Modern Wireless Networks

Cellular Networks

ICEN 574– Spring 2019

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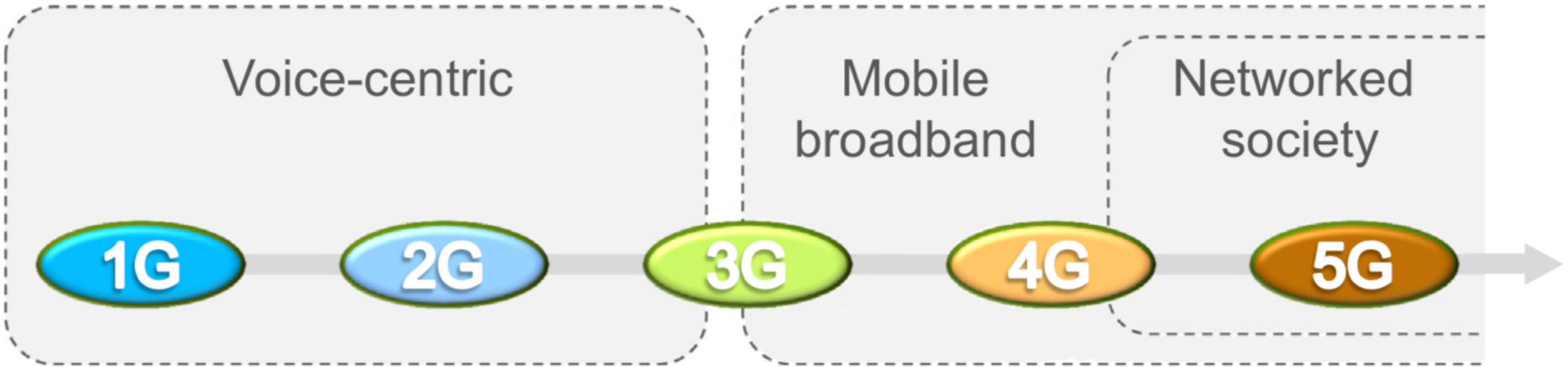
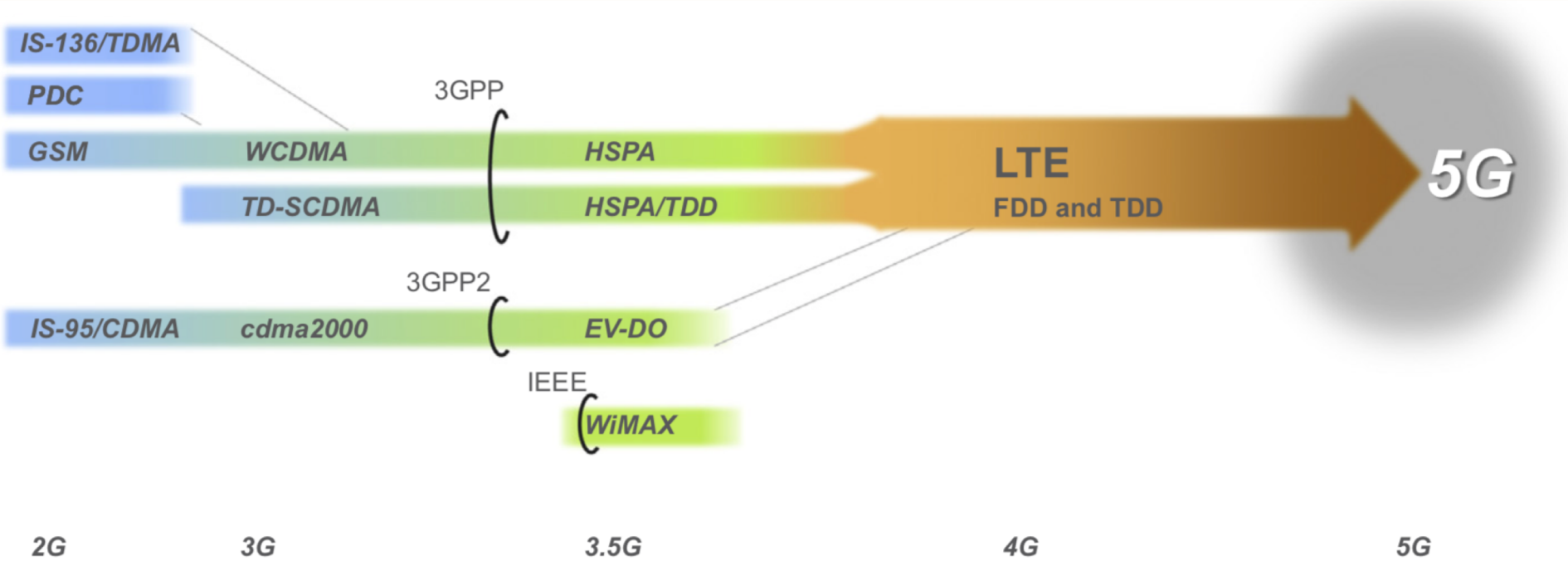
Cellular Generations



