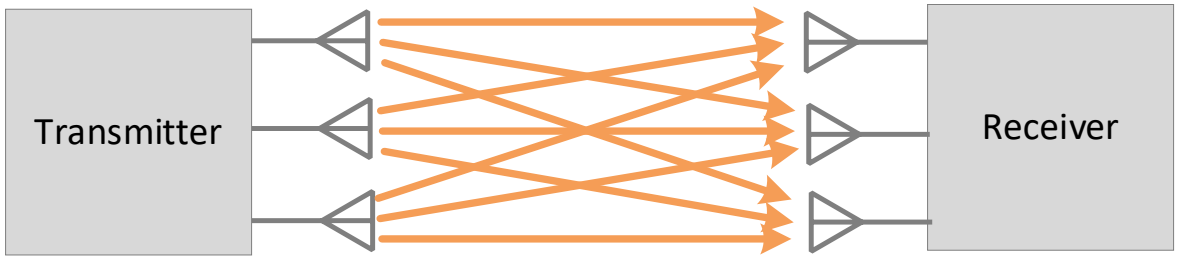
Standalone vs. Non-Standalone



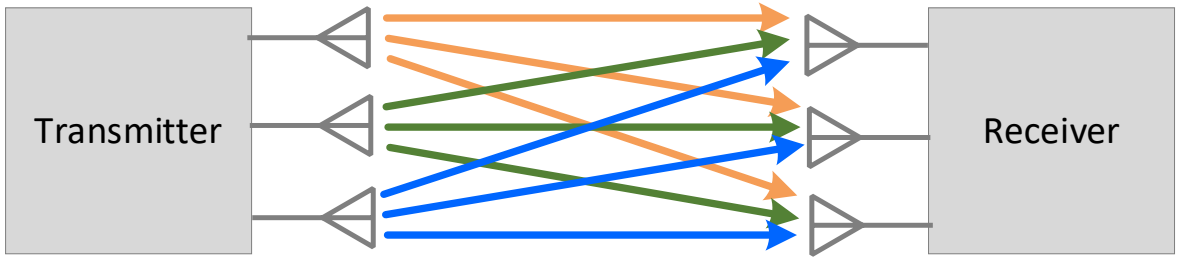
https://www.3gpp.org/news-events/3gpp-news/sys-architecture

Antenna: MIMO
(Multiple Input Multiple Output)

- Spatial Diversity: Improve Coverage



- Spatial Multiplexing: Higher Data Rate (Spectral Efficiency)



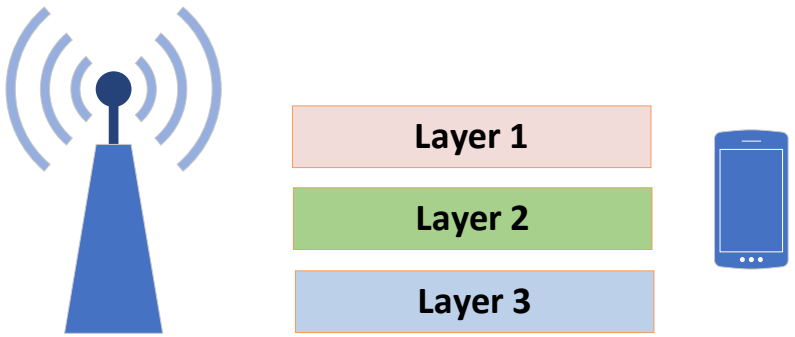
- => mMIMO (massive MIMO)
  - Standard MIMO usually uses 2 or 4 antennas.
  - mMIMO uses as many as 96 to 128 antennas.

