3GPP LTE/5G Networks
- Introduction to Cellular Networks -

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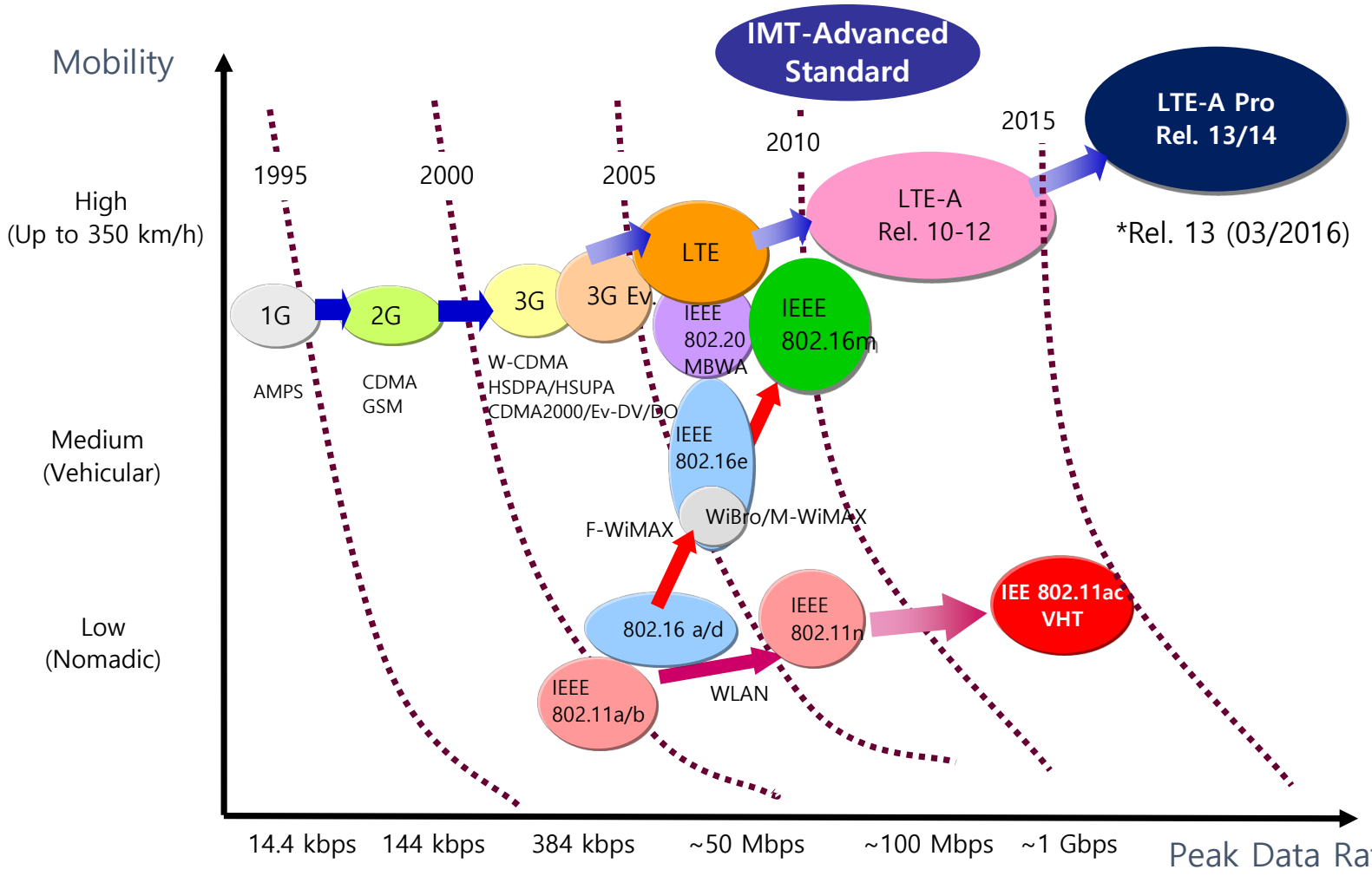
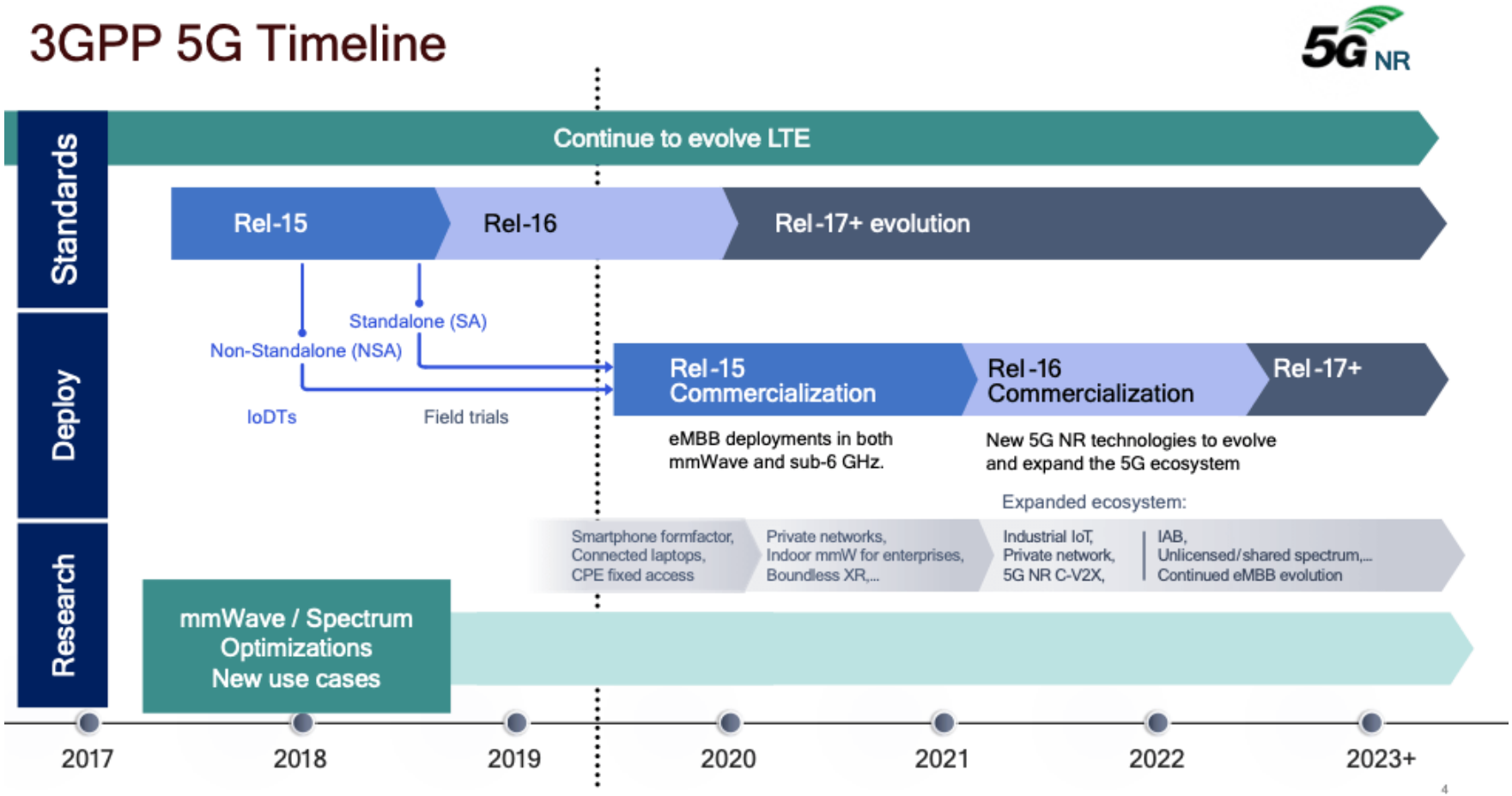
Adapted from Prof. Sunghyun Choi's slides