Convergence of Wireless Technologies

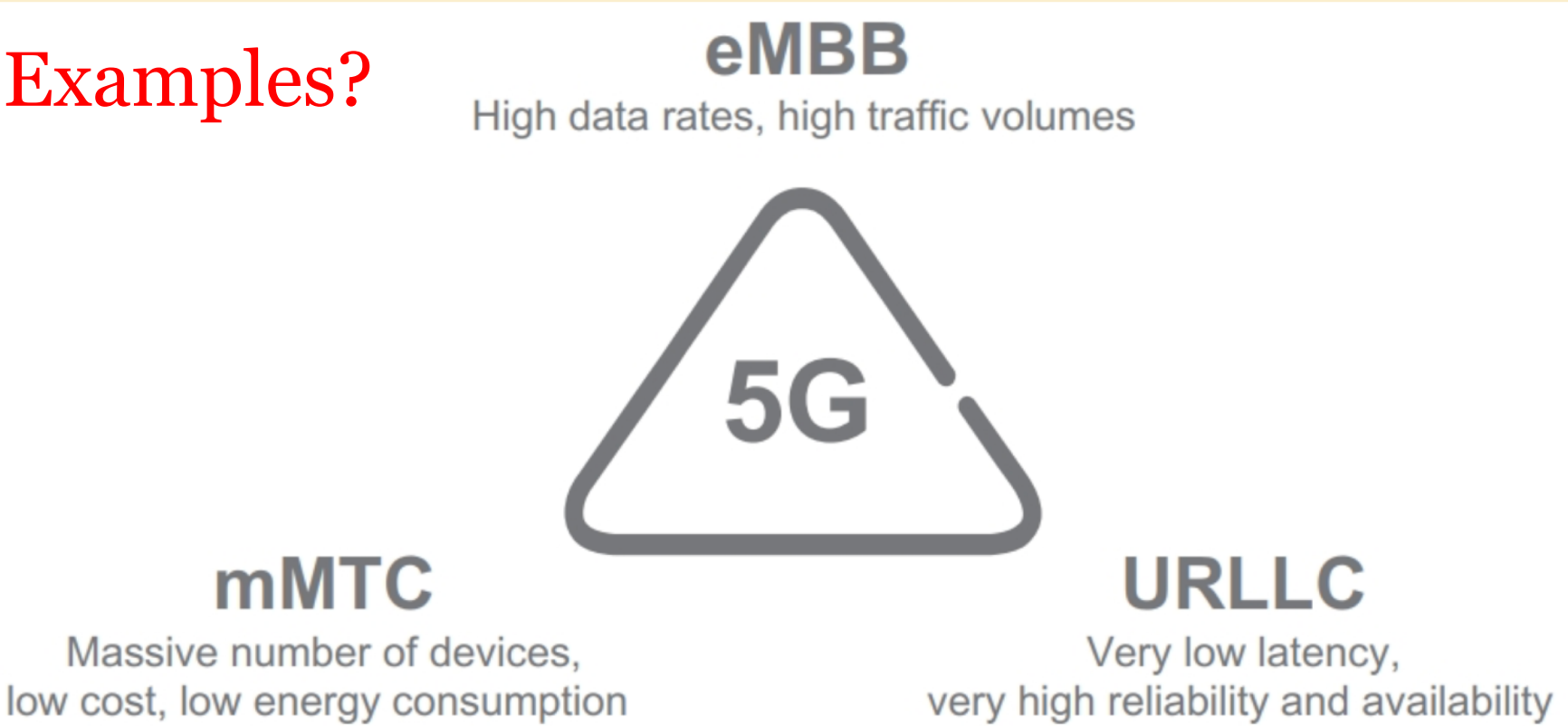


The Next Generation – 5G/NR

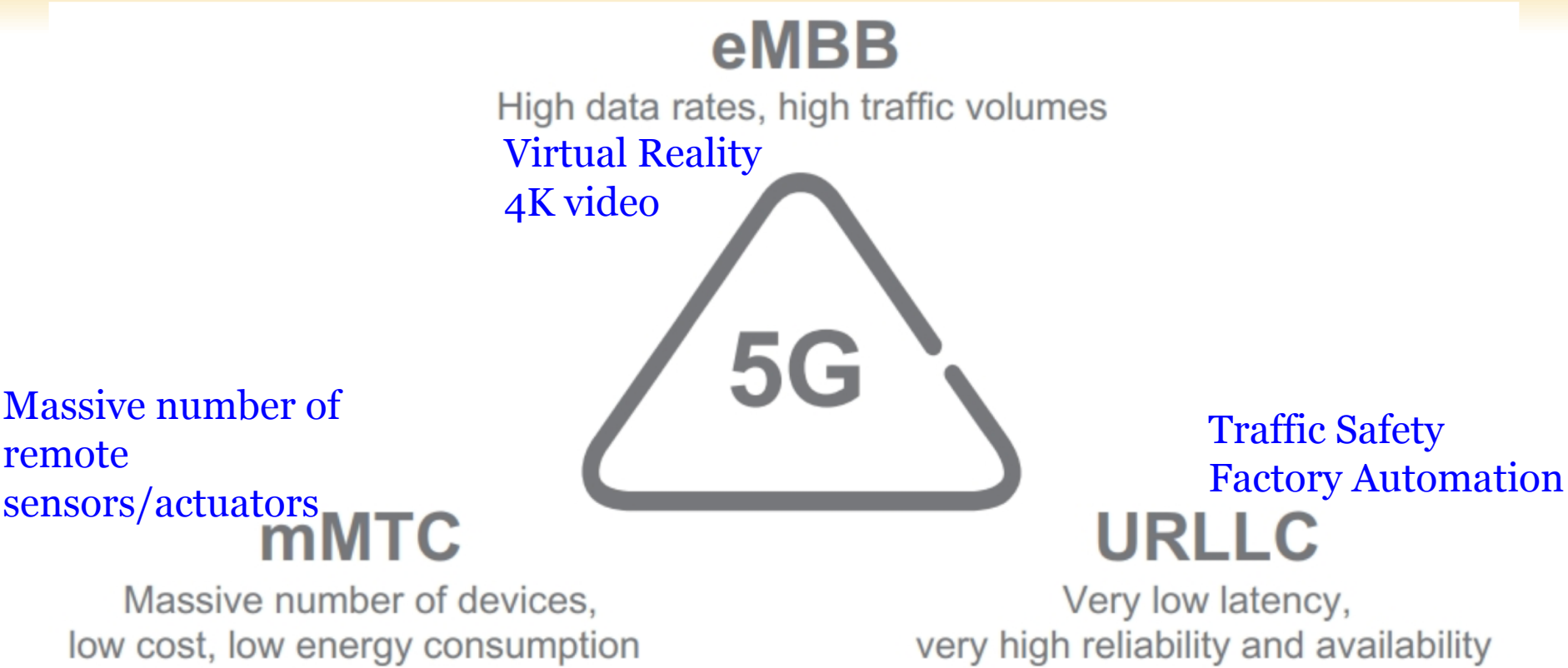
- Discussions on fifth-generation (5G) mobile communication began around 2012.
- The term 5G is *often* used to refer to specific new 5G radio-access technology.
- 5G Use Cases:
  - enhanced mobile broadband (eMBB),
  - massive machine-type communication (mMTC), and
  - ultra-reliable and low-latency communication (URLLC)

5G Use Case Classification

Examples?

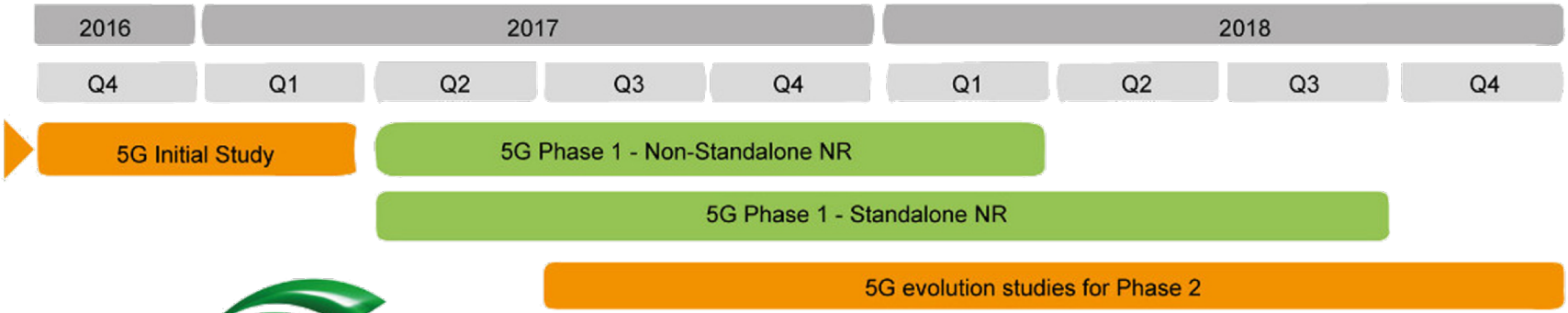


5G Use Case Classification



NR – The New 5G Radio-Access Technology

- All requirements were not met by LTE
- 3GPP initiated the development of a new radio-access technology known as NR (New Radio)



5G

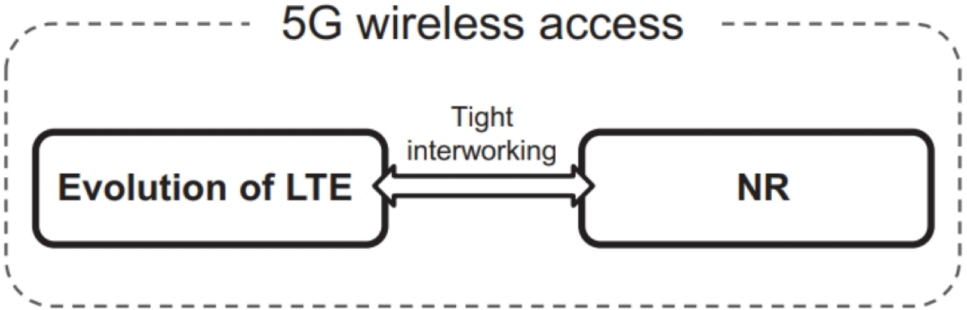
Non-Standalone
Uses LTE core and LTE radio anchor with a 5G small cell
Mobile BroadBand capacity boost

Standalone
Uses 5G core and 5G radio anchor
5G overlay
Expansion of the wireless ecosystem

"5G product supports either 'NG NR' or 'access via a 5G CN' or both."
Erik Guttman, 3GPP SA Chairman

5G Wireless Access

- More Spectrum
- Tight interworking with LTE
- Not restricted to be backward compatible
- Standalone mode
- 5G Core Network (5GCN) is under development



Standardization

- Coordinated international effort by wireless industry
- Depends on Global & Regional regulations
- Interoperability of the products
- Multiple organizations involved in creating technical specifications and standards as well as regulation
  - Standards Developing Organizations (SDOs)
  - Regulatory bodies and administrations
  - Industry Forums

Standards Developing Organizations (SDOs)

- Develop and agree on technical standards for mobile communications systems
- Protocol to communicate is standardized
- Proprietary solutions possible (like scheduling)
- Usually nonprofit industry organizations and not government controlled
- Example: 3GPP

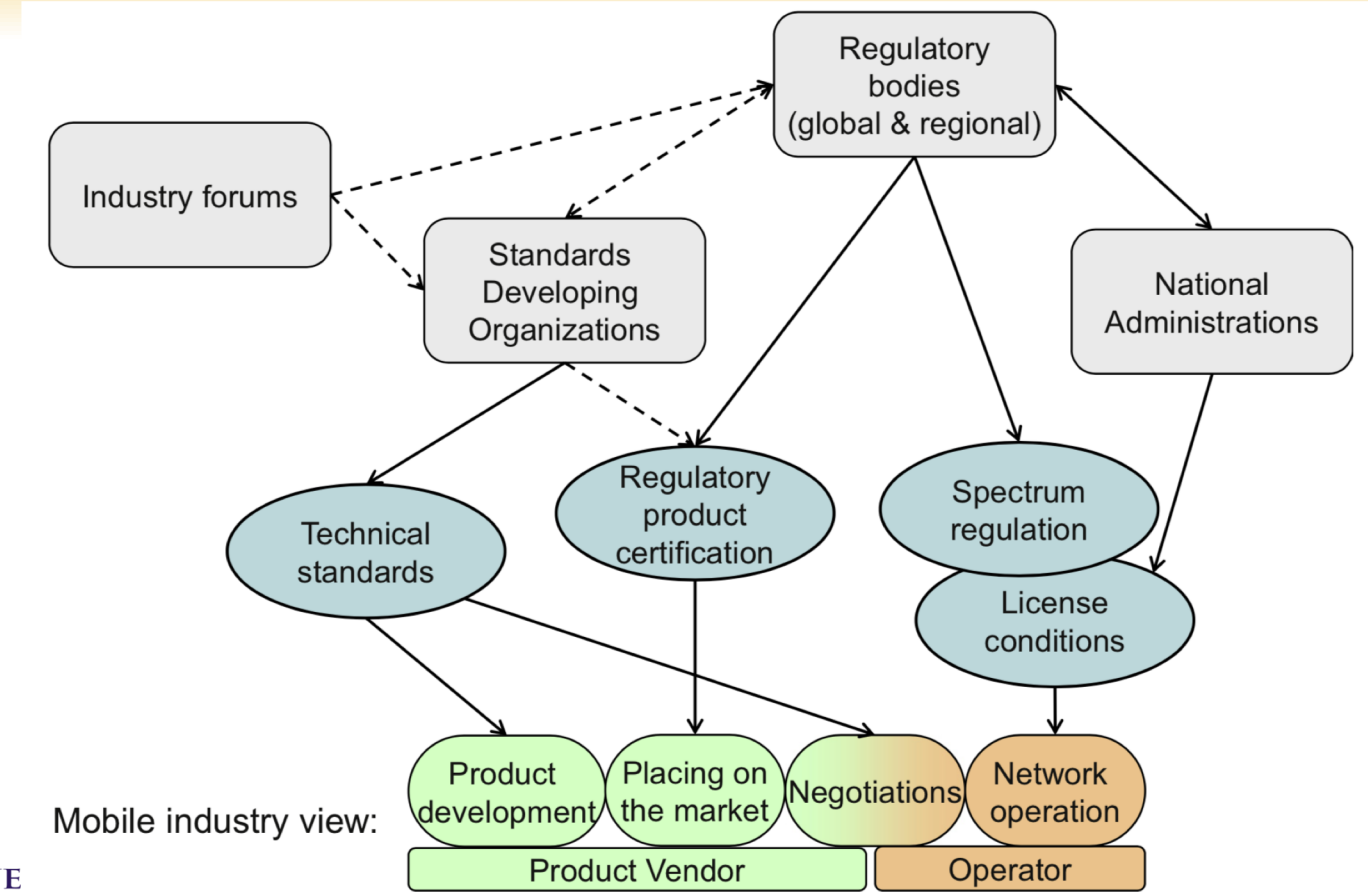
Regulatory bodies and administrations

- Government-led organizations that set regulatory and legal requirements for selling, deploying, and operating mobile systems and other telecommunication products.
- Spectrum allocation, amount of emisions from a Tx.
- International Telecommunications Union (ITU) handles spectrum regulation on a Global level.
- Federal Communications Communications (FCC) for USA.

