5G: An Advanced Introduction

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Legal Disclaimer

This presentation is intended to stimulate discussion on some of the exciting current and future developments in digital communications technology and networks. It also contains some forward looking statements, research and speculation that may never become part of standards.

It strives to provide the latest and most correct information. Due to the vastness of standards, constant change and revision, it is possible that the following information may not be entirely up to date or correct. E&OE.

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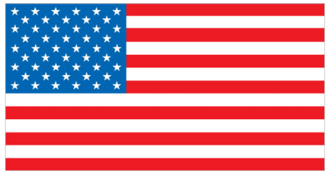
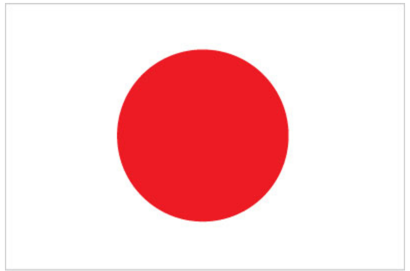
It would not be prudent to make any financial or investment decisions based on this presentation.

Agenda: Session 1

- Mobile Technology Generations
- Why is 5G called 5G?
- ITU and IMT-2020
- 5G Standards
- Spectrum for 5G
- State of market, trials, etc.
- 5G Motivation and Use cases

Different 2G Systems





D-AMPS – Digital AMPS

- 1993 – 2009
- IS-54 & IS-136
- TDMA based technology

cdmaOne

- 1995 – 2001
- Championed by Qualcomm
- IS-95
- CDMA based technology
- Supplanted by CDMA2000 (3G) technology

GSM – Global System for Mobile communications

- Originally ‘Groupe Spécial Mobile’
- 1991 - present
- First deployed in Finland, Dec. 1991
- Launched in UK, 1993
- Most popular 2G system in use worldwide
- Uses mainly 900MHz or 1800MHz
- Originally designed for voice only
- SMS was commercially launched in 1995
- Data was supported using High-Speed, Circuit-Switched Data (HSCSD) giving max data rates of 57.6Kbps

PDC – Personal Digital Cellular

- 1993 – 2012

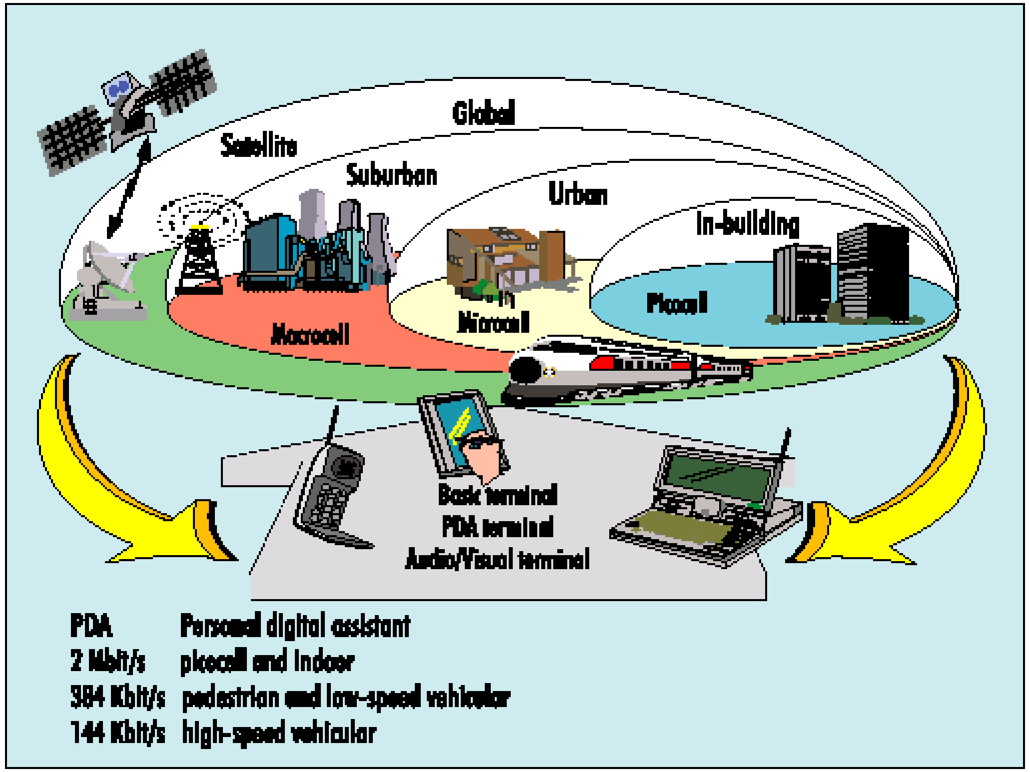
GSM – Most popular 2G system

GSM®
GLOBAL SYSTEM FOR
MOBILE COMMUNICATIONS

GSM™

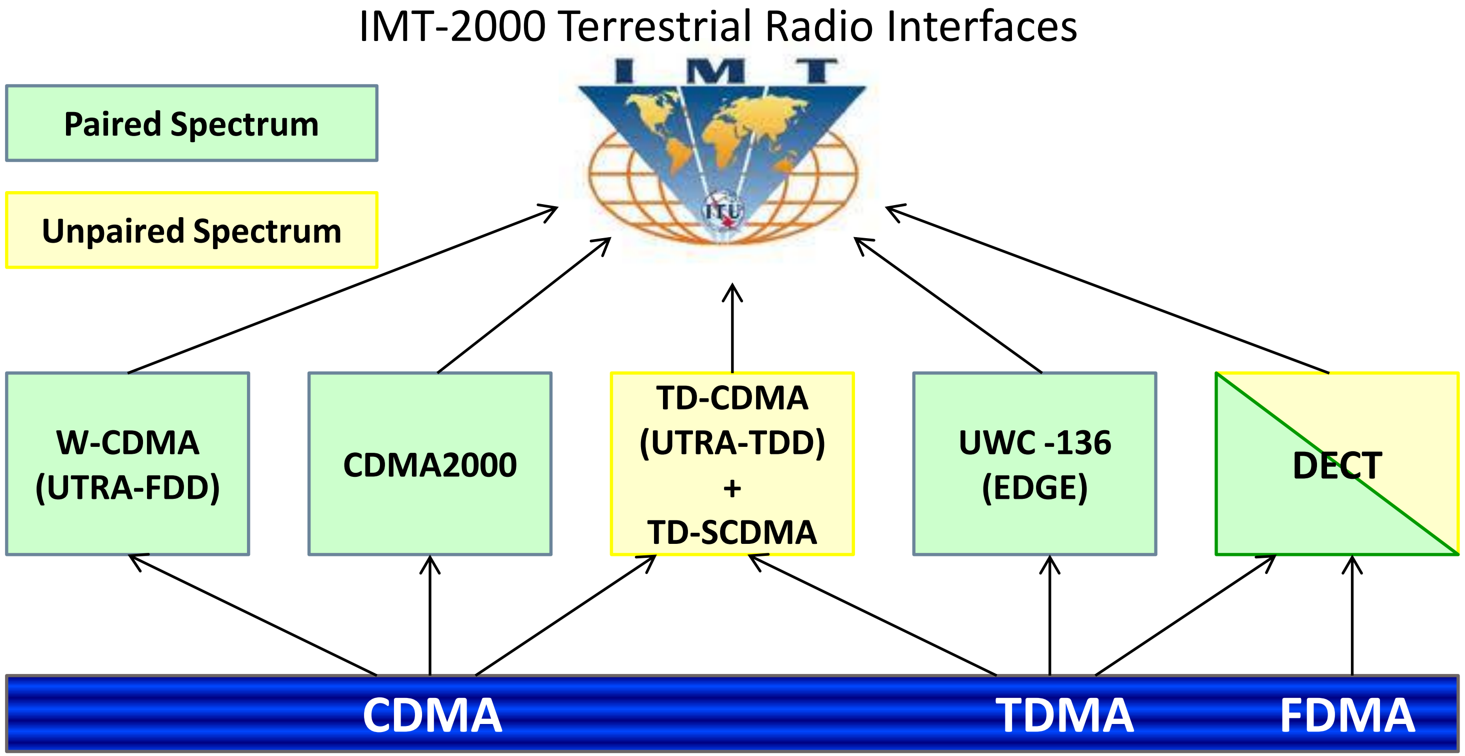
International Mobile Telecommunications-2000 (IMT-2000)

Figure 4 — IMT-2000, a flexible, multi-functional network



Source: European Commission.

IMT-2000 Technologies



Third Generation (3 'G') Mobile System

3rd Generation Partnership Project 2 "3GPP2"

3GPP A GLOBAL INITIATIVE

MA V-DO

- ta Optimized
- Fu lved to
  ev. A
  EV- B

Universal Mobile Telecommunications System (UMTS)

- Based on Wideband CDMA (WCDMA)
- Uses FDD
- Foundation of 3G systems worldwide, except some networks

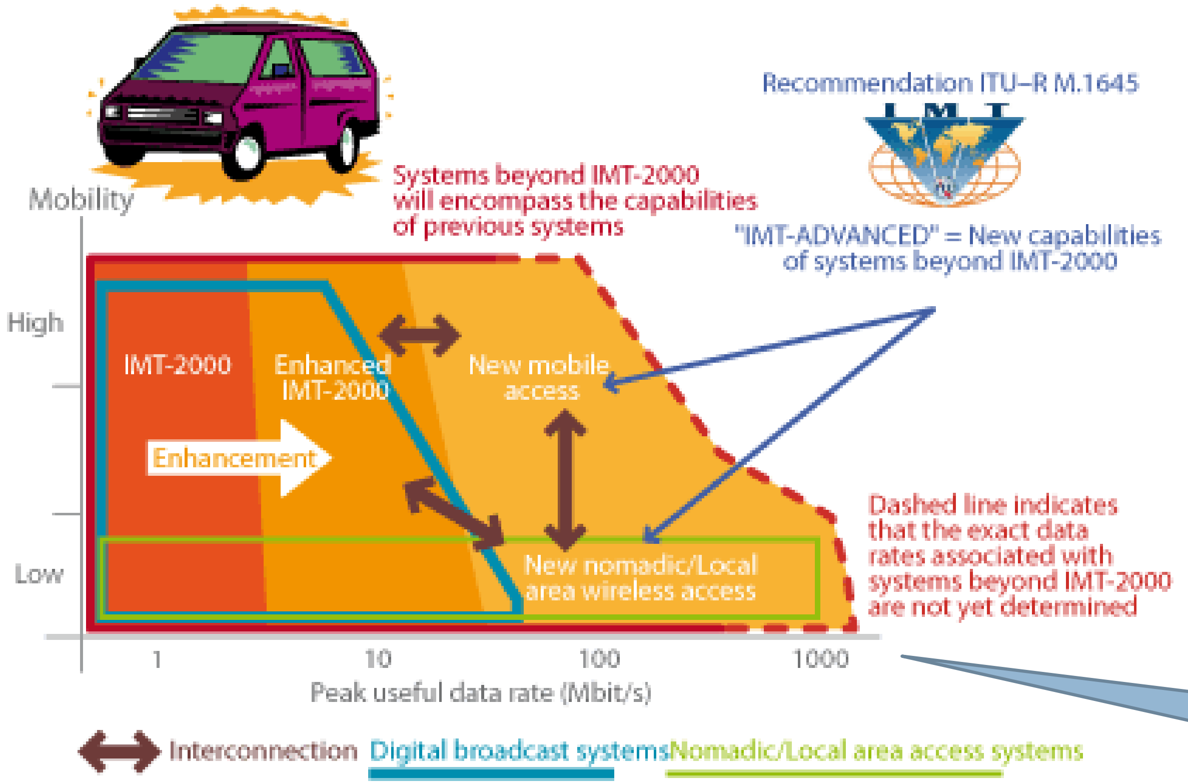
Time Divisi ynchron ode division iple s (TD-S

- Designed esp for China
- Used by o ope 'China e'
- Based on Narrowband TDD

3 ‘G’ Evolution

- Rel-99: DL = 384Kbps, UL = 384Kbps
- Rel-5: HSDPA (3.5G) – DL = 14Mbps, UL = 384Kbps
- Rel-6: HSUPA (3.6G) – DL = 14Mbps, UL = 5.75Mbps
- Rel-7: HSPA+ (3.7G) – DL = 28Mbps, UL = 11.52Mbps
- Rel-8: HSPA+ (3.75G) – DL = 42Mbps, UL = 11.52Mbps
- Rel-9: HSPA+ (3.8G) – DL = 84Mbps, UL = 23Mbps
- Rel-10: HSPA+ (3.8G) – DL = 168Mbps, UL = 23Mbps
- Rel-11: HSPA+ (3.85G) – DL = 672Mbps, UL = 70Mbps

Fourth Generation (4 'G') Mobile System



Notice the peak data rate

- 3G / UMTS → IMT-2000
- HSPA/HSPA+ → Enhanced IMT-2000
- 4G / LTE → IMT-Advanced

4G Claims

TechRepublic. SEARCH

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MOBILITY

How AT&T and T-Mobile conjured 4G networks out of thin air

One of the biggest surprises of CES 2011 was AT&T and T-Mobile magically pulling 4G networks out their hats. The real story isn't quite as magical.

By Jason Hiner | in Tech Sanity Check, January 12, 2011, 11:51 AM PST

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The biggest surprise at this year's Consumer Electronics Show was how AT&T and T-Mobile showed off their 4G networks. If that sounds confusing to you because you didn't know that either them were in the 4G game, then you had the same reaction I did. Unlike Sprint/Clearwire (with WiMAX) and Verizon (with LTE), neither AT&T nor T-Mobile has been building out 4G networks in the US. So how did they make 4G networks appear out of thin air? Well, the short answer is that they didn't.

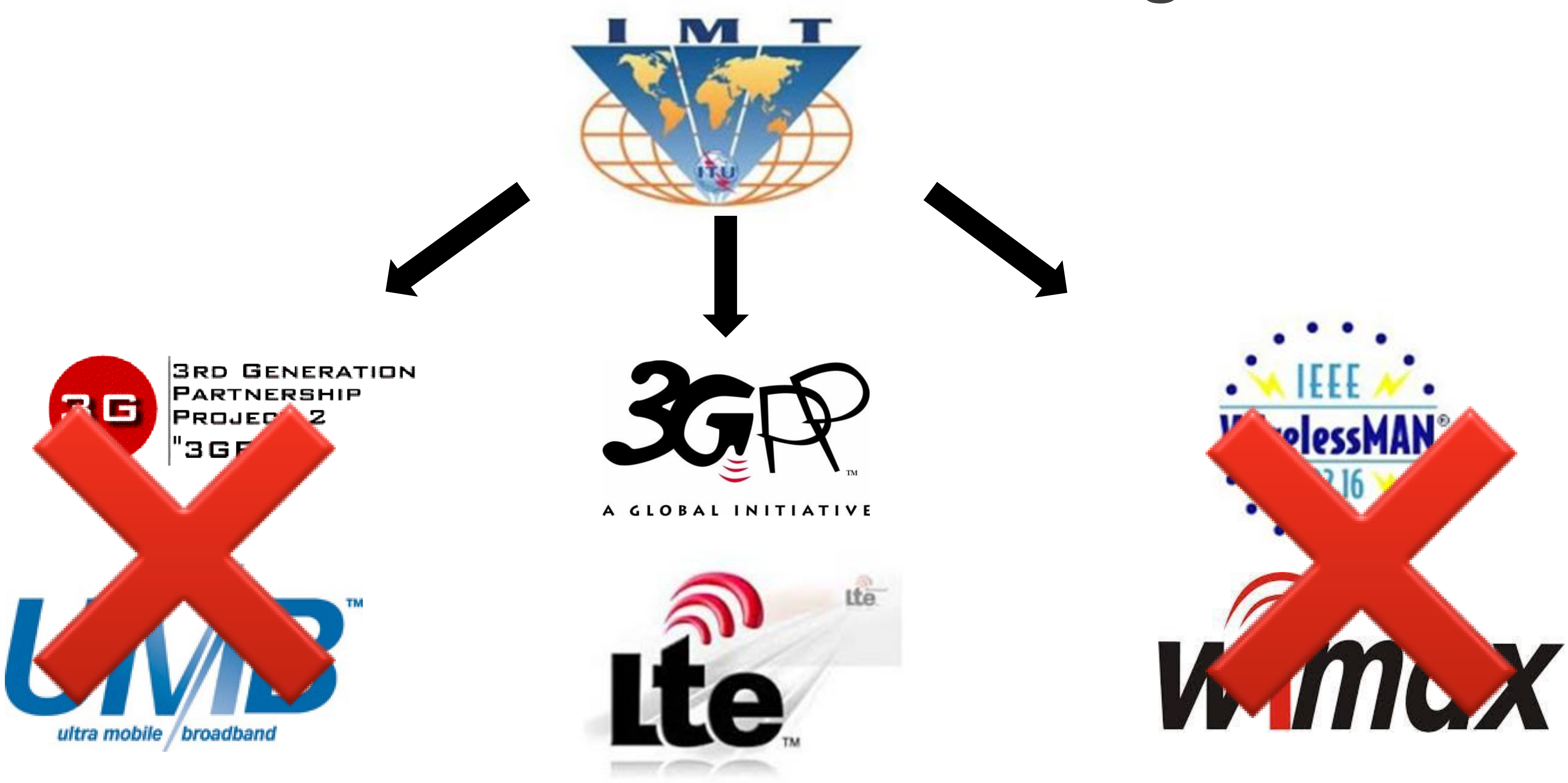
What AT&T and T-Mobile did was to re-brand their enhanced 3G networks (sometimes called 3.5G) by simply renaming them "4G" networks. Voila! In other words, this is mostly a marketing ploy.

However, to be fair, both T-Mobile and AT&T have been making legitimate upgrades to their 3G networks that actually approach 4G speeds — at least the same kinds of 4G speeds that Sprint/Clearwire sees on its WiMAX network. Verizon's LTE has even

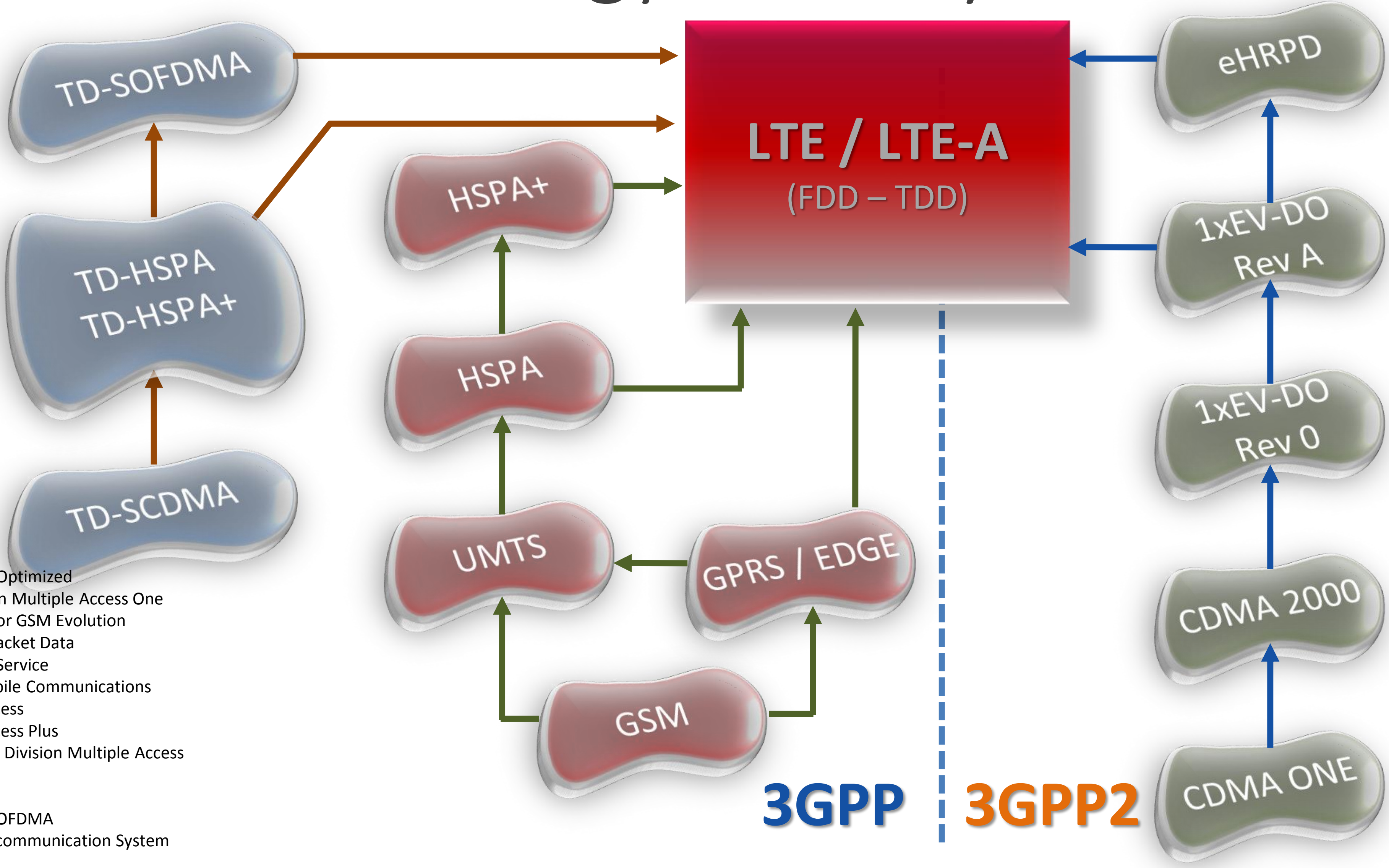
EDITOR'S PICKS

Source: TechRepublic

IMT-Advanced and 4G Technologies



LTE: One Technology to Unify Them All



1xEV-DO: Enhanced Voice-Data Optimized
CDMA ONE: Code Division Multiple Access One
EDGE: Enhanced Data rates for GSM Evolution
eHRPD: Enhanced High Rate Packet Data
GPRS: General Packet Radio Service
GSM: Global System for Mobile Communications
HSPA: High Speed Packet Access
HSPA+: High Speed Packet Access Plus
OFDMA: Orthogonal Frequency Division Multiple Access
SCDMA: Synchronous CDMA
TD: Time Division
TD-SOFDMA TD Scalable OFDMA
UMTS: Universal Mobile Telecommunication System

4G Evolution

3.9G? 4G?

4G? 4G+? Advanced 4G? 4.5G?

4.5G? 4.9G? 5G?

5G Confusion?

Data Centre ▸ Networks

Turkey president: Nuts to 4G networks, we're cutting straight to 5G

It's not just the Chinese who think 4 is a bad number

By Simon Rockman 15 May 2015 at 17:45 14 SHARE ▼

Leap of faith: Recep Tayyip Erdogan thinks Turkey should jump straight to 5G

Turkey's president Recep Tayyip Erdogan has said that as Turkey doesn't have 4G yet, the country might as well wait a couple of years and go straight to 5G.

This is a pretty bold move given that we don't even know what 5G is yet – although there are expected to be some announcements from the ITU in June.

Most read

Parity's $280m Ethereum wallet freeze was no

Source: The Register

HOME > RESEARCH SERVICES > COMMSUPDATE

Turk Telekom to introduce '5G-like' technology via KT Corp deal

25 Feb 2016

Turkey

Turk Telekom (TT) has said it will establish '5G-like' internet speeds in April after signing a deal with South Korean full-service telco KT Corp, reports local site Hurriyet Daily News. The agreement was inked on 22 February at the World Mobile Congress, Barcelona, and will see TT combine '4.5G' services – already offered by KT Corp in South Korea – with its Wi-Fi connection to enable the provision of data speeds of up to 1Gbps. TT Group CEO Rami Aslan was cited as saying: 'We are ready to offer the highest 4.5G capacity to Turkey with our 1800MHz frequencies and wider fibre infrastructure very soon … We will bring 5G internet to Turkey by April 1 in line with our cooperation deal with KT Corp. Our customers will enjoy one of the speediest mobile internet experiences of the world.'

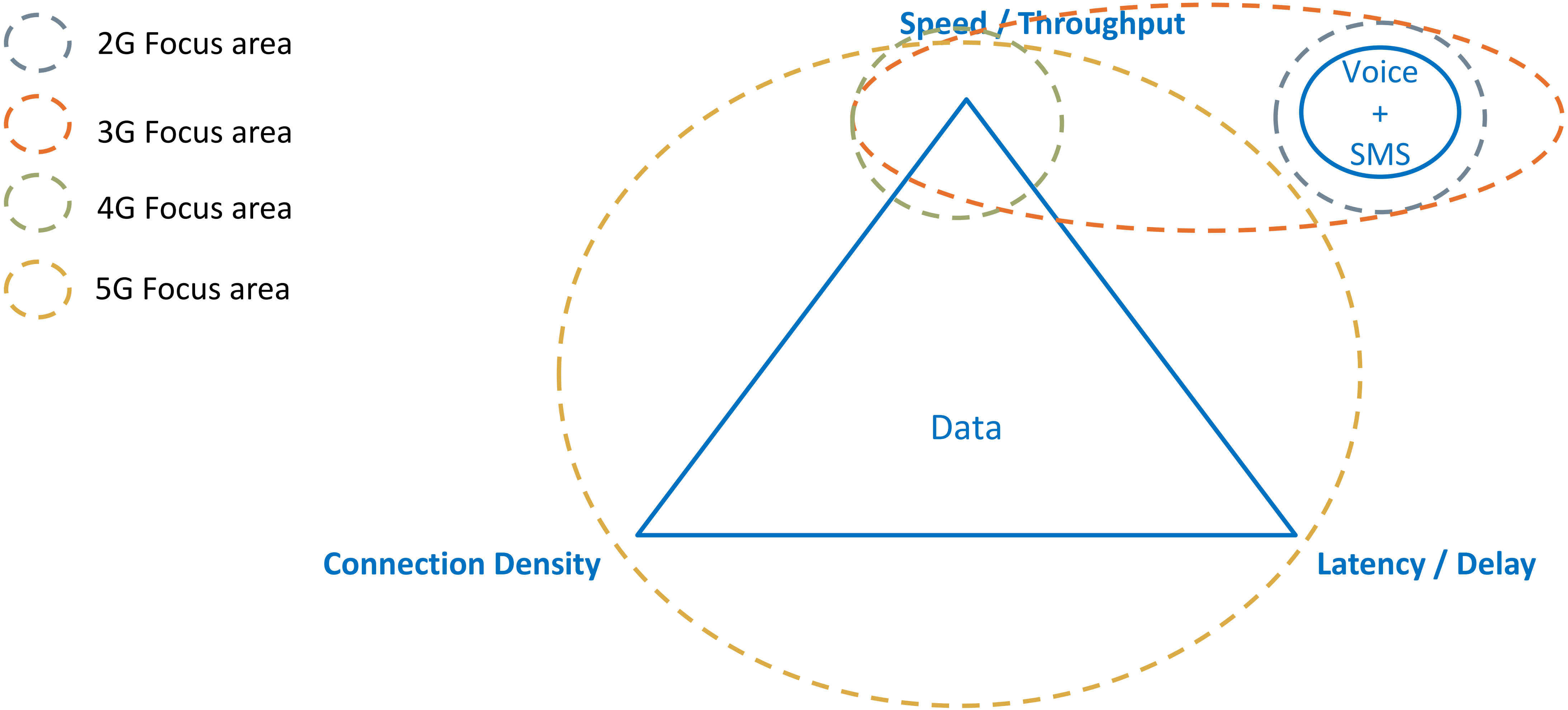
As previously reported by TeleGeography's CommsUpdate, Turkey's three incumbent mobile network operators (MNOs), Avea (mobile unit of TT), British-owned Vodafone and Turkish-owned Turkcell, each won 4G spectrum in the 26 August 2015 tender held by the Information and Communication Technologies Authority (BTK), with commercial launch of 4.5G technology mooted for 1 April 2016. Meanwhile, also in August 2015, TT became the sole owner of its Avea subsidiary, following the successful transfer of a 10.0035% stake from its partner Is Bankasi (IS Bank). January 2016 saw TT announce the merging of its respective mobile and ISP (TTNet) units under the unified Turk Telekom brand name, logo and website. Avea and TTNet remain distinct legal entities as wholly owned subsidiaries of TT.