NXC LAB

Wireless Networks - Roadmap



Wireless Networks - Roadmap



Source: https://semiengineering.com/should-we-even-be-talking-about-6g/

History

- LTE (Long Term Evolution)
  - LTE is 3GPP system for the years 2010 to 2020 and beyond
  - It must keep the support for high mobility users like in GSM/UMTS
  - LTE(-A) is the latest standard in the mobile network technology tree that previously realized the GSM/EDGE and UMTS/HSPA network technologies

- LTE–Advanced
  - LTE-A is often used for LTE Release 10 and beyond
  - Formal name is Advanced E-UTRA (evolved universal terrestrial radio access)
  - Cost-efficient support for backward and forward compatibility between LTE and LTE-A

Standardization for LTE-A

- 3GPP (Third Generation Partnership Project)
  - 3GPP was to make a globally applicable third-generation (3G) mobile phone system specification based on evolved Global System for Mobile Communications (GSM) within the scope of the IMT-2000 project
  - Organizational partners
    - ETSI (Europe), T1 (USA), TTA (Korea), TTC (Japan), CWTS (China)

3GPP Organization Structure

Radio Access Network (RAN) Technical Specification Group Defines the radio communications between UEs and core network	Service/System Aspects (SA) Technical Specification Group Responsible for overall architecture & service capabilities	Core network & Terminals (CT) Technical Specification Group Responsible for core network; defines terminal interfaces & capabilities
RAN WG1 Layer 1 (Physical) spec	SA WG1 Service requirements	CT WG1 Mobility Mgmt, Call Ctrl, Session Mgmt
RAN WG2 Layer 2 and 3 (RR) protocols	SA WG2 Architecture	CT WG3 Policy, QoS and Interworking
RAN WG3 Access network interfaces + O&M	SA WG3 Security	CT WG4 Network protocols
RAN WG4 Performance requirements	SA WG4 Codecs, multimedia system	CT WG6 Smart card application
RAN WG5 UE conformance testing	SA WG5 Telecom management	
RAN WG6 Legacy RAN, e.g. GSM, HSPA	SA WG6 Mission-critical services	

https://www.qualcomm.com/news/onq/2017/08/02/understanding-3gpp-starting-basics

Motivation

- Need for higher data rates and greater spectral efficiency
  - New air interface defined by 3GPP LTE
- Need for packet switched optimized system
  - Evolve UMTS towards packet only system

- Need for high quality of services (QoS)
  - Use of licensed frequency to guarantee QoS
  - Reduce round trip delay
- Need for cheaper infrastructure
  - Simplify architecture
  - Reduce number of network elements

Terminology

- LTE (Long Term Evolution)
  - Evolution of 3GPP Radio Access Technology
  - E-UTRAN (Evolved Universal Terrestrial Radio Access Network)

- SAE (System Architecture Evolution)
  - Evolution of 3GPP Core network technology (started from 3GPP rel.8)
  - EPC (Evolved Packet Core)
    - No more consideration for circuit switching (GSM) or circuit/packet dual (GPRS, UMTS)

- EPS (Evolved Packet System)
  - Evolution of the complete 3GPP UMTS Radio Access, Packet Core and its integration into legacy 3GPP/non-3GPP networks
  - E-UTRAN + EPC

Overview of LTE Design Benefits

- New architecture
  - Flat architecture: one type of node, i.e., eNB
  - PS core network optimized
  - No CS core network

- New interfaces design
  - Simplified protocol stack
  - Simple, more efficient QoS
  - IP network layer

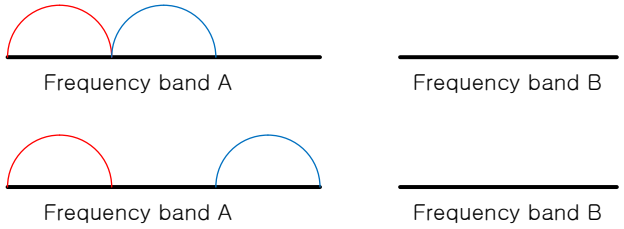
Key Features of LTE(-A)

- Bandwidth support
  - Flexible component carrier from 1.4 MHz to 20 MHz
  - Maximum 100 MHz by aggregating 5 component carriers
- Multiple access scheme
  - Downlink: OFDMA
  - Uplink: Single Carrier FDMA (SC-FDMA)
- Duplex mode
  - FDD: Frequency division duplexing
    - Full-duplex and half duplex
  - TDD: Time division duplexing
    - Half duplex