Industry Forums

- Industry-led groups promoting and lobbying for specific technologies or other interests
- Mostly led by network operators
- Examples: Next Generation Mobile Networks (NGMN), 5G Americas

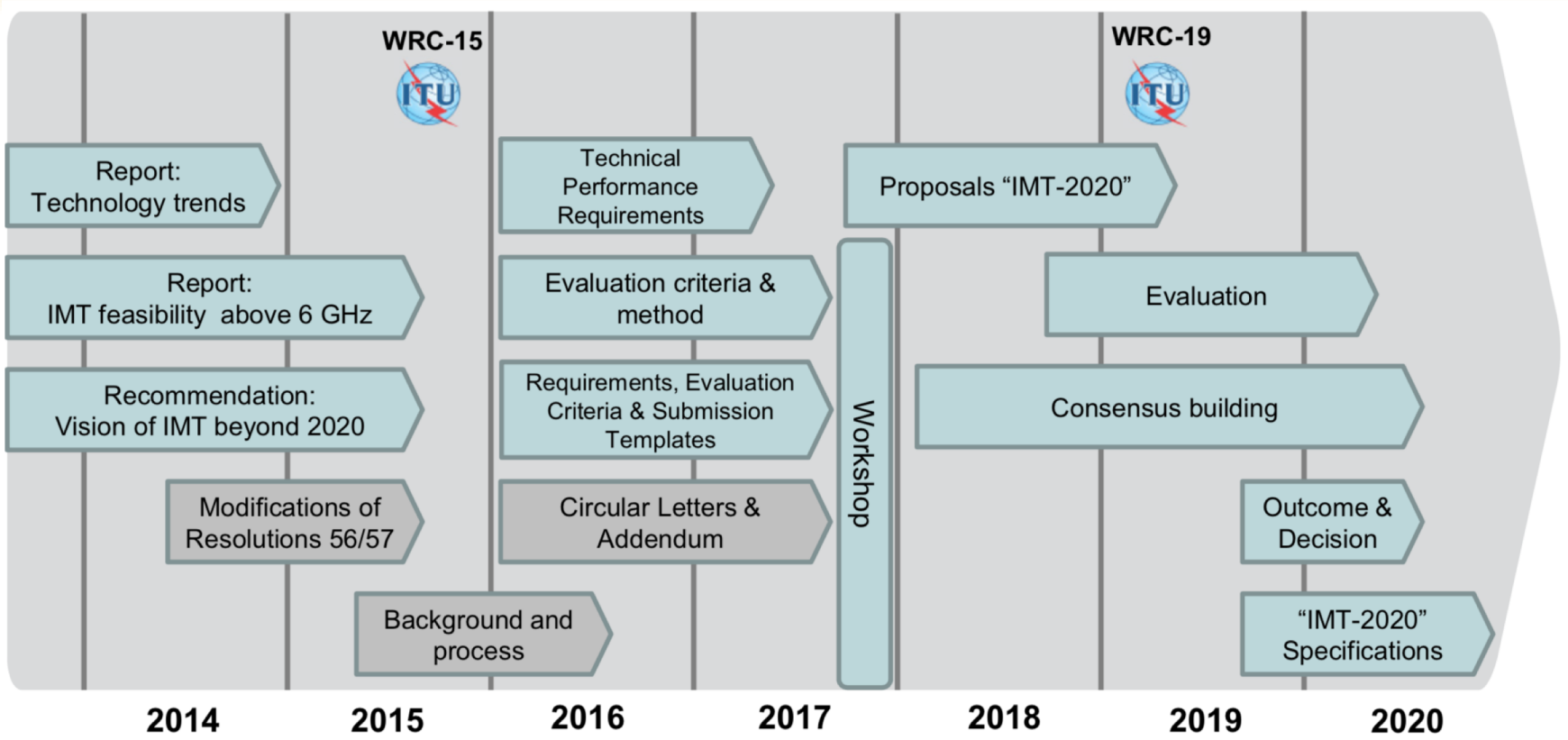
Organizations in Cellular Network



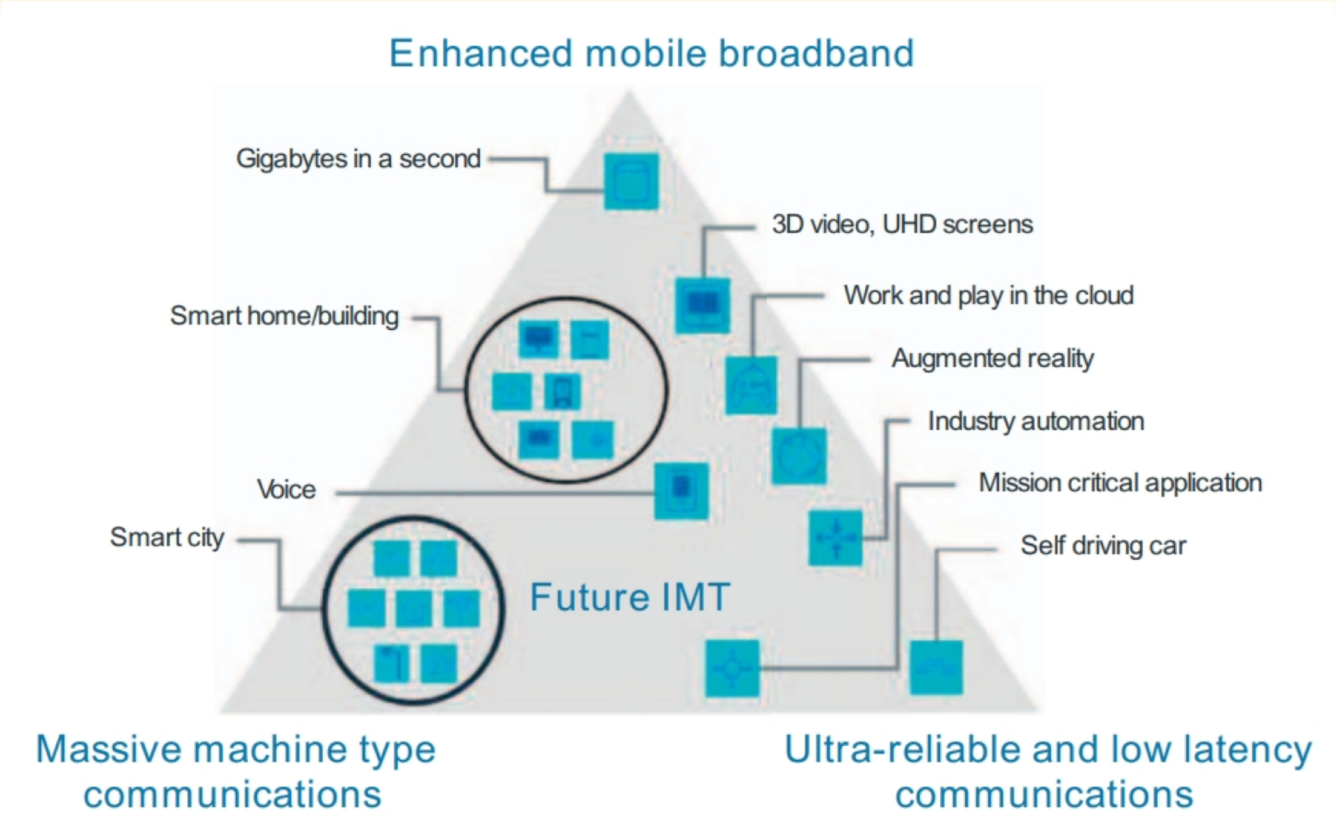
Requirements

- ITU-R is the radio communications sector of the International Telecommunications Union (ITU).
- ITU-R defines the spectrum for different services in the RF spectrum
- International Mobile Telecommunications (IMT) – requirements issued by ITU-R.
- The framework and objective for IMT-2020 is outlined in ITU-R Recommendation M.2083.

