教育部「5G行動寬頻人才培育跨校教學聯盟計畫」

5G行動網路協定與核網技術聯盟中心

「5G行動寬頻協同網路」課程模組

單元1
5G行動網路簡介

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Outline

- Syllabus
- Introduction to Cellular/Mobile Networks
  - Past and Present: 1G to 4G
- Overview of 5G
  - ITU-R IMT-2020 Requirements
  - Features of 5G
  - 3GPP Standardization
- Introduction to 3GPP 5G Specifications
  - 5G Requirements and Key Performance Indicators
  - The 5G System Architecture
  - 5G NR Radio Interface
  - 5G Radio Access Network (NG-RAN)
  - 5G Core Network

Reference:

Journal of Information and Communication Technology, Vol. 6, No. 1&2, River Publishers, 2018

教學目標

本課程介紹3GPP標準中，與4G及5G整合相關的行動網路協定與核網技術。LTE除了傳統的直接連線模式外，5G更進一步提出支援間接連線及多重連線的模式。課程將涵蓋各種先進的協同網路協定架構與方法，包括Standalone(SA)與Non-Standalone (NSA)等5G架構中，如何利用Dual Connectivity (DC)及EN-DC (E-UTRAN New-Radio - Dual Connectivity)技術來進行4G、5G、Non-3GPP等各式無線網路的協同運作與整合。重點包括：

1) 5G系統架構

2) Dual Connectivity (DC)協同網路

3) 5G Service-Based Architecture (SBA)核網技術

4) 5G運作流程

參考教材

- Protocols (Specifications)
  - 3GPP LTE-Advanced Pro, 5G
  - ITU IMT-2020
  - NGMN, 5G Americas, 5G PPP
- Programs (Codes)
  - srsLTE: srsUE/srsENB/srsEPC
  - Free5GC
- Platform
  - USRP B210, LimeSDR
- Papers
  - Special Issues on 3GPP 5G Standardizations, *Journal of Information and Communication Technology*, Vol. 6, No. 1&2, River Publishers, 2018

課程內容與進度

主題1：行動網路演進：從1G到5G 主題2：LTE-A 4G系統簡介：EPC與eNB 主題3：5G系統簡介：5GC與gNB 主題4：5G架構介紹：NSA與SA 主題5：4G/5G平台暨開源碼介紹 主題6：實驗1：開源碼srsLTE平台建置與基本量測
主題7：Dual Connectivity (DC) 主題8：4G與non-3GPP協同存取 主題9：4G與5G協同存取 主題10：實驗2：DC效能量測與分析
主題11：期中報告
主題12：5G Service-Based Architecture (SBA)介紹 主題13：5G系統流程(I) 主題14：5G系統流程(II) 主題15：實驗3：SBA建置與協定分析 主題16：5G模擬器介紹 主題17：實驗4：5G Emulator仿真模擬實驗
主題18週：期末專題

實驗內容

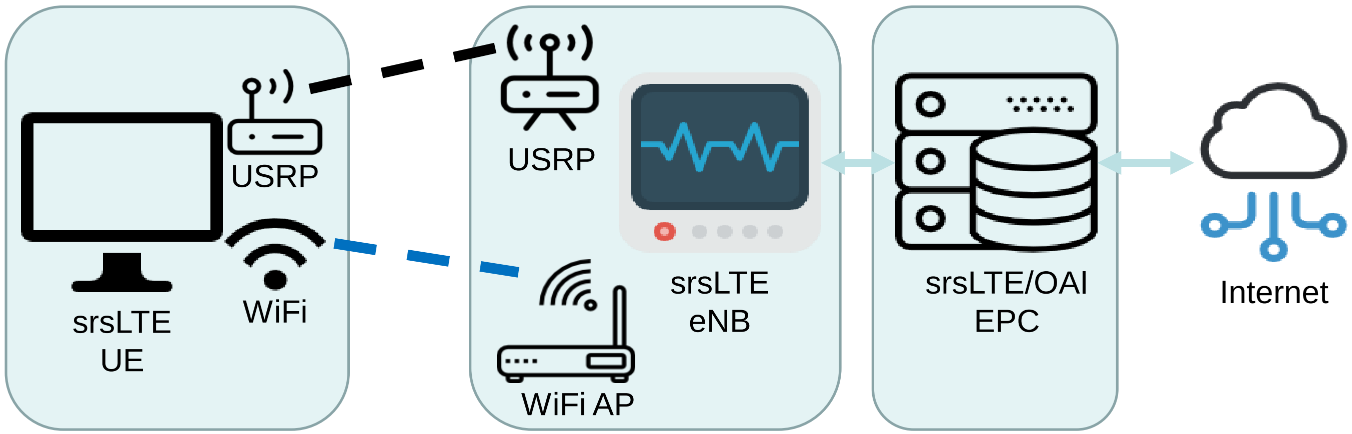
實驗項目	內容說明
實驗一：開源碼srsLTE平台建置與基本量測	1. 建置srsLTE的srsUE、srsENB+srsEPC，讓學生學會建立srsLTE行動通訊網路開源碼平台 2. 透過srsUE以SDR連接srsENB+srsEPC進行觀察與量測，讓學生熟悉網路偵錯及量測工具
實驗二：DC效能量測與分析	1. 了解如何修改srsLTE開源碼以支援DC，讓學生熟悉3GPP系統架構及srsLTE軟體結構 2. 調整srsLTE的設定及控制DC的傳輸比例，讓學生深入了解DC的運作原理及效能議題
實驗三：SBA建置與協定分析	1. 建置支援SBA的5GC開源系統，讓學生學會建立5GC核網系統並了解5G核網架構 2. 設定4G的UE及eNB並連接5GC，讓學生觀察4G與5G網路的協同運作並分析協定
實驗四：5G Emulator實驗	1. 建置兩個小基站以模擬EN-DC的協同運作，讓學生熟悉NSA的5G協同網路架構 2. 透過srsUE連線來觀察封包的內容及傳遞過程，讓學生熟悉NSA運作流程及協定

核心能力

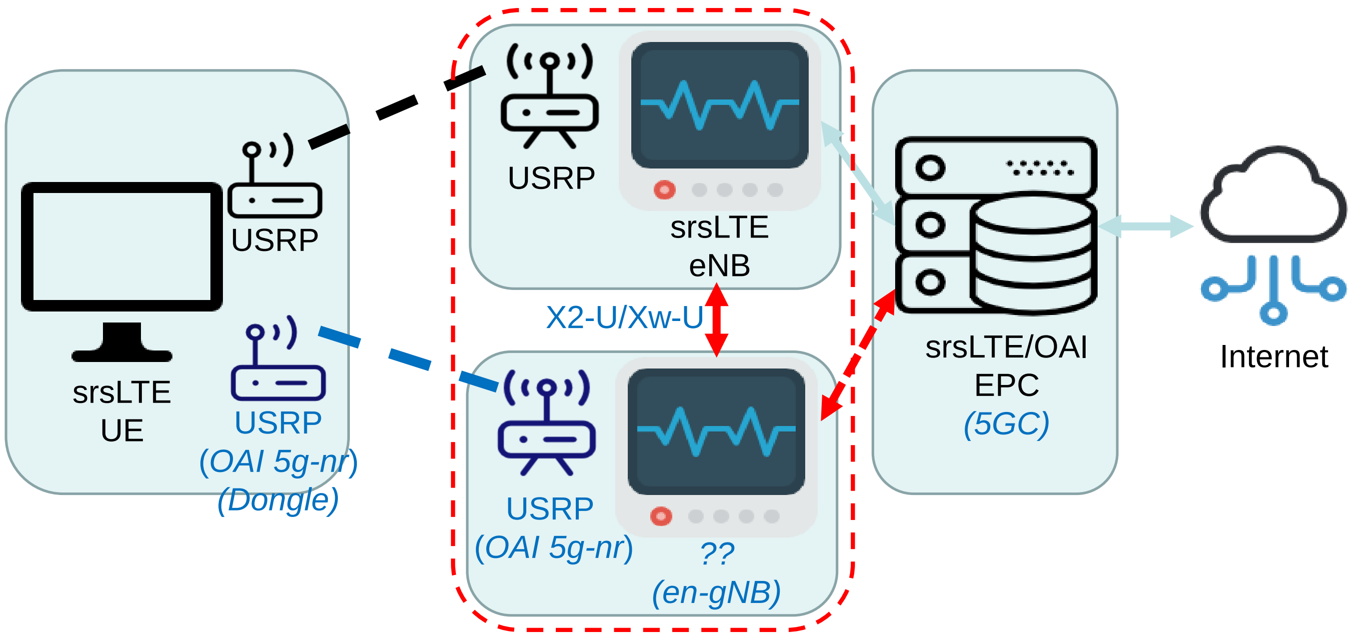
1. 學習在Linux上架設及修改UE、eNB、EPC及5GC開源碼，培養行動網路建置及偵錯分析的基本能力
2. 熟悉5G行動寬頻網路重要的DC及SBA技術，了解5G行動寬頻協同網路的運作及原理
3. 學會在5G模擬實驗環境進行效能量測及協定分析，培養在5G行動寬頻網路的實務能力

實驗平台

nukLWA



nukxDC



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Pre-history of Cellular/Mobile Networks

- Motorola announced DynaTAC 8000x in 1984
  - 4,000 USD, 30-min talk/8hr standby, 30 entries
  - First prototype in 1974
  - SCR-300 in 1941 (16kg/12.9km, FM)

- Advanced Mobile Phone System (AMPS) developed by Bell Labs on October 13, **1983**
  - 1989年台灣交通部電信總局引進，手機俗稱**大哥大**、**黑金剛**

History of Cellular/Mobile Networks

- European Conference of Postal and Telecommunications Administrations (CEPT) set up the Groupe Spécial Mobile (GSM) committee in 1983
  - Feb 1987 - produced the first GSM technical specification
    - GSM renamed as *Global System for Mobile Communications*
    - 1989 transferred to European Telecommunications Standards Institute (ETSI)
  - Dec **1991** - first deployed in Finland
    - 1995 GSM Association (GSMA) formed
      - MoU signed in 1987, Mobile World Congress (MWC) began
  - 1996年台灣通過電信三法，開啟電信自由化、民營化
    - 《電信法》修正案、《交通部電信總局組織條例》修正案、《中華電信股份有限公司條例》
    - 1997年開放行動電話、無線電叫人、行動數據與中繼式無線電話等四項行動通信業務
- Third Generation Partnership Project (3GPP) started in Dec 1998
    - Seven organizations including ETSI and GSMA
  - Release 99 standardized UMTS 3G in **2000**
    - 2002年台灣開放3G
  - Release 10 (LTE-A) met ITU IMT-Advanced (4G) in **2011**
    - 2013年台灣4G競標並於2014年開台
  - Release 15 (LTE 5G phase 1) drafted in Q4 2017
    - Finalized in Q1 2019
    - 台灣預計於2019/12競標、2020/01發照

Mobile Phone Generations

1G (1979)	AMPS
2G (1991)	GSM, PHS
2G transitional (2.5G, 2.75G)	GSM/3GPP - GPRS, EDGE, CDMA2000
3G (2001)	3GPP R99 - UMTS, W-CDMA
3G transitional (3.5G, 3.75G, 3.9G)	3GPP - HSPA, LTE (E-UTRA); IEEE WiMAX 802.16e
4G (2013) (IMT Advanced)	3GPP R10 - LTE-A, LTE-A Pro (4.5G-4.9G); IEEE WiMAX 802.16m
Under development (IMT-2020)	3GPP R15/R16 - 5G (2020)

Source: https://en.wikipedia.org/wiki/Template:Cellular_network_standards

Mobile OS Milestones

Before 1992 Mobile phones / PDA

1993 Apple Newton OS (Personal Digital Assistant, PDA)

1996 Palm OS

1999 Nokia S40 OS

2000 Symbian for Ericsson

2002 Windows CE (Pocket PC)

2003 BlackBerry

2005 Nokia Maemo OS on the first Internet tablet N770
Google acquired Android Inc. on August 17, 2005

2007 Apple iPhone with iOS introduced as an iPhone
- mobile phone and Internet communicator

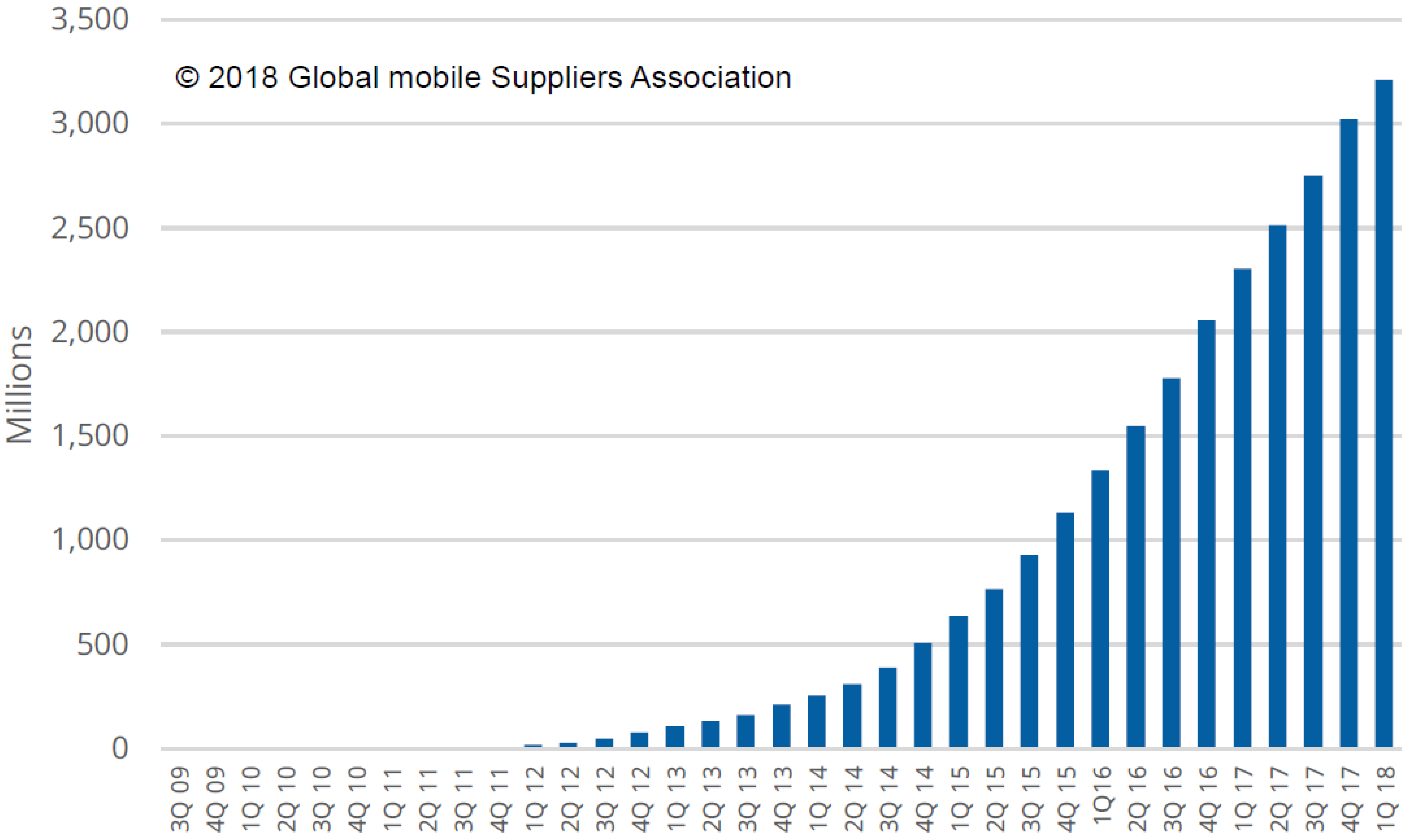
2007 Open Handset Alliance (OHA) formed by Google, HTC, Sony, Dell, Intel, Motorola, Samsung, LG, etc

2007 Microsoft Windows Mobile 6 (Derived from Windows CE)

2008 OHA releases Android 1.0 with the HTC Dream (T-Mobile G1) as the first Android phone

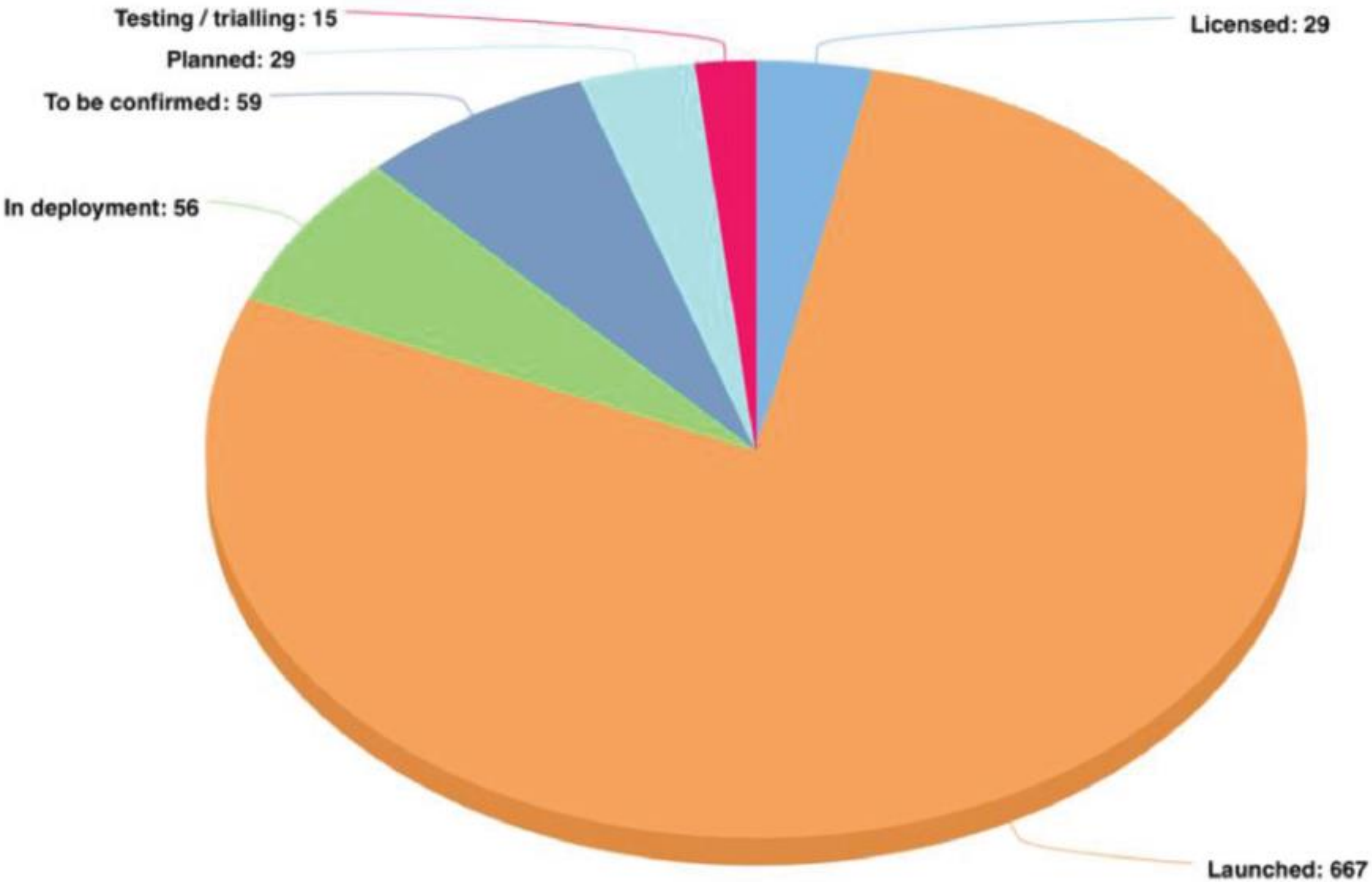
2010 Microsoft Windows Phone (Metro Design Language)

LTE Subscription Growth



Reference: Joe Barrett , Outlining the Roadmap to 5G , Journal of ICT(Information and Communication Technology), Vol. 6 1&2, River Publishers, 2018

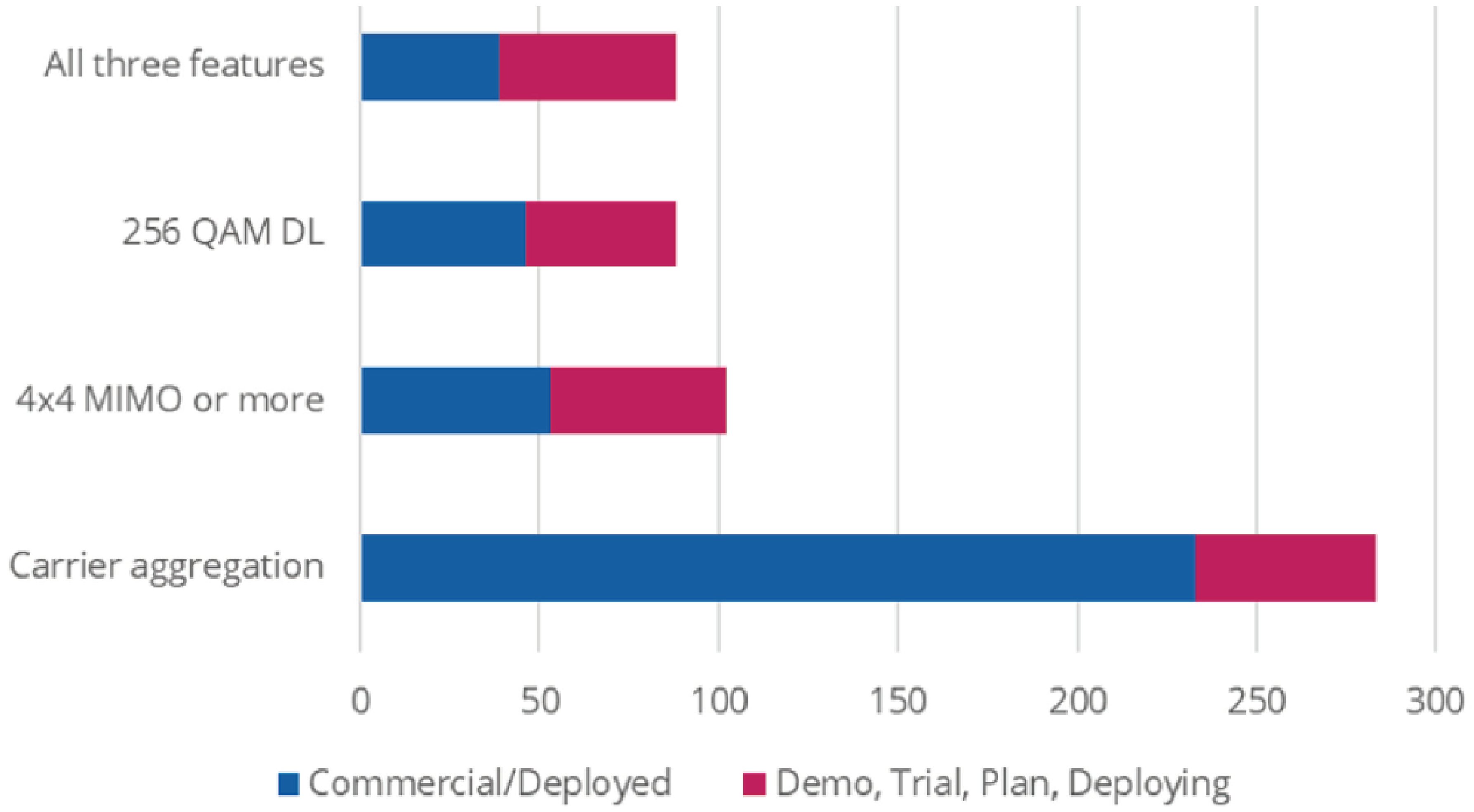
LTE Network Investments and Launches



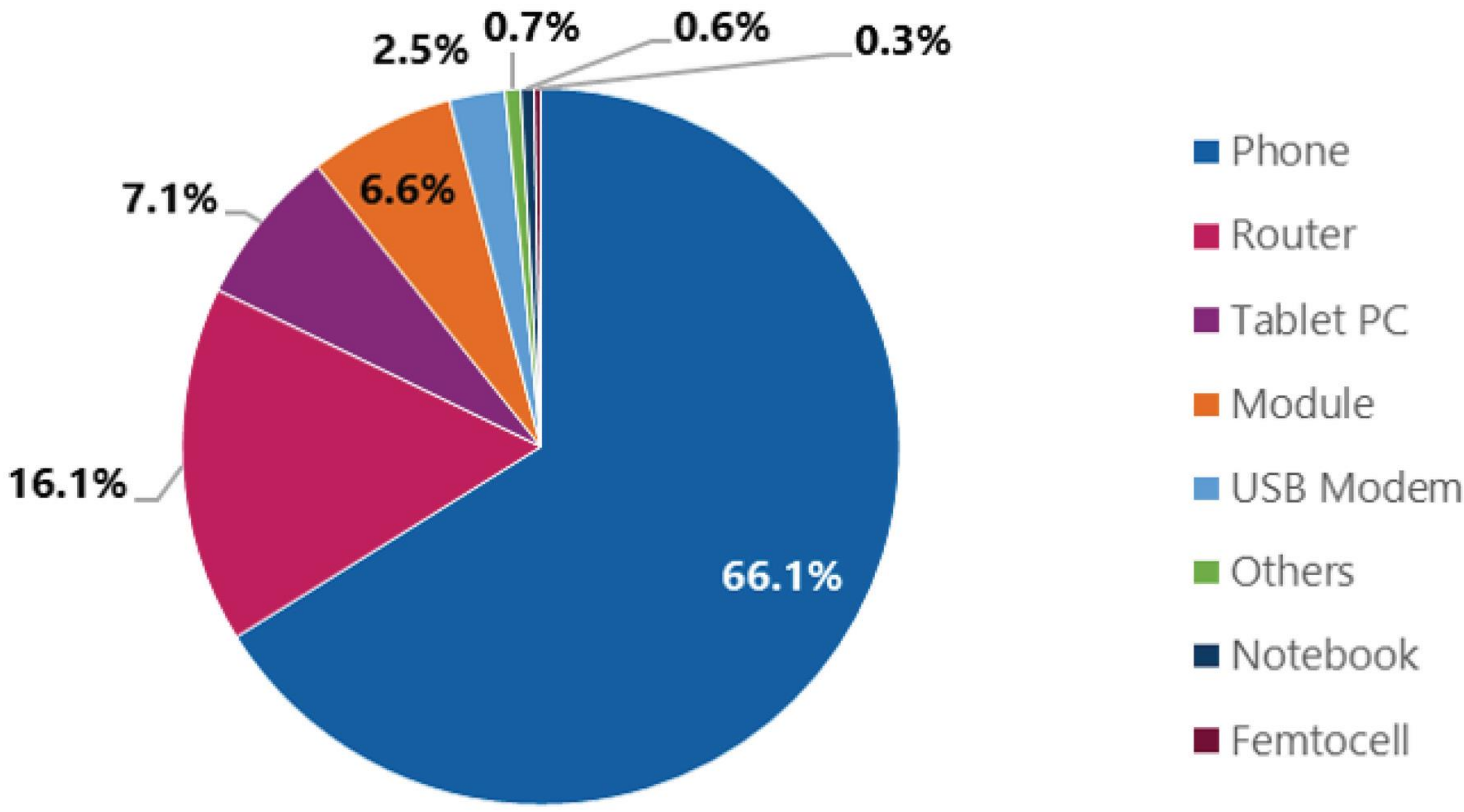
LTE Deployment Facts (Reported by GSA)

• LTE-Advanced	239 networks launched
• LTE-Advanced Pro	123 networks launched or trailing
• LTE-TDD	109 networks launched
• Carrier Aggregation	290 networks launched or trialing
• 4x4 MIMO	114 networks launched or trialing
• 256QAM	96 operators have launched or using in DL
• VoLTE	221 investing – 143 launched
• eMBMS	LTE Broadcast – 45 operators evaluating – 3 have launched

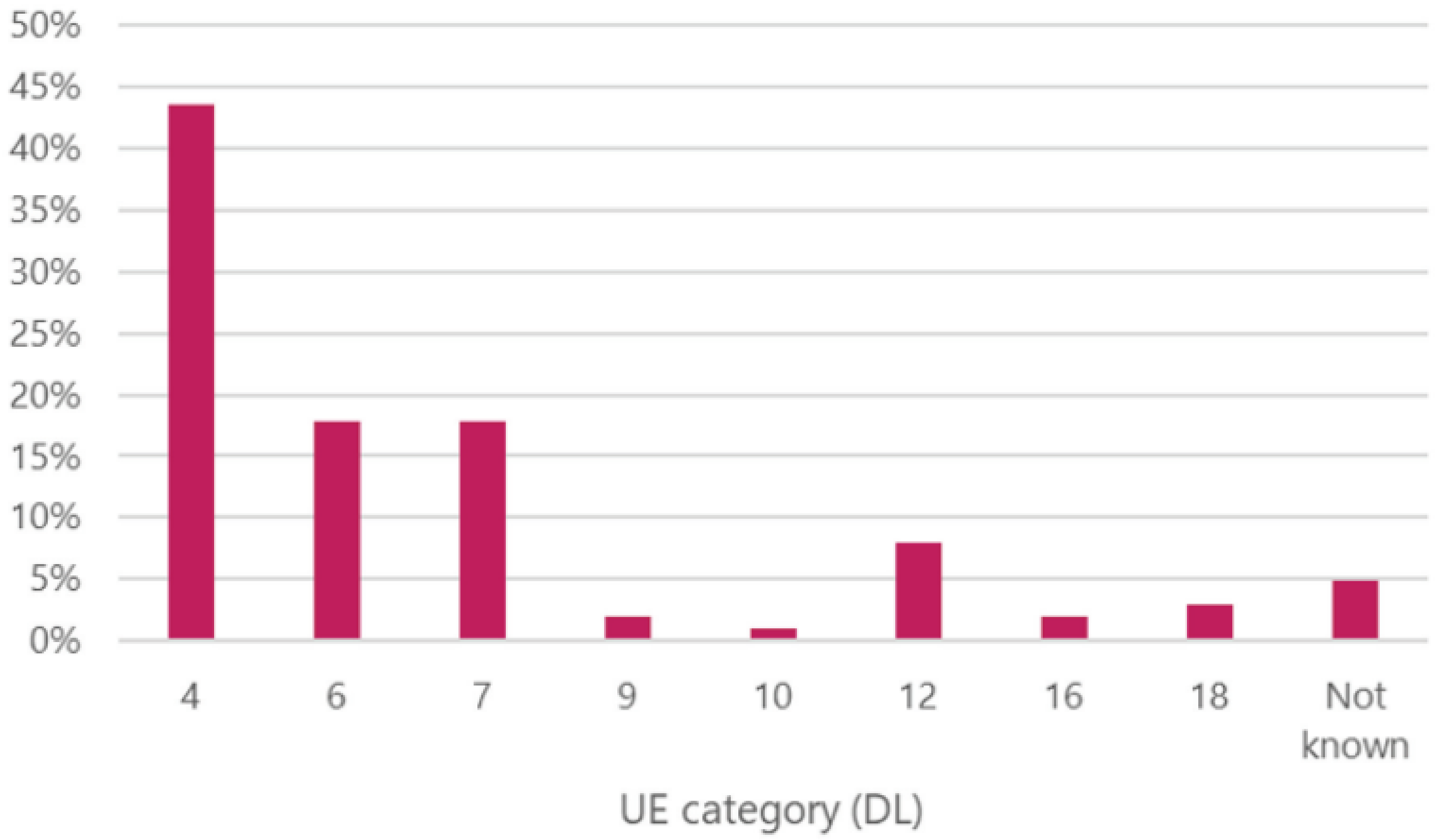
Using Three Core LTE-Advanced Features



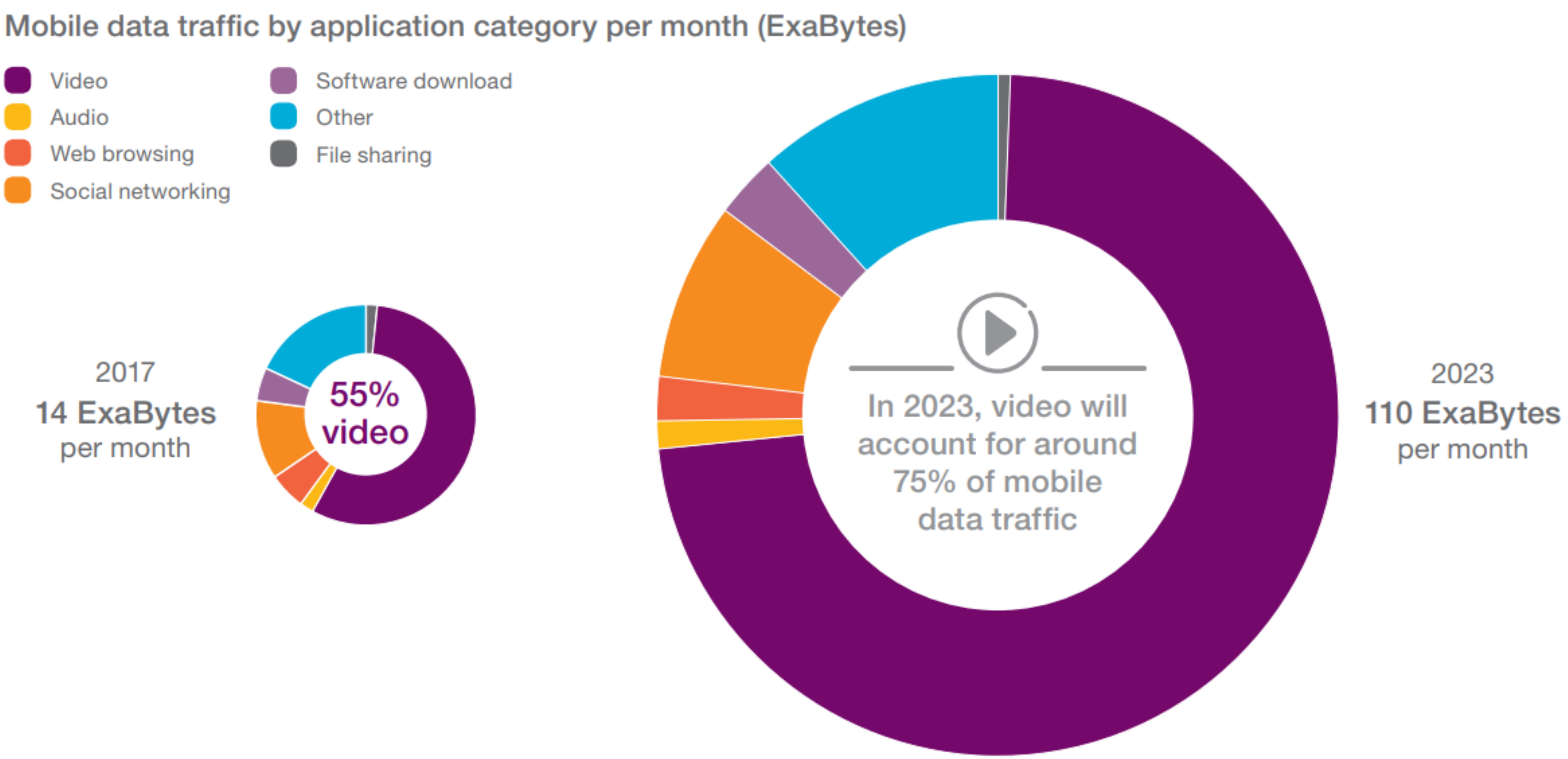
LTE Ecosystem by Form Factor February 2018



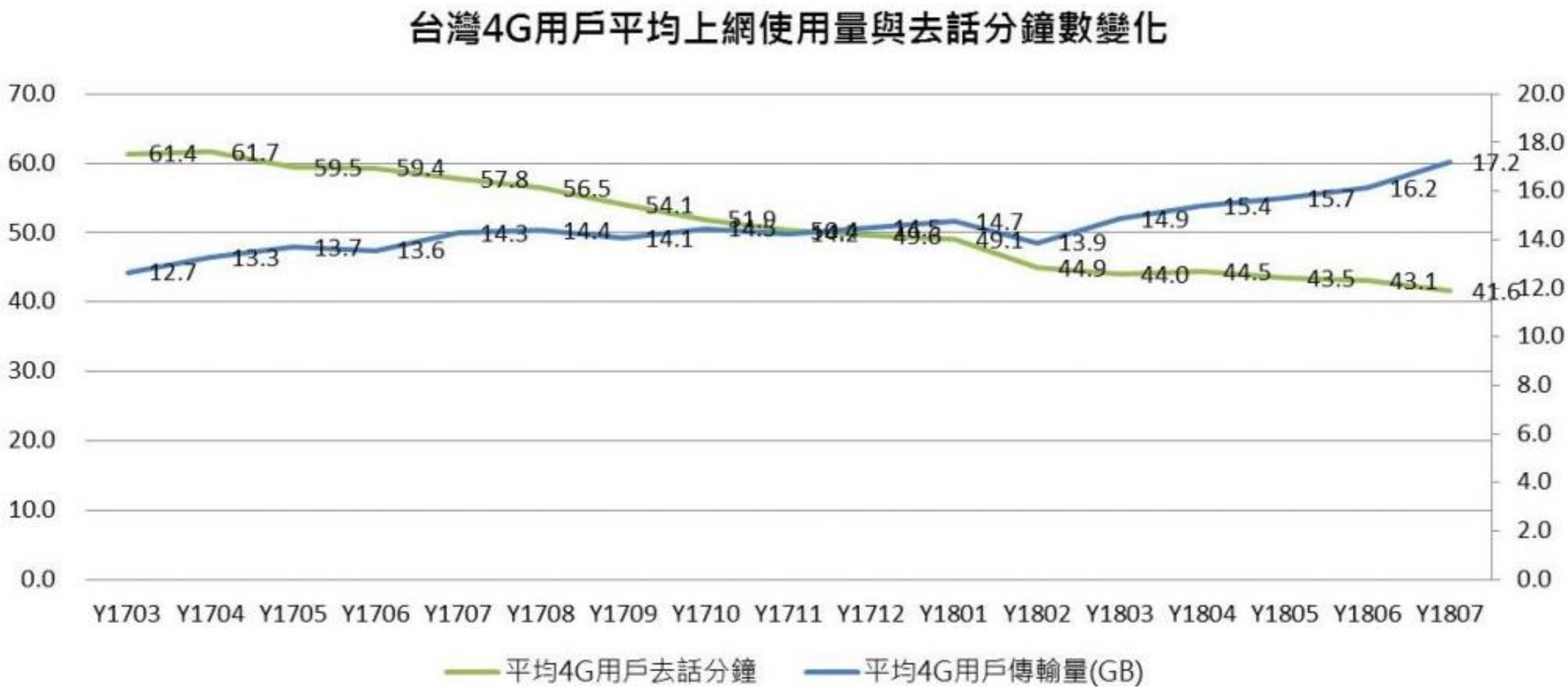
Supporting Specific UE Categories



Mobile Data Traffic Forecast

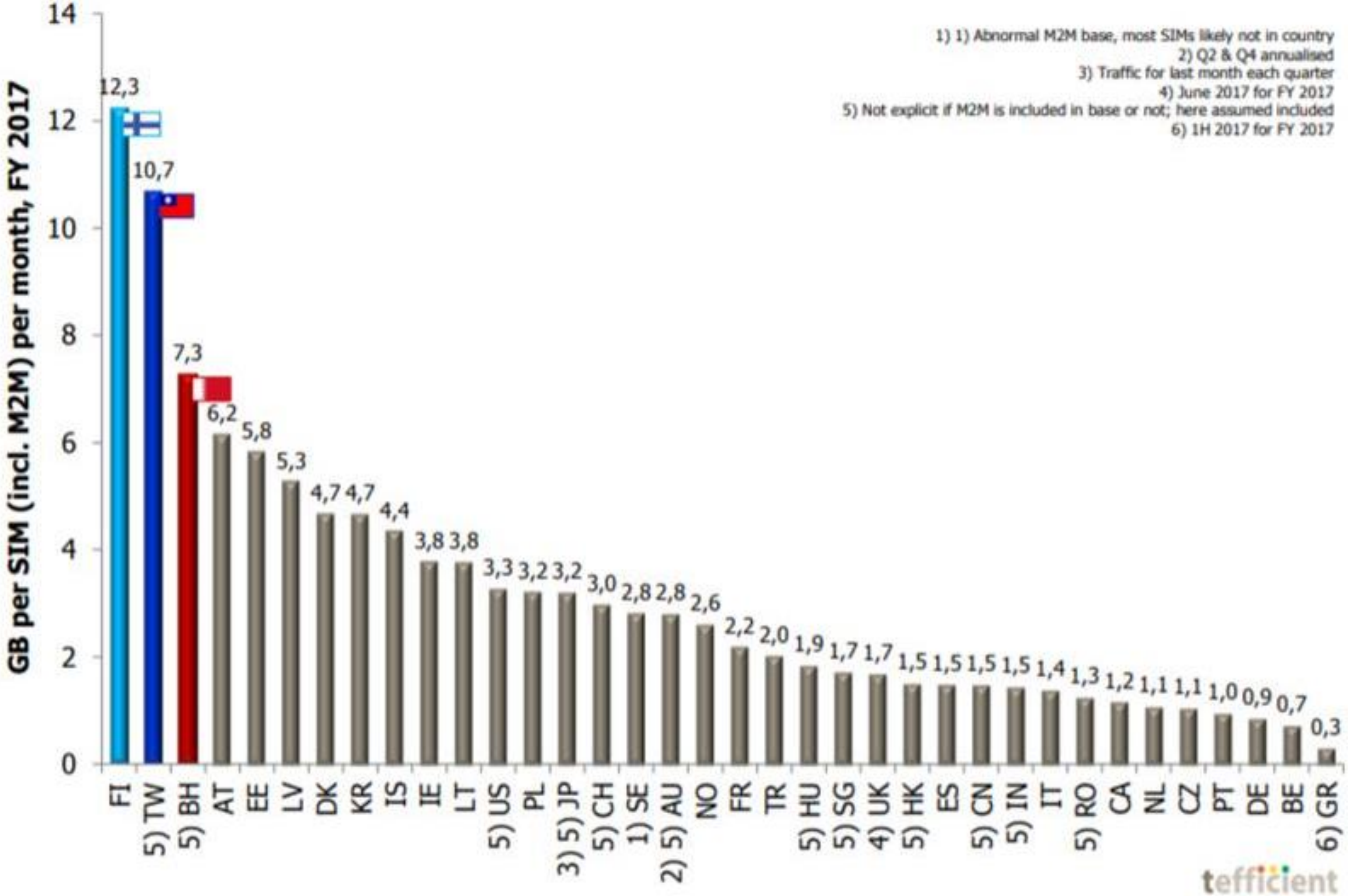


台灣4G用戶平均每月上網使用量與去話分鐘



- 重上網、輕語音的使用趨勢
  - 數據量：2018年7月已達17.2GB，較2017/7的14.3GB成長20.6%
  - 語音量：2018年7月降至41.6分鐘，較2017/7的57.8分鐘衰退28%
  - 2019年6月：4G用戶數為2,925萬，平均傳輸量為17.9GB，通話35.8分鐘
- 資料來源：NCC https://www.ncc.gov.tw/chinese/opendata.aspx?site_content_sn=3507