Turkey, Turk Telekom, KT Corp, Wireless, 5G, LTE

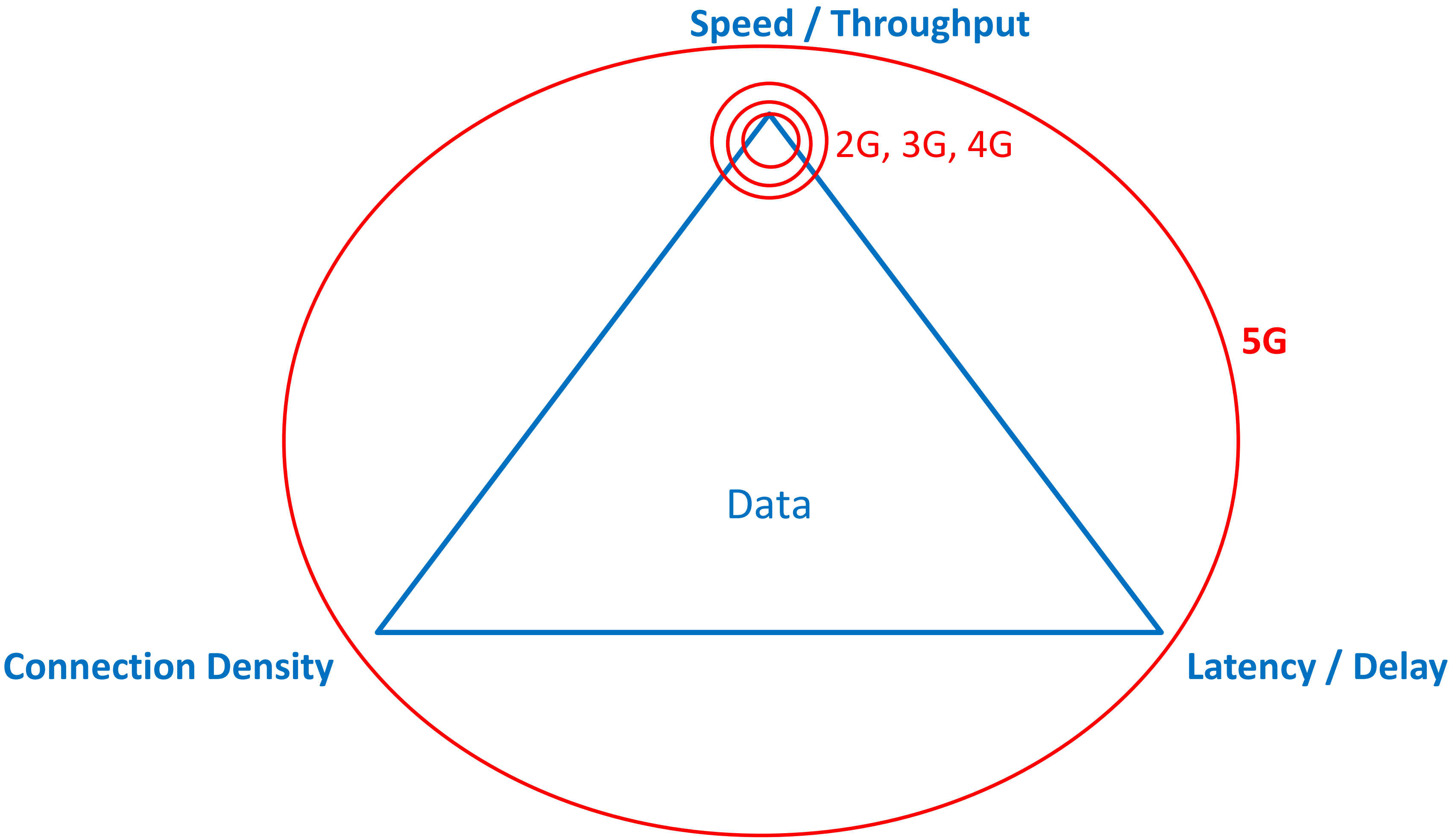
Source: TeleGeography

5G → IMT-2020

Focus area for different technology generations



Focus area for different technology generations

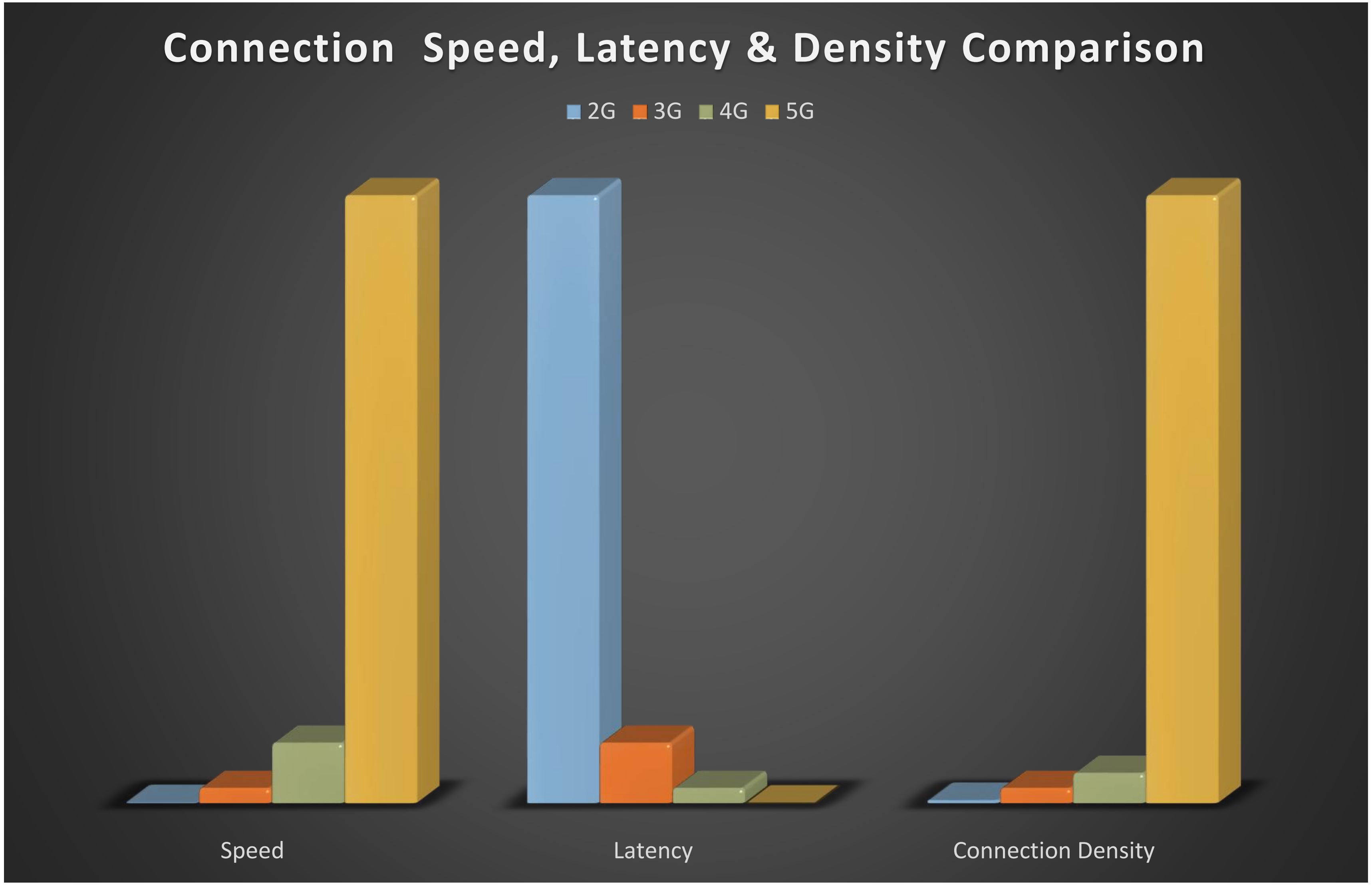


Mobile Technology Evolution

1G	2G	3G	4G	5G
Analog	Digital	Mobile Data	Mobile Broadband	eMBB, mMTC, URLLC
Voice only, Limited coverage and mobility. Example: AMPS	Improved voice, security, coverage. SMS, data. Example GSM, CDMA	Higher data rates, smartphones, better voice. Example: HSPA / HSPA+	High speed data, better smartphones. Example: LTE / LTE-A	Even higher speeds, ultra-reliable, low latency, high connection density

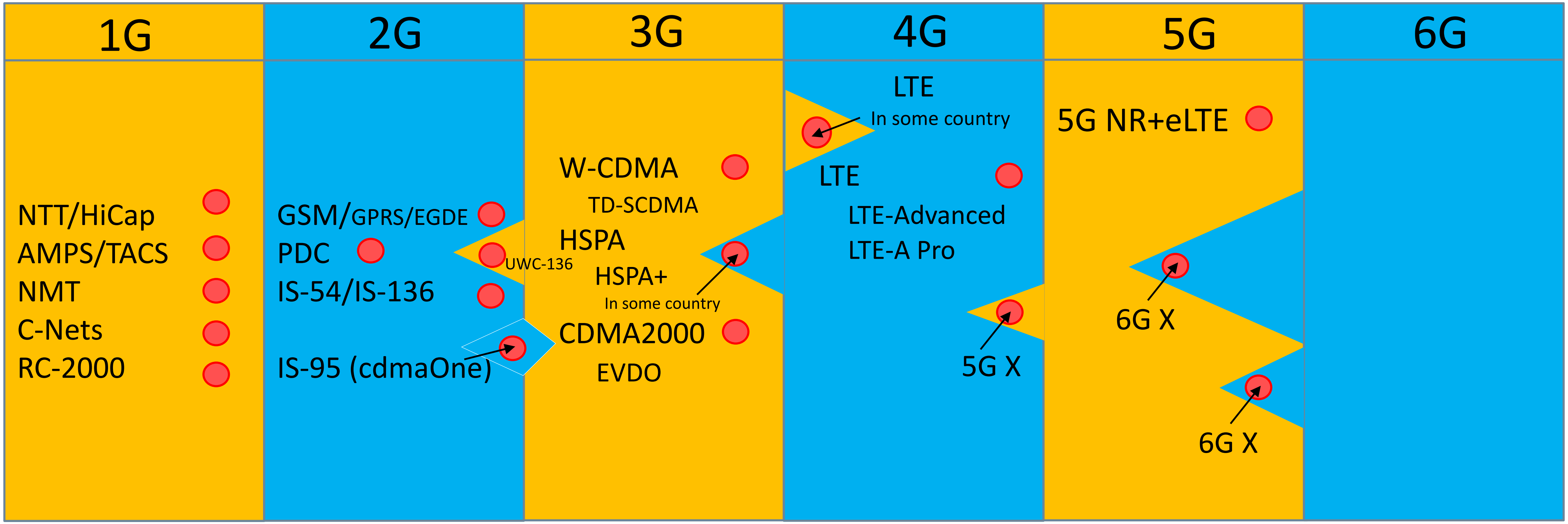
1980 1990 2000 2010 2020

Comparison of 2G, 3G, 4G & 5G technologies



Example only.
Not according to scale

Mobile Generation By Standards



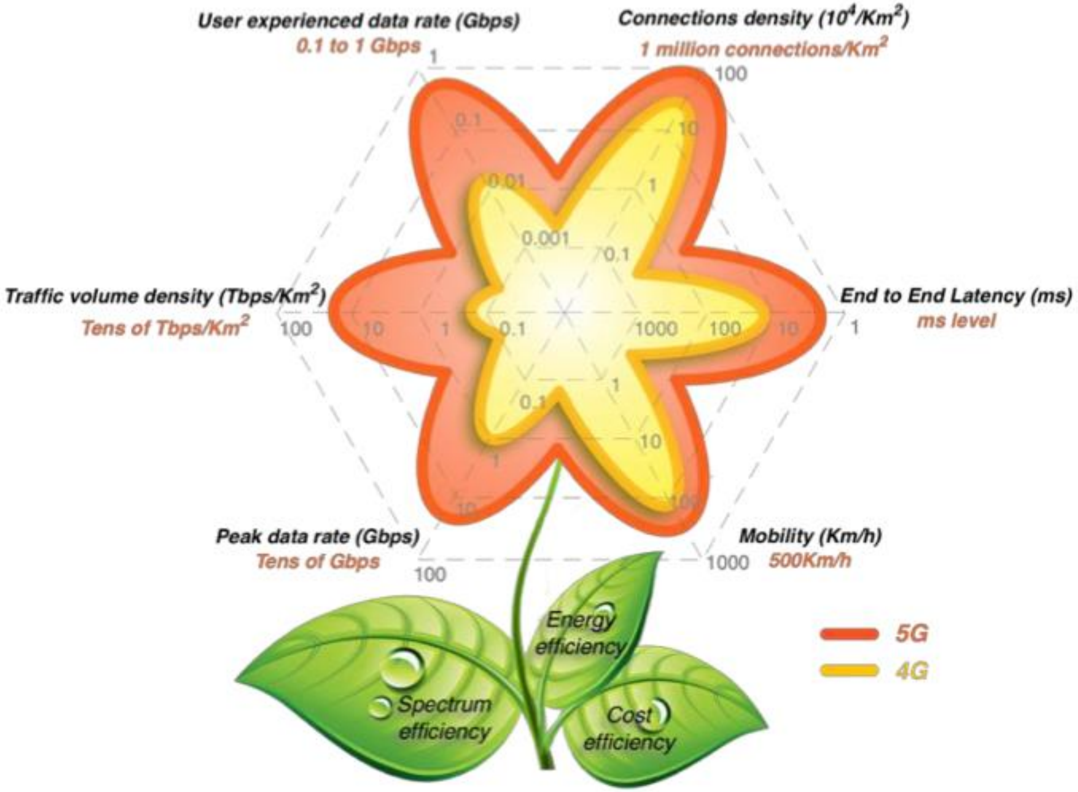
There is constant battle between standards, technology and marketing with regards to naming for different generations. Marketing generally wins!

Based on Slides by Seizo Onoe, Chief Technology Architect at NTT DOCOMO, Inc.

4G vs 5G

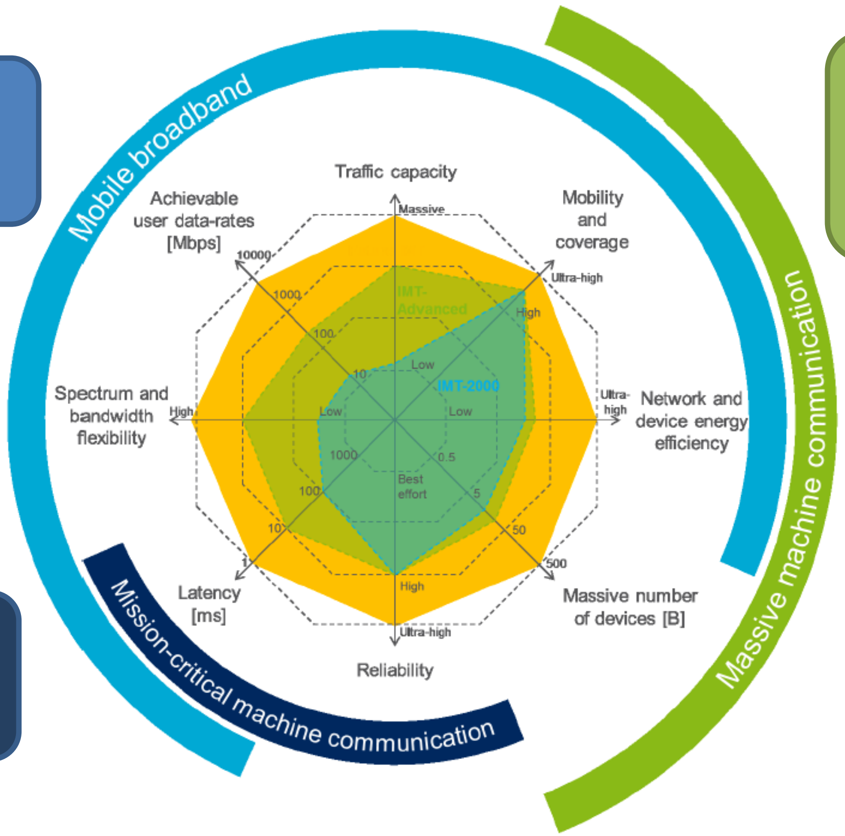
Performance Requirements

Efficiency Requirements



5G Requirements

Optimize for data rate



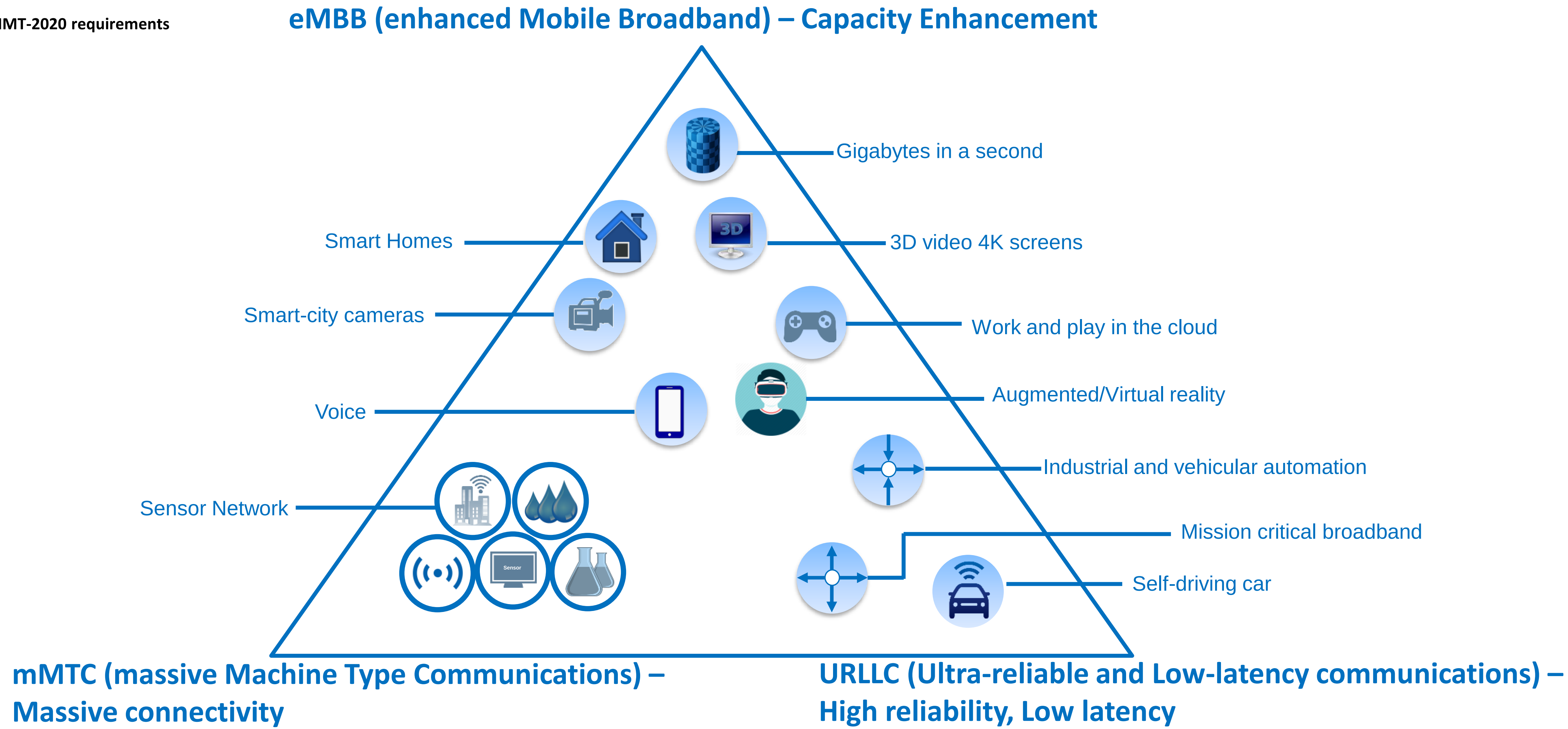
Optimize for connection numbers

Optimize for delay

Image Source: 5G-From Research to Standardisation - Bernard Barani European Commission, Globecom2014