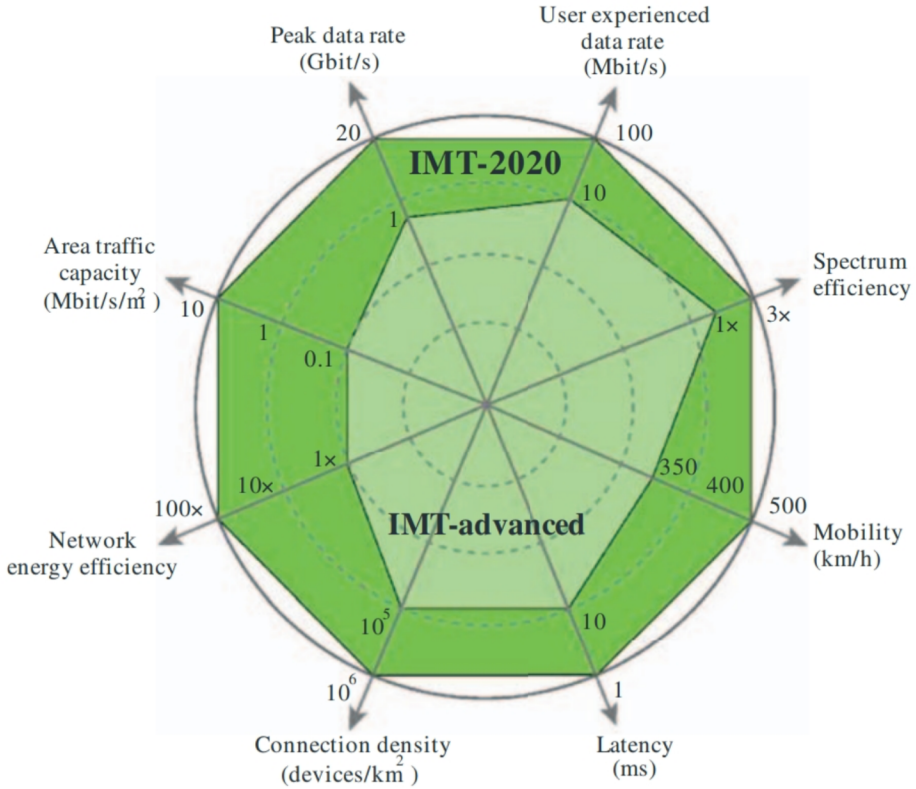
Workplan for IMT-2020 in ITU-R

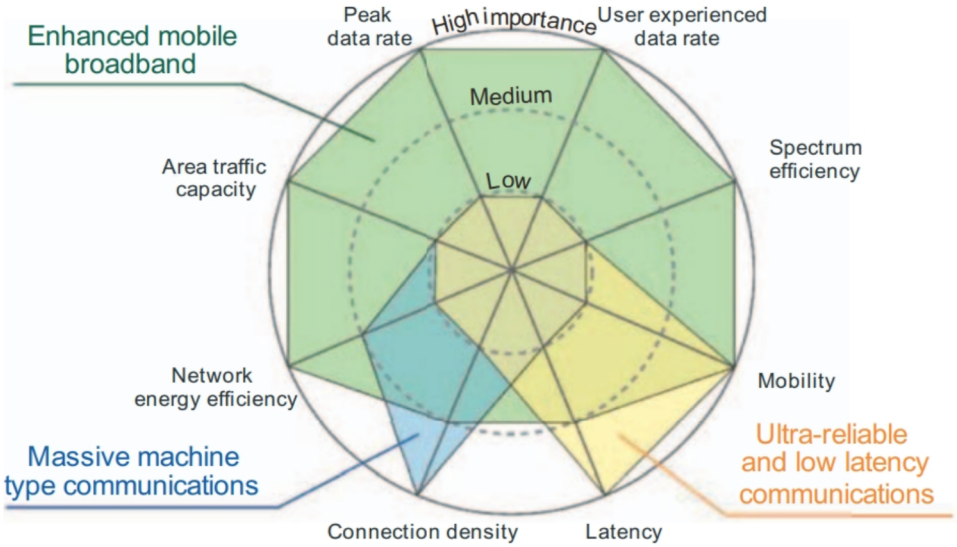


IMT 2020 Requirement from ITU-R M.2083



Recommendation ITU-R M.2083 - Capabilities





Capabilities – IMT 2020

- Peak data rate
  - = System bandwidth x Peak spectral efficiency
- The user experienced data rate
  - the data rate that can be achieved over a large coverage area for a majority of the users
- Spectrum efficiency
  - the average data throughput per Hz of spectrum and per "cell" (or TRP)
- Area traffic capacity
  - = Spectrum efficiency x BW x TRP density

TRP- Transmission/Reception Point

Capabilities – IMT 2020

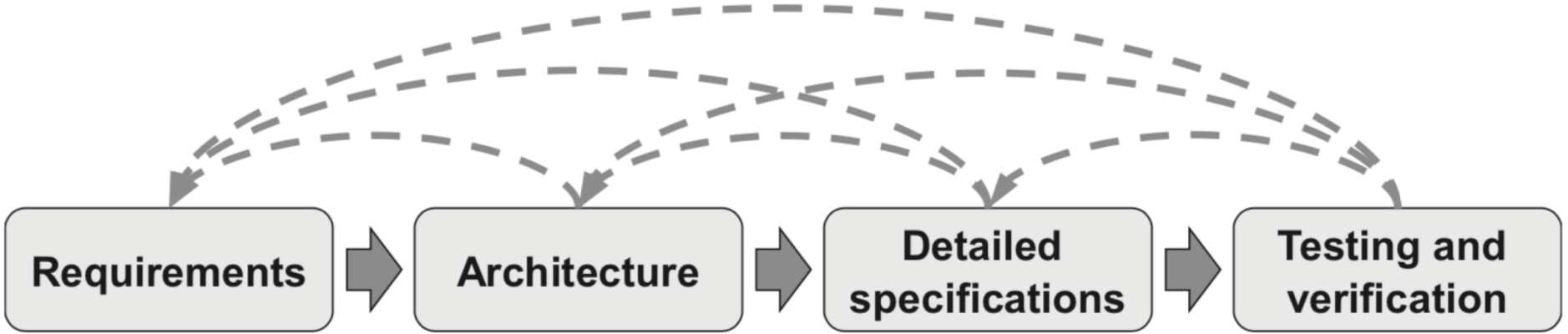
- Network energy efficiency
  - Energy consumed per bit of data (Tx & Rx)
- Latency (10 fold reduction compared to IMT Advanced)
- Mobility (500Km/hr)
- Connection Density

Additional Capabilities – IMT 2020

- Spectrum and bandwidth flexibility
- Reliability (very high level of availability)
- Resilience (operate correctly after disturbance)
- Security & Privacy
- Operational lifetime (example, machine-type devices requiring a very long battery life > 10 years)

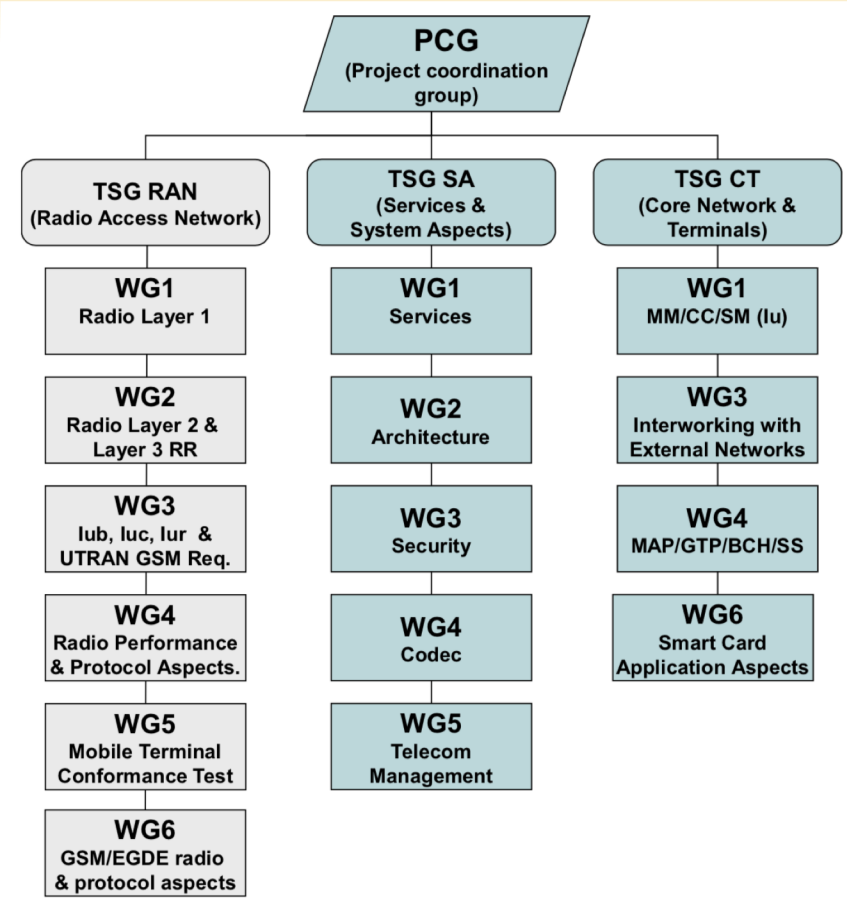
3GPP Standardization

- Requirements: what is to be achieved by the specification.
- Architecture: the main building blocks and interfaces are decided.
- Detailed specifications: every interface is specified in detail.
- Testing and verification: the interface specifications are proven to work with real-life equipment.



3GPP Technical Specifications Groups

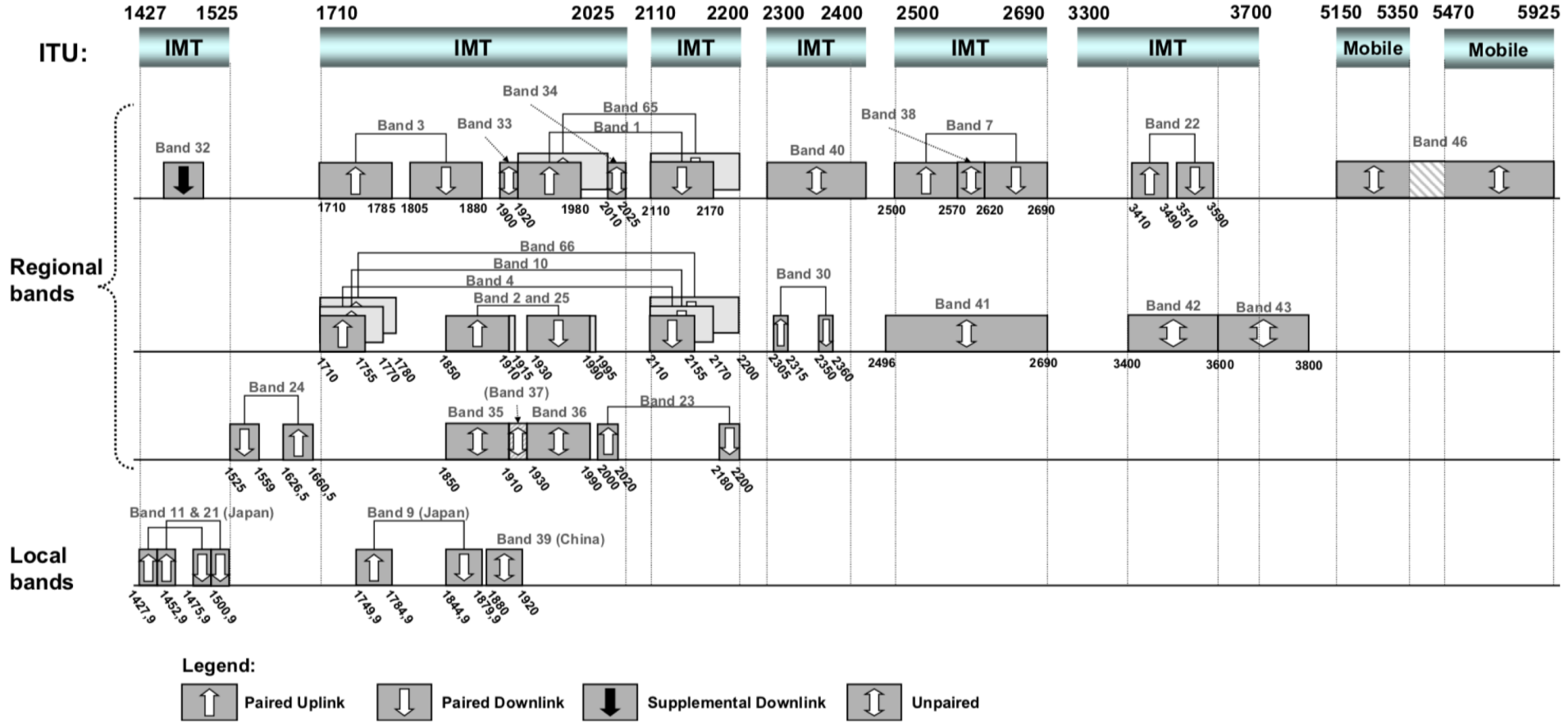
- RAN
- Services & System Aspects
- Core Network & Terminals