2017年各國每用戶每月行動數據資料量



- 台灣為全球第二，亞洲第一(南韓的兩倍、日本的三倍+，新加坡的近六倍)
- 資料來源：Tefficient產業分析公司

持有手機民眾數位機會調查

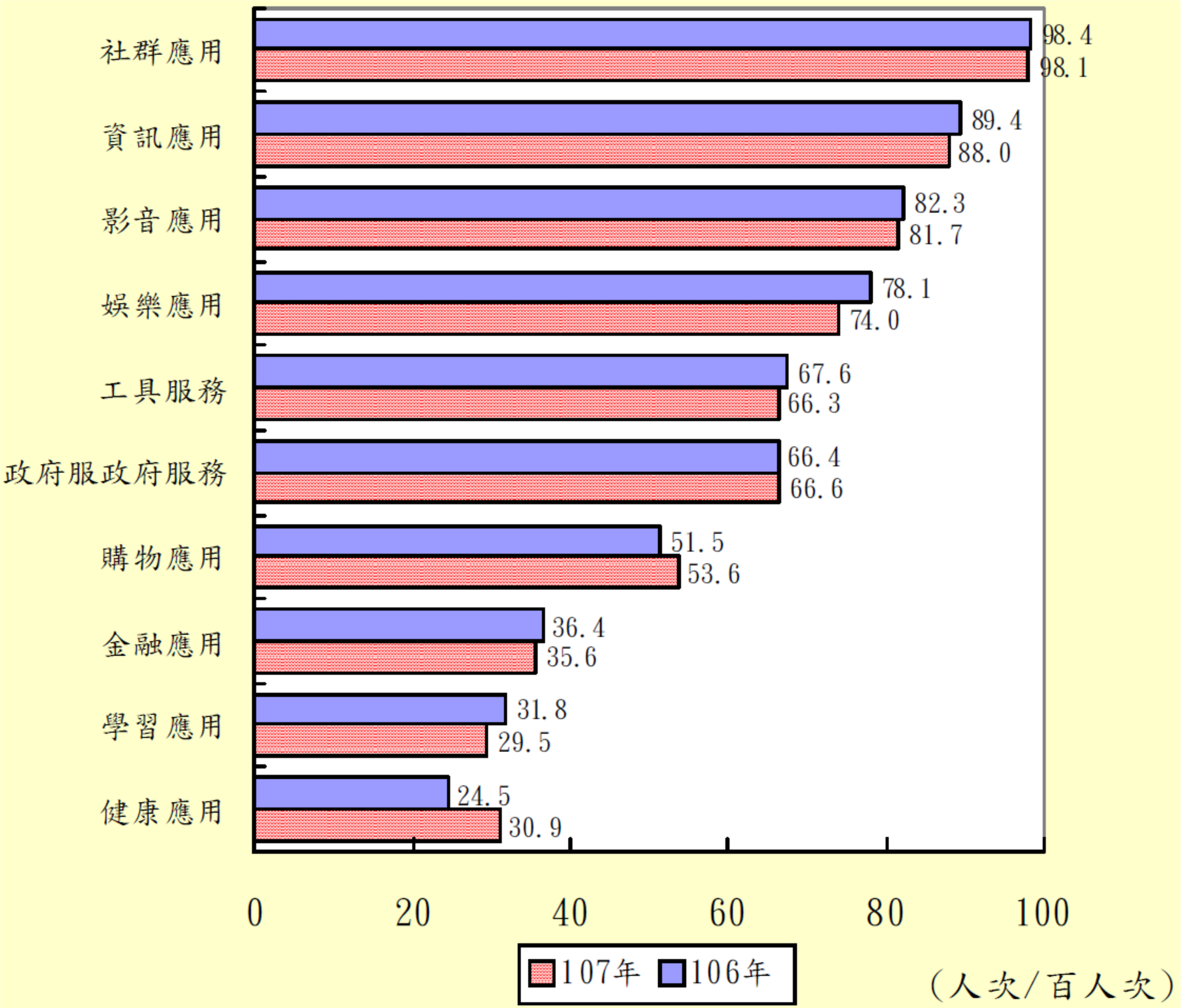
- 手機族曾透過手機上網的比率從100年的35.3% 大幅成長為106年的87.4%，107年再略增為88.2%
  - 4G 吃到飽方案(71.6%)為目前最主流的行動連網方式
  - 單純仰賴手機上網的人口越來越多，由105 年的11.9%、106年的18.7%再增為今年的28.0%，兩年來成長16.1 %
  - 同時申裝固網及手機行動上網服務的人則比106 年減少6.3 %
- 每天手機上網時間逐年攀升

100年	104年	105年	106年	107年
92分鐘	179分鐘	201分鐘	204分鐘	211分鐘

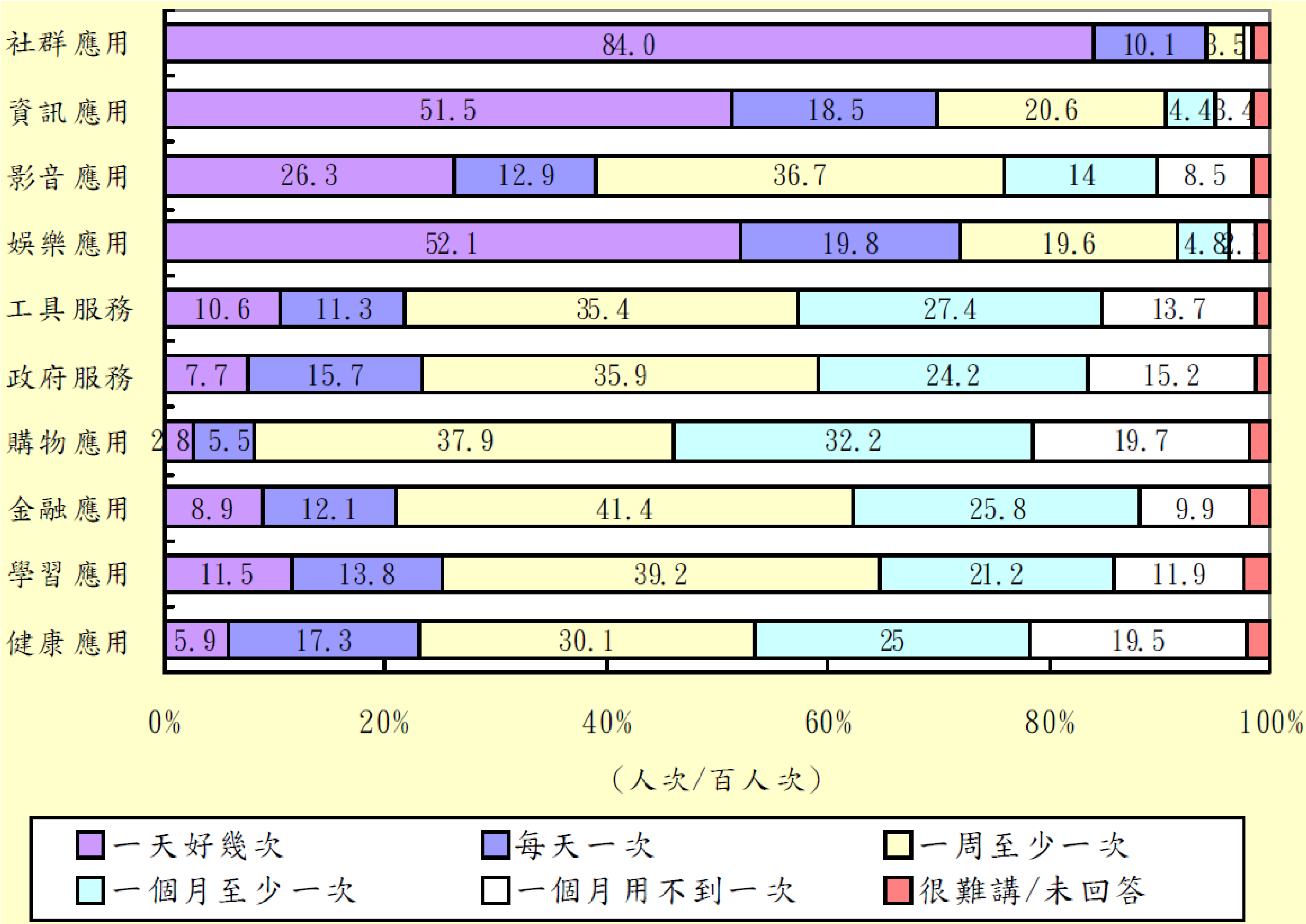
  - 女性滑手機平均時間達230 分鐘，比男性高出31 分鐘
  - 各年齡層中，以未滿20 歲手機行動上網族的連網時間最長，達282 分鐘

資料來源：國家發展委員會，107 年持有手機民眾數位機會調查報告，2018年9月

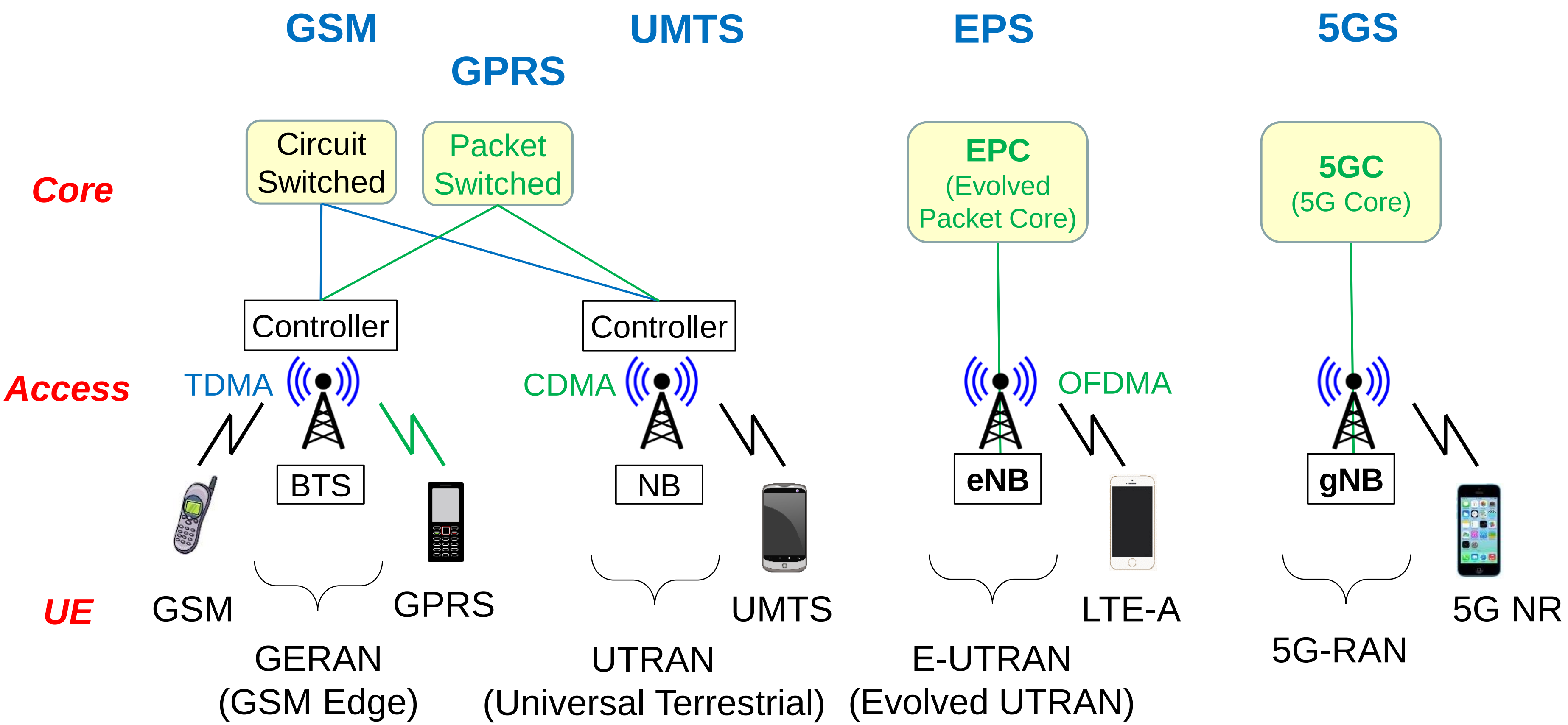
手機行動上網族手機活動類型



各類手機APP使用者的使用頻率



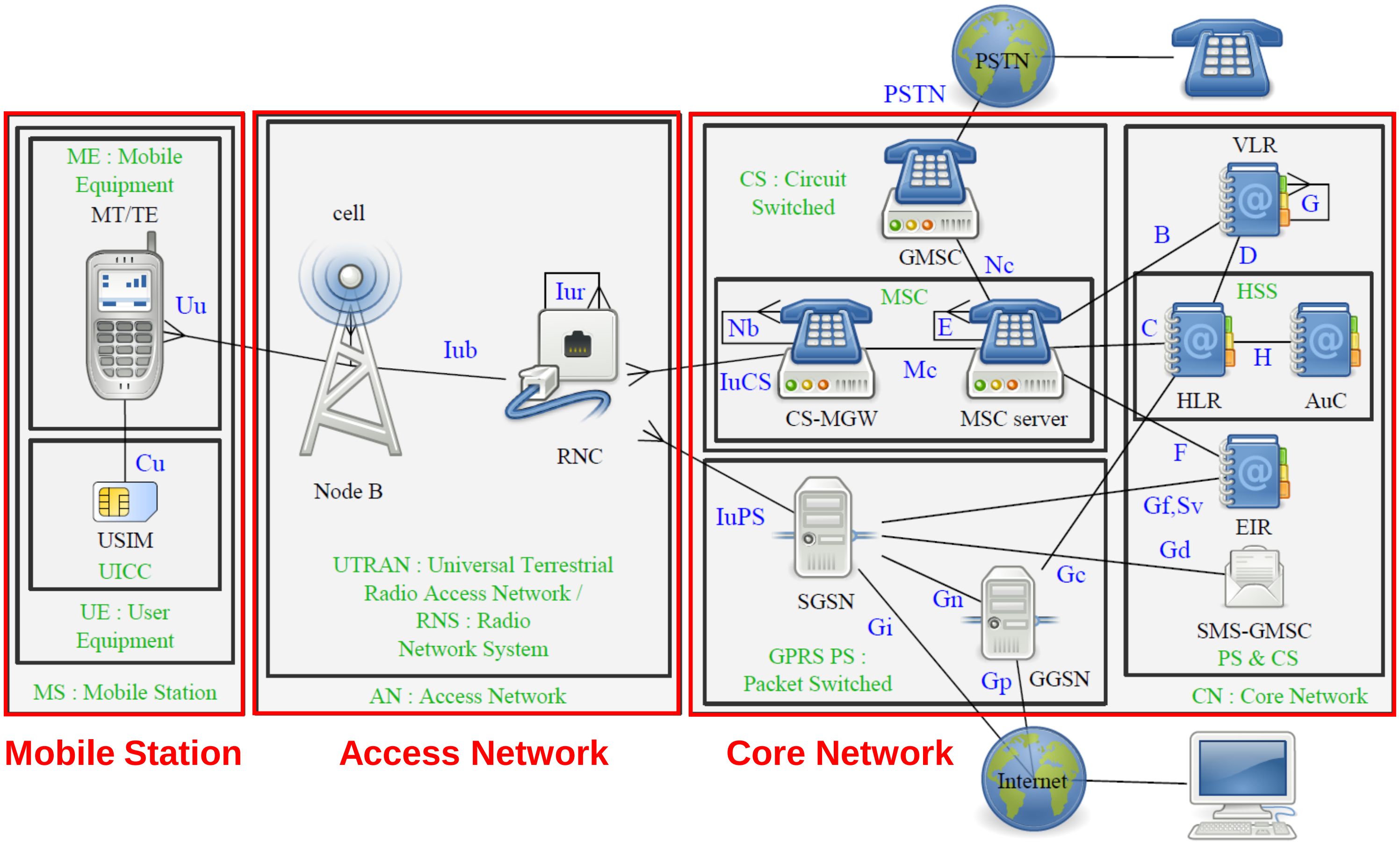
Mobile Networks from GSM to 5G NR



Mobile Networks from GSM to 5G NR (Cont.)

- GSM: developed to carry real time services, in a circuit switched manner
- GPRS: the first step towards an IP based packet switched solution
  - Using the same air interface and access method, TDMA (Time Division Multiple Access)
- UMTS: 3G standard based on GSM
  - Developing UTRAN and WCDMA
- EPS (Evolved Packet System): purely IP based
  - A flat, all-IP architecture with separation of control plane and user plane traffic
  - Composed with E-UTRAN/LTE and packet-switched EPC (Evolved Packet Core)
- **5GS**: Service-based Architecture and Network Slicing
  - Architecture elements are defined as network functions
    - Principles like modularity, reusability and self-containment of network functions
  - Allows for controlled composition of a PLMN from the specified network functions with their specifics and provided services that are required for a specific usage scenario

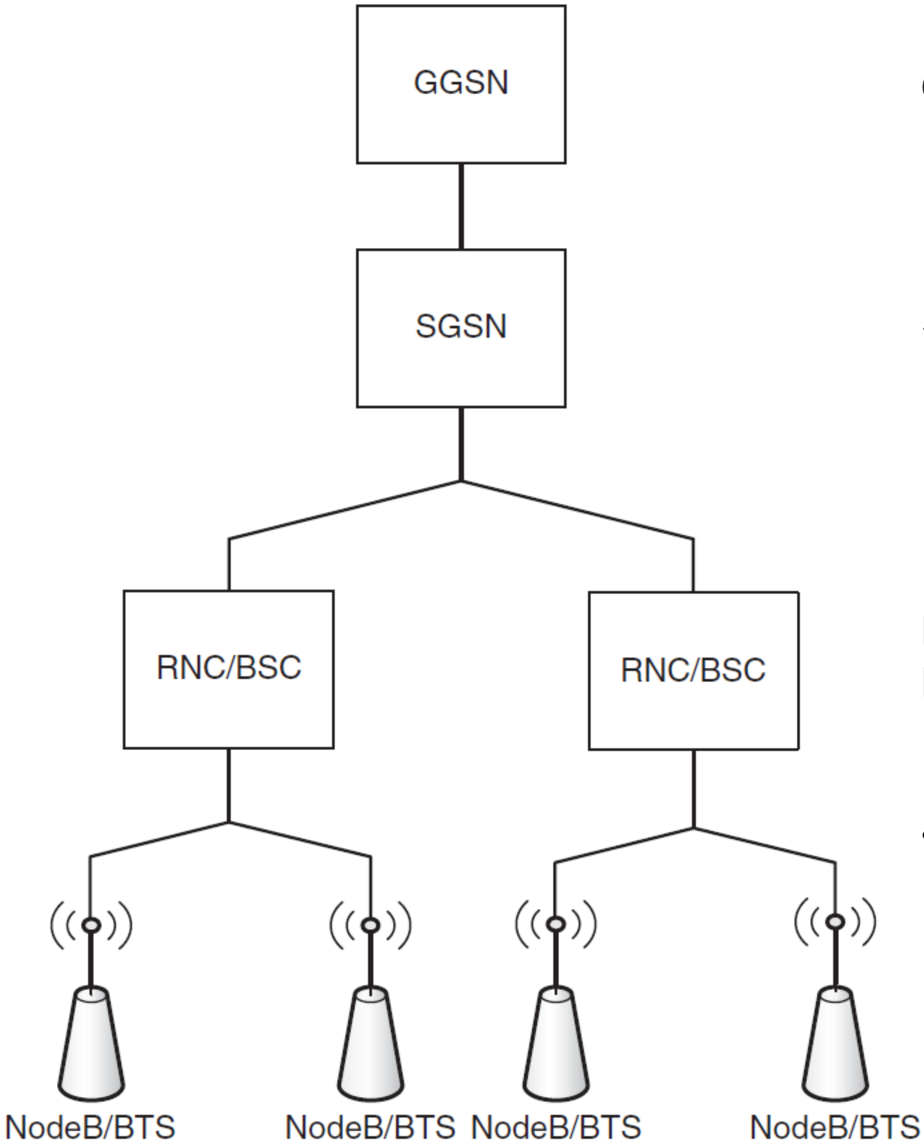
Network Structure of UMTS (Universal Mobile Telecommunications System)



Mobile Station **Access Network** **Core Network**

- Emulating a circuit switched connection for real time services and a packet switched connection for datacom services
  - Incoming datacom services are still relying upon the circuit switched core for paging
  - An IP address is allocated to the UE when a datacom service is established and released when the service is released

Overall UMTS Architecture



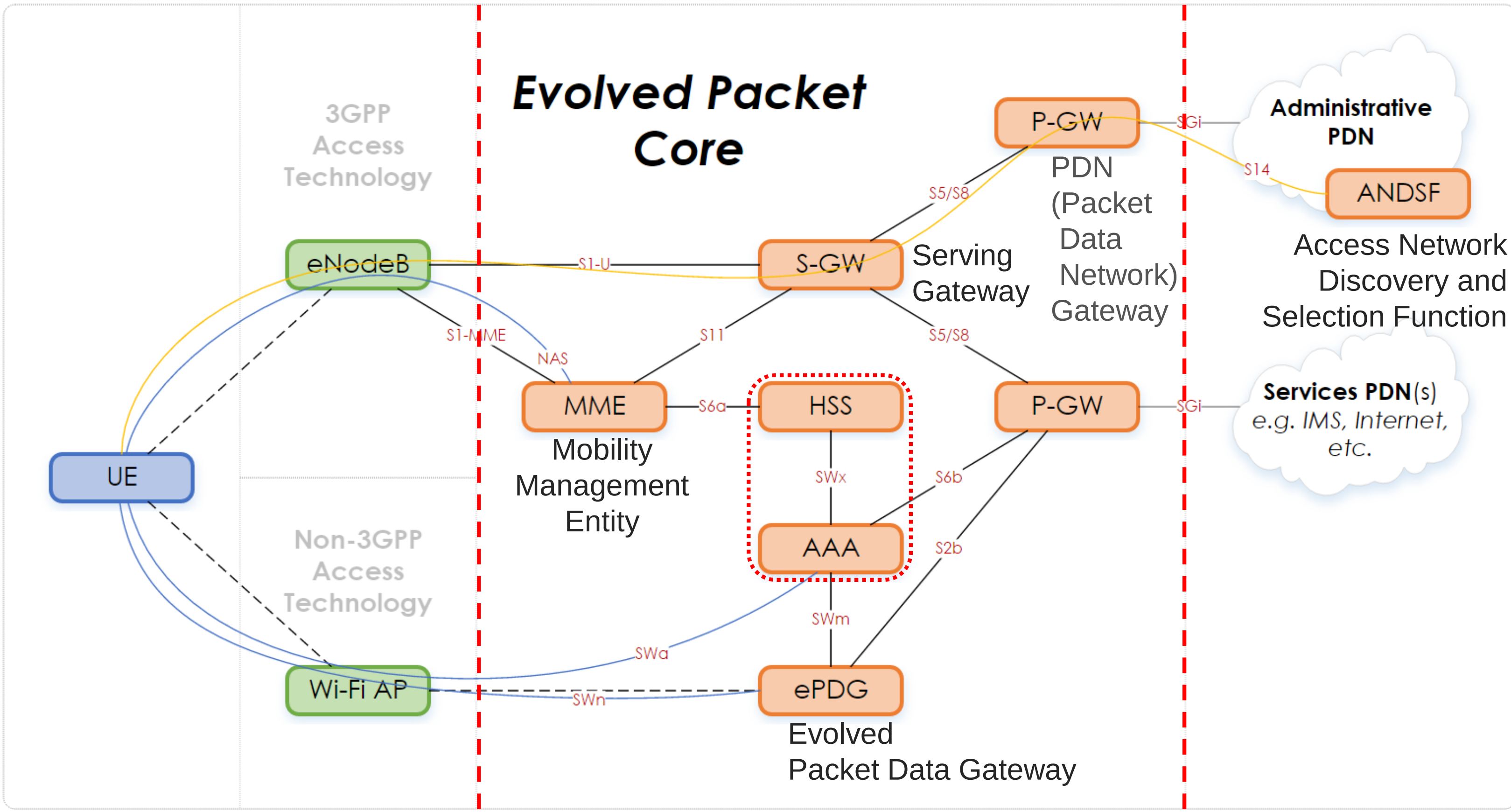
Gateway GPRS Support Node

Serving GPRS Support Node

Base Station Controller (BSC) for GSM
Radio Network Controller (RNC) for UMTS

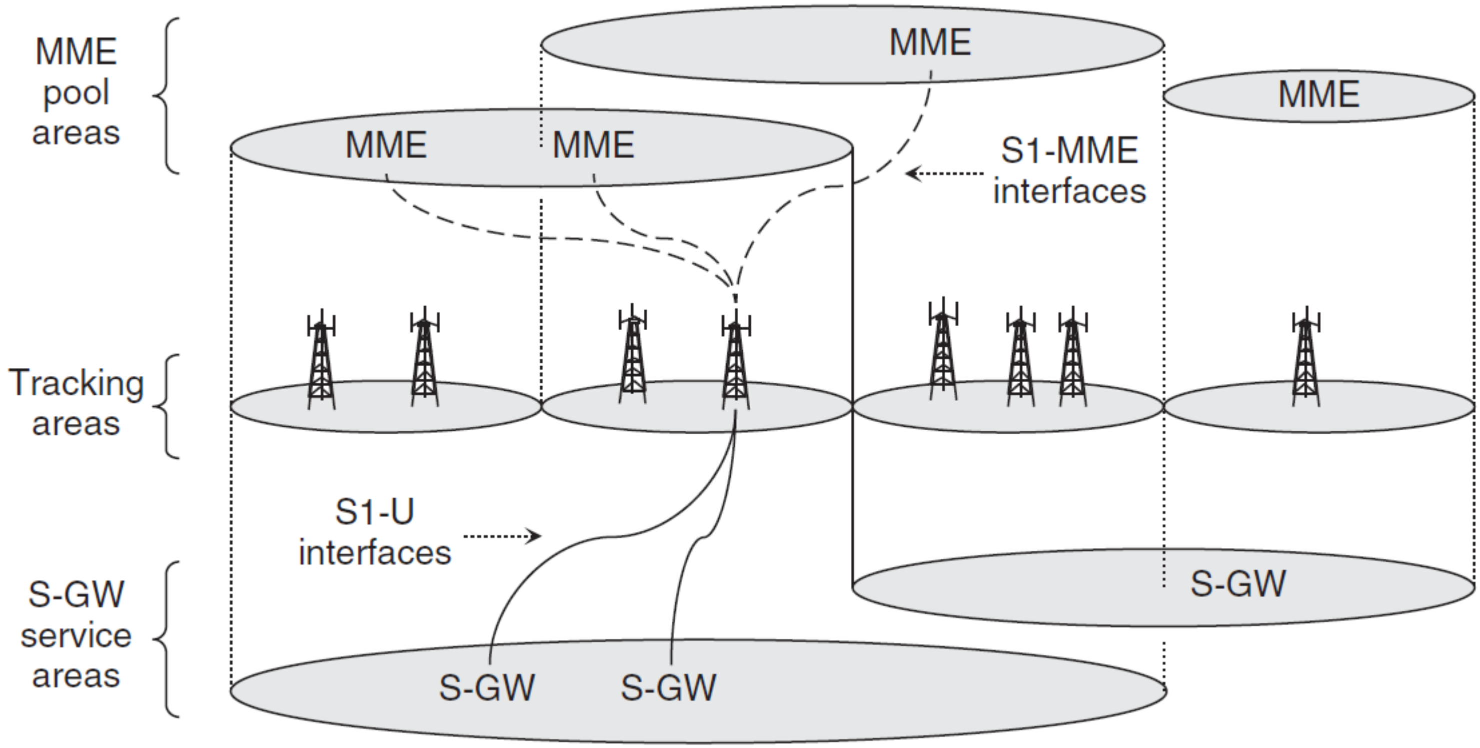
- Several Base Transceiver Stations (BTS) controlled by a BSC
  - If a BSC malfunctions, a large coverage area incorporating many BTSs is affected
  - Not occurred In LTE since BTS and BSC are combined in the eNodeB

EPS (Evolved Packet System) / SAE



- EPC (Evolved Packet Core): main component of EPS, includes
  - MME: key control-node for LTE – UE paging; chooses S-GW for UE during attach and handover
    - Authenticating the user (by interacting with HSS - Home Subscriber Server)
  - S-GW: manages and stores UE contexts; routes and forwards user data packets
  - P-GW: provides connectivity from the UE to external packet data networks
  - ePDG: secures data transmission with UE connected to EPC over untrusted non-3GPP access
  - ANDSF: provides information to UE to discover available access networks (either 3GPP or not)

Three Types of EPC Geographical Areas



- **Tracking area**: smaller, *non-overlapping* units
  - Track the locations of mobiles
- **MME pool area**: an area through which the mobile can move without a change of serving MME
  - A network operator might configure a pool area to cover a large region of the network such as a major city
- **S-GW service area**: an area served by one or more serving gateways, through which the mobile can move without a change of serving gateway

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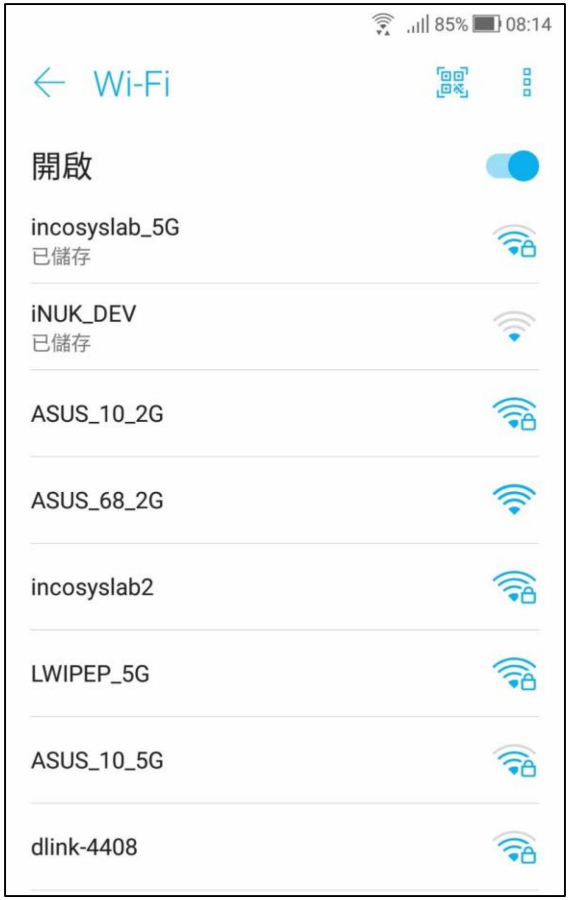
什麼是5G？

- 5 GHz?
- 5 GB?
- 5th Generation
  - ITU-R IMT-2020 Requirements
  - 3GPP Release 15/16~ Specifications

Welcome to the Invention Age (Qualcomm, Jan 2019)
https://www.youtube.com/watch?v=TNIg5YeLaQU
Qualcomm presents: A History of 5G
https://www.digitaltrends.com/?page_id=2285944

What is 5G? | CNBC Explains
https://www.youtube.com/watch?v=2DG3pMcNNlw

連結5G以後的世界(日本)
https://www.youtube.com/watch?v=lDJC_yJTXIc



International Telecommunication Union

- A specialised agency of the United Nations that is responsible for issues that concern information and communication technologies
- Comprises three sectors
  - Radio communication (ITU-R)
    - Established in 1927 as the International Radio Consultative Committee (CCIR)
      - Became the ITU-R in 1992
    - Manages the international radio-frequency spectrum and satellite orbit resources
    - Develops standards for radiocommunication systems with the objective of ensuring the effective use of the spectrum
  - Standardisation (ITU-T)
    - Established in 1956 as the International Telephone and Telegraph Consultative Committee (CCITT)
      - Became the ITU-T in 1993
    - Standardizes global telecommunications (except for radio)
  - Development (ITU-D)
    - Established in 1992
    - Helps spread equitable, sustainable and affordable access to information and communication technologies (ICT)

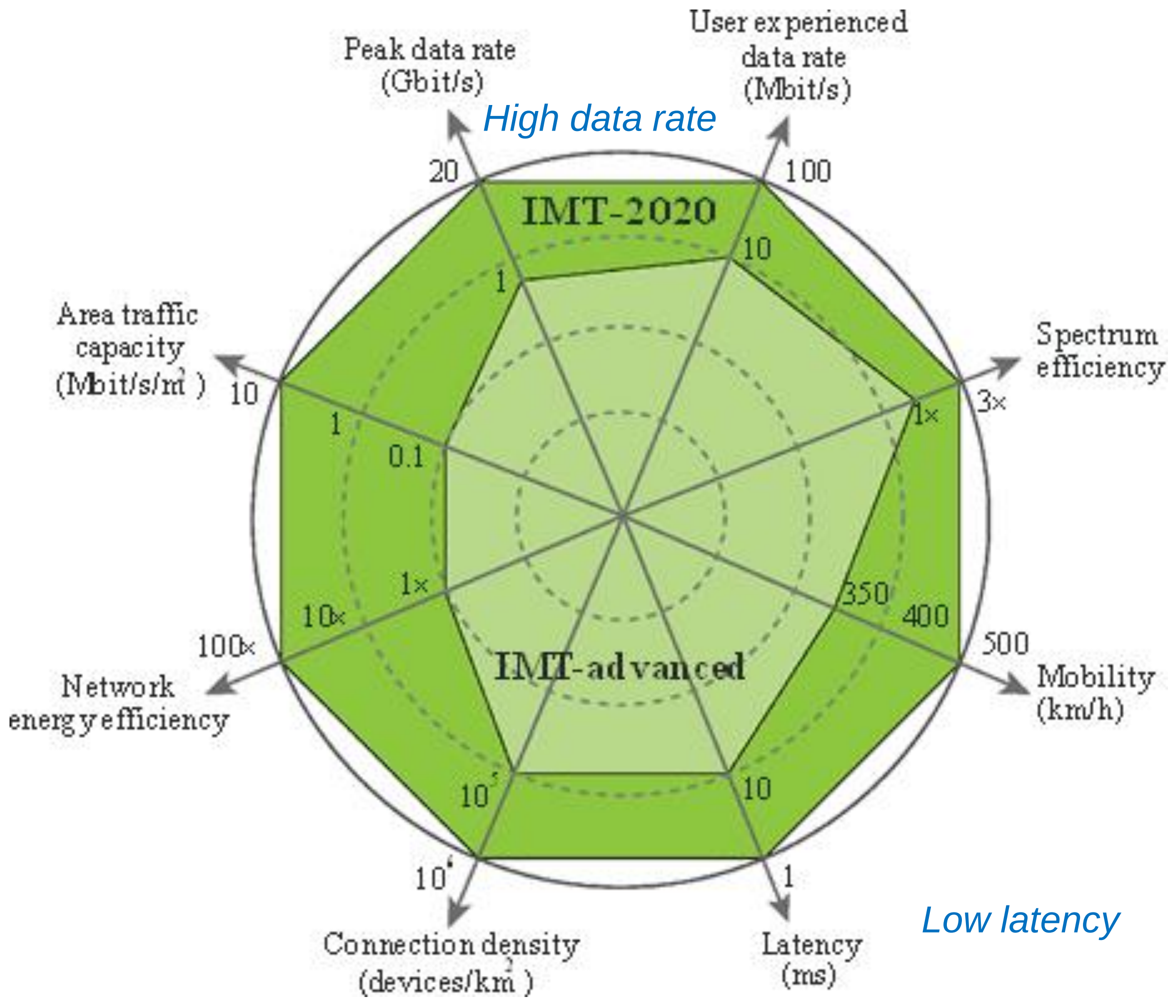
https://en.wikipedia.org/wiki/International_Telecommunication_Union

International Mobile Telecommunications-2020 (ITU-R IMT-2020 Standard)

- The requirements issued by the ITU-R in 2015 for 5G networks, devices and services

Capability	Description	5G Target	Scenario
Peak data rate	Maximum achievable data rate	20 Gbit/s	eMBB
User experienced data rate	Achievable data rate across the coverage area (hotspot cases)	1 Gbit/s	eMBB
	Achievable data rate across the coverage area	100 Mbit/s	eMBB
Latency	Radio network contribution to packet travel time	1 ms	URLLC
Mobility	Maximum speed for handoff and QoS requirements	500 km/h	eMBB/URLLC
Connection density	Total number of devices per unit area	$10^6/km^2$	MMTC
Energy efficiency	Data sent/received per unit energy consumption (by device or network)	Equal to 4G	eMBB
Area traffic capacity	Total traffic across coverage area	1000 $(Mbit/s)/m^2$	eMBB
Spectrum efficiency	Throughput per unit wireless bandwidth and per network cell	3–4x 4G	eMBB

Enhancement of Key Capabilities from IMT-Advanced (4G) to IMT-2020 (5G)

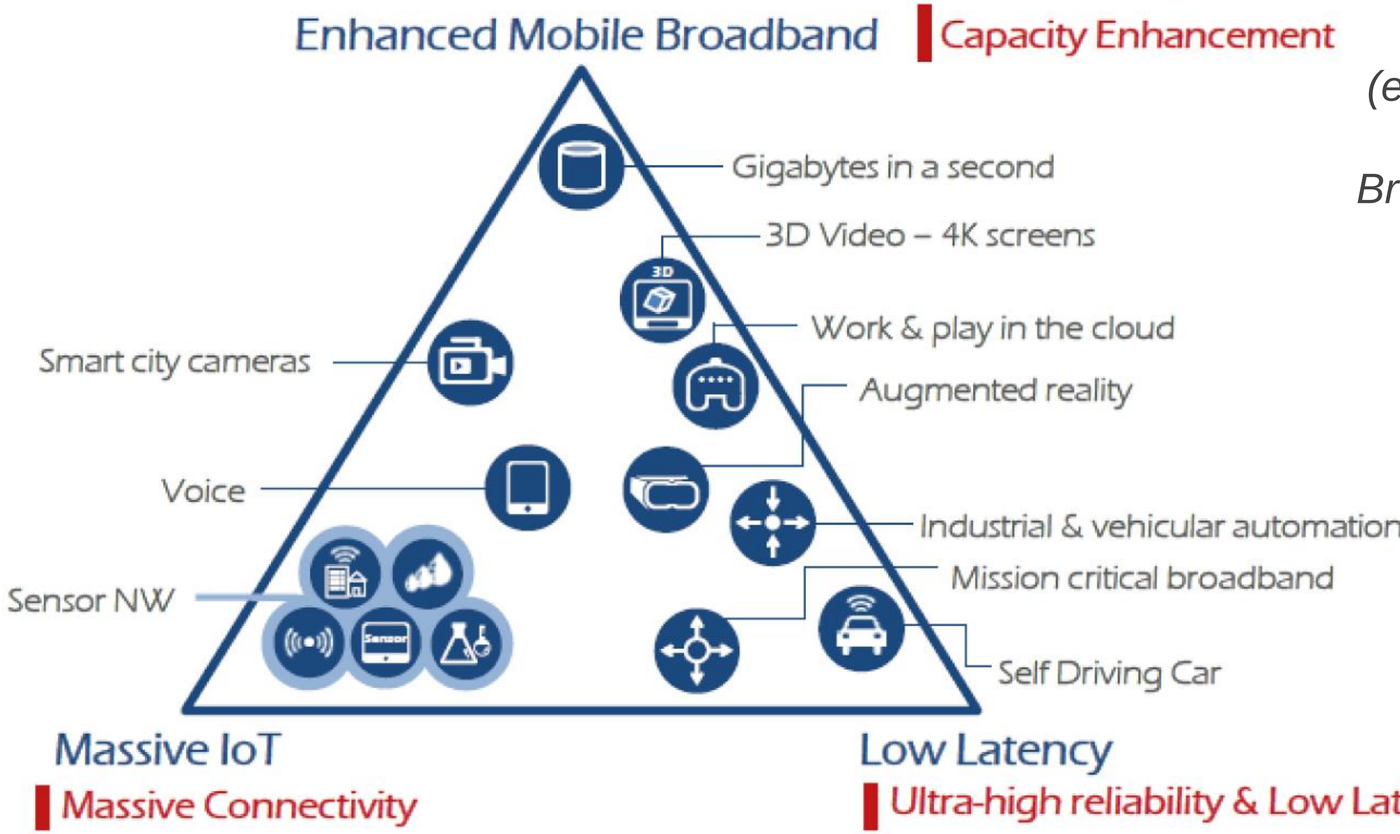


- High data rate
- Low latency
- High reliability
- High density

大頻寬、低延遲、高可靠

Source: ITU-R M.2083-0 (Sep 2015)

Three Dimensions to Performance Improvements with Usage Scenarios for 2020 and Beyond



eMBB
(enhanced Mobile Broadband)

mMTC
(massive Machine Type Communications)

URLLC
(Ultra-Reliable and Low Latency Communications)

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

Source: ITU-R IMT 2020 Requirements (ITU-R M.2083, 2015)

What is the Difference between 4G and 5G?