5G (IMT-2020) Requirements

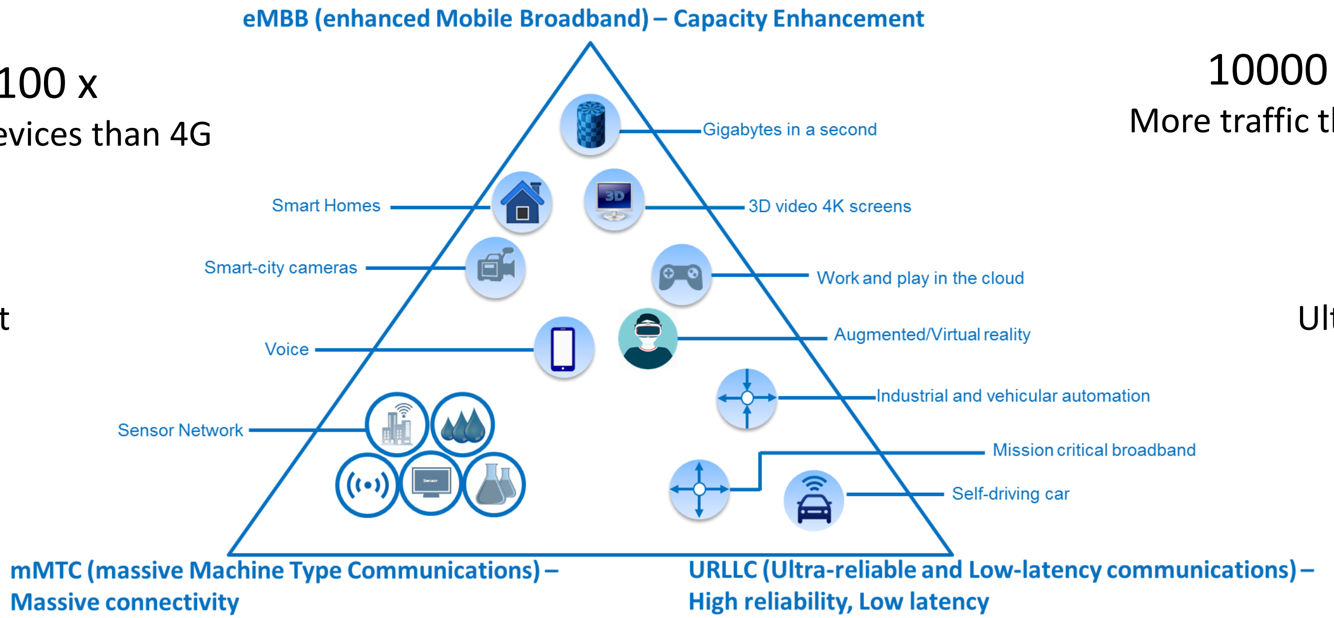
ITU-R IMT-2020 requirements



5G High Level Requirements and Wish List

>10 Gbps
Peak data rates

100 Mbps
Whenever needed



100 x
More devices than 4G

10000 x
More traffic than 4G

M2M
Ultra low cost

UR
Ultra-Reliable

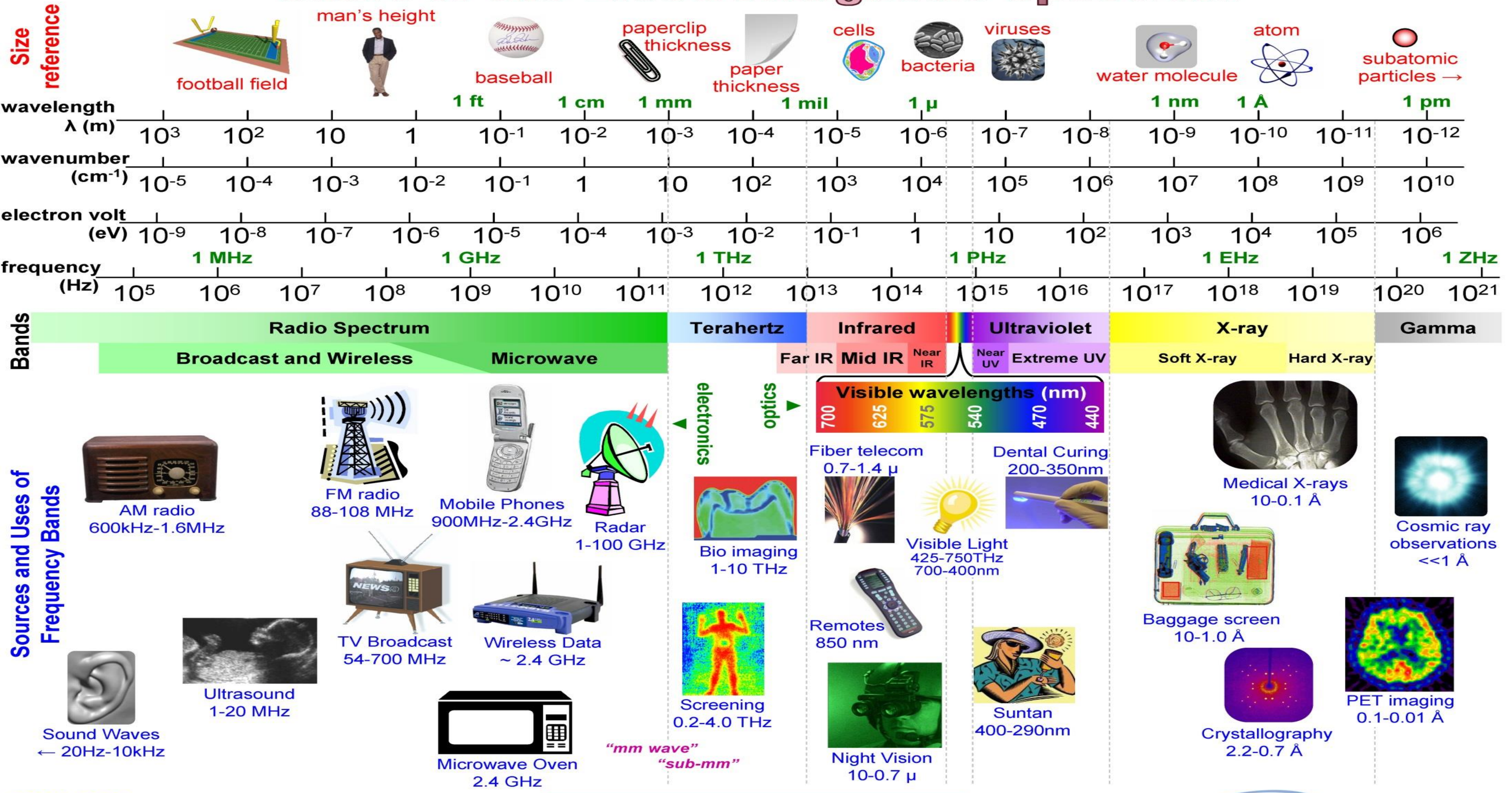
10 years
battery life

< 1 ms
Low latency on radio interface

Evolution of Speeds: Fixed, Wi-Fi & Mobile

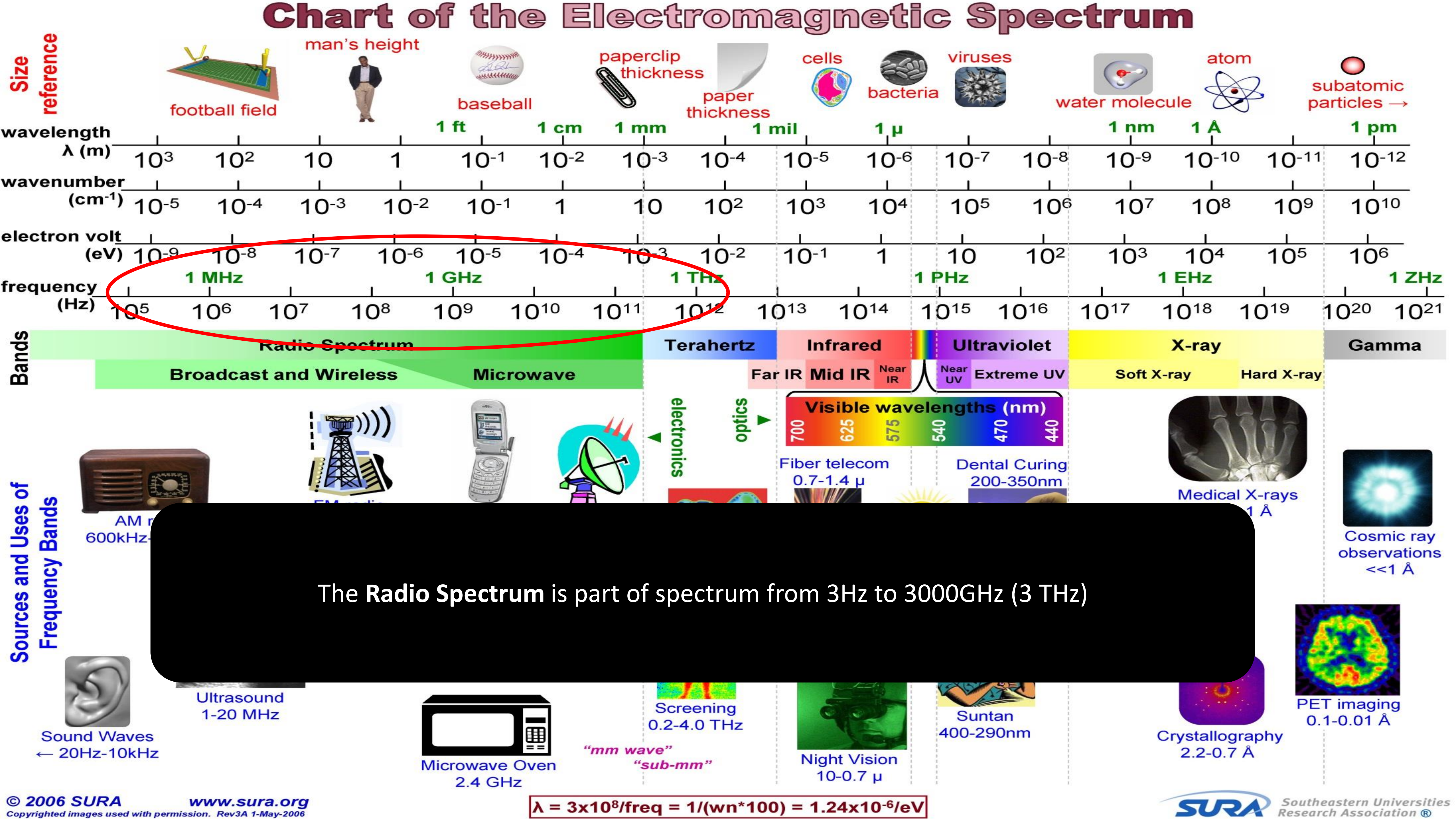
IEEE Standard	Year Adopted	Frequency	Max. Data Rate	Max. Range
802.11a	1999	5 GHz	54 Mbps	400 ft.
802.11b	1999	2.4 GHz	11 Mbps	450 ft.
802.11g	2003	2.4 GHz	54 Mbps	450 ft.
802.11n	2009	2.4/5 GHz	600 Mbps	825 ft.
802.11ac	2014	5 GHz	1 Gbps	1,000 ft.
802.11ac Wave 2	2015	5 GHz	3.47 Gbps	10 m.
802.11ad	2016	60 GHz	7 Gbps	30 ft.
802.11af	2014	2.4/5 GHz	26.7 Mbps – 568.9 Mbps (depending on channel)	1,000 m.
802.11ah	2016	2.4/5 GHz	347 Mbps	1,000 m.
802.11ax	2019 (expected)	2.4/5 GHz	10 Gbps	1,000 ft.
802.11ay	late 2019 (expected)	60 GHz	100 Gbps	300-500 m.
802.11az	2021 (expected)	60 GHz	Device tracking refresh rate 0.1-0.5 Hz	Accuracy <1m to <0.1m

Chart of the Electromagnetic Spectrum



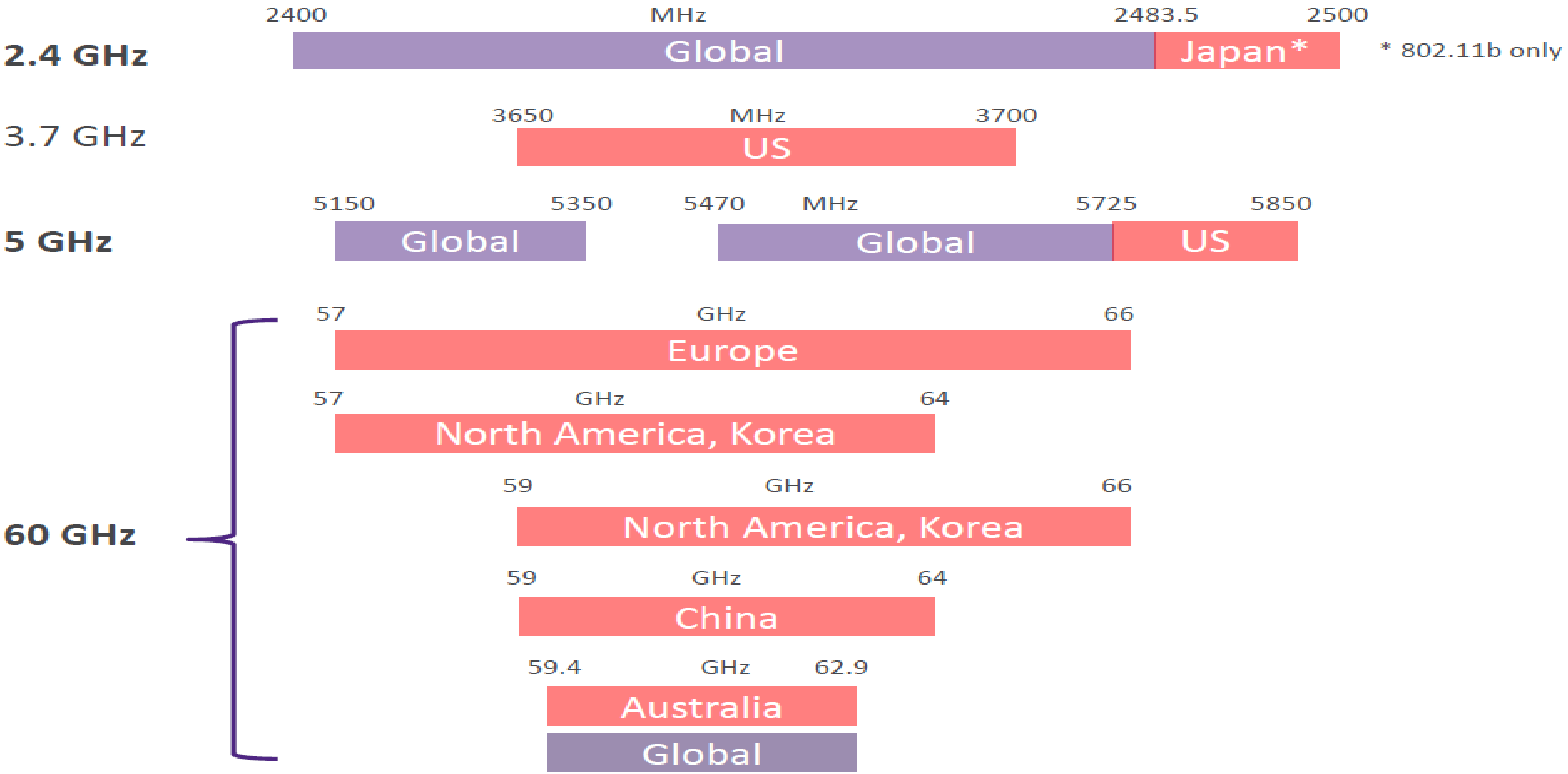
$$\lambda = 3x10^8/freq = 1/(wn*100) = 1.24x10^{-6}/eV$$

SURA Southeastern Universities Research Association ®



The **Radio Spectrum** is part of spectrum from 3Hz to 3000GHz (3 THz)

Wi-Fi Spectrum around the world



Bandwidth in mobile networks

The simplest way to understand bandwidth is to think of them as pipes. The fatter the pipe, the more the bandwidth

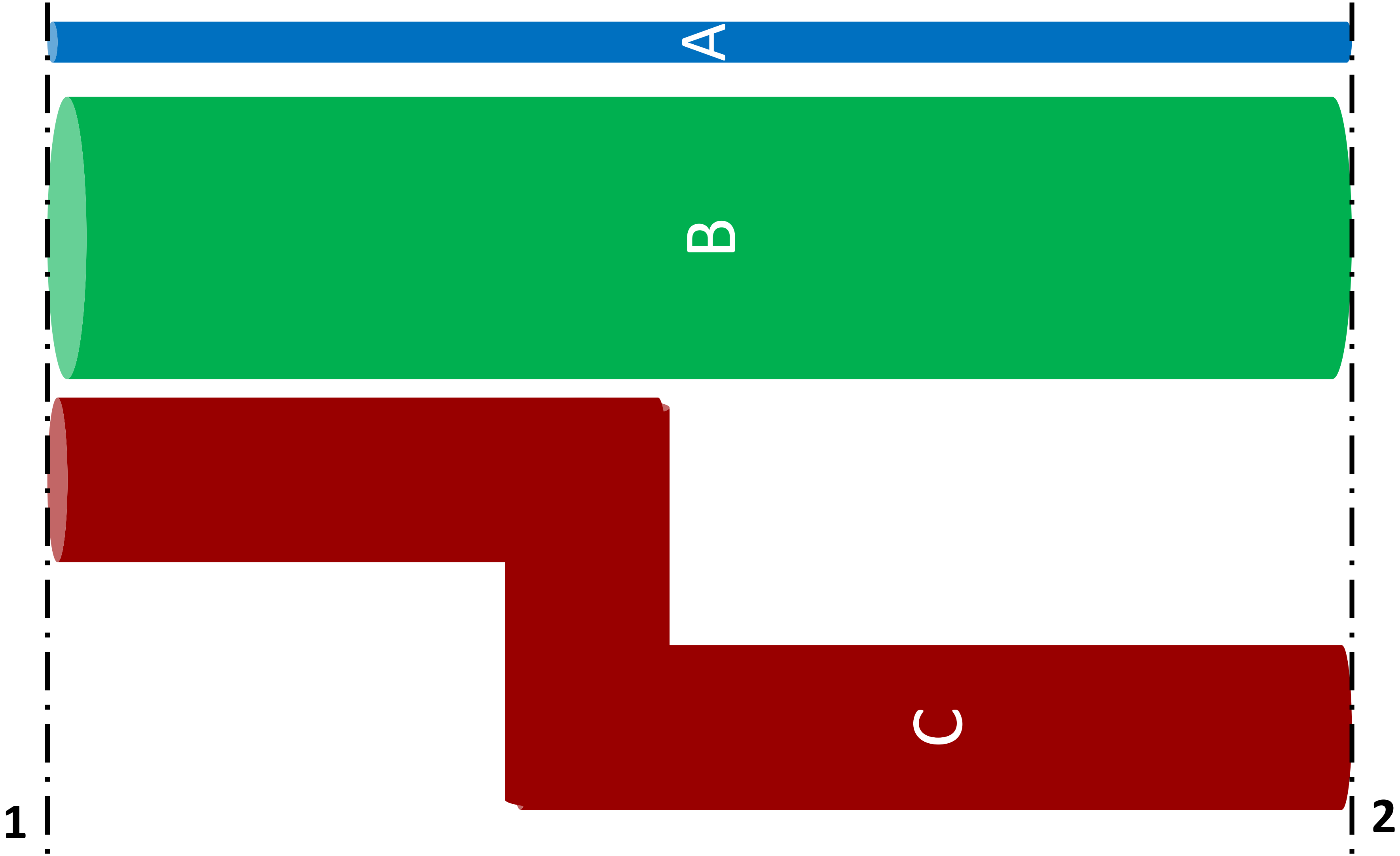
Latency & Jitter

Latency is generally defined as the time it takes for a source to send a packet of data to a receiver. In simple terms, half of Ping time. This is also referred to as **one way latency**.

Sometimes the term **Round trip latency** or round trip time (RTT) is also used to define latency. This is the same as ping time.

Jitter is defined as the variation in the delay (or latency) of received packets. It is also referred to as 'delay jitter'.

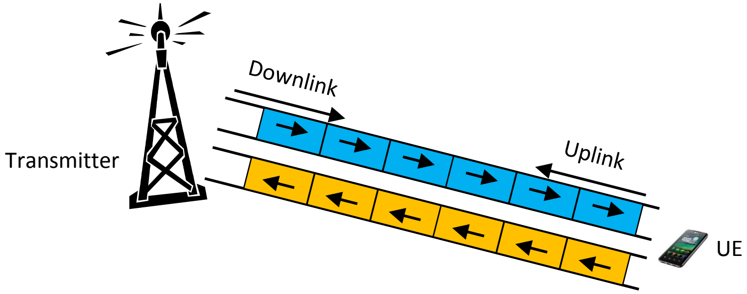
Explaining Latency vs Bandwidth

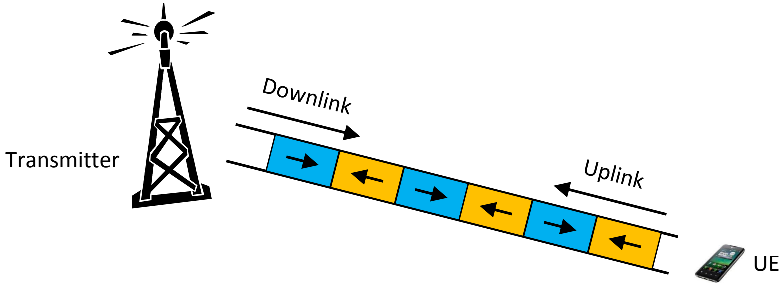


Bandwidth is often referred to as a measure of capacity.

While **Latency** is a measure of delay.

TDD v/s FDD





<u>Frequency Division Duplex (FDD)</u>	**<u>Time Division Duplex (TDD)</u>**
Simpler to implement	Implementation is complex
Simultaneous downlink and uplink transmission	Only uplink (UL) or downlink (DL) at any time
No need for synchronisation hence simpler implementation	Need for synchronisation within the whole network
Needs paired spectrum	No need for paired spectrum
UL/DL ratio is fixed.	Number of UL/DL ratio is changeable

UK: Frequency Allocation for mobile – July 2017

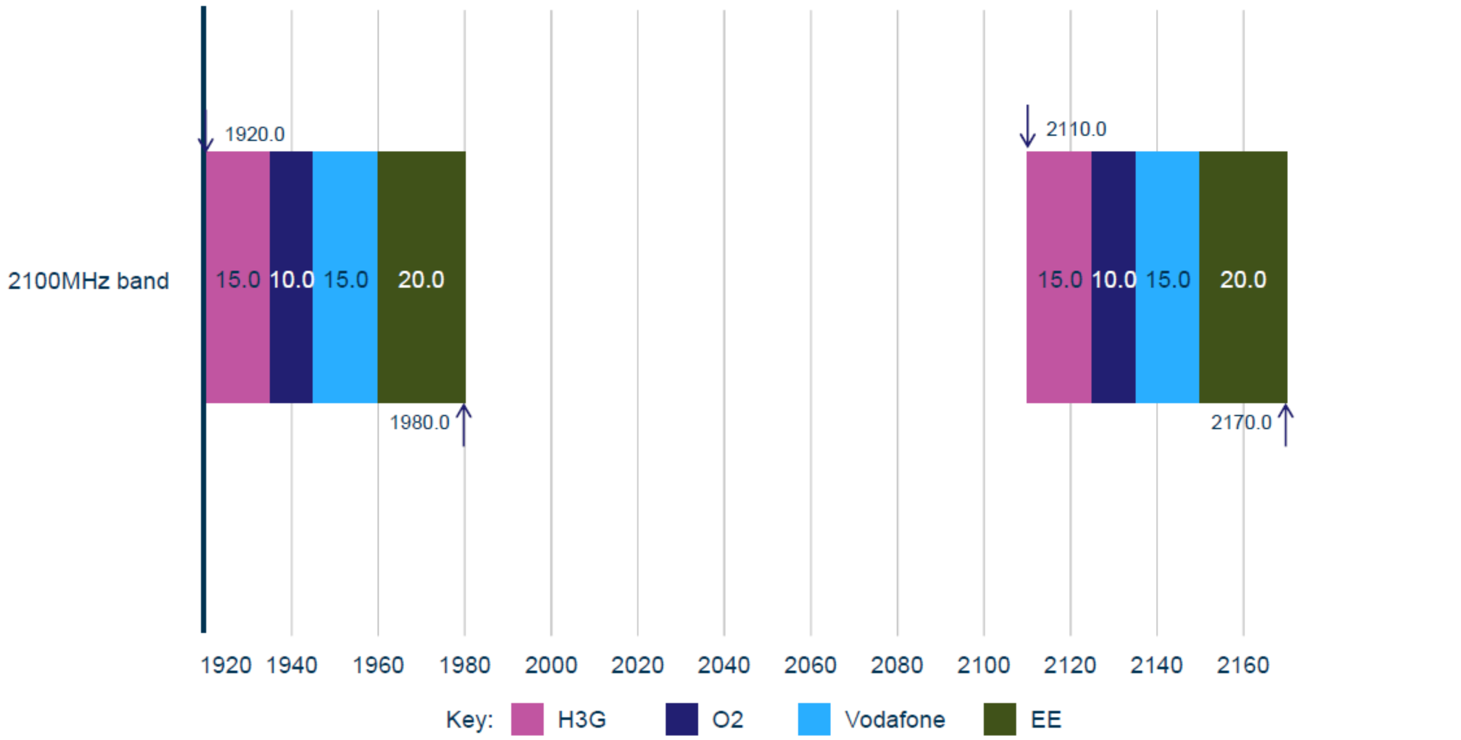
Figure 5.1: Current holdings of allocated mobile spectrum[26]

Spectrum Band	Type	BT/EE	Vodafone	O2	H3G	Total
800 MHz	FDD	10	20	20	10	60.0
900MHz	FDD	0	34.8	34.8	0	69.6
1452-1492 MHz	SDL	0	20	0	20	40.0
1800 MHz	FDD	90	11.6	11.6	30	143.2
2100 MHz	FDD	40	29.6	20	29.5	119.1
2.6 GHz (paired)	FDD	100	40	0	0	140.0
2.6 GHz (unpaired)	TDD	15	20	0	0	35.0
3.4 GHz	TDD	0	0	0	40	40.0
3.6-3.8 GHz	TDD	0	0	0	84	84.0
Total holdings		**255.0**	**176.0**	**86.4**	**213.5**	**730.9**
Share of spectrum		**35%**	**24%**	**12%**	**29%**	

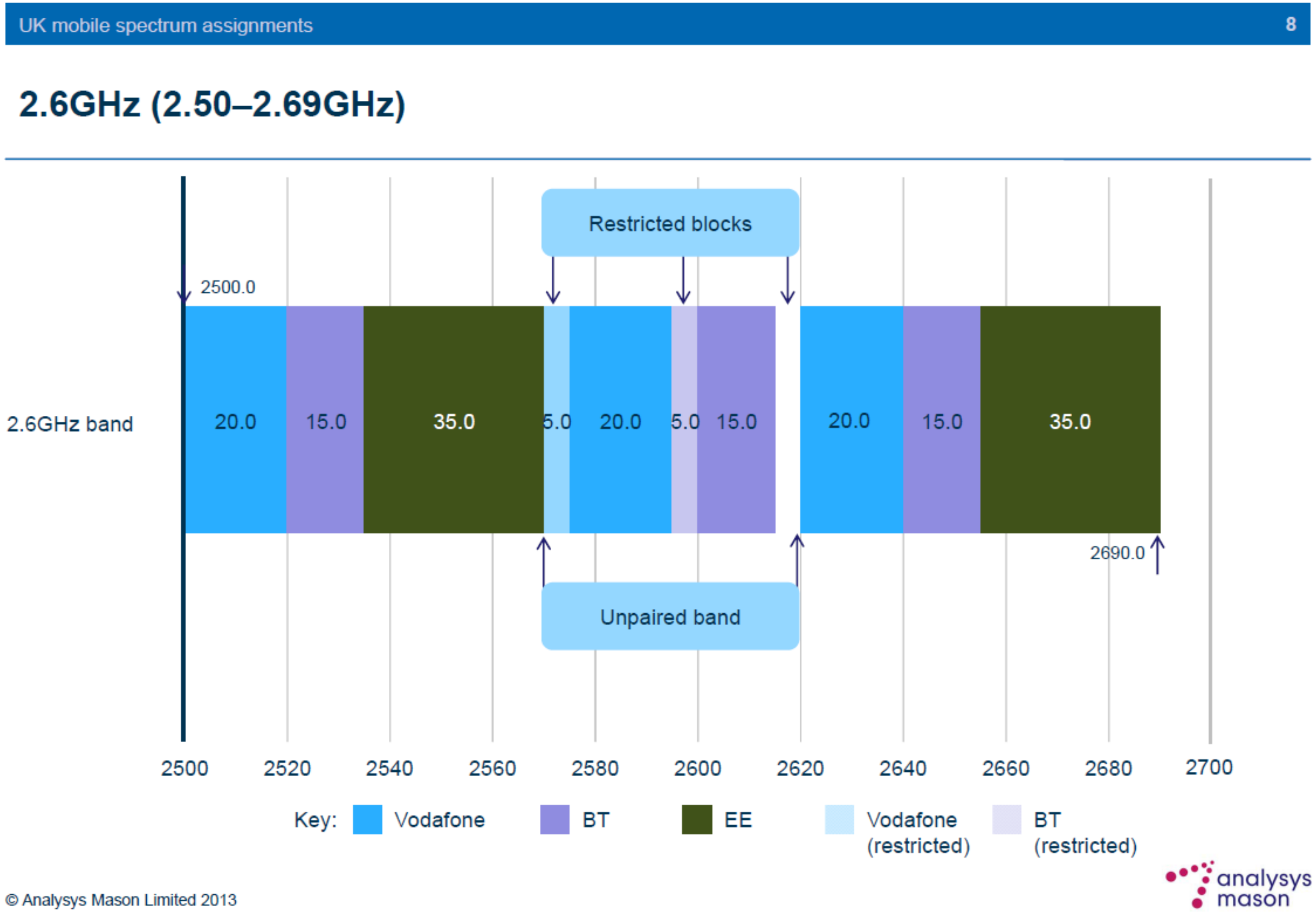
Source: Ofcom

UK: 2100MHz (2.1GHz)