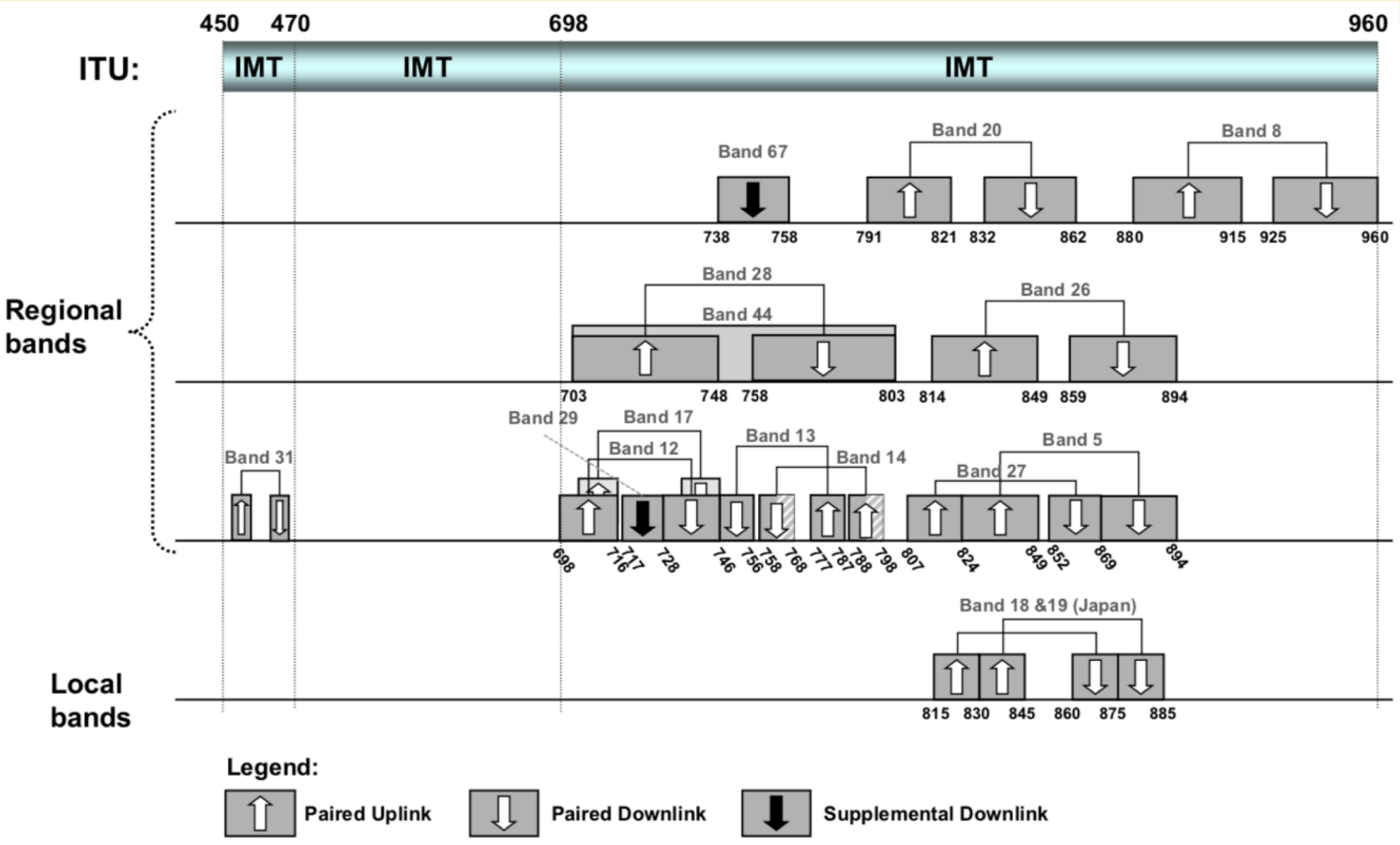
Spectrum for LTE

- Paired bands
  - separated frequency ranges are assigned for uplink and downlink
  - used for Frequency Division Duplex (FDD) operation
- Unpaired bands
  - single shared frequency range for both uplink and downlink
  - used for Time Division Duplex (TDD) operation
- Unpaired downlink only bands
  - used for carrier aggregation for supplemental downlink