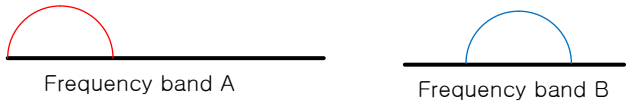
Carrier Aggregation

- Carrier Aggregation (CA)
  - Transmission Bandwidth can be further extended by means of CA
  - Up to 5 component carriers can be aggregated for transmission bandwidth up to 100 MHz
  - CA systems are deployed to improve data rates for users
  - Backwards compatablity is supported for Rel. 8/9 users

- Intra-band CA
  - Contiguous component carriers
  - Non-contiguous component carriers



- Inter-band CA
  - Non-contiguous component carriers



UE Categories

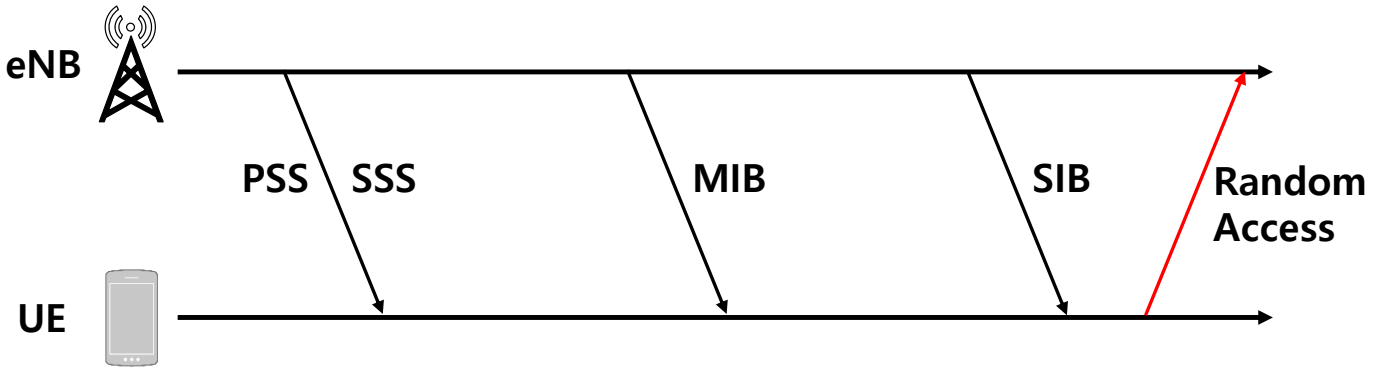
- UE categories depending on maximum peak data rate and MIMO capabilities support

Category		3GPP release	Downlink						Uplink			
			Maximum number of DL-SCH transport block bits received within a TTI		Maximum number of bits of a DL-SCH transport block received within a TTI	Total number of soft channel bits	Maximum number of supported layers for spatial multiplexing in DL	Support for 256QAM in DL	Maximum number of UL-SCH transport block bits transmitted within a TTI		Maximum number of bits of an UL-SCH transport block transmitted within a TTI	Support for 64QAM in UL
				(Mbit/s)						(Mbit/s)		
0		12	1000	1	1000	25344	1	No	1000	1	1000	No
1		8	10296	10	10296	250368	1	No	5160	5	5160	No
2		8	51024	51	51024	1237248	2	No	25456	25	25456	No
3		8	102048	102	75376	1237248	2	No	51024	51	51024	No
4		8	150752	150	75376	1827072	2	No	51024	51	51024	No
5		8	299552	299	149776	3667200	4	No	75376	75	75376	Yes
6	4	10	301504	301	75376 (2 layers) 149776 (4 layers)	3654144	2 or 4	No	51024	51	51024	No
7	4	10	301504	301	75376 (2 layers) 149776 (4 layers)	3654144	2 or 4	No	102048	102	51024	No
8	5	10	2998560	2998	299856	35982720	8	No	1497760	1497	149776	Yes
9	6,4	11	452256	452	75376 (2 layers) 149776 (4 layers)	5481216	2 or 4	No	51024	51	51024	No
10	7,4	11	452256	452	75376 (2 layers) 149776 (4 layers)	5481216	2 or 4	No	102048	102	51024	No
11	9,6,4	11	603008	603	75376 (2 layers, 64QAM) 97896 (2 layers, 256QAM) 149776 (4 layers, 64QAM) 195816 (4 layers, 256QAM)	7308288	2 or 4	Optional	51024	51	51024	No
12	10,7,4	11	603008	603	75376 (2 layers, 64QAM) 97896 (2 layers, 256QAM) 149776 (4 layers, 64QAM) 195816 (4 layers, 256QAM)	7308288	2 or 4	Optional	102048	102	51024	No
13		12	391632	391	97896 (2 layers) 195816 (4 layers)	3654144	2 or 4	Yes	150752	150	75376	Yes
14		12	3916560	3916	391656	47431680	8	Yes				

Note: Total number of soft channel bits for HARQ ≈ 8 (# of Independent HARQ process IDs) × 3 (# of retransmitted data) × maximum number of bits of DL-SCH TB received within a TTI

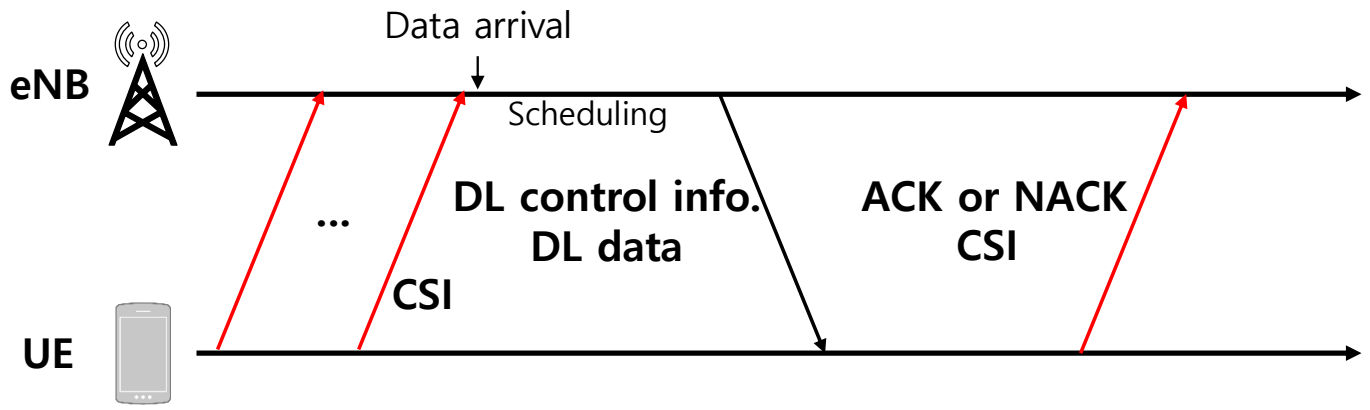
Initial Cell Search and Selection

- Primary Synchronization Signal (PSS) & Secondary Synchronization Signal (SSS)
  - Frequency and time synchronization
  - Physical layer cell ID determination
- Master Information Block (MIB)
  - Transmission bandwidth and system frame number
- System Information Block (SIB)
  - Cell access configuration