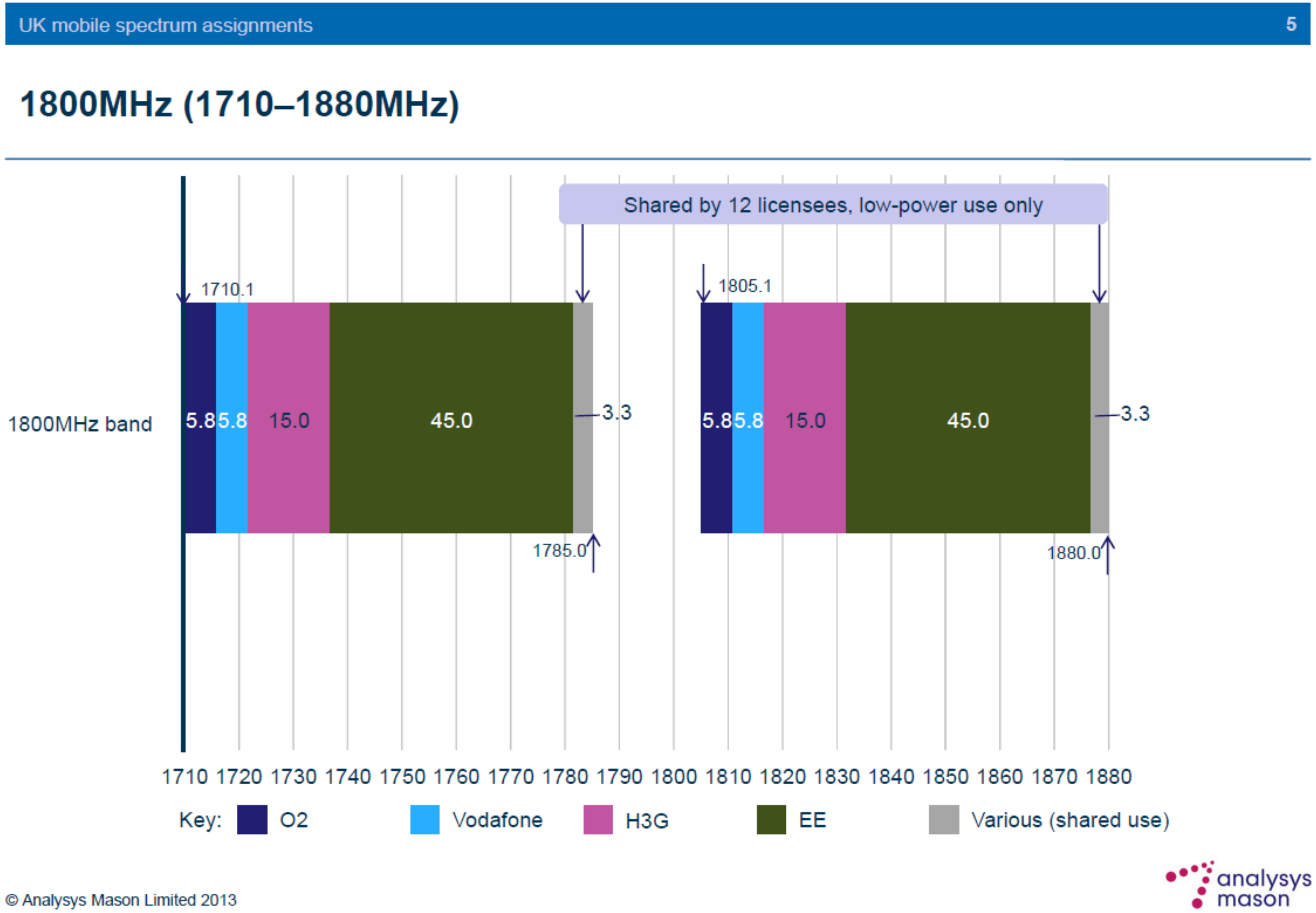
2100MHz (1920–2170MHz)



UK: 2600 MHz (2.6 GHz)



UK: 1800 MHz

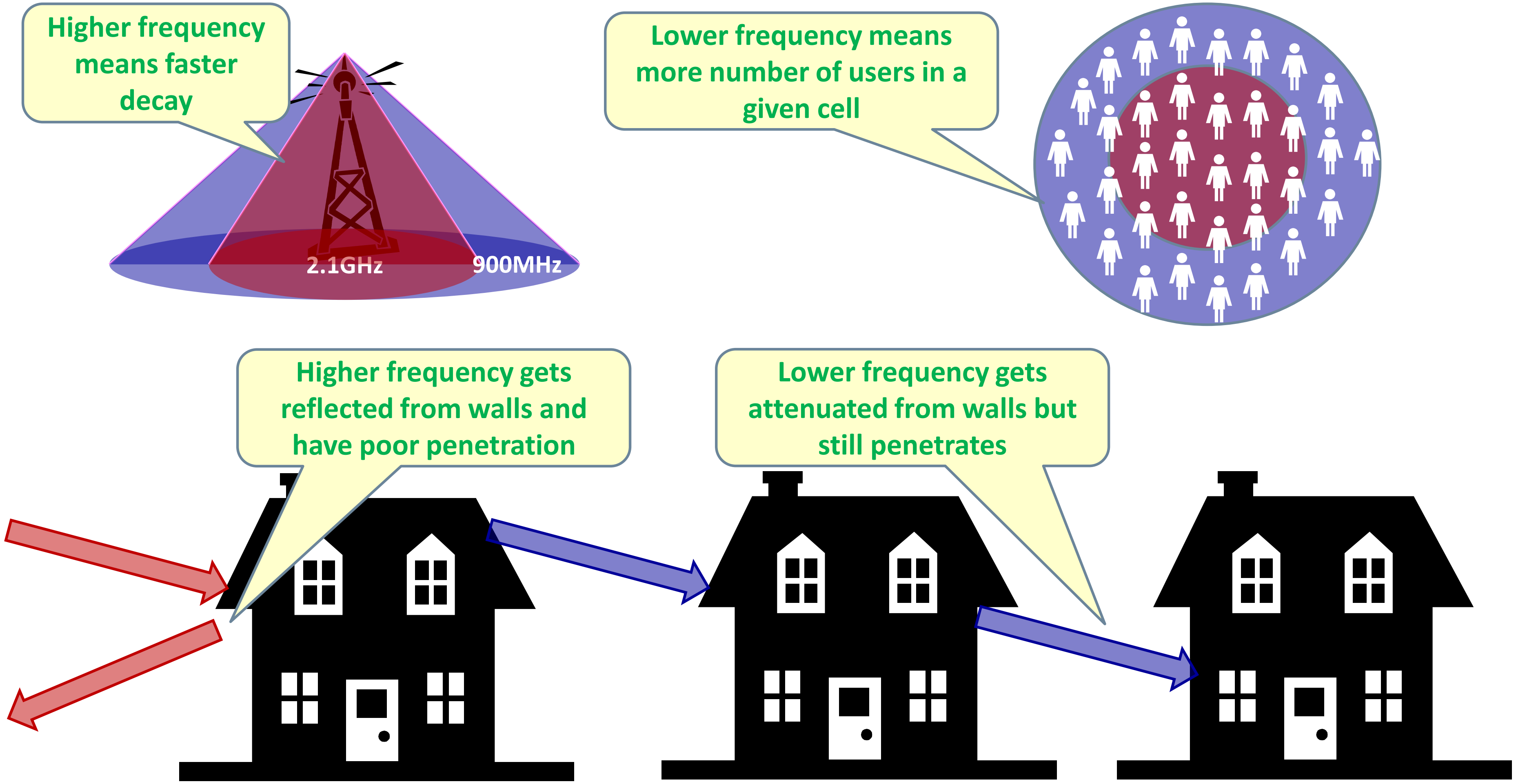

UK mobile spectrum assignments
5
1800MHz (1710–1880MHz)
Shared by 12 licensees, low-power use only
1710.1
1805.1
1800MHz band
5.8
5.8
15.0
45.0
3.3
5.8
5.8
15.0
45.0
3.3
1785.0
1880.0
1710 1720 1730 1740 1750 1760 1770 1780 1790 1800 1810 1820 1830 1840 1850 1860 1870 1880
Key: O2 Vodafone H3G EE Various (shared use)
© Analysys Mason Limited 2013
analysys mason

UK: 2.3 and 3.4 GHz spectrum auction Results

Winning bidders to whom licence granted	Frequencies	Total base price[1]	Additional prices[2]	Licence fees paid[3]
EE Limited	3540 – 3580 MHz	£302,592,000	£1,002,000	£303,594,000
Hutchison 3G UK Limited	3460 – 3480 MHz	£151,296,000	£13,133,000	£164,429,000
Telefónica UK Limited	2350 – 2390 MHz	£205,896,000	N/A	£205,896,000
	3500 – 3540 MHz	£317,720,000	0	£317,720,000
Vodafone Limited	3410 – 3460 MHz	£378,240,000	0	£378,240,000

Source: Ofcom

Importance of Frequency selection



5G Spectrum

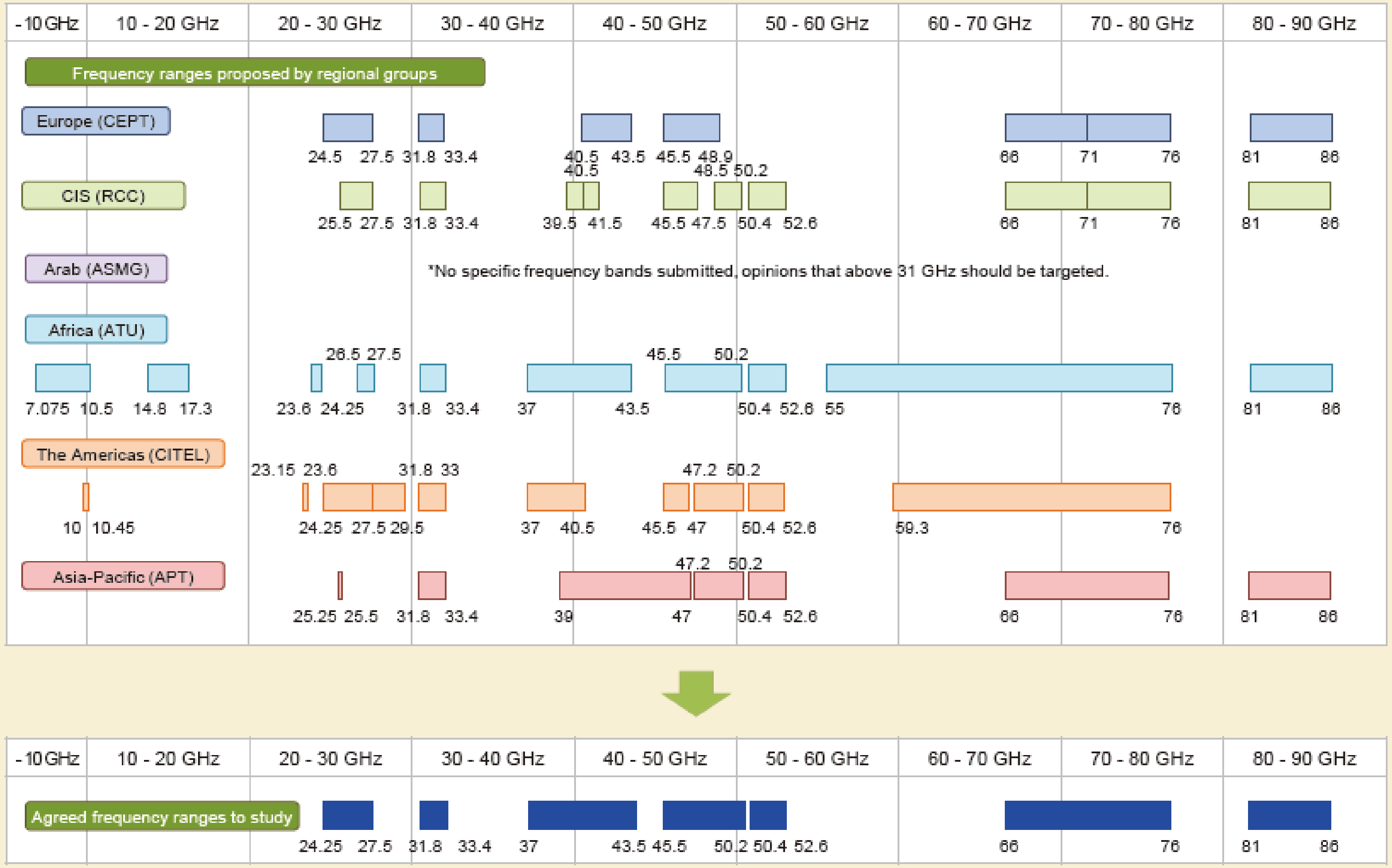
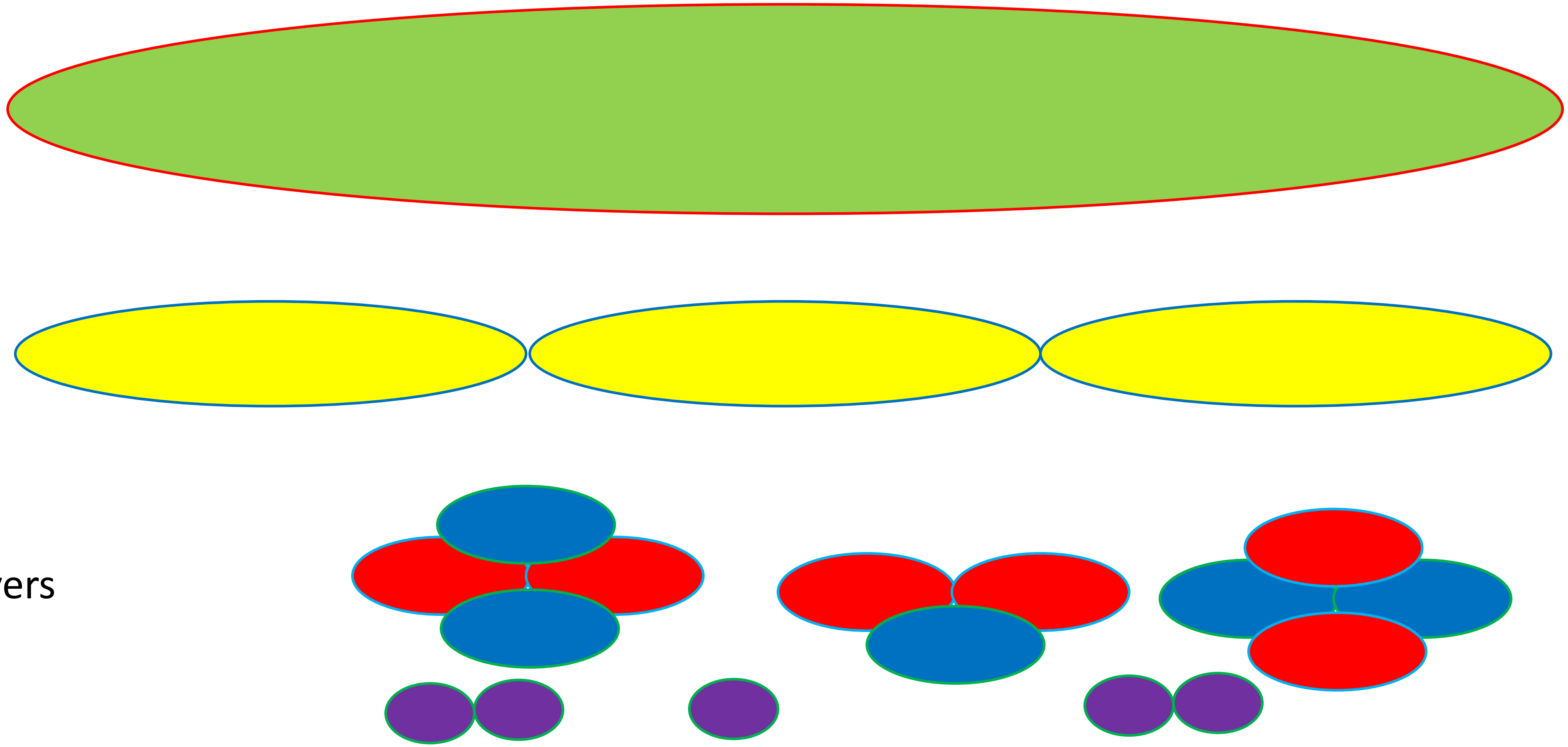


Figure 2 Frequency ranges to study for IMT identification in WRC-19

5G: Multiple Layers for multiple needs

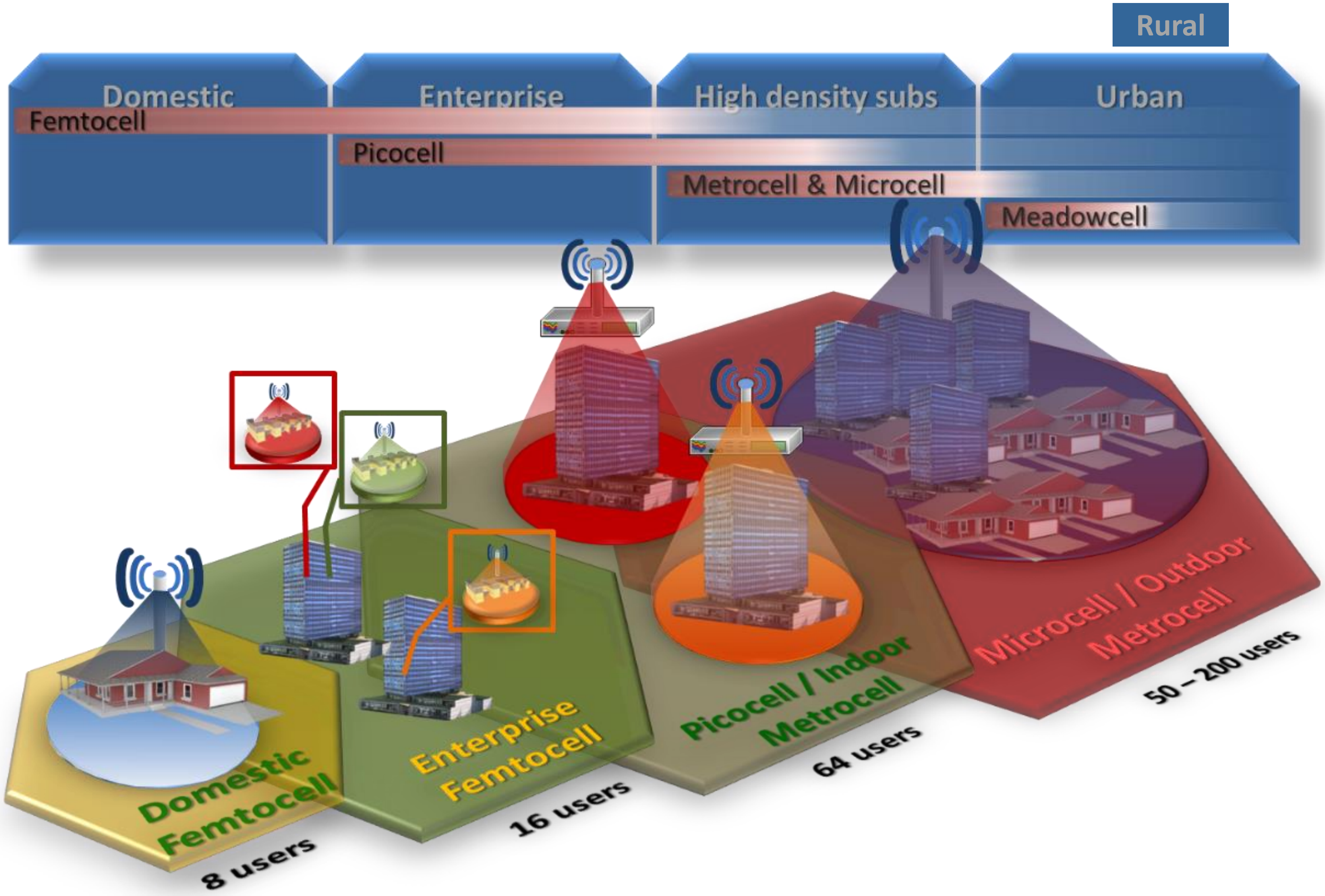


Coverage Layer
Sub-1GHz

Capacity Layer
1GHz – 6GHz

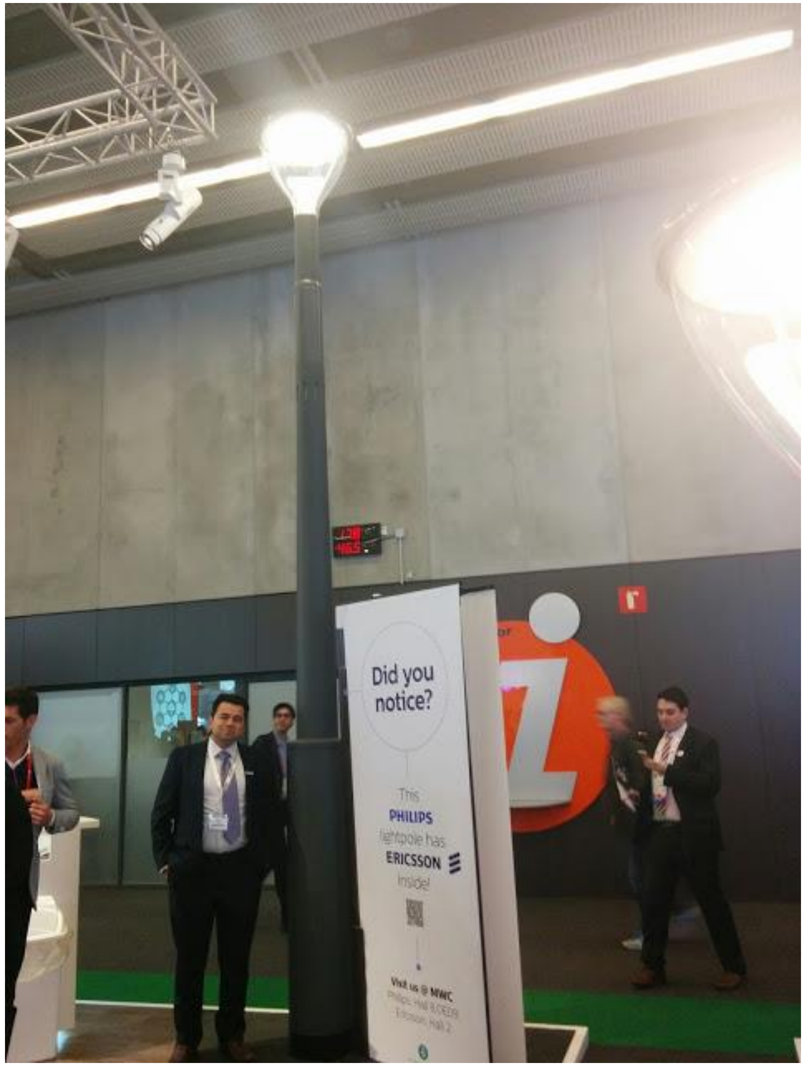
High Throughput Layers
6GHz – 100GHz

Types of Small Cells



Mobile Towers or Macrocells

Examples of Small Cells



End-to-end (E2E) Latency

End-to-end (E2E) latency: the time that takes to transfer a given piece of information from a source to a destination, measured at the communication interface, from the moment it is transmitted by the source to the moment it is successfully received at the destination.

5G Latency Requirements - Industry Targets

NGMN 5G Requirements

- 5G E2E Latency (eMBB) = **10ms** (i.e. RTT from UE-Application-UE)
- 5G E2E Latency (URLLC) = **1ms** (i.e. RTT from UE-Application-UE – or just UE-UE)

In both cases, the values are defined as capabilities that should be supported by the 5G System.

GSMA 5G Requirements

- 5G E2E Latency = **1ms** (again, defined as a capability target, not as a universal requirement)

ITU-R IMT-2020 Requirements

- eMBB User Plane Latency (one-way) = **4ms** [radio network contribution]
- URLLC User Plane Latency (one-way) = **1ms** [radio network contribution]
- Control Plane Latency = **20ms (10ms target)** [UE transition from Idle to Active via network]

Low Latency Use Case Requirements (various sources)

- Virtual Reality & Augmented Reality: **7-12ms**
- Tactile Internet (e.g. Remote Surgery, Remote Diagnosis, Remote Sales): < **10ms**
- Vehicle-to-Vehicle (Co-operative Driving, Platooning, Collision Avoidance): < **10ms**
- Manufacturing & Robotic Control / Safety Systems: **1-10ms**

Source: Andy Sutton

State of market, trials, etc.