Tx arrays	Rx arrays	MIMO
2	2	2*2
4	2	4*2
2	4	2*4
4	4	4*4
8	8	8*8

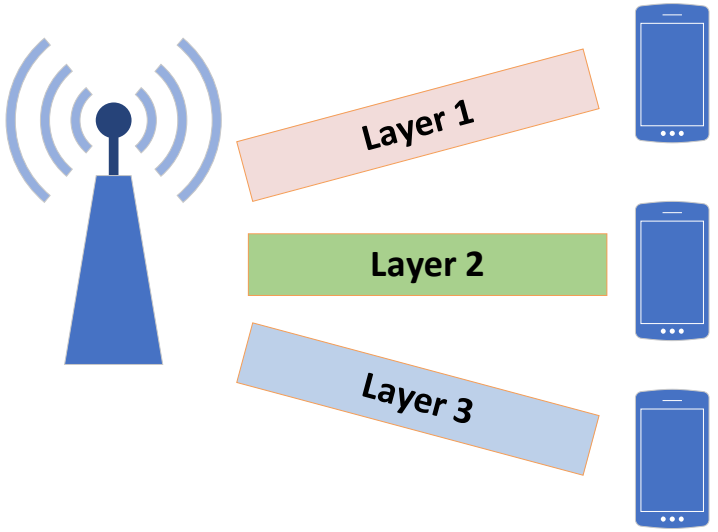
Beaming

Spatial Multiplexing - MIMO

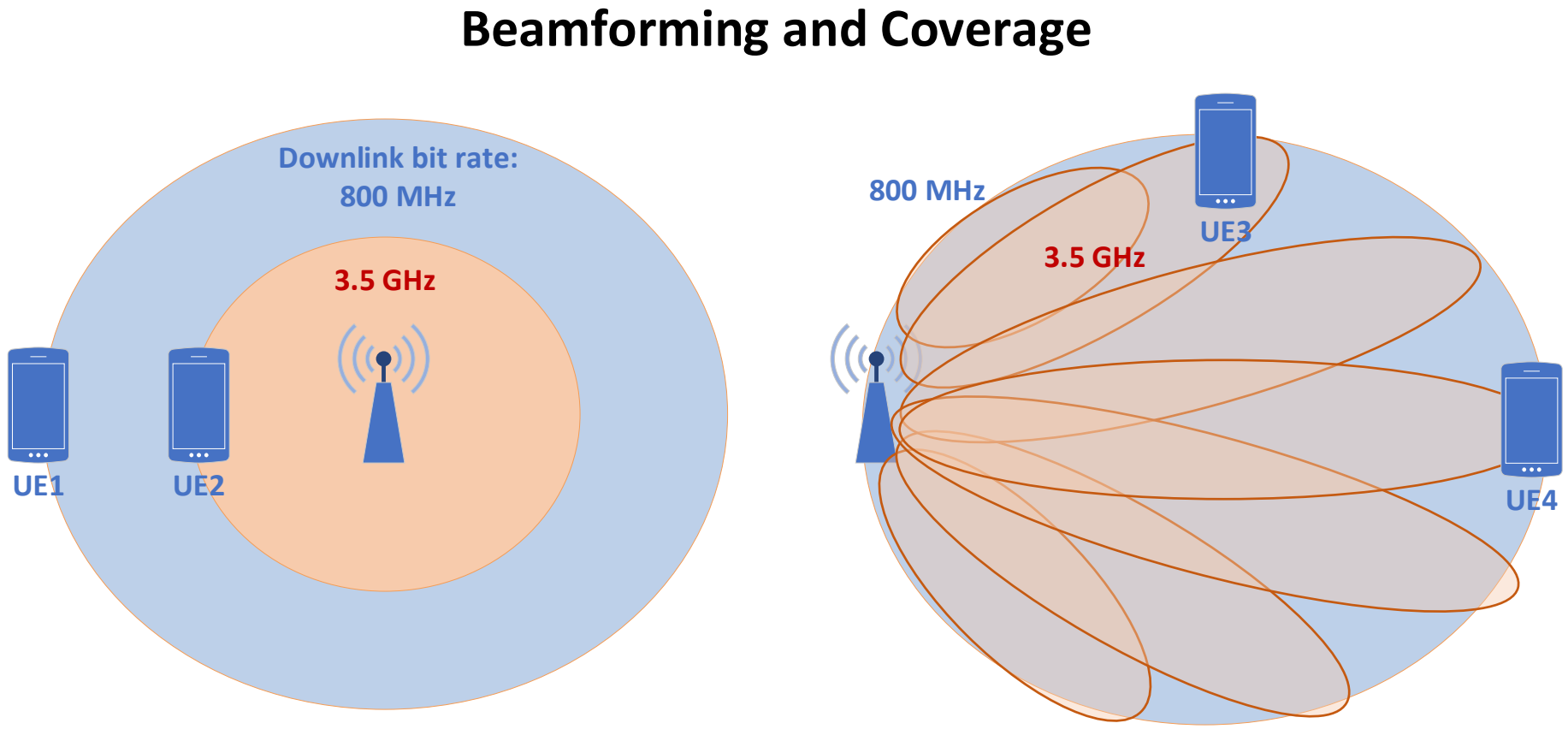
Static Beaming



Dynamic Beaming



Beamforming and Coverage



5G Security Issues

[References] https://en.wikipedia.org/wiki/5G

- The attack surface is getting bigger
  - IoT devices, enabled by 5G technology, from 7 billion in 2018 to 21.5 billion by 2025:
    - (ex) the capacity for DDoS attacks, cryptojacking, and other cyberattacks
  - "immature and insufficiently tested," and "enables the movement and access of vastly higher quantities of data, and thus broadens attack surfaces" Reference: "A Formal Analysis of 5G Authentication," ETH Zurich, the University of Lorraine and the University of Dundee, October 18, 2018

- Fears of potential espionage of users of Chinese equipment vendors

- Electromagnetic Interference

- "The Clean Network"
  - Launched in August, 2020
    - the U.S. State Department launched "The Clean Network" as a U.S. government-led, bi-partisan effort to address:
      - "the long-term threat to data privacy, security, human rights and principled collaboration posed to the free world from authoritarian malign actors".
  - More than 60 nations had publicly committed by December 2020
    - The United States announced that:
      - more than 60 nations, representing more than two thirds of the world's gross domestic product,
      - and 200 telecom companies
    - This alliance of democracies included:
      - 27 of the 30 NATO members; 26 of the 27 EU members, 31 of the 37 OECD nations, 11 of the 12 Three Seas nations as well as South Korea, Japan, Israel, Australia, Singapore, Taiwan, Canada, Vietnam, and India.

Summary & Wrap-up

Summary

- Why 5G Communications?
- Possible Applications using 5G
- Network Fundamentals
- Before 5G Communications
- 5G Communications
- Security Issues
- Summary