A: There are several differences between 4G vs 5G

- User's Views
  - 5G is faster than 4G
  - 5G has lower latency than 4G
- System's Views
  - 5G uses spectrum better than 4G
  - 5G has more capacity than 4G
  - 5G is a unified platform that is more capable than 4G

Source: https://www.qualcomm.com/invention/5g/what-is-5g

Third Generation Partnership Project (3GPP)

- A global partnership created and managed by regional standards organizations
  - Established in Dec 1998 with the goal of developing a specification for a 3G mobile phone system based on the 2G GSM system
- Members
  - Organizational partners: Seven regional telecommunication associations as primary members
    - ETSI
  - Market representation partners: other organizations as associate members
    - GSMA
- Work in Working Groups (WGs) of three Technical Specification Groups (TSGs)
  - Radio Access Networks (RAN)
  - Services and Systems Aspects (SA)
  - Core Network and Terminals (CT)

A GLOBAL INITIATIVE

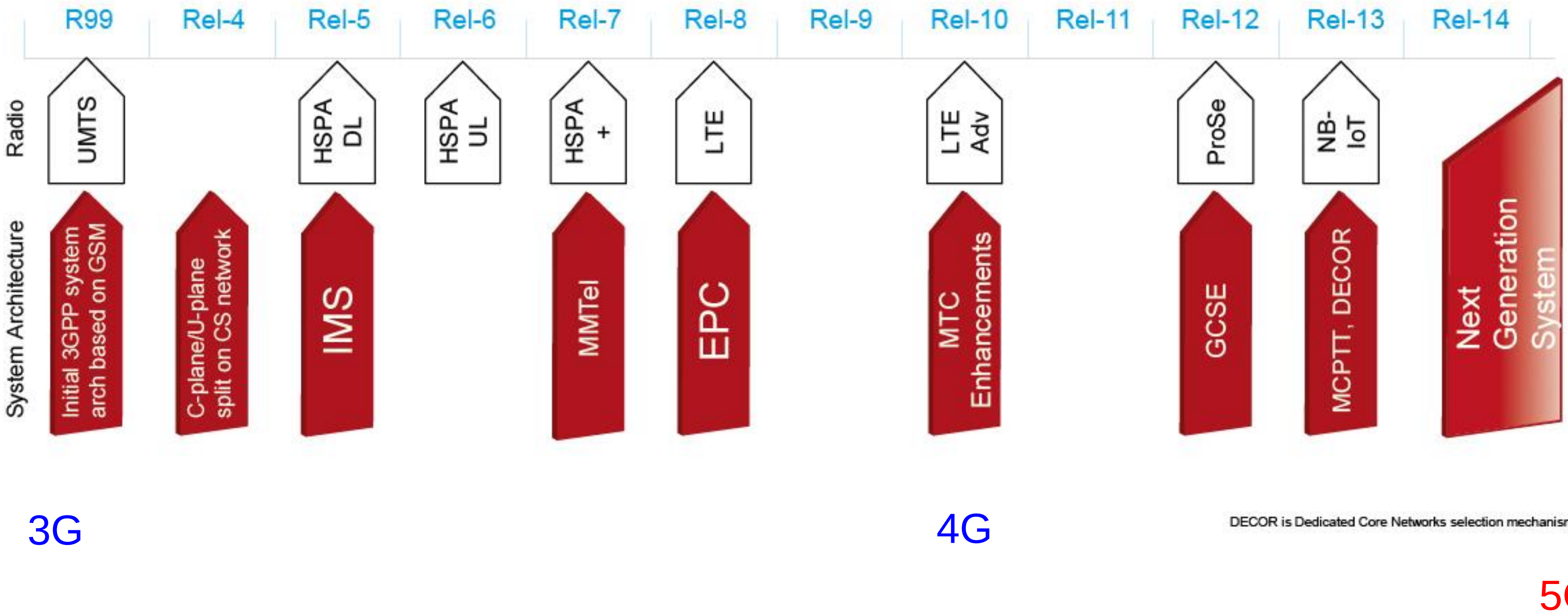
https://en.wikipedia.org/wiki/3GPP

3GPP TSGs and WGs

Project Co-ordination Group (PCG)		
TSG RAN Radio Access Network	TSG SA Service & Systems Aspects	TSG CT Core Network & Terminals
RAN WG1 Radio Layer 1 spec	SA WG1 Services	CT WG1 MM/CC/SM (lu)
RAN WG2 Radio Layer 2 spec Radio Layer 3 RR spec	SA WG2 Architecture	CT WG3 Interworking with external networks
RAN WG3 lub spec, lur spec, lu spec UTRAN O&M requirements	SA WG3 Security	CT WG4 MAP/GTP/BCH/SS
RAN WG4 Radio Performance Protocol aspects	SA WG4 Codec	CT WG6 Smart Card Application Aspects
RAN WG5 Mobile Terminal Conformance Testing	SA WG5 Telecom Management	
RAN WG6 Legacy RAN radio and protocol	SA WG6 Mission-critical applications	

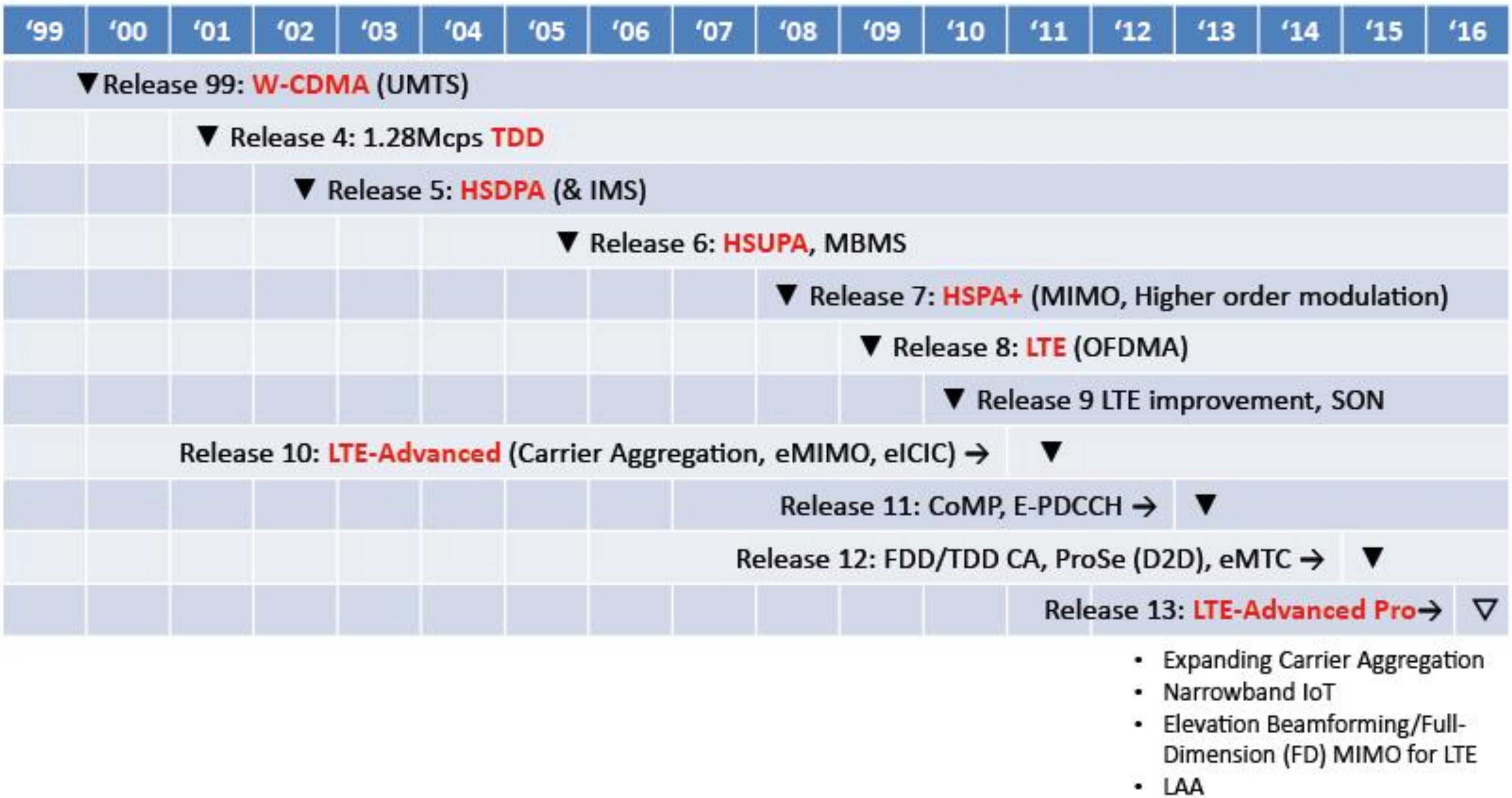
https://www.3gpp.org/specifications-groups

Core Network Evolution



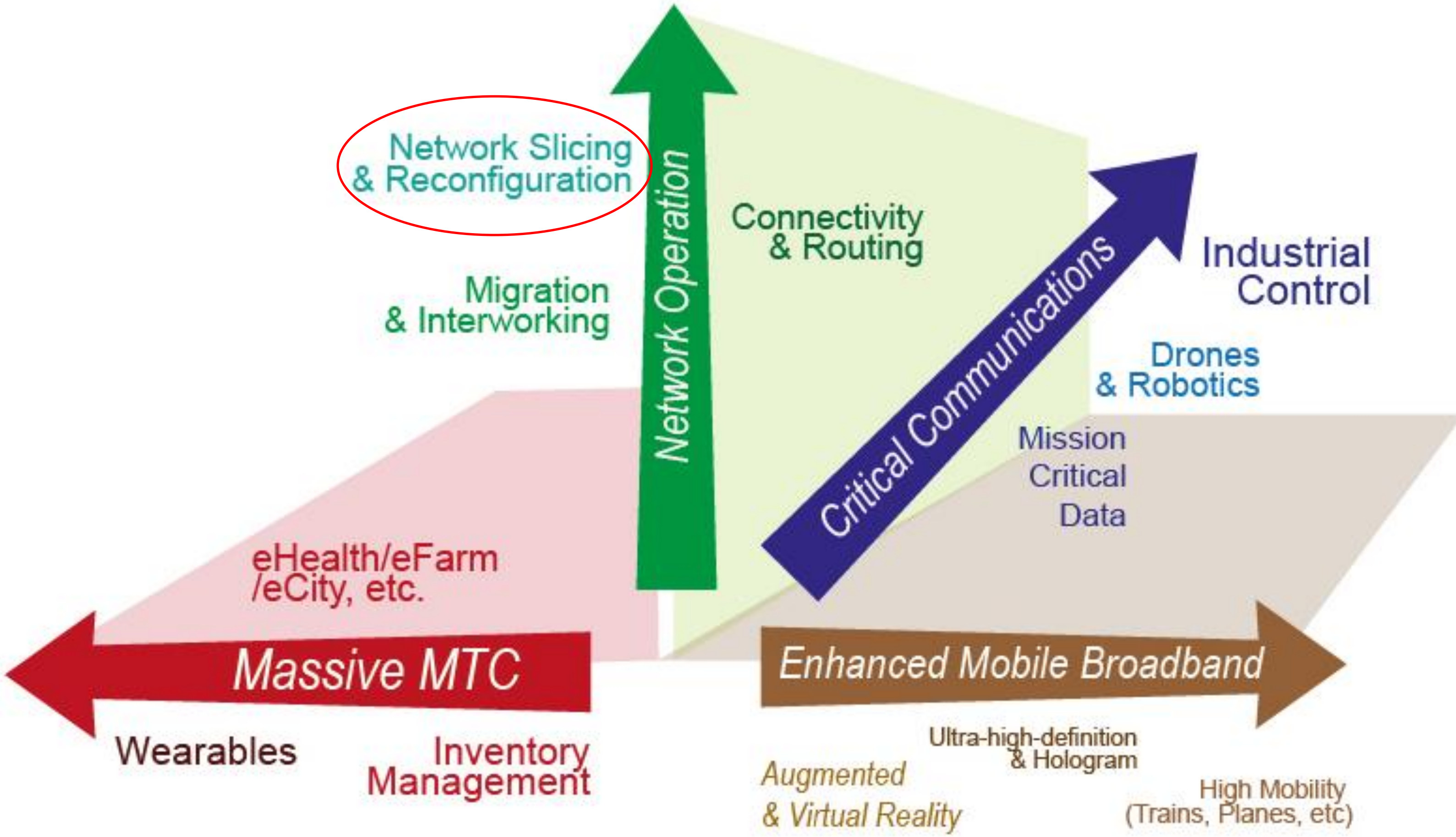
Source: http://www.3gpp.org/about-3gpp/about-3gpp

Radio Access Milestones



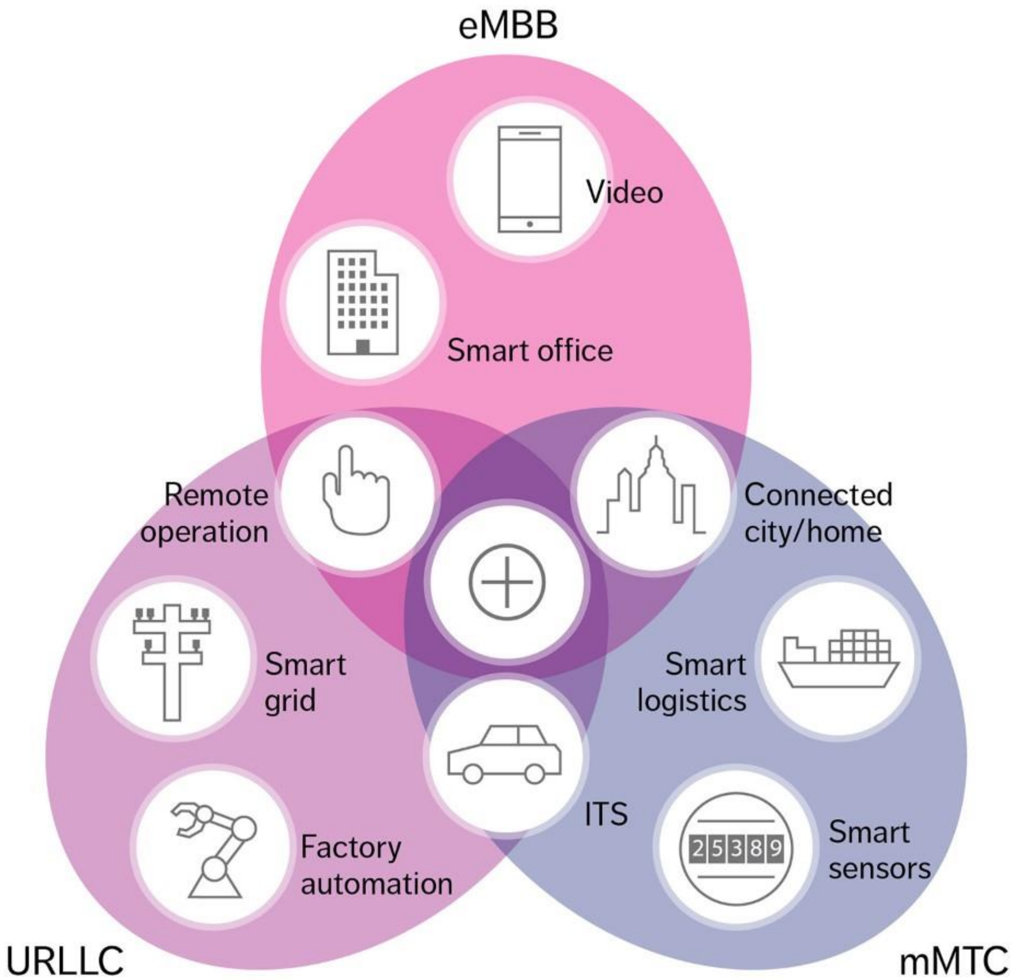
Source: http://www.3gpp.org/about-3gpp/about-3gpp

3GPP 5G Requirements



TR22.891 with 70s different user cases of four groups (SA1 finalized June 2016)

Three Main 5G Cases and Examples



eMBB (enhanced Mobile Broadband)
mMTC (massive Machine Type Communications)
URLLC (Ultra-Reliable and Low Latency Communications)

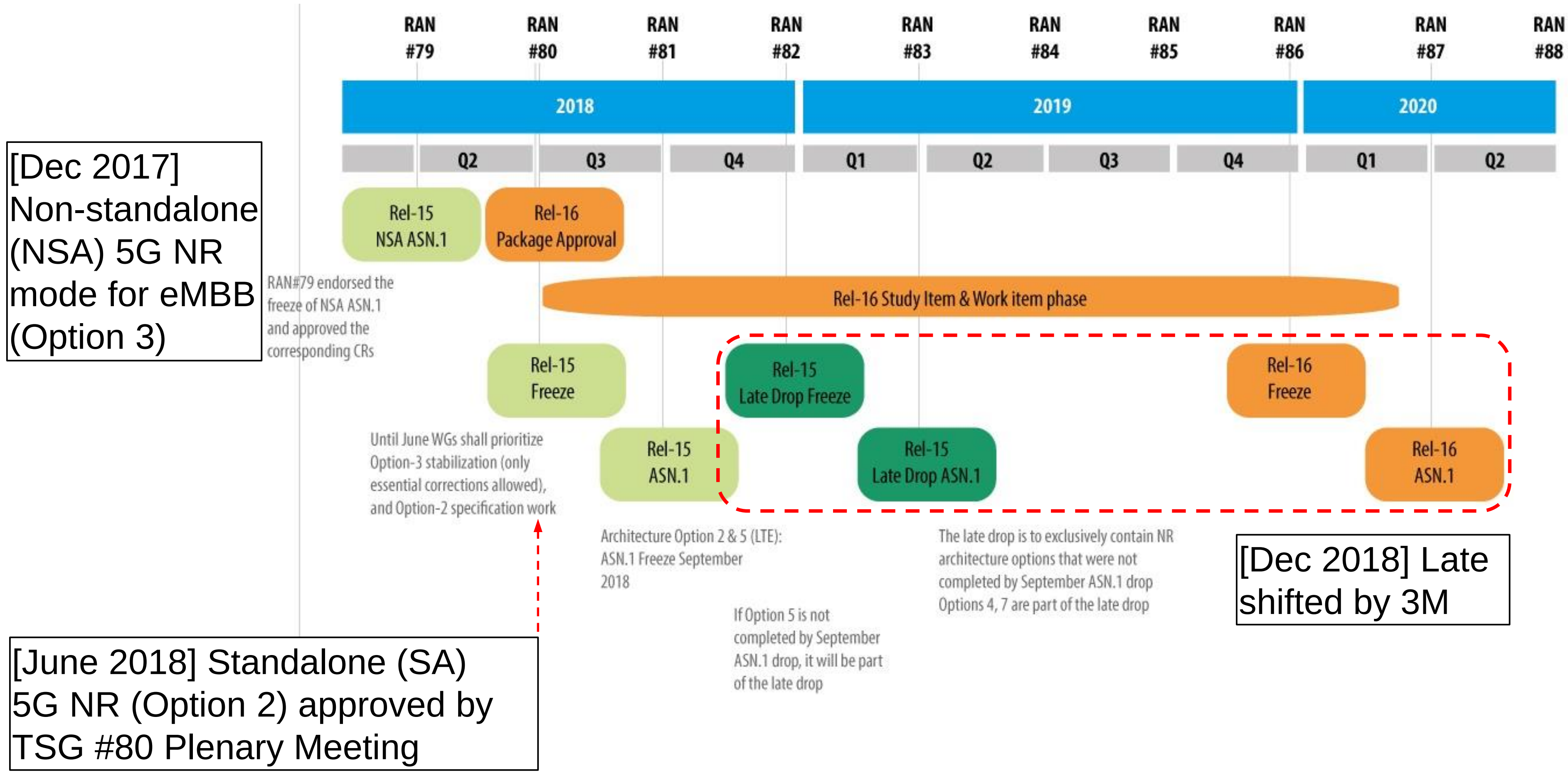
Features of 5G System Architecture

- Service Based Architecture
  - The architecture elements are defined as *network functions*
  - Adopts principles like modularity, reusability and self-containment of network functions
- Common Core Network
  - Enables to operate with different access networks
- Network Slicing
  - Allows for controlled composition of a PLMN from the specified network functions with their specifics and provided services that are required for a specific usage scenario
- Application Support
  - A new QoS model enables differentiated data services to support diverse application requirements

Vertical Applications

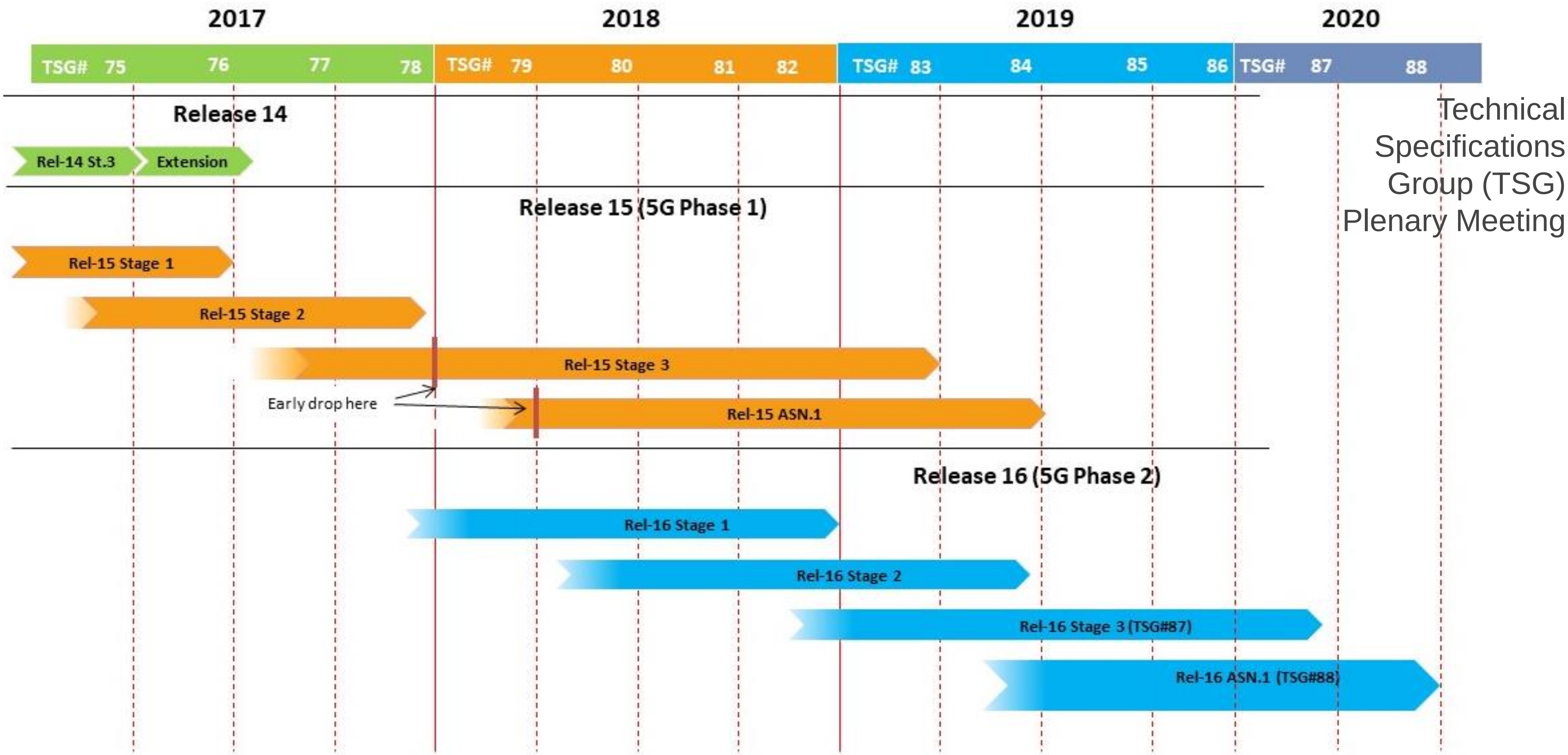
- Network Slicing
- Efficiency
- Priority, QoS and Policy Control
- V2X (Vehicle to Anything) communication is a vertical application that has influenced 5G requirements

R15 and R16 NR Milestones



- **5G Non-Standalone (NSA)**: The existing LTE radio access and core network (EPC) is used as an anchor for mobility management and coverage to add the 5G carrier
- **5G Standalone (SA)**: A new 5G Packet Core comprising of 5G New Radio (5G NR) and 5G Core Network (5GC/~~NGC~~) is introduced with several new capabilities built inherently

3GPP Ongoing Releases



Stage 1: an overall service description *from the user's standpoint*
Stage 2: an overall description of the *organization of the network functions* to map service requirements into network capabilities
Stage 3: the definition of *switching and signalling capabilities* needed to support services defined in stage 1
ASN.1: Standard interface description for defining data structures

https://www.3gpp.org/specifications/67-releases

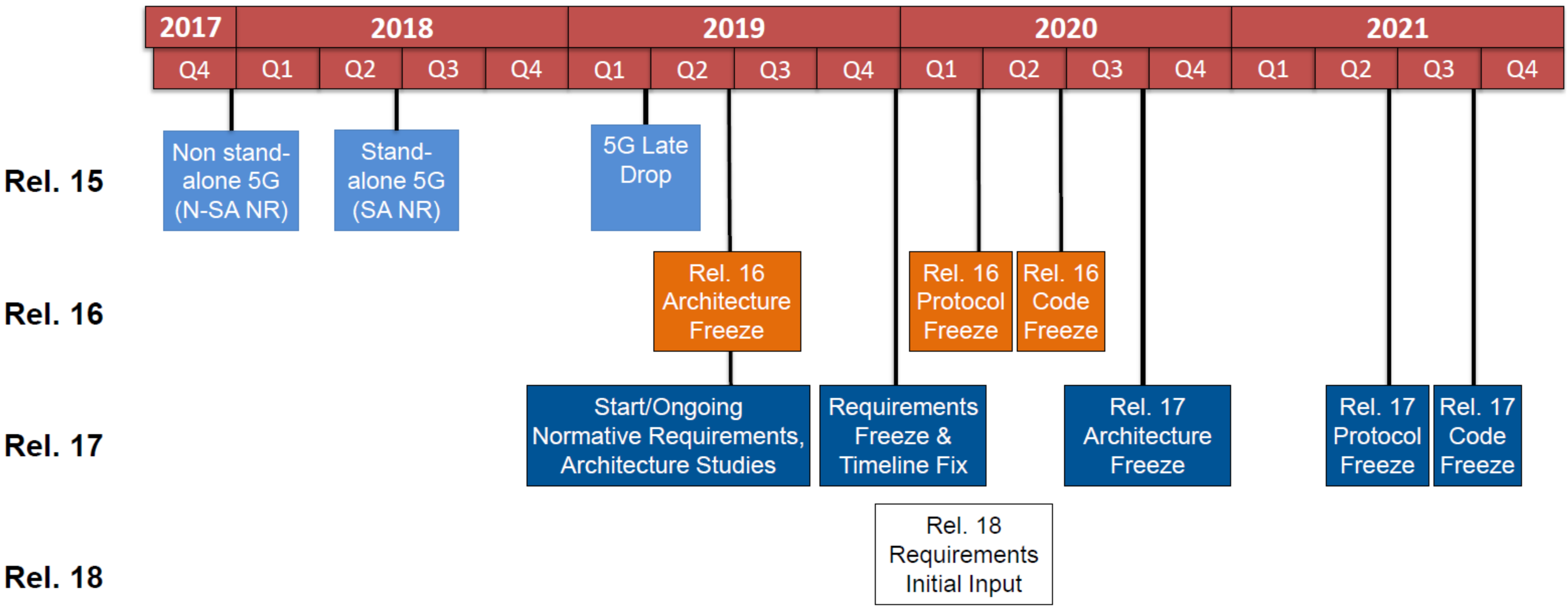
3GPP ASN.1

- ccitt | itu-t (0)
  - identified-organization (4)
    - etsi (0)
      - mobileDomain (0) — ETSI EG 200 351
        - mobileDomainDefinitions (0) — ETSI ETR 091
        - gsm-Network | umts-Network (1) — ETSI ETR 091
        - gsm-Access (2) — ETSI ETR 091
        - gsm-Operation-Maintenance | umts-Operation-Maintenance (3) — ETSI ETR 091
        - gsm-Messaging (4) — ETSI ETR 091
        - charging (5)
        - umts-Access (20)
        - eps-Access (21) — 3GPP TS 36.413
          - modules (3) — 3GPP TS 36.413
            - s1ap (1) — 3GPP TS 36.413
            - x2ap (2) — 3GPP TS 36.423
            - sbc-AP (3) — 3GPP TS 29.168
            - m2ap (4) — 3GPP TS 36.443
            - m3ap (5) — 3GPP TS 36.444
            - lppa (6) — 3GPP TS 36.455
            - lpp (7) — not in 3GPP TS 36.355
            - xwap (8) — 3GPP TS 36.463
            - slmap (50) — 3GPP TS 36.459
        - ngran-access (22) — 3GPP TS 38.413
          - modules (3) — 3GPP TS 38.413
            - ngap (1) — 3GPP TS 38.413
            - xnap (2) — 3GPP TS 38.423
            - f1ap (3) — 3GPP TS 38.473
            - nrppa (4) — 3GPP TS 38.445
            - e1ap (5) — 3GPP TS 38.463

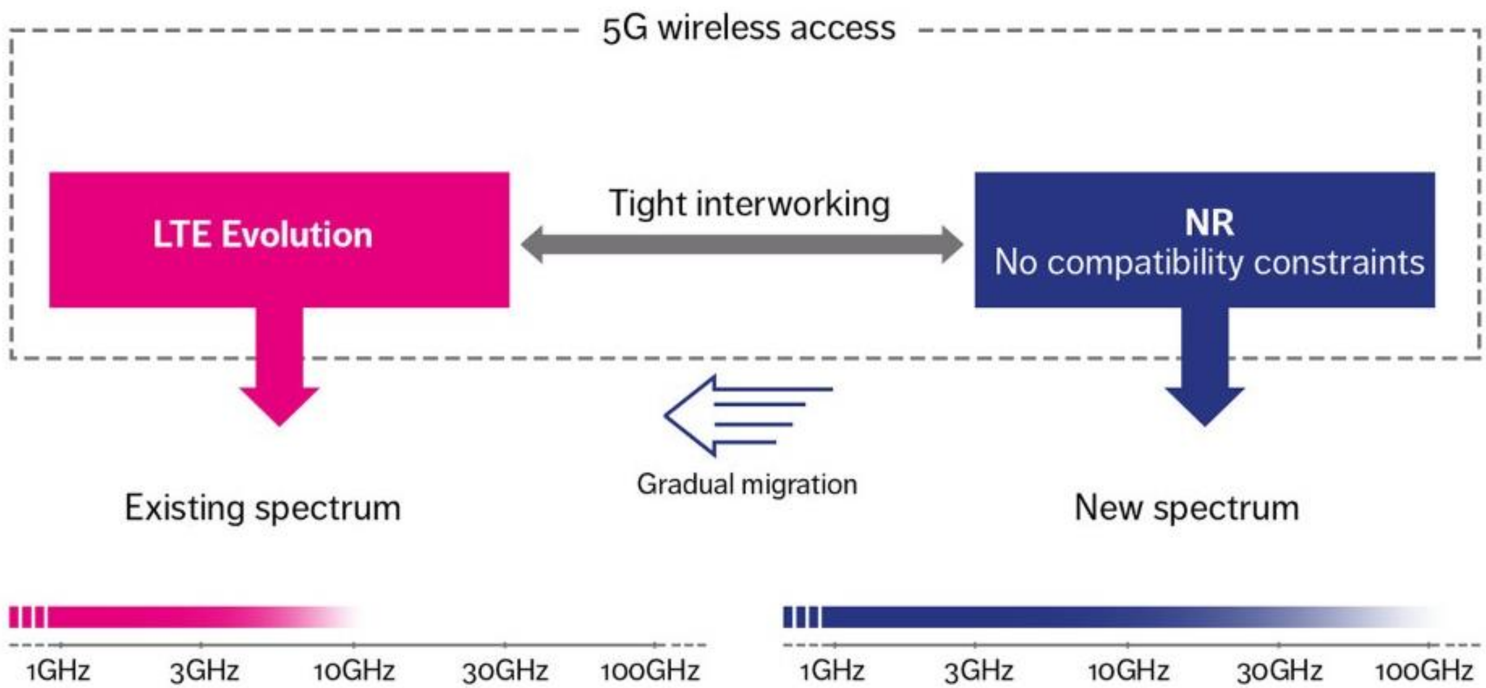
- ASN.1 (Abstract syntax notation)
  - A standard interface description language for defining data structures that can be serialized and deserialized in a cross-platform way (Wiki)
- Object identifiers maintained by ETSI EG 200 351
  - ccitt|itu-t / identified-organization / etsi / mobileDomain
    - / eps-Access
    - / ngran-access

https://webapp.etsi.org/ASN1ObjectTree/ASN1.asp

3GPP Release Timetable



5G Radio Access Roadmap



- Two tracks
  - Evolution of LTE (Non Standalone)
  - New Radio (NR, LTE-5G)
    - Free from backward compatibility requirements / network slicing
    - Targeting spectrum at high (mm-wave) frequencies
- Two main features
  - FD-MIMO (Full-Dimension)
  - Unlicensed operations

5G NR

- Frequencies
  - FR1: Lower frequencies (below 6 GHz)
  - FR2: Higher Frequencies (above 24 GHz)
- Enabling Technologies

Scalable Numerology	Flexible Frame Structure	Advanced Channel Coding	Enhanced MIMO	Beam Forming
Single framework for f_c = sub 1-GHz – 50+ GHz Low latency* * One way latency ~ 1ms	Forward compatible design Flexible TDD	**LDPC** for high through-put low latency data channels. **Polar** codes for control channels.	Higher spectral efficiency MU-MIMO support	mmWave support Enhanced coverage

- R17 work areas under consideration

NR Light	Multi-SIM	IIoT/URLLC enhancements	NR-U Enhancements
Small data Enhancements	NR Multicast/ Broadcast	MIMO Enhancements	Power saving Enhancements
Sidelink Enhancements	Coverage Enhancements	NTN Enhancements	Data collection Enhancements
Above 52.6 GHz	NB-IoT Enhancements	IAB Enhancements	Positioning Enhancements

https://www.3gpp.org/news-events/partners-news/2061-atis-webinar-%E2%80%93-5g-standards-development

5G/NR MmWave Bands

5G/NR – mmWave			
Band	Frequencies [GHz]	BW [MHz]	Duplex mode
n257	26.5–29.5	50–400	TDD
n258	24.25–27.5	50–400	TDD
n260	37.0–40.0	50–400	TDD
TBD	37.0–43.5	50–400	TDD