- June 2018: Vodafone to kick off UK 5G trials in seven UK cities ahead of 2020 launch
- June 2018: EE confirms October 2018 UK launch date for first 5G live trials
- June 2018: Elisa claims "first in world to launch commercial 5G"
- May 2018: Three Middle East Operators launch 'World's First' 5G Networks – Ooredoo, Qatar, STC, Saudi Arabia and Etisalat, UAE
- May 2018: Verizon CEO: 5G coming end of 2018; expect competition on capability, not price
- March 2018: KT, South Korea announces launch of 5G Network in 2019
- Feb 2018: T-Mobile USA announces that they will launch 5G in 12 cities by end of 2018 using 600 MHz
- Jan 2018: AT&T to Launch Mobile 5G in 2018

NGMN 5G Use Cases Example

Broadband access in dense areas

PERVASIVE VIDEO

Broadband access everywhere

50+ MBPS EVERYWHERE

Higher user mobility

HIGH SPEED TRAIN

Massive Internet of Things

SENSOR NETWORKS

Extreme real-time communications

TACTILE INTERNET

Lifeline communications

NATURAL DISASTER

Ultra-reliable communications

E-HEALTH SERVICES

Broadcast-like services

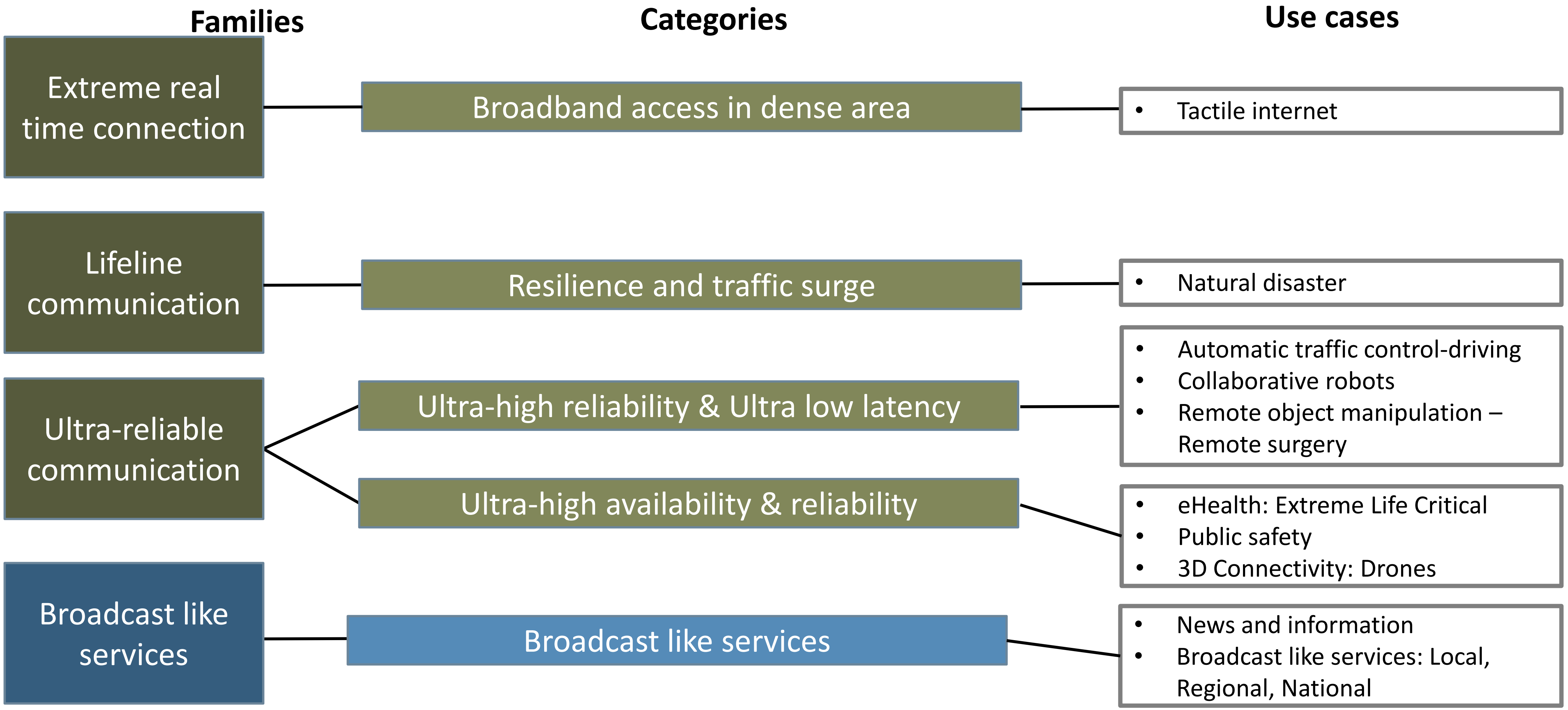
BROADCAST SERVICES

5G use case families and related examples

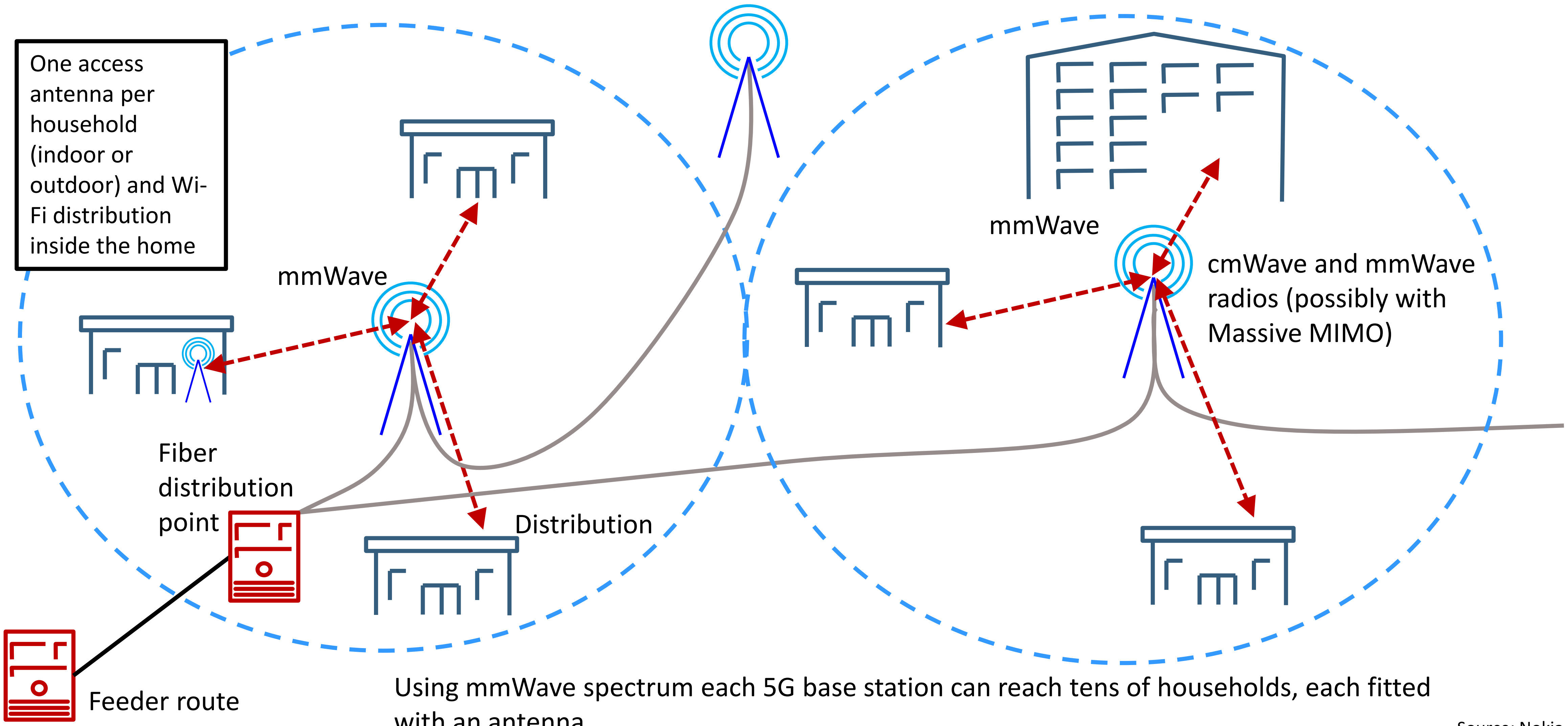
NGMN: 5G Families, Categories & Use Cases

Families	Categories	Use cases
Broadband access in dense area	Broadband access in dense area	• Pervasive video • Operator cloud services • Dense urban cloud services
	Indoor ultra-high broadband access	• Smart Office
	Broadband access in a crowd	• HD video/photo sharing in stadium/open-air gathering
Broadband access everywhere	50+Mbps everywhere	• 50 Mbps everywhere
	Ultra low-cost broadband access for low ARPU areas	• Ultra-low cost networks
High user mobility	Mobile broadband in vehicles	• High speed train • Moving Hot Spots • Remote computing
	Airplanes connectivity	• 3D Connectivity: Aircrafts
Massive Internet of Things	Massive low-cost/long-range/low-power MTC Broadband MTC	• Smart wearables (clothes) • Sensor networks • Mobile video surveillance

NGMN: 5G Families, Categories & Use Cases



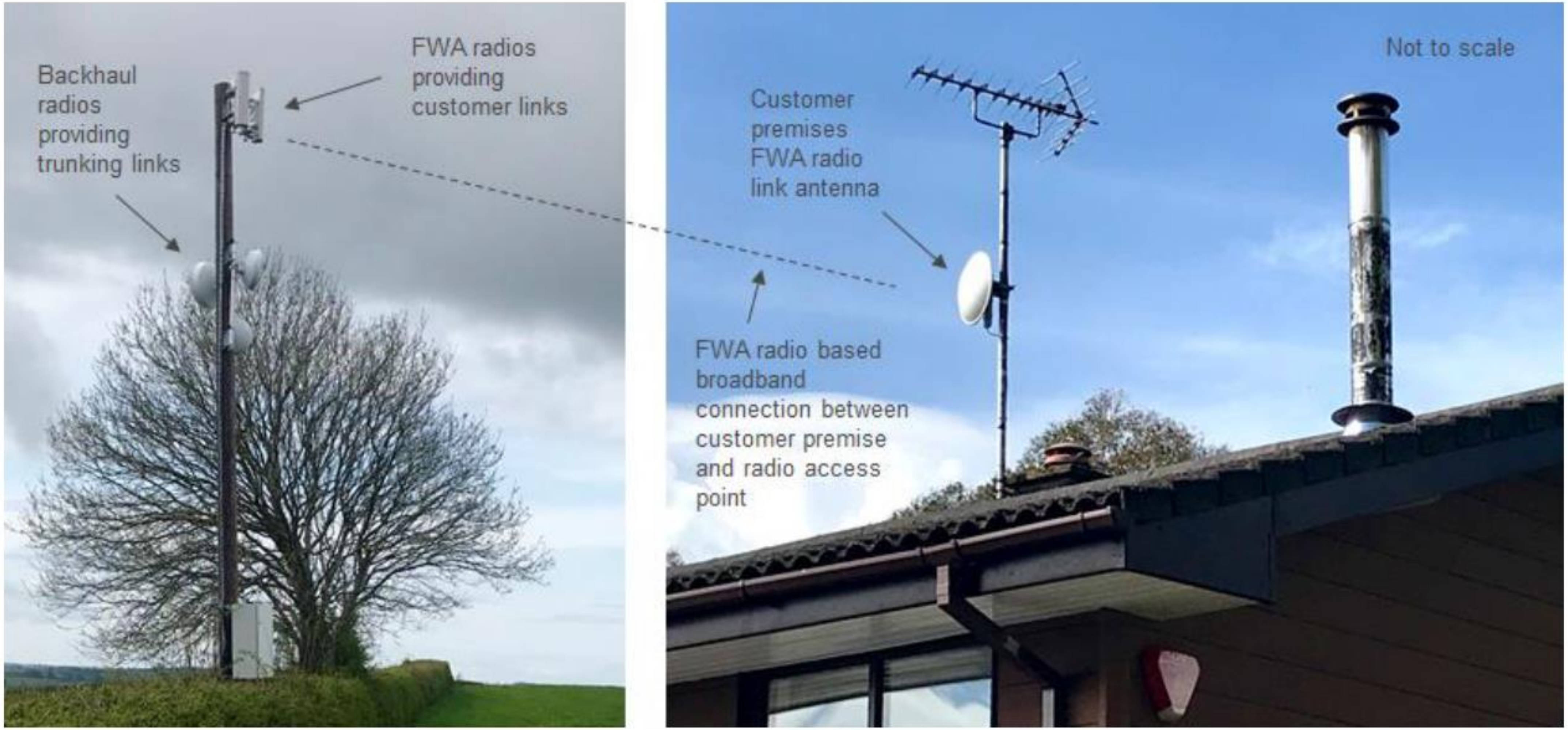
Fixed Wireless Access (FWA): 5G-to-the-Home



Using mmWave spectrum each 5G base station can reach tens of households, each fitted with an antenna

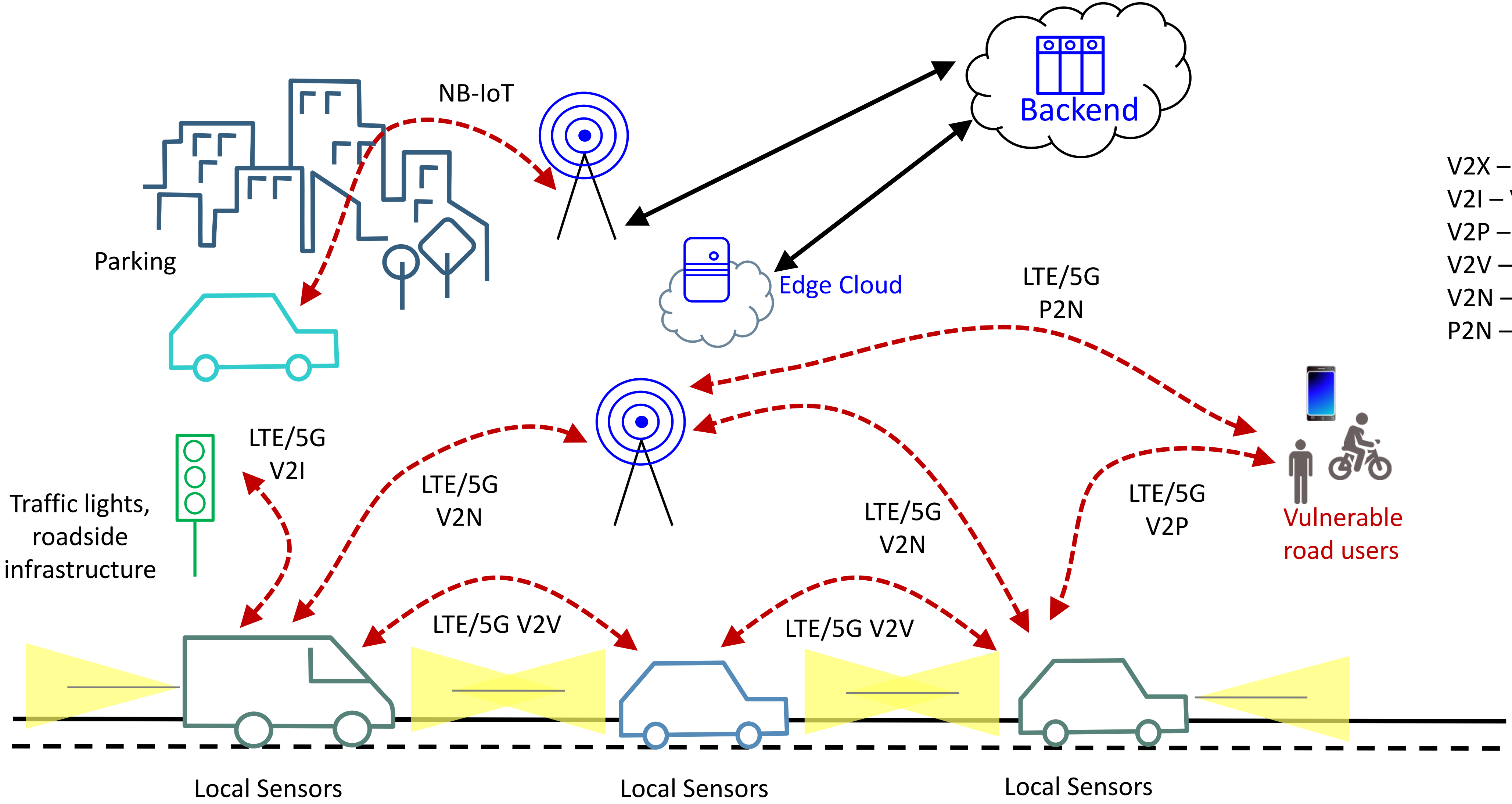
Source: Nokia

5.8 GHz FWA installation Example



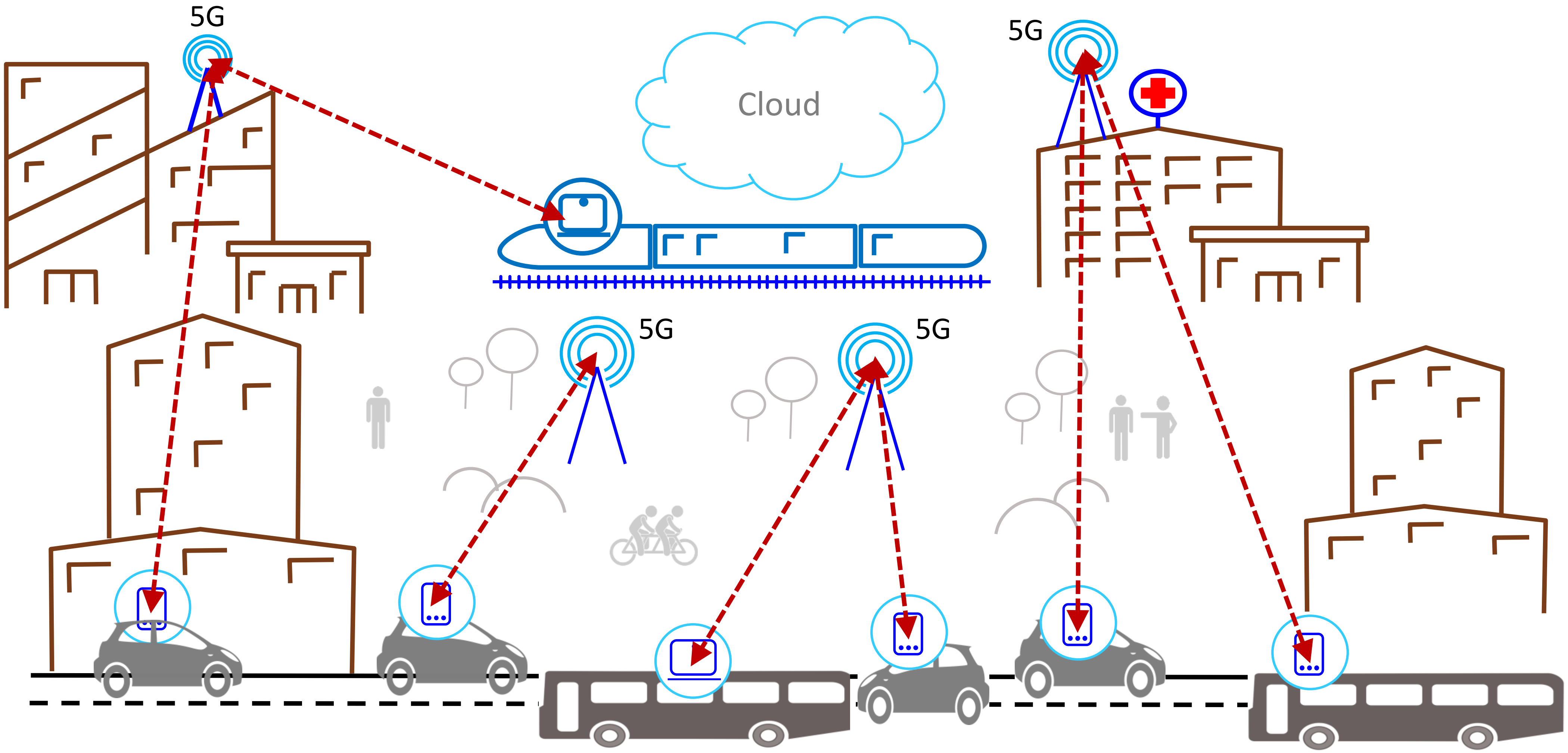
Source: Plum Consulting Whitepaper on FWA

Cellular V2X Concept



V2X – Vehicle to Everything
V2I – Vehicle to Infrastructure
V2P – Vehicle to Pedestrian
V2V – Vehicle to Vehicle
V2N – Vehicle to Network
P2N – Pedestrian to Network

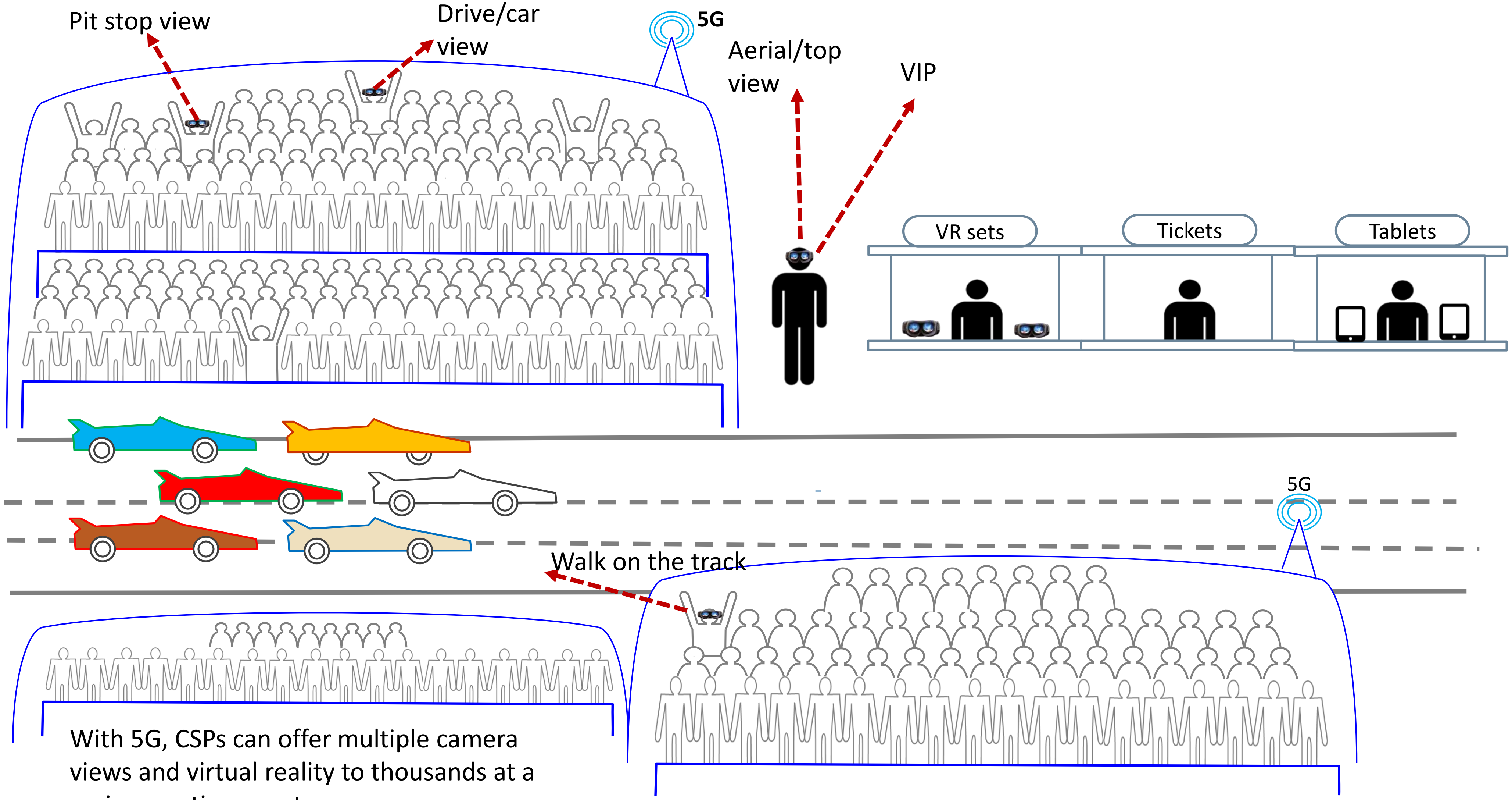
5G Connected Car: In-vehicle infotainment



A dense city center deployment of 5G deliver mobile broadband and infotainment services to customers using public transport

Source: Nokia

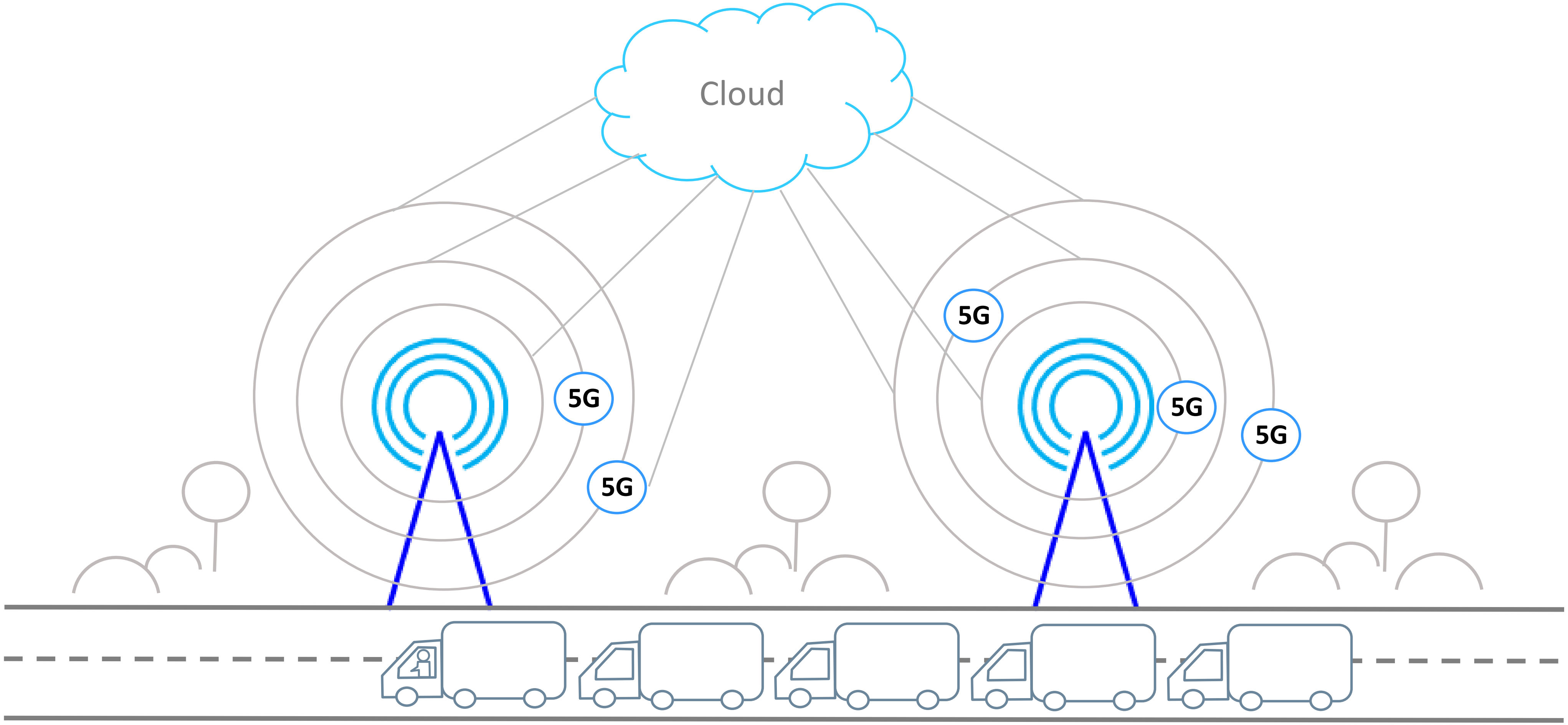
5G Connected Stadiums



With 5G, CSPs can offer multiple camera views and virtual reality to thousands at a major sporting event