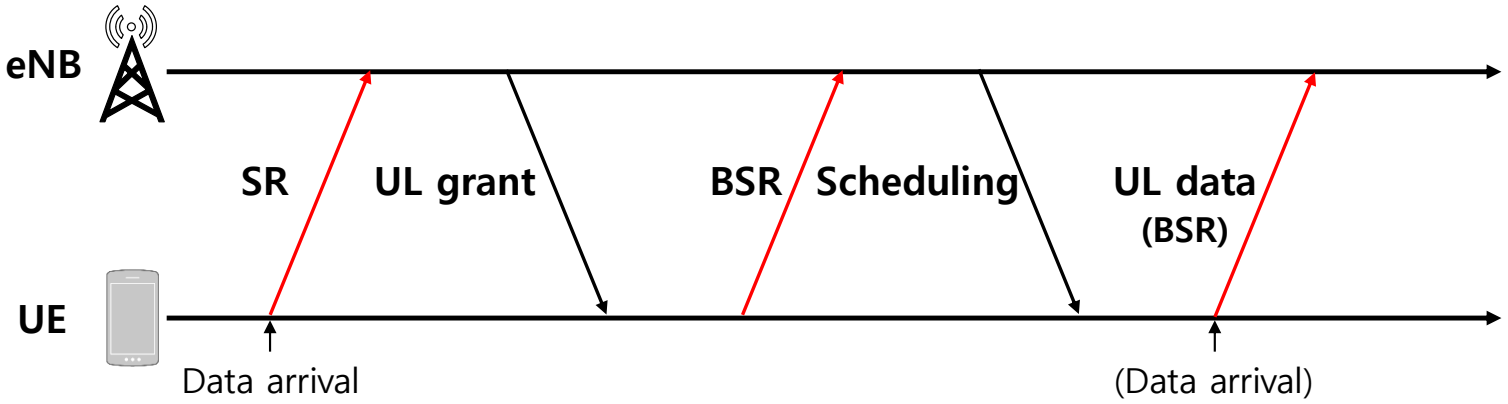
Downlink Data Transmission

- Channel State Information (CSI)
  - Channel Quality Indicator (CQI), etc.
- Scheduling
  - Based on CQI
- HARQ ACK (or NACK) and CSI