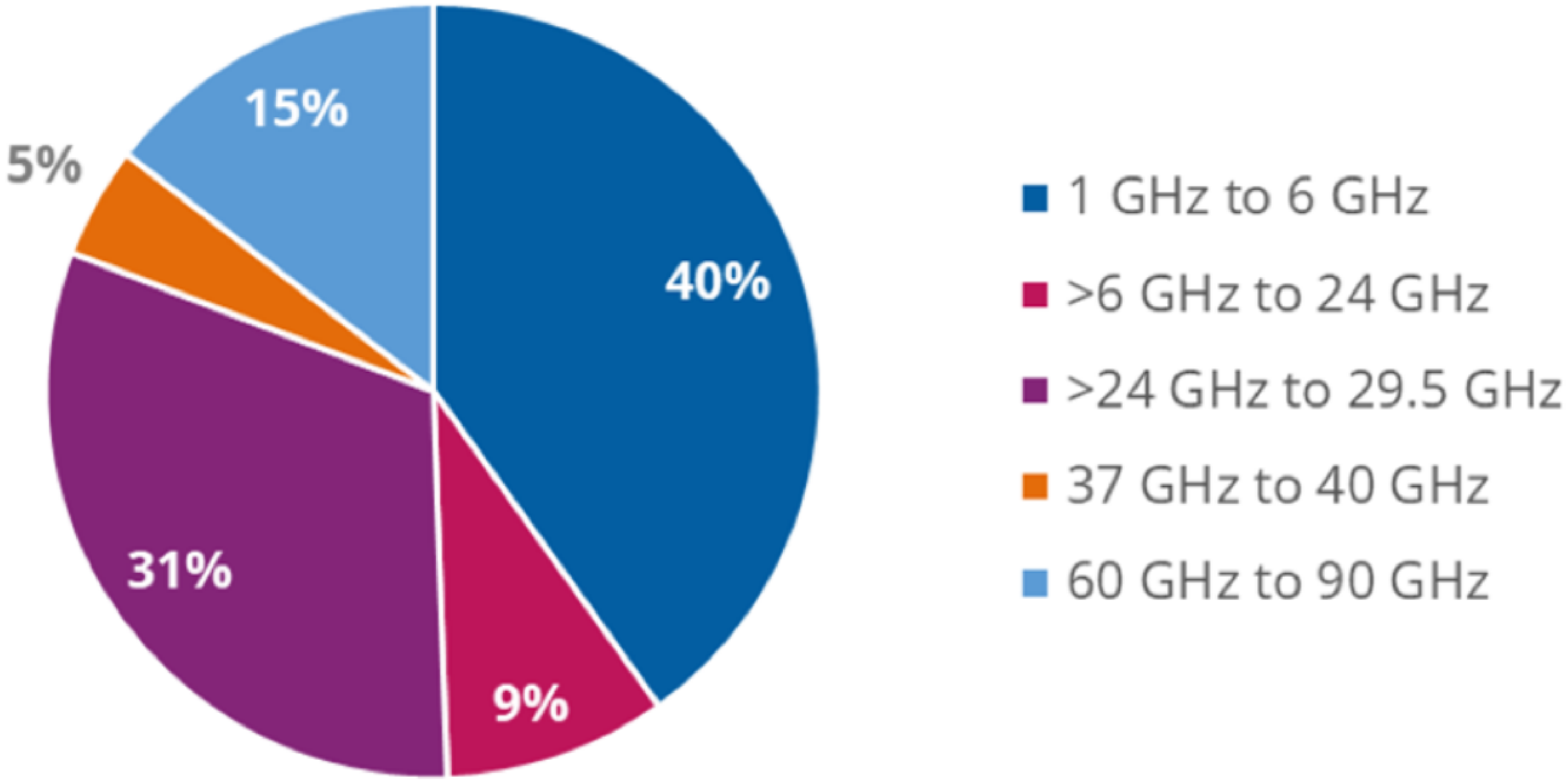
5G/NR Spectrum Below 6 GHz

Band	Frequencies [MHz]	BW [MHz]	Duplex mode
n77	3300–4200	10–100	TOD
n78	3300–3800	10–100	TOD
n79	4400–5000	40–100	TOD
n80	1710–1785/N/A	5–30	SUL
n81	880–915/N/A	5–20	SUL
n82	832–862/N/A	5–20	SUL
n83	703–748/N/A	5–20	SUL
n84	1920–1980/N/A	5–20	SUL

5G/NR Re-farmed Spectrum

Band	Identifier	Frequencies [MHz]	BW [MHz]
n1	IMF Core Band	1920–1980/2110–2170	5–20
n2	PCS 1900	1850–1910/1930–1990	5–20
n3	1800	1710–1785/1805–1880	5–30
n5	850	824–849/869–894	5–20
n7	IMF Extension	2500–2570/2620–2690	5–20
n8	900	880–915/925–960	5–20
n13	US 700 Upper C	777–787/746–756	tbd
n20	CEPT800	832–862/791–821	5–20
n25	PCS1900G	1850–1915/1930–1995	tbd
n26	E850 Upper	814–849/859–894	tbd
n28	APT 700	703–748/758–8035–20	5–20
n34	TDD 2000 Upper	2010–2025	tbd
n38	IMF Extension Gap	2570–2620	5–20
n39	China TDD 1900	1880–1920	tbd
n40	TDD 2300	2300–2400	tbd
n41	TDD 2600	2496–2690	10–100
n50	TDDL-band	1432–1517	5–80
n51	TDDL-band, local	1427–1432	5
n66	AWS Extension	1710–1780/2110–2200	5–40
n70	AWS-3/4	1695–1710/1995–2020	5–25
n71	US 600	663–698/617–652	5–20
n74	FDDL-band	1427–1470/1475–1517	5–20
n75	Extended SDL L-band	N/A/1432–1517	5–20
n76	Extended SDL L-band, local	N/A /1427–1432	5

5G Trials – Snapshot April 2018



Key 5G Features from 4G

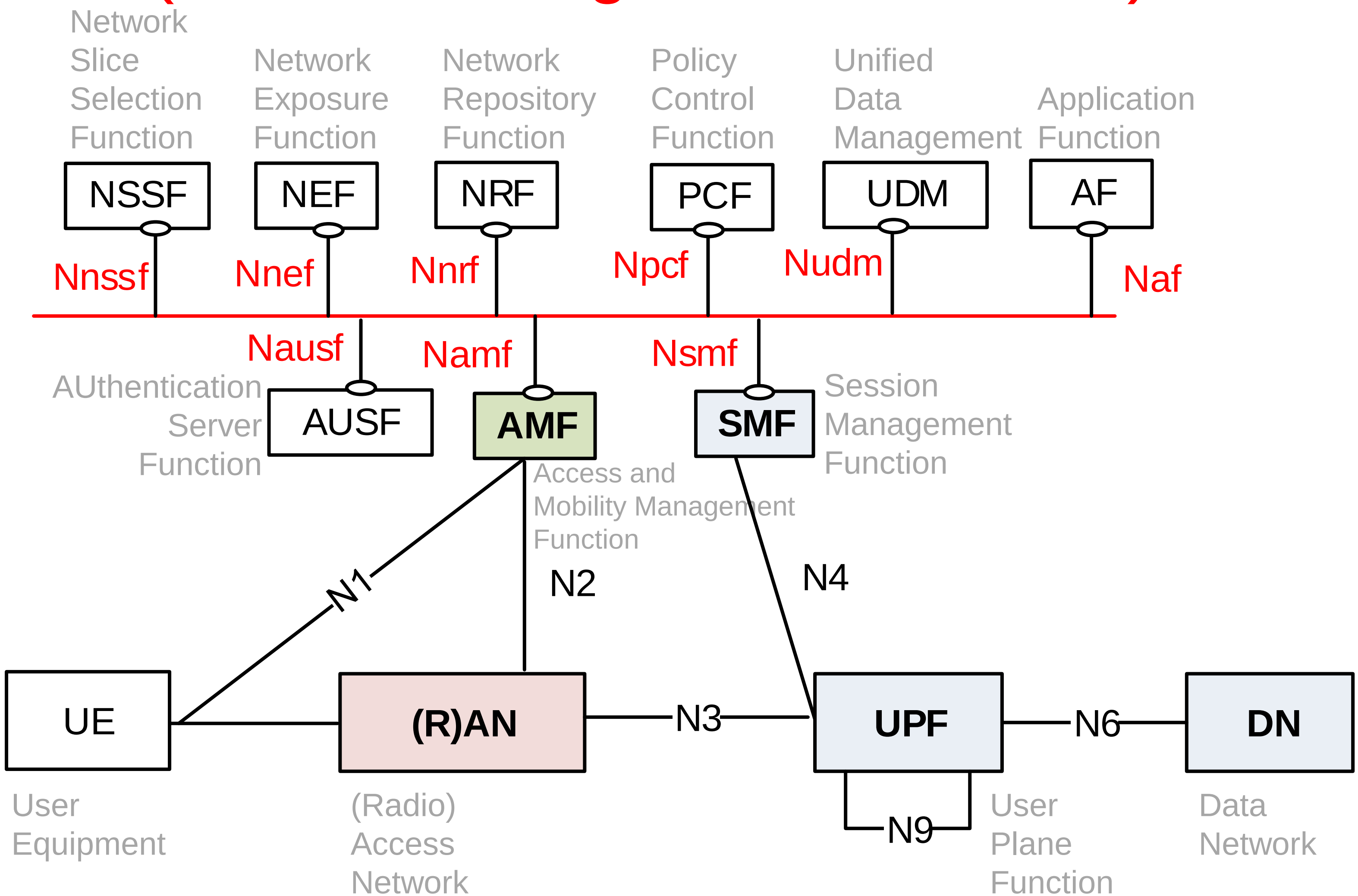
- Essentially 5G had to support almost everything that 4G did
  - The 5G system shall support all EPS capabilities
    - e.g., from TSs 22.011, 22.101, 22.278, 22.185, 22.071, 22.115, 22.153, 22.173
- With the following exceptions:
  - Circuit Switched (CS) fallback to GERAN or UTRAN
  - Seamless handover between 5G-RAN and GERAN
  - Seamless handover between 5G-RAN and UTRAN
  - Access to a 5G core network via GERAN or UTRAN

Key 5G Features from Telecommunication Industry

- Service Based Architecture (SBA)
- Network Slicing
- User Plane/Control Plane (UP/CP) separation
- Integration of cloud/edge computing
- Flow based QoS
- Enhancements
  - RRC-Inactive
  - Latency reduction features
  - Non-Access Stratum (NAS) capability indication
  - Security aspects

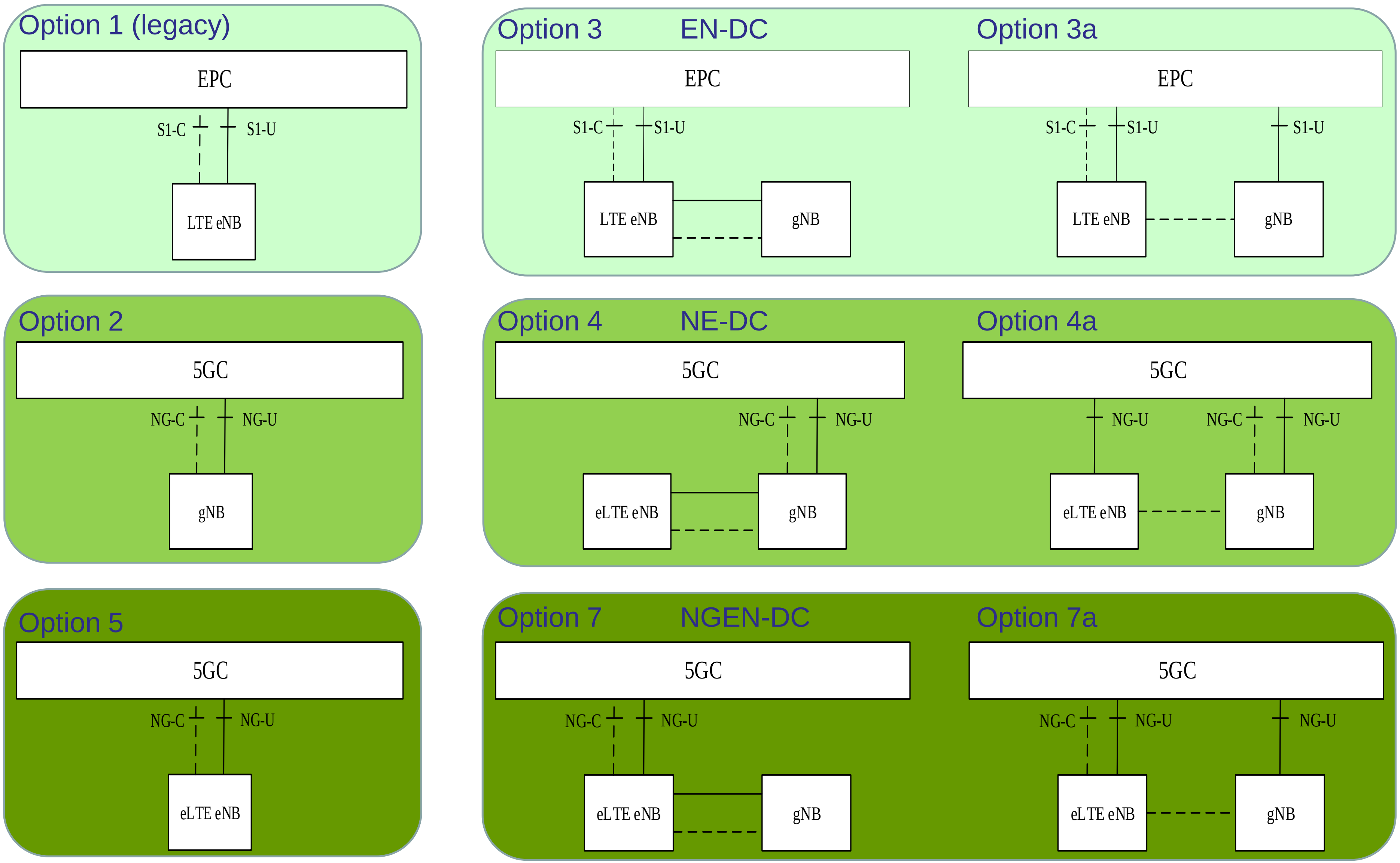
- Evolved Packet Core (EPC) enhancements to support 5G New Radio via Dual Connectivity
  - QoS enhancements
  - Usage restriction
  - Selection of Serving Gateway (SGW) / PDN Gateway (PGW) optimized for NR
  - Security aspects

5G System Architecture (Non-Roaming Service-Based)



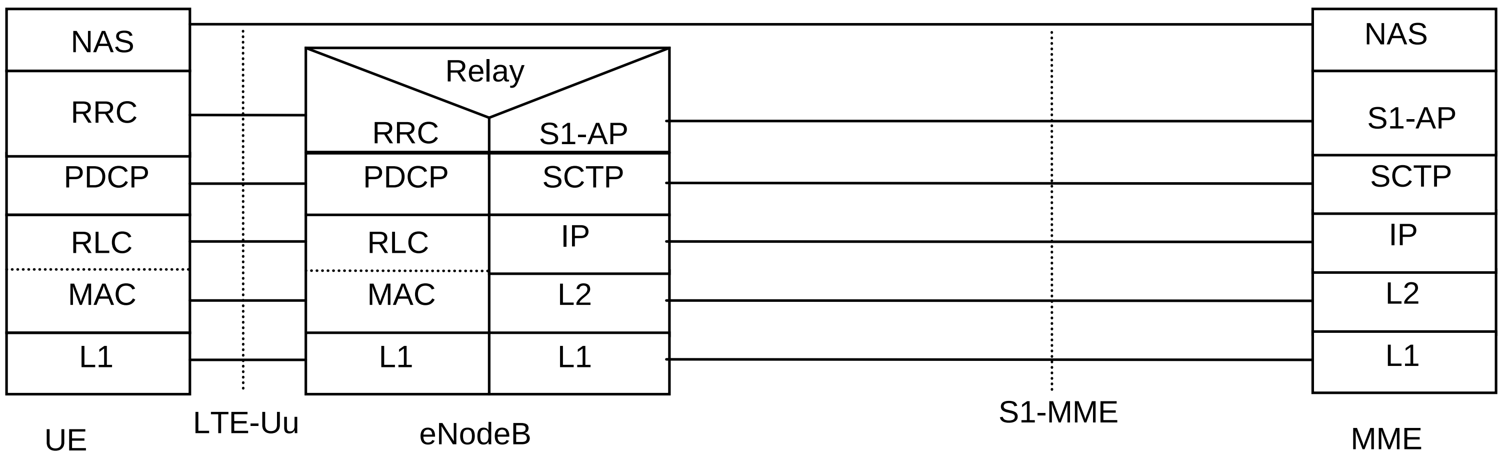
The non-roaming reference architecture with service-based interfaces used within the Control Plane (TS23.501)

5G Architecture Options (TR38.801)

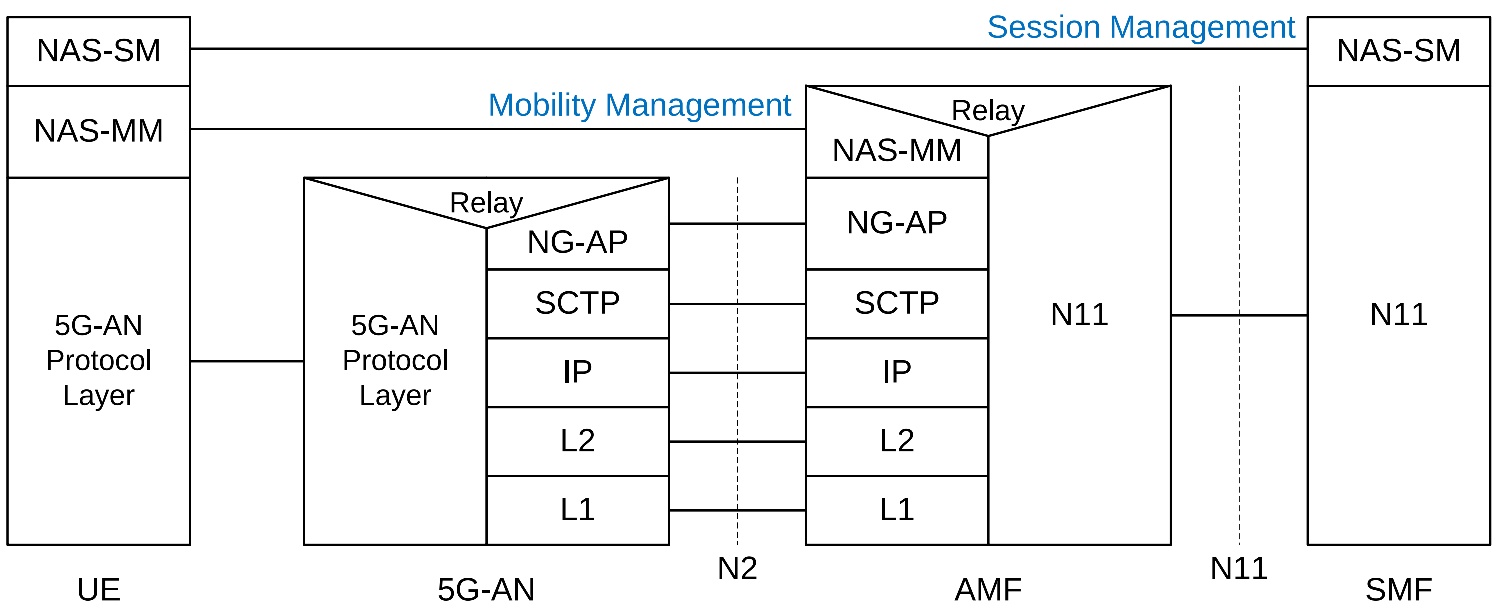


4G/5G Control Plane Protocol Stack

4G (Option 1)

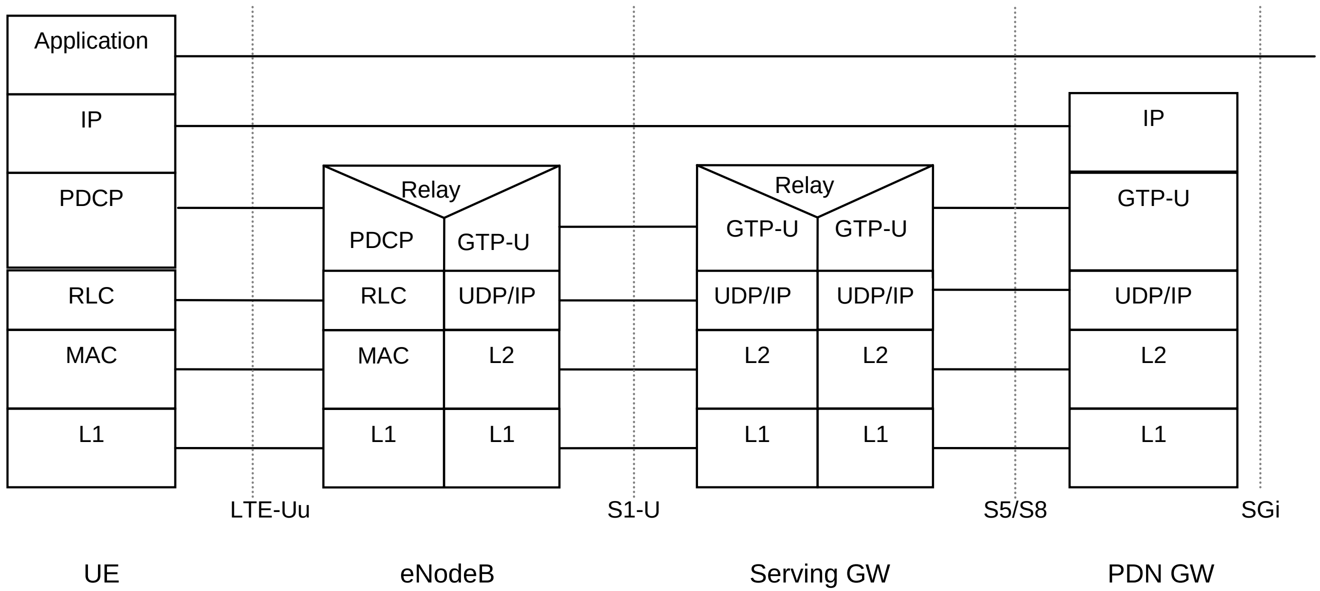


5G (Option 2)

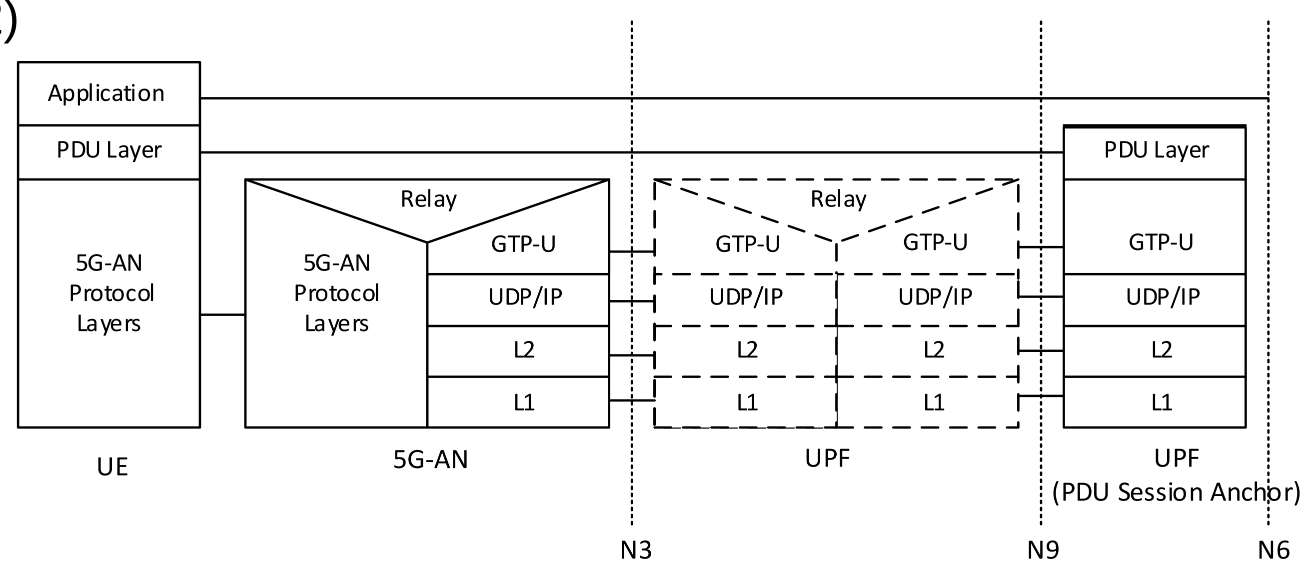


4G/5G User Plane Protocol Stack for 3GPP Access

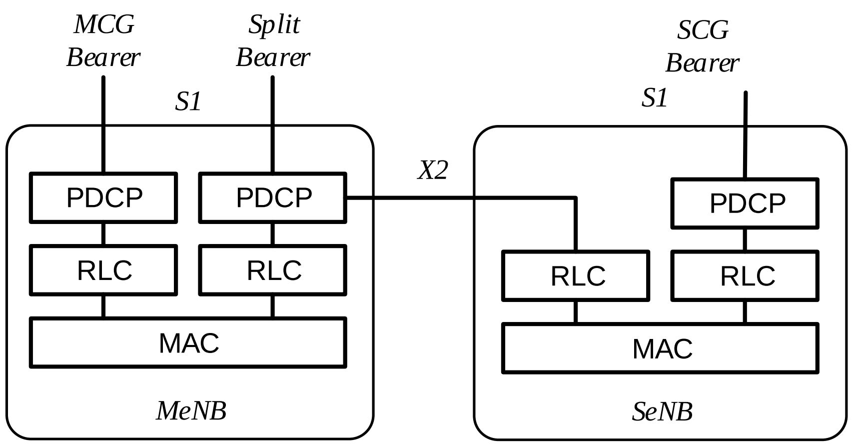
4G (Option 1)



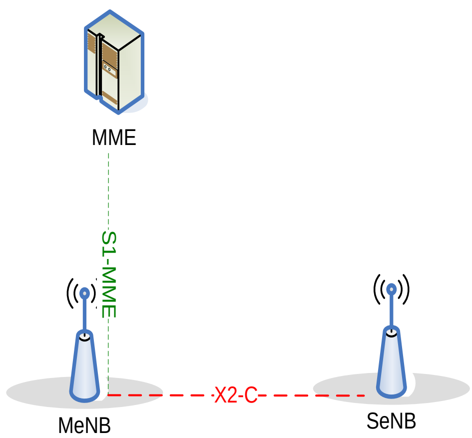
5G (Option 2)



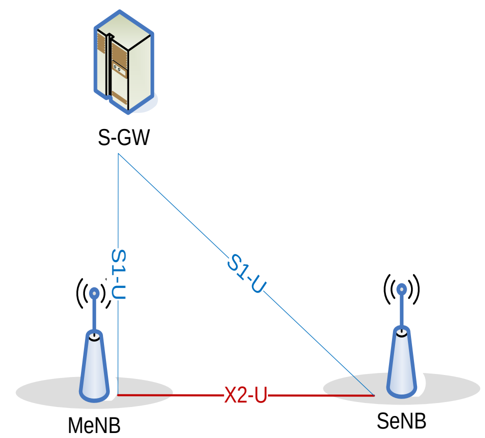
E-UTRAN for Dual Connectivity (DC) (TS36.300)



Radio Protocol Architecture



C-Plane

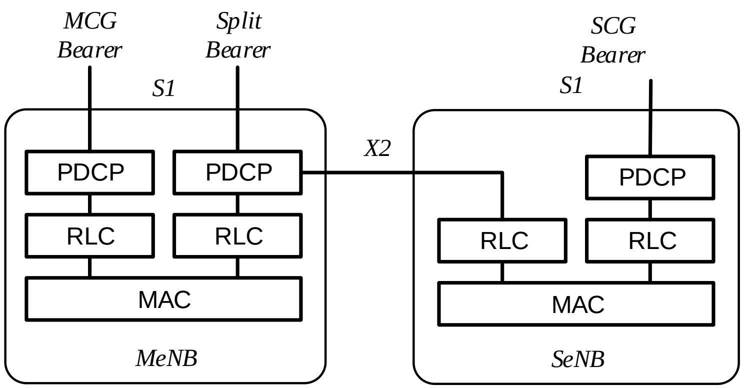


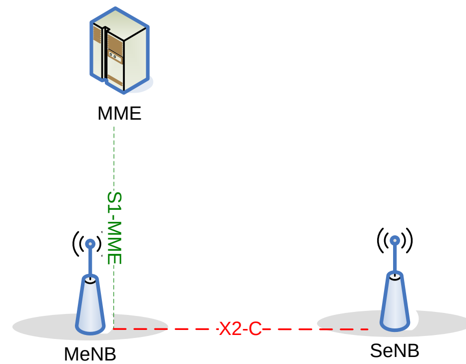
U-Plane

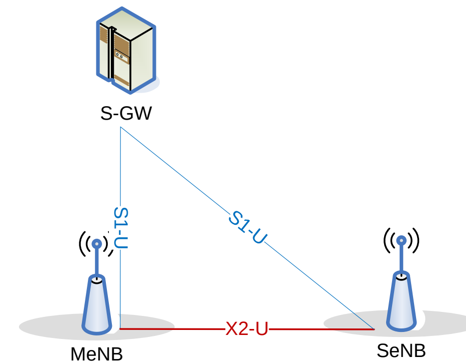
- Three bearer types exist
  - MCG bearer (Master Cell Group)
  - SCG bearer (Secondary Cell Group) and
  - Split bearer
- Network Interfaces
  - C-Plane: by means of X2 interface signalling
    - There is only one S1-MME connection per DC UE between the MeNB and the MME
  - U-Plane: two different user plane architectures are allowed
    - One in which the S1-U only terminates in the MeNB and the user plane data is transferred from MeNB to SeNB using the X2-U, and
    - A second architecture where the S1-U can terminate in the SeNB

E-UTRAN for LWA (LTE-WLAN Aggregation)

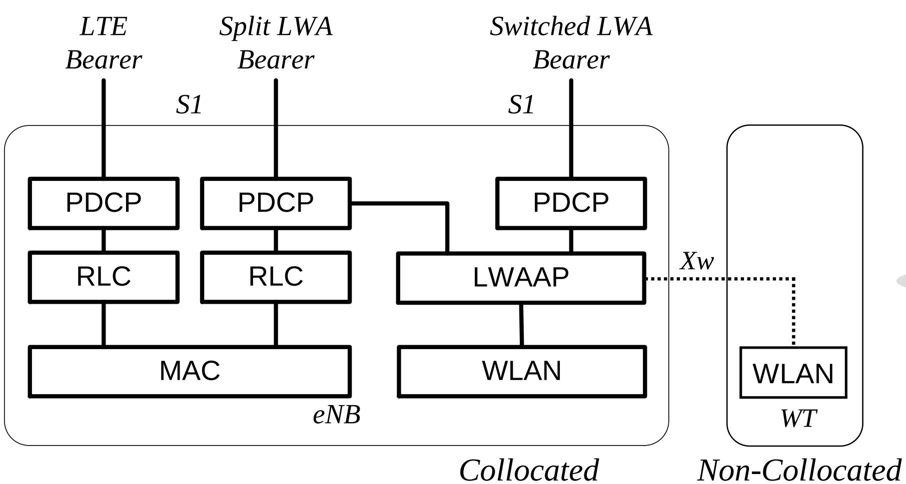
DC

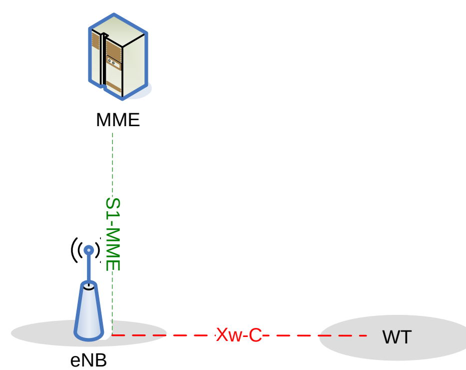


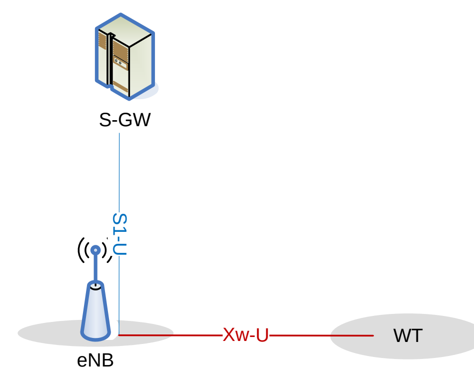




LWA







Radio Protocol Architecture　　C-Plane　　U-Plane

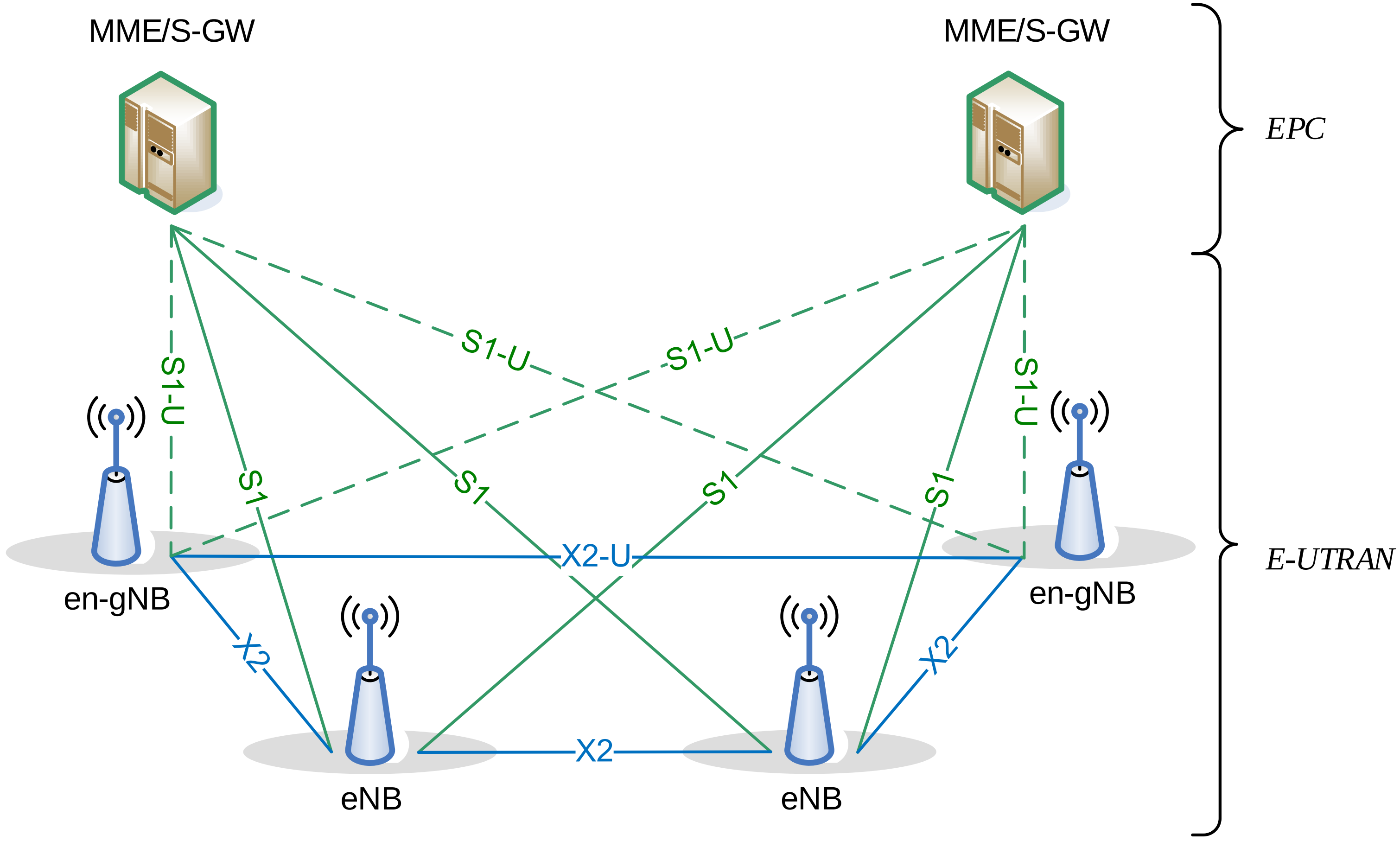
Multi-RAT Dual Connectivity (MR-DC) (TS37.340)

- MR-DC: two different nodes connected via non-ideal backhaul, one providing E-UTRA access and the other one providing NR access
  - One node acts as the MN and the other as the SN
  - The MN and SN are connected via a network interface and at least the MN is connected to the core network
- MR-DC with the **EPC**
  - E-UTRAN supports MR-DC via **E**-UTRA-**N**R Dual Connectivity (EN-DC) [Option 3]
    - A UE is connected to one eNB that acts as a MN and one en-gNB that acts as a SN
      - The **eNB** is connected to the EPC via the S1 interface and to the en-gNB via the X2 interface
      - The **en-gNB** might also be connected to the EPC via the S1-U interface and other en-gNBs via the X2-U interface
- MR-DC with the **5GC**
  - NG-RAN supports **N**R-**E**-UTRA Dual Connectivity (NE-DC) [Option 4]
    - A UE is connected to one gNB that acts as a MN and one ng-eNB that acts as a SN
      - The **gNB** is connected to the 5GC and
      - The **ng-eNB** is connected to the gNB via the Xn interface
  - NG-RAN supports **NG**-RAN **E**-UTRA-**N**R Dual Connectivity (NGEN-DC) [Option 7]
    - A UE is connected to one ng-eNB that acts as a MN and one gNB that acts as a SN
      - The **ng-eNB** is connected to the 5GC and
      - The **gNB** is connected to the ng-eNB via the Xn interface

MR-DC with the 5GC is not complete and is targeted for completion in December 2018

Agreements for MR-DC, V15.4.0 (2018-12)

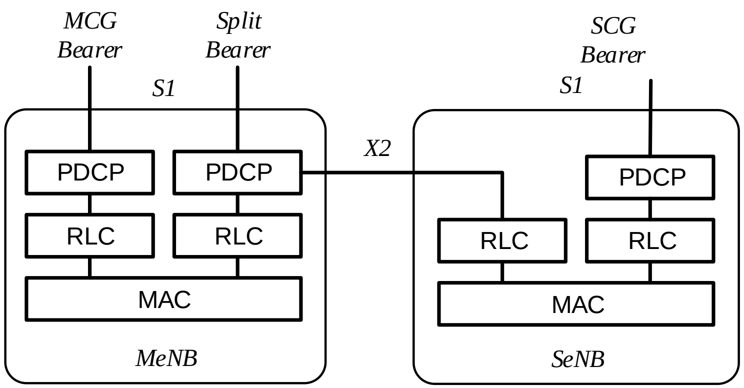
EN-DC Overall Architecture

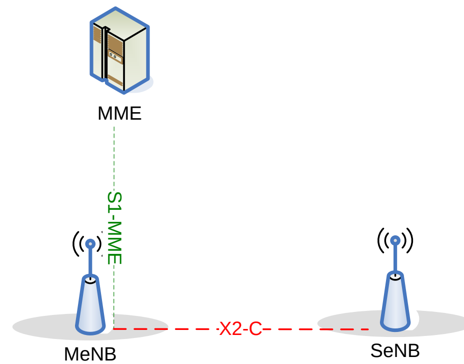


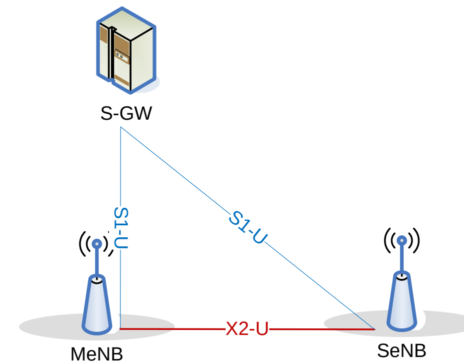
en-gNB: node providing NR user plane and control plane protocol terminations towards the UE, and acting as *Secondary Node* in EN-DC (TS 37.340 Clause 4)