Bands allocated above 1GHz for LTE



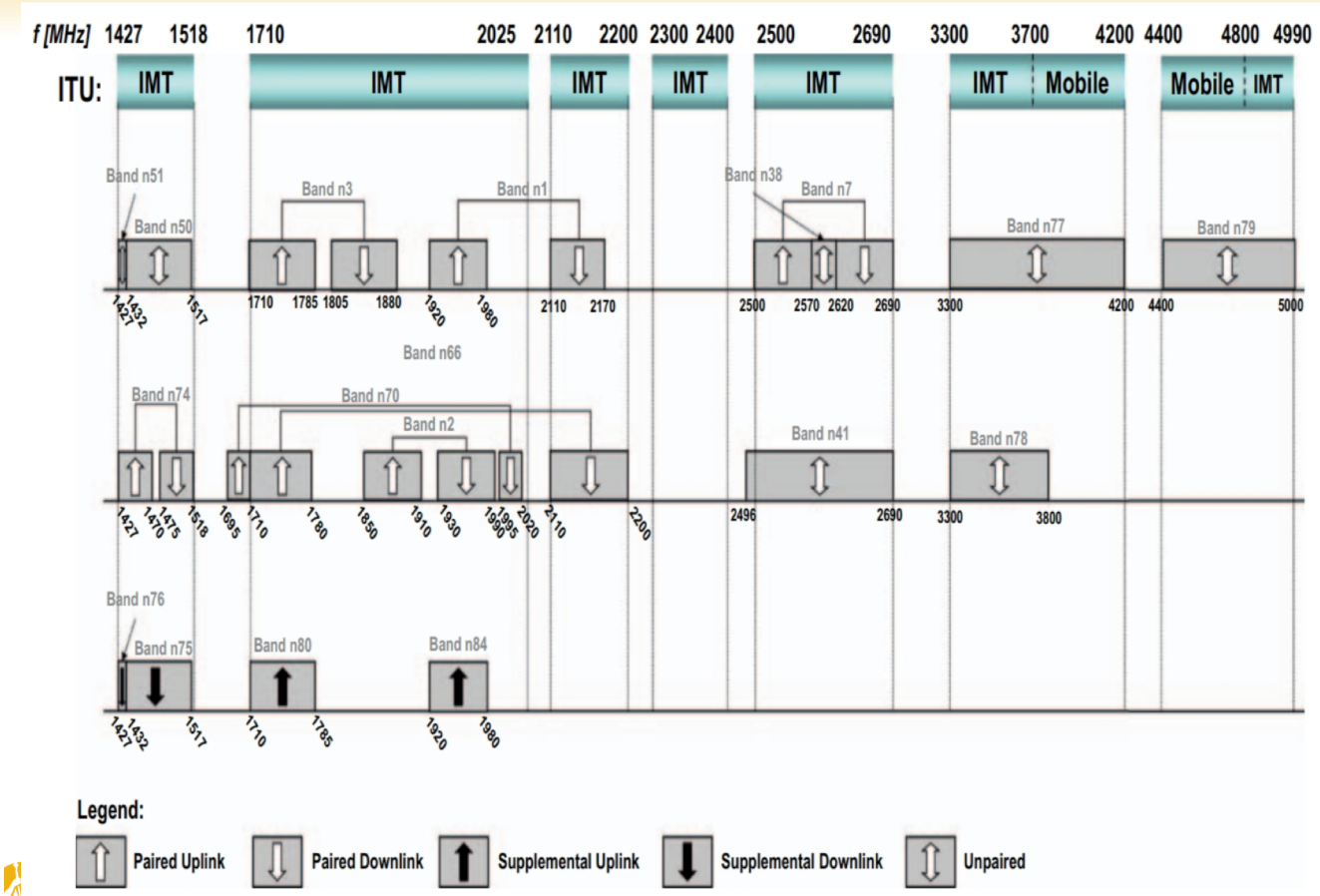
Bands Allocated below 1GHz for LTE



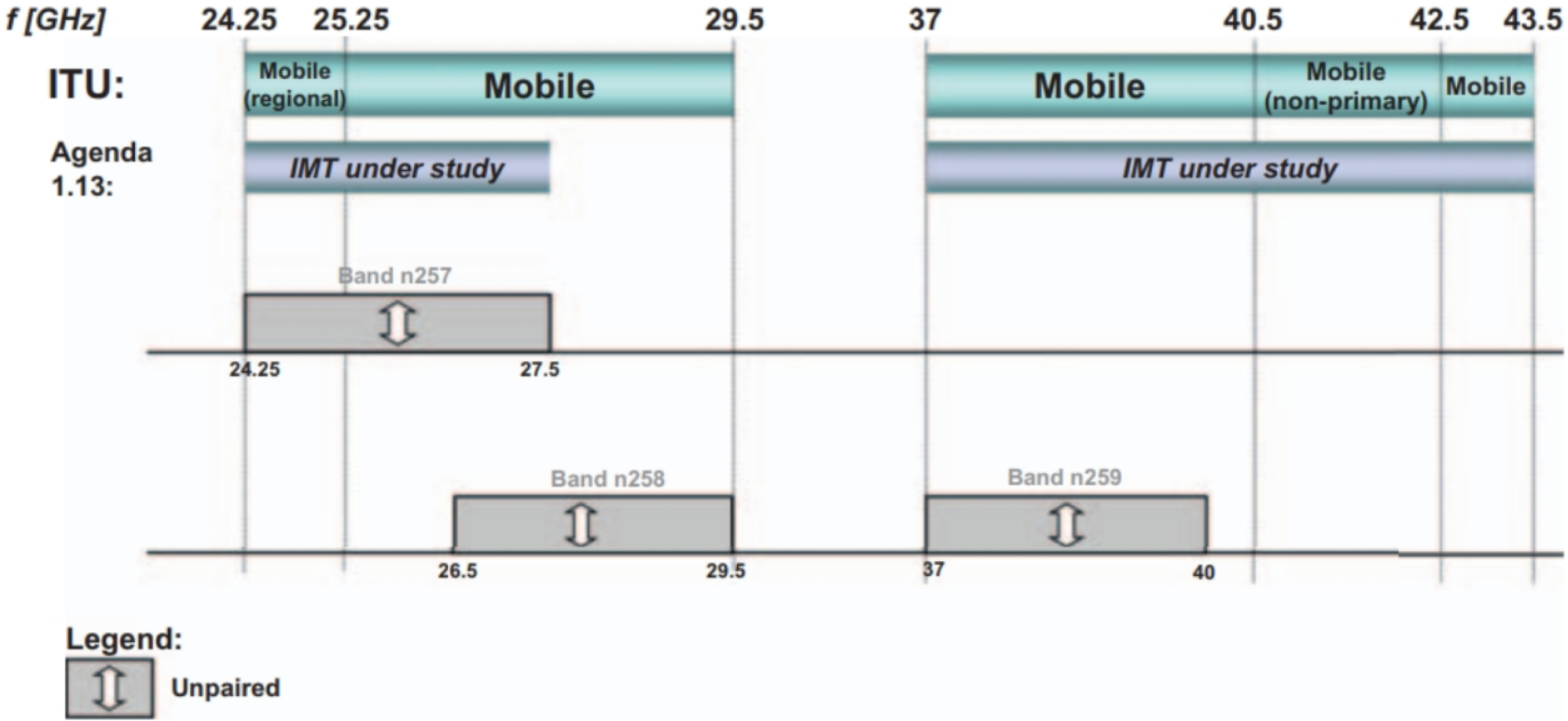
Spectrum for 5G (All bands in LTE + More)

- Bands to be studied already assigned to the mobile service on a primary basis
  - 24.25-27.5 GHz
  - 37-40.5 GHz
  - 42.5-43.5 GHz
  - 45.5-47 GHz
  - 47.2-50.2 GHz
  - 50.4-52.6 GHz
  - 66-76 GHz
  - 81-86 GHz
- Bands to be studied not assigned to the mobile service on a primary basis
  - 31.8-33.4 GHz (aeronautical and shipborne radar)
  - 40.5-42.5 GHz (satellite)
  - 47-47.2 GHz (amateur satellite radio)

Bands for 5G NR in FR1 (below 6 GHz)



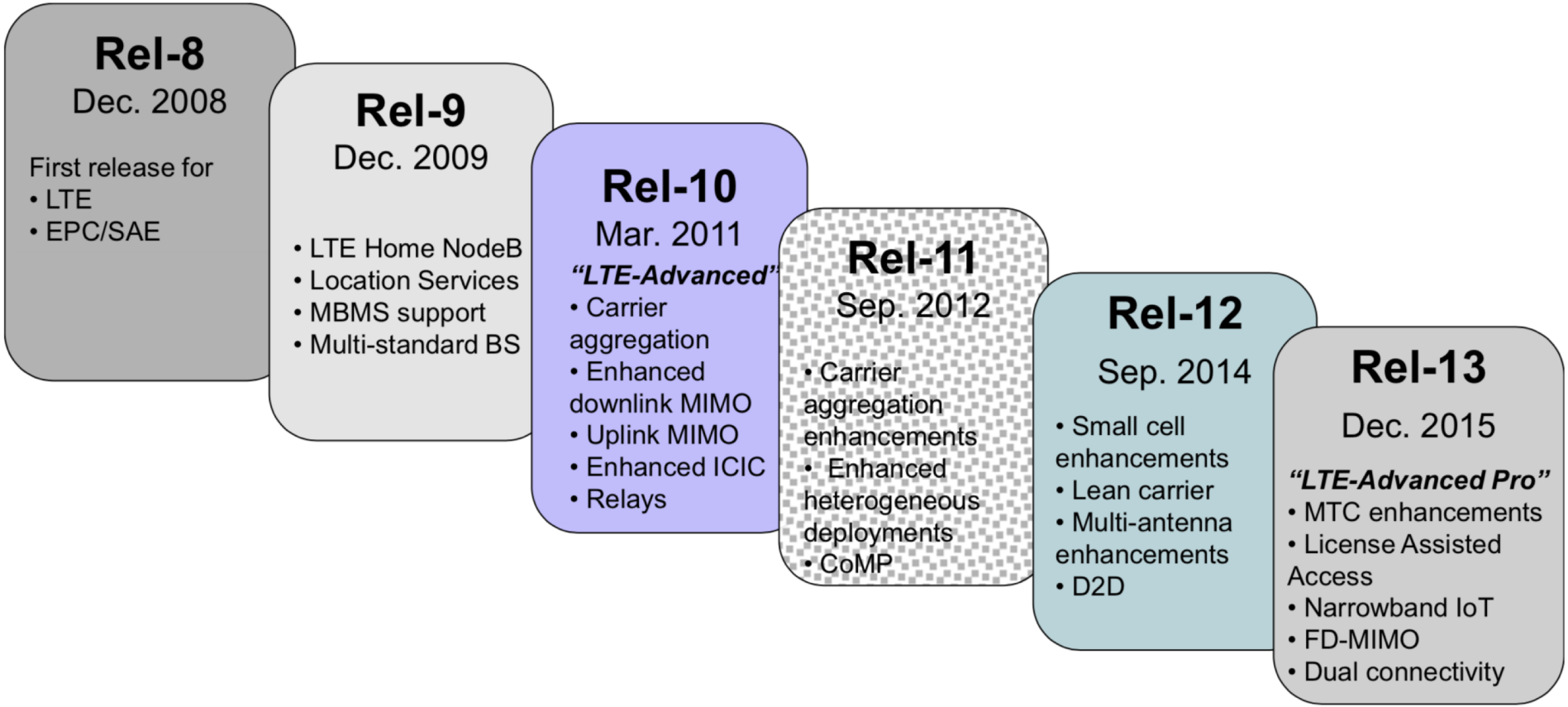
Bands for 5G NR in FR2 (24.2-52.6 GHz.)



RF Exposure Limits

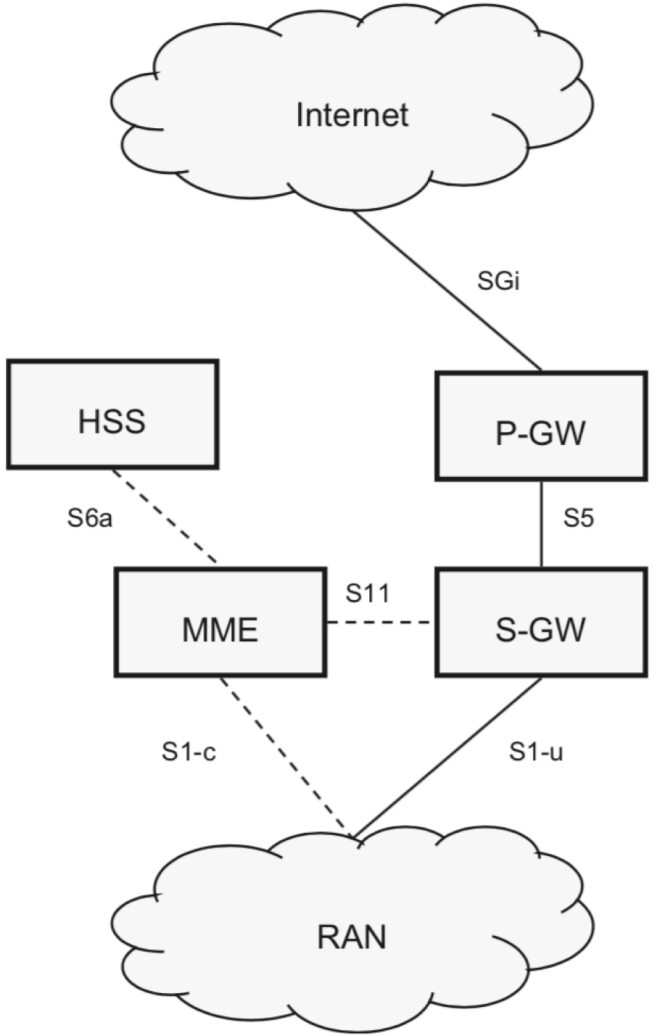
- Mandated
  - Recommended by International Commission on Non-Ionizing Radiation (ICNIRP)
  - Specified by the Federal Communications Commission (FCC) in the US
- Set with wide safety margins to protect against excessive heating of tissue due to energy absorption
- Energy absorption in tissue becomes increasingly superficial with increasing frequency, and thereby more difficult to measure
- To be compliant with ICNIRP at the higher frequencies, the transmit power might have to be **up to 10 dB below** the power levels used for current cellular technologies