Source: Nokia

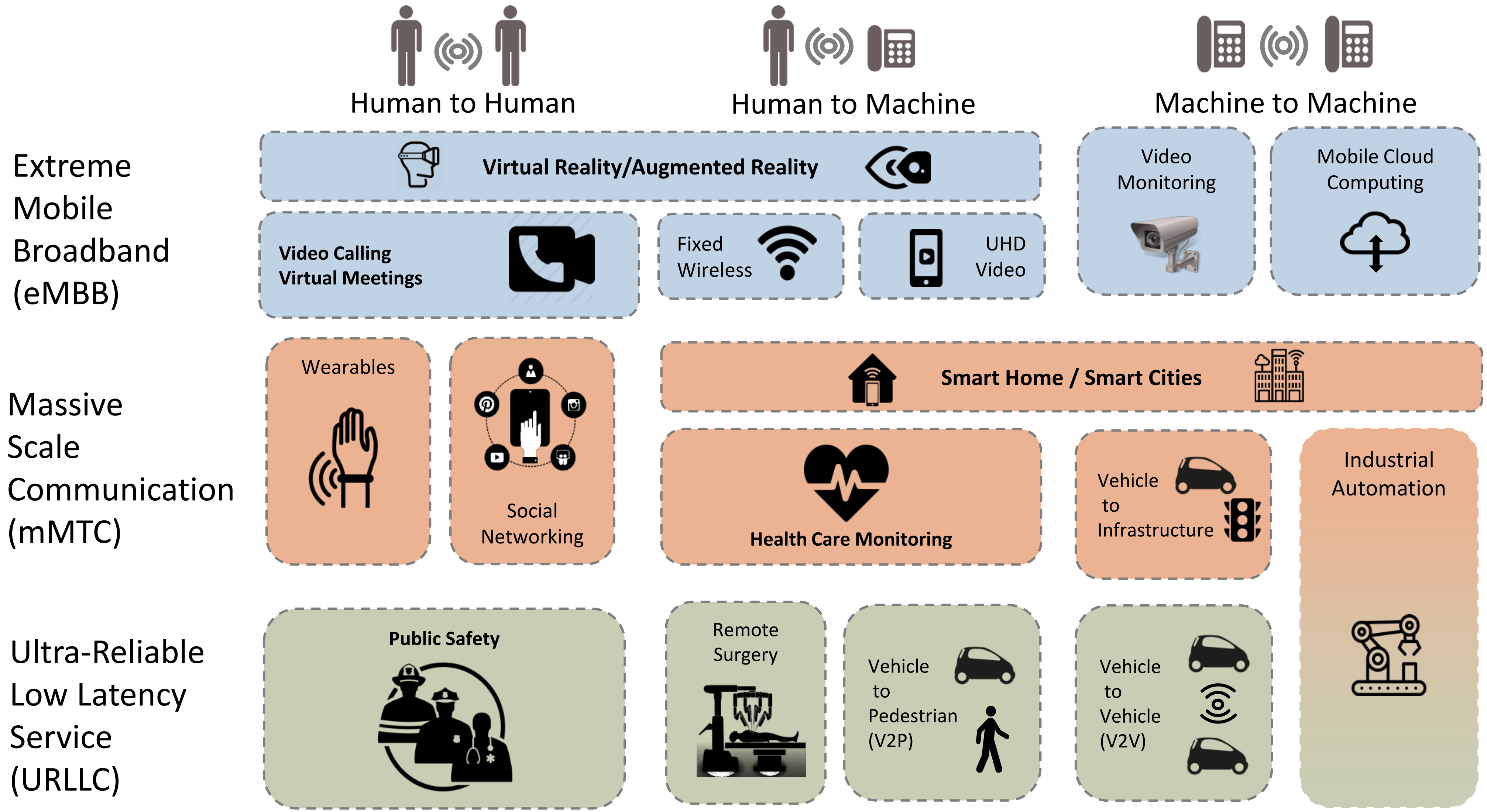
5G Autonomous Driving: Platooning



5G is the most promising enabler of truck platooning in which long convoys of trucks are automatically governed and require only a single driver in the lead vehicle

Source: Nokia

Summary of 5G Use Cases



Source: 5G Americas

Break!

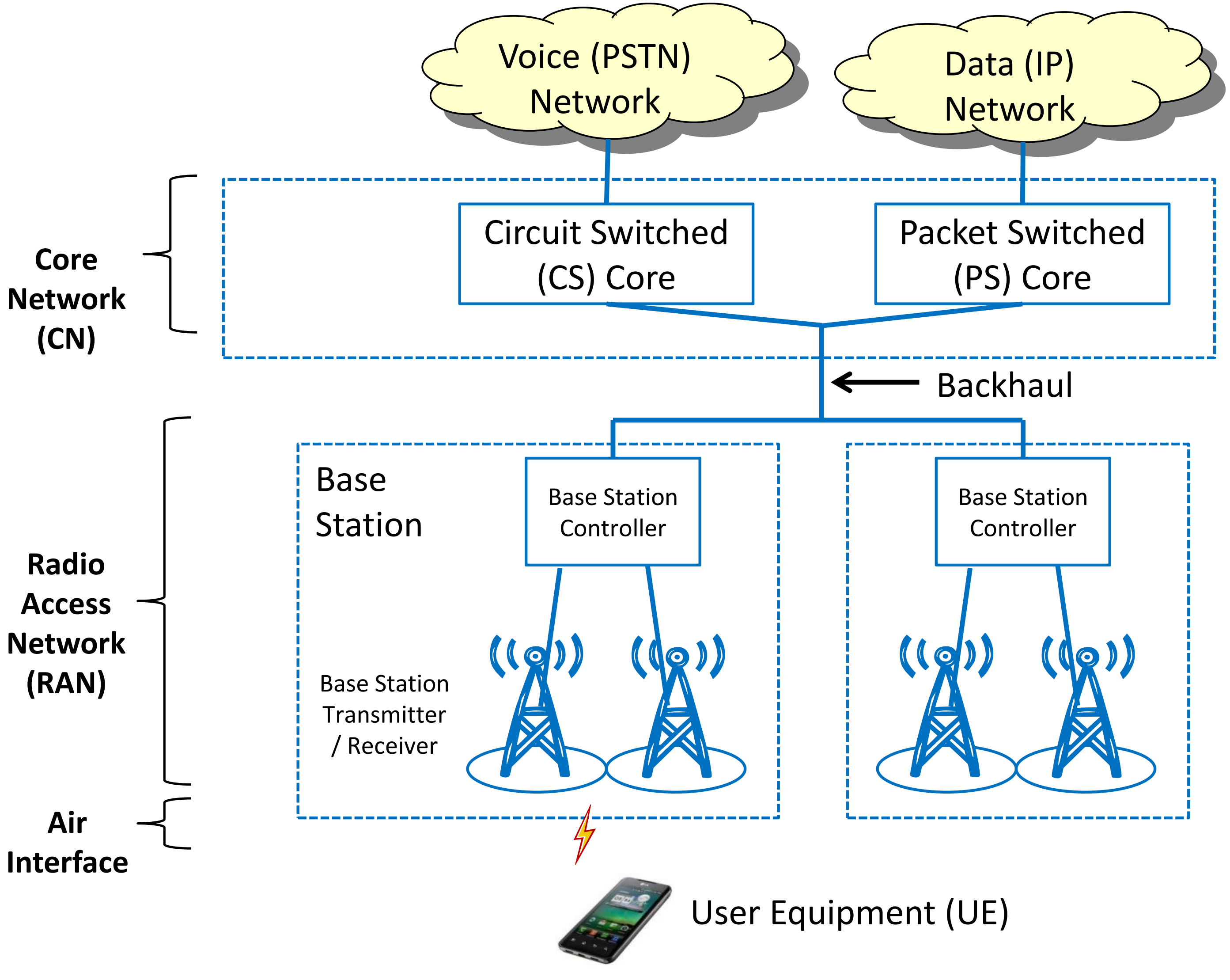
- Videos (time permitting)

Agenda: Session 2

- 5G Network Architecture
- 5G System (5GS) and 5G Core (5GC)
- SDN / NFV
- Network Slicing
- Edge Computing
- 5G New Radio (NR) and RAN Architecture
- Massive MIMO, beamforming, etc.
- 5G Core Architecture
- 5G Deployment Options: Non-Standalone (NSA) and Standalone (SA)

5G Resources, including Tutorials and Videos at 3G4G: https://www.3g4g.co.uk/5G/

2G / 3G Mobile Network Architecture

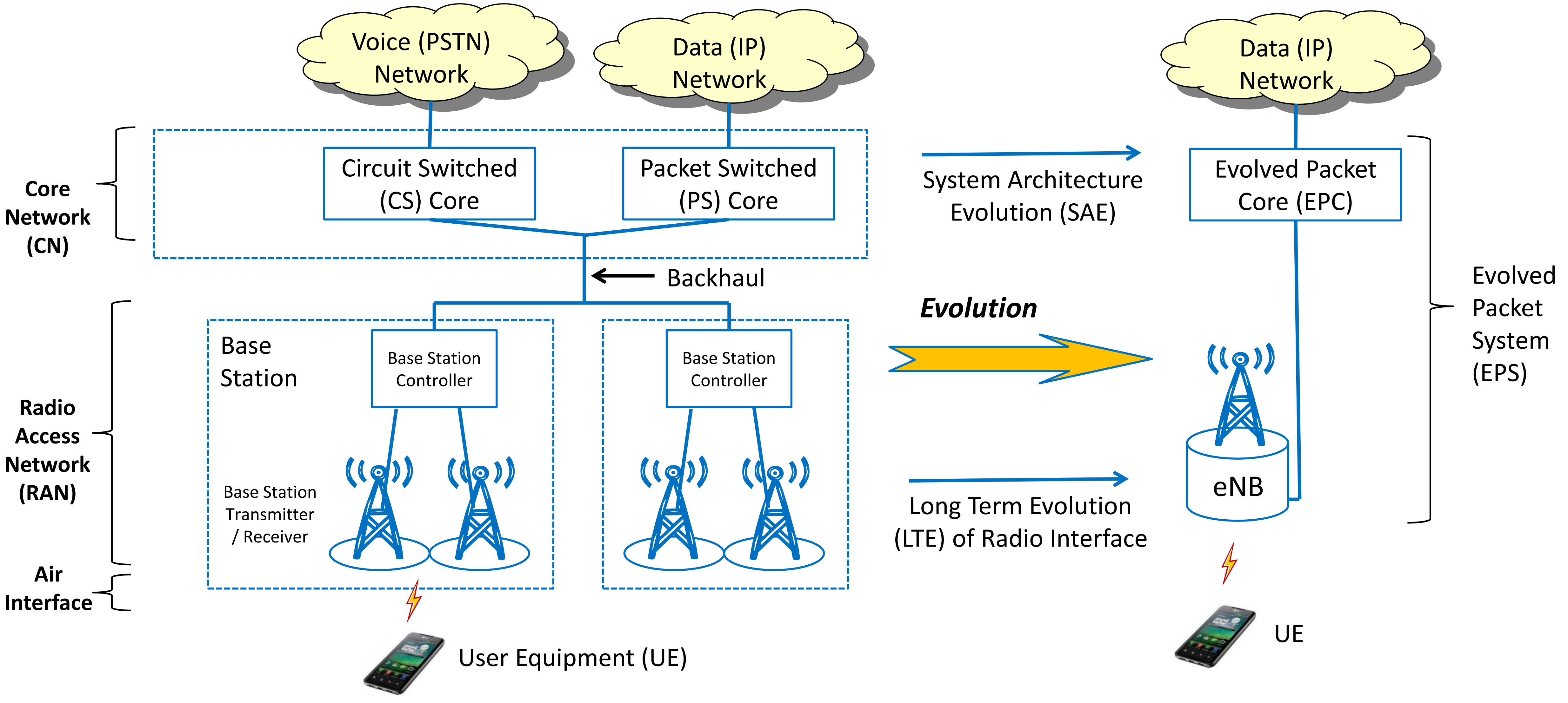


Core Network
- Connects to voice and data networks
- Provides Security and Authentication
- Billing / Charging
- Roaming

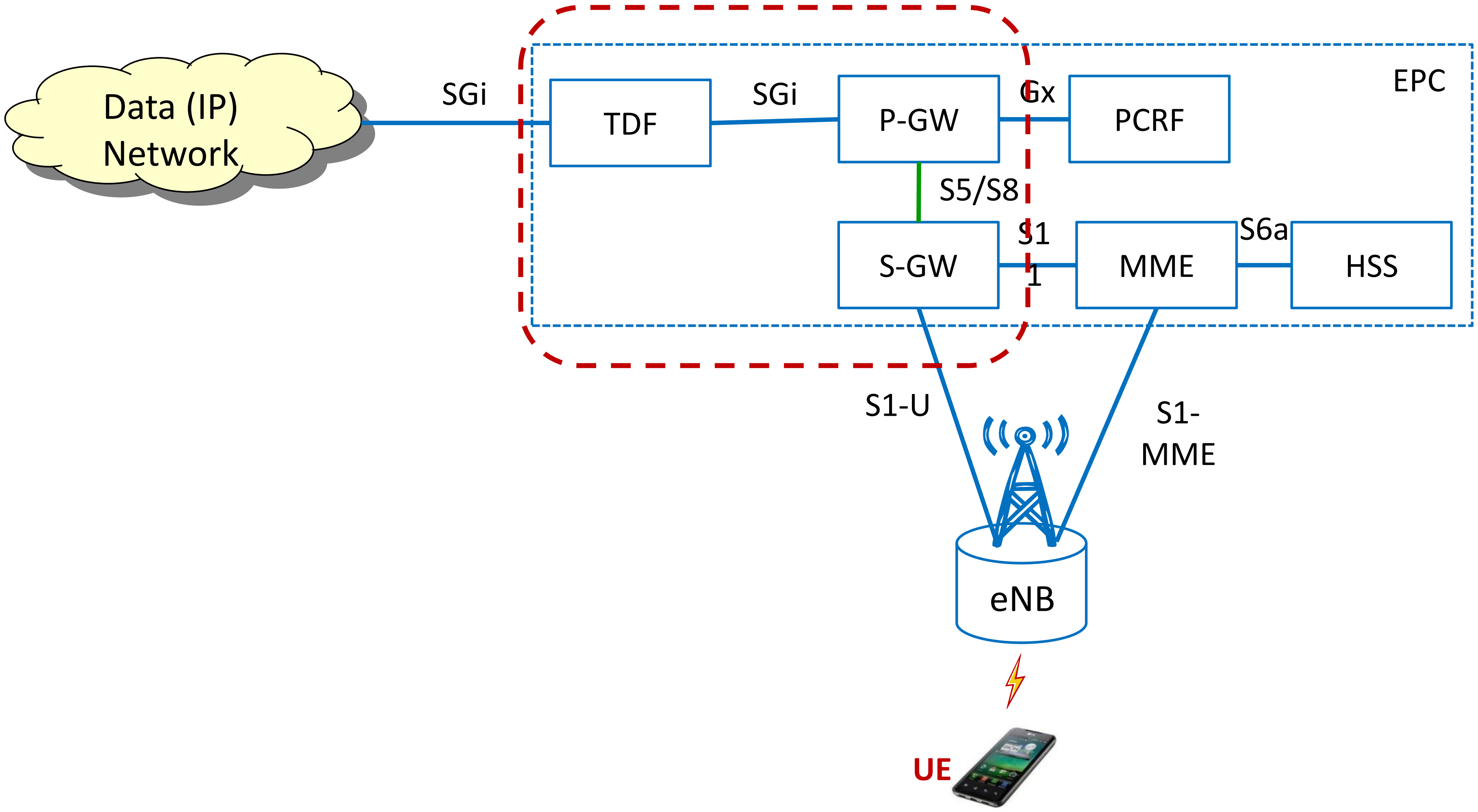
Backhaul
- Connects access network with core network
- Example: Fiber, microwave, satellite, mesh, etc.

Access Network
- Connects devices over the air
- Allows mobility and handovers

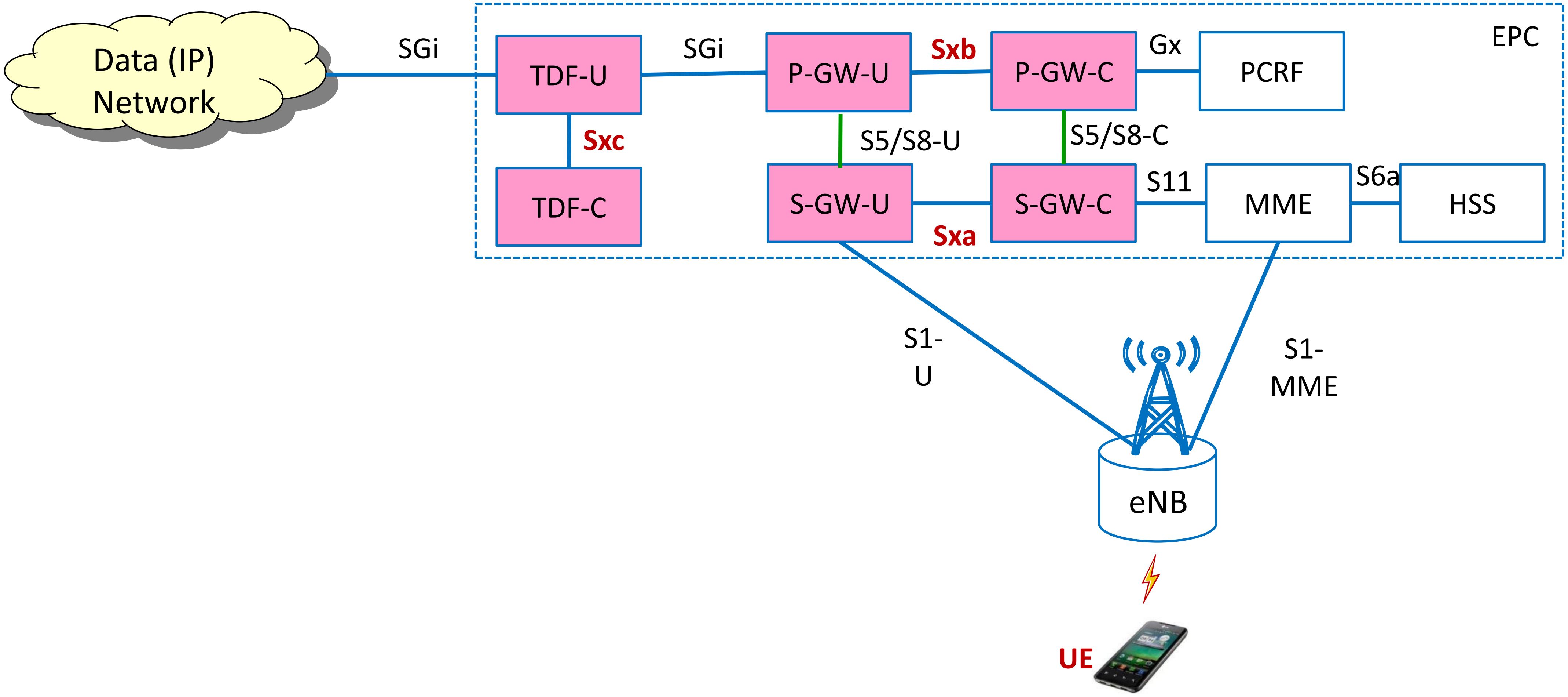
4G Mobile Network Architecture



EPC before CUPS (Control and User Plane Separation of EPC nodes)



EPC after CUPS



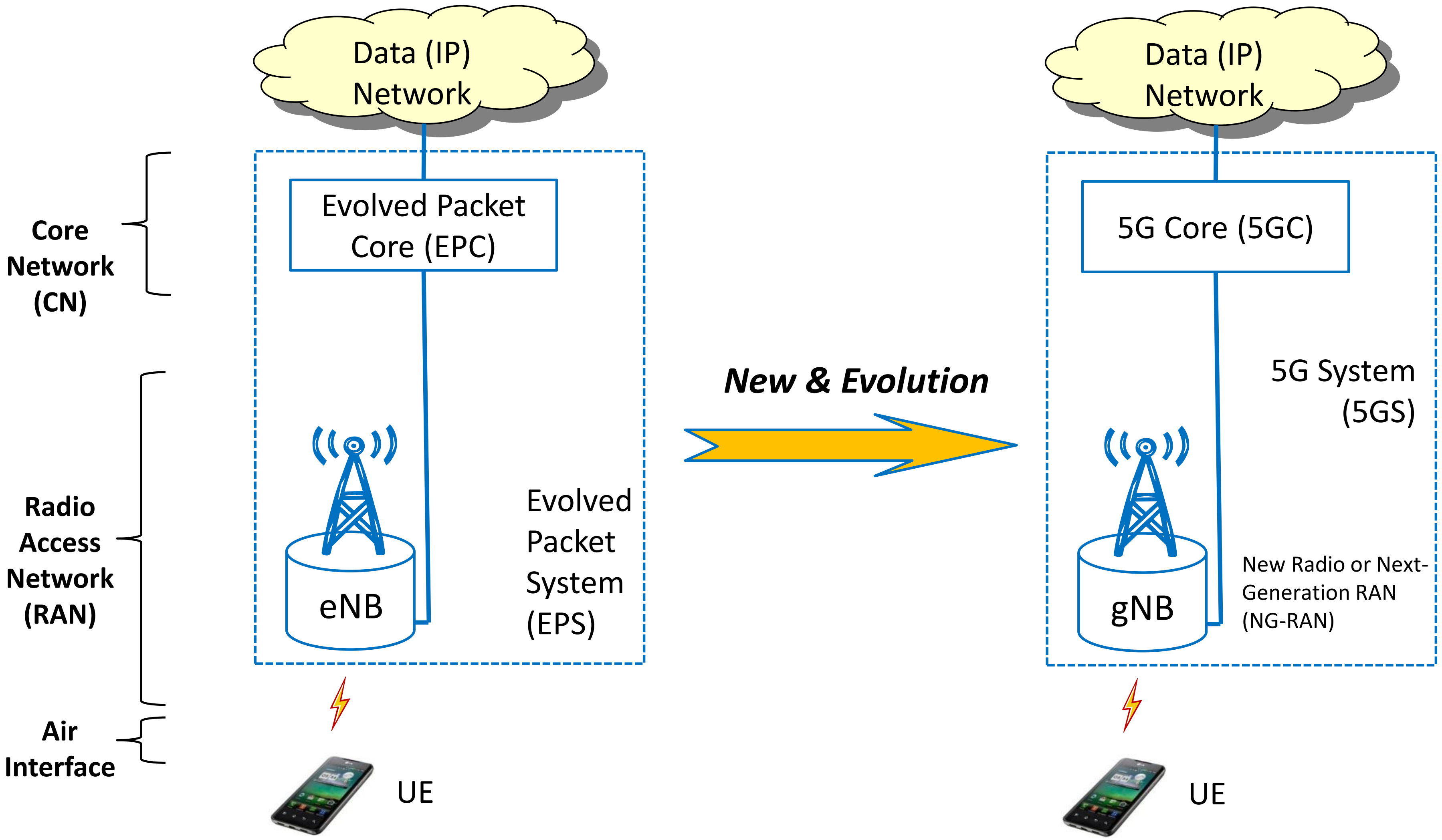
High Level Principles for CUPS Architecture

- The CP function terminates the Control Plane 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
- A legacy SGW, PGW and TDF can be replaced by a split node without effecting connected legacy nodes.

Advantages of CUPS Architecture

- 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.

5G Mobile Network Architecture

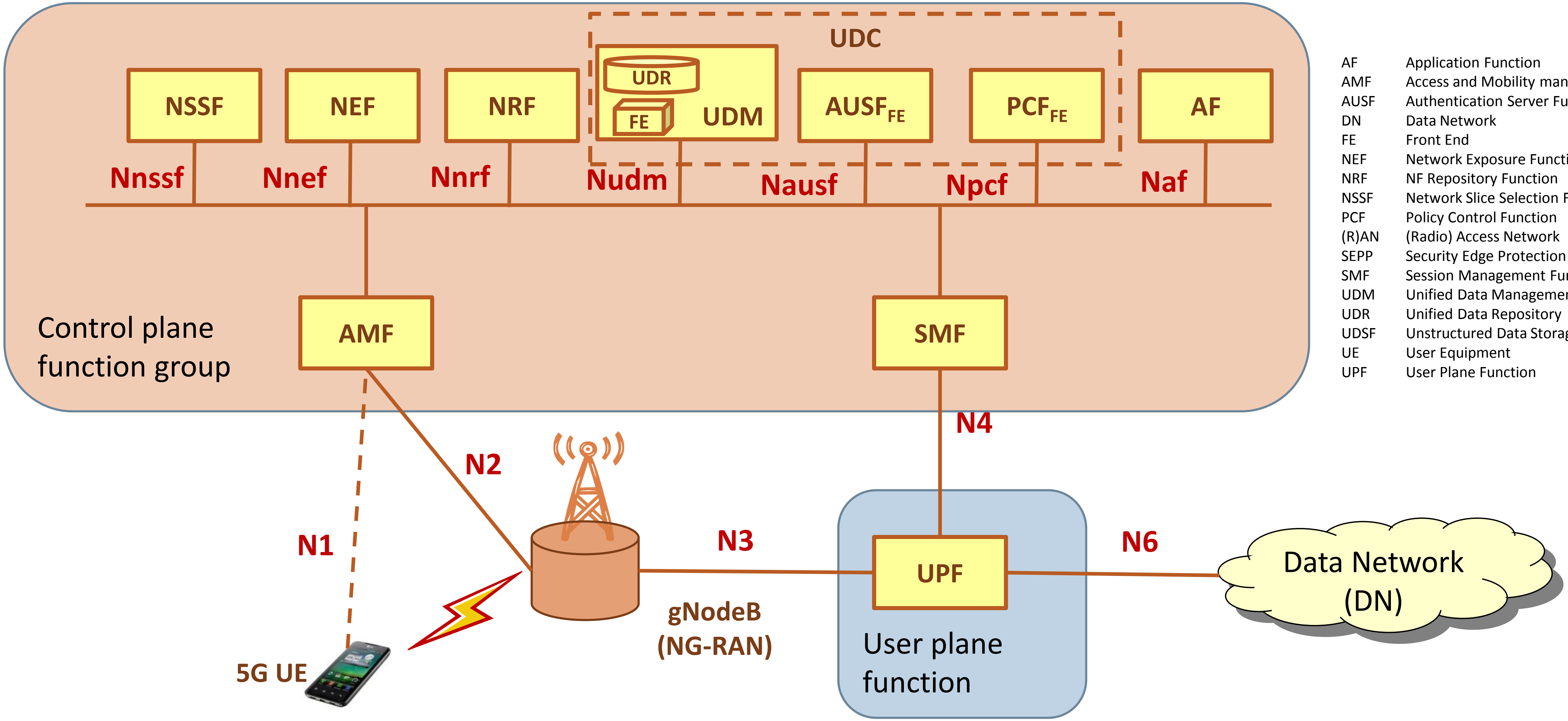


5G System is defined as 3GPP system consisting of 5G Access Network (AN), 5G Core Network and UE. The 5G System provides data connectivity and services.