DC and EN-DC

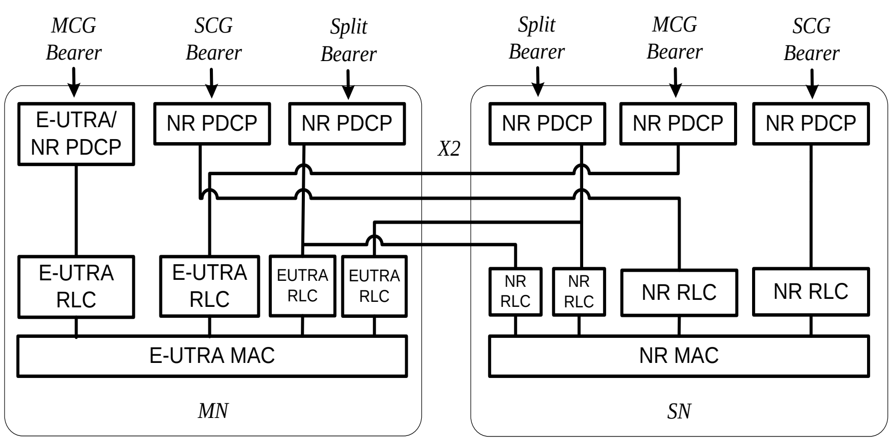
DC

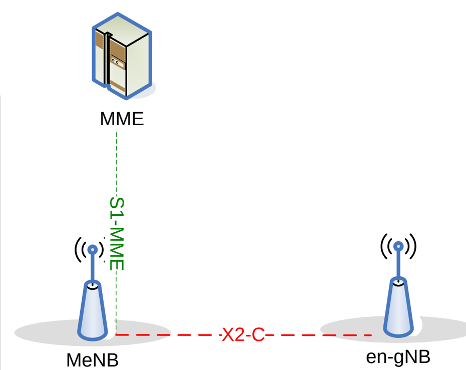


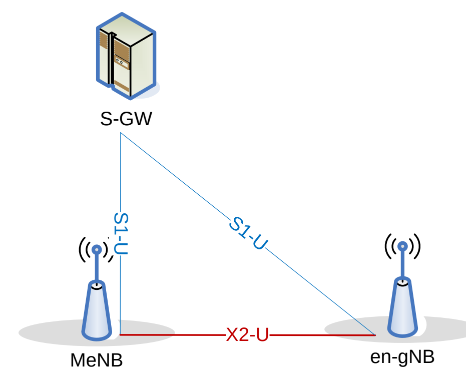




EN-DC



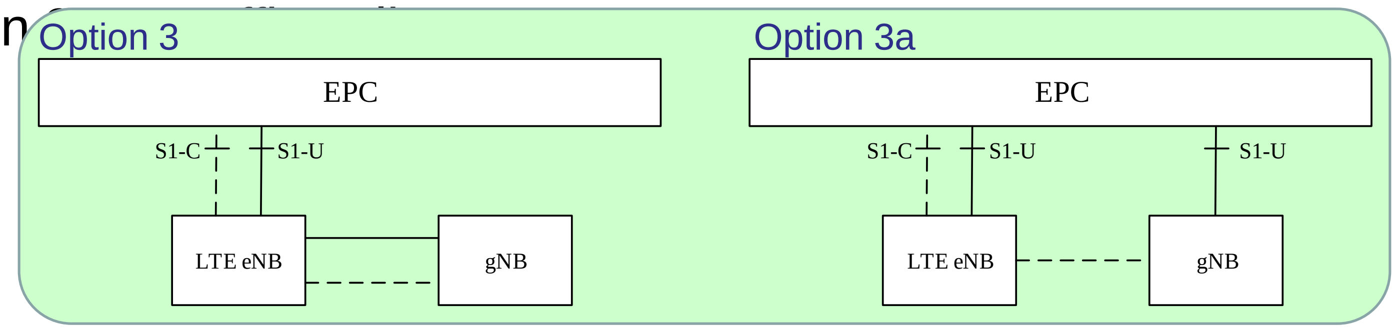


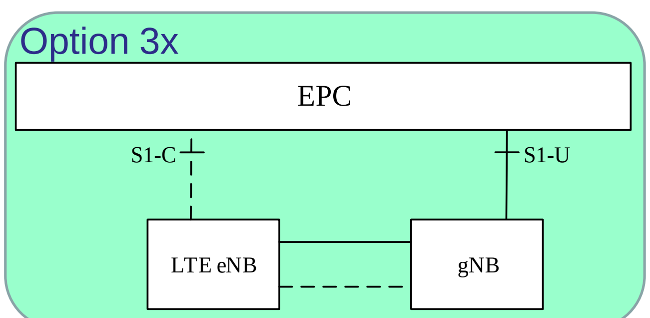


Radio Protocol Architecture C-Plane U-Plane

5G NSA (Release 15)

- Focus on eMBB, and Options 3 and 2
- Three models of NSA with EN-DC
  - – Option 3 – Traffic split at eNB
  - – Option 3a – Traffic split at S-GW
  - – Option





Release 16

- SA1 requirements went into much greater detail on the support for verticals in 5G
  - Cyber-physical control applications in vertical domains (CAV)
  - LAN support in 5G (5GLAN)
  - 5G positioning services (HYPOS)
  - Integration of Satellite Access in 5G (5GSAT)

- 3GPP SA also made a decision to focus new work on the 5G system rather than evolving the 4G system further
  - Exceptions may apply

- Some work continued in both 4G and 5G to enable verticals
  - Remote Identification of Unmanned Aerial Systems (ID_UAS)
  - Improvement of V2X service Handling (V2XIMP)

Source: https://www.atis.org/01_news_events/webinar-pptslides/5g-slides7312019.pdf

Release 17

- The pace of 5G development is slowing in SA1; more evolution, less revolution
- Verticals are still contributing:
  - Audio-visual production, AR/VR, online gaming, edge services
- Key features are still to be determined but expect the following:
  - Strict KPIs on audio/visual sync
  - High bandwidth Sidelink
  - Multi-hop UE to network relays
  - Enhanced integrated Edge

Source: https://www.atis.org/01_news_events/webinar-pptslides/5g-slides7312019.pdf

Some Release 17 Feature or Study Items

- Enhancements for cyber-physical control applications in vertical domains (eCAV)
- 5G Enhancement for UAVs
- Complete Gap Analysis for Railways Mobile Communication System (MONASTERYEND)
- Audio-Visual Service Production (AVPROD)
  - Requirements for using 5GS for the production and contribution of audio-visual content and
- Network Controlled Interactive Service (NCIS)
  - Specify KPIs for interactive service
- Support for Multi-USIM Devices (MUSIM)
- Multimedia Priority Service (MPS) Phase 2 (MPS2)

Full list: https://www.3gpp.org/dynareport/TSG-WG--S1--wis.htm?Itemid=438

Source: https://www.atis.org/01_news_events/webinar-pptslides/5g-slides7312019.pdf

Outlook to Future Requirements

- LAN support in 5G
- Communication for automation in vertical domains
- Using satellite access in 5G
- 5G message service for massive IoT
- Positioning use cases
- Enhancements to IMS for new real time communication services
- Layer for centric identifiers and authentication

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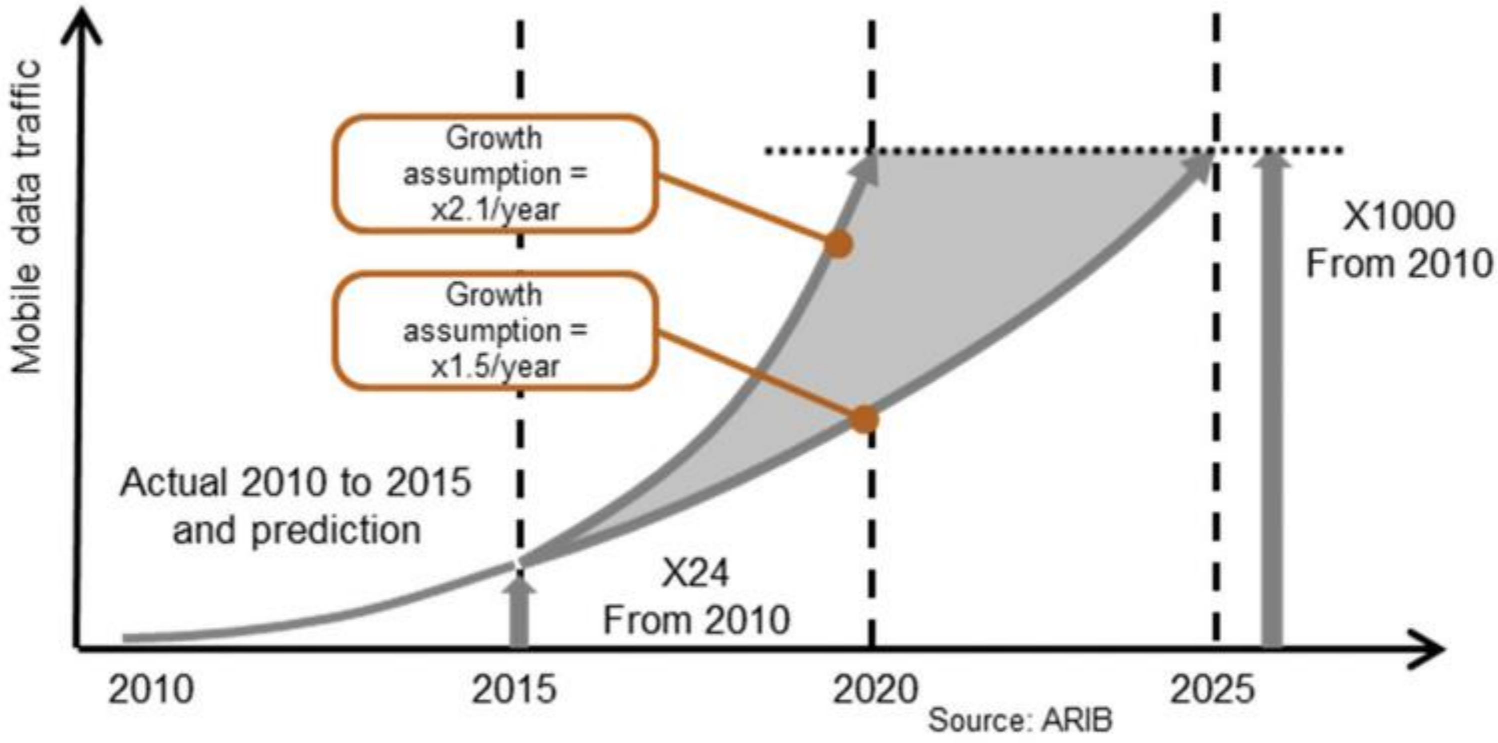
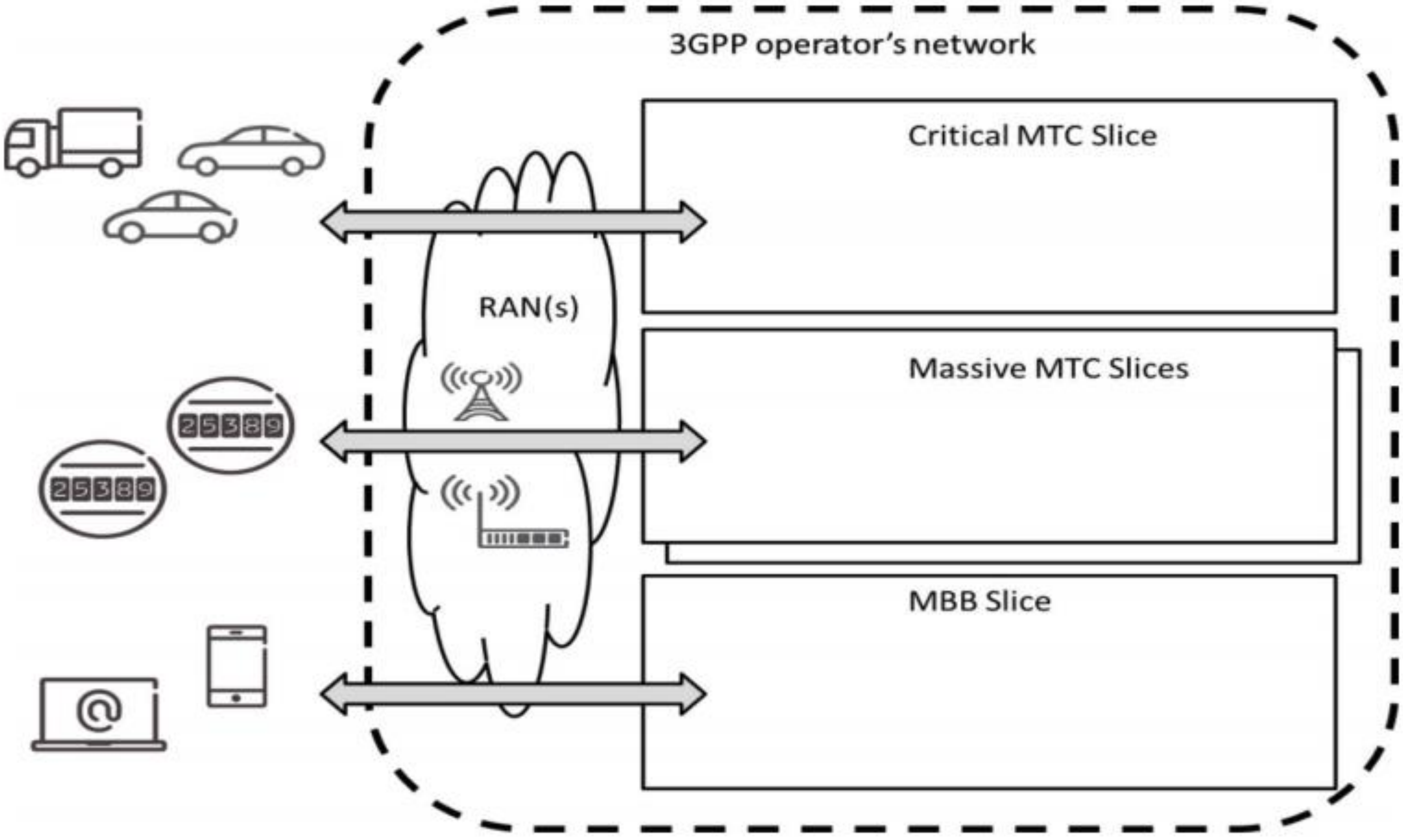
Projected Growth of Mobile Data



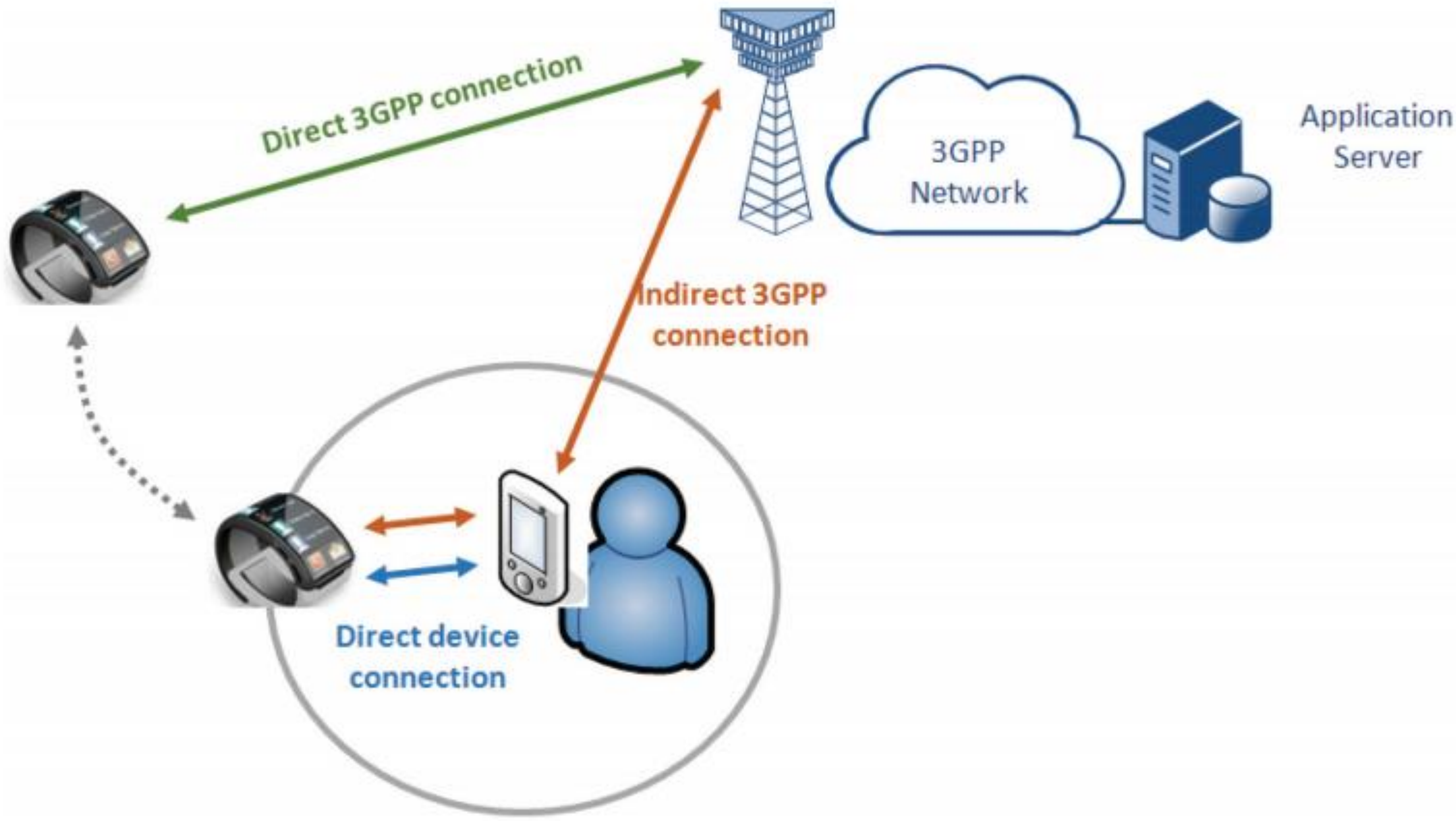
The Concept of Slicing



Diverse Mobility Management

- Stationary during their entire usable life
  - e.g., sensors embedded in infrastructure
- Stationary during active periods, but nomadic between activations
  - e.g., fixed access
- Mobile within a constrained and well-defined space
  - e.g., in a factory
- Fully mobile

Connectivity Modes for Devices



5G Performance Requirements

- High data rate
- Traffic density
- High reliability
- Low latency

5G Require High Data Rate and Traffic Density

Scenario	Experienced Data Rate (Downlink)	Experienced Data Rate (Uplink)	Area Traffic Capacity (Downlink)	Area Traffic Capacity (Uplink)	Overall User Density	UE Speed
Indoor hotspot	1 Gbps	500 Mbps	15 Tbps/km^2	2 Tbps/km^2	250 000/km^2	Pedestrians
Dense urban	300 Mbps	50 Mbps	750 Gbps/km^2	125 Gbps/km^2	25 000/km^2	Pedestrians and users in vehicles (up to 60 km/h)
Urban macro	50 Mbps	25 Mbps	100 Gbps/km^2	50 Gbps/km^2	10 000/km^2	Pedestrians and users in vehicles (up to 120 km/h
Rural macro	50 Mbps	25 Mbps	1 Gbps/km^2	500 Mbps/km^2	100/km^2	Pedestrians and users in vehicles (up to 120 km/h
Broadband in a crowd	25 Mbps	50 Mbps	3,75 Tbps/km^2	7,5 Tbps/km^2	500 000/km^2	Pedestrians
Broadcast-like services	Maximum 200 Mbps (TV channel)	Modest (e.g., 500 kbps per user)	N/A	N/A	15 TV channels of 20 Mbps	Stationary to in vehicles (up to 500 km/h)
High-speed train	50 Mbps	25 Mbps	15 Gbps/train	7,5 Gbps/train	1000/train	Users in trains (up to 500 km/h)
High-speed vehicle	50 Mbps	25 Mbps	100 Gbps/km^2	50 Gbps/km^2	4000/km^2	Users in vehicles (up to 250 km/h)
Airplanes connectivity	15 Mbps	7,5 Mbps	1,2 Gbps/plane	600 Mbps/plane	400/plane	Users in airplanes (up to 1000 km/h)

5G Require Low Latency and High Reliability

Scenario	End-to-End Latency	Communication Service Availability	Reliability	User Experienced Data Rate	Connection Density	Service Area Dimension
Discrete automation – motion control	1 ms	99,9999%	99,9999%	1 Mbps to 10 Mbps	100 000/km^2	100 × 100 × 30 m
Process automation – remote control	50 ms	99,9999%	99,9999%	1 Mbps to 100 Mbps	1000/km^2	300 × 300 × 50 m
Process automation – monitoring	50 ms	99,9%	99,9%	1 Mbps	10 000/km^2	300 × 300 × 50
Electricity distribution – medium voltage	25 ms	99,9%	99,9%	10 Mbps	1000/km^2	100 km along power line
Electricity distribution – high voltage	5 ms	99,9999%	99,9999%	10 Mbps	1000/km^2	200 km along power line
Intelligent transport – infrastructure backhaul	10 ms	99,9999%	99,9999%	10 Mbps	1000/km^2	2 km along a road

Vertical Applications

- Network Slicing
- Efficiency
- Priority, QoS and Policy Control

◆V2X (Vehicle to Anything) communication is a vertical application that has influenced 5G requirements

Outlook to Future Requirements

- LAN support in 5G
  - Aims to support 5G LAN-type services over the 5G system
    - In this context, 5G LAN-type services allow a restricted set of devices to communicate amongst each other using Ethernet style data transport
- Communication for automation in vertical domains
  - Identifies key performance indicators for various vertical use cases. Communication for vertical sectors may take place in separate, privately owned networks
- Using satellite access in 5G
  - A study on how to integrate satellite communication with land based 5G networks
    - An example is how to support network selection when multiple land based mobile networks share a common satellite based access
- 5G message service for massive IoT
  - Aims to specify a light weight message service that can be used between (groups of) devices or between devices and application servers

Outlook to Future Requirements (Cont.)

- Positioning use cases
  - Identifies new use cases, their scope and environment of use along with the related key performance indicators
  - Requirements can be achieved with a combination of 3GPP and non-3GPP positioning technologies
- Enhancements to IMS for new real time communication services
  - For new real time communication services identifies a number of use cases (e.g. AR/VR), where IMS and/or mission critical specifications need to be enhanced for new 5G real time communication services
- Layer for centric identifiers and authentication
  - Aims to enable network operators to become identity providers
  - Use cases include how to use the new user identifier within the 3GPP system
    - e.g. to provide customized services and how to provide this identifier to external parties to enable authentication for systems and services outside 3GPP

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5G System

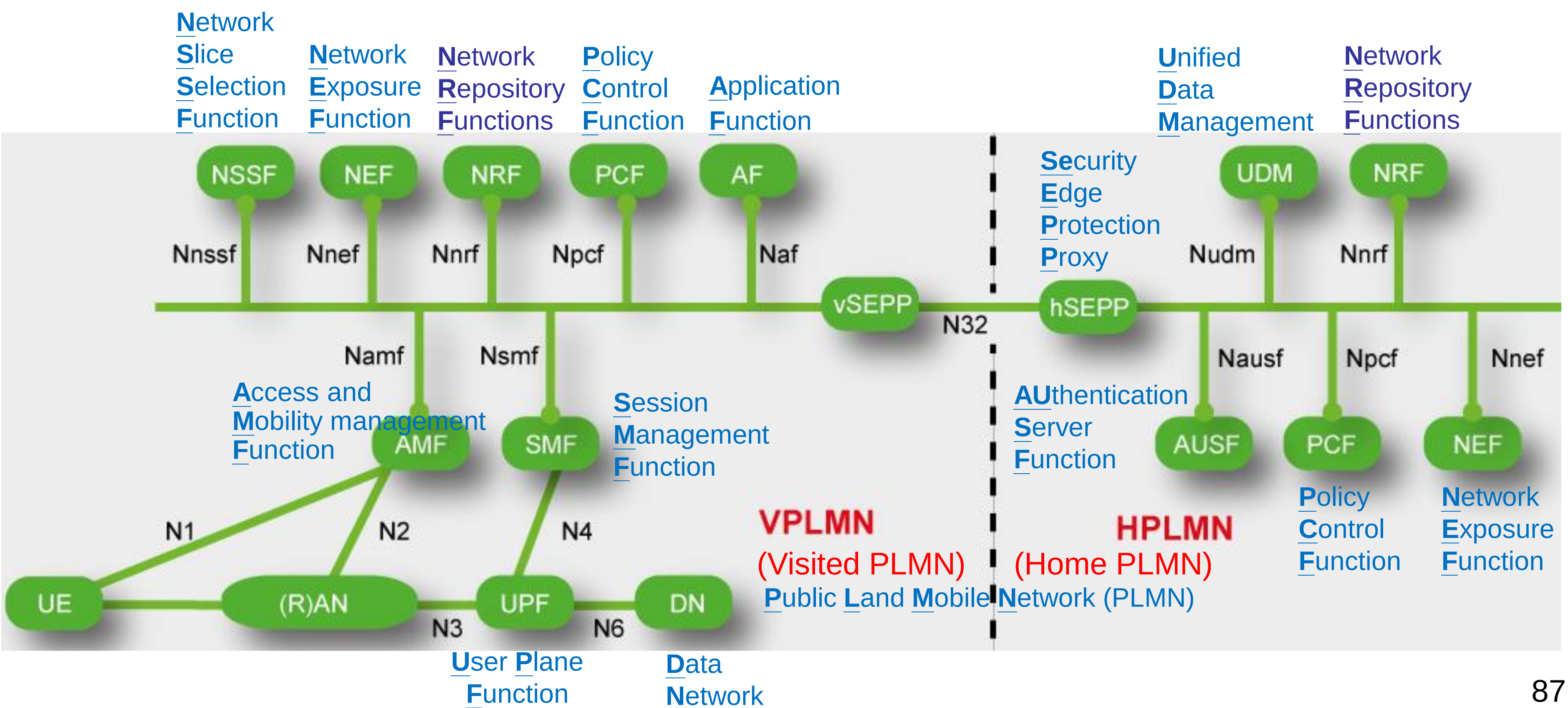
- First published in 3GPP Release 15 in December 2017
- The complete description is provided by the 3GPP specifications
  - TS 23.501
  - TS 23.502
  - TS 23.503
- These 5G stage 2 level specifications include
  - Overall architecture model and principles
  - Support of broadband data services
  - Subscriber authentication and service usage authorization
  - Application support in general and specifically for applications closer to the radio as with edge computing
- The 5G system architecture model
  – Uniformly enables user services with different access systems, like fixed network access or interworked WLAN, from the onset
  – Provides interworking with and migration from 4G, network capability exposure and numerous other functionalities

Service Based Architecture

- The 3GPP 5G system architecture is service based - the architectural elements are defined as **network functions** that offer their services via **interfaces** of a common framework to any network functions that are permitted to make use of these provided services
  - Adopts principles like modularity, reusability and self-containment of network functions
  - **Reference point** based architecture figures are also provided by the stage 2 specifications, which represent more specifically the interactions between network functions for providing system level functionality and to show inter-PLMN interconnection across various network functions

5G Service-Based Architecture

- General network functions for discovery and storing contexts
  - ***Network Repository Functions (NRF)*** allow every network function to discover the services offered by other network functions
  - Network functions may store their contexts in ***Data Storage Functions (DSF)***



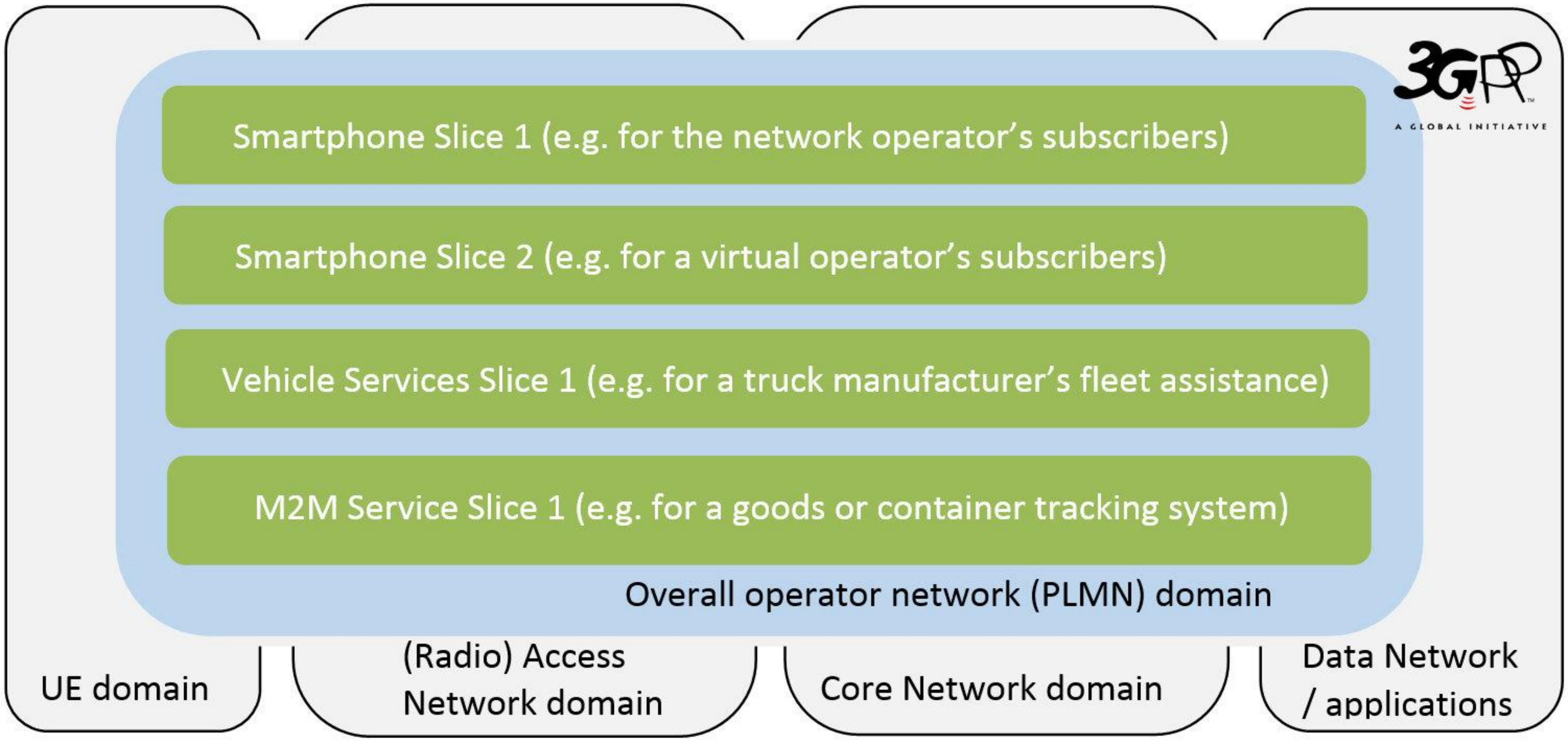
Common Core Network

- To enable 5G common Core Network to operate with different Access Networks
  - The generalised design of the functionalities and
  - A forward compatible Access Network – Core Network interface
- In 3GPP Release 15 these are
  - The 3GPP defined NG-RAN and
  - The 3GPP defined untrusted WLAN access
  - Other access systems that may be used in future releases
- Features
  - Allows for serving both Access Networks by the same AMF and thereby also for ***seamless mobility*** between those 3GPP and non-3GPP accesses
  - The separated authentication function together with a unified authentication framework are for ***enabling customization of the user authentication*** according to the needs of the different usage scenarios, e.g. using different authentication procedures per network slice
  - Most of the other 5G system architecture functionality introduced by this article is ***common for different Access Networks***

Network Slicing

- A distinct key feature of the 5G system architecture
- a network slice refers to
  - The set of 3GPP defined features and functionalities that together
  - Form a complete PLMN for providing services to UEs
- Network slicing allows for
  - Controlled composition of a PLMN from the specified network functions with
  - Their specifics and provided services that are required for a specific usage scenario
- Comparison
  - Earlier system architectures enabled typically rather *a single* deployment of a PLMN to provide all features, capabilities and services required for all wanted usage scenarios
  - Network slicing enables the network operator to deploy *multiple, independent* PLMNs where each is customized by instantiating only the features, capabilities and services required to satisfy the subset of the served users/UEs or a related business customer needs

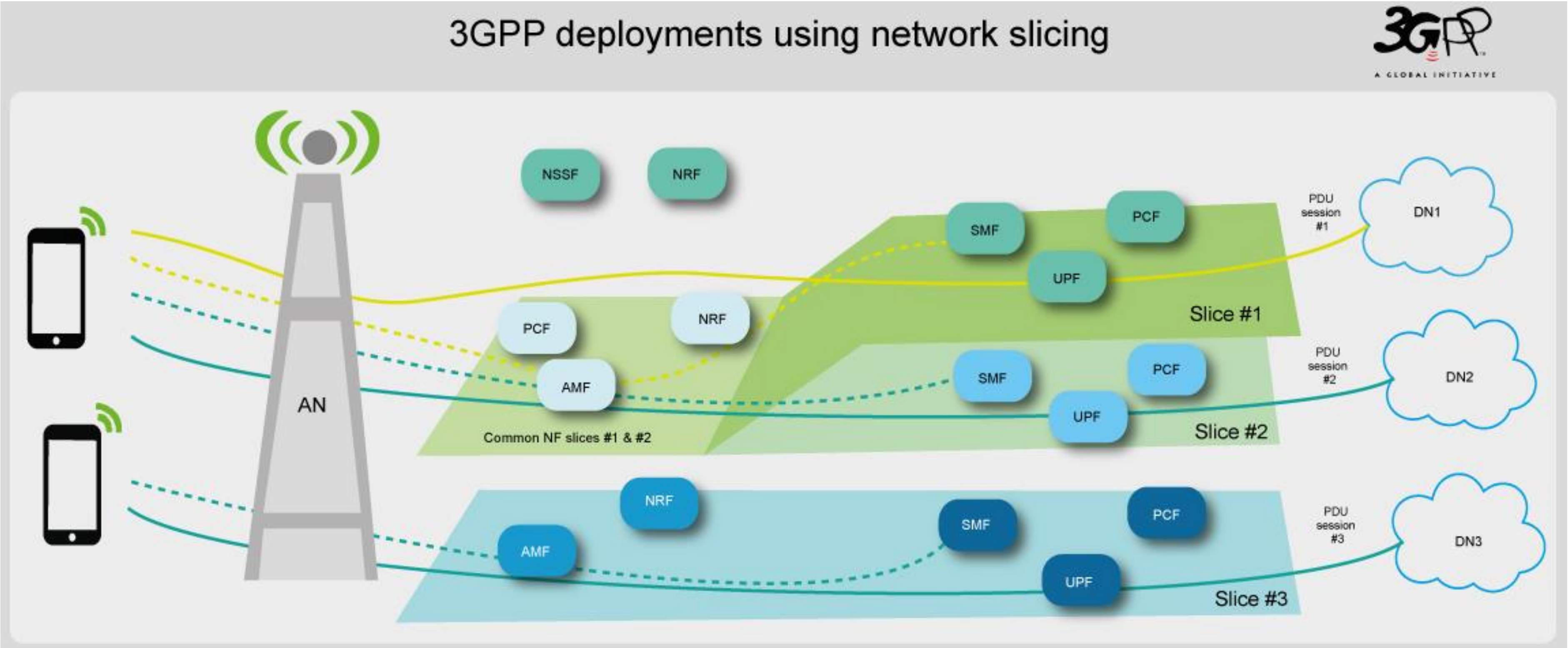
Abstract Representation of a Network Deploying Network Slices



An example of a PLMN deploying four network slices,
each includes all what is necessary to form a complete PLMN

* The M2M network slice could offer UE battery power saving features unsuitable for smartphone slices, as those features imply latencies not acceptable for typical smart phone usages

Network Functions Composing Network Slices

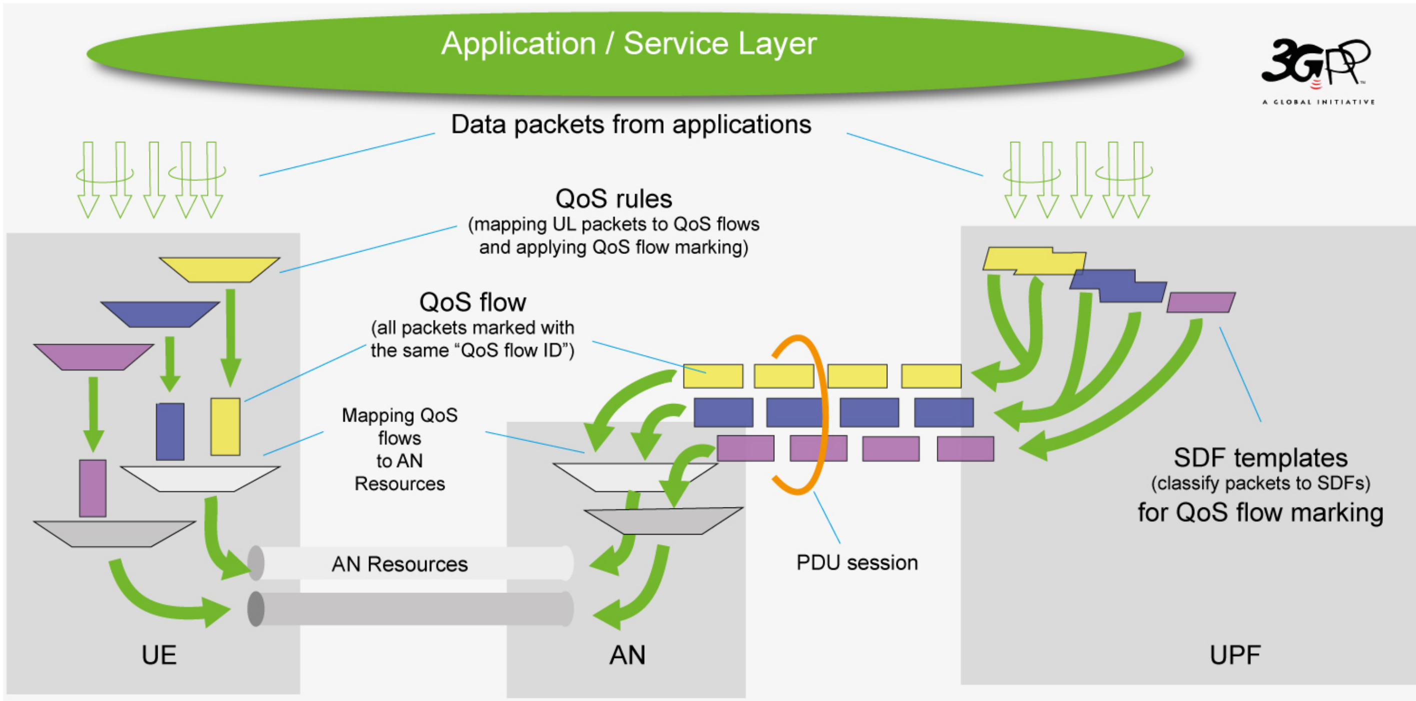


- Network slice #3 is a straightforward deployment where all network functions serve a single network slice only
- A UE receives service from multiple network slices, #1 and #2
- Slice #1 provides the UE with data services for Data Network #1
- Slice #2 for Data Network #2

Application Support

- Data services are the basis of the application support
  - Offer considerably more flexibility for customization
- A main part of this is the new QoS model of the 3GPP 5G system architecture