LTE Releases



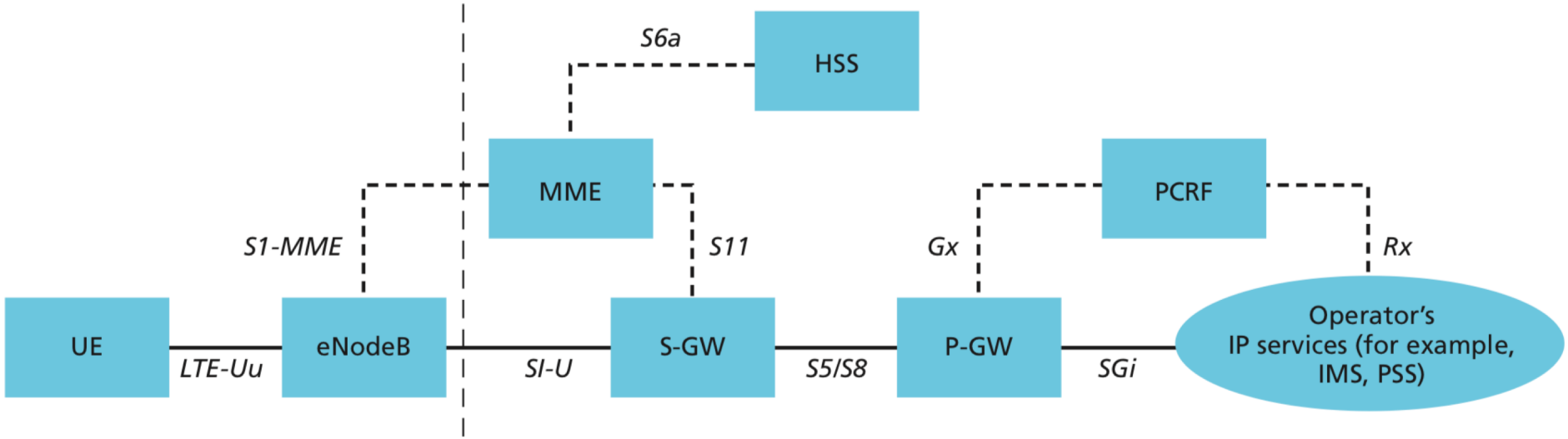
LTE Core Network Architecture

- RAN: Radio Access Network
- S-GW: Serving Gateway
- P-GW: Packet Data Network Gateway
- MME: Mobility Management Entity
- HSS: Home Subscriber Service
- EPC: Evolved Packet Core
- EPC and LTE RAN is together termed EPS (Evolved Packet Service)



Path to Internet

- User Equipment (UE) to the Internet



Evolved Packet System (EPS)

- RAN: Radio related functionalities
  - scheduling, radio-resource handling, retransmission protocols, cod- ing, and various multi-antenna schemes
- EPC: functionalities needed for providing a complete mobile-broadband network
  - authentication, charging functionality, and setup of end-to-end connections
- Why two separate entities?

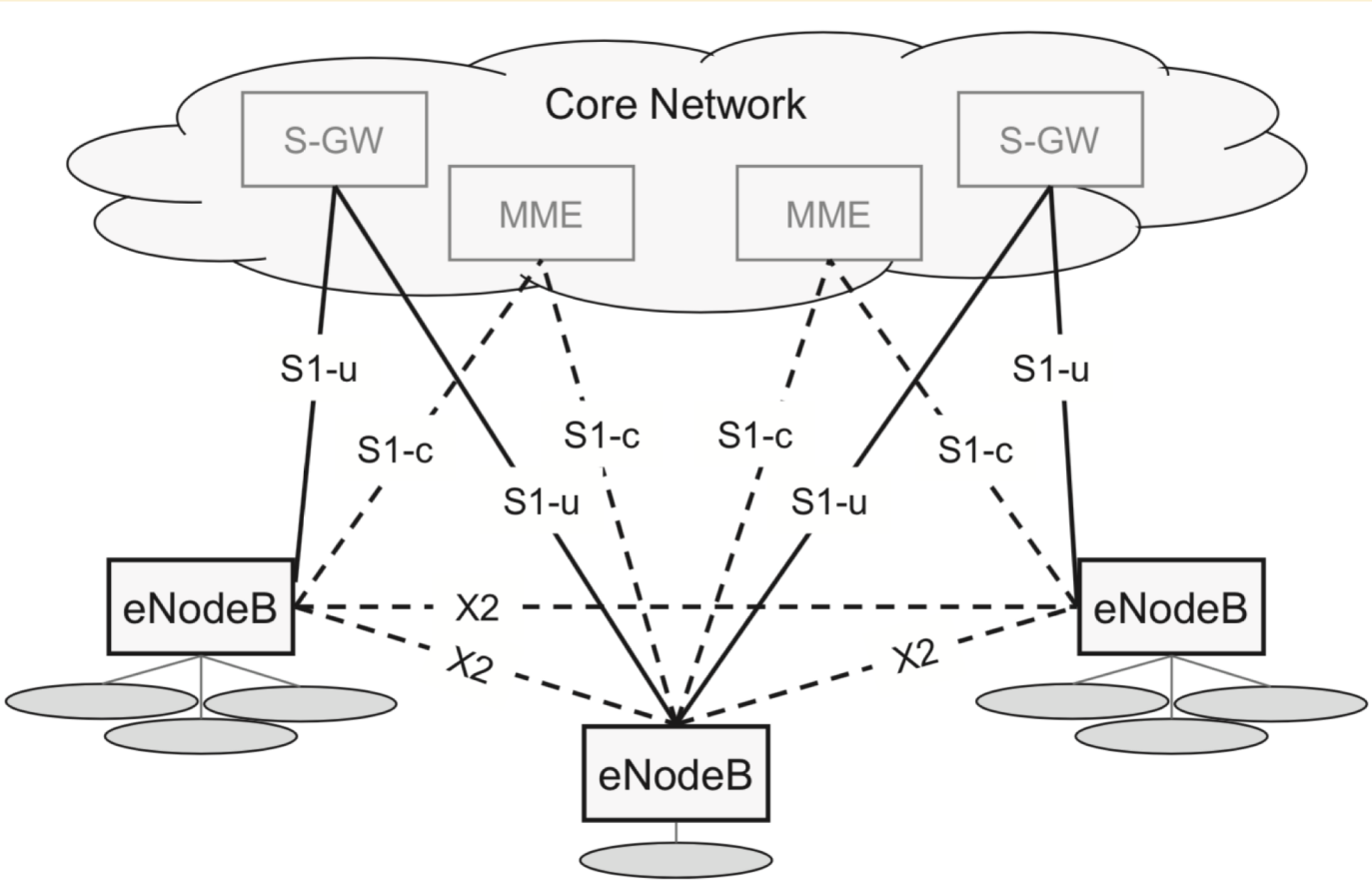
Modules of EPC

- MME
  - Control-plane node of the EPC.
  - Handles connection/release of bearers to a device, handling of IDLE to ACTIVE transitions, and handling of security keys.
- S-GW
  - User-plane node connecting the EPC to the LTE RAN.
  - The S-GW acts as a mobility anchor when devices move between eNodeBs.
  - Collection of information and statistics necessary for charging is also handled by the S-GW.

Modules of EPC

- P-GW
  - connects the EPC to the internet
  - Allocation of the IP address for a specific device
  - quality- of-service (QoS) enforcement
- HSS
  - a database containing subscriber information
- Other modules:
  - Multimedia Broadcast Multicast Services (MBMS)
  - The Policy Control and Charging Rules Function (PCRF)

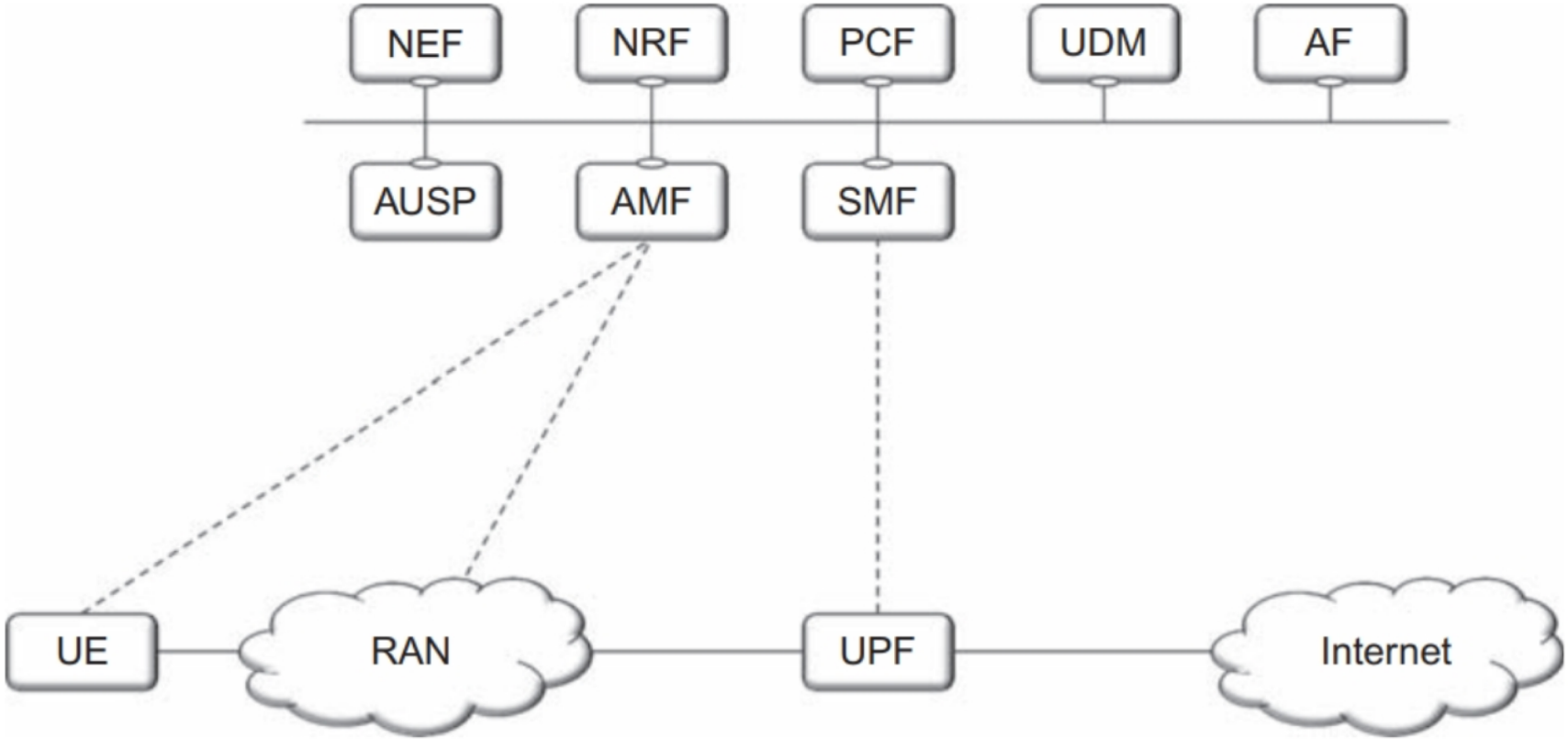
Radio Access Network Interfaces



eNodeB

- eNodeB:
  - logical representation
  - physical implementation can be a three-sector BS
  - can be a BBU pool, where RRH are connected remotely
- Interfaces:
  - S1: connection between eNB and EPC (S1-U and S1-C)
  - X2: connecting eNBs for active mode mobility, multi-cell radio resource management (RRM)