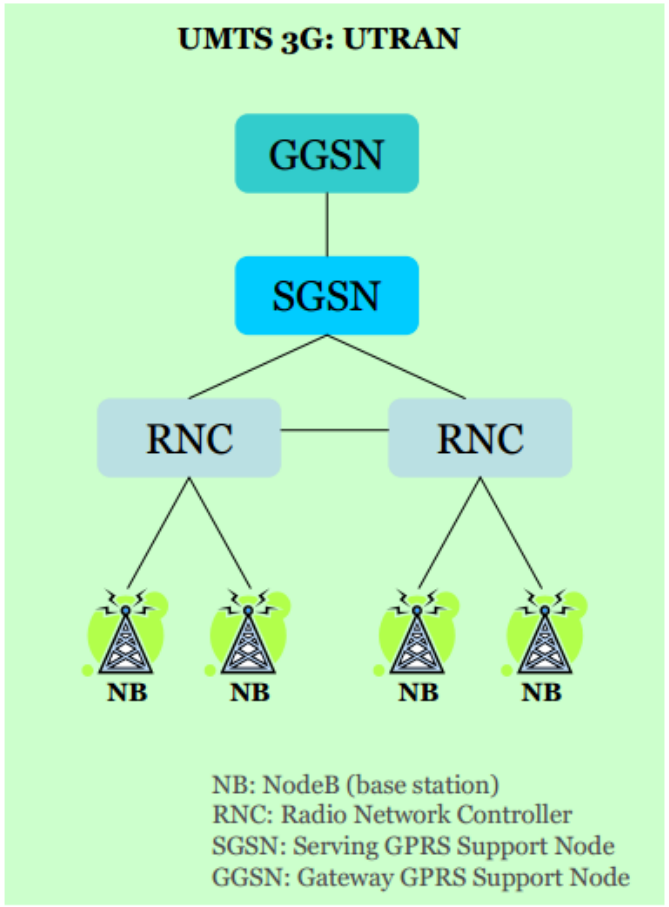


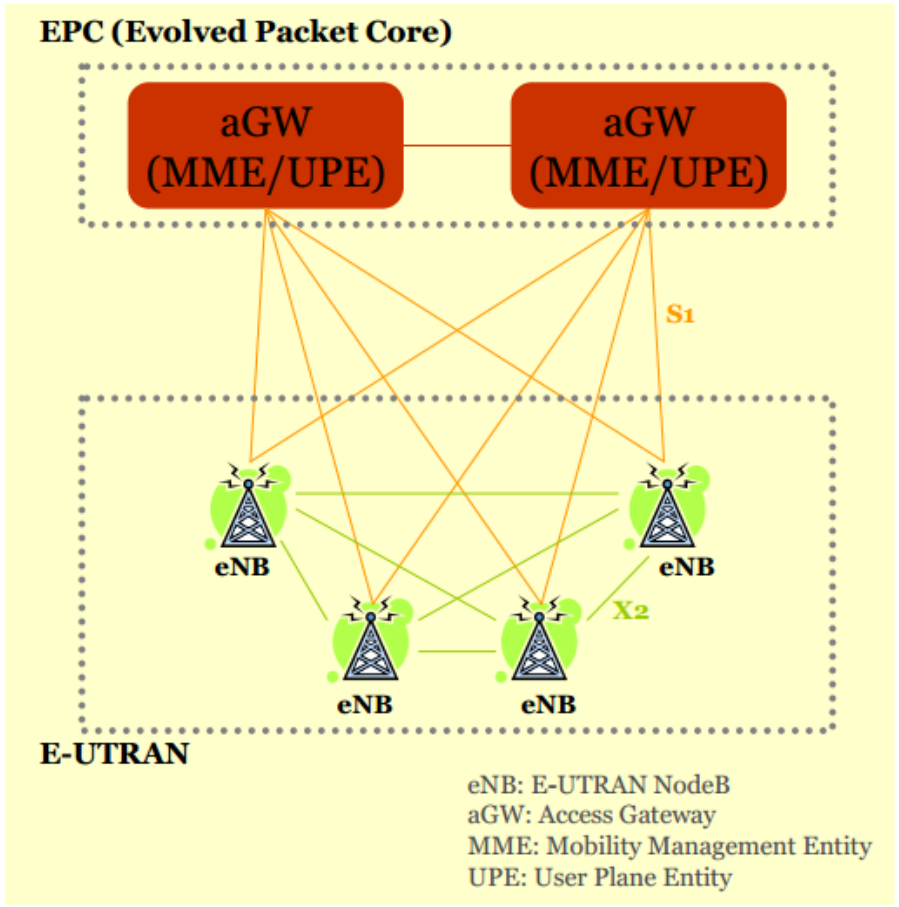
Uplink Data Transmission

- Scheduling Request (SR)
- Uplink grant
- Buffer Status Report (BSR)
- Uplink resource scheduling
- Uplink data transmission
  - If more uplink data arrives → piggybacking BSR



LTE Network Architecture



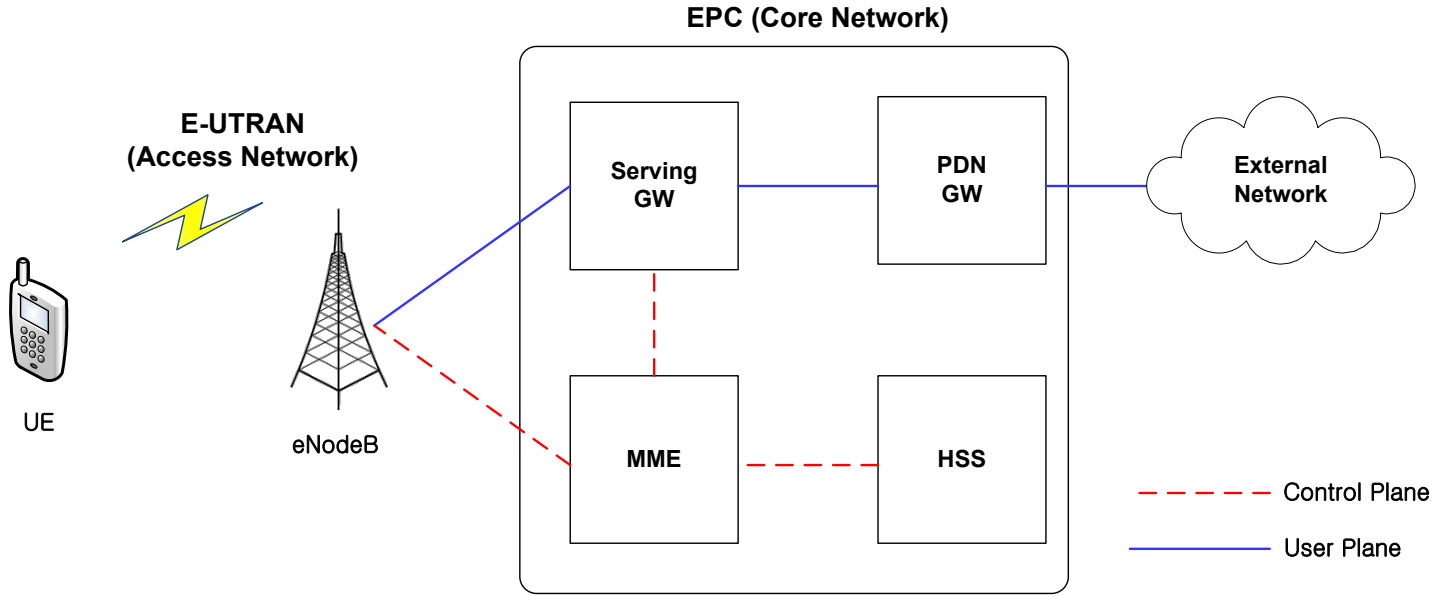


UMTS (3G)

LTE (4G)

Overall Architecture

- Basic EPC architecture with E-UTRAN
  - User plane (data plane)
    - AII-IP packet for a UE is encapsulated and tunneled between the P-GW and eNodeB
    - Protocol support GTP (GPRS Tunneling Protocol) tunnel associated with each EPS bearer
  - Control plane
    - Control signals (channel setup, mobility support, security, etc.) between UE and MME
    - Signals for establishing the radio bearers and configuration



Functional LTE Network Elements

- Evolved Node B (eNB)
  - Supporting LTE radio interface
  - Performing radio resource management

- Mobility Management Entity (MME)
  - Managing user equipment mobility, identity and security parameters
- Home Subscriber Server (HSS)
  - Managing all subscriber information of a network service provider