QoS Model of the 3GPP 5G System Architecture



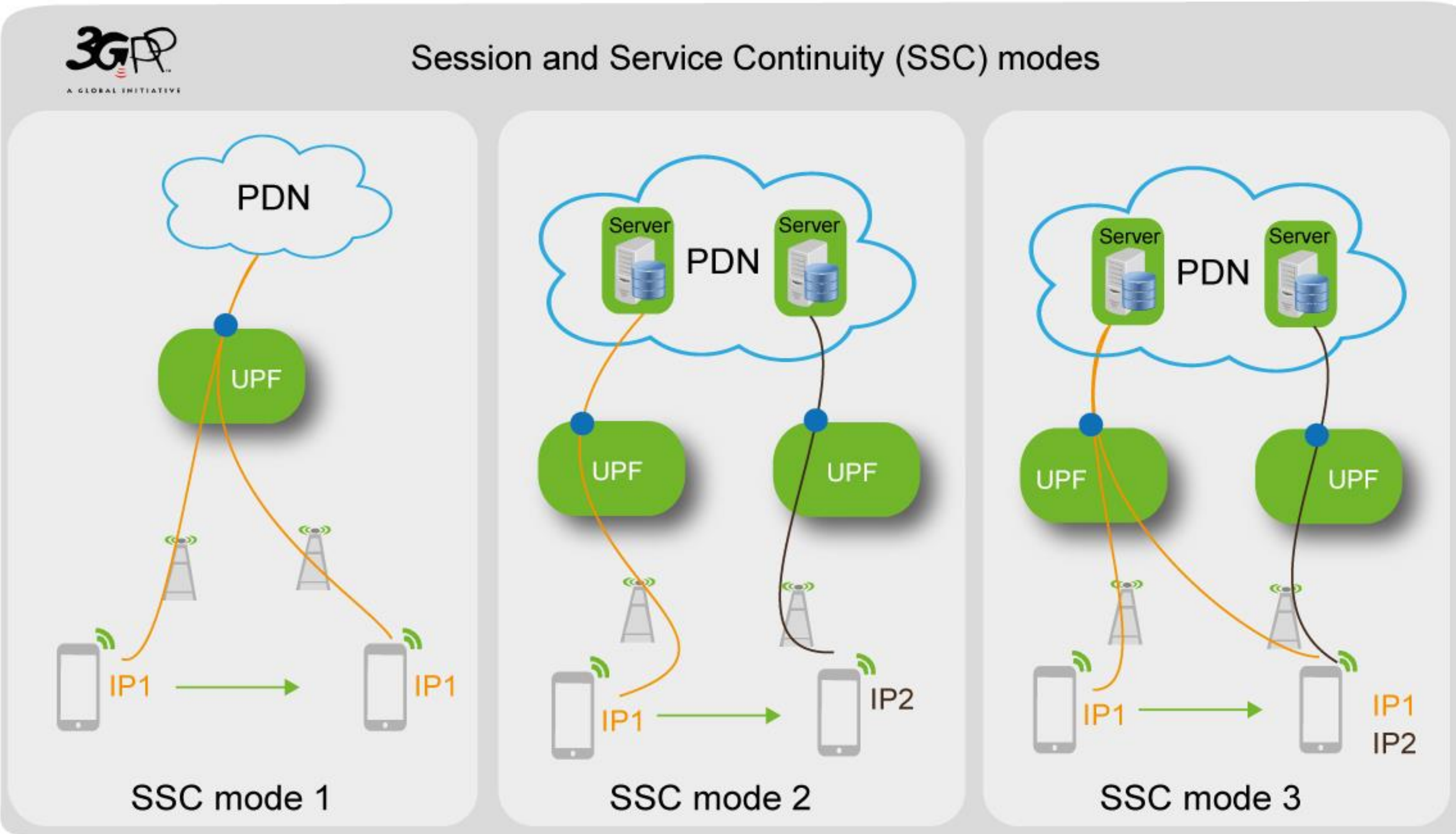
- Enables differentiated data services to support diverse application requirements while using radio resources efficiently
  - Service Data Flows (SDF) denote user plane data that certain QoS rules apply to
    - The actual description of SDFs is using SDF templates
- Further, designed to support different Access Networks, including fixed accesses where QoS without extra signaling may be desirable
  - Standardized packet marking informs QoS enforcement functions what QoS to provide without any QoS signaling
    - While the option with QoS signaling offers more flexibility and QoS granularity
- Furthermore, symmetric QoS differentiation over downlink and uplink is supported with minimal control plane signaling by the newly introduced Reflective QoS

Session and Service Continuity (SSC) Modes

- A large part of the functionality providing data connectivity is for supporting flexible deployment of application functions in the network topology as needed for edge computing, which is supported
  - via three different Session and Service Continuity (SSC) modes
  - via the functionality of Uplink Classifiers and Branching Points

- The SSC modes include the more traditional mode (SSC 1) and two new modes (SSC 2 and 3)
  - Traditional mode (SSC mode 1)
    - Where the IP anchor remains stable to provide continual support of applications and maintenance of the path towards the UE as its location is updated
  - Break-before-make (SSC mode 2)
  - Make-before-break (SSC mode 3)

Session and Service Continuity Modes



Break-before-make   Make-before-break

The architecture enables applications to influence selection of suitable data service characteristics and SSC mode

Continuation of the Work

- The delivered stage 2 level specifications define the 3GPP 5G system from an overall, architectural perspective
  - The related work in the RAN, security, OAM and CT working groups continued with some specific stage 2 level aspects and with delivering stage 3 level specifications until June 2018

- Specification work in 3GPP is a continuous process. More and up-to-date information can be found at 3GPP.org

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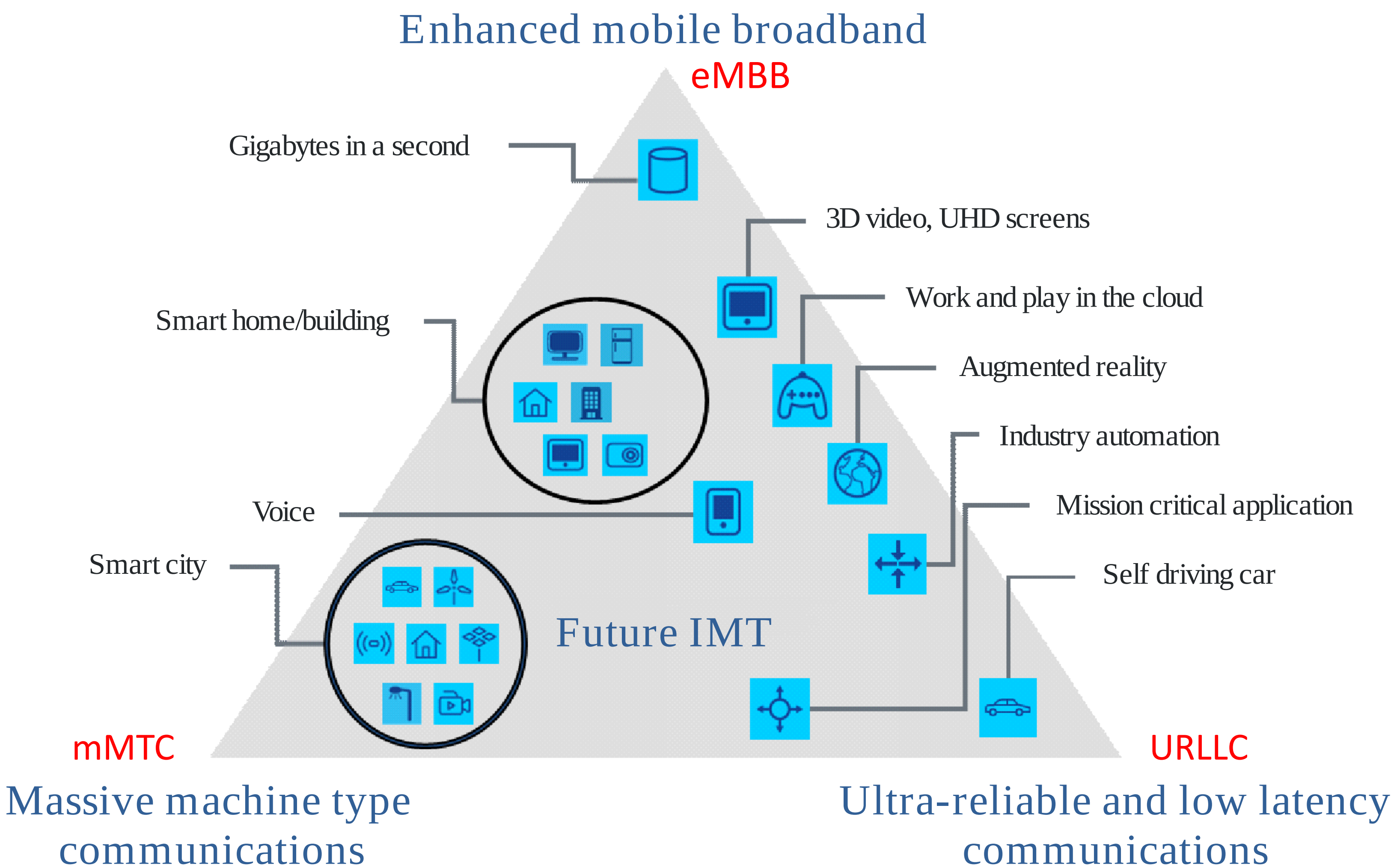
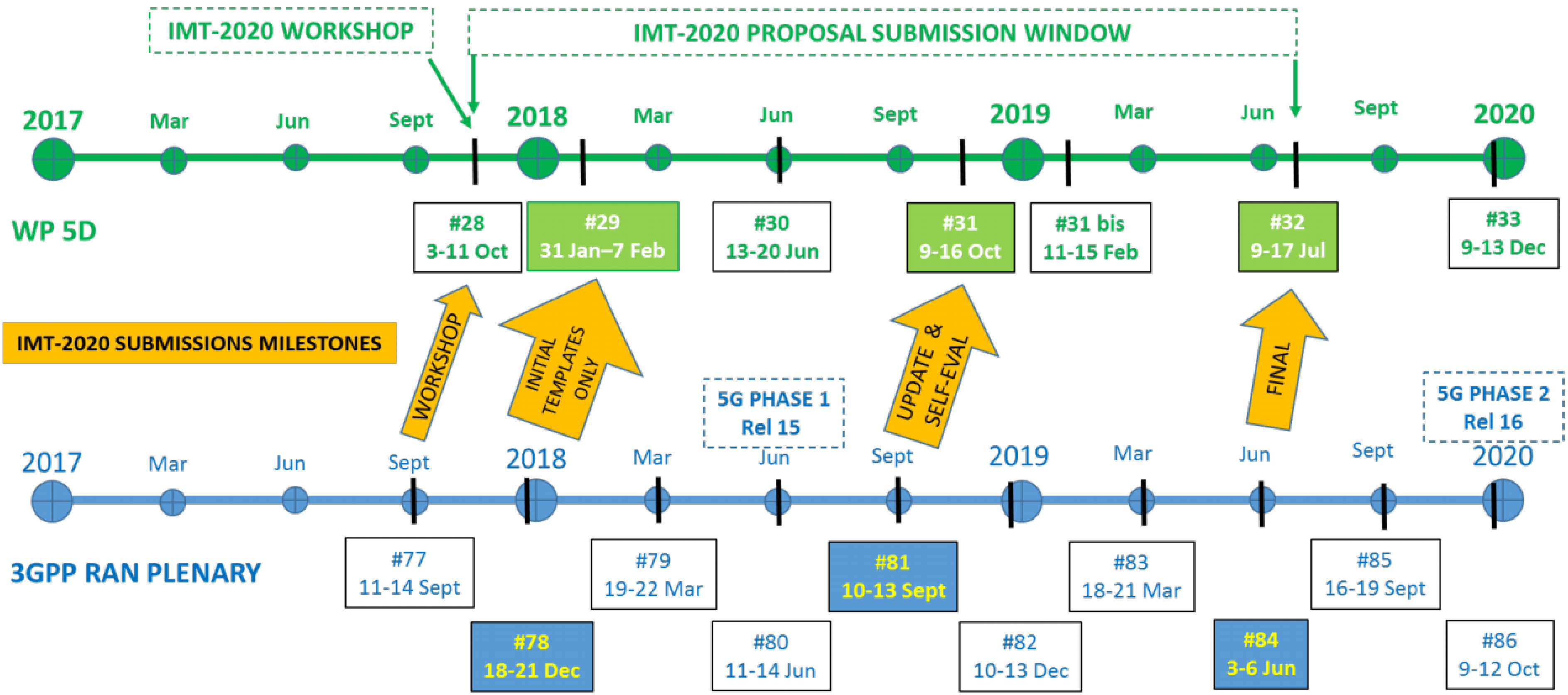
3GPP 5G NR Standards Process in the Context of IMT2020



5G Use Case Landscape (ITU-R M.2083, 2015)

IMT-2020 Submission – Time Plan



Overall time plan for 3GPP technology submissions to IMT2020

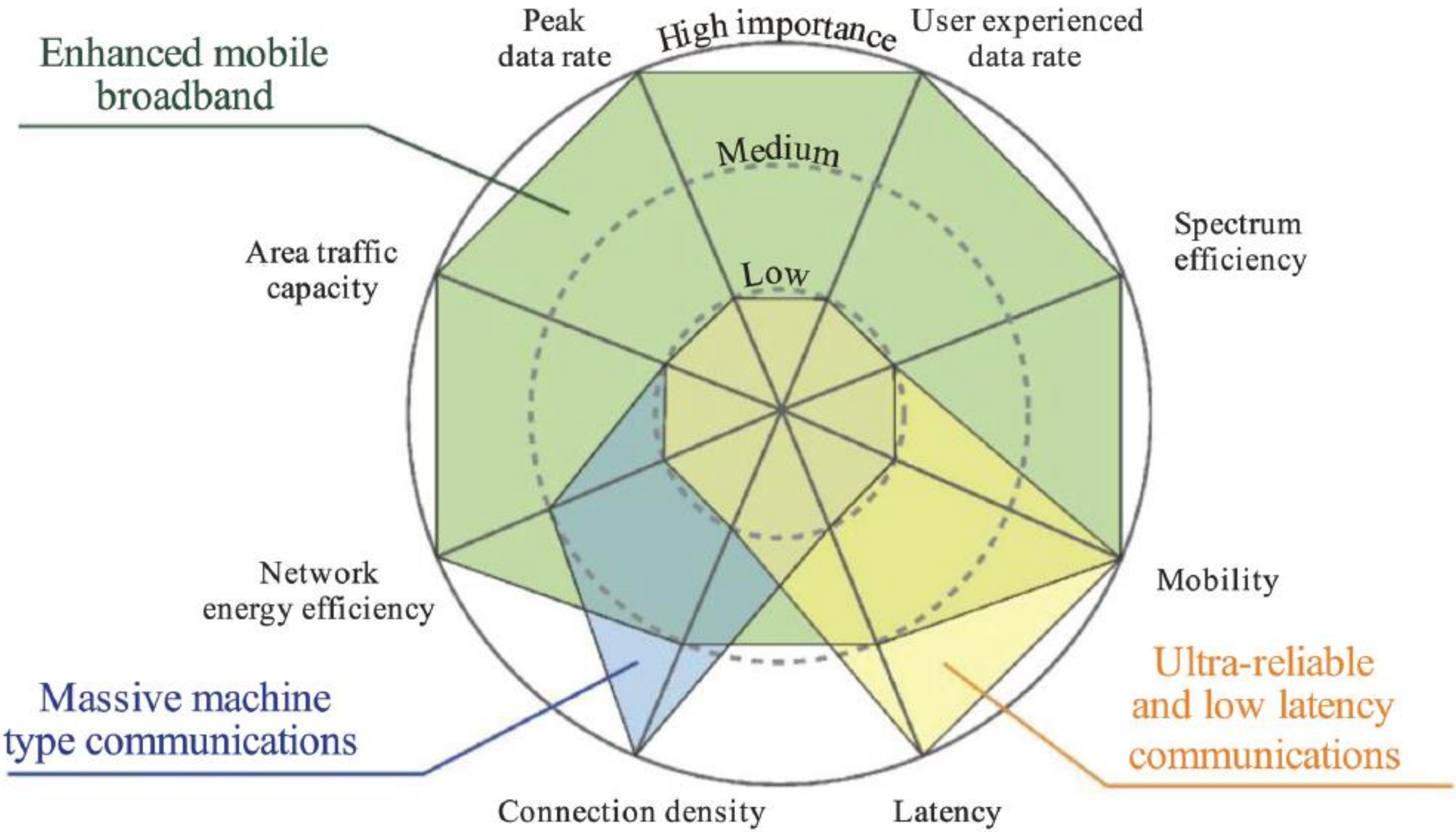
Design Criteria and Requirements

- For Enhanced Mobile Broadband (eMBB)
  - 100 Mbps user experience data rate and
  - Area traffic capacity of 10 Mbps/m^2
  - 3 times spectral efficiency improvement as compared to 4G

- For Massive Machine Type Communications (mMTC)
  - Connection density is expected to reach 1,000,000 devices per km^2
    - 1 device/m^2

- For Ultra Reliable Low Latency (URLLC)
  - 1 ms latency with very high reliability (99.999%)

Key Capabilities of 5G Networks



5G NR Radio Interface Technology Components

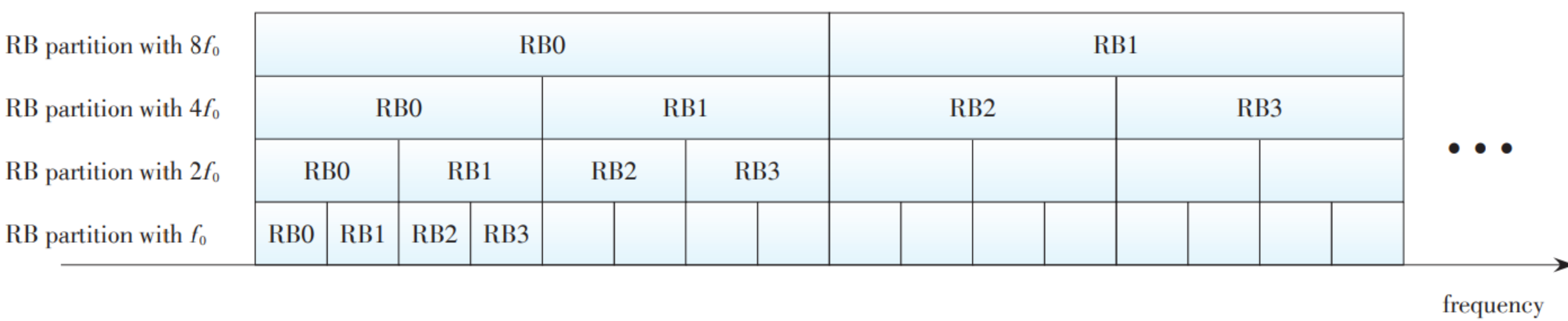
- Physical Layer Structure
- Initial Access and Mobility
- Channel Coding and Modulation
- Scheduling and Hybrid ARQ
- MIMO

Physical Layer Structure

- In NR, similar to LTE
  - A radio frame is fixed to be 10 ms
  - Which consists of 10 subframes each of 1 ms
- NR supports scalable numerology covering a wide range of services and carrier frequencies
  - Different from LTE which has a fixed **Sub-Carrier Spacing (SCS)** for 15 kHz
  - f_0 = 15 kHz * 2^m, where m = {0,1,2,3,4}, i.e., f_0 = {15,30,60,120,240} kHz
  - Sub-6 (6 GHz of lower): 15 kHz, 30 kHz and 60 kHz
  - Above 6 GHz: 60 kHz, 120 kHz and 240 kHz

Subframe Duration

- The subframe duration of 1ms is based on 15 kHz reference numerology with 14 symbols per subframe for the case of **Normal Cyclic Prefix (NCP)**
  - It is also called a slot for 15 kHz SCS
  - For other SCSs, 14-symbol per slot is always assumed for NCP (except for 240 kHz, where 28-symbol per slot is assumed for NCP)
- Illustration of nested RB-structure across numerologies
  - A 30 kHz SCS has a slot duration of 0.5 ms, which can be mapped to two slots (each of 0.25 ms) for a 60 kHz SCS
  - Moreover, frequency-alignment within the channel is also achieved via nested **Resource Blocks** (or **RB**s, each of 12 frequency-consecutive tones) structure across numerologies



NR Supports Up to Two DL/UL Switching Points in a Slot

- *Zero switching point* within a slot
  - Which implies 14 ‘DL’ symbols, 14 ‘flexible’ symbols, or 14 ‘UL’ symbols
  - The flexible symbols can be dynamically and UE-specifically indicated for DL or UL symbols based on actual need
- *One switching point* within a slot
  - Which starts with zero or more DL symbols and ends with zero or more UL symbols, with necessary ‘flexible’ symbols in between
- *Two switching points* within a slot
  - Where the first (or second) 7 symbols start with zero or more DL symbols and ends with at least one UL symbol at symbol #6, with zero or more ‘flexible’ symbols in between

Maximum Channel Bandwidth

- The maximum channel bandwidth supported by NR is 100 MHz for sub-6 and 400 MHz otherwise
  - Note that the maximum supported UL/DL channel bandwidth in the same band can be different
- The minimum channel bandwidth is 5 MHz for sub-6 and 50 MHz otherwise
  - New maximum channel bandwidths, if necessary, can be added in future releases as NR is designed to ensure forward compatibility
  - The channel bandwidth of a cell that can be utilized for communications is as high as 98%

Initial Access and Mobility

- NR supports up to 1008 physical cell identities, twice as many as that of LTE

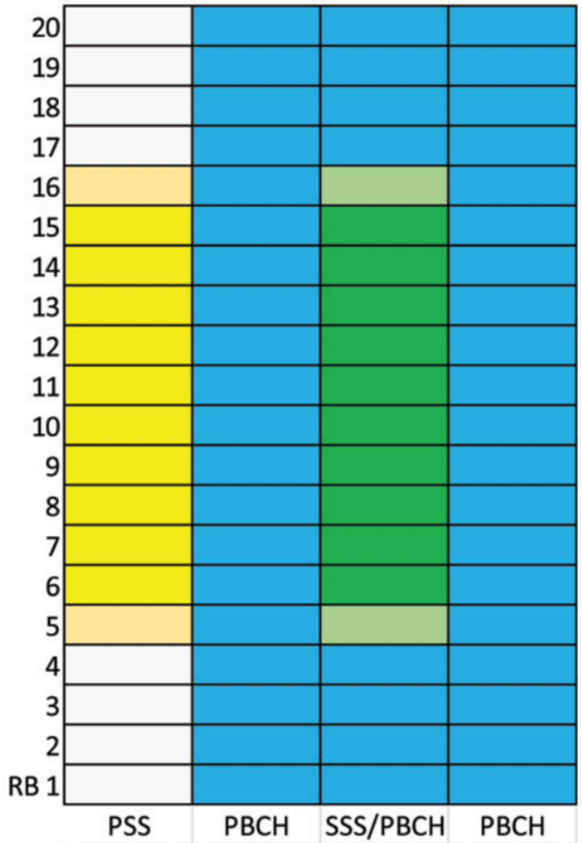
- It follows a similar two-step cell identification procedure as in LTE, via detection of primary synchronization signal (PSS) and secondary synchronization signal (SSS)

- Time synchronization (in terms of symbol-level and slot-level) and frequency synchronization are also realized via PSS/SSS

Master Information Block (MIB) for Initial Access

- Master information block (MIB) of a cell is detected via a channel called primary broadcast channel (PBCH)
  - System frame number (SFN) synchronization is acquired accordingly
- PBCH demodulation enables reception of subsequent physical downlink control channels (PDCCH) and physical downlink shared channels (PDSCH)
  - Which schedule remaining minimum system information (RMSI), other system information (OSI), and paging messages

SS Block and SS Burst Set



RB – Resource Block
PSS - Primary Synchronization Signal
SSS - Secondary Synchronization Signal
PBCH - Primary Broadcast Channel
SSB - Synchronization Signal Block

- For initial access, an essential building block called **Synchronization Signal Block (SSB)** is defined
  - A 4-symbol SSB consists of a 1-symbol PSS, a 1-symbol SSS, and a 2-symbol (and a bit extra) PBCH
  - Frequency range
    - sub-6 GHz: 15 kHz or 30 kHz for SSB
    - above-6 GHz: 120 kHz or 240 kHz for SSB

- A **SS burst set** is comprised of a set of SS blocks (SSB)
  - Each SS burst set is limited to a 5 ms window regardless of the periodicity, which can be {5, 10, 20, 40, 80, 160} ms as indicated in RMSI, configured for SS burst sets
  - For initial cell selection, the SS burst set periodicity is default at 20 ms for all frequency range

Tones of SS

- Both the number of SS blocks (L) within a SS burst set and the location of SS burst set within the 5 ms window depend on the carrier frequency range. As an example,
  - For carrier frequency range up to 3 GHz, L = 4
  - For carrier frequency range from 3 GHz to 6 GHz, L = 8
  - For carrier frequency range from 6 GHz to 52.6 GHz, L = 64
- The number of possible PSS sequences is 3, each of a frequency-domain BPSK length-127 M-sequence
  - SSS sequence also has a length of 127 and it is a scrambled M-sequence
- Both PSS and SSS are mapped to 127 consecutive tones within 12 RBs, where among the 144 tones, 8 tones and 9 tones are reserved on the two sides respectively (144 = 8 + 127 + 9)
  - A 56-bit payload PBCH (including CRC) is mapped to a total of 240 tones
- PBCH has a transmit-time-interval (TTI) of 80 ms
  - PBCH contents, including information such as SFN, SSB index, raster offset, default DL numerology, RMSI configuration, DM-RS location, etc., are updated every 80 ms
  - PSS, SSS, and PBCH are all one port only and share the same port

Paging

- A UE is explicitly signalled paging occasion configuration
  - e.g., time offset, duration, periodicity, etc

- Paging CORESET reuses the same configuration for RMSI CORESET
- Two paging mechanisms are supported:
  - Paging is done via PDSCH scheduled PDCCH, both channels in the same slot
  - Paging is done via PDCCH only, useful for short paging messages

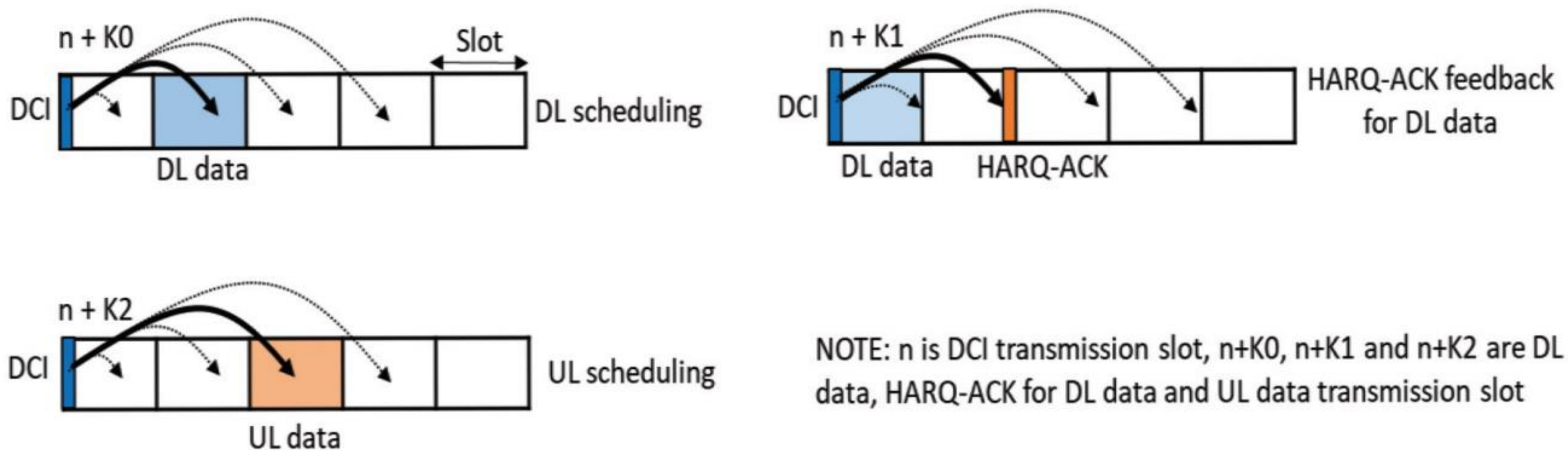
Random Access (RA)

- Enables a UE to access a cell
- It is performed by a 4-step procedure, similar to LTE
  - Message 1 (RA channel preamble): UE → gNB
    - It is based on Zadoff-Chu sequence with two sequence lengths, called long sequences and short sequences
    - Both contention-based RA (CBRA) and contention-free based RA (CFRA) are supported
    - One or multiple SSBs can be mapped to one PRACH transmission occasion
  - Message 2 (Random access response or RAR): gNB → UE
    - It carries information such as TA commands, temporary ID, etc.
  - Message 3 (First PUSCH transmission): UE → gNB
    - It is scheduled by the UL grant in RAR
  - Message 4 (PDCCH/PDSCH): gNB → UE

Differences between NR and LTE

- Highly symmetric properties in the downlink and uplink scheduling and HARQ
  - Hybrid Automatic Repeat Request (FEC + ARQ)
  - In LTE, radio resource allocation schemes are different between downlink and uplink due to different multi access schemes, and downlink HARQ is basically asynchronous and adaptive while uplink HARQ is synchronous and non-adaptive
  - In NR, almost all scheduling and HARQ mechanisms are common between downlink and uplink such as:
    - (1) radio resource allocation schemes
    - (2) Rank/modulation/coding adaptations
    - (3) asynchronous and adaptive Hybrid ARQ
- High flexibility in the time-domain
  - In LTE, time-domain radio resources for scheduled data and/or HARQ-feedback are basically not informed by the scheduling DCI, and it is determined by the frame structure and the UL-DL configuration
  - In NR, the scheduling DCI basically includes time-domain information of the scheduled data (and time-domain information of HARQ-ACK feedback in case of downlink) where the time-domain information here refers to the combination of the scheduled slot, the start symbol position, and the transmission duration

Scheduling and Hybrid ARQ



- NR can easily realize various operations
  - e.g., full/half duplex FDD, dynamic/semi-static TDD, and unlicensed operation etc.
- Satisfy different UE's requirements
  - e.g., lower latency, higher data rates

NR Bands, Sub-carrier Spacing, Channel Bandwidth

Two frequency ranges are categorized
Frequency Range 1 (FR1) 450 MHz–6 GHz and

Band	Duplex Mode	ƒ (MHz)	Uplink/Downlink (MHz)	Channel bandwidths (MHz)
n77	TDD	3700	3300 – 4200	10, 20, 40, 50, 60, 80, 100
n78	TDD	3500	3300 – 3800	10, 20, 40, 50, 60, 80, 100
n79	TDD	4700	4400 – 5000	40, 50, 60, 80, 100

Frequency Range 2 (FR2) 24.25 GHz–52.6 GHz

Band	ƒ (GHz)	Common name	Subset of band	Uplink / Downlink[B 1] (GHz)	Channel bandwidths[5] (MHz)
n257	26	LMDS		26.50 – 29.50	50, 100, 200, 400
n258	24	K-band		24.25 – 27.50	50, 100, 200, 400
n260	39	Ka-band		37.00 – 40.00	50, 100, 200, 400
n261	28	Ka-band	n257	27.50 – 28.35	50, 100, 200, 400

Prefix “n” with Arabic numerals is used to label the NR bands to differentiate the LTE bands labelled in Arabic numerals and UTRA bands labelled in Roman numerals

https://en.wikipedia.org/wiki/5G_NR_frequency_bands

Overview of RRM Core Requirements

- The SS/PBCH block (SSB) burst consists of multiple SSB-s, which are associated with the different SSB indices and potentially with the different transmission beams
- The CSI-RS signals can also be configured for beam management and measurement
- The SSB-based measurement timing configuration (SMTC) with a certain duration and periodicity is used to restrict the UE measurement on the certain resources to reduce the UE power consumptions
- The RRM requirements guarantee the initial access and mobility performance for the LTE-NR DC, Supplemental Uplink (SUP), and NR-NR Carrier Aggregation (CA)

RRM Core Requirements for E-UTRA-NR DC (NSA) and SA

Core Requirements	SA and NSA Common	NSA Specific	SA Specific
RRC_IDLE state mobility	–	–	Cell selection
	–	–	Cell re-selection and interruption in paging reception
RRC_INACTIVE	–	–	Cell re-selection
	–	–	RRC_INACTIVE mobility control
RRC Connection Mobility Control	–	–	Handover
	–	–	RRC Re-establishment
	–	Random access for NR PSCell	Random access for NR PCell
	–		RRC connection release with redirection
Timing	UE transmit timing	–	–
	UE timer accuracy	–	–
	timing advance	–	–
	Cell phase synchronization accuracy for NR TDD BS	–	–
	–	Maximum transmission timing difference (MTTD) for E-UTRA-NR DC	–

(*Continued*)

RRM Core Requirements for E-UTRA-NR DC (NSA) and SA(cont.)

Core Requirements	SA and NSA Common	NSA Specific	SA Specific
	–	Maximum receive timing difference (MRTD) for E-UTRA-NR DC	Maximum receive timing difference (MRTD) for NR CA
Signal characteristics	RLM	–	–
	–	Interruption on NR PSCell due to the operations for E-UTRA PCell/SCell or UL carrier RRC reconfiguration	–
	–	Interruption on E-UTRA PCell/SCell due to the operation for NR PSCell/SCell or UL carrier RRC reconfiguration	–
	–	Activation/deactivation SCell in SCG for E-UTRA-NR DC	–
	UE UL carrier RRC reconfiguration delay	–	–
RRM measurement	–	Measurement capability for E-UTRA-NR DC	Measurement capability for SA NR
	Intra-frequency measurement with gap	–	–
	Intra-frequency measurement without gap	–	–
	Inter-frequency measurement	–	–
	–	–	Inter-RAT measurement

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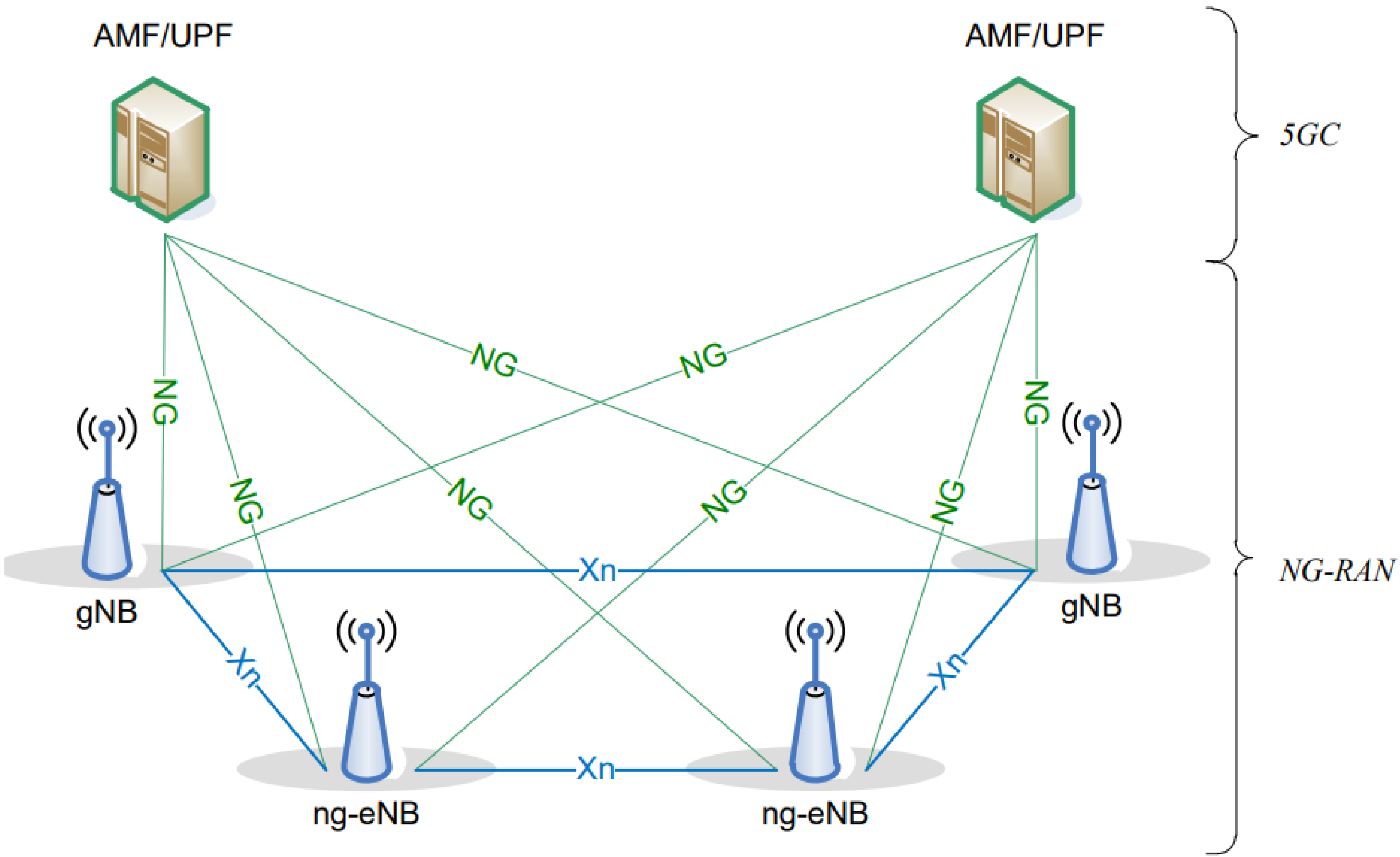
  - 3GPP Standardization
- Introduction to 3GPP 5G Specifications
  - 5G Requirements and Key Performance Indicators
  - The 5G System Architecture
  - 5G NR Radio Interface
  - 5G Radio Access Network (NG-RAN)
  - 5G Core Network

Overview of the NG-RAN Architecture

- The NG-RAN represents the newly defined radio access network for 5G
  - NG-RAN provides both NR and LTE radio access
- An NG-RAN node (i.e. base station) is either
  - A gNB (i.e. a 5G base station), providing NR user plane and control plane services
  - An ng-eNB, providing LTE/E-UTRAN services towards the UE

NG-RAN in Relation to the 5G System



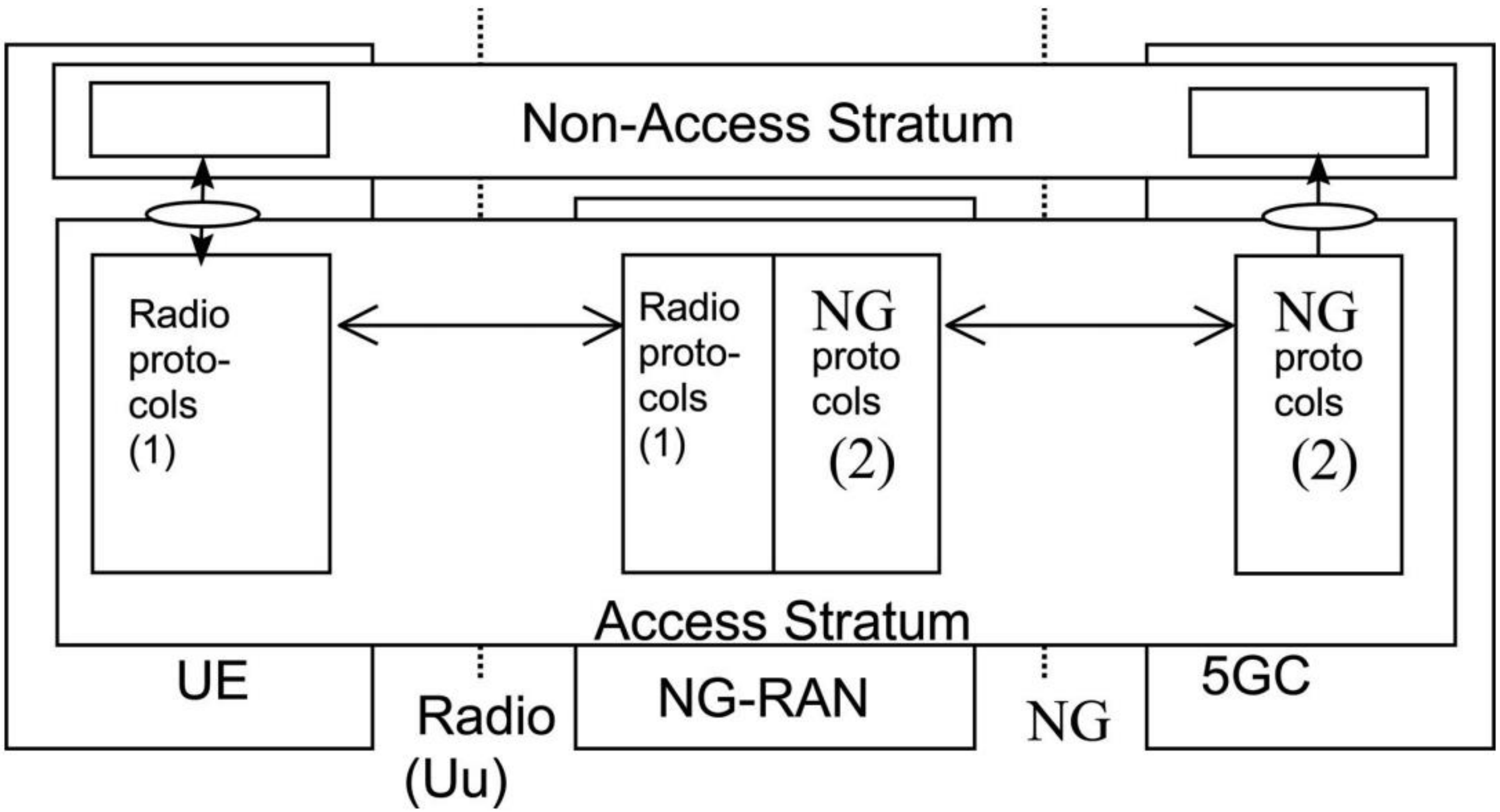
ng-eNB: enhanced node providing E-UTRAN user plane and control plane protocol terminations and connecting to 5GC