3GPP TS 23.501: System Architecture for the 5G System; Stage 2

3GPP TS 23.502: Procedures for the 5G System; Stage 2

5G System (5GS) – Actual

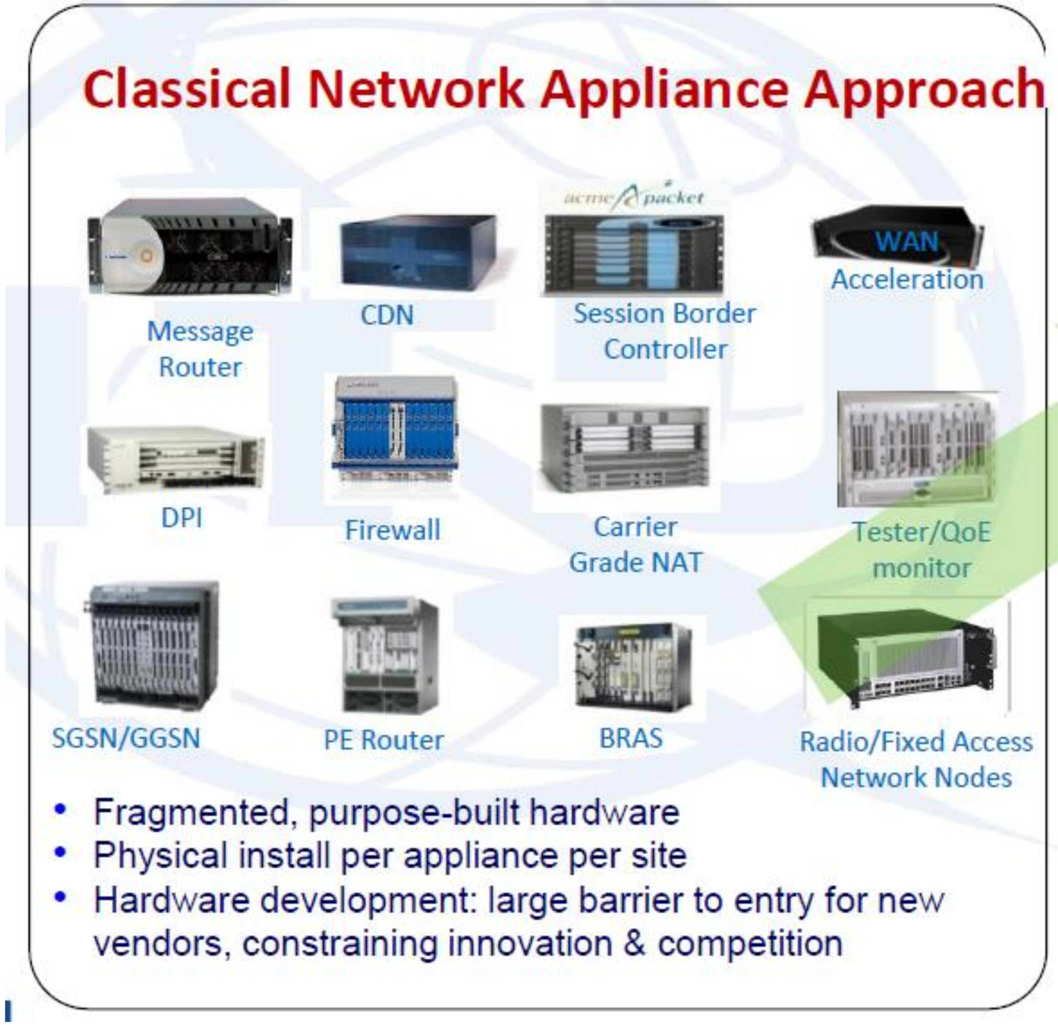


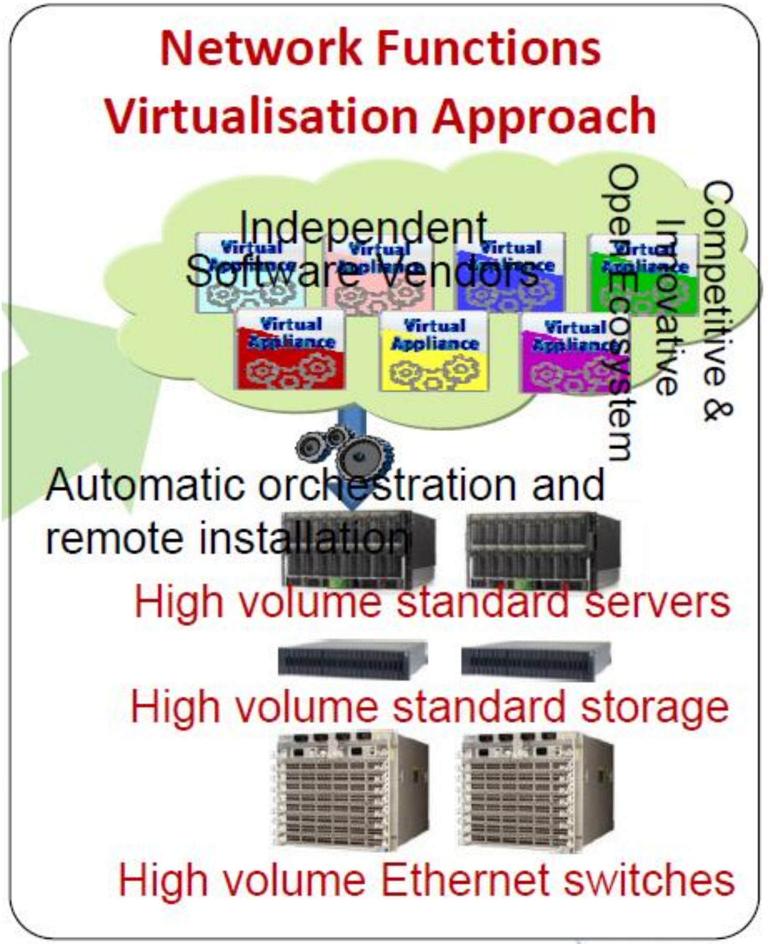
AF	Application Function
AMF	Access and Mobility management Function
AUSF	Authentication Server Function
DN	Data Network
FE	Front End
NEF	Network Exposure Function
NRF	NF Repository Function
NSSF	Network Slice Selection Function
PCF	Policy Control Function
(R)AN	(Radio) Access Network
SEPP	Security Edge Protection Proxy
SMF	Session Management Function
UDM	Unified Data Management
UDR	Unified Data Repository
UDSF	Unstructured Data Storage Function
UE	User Equipment
UPF	User Plane Function

NFV: Moving Hardware into Software

1994 | 2014

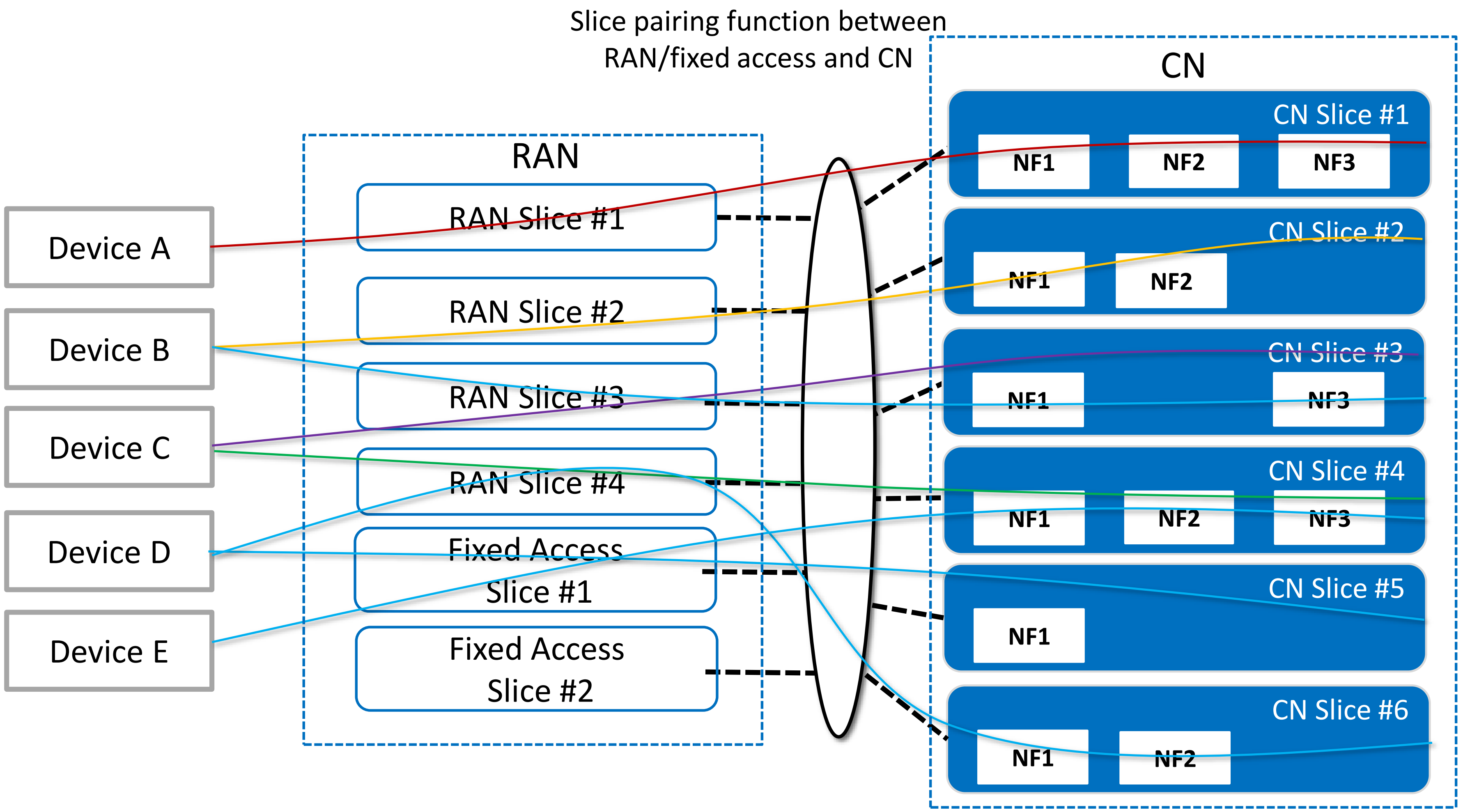
The Networks are also changing physically





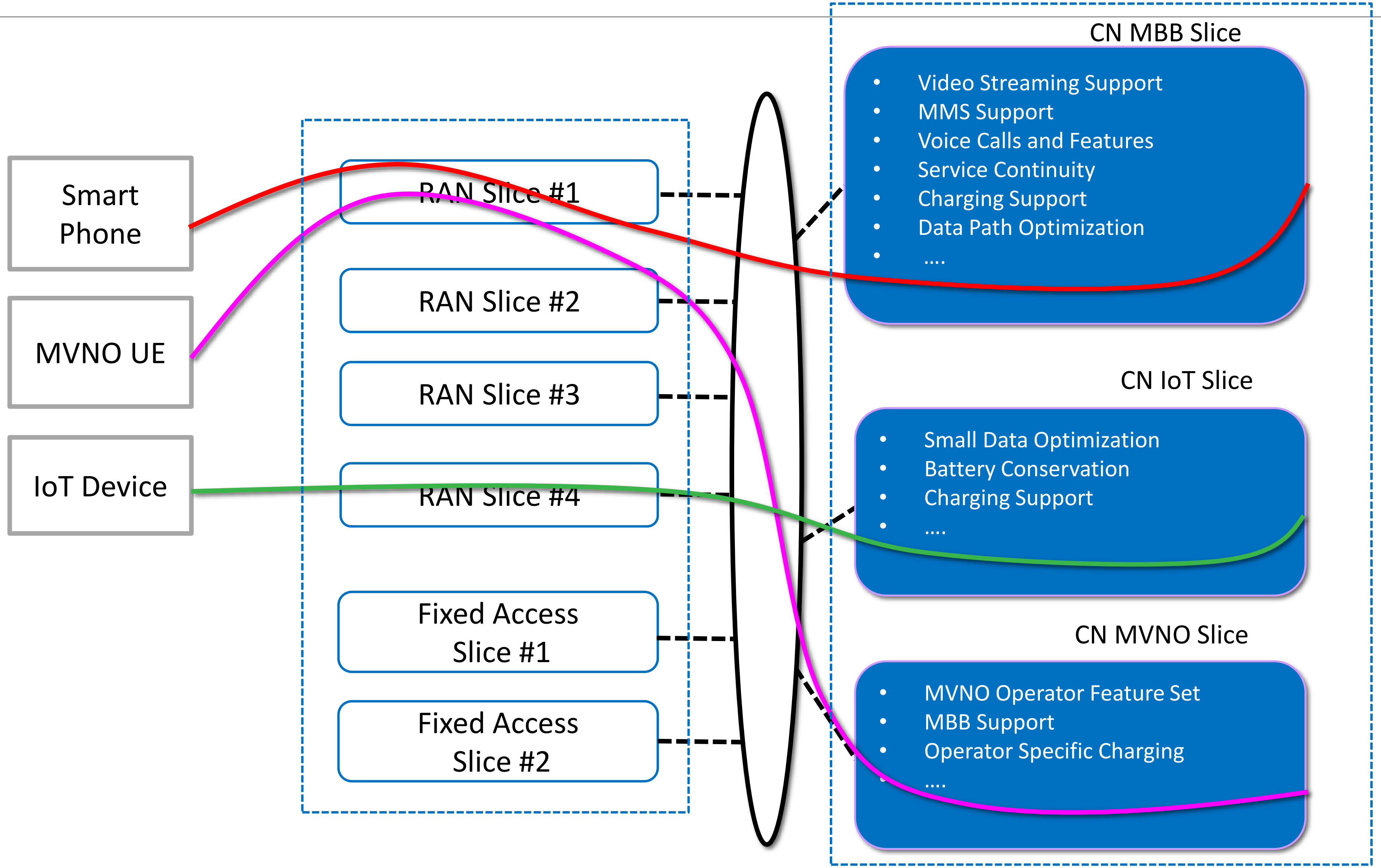
Commercial off-the-shelf (COTS) Hardware

Network Slicing

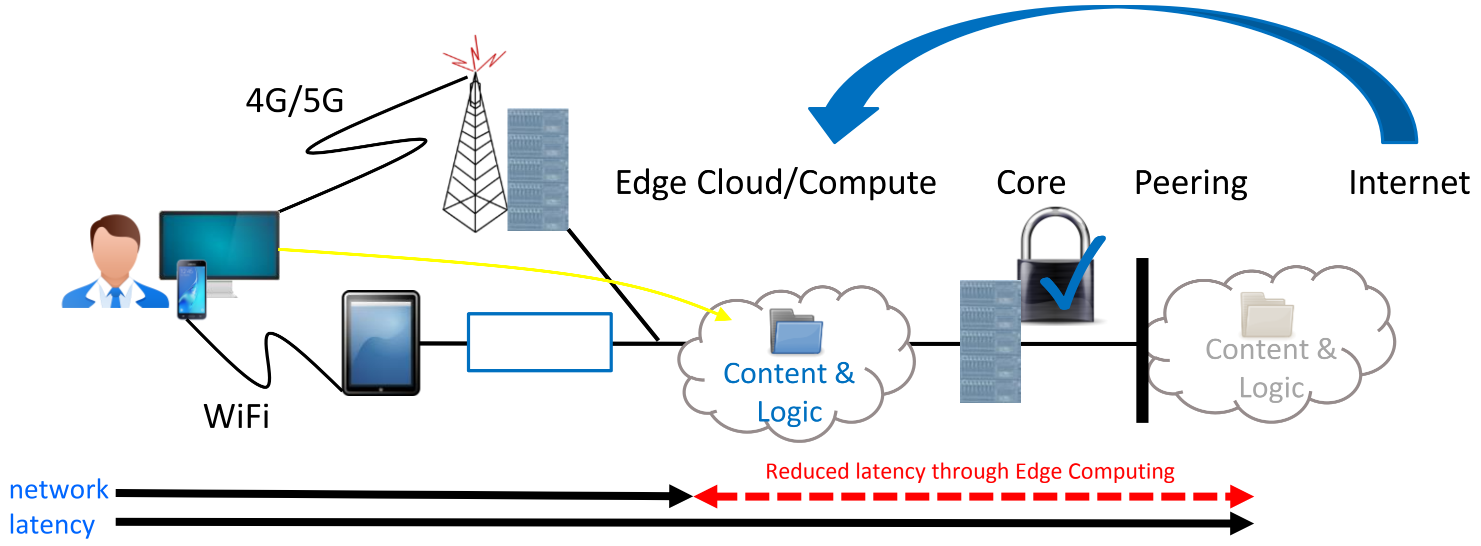


Same physical Infrastructure, different logical functions

Network Slicing Example



Edge Computing: computing and storage resources next to the user



Edge Computing benefits

- (Ultra-) low latency: disruptive improvement of customer experience
- Reduction of backhaul/core network traffic: cloud services (e.g., big data) near to user
- In-network data processing

Some issues to be fully addressed, incl.

Resource limitation, more complexity inefficient application execution, service continuity and mobility

Low latency applications

Autonomous Devices

- Drones
- Self-Driving Cars
- Robotics

Immersive Experiences

- Interactive Environments
- Virtual Reality
- Augmented Reality

Natural Interfaces

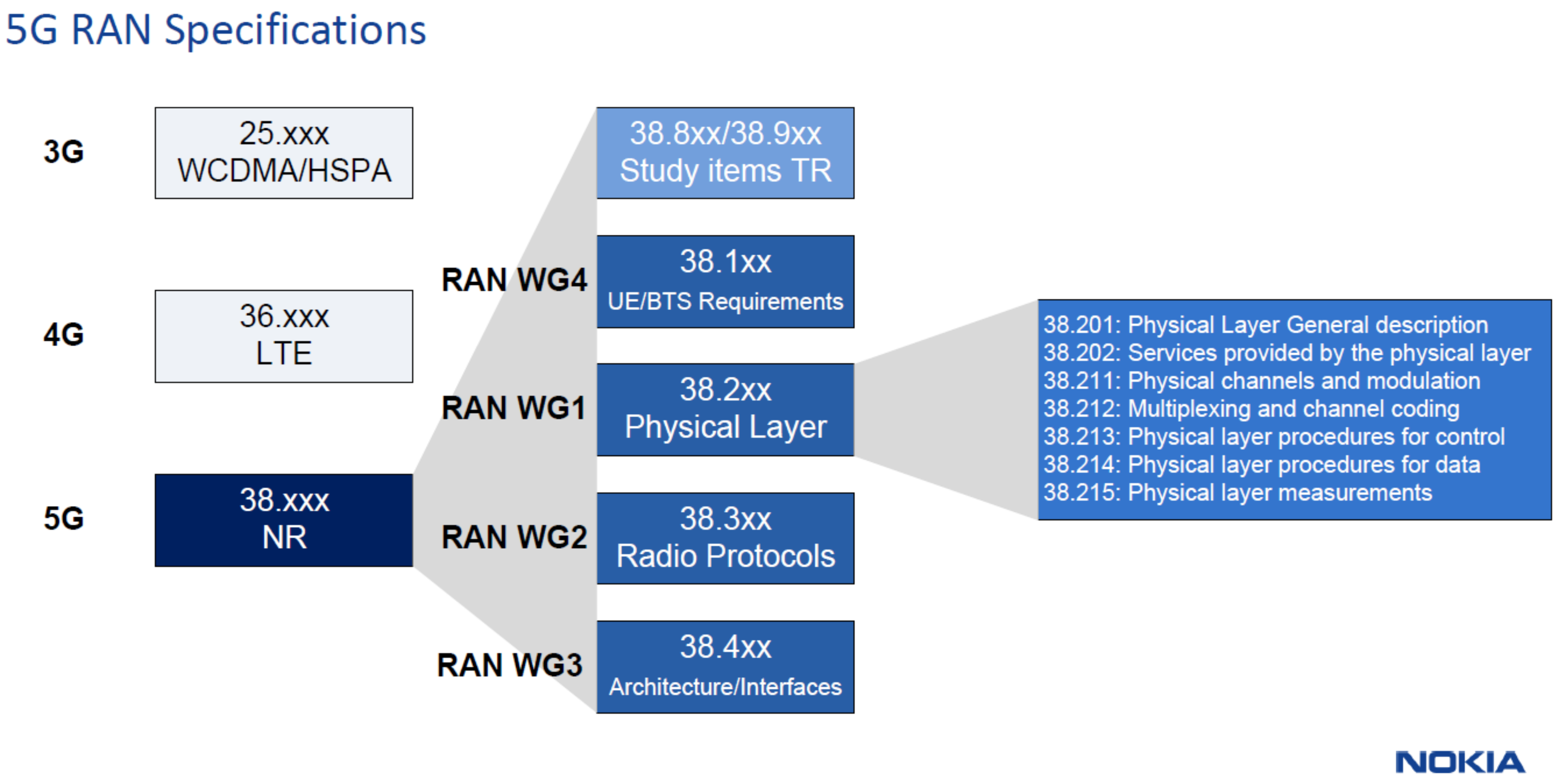
- Voice Control
- Motion Control
- Eye- Tracking

[Ultra Latency < 20 ms]

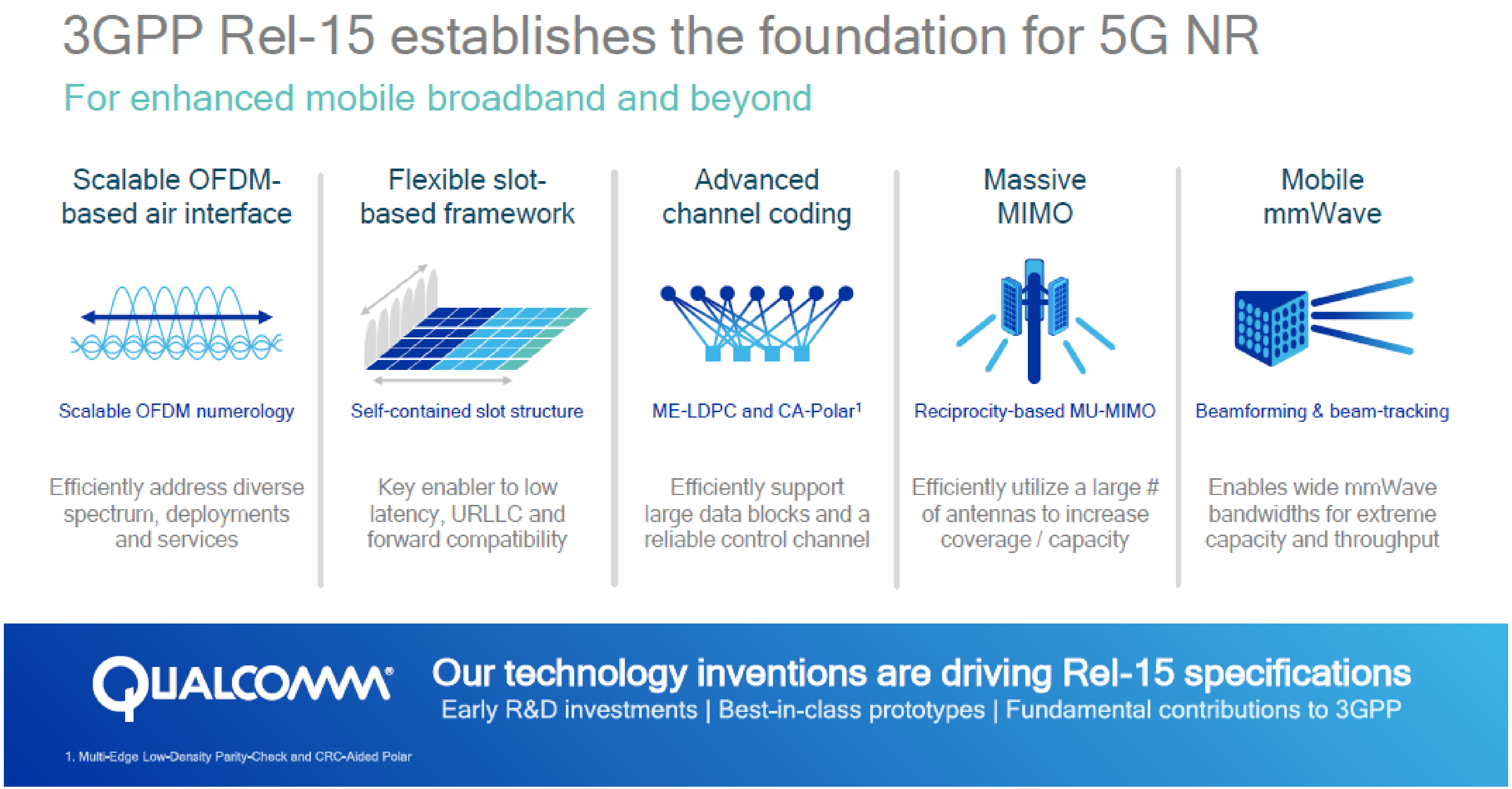
Edge Computing….and more: Fog/Device Computing

5G New Radio (NR)

A new 5G-specific radio communication system called New Radio (NR) has been defined with no backward compatibility with the existing LTE and LTE-Advanced systems.



5G New Radio (NR)



eNB, ng-eNB, gNB

- eNodeB (**eNB**) – LTE access network from 3GPP Rel-8 up to 3GPP Rel-14
- Next generation eNodeB (**ng-eNB**) – LTE access network from 3GPP Rel-15 onwards
  - node providing E-UTRA user plane and control plane protocol terminations towards the UE, and connected via the NG interface to the 5GC.
- Next generation NodeB (**gNB**) – 5G access network from 3GPP Rel-15 onwards.
  - node providing NR user plane and control plane protocol terminations towards the UE, and connected via the NG interface to the 5GC.