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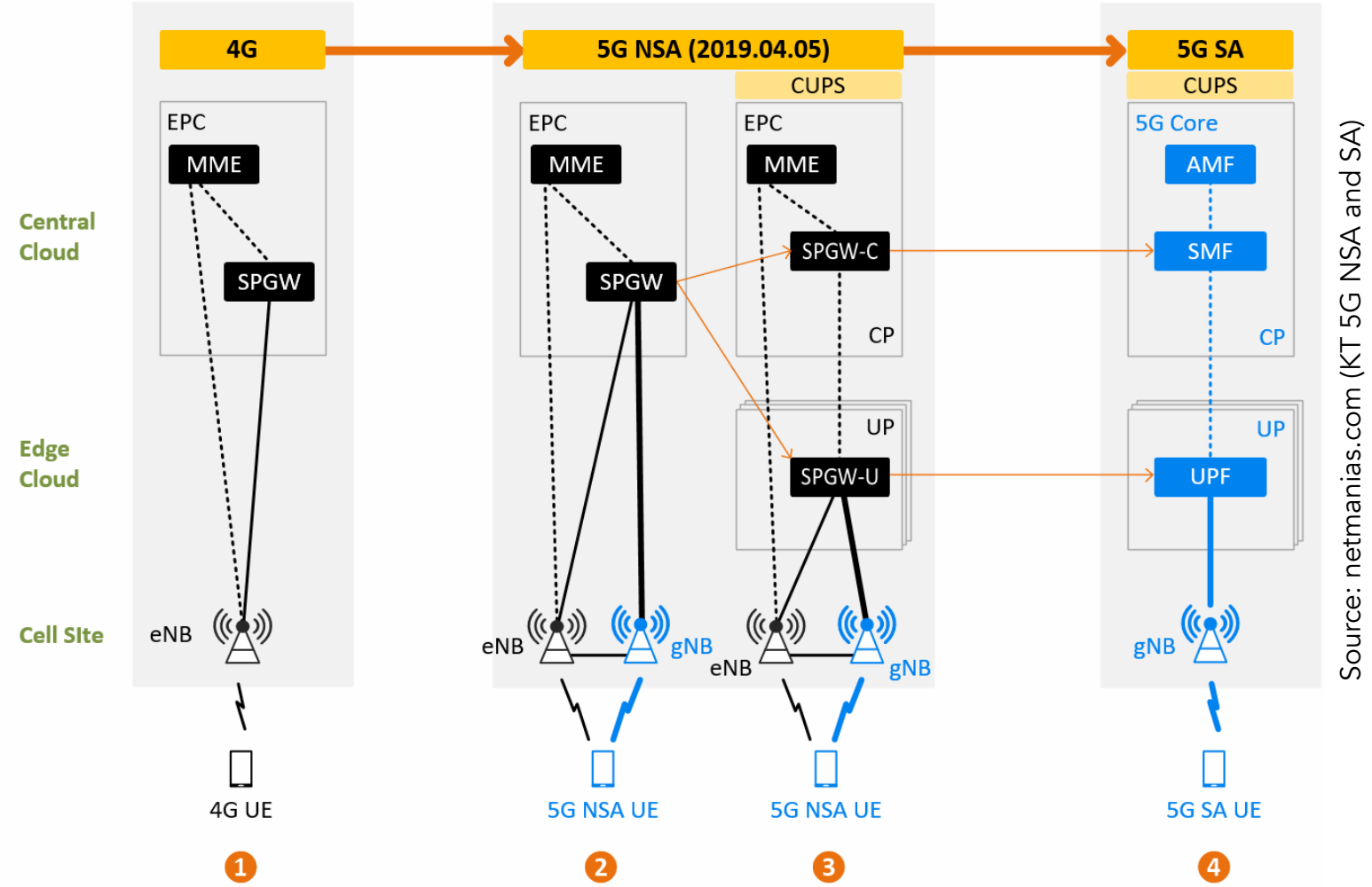
- Serving Gateway (S-GW)
  - Routing/forwarding data packets
  - Mobility anchoring for 3GPP mobility
- Packet Data Network Gateway (PDN-GW)
  - UE IP address allocation
  - Mobility anchoring for non-3GPP mobility

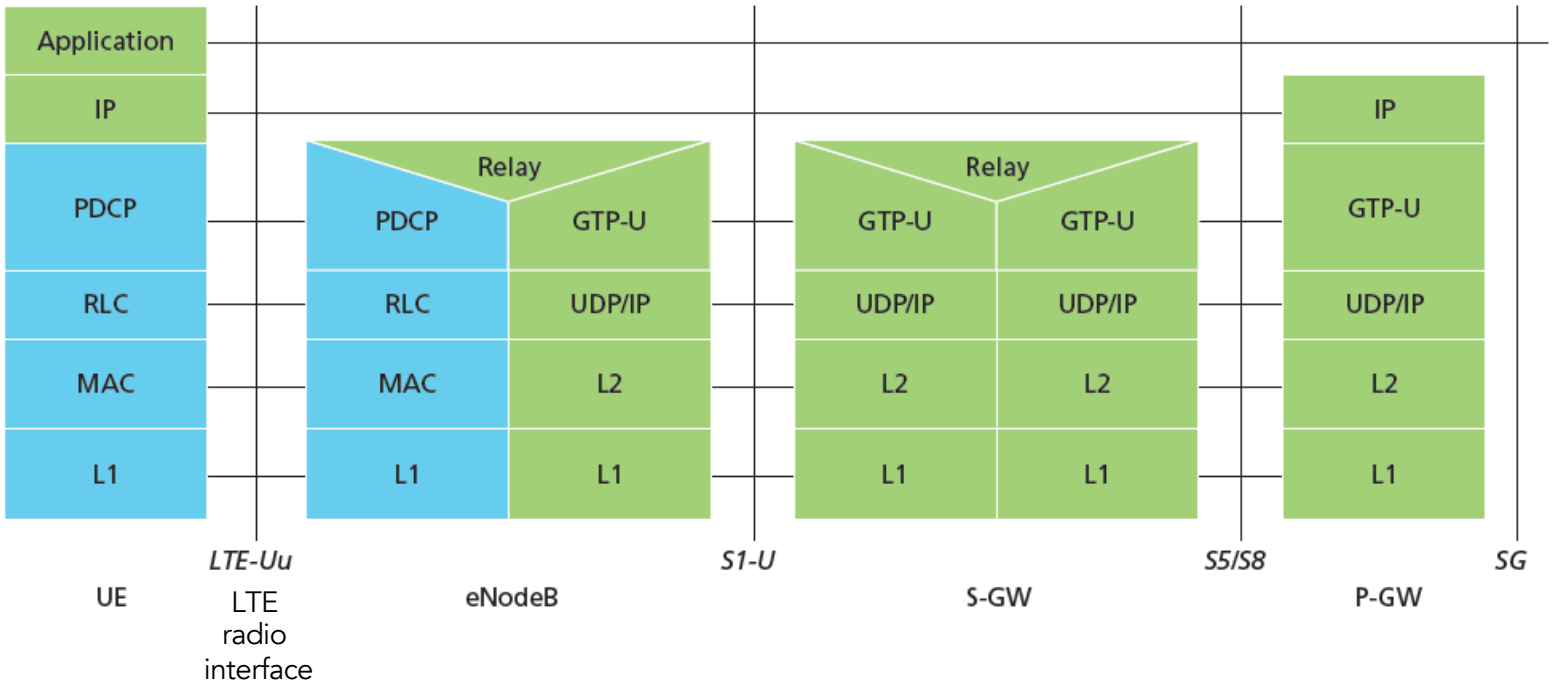
LTE to 5G (NSA and SA)