Architecture Options and Migration Paths

Two operation modes:

- Stand-Alone (SA) operation: gNB connected to 5GC
- Non-Stand-Alone (NSA): NR and LTE are tightly integrated and connect to the existing 4G Core Network (EPC)
  - Leveraging Dual Connectivity (DC): a Master Node (MN) and a Secondary Node (SN) concurrently provide radio resources towards the terminal for enhanced end-user bit rates
    - Multi-RAT DC

Overall NG-RAN Architecture

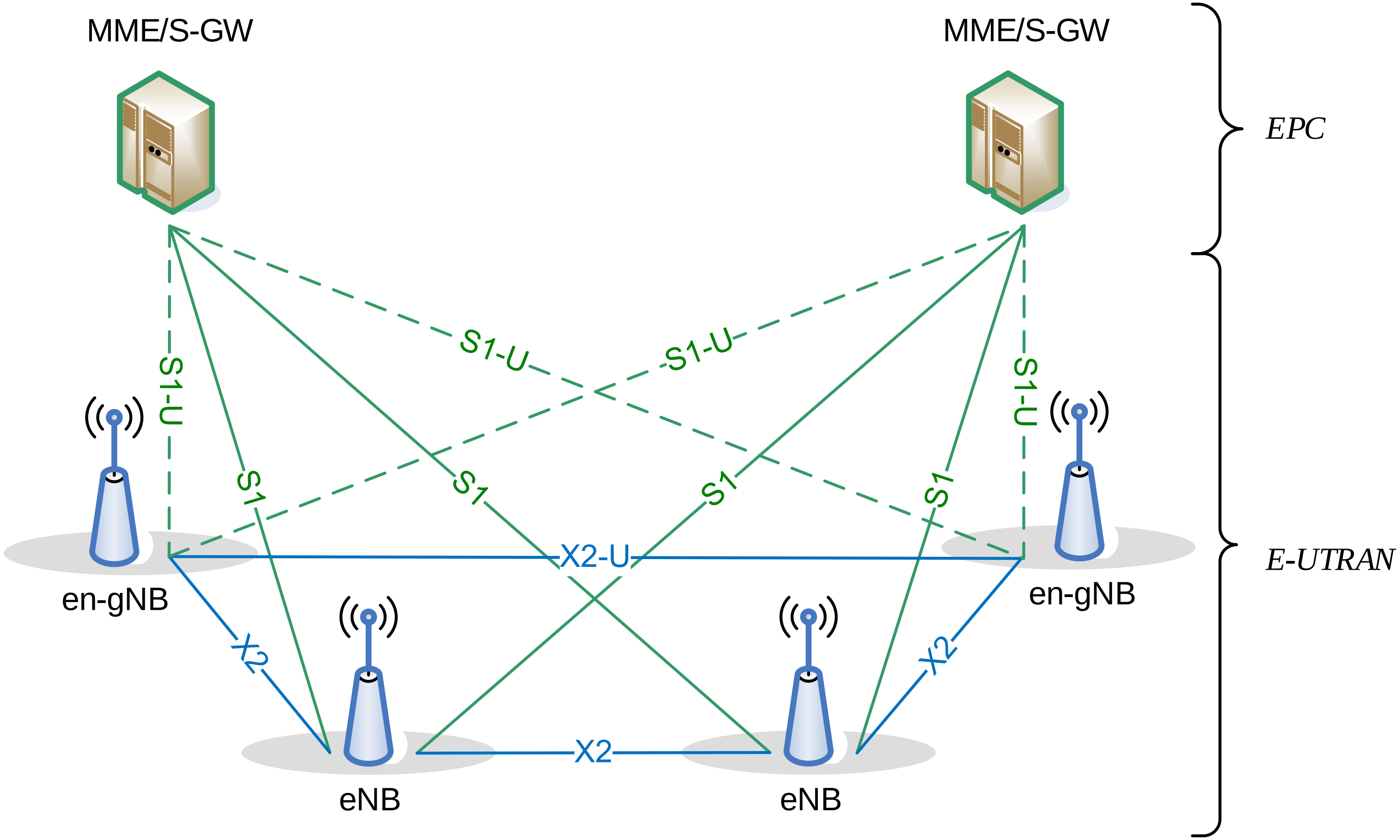


Both the user plane and control plane architectures for NG-RAN follow the same high-level architecture scheme

Architecture Options

- NR gNB Connected to the 5GC (Option 2)
  - The gNBs are connected to the 5G Core Network (5GC) through the NG interface
  - The gNBs interconnect through the Xn interface
- Multi-RAT DC with the EPC (Option 3)
  - Commonly known as EN-DC (LTE-NR Dual Connectivity),
  - A UE is connected to an eNB that acts as a MN and to an en-gNB that acts as a SN
- Multi-RAT DC with the 5GC, NR as Master (Option 4)
  - A UE is connected to a gNB that acts as a MN and to an ngeNB that acts as an SN
  - The gNB is connected to 5GC and the ng-eNB is connected to the gNB via the Xn interface
  - The ng-eNB may send UP to the 5G Core either directly or via the gNB
- LTE ng-eNB Connected to the 5GC (Option 5)
  - The ng-eNBs are connected to the 5G Core Network (5GC) through the NG interface
  - The ng-eNBs interconnect through the Xn interface. Essentially this option allows the existing LTE radio infrastructure (through an upgrade to the eNB) to connect to the new 5G Core
- Multi-RAT DC with the 5GC, E-UTRA as Master (Option 7)
  - A UE is connected to an ng-eNB that acts as a MN and to a gNB that acts as an SN
  - The ng-eNB is connected to the 5GC, and the gNB is connected to the ng-eNB via the Xn interface
  - The gNB may send UP to the 5GC either directly or via the ng-eNB

Overall EN-DC Architecture (LTE E-UTRAN – NR)



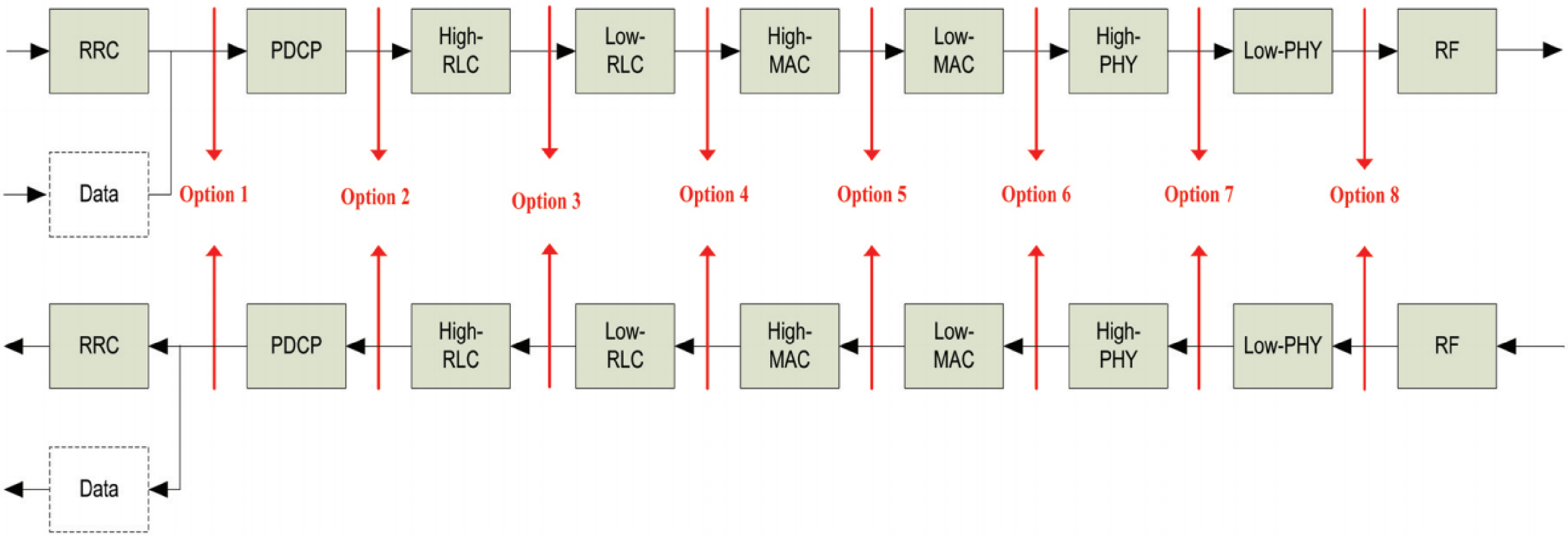
en-gNB: node providing NR user plane and control plane protocol terminations towards the UE, and acting as *Secondary Node* in EN-DC (TS 37.340 Clause 4)

5G NR Base Station (gNB) Architecture

Splitting up the gNB (the NR logical node) between Central Units (CUs) and Distributed Units (DUs)

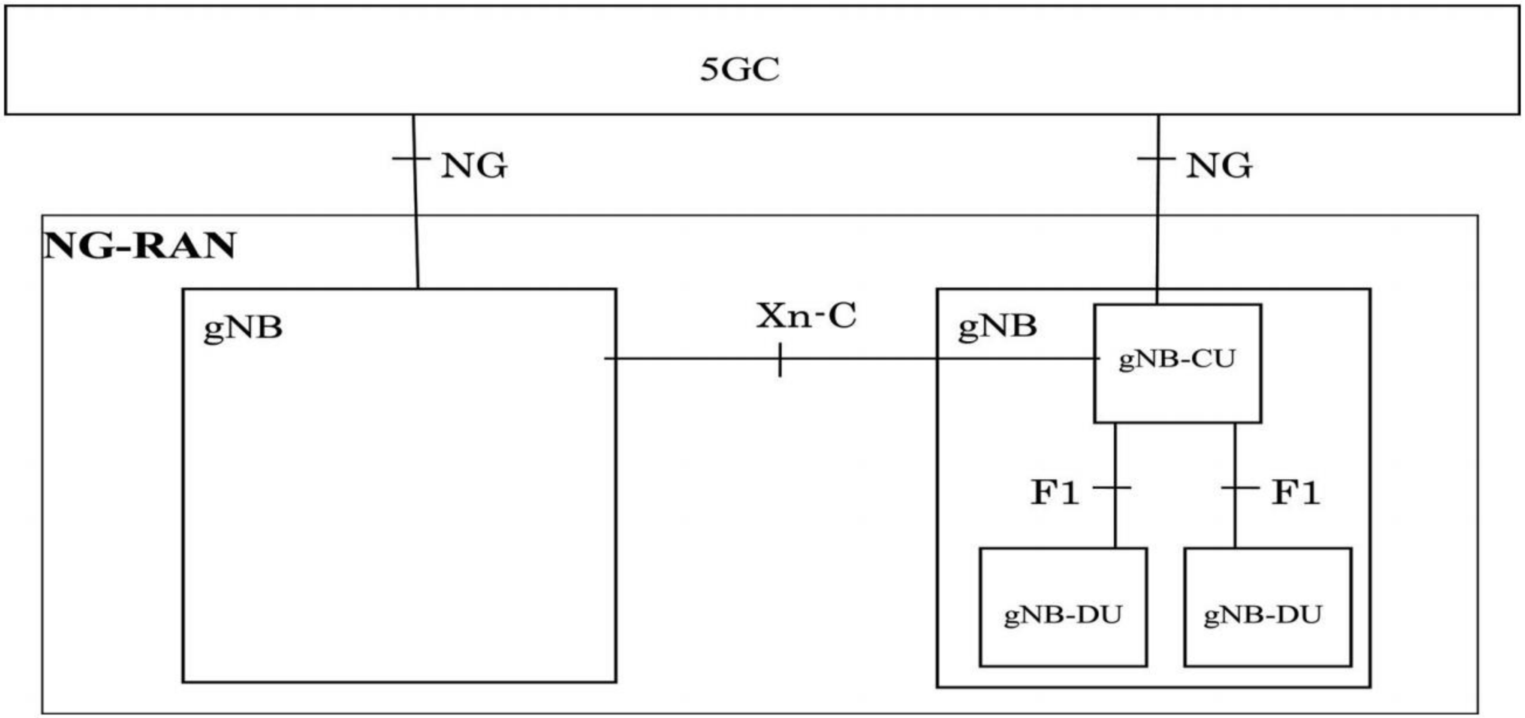
- A split architecture
  - Allows coordination of performance features, load management and real-time performance optimization
  - Enables virtualized deployments
- A flexible 5G hardware implementation
  - Allows scalable cost-effective solutions
    - ➢ 4G RAN architecture was based on a “monolithic” building block, the eNB
- Configurable functional splits
  - Enable adaptation to various use cases, such as variable transport latency

Function Split Alternatives



- 3GPP decided to take Option 2 as a basis for normative specification work
  - Based on centralised PDCP/RRC and decentralised RLC/MAC/PHY
- The prime reason for selecting this option was the close similarity to the protocol stack split applied in Dual Connectivity
  - In a DC configuration, the Master Node (MN) and the Secondary Node (SN) are "split" along the same point as Option 2

Higher Layer Split of the gNB



- The F1 interface
  - Supports signaling exchange and data transmission between the endpoints
  - Separates Radio Network Layer and Transport Network Layer
  - Enables the exchange of UE-associated and non-UE-associated signaling
- F1 interface functions are divided into F1-C and F1-U functions

F1-C (Control Plane) Functions

- F1 Interface Management Functions
  - These consist of F1 setup, gNB-CU Configuration Update, gNB-DU Configuration Update, error indication and reset function
- System Information Management Functions
  - The gNB-DU is responsible for the scheduling and broadcasting of system information
- F1 UE Context Management Functions
  - These functions are responsible for the establishment and modification of the necessary UE context.
- RRC Message Transfer Function
  - This function is responsible for the transferring of RRC messages from the gNB-CU to the gNB-DU, and vice versa

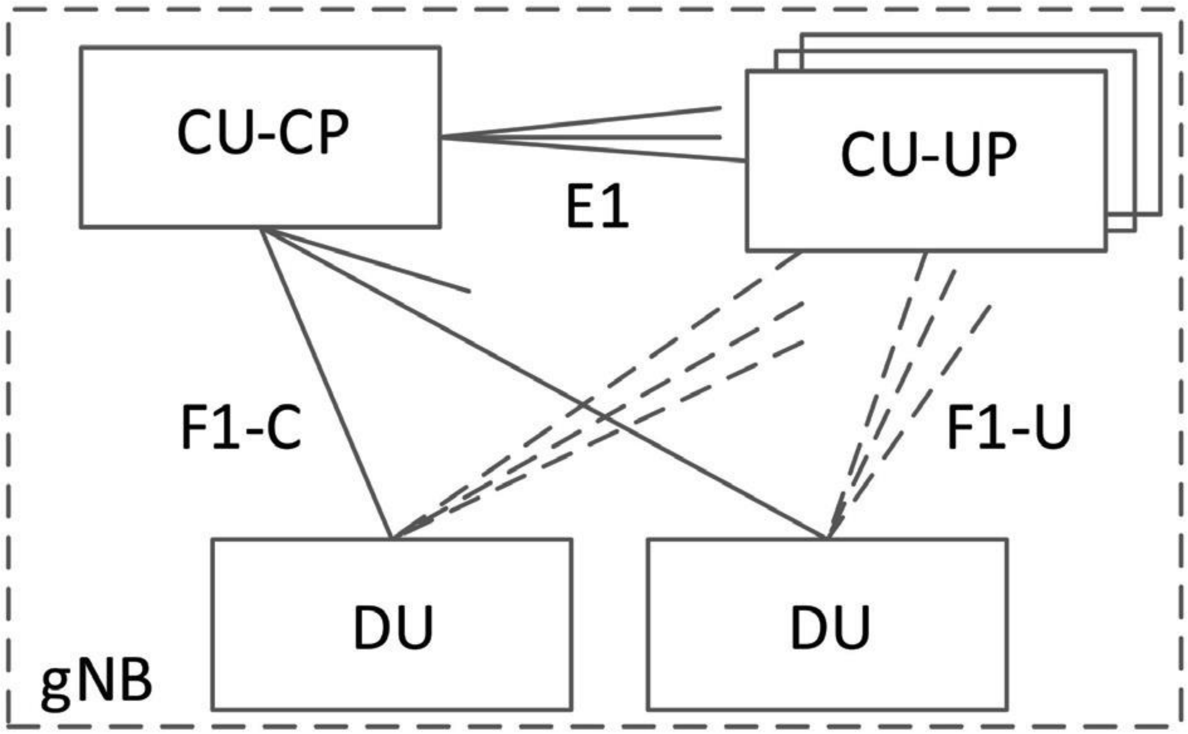
F1-U (User Plane) Functions

- Transfer of User Data
  - This function allows to transfer user data between gNB-CU and gNB-DU.
- Flow Control Function
  - This function allows to control the downlink user data transmission towards the gNB-DU
  - Several functionalities are introduced for improved performance on data transmission, like fast retransmission of PDCP PDUs lost due to radio link outage, discarding redundant PDUs, the retransmitted data indication, and the status report

CU-DU Split in Connected-mode Mobility

- Inter-gNB-DU Mobility
  - The UE moves from one gNB-DU to another within the same gNB-CU
- Intra-gNB-DU inter-cell mobility
  - The UE moves from one cell to another within the same gNB-DU, supported by UE Context Modification (gNBCU initiated) procedure
- EN-DC Mobility with Inter-gNB-DU Mobility using MCG SRB
  - The UE moves from one gNB-DU to another within the same gNB-CU when only MCG SRB is available during EN-DC operation
- EN-DC Mobility with Inter-gNB-DU Mobility using SCG SRB
  - The UE moves from one gNB-DU to another when SCG SRB is available during EN-DC operation

Separation of CP and UP with Higher Layer Split(HLS)



Overall RAN Architecture with CU-CP and CU-UP Separation

A gNB may consist of a gNB-CU-CP, multiple gNB-CU-UPs, and multiple gNB-DUs

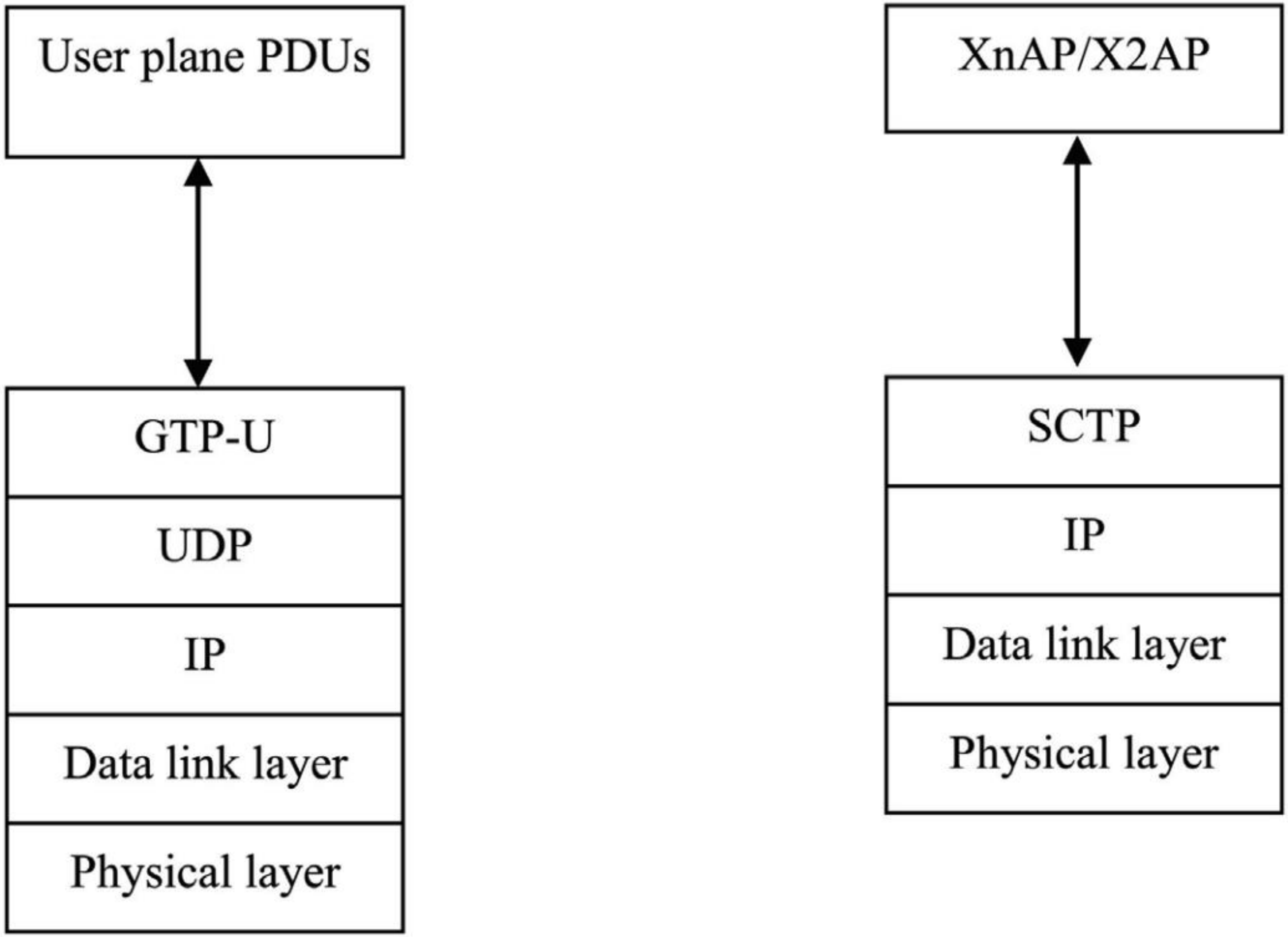
- One gNB-CU-UP is connected to only one gNB-CU-CP, but implementations allowing a gNB-CU-UP to connect to multiple gNB-CU-CPs, e.g. for added resiliency, are not precluded
- One gNB-DU can be connected to multiple gNB-CU-UPs under control of same gNB-CU-CP
- One gNB-CU-UP can be connected to multiple DUs under the control of the same gNB-CU-CP

Xx Interface Family

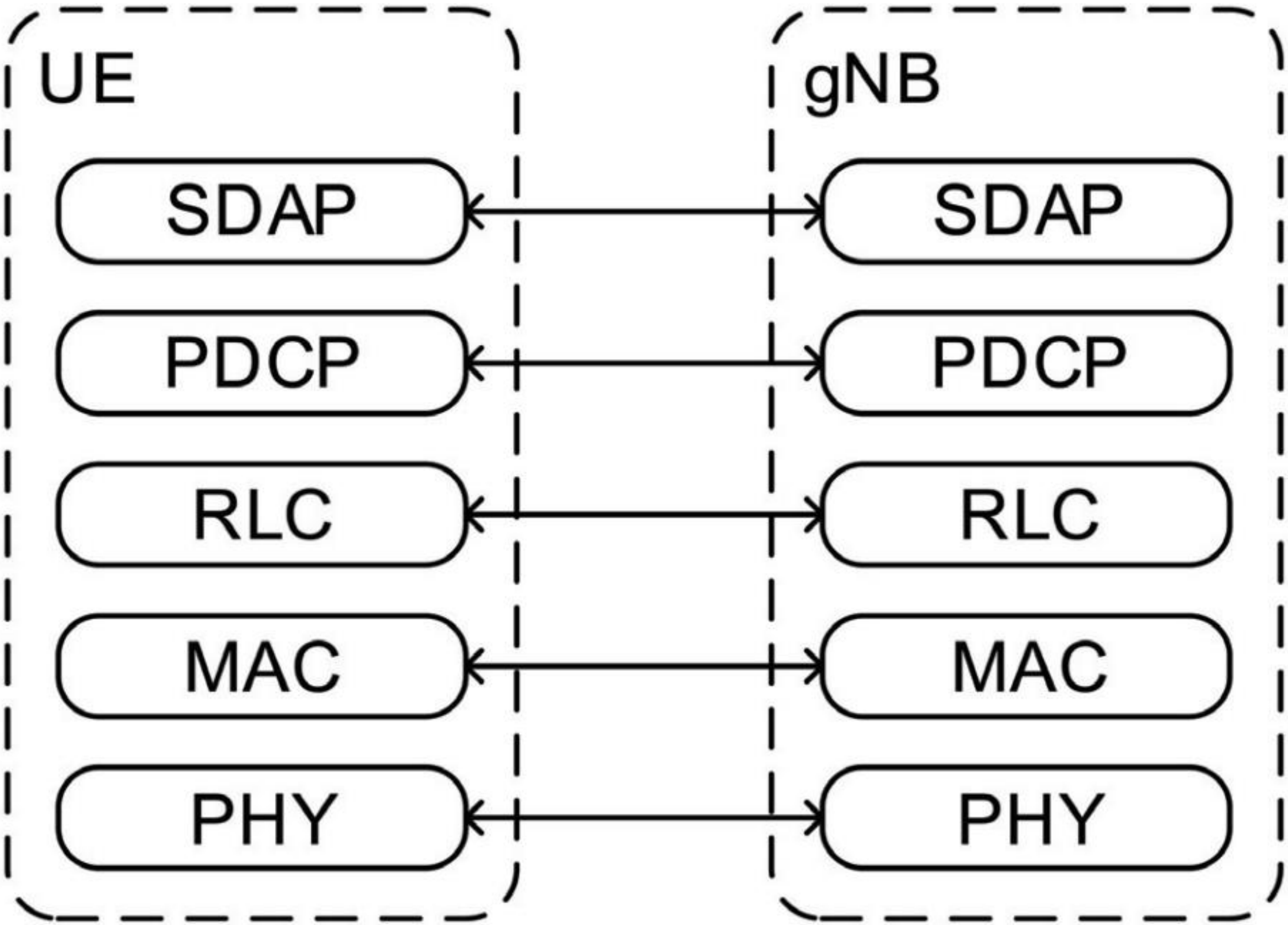
- The Xn-U/X2-U interface provides non-guaranteed delivery of user plane PDUs between two NG-RAN nodes to support dual/multi connectivity or mobility operation
  - Additionally, it supports the flow control function through Downlink Data Delivery Status procedure

- The Xn-C/X2-C interface uses Xn-AP/X2-AP protocols respectively for interface maintenance, mobility (handover, UE context retrieval, etc.) and dual/multi connectivity operation

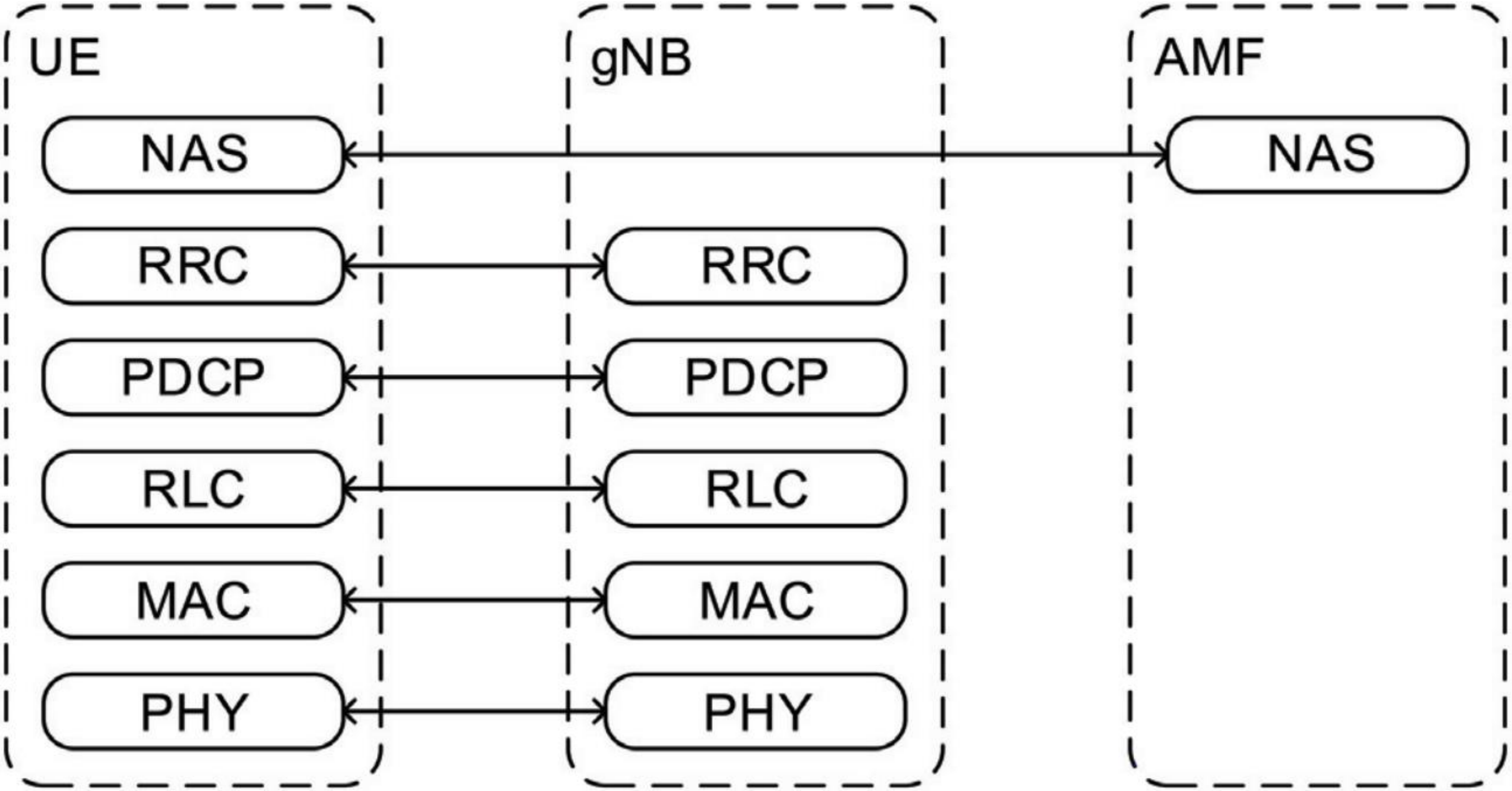
Xn and X2 Protocol Stacks



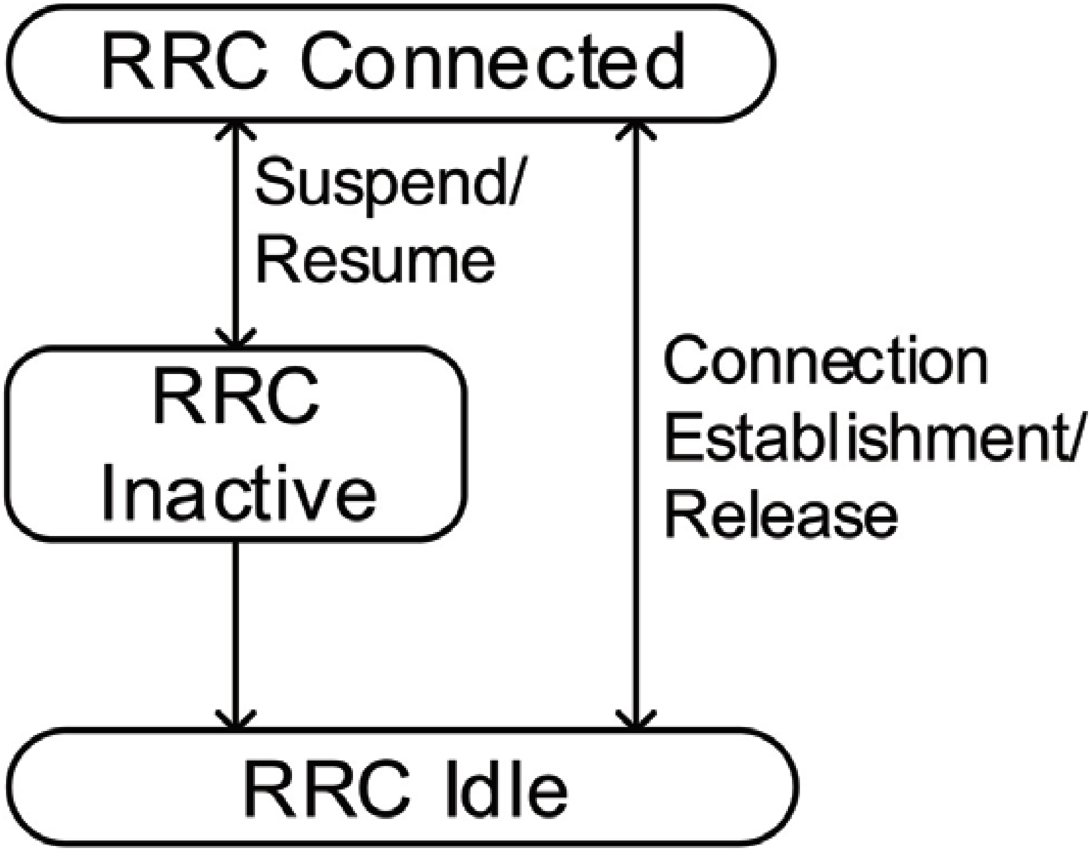
User Plane Protocol Stack



Control Plane Protocol Stack



NR RRC State Model



The NG-RAN so that transitions to/from RRC Connected are faster and incur less signalling overhead

Outline

- Syllabus
- Introduction to Cellular/Mobile Networks
  - Past and Present: 1G to 4G
- Overview of 5G
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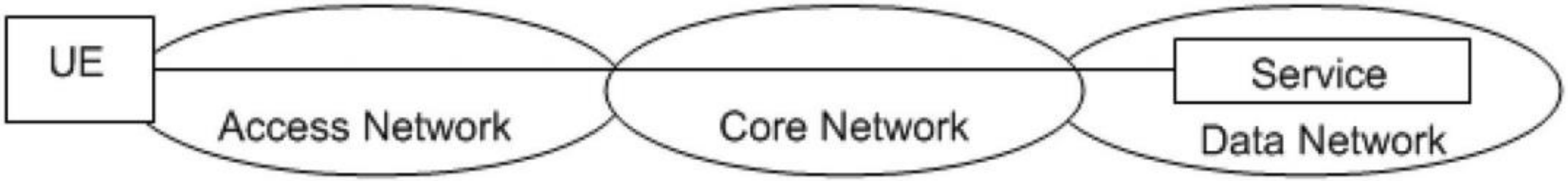
  - 5G Core Network

Generations

Every decade, a new set of standards are developed for the core network

- 2.5G added packet data support to Global System for Mobile Telecommunications (GSM)
- The European Technical Standards Institute (ETSI) and more fully in 3G
  - 3GPP introduced the Generic Packet Radio Service (GPRS)
- A further evolution of this system occurred with the introduction of 4G
  - Enhanced Packet System (EPS)
  - Enhanced Packet Core (EPC)
- 5G architecture features a new 5G Core Network (5GC)

A Simple Model of Service Access Using the 3GPP System



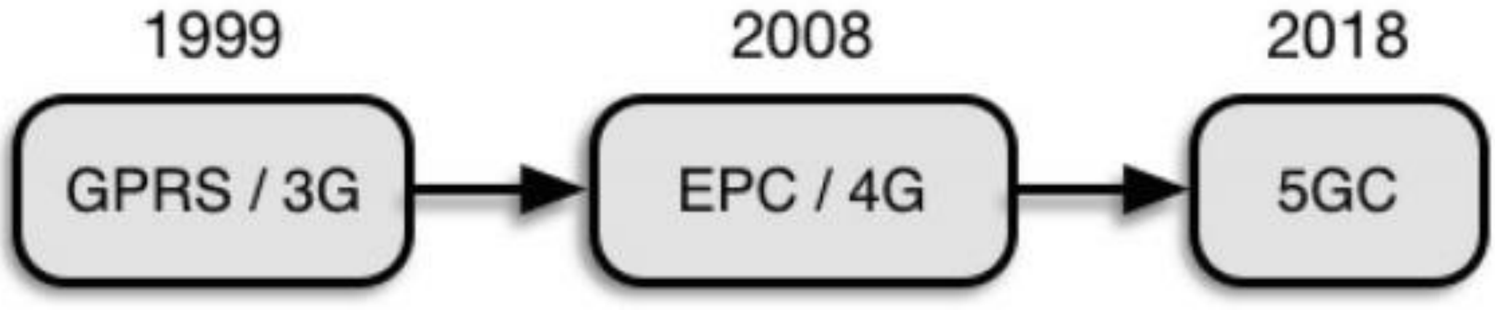
- The purpose of the 3GPP system is to efficiently provide terminals, referred to as User Equipment (UE), with access to services (voice, text, data, etc.) available in data networks
- UE access to the Data Network involves two other distinct networking domains: the Access Network (e.g. Radio Access Network) and Core Network (GPRS, EPC or 5GC)

Core Network

The Core Network supports several functions

- Most essentially access control
- Data packet routing and forwarding
- Mobility management
- Radio resource management
- UE reachability functions

Core Network Evolution through Generations



- Once a mobile device can communicate using an access network, the UE can register with the network
  - Millions of these devices must be supported, even as they periodically cease communication or leave coverage, so that data and other services can be delivered at the first opportunity, both to the UE and from the UE
- Within the Core Network, control plane interactions occur as needed, associated with each UE registered with the network
  - It is therefore imperative that the control plane interactions occur efficiently

Control Plane

- The ‘control plane’ is the term used for all signalling used to support the functions in the mobile telecommunications system that establish and maintain the user plane
- The control plane is itself a forwarding path to exchange information for operation of the service
  - As ‘overhead’ (it enables services but is not a service itself), the control plane must be efficient, scalable, reliable and suited to the needs of mobile network operators

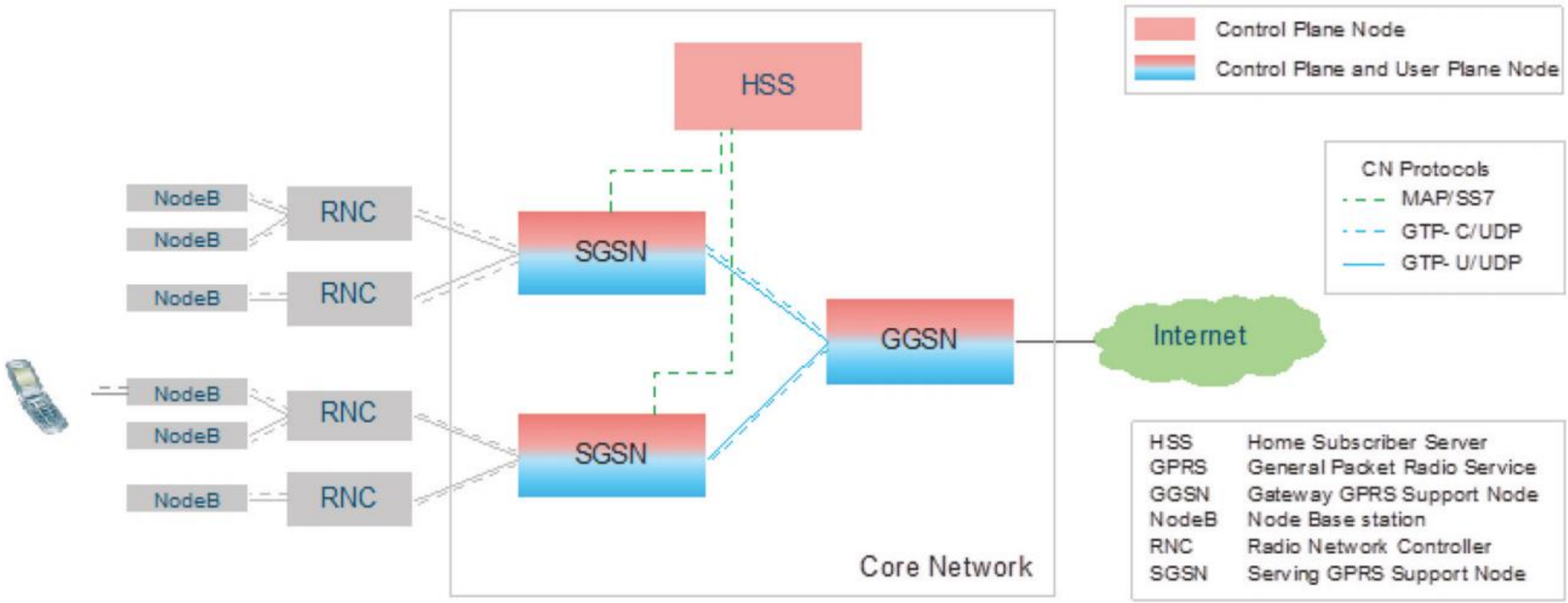
Control Plane and User Plane Separation (CUPS)