5G Core Network Architecture



Modules of 5G

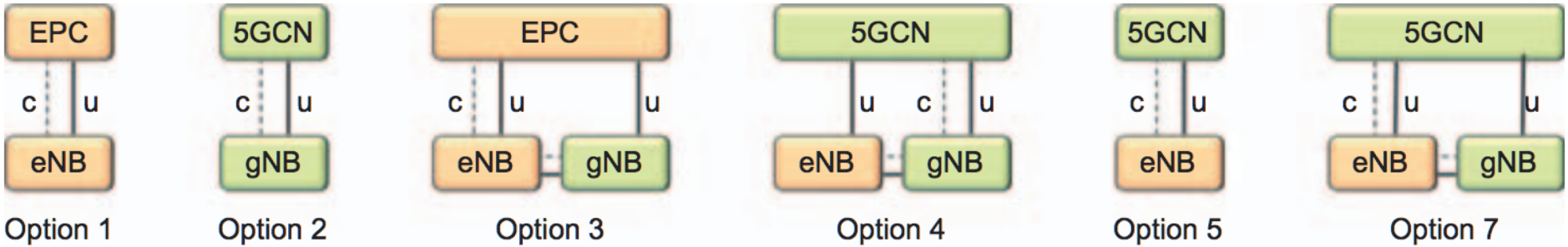
- User Plane Function (UPF):
  - Gateway between the RAN and external networks such as the Internet.
  - Handles packet routing and forwarding, packet inspection, quality-of-service handling and packet filtering, and traffic measurements.
  - Serves as an anchor point for (inter-RAT) mobility when necessary.
- Session Management Function (SMF):
  - Handles IP address allocation for the UE, control of policy enforcement, and general session-management functions.

Modules of 5G

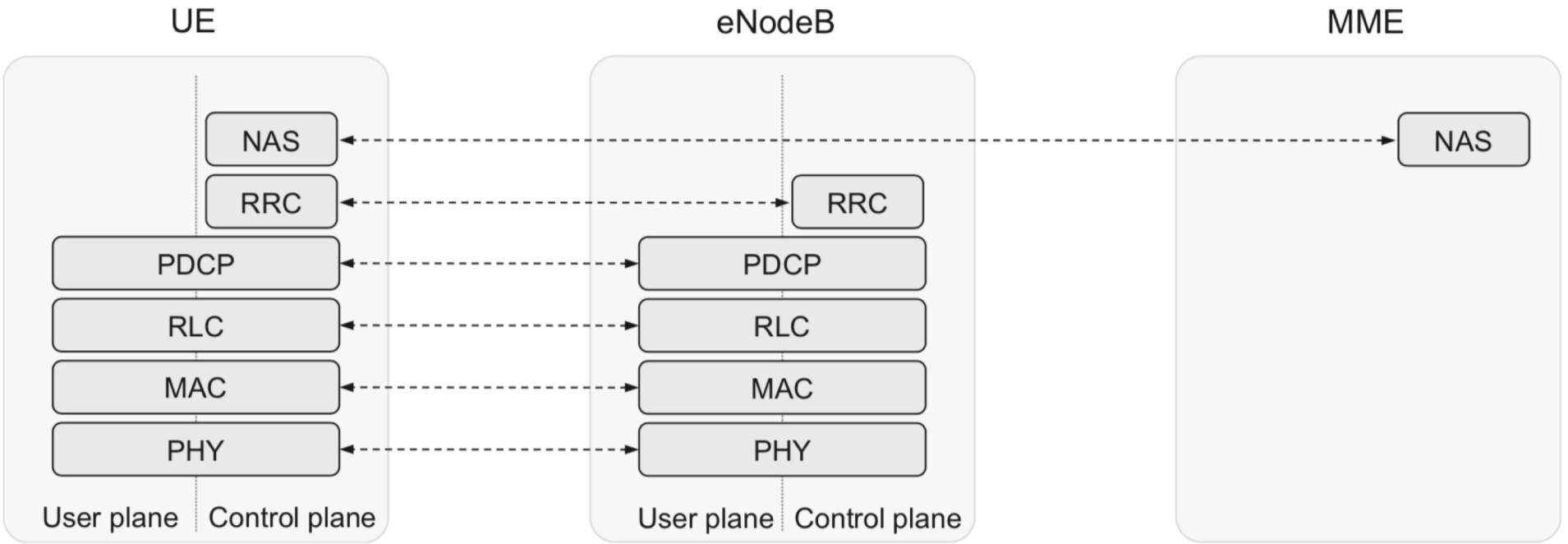
- The Access and Mobility Management Function (AMF):
  - handles control signaling between the core network and the device, security for user data, idle-state mobility, and authentication.
- Other functions:
  - the Policy Control Function (PCF) responsible for policy rules,
  - the Unified Data Management (UDM) responsible for authentication credentials and access authorization
  - the Network Exposure Function (NEF)
  - the NR Repository Function (NRF)
  - the Authentication Server Function (AUSF) handing authentication functionality
  - the Application Function (AF).

Combinations of Core Networks and RATs

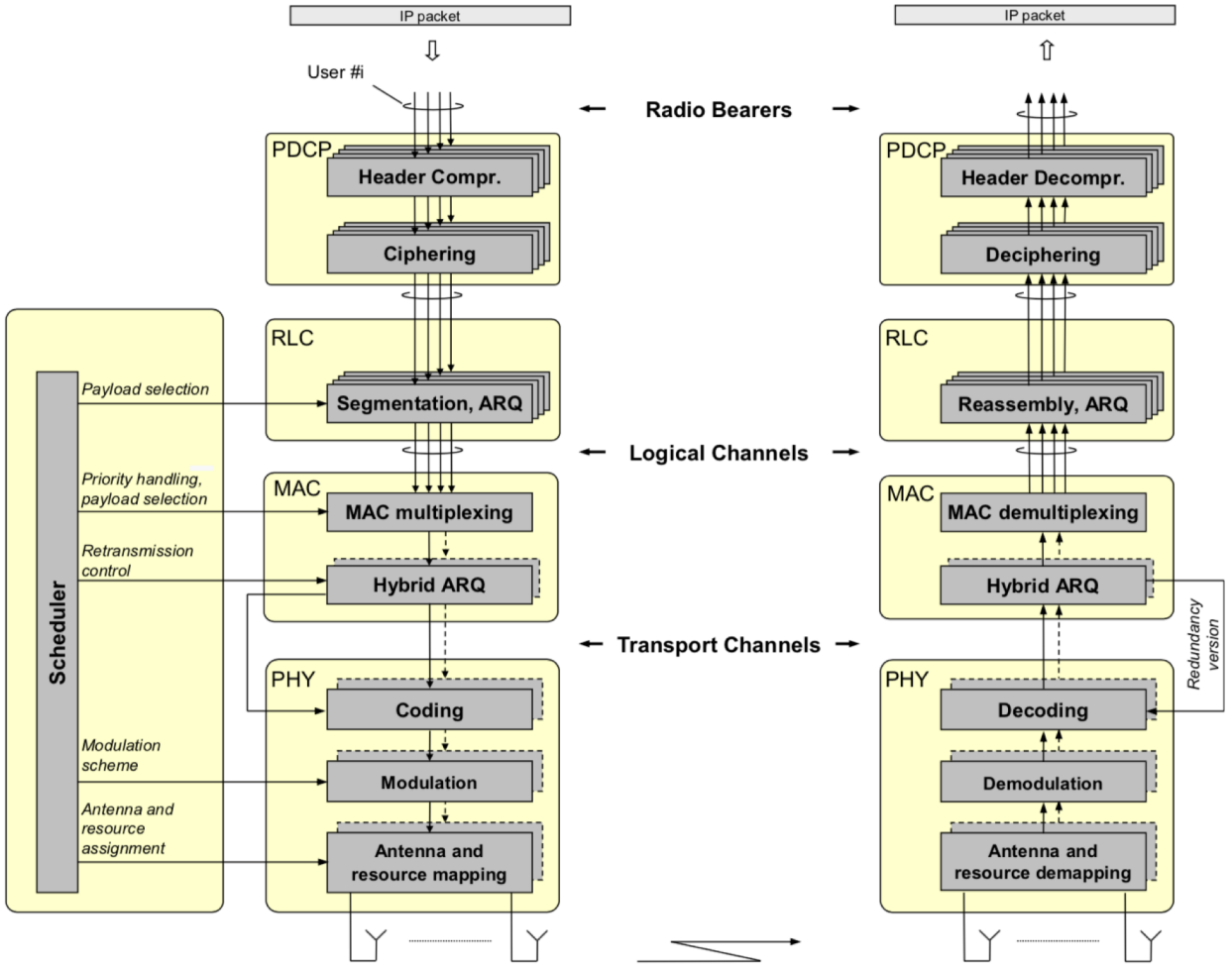
- eNodeB – evolved Node B
- gNodeB – generalized Node B



RAN Protocol Architecture



Protocol



eNodeB

mobile terminal (UE)

Protocol Entities of the RAN

- Packet data convergence protocol (PDCP)
  - performs IP header compression, ciphering, and integrity protection.
  - handles in-sequence delivery and duplicate removal in case of handover.
- Radio-link control (RLC)
  - responsible for segmentation/concatenation, retransmission handling, duplicate detection, and in-sequence delivery to higher layers.
  - provides services to the PDCP.

Protocol Entities of the RAN

- Medium-access control (MAC)
  - handles multiplexing of logical channels, hybrid-ARQ retransmissions, and uplink and downlink scheduling.
  - The scheduling functionality is located in the eNodeB for both uplink and downlink.
  - The hybrid-ARQ protocol part is present in both the transmitting and receiving ends of the MAC protocol.
  - The MAC provides services to the RLC in the form of logical channels.

Protocol Entities of the RAN

- Physical layer (PHY)
  - coding/decoding, modulation/demodulation, multi-antenna mapping, and other typical physical-layer functions.
  - The physical layer offers services to the MAC layer in the form of transport channels.

LTE Data Flow