- AMF: Access and Mobility Management Function, SMF: Session Management Function
- UPF: User Plane Function, CUPS: Control and User Plane Separation

User Plane

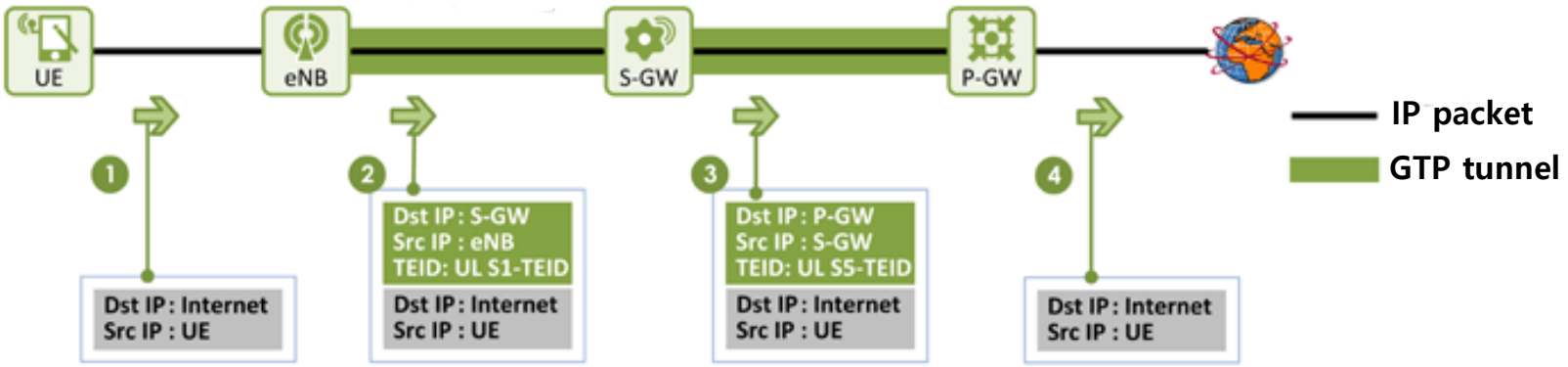
- User plane protocol architecture
  - E-UTRAN user plane protocol stack, shown in blue color
  - Consists of the Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC), and Medium Access Control (MAC) sublayers, which are terminated in the eNB on the network side



GPRS Tunneling Protocol (GTP)

- Why is GTP used in LTE?
  - It provides mobility
  - Multiple tunnels can be used by same UE to obtain different network QoS
  - Main IP remains hidden so that it provides security as well
    - UE does not know the IP addresses of core network nodes

- GTP tunnel example



User Plane

- PHY
  - Coding
  - Modulation
  - Antenna and resource mapping
- MAC
  - MAC multiplexing
  - Transmission scheduling
  - Payload selection
  - Priority handling
  - Making a decision for modulation and resource
  - Hybrid ARQ

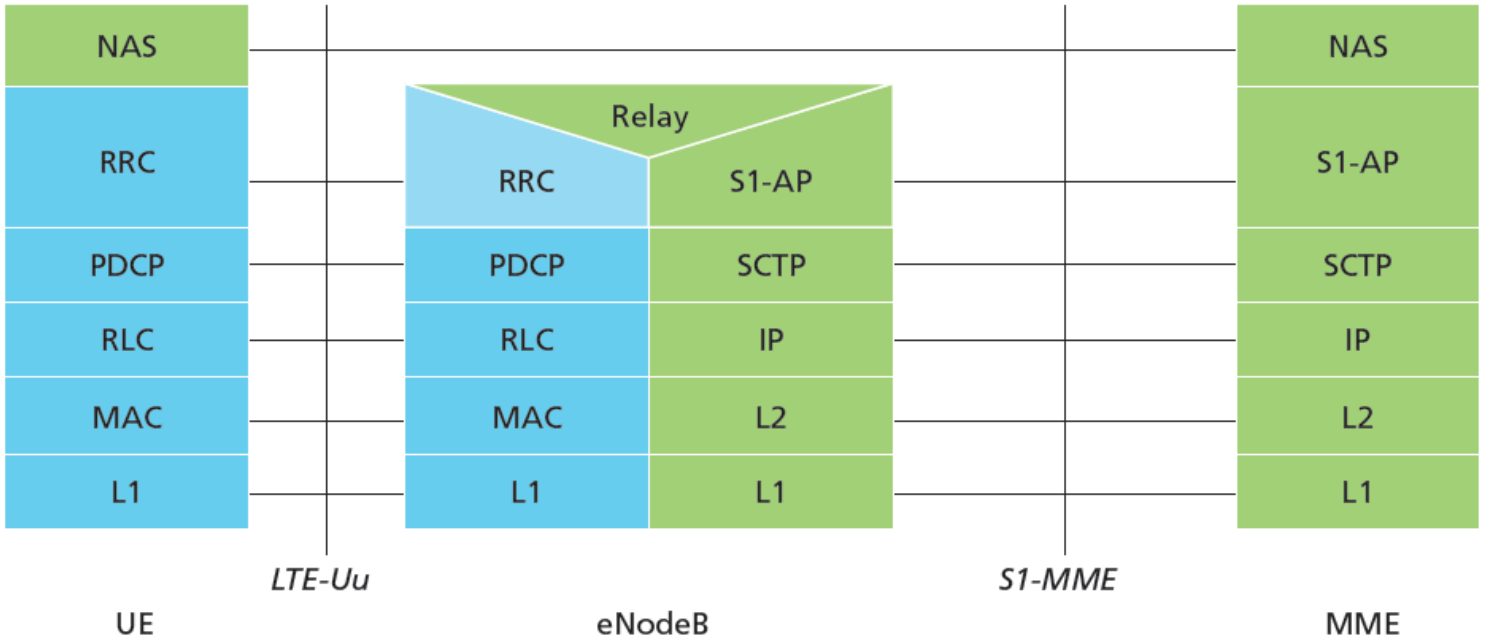
User Plane

- RLC (Radio Link Control)
  - Transferring PDUs from higher layers (from either RRC or PDCP)
  - Error correction with ARQ
  - Concatenation/segmentation
  - In-sequence delivery and duplicate detection