- Provides the architecture enhancements for the separation of functionality in the EPC's SGW, PGW and TDF (Traffic Detection Function)
- Enables flexible network deployment and operation, by distributed or centralized deployment and the independent scaling between control plane and user plane functions
  - While not affecting the functionality of the existing nodes subject to this split

Features of CUPS

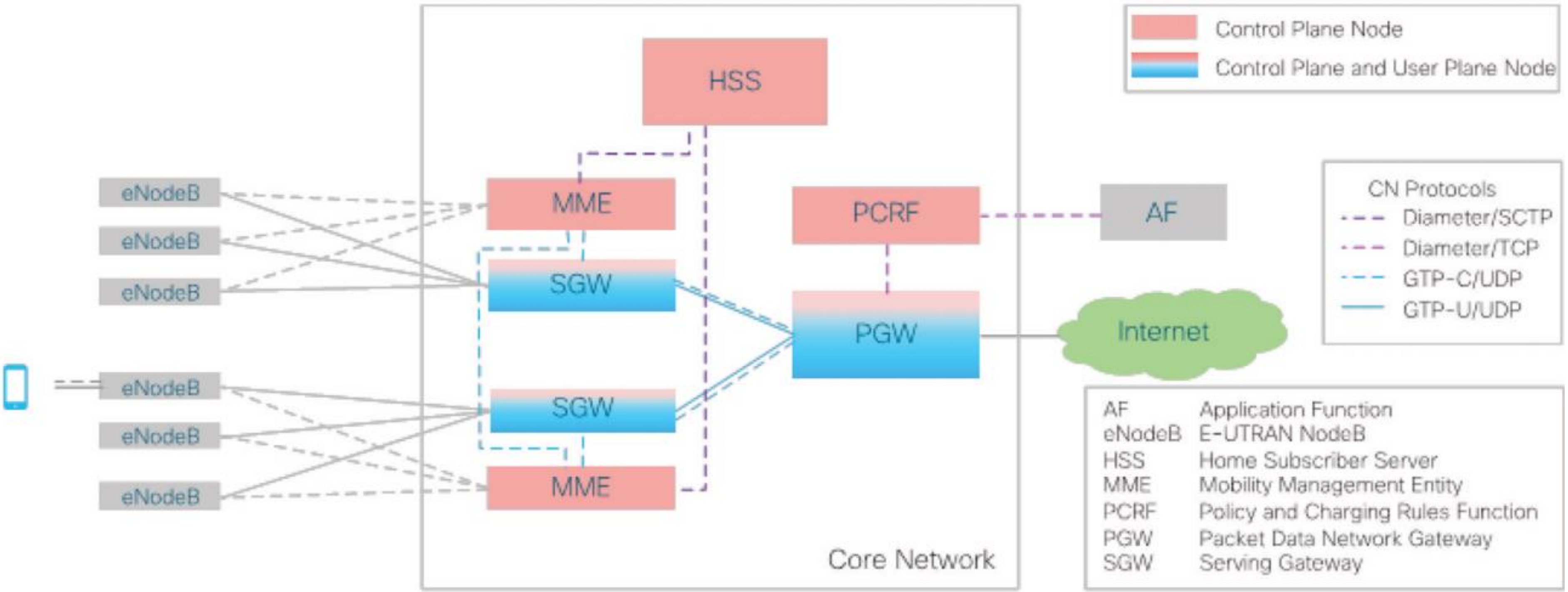
- Reducing Latency on application service
  - e.g. by selecting User plane nodes which are closer to the RAN or more appropriate for the intended UE usage type without increasing the number of control plane nodes
- Supporting Increase of Data Traffic
  - By enabling to add user plane nodes without changing the number of SGW-C, PGW-C and TDF-C in the network
- Locating and Scaling the CP and UP resources of the EPC nodes independently
- Independent evolution of the CP and UP functions
- Enabling Software Defined Networking to deliver user plane data more efficiently

GPRS – the 3G Core Network



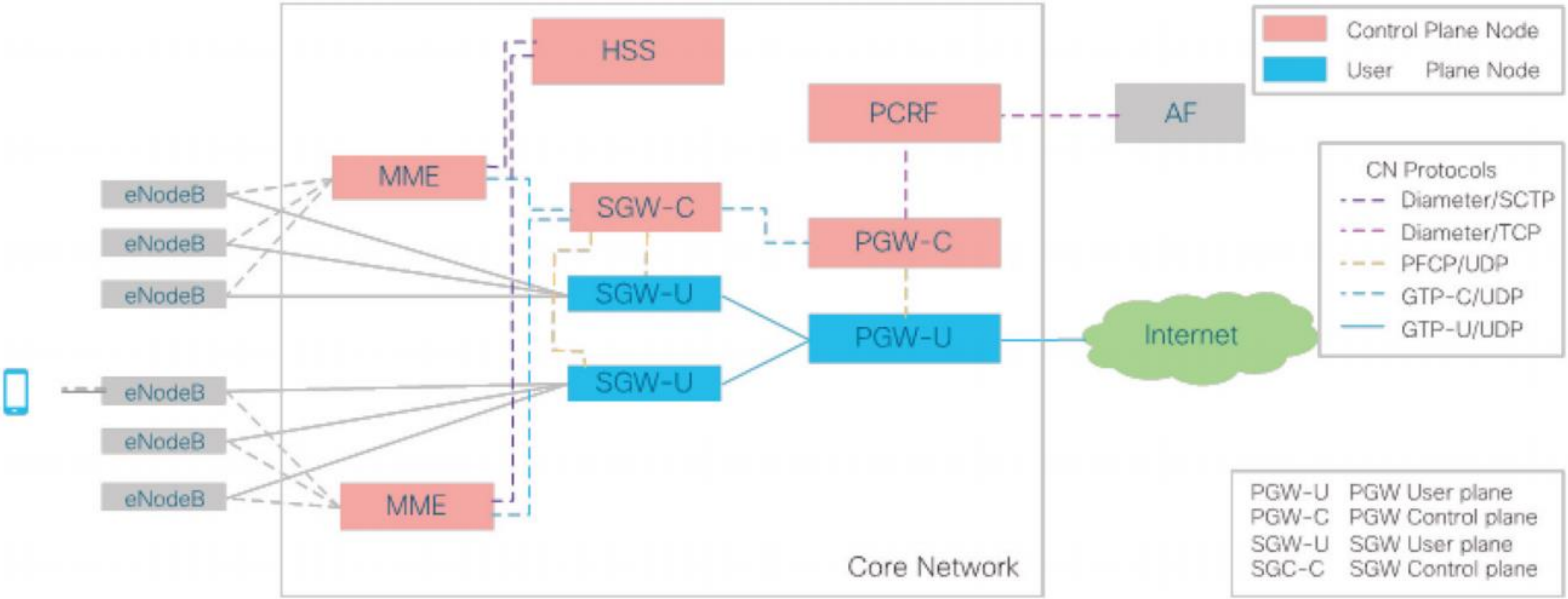
- In GPRS , the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN) terminate both user plane and control plane interfaces
- The implementation and implicitly the deployment of these entities tightly couples the control and user planes

EPC – the 4G Core Network



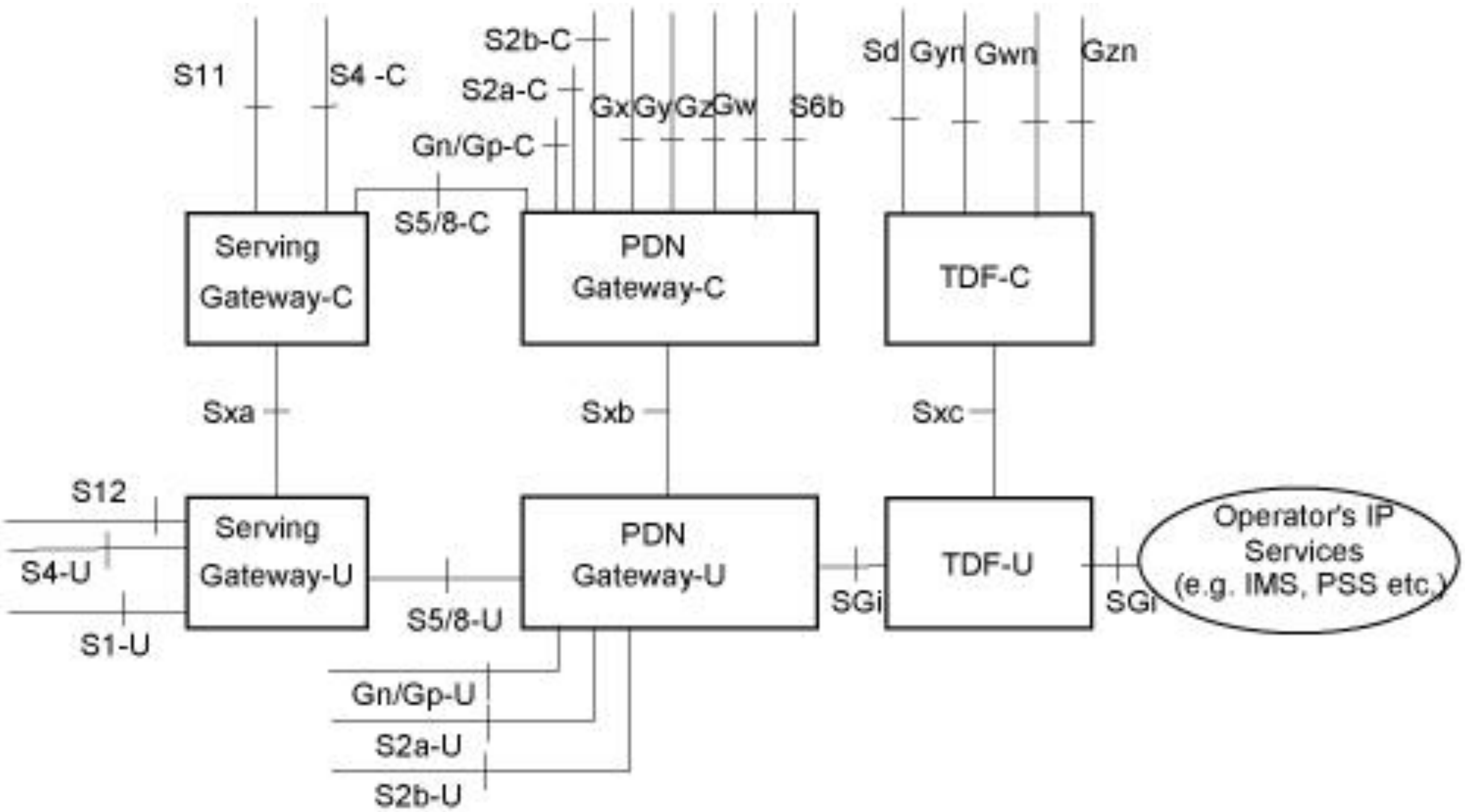
- In EPC, the mobility management (including authentication) functionality of the SGSN was separated out into the Mobility Management Entity (MME) and data-plane functionality of the SGSN separated into the Serving Gateway (SGW)
- This provides the opportunity to some extent to scale the control aspects in the MME independently of the session management and data forwarding aspects in the SGW and Packet Gateway (PGW)

EPC with CUPS Enhancement



- In Release 14, the architecture allowed a full separation of user plane and control plane, splitting the SGW and PGW into control and user plane aspects
- This allows much more flexible, efficient and higher performance deployments of the user plane
    - e.g. to improve the placement, network control and resource management
- This enabled the centralization of the control functionality of the SGW and PGW, where a single SGW-C controls both the SGW-U network elements
- The PCRF to provide dynamic QoS and charging policies to the network

CUPS of EPC Architecture



CUPS introduces 3 new interfaces, Sxa, Sxb and Sxc between the CP and UP functions of the SGW, PGW and TDF respectively

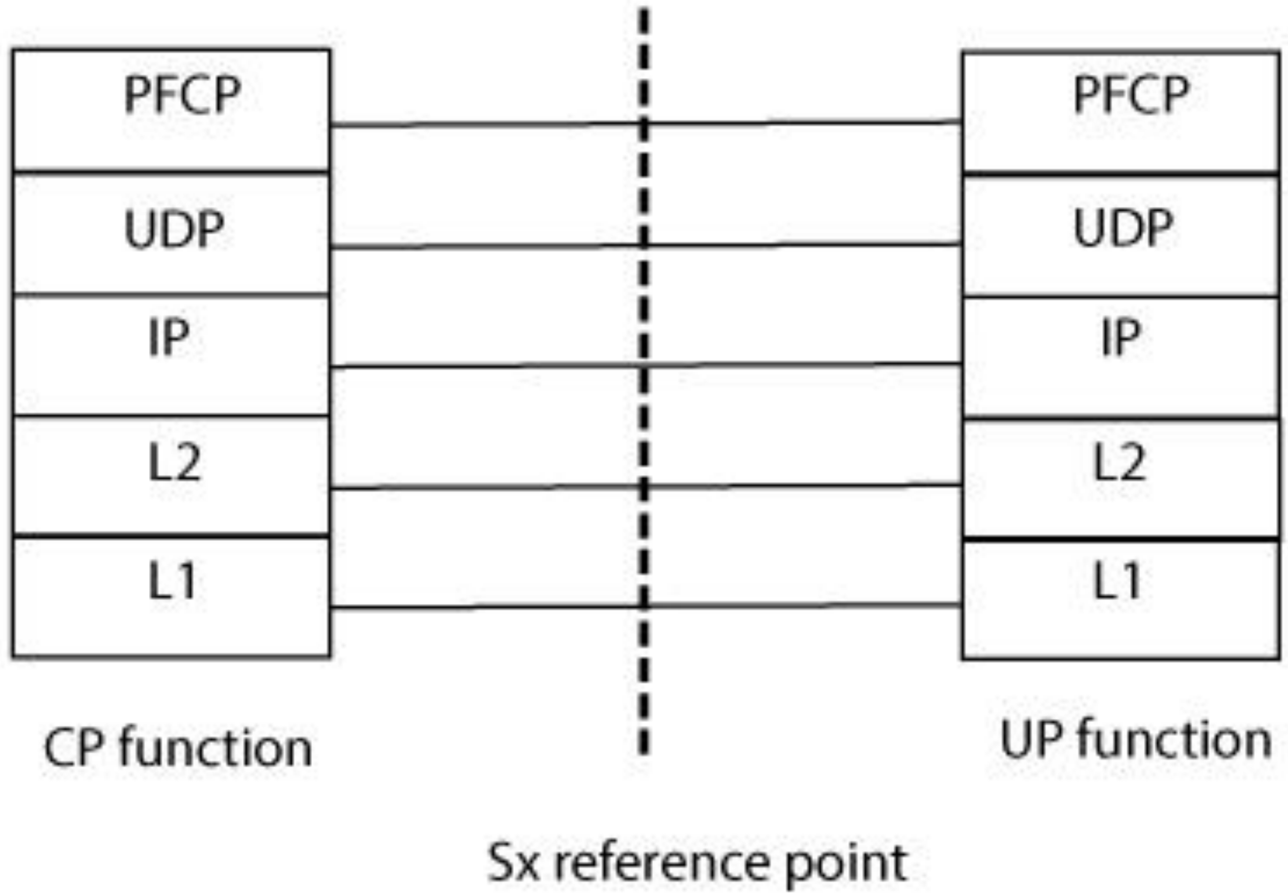
https://www.3gpp.org/news-events/3gpp-news/1882-cups

Architecture Principles of EPC CUPS

- The CP function terminates the CP protocols: GTP-C, Diameter (Gx, Gy, Gz)
- A CP function can interface multiple UP functions, and a UP function can be shared by multiple CP functions
- An UE is served by a single SGW-CP but multiple SGW-UPs can be selected for different PDN connections
  - A user plane data packet may traverse multiple UP functions
- The CP function controls the processing of the packets in the UP function by provisioning a set of rules in Sx sessions
  - i.e. Packet Detection Rules for packets inspection, Forwarding Action Rules for packets handling (e.g. forward, duplicate, buffer, drop), Qos Enforcement Rules to enforce QoS policing on the packets, Usage Reporting Rules for measuring the traffic usage
- All 3GPP features impacting UP function (PCC, Charging, Lawful Interception, etc) are supported, while the UP function is designed as much as possible 3GPP agnostic
  - For example, the UPF is not aware of bearer concept
- Charging and Usage Monitoring are supported by instructing the UP function to measure and report traffic usage, using Usage Reporting Rule(s)
  - No impact is expected to OFCS, OCS and the PCRF
- The CP or UP function is responsible for GTP-u F-TEID allocation
- A legacy SGW, PGW and TDF can be replaced by a split node without effecting connected legacy nodes

Packet Forwarding Control Plane (PFCP) Protocol

- A 3GPP native protocol with TLV encoded messages over UDP/IP, called Packet Forwarding Control Plane (PFCP) protocol, for the Sxa, Sxb and Sxc interfaces



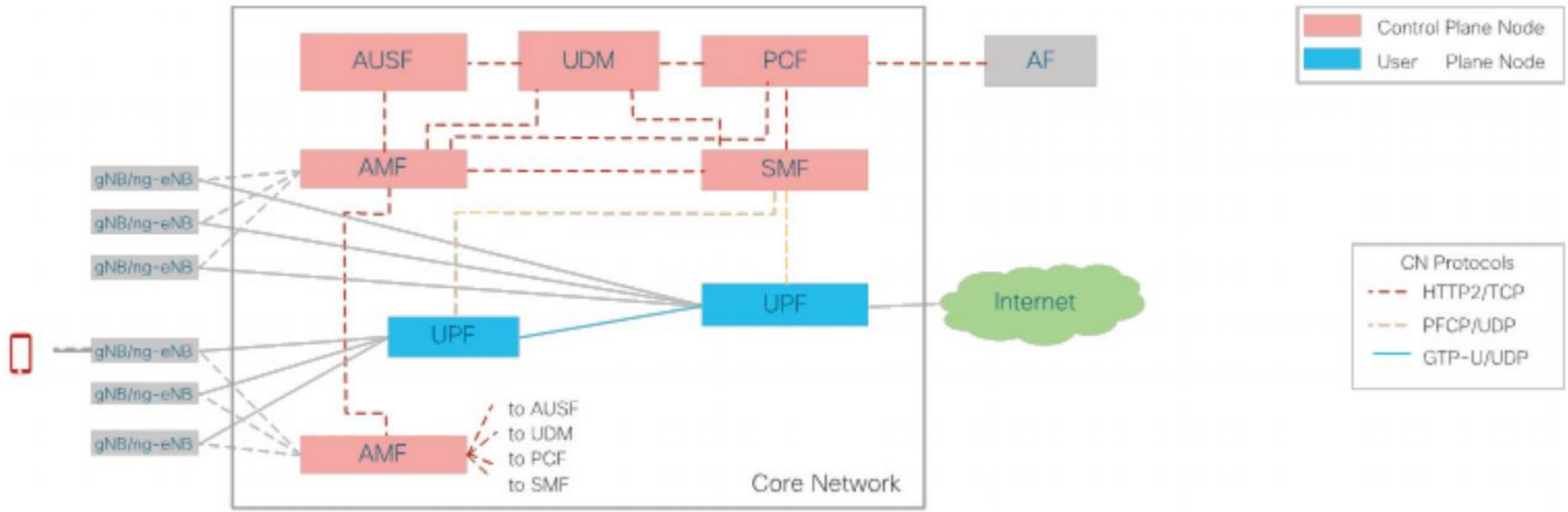
PFCP Main Properties

- One Sx Association shall be setup between a CP function and a UP function before being able to establish Sx sessions on the UP function
  - The Sx association may be established by the CP function (mandatory support) or by the UP function (optional support)
- An Sx session is established in the UP function to provision rules instructing the UP function how to process a certain traffic
  - An Sx Session may correspond to an individual PDN connection, TDF session or this can be a standalone session not tied to any PDN connection/TDF session
    - e.g. for forwarding DHCP/RADIUS/DIAMETER signalling between PGW-C and PDN (SGi)
- Data Forwarding between the CP and UP functions is supported by GTP-U encapsulation or forwarding user plane data to the SGW-C when buffering of DL packets is done in the CP function
  - , e.g. for forwarding RS/RA/DHCP signalling between UE and PGW-C
- PFCP supports reliable delivery of messages
- New DNS procedures are defined for UP function selection
  - The CP function selects a UP function based on DNS or local configuration, the capabilities of the UP function and the overload control information provided by the UP function

PFCP Procedures

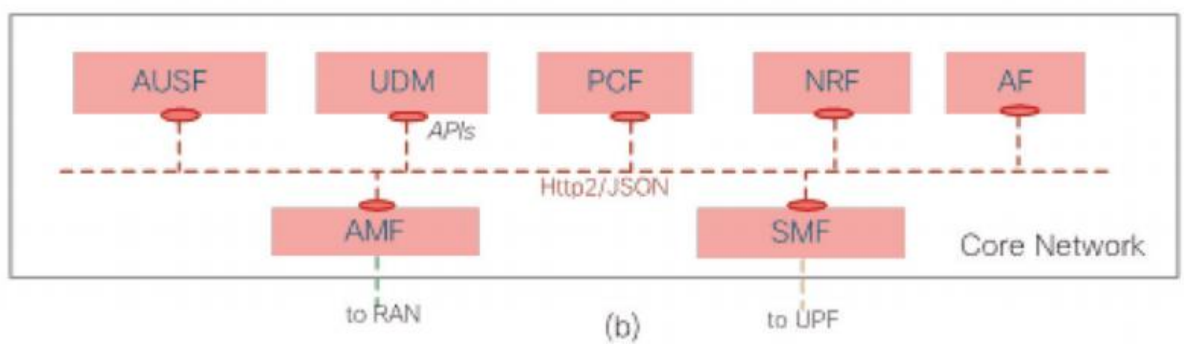
- Sx Node related procedures
  - Sx Association Setup / Update / Release procedures
  - Heartbeat procedure to check that a PFCP peer is alive
  - Load Control and Overload Control procedures to balance the load across UP functions and reduce signalling towards UP function in overload
  - Sx PFD Management procedure to provision PFDs (Packet Flow Descriptions) for one or more Application Identifiers in the UP function (SDCI)
- Sx Session related procedures
  - Sx Session Establishment / Modification / Deletion procedures
  - Sx Session Report procedure to report traffic usage or specific events (e.g. arrival of a DL data packet, start of an application)

5G Core Network - Interface Representation



- The 5GC also separates the control plane and user plane
- The Access and Mobility Management Function (AMF) provides mobility management functions, analogous to mobility management functionsof the MME
- The session management functions of the MME are separated out and combined with the data plane control functions of the SGW and GPW to create the Session Management Function (SMF)
  - Thus the AMF, unlike the MME, does not include session management aspects

5G Core Network - API Level Representation



AF	Application Function
AMF	Access and mobility management Function
AUSF	Authentication Server Function
NRF	Network function Repository Function
PCF	Policy Control Function
PFCP	Packet Forwarding Control Protocol
SMF	Session Management Function
UDM	Unified Data Management
UPF	User Plane Function

- In the 5GC, session management aspects of control messages from the UE are terminated by the SMF, whereas in the EPC, these would be terminated by the MME
  - One advantage of this mobility management and session management separation is that AMF can be adapted for non-3GPP access networks also
- The session management aspects are very access specific and hence are specified initially for the Next Generation Radio Access Network (NG-RAN)

5G Core Network Architecture

- Another important development in successive releases is a consolidation of the number of protocols used between functions in the control plane of the system
- More importantly, in 5GC the protocol for interaction between all control-plane entities is HTTP, which is a protocol widely used in the Internet and not telecom-specific like dedicated Diameter applications or GTP-C

5G Service-Based Architecture (SBA)

A key advance in the 5GC architecture is the introduction of the service-based architecture

- In GPRS and EPC control plane design
  - procedures defined all interactions between network functions as a series of message exchanges, carried out by protocol interactions
- In the 5GC
  - Network functions employing the Service Based Architecture offer and consume services of other network functions
  - Allowing any other network function to consume services offered by a network function enables direct interactions between network functions

Advantages of SBA

- Allowing any other network function to consume services offered by a network function enables direct interactions between network functions
  - In the past, several kinds of interactions piggybacked (or reused) messages exchanged along general purpose paths, since a direct interface does not exist between the consumer and producer network function
- For example, the Policy Control Function (PCF)
  - In the 5GC, it can directly subscribe to location change service offered by the AMF rather than having to have this event proxied via the SMF
  - In the EPC, by contrast, analogous information followed a hop by hop path from the MME, to the SGW, to the PGW and finally the Policy and Charging Rules Function (PCRF)
- There are other advantages at the protocol level
  - E.g. uniformity of network protocols leading to simpler implementations, use of modern transport and application protocol frameworks that are more extensible and efficient, etc.

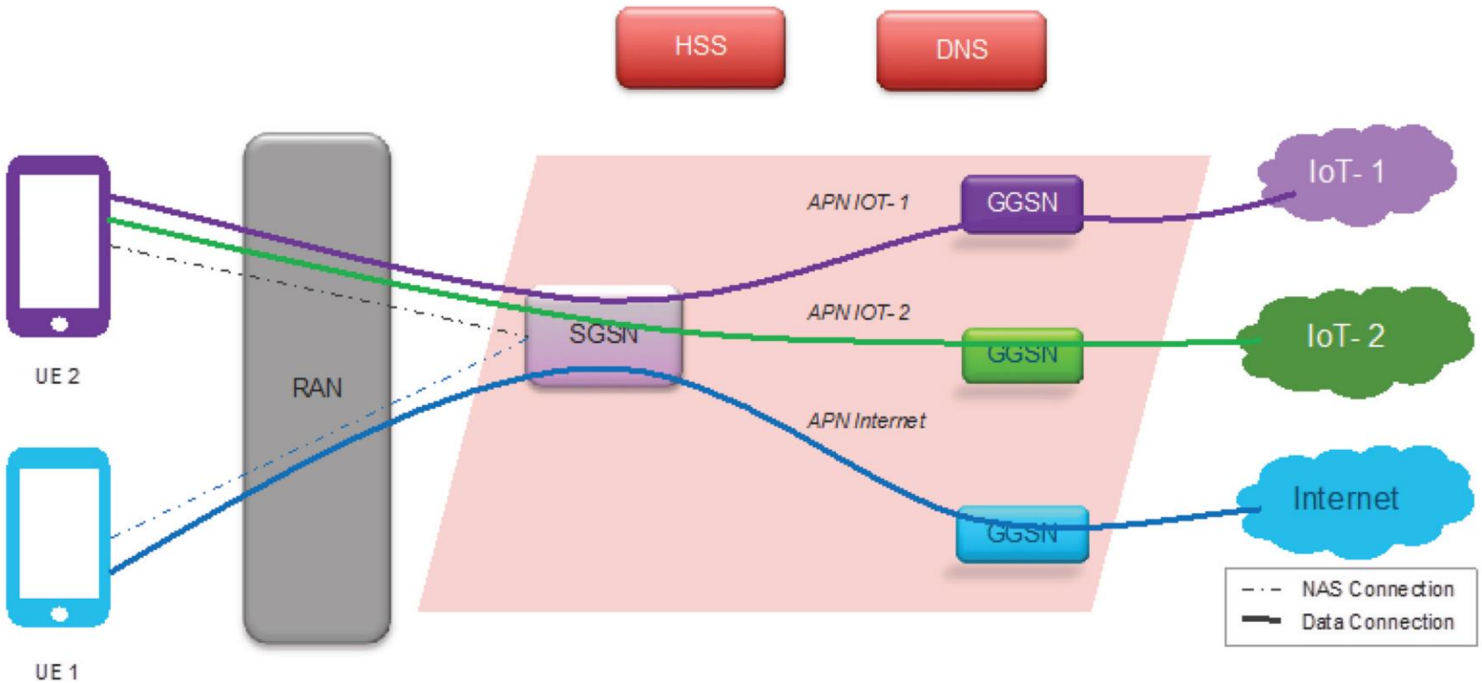
Advances of 5GC State Management

- In the EPC, GPRS and EPC control entities defined state associated with a registered UE, called “context”
  – This information, both subscription information retrieved from the HSS, and dynamic information corresponding to the registered UE is stored in the SGSN and GGSN in the GPRS architecture and the MME, SGW and PGW in the EPC
  – As the UE moves, the SGSN (in GPRS) or MME and SGW (in EPC) may be relocated and new serving nodes may be selected
    - This procedure requires the ‘context’ to be transferred between the old and new entity, and additional state to be fetched, e.g. the subscription data to the new MME
- In the 5GC, state may be stored centrally
  – This can ease network function implementations in which state storage per network function and context transfer between network functions are not desirable
  – In Rel-15, procedures for AMF relocation specify context transfer procedures, as in 3G and 4G
    - In future, use of centralized storage may be defined to eliminate this requirement
  – Also in Rel-15, the centralized Unified Data Management (UDM) function is employed for some procedures for retrieval of state, for example, in the Registration with AMF-reallocation procedure
  - In this procedure, per slice subscriber data including access and mobility information is stored by the initial AMF and retrieved by the target AMF

Slicing

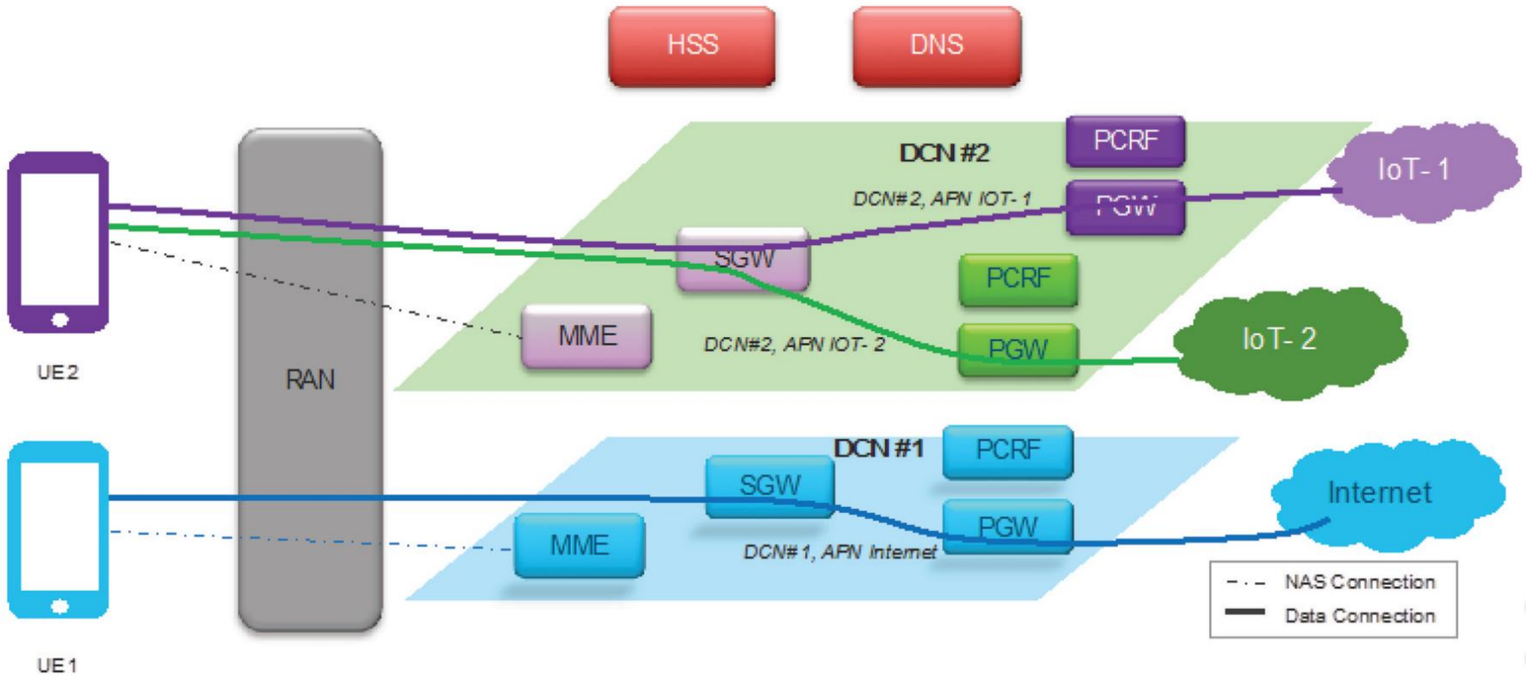
- Slicing is the concept of creating logically separated networks consisting of network elements dedicated to that slice
  - For example, to serve different traffic types: a slice designed for enhanced Mobile Broadband (eMBB) traffic is able to handle very high per user throughput. Another slice, for massive IoT (mIoT) rather serves large number of subscribers that transmit small data infrequently
- Slicing is a facility to support multiple instances of the same network function
  - Associating each network function instance with a specific slice and then selecting a slice that serves a subscriber
  - The subscriber's user and control plane is established and maintained by network functions of that slice
- Though slicing as a term is new and used specifically with the advent of 5G networks, variants of this functionality have existed and evolved from GPRS through EPS to 5GS

Use of APNs for Selection of GGSN in GPRS



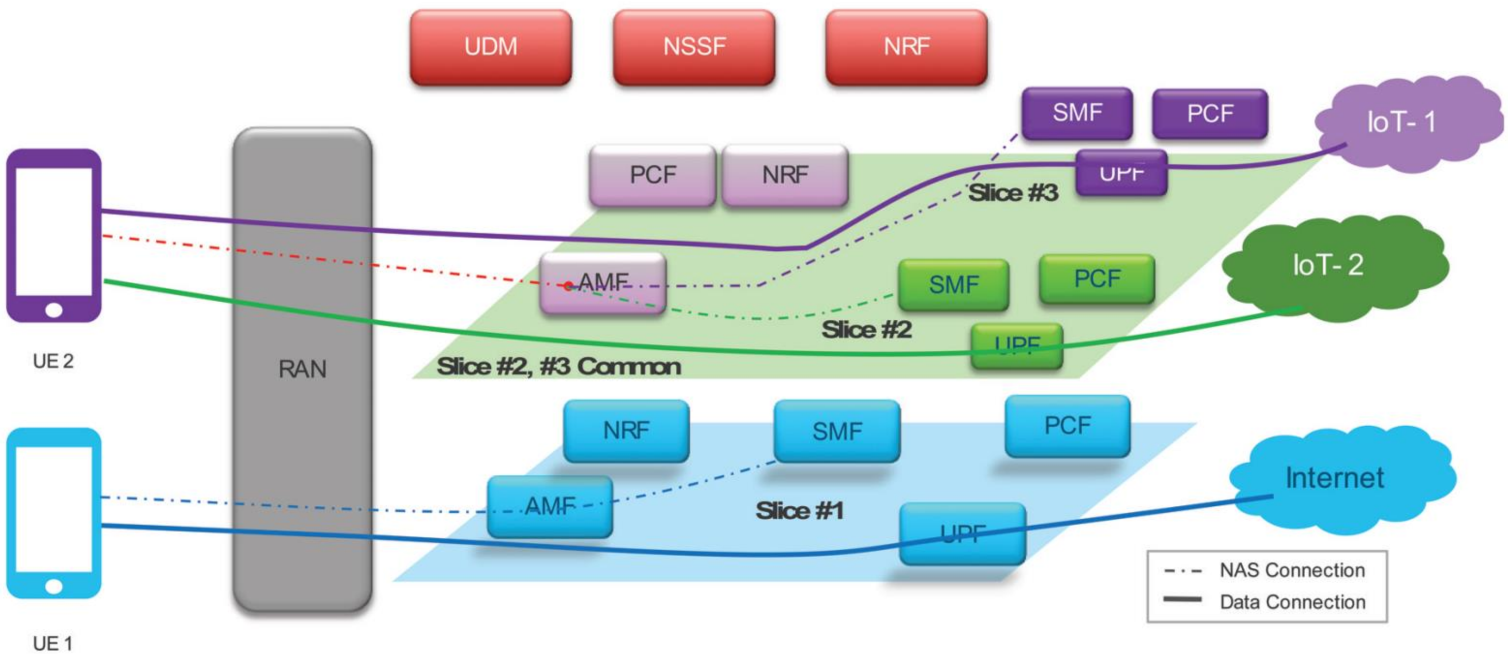
- UE 1 communicates with servers in the Internet and UE 2 communicates with servers in two different IoT data networks, IoT-1 and IoT-2
  - 3GPP core networks enable this functionality by providing the UE with multiple IP addresses to a subscriber, with the subscriber using the data network specific IP address to access the servers in the appropriate data network
- Access to these data networks requires the selection of gateways that serve the specific data networks and provide the UE with an address from that data network

Dedicated Core Networks (DCNs) for EPS



- For the UE's NAS connection, the UE 1 is assigned MME from DCN#1 and UE 2 is assigned MME from DNC#2
  - Note that this is not possible for GPRS networks
- In addition the SGWs for the two UEs are different in the two DCNs
  - The selection of the SGW and PGW is based on both the DCN-ID and APN of the PDN Connection
  - Similar to GPRS, there is a single DNS common to the two DCNs

Network Slicing Applied to 5GS



- All 5GS capable UEs and networks are required to support network slicing
  - In the user plane, each data connection of the UE is served by an SMF+UPF belonging to the same assigned slice
  - A UE can have data connections to different slices
- However, there is a single AMF allocated to terminate the UE's NAS connection, which proxies session management messages to and from SMFs in the different slices
- Also, (not shown in 5GS), UE can have
  - Multiple PDU sessions in a slice to different data networks, or
  - Multiple PDU sessions to the same data network via different slices, via the combination of slice identifier and APN

Network Slicing Feature Supported in 5GS

- Policies to bind applications to slices and APNs can be provided to the UE during registration or can be configured on the UE
  - These policies can be subsequently updated at a later time, using NAS procedures
  - All 5GS UEs support these procedures
- In the network, operator policies for selection of network slices can be centralized in a network function called the Network Slice Selection Function (NSSF) or can be configured in each AMF
  - The centralization of network policies for slice selection in NSSF improves the operability of the network
- The discovery of network functions (eg. SMF, UPF, PCF) is performed using a function called Network Function (NF) repository function (NRF)
  - NRF can be slice-specific or shared across slices
  - Having slice-specific NRFs enables isolation between slices, with network configuration of one slice not being visible in another slice
    - This is not possible for EPS where the DNS is shared across DCNs
- In 5GS there is support for RAN-slicing
  - where the slice IDs of PDU session is provided to the RAN
- The 5G Core Network has been designed to take advantage of network orchestration mechanisms to instantiate, maintain and delete slices

Summary

- Past, present and future mobile networks are introduced
- ITU-R and 3GPP standardize 5G specifications
- 3GPP standards maintain backwards compatibility from release to release, even as the network architecture evolves
  - Each new core network generation evolves from the previous ones and at the same time introduces new features