- PDCP (Packet Data Convergence Protocol)
  - Header compression and corresponding decompression
  - Ciphering and deciphering
  - Integrity protection and verification

Control plane

- Control plane protocol stack
  - E-UTRAN control plane protocol stack, shown in blue color
  - Lower layers perform the same functions as those for the user plane with the exception that there is no header compression

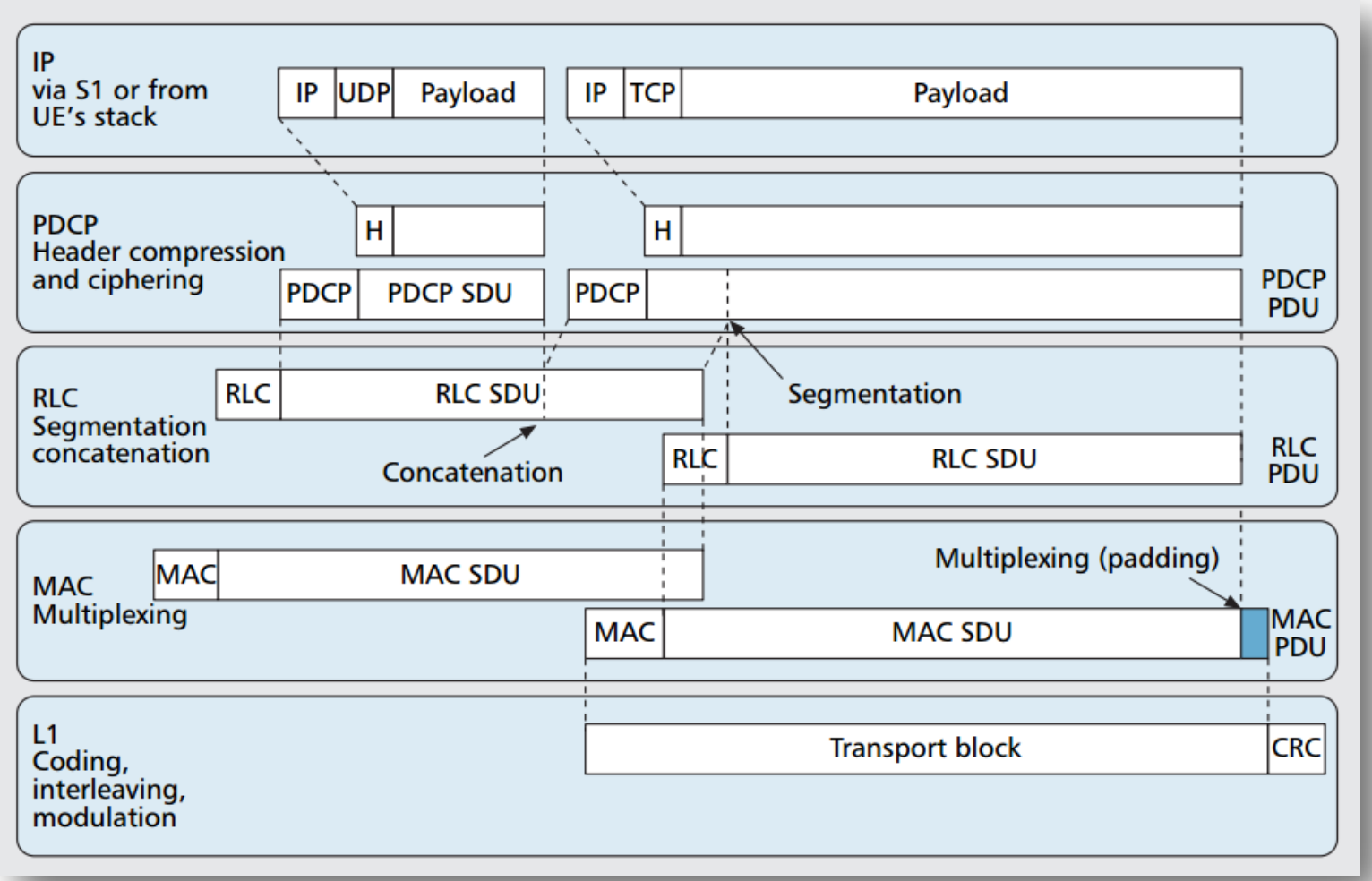


Control plane

- RRC (Radio Resource Control)
  - Broadcast
  - Paging
  - RRC connection management
  - RB control
  - Mobility functions
  - UE measurement reporting and control
- NAS (Non-Access Stratum)
  - EPS bearer management
  - Authentication
  - ECM-IDLE mobility handling
  - Paging origination in ECM-IDLE
  - Security Control

* ECM: EPS Connection Management

Downlink Flow in Link Layer Protocol



Larmo, Anna, et al. "The LTE link-layer design," Communications Magazine, IEEE 47.4 (2009).

QoS and EPS bearer

- EPS Bearers
  - In order to support multiple QoS requirements, different bearers are set up within EPS
- Minimum Guaranteed Bit Rate (GBR) bearers
  - Dedicated resources are allocated
  - By admission control function in eNB
  - Bit rates higher than the GBR may be allowed for a GBR bearer if resources are available
  - For such applications as VoIP
- Non-GBR bearers
  - Used for Web browsing, FTP transfer, etc.

QCI (QoS Class Identifier)

- Standardized QCIs for LTE

QCI	Bearer	Priority	Delay	PELR	Examples
1	GBR	2	100 ms	10^{-2}	Conversational voice
2		4	150 ms	10^{-3}	Conversational video
3		3	50 ms	10^{-3}	Real-time games
4		5	300 ms	10^{-6}	Streaming video
5	Non-GBR	1	100 ms	10^{-6}	IMS signalling
6		6	300 ms	10^{-6}	Streaming video, web, EMail
7		7	100 ms	10^{-3}	Voice, video, games
8		8	300 ms	10^{-6}	Streaming video, web, EMail
9		9			

QoS and EPS bearer

- Establishment time
  - Default bearer
    - Established when UE connects to PDN
    - Provides always-on connectivity and always non-GBR
  - Dedicated bearer established later
    - Can be GBR or non-GBR
- Each EPS bearer has
  - QoS class identifier (QCI)
  - Allocation and retention priority (ARP)
    - Determines whether a bearer can be dropped if the network gets congested

Check the book for more details!