Next Generation Radio Access Network (NG-RAN)

An NG-RAN node is either:

- a **gNB**, providing NR user plane and control plane protocol terminations towards the UE; or
- an **ng-eNB**, providing E-UTRA user plane and control plane protocol terminations towards the UE.

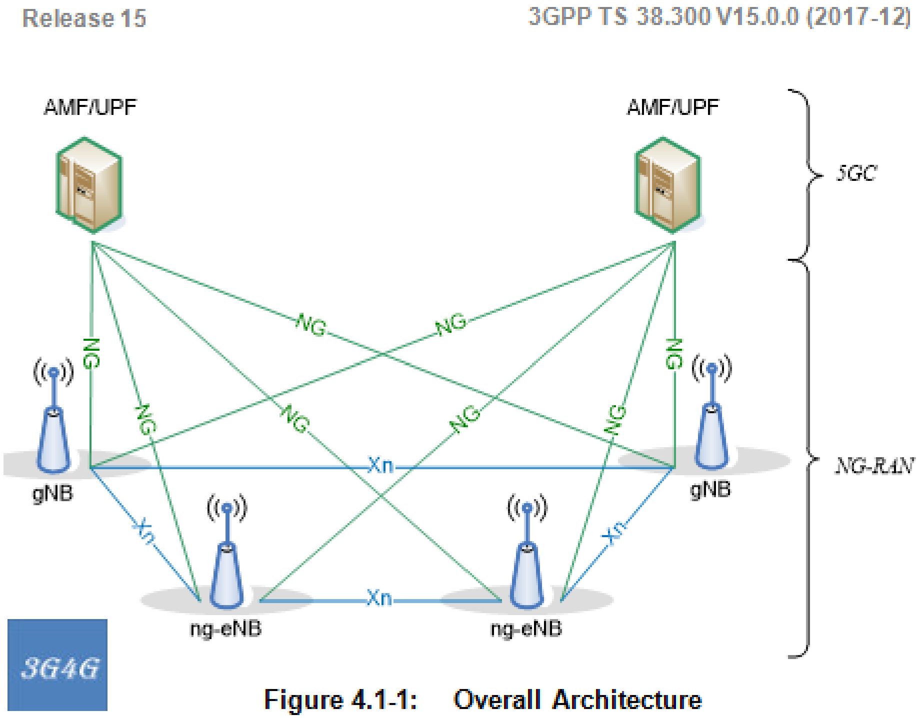
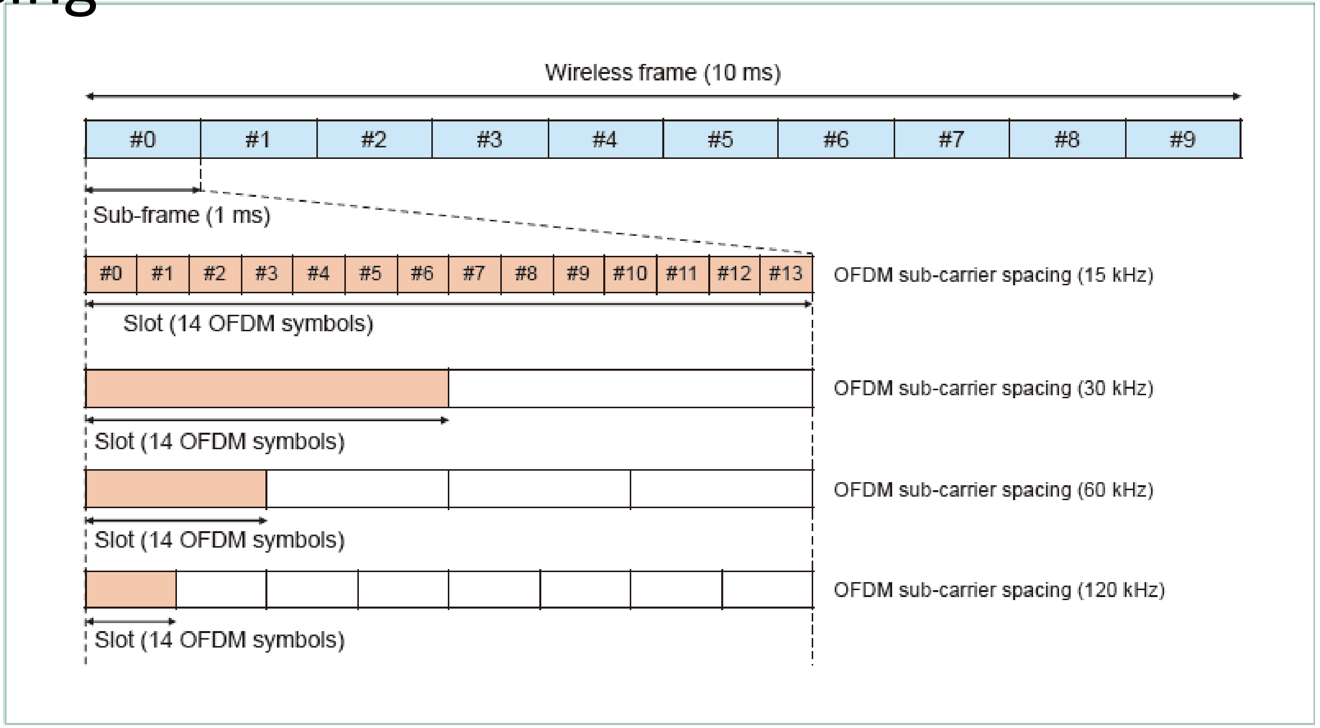


Figure 4.1-1: Overall Architecture

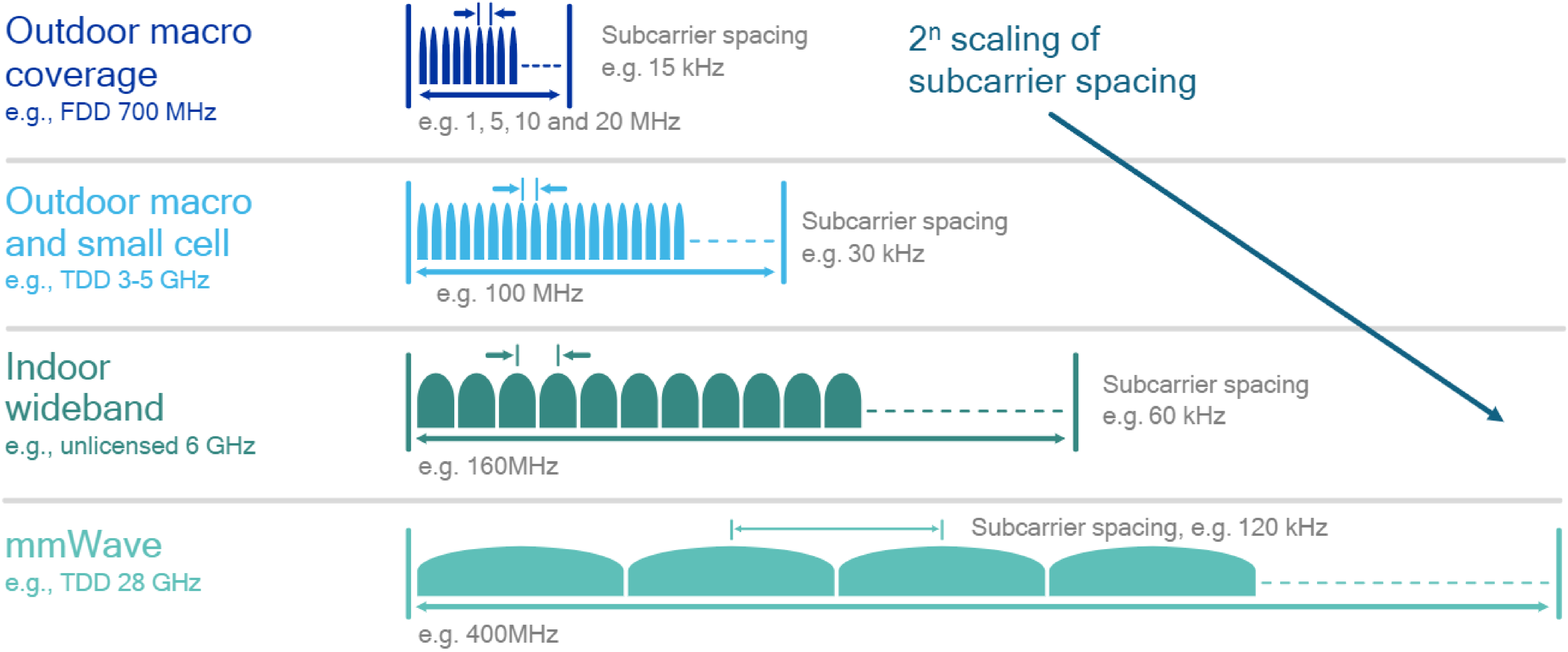
5G NR (New Radio) Radio Frame

- The 5G NR Radio Frame is in units of 10ms
- Subframes are defined in units of 1ms
- Slots are defines as 14 OFDM Symbols and their time interval depends on sub-carrier spacing



Source: NTT Docomo

Scalable OFDM numerology to efficiently address diverse spectrum, deployments, and services



Example usage models and channel bandwidths

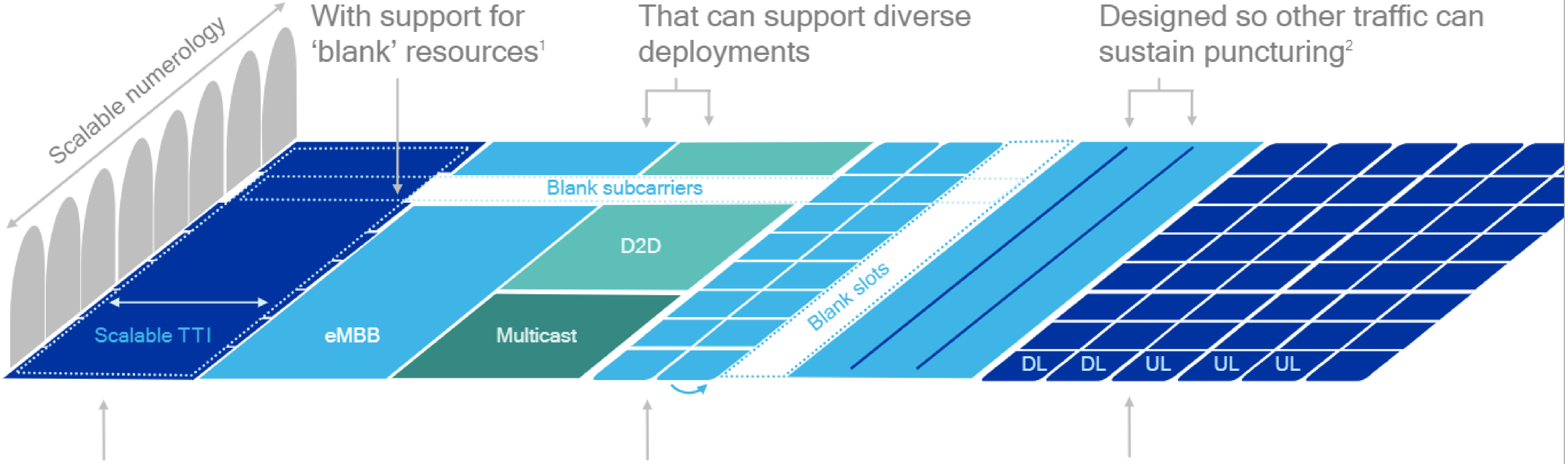
Source: Qualcomm

Flexible, forward compatible framework efficiently multiplexes envisioned and future 5G services

Forward compatibility
With support for 'blank' resources[1]

Integrated framework
That can support diverse deployments

Mission-critical transmissions
Designed so other traffic can sustain puncturing[2]



Scalable transmission time interval (TTI)
Capable of latencies an order of magnitude lower than LTE

Self-contained slot structure
UL/DL scheduling info, data and ACK in the same slot

Dynamic uplink/downlink
Faster switching for more flexible capacity allocation

1. Blank resources may still be utilized, but are designed in a way to not limit future feature introductions
2. Nominal 5G access to be designed such that it is capable to sustain puncturing from mission-critical transmission or bursty interference

Source: Qualcomm

5G Numerology?

In the context of 3GPP 5G standardization contributions, the term numerology refers to the configuration of waveform parameters, and different numerologies are considered as OFDM-based sub-frames having different parameters such as subcarrier spacing/symbol time, CP size, etc.

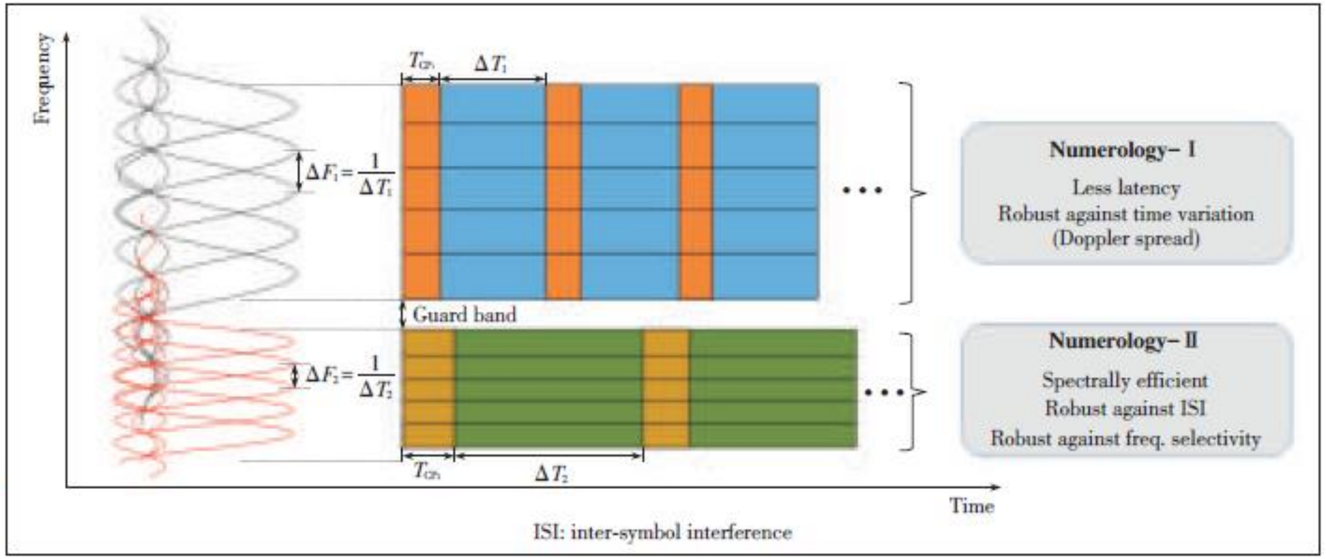


Figure 4. Illustration of different numerologies.

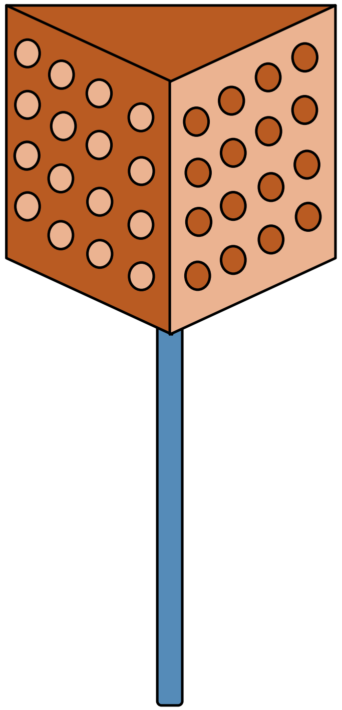
Source: ZTE

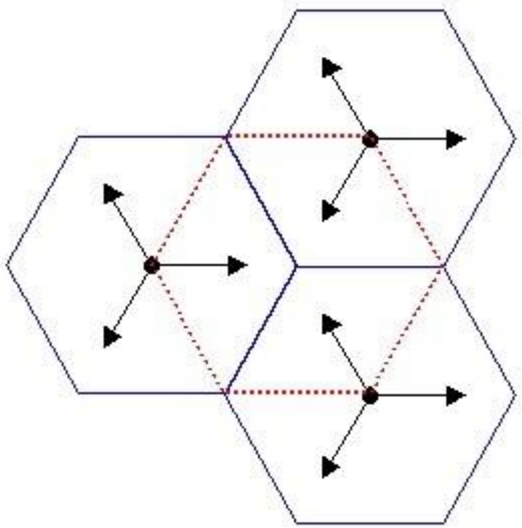
June 2017 Vol.15 No. S1 ZTE COMMUNICATIONS 17

Subcarrier Spacing

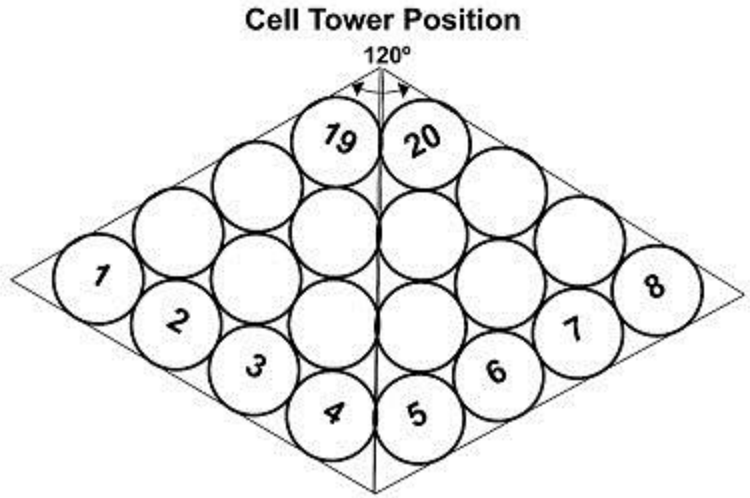
- The NR subcarrier spacing is defined as 15×2^n kHz, where n can take positive values at the moment
  - $n = 0$, $15 \times 2^0 = 15$ kHz
  - $n = 1$, $15 \times 2^1 = 30$ kHz
  - $n = 2$, $15 \times 2^2 = 60$ kHz
  - $n = 3$, $15 \times 2^3 = 120$ kHz
  - $n = 4$, $15 \times 2^4 = 240$ kHz
- In future n can take both positive and negative values
  - $n = -1$, $15 \times 2^{-1} = 7.5$ kHz
  - $n = -2$, $15 \times 2^{-2} = 3.75$ kHz → same as LTE NB-IoT subcarrier spacing

Massive MIMO: Wide Beams to Narrow Beams





3-sector wide beams, each covering 120°



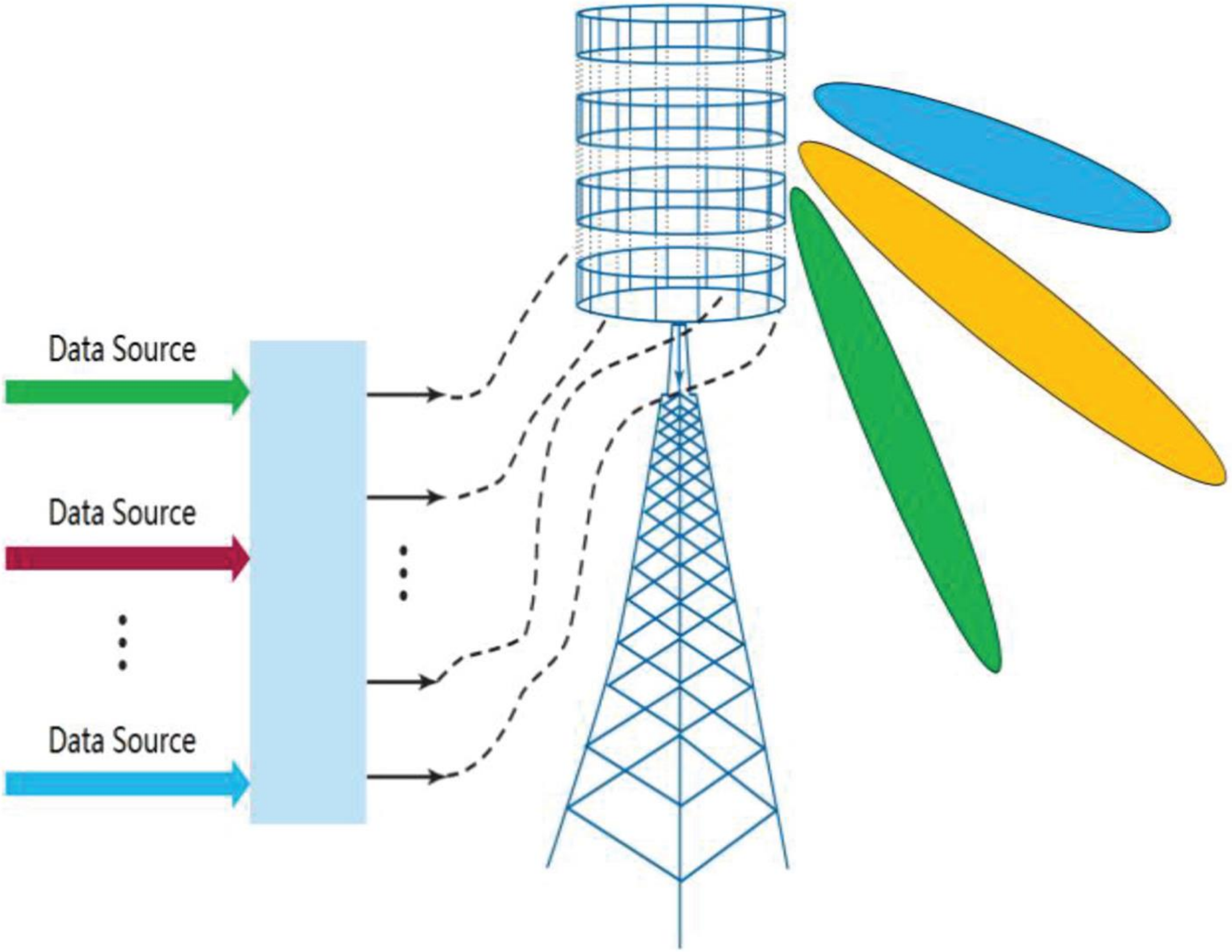
20 beams Massive-MIMO system covering 120° cell sector

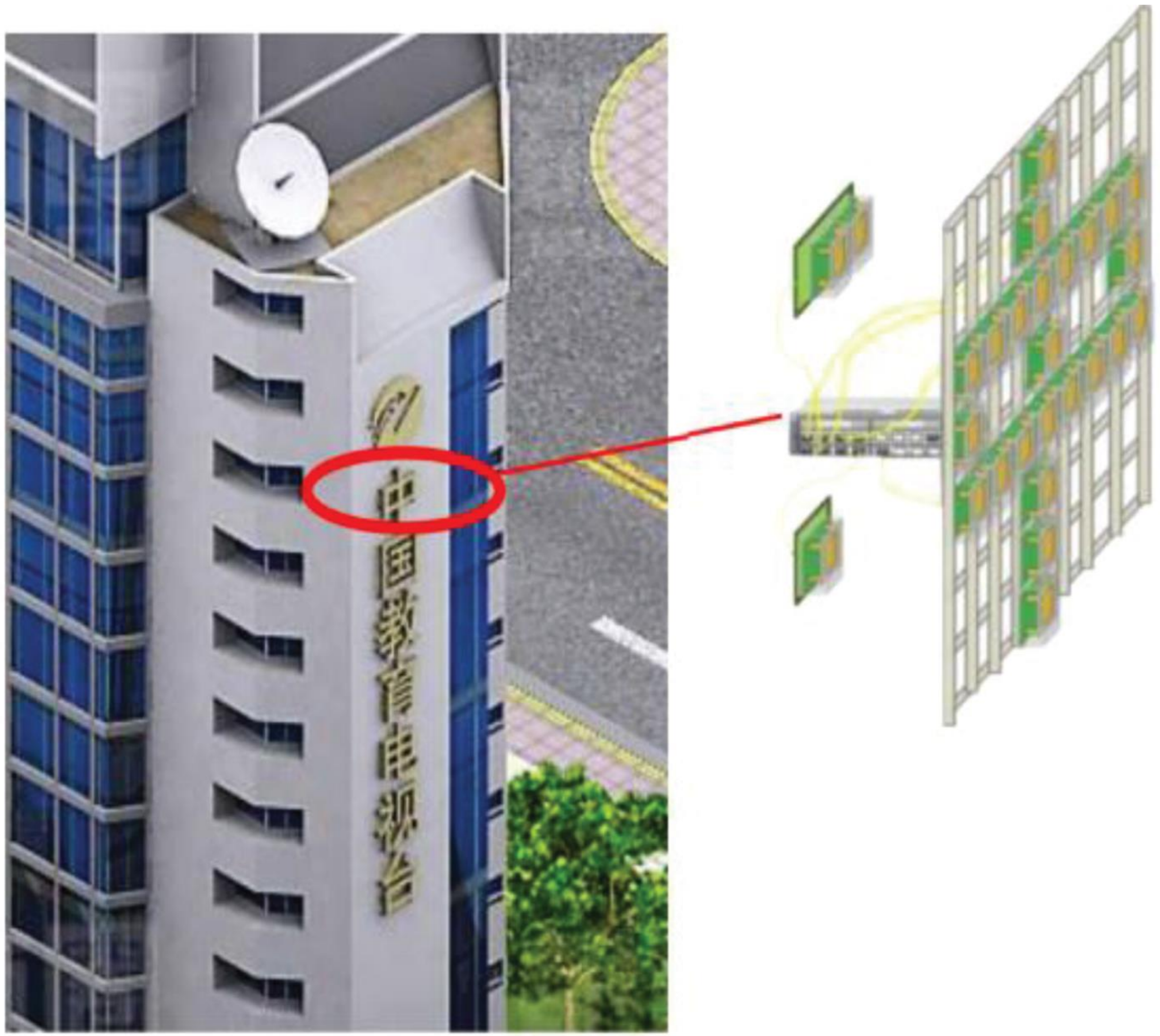
Source: 5G NR Beam Management and Beam Scheduling, Manoharan Ramalingam

Nokia has a system with 128 antennas all working together to form 32 beams and wants to schedule up to four beams in a specified amount of time. The number of possible ways to schedule four of 32 beams mathematically adds up to more than 30,000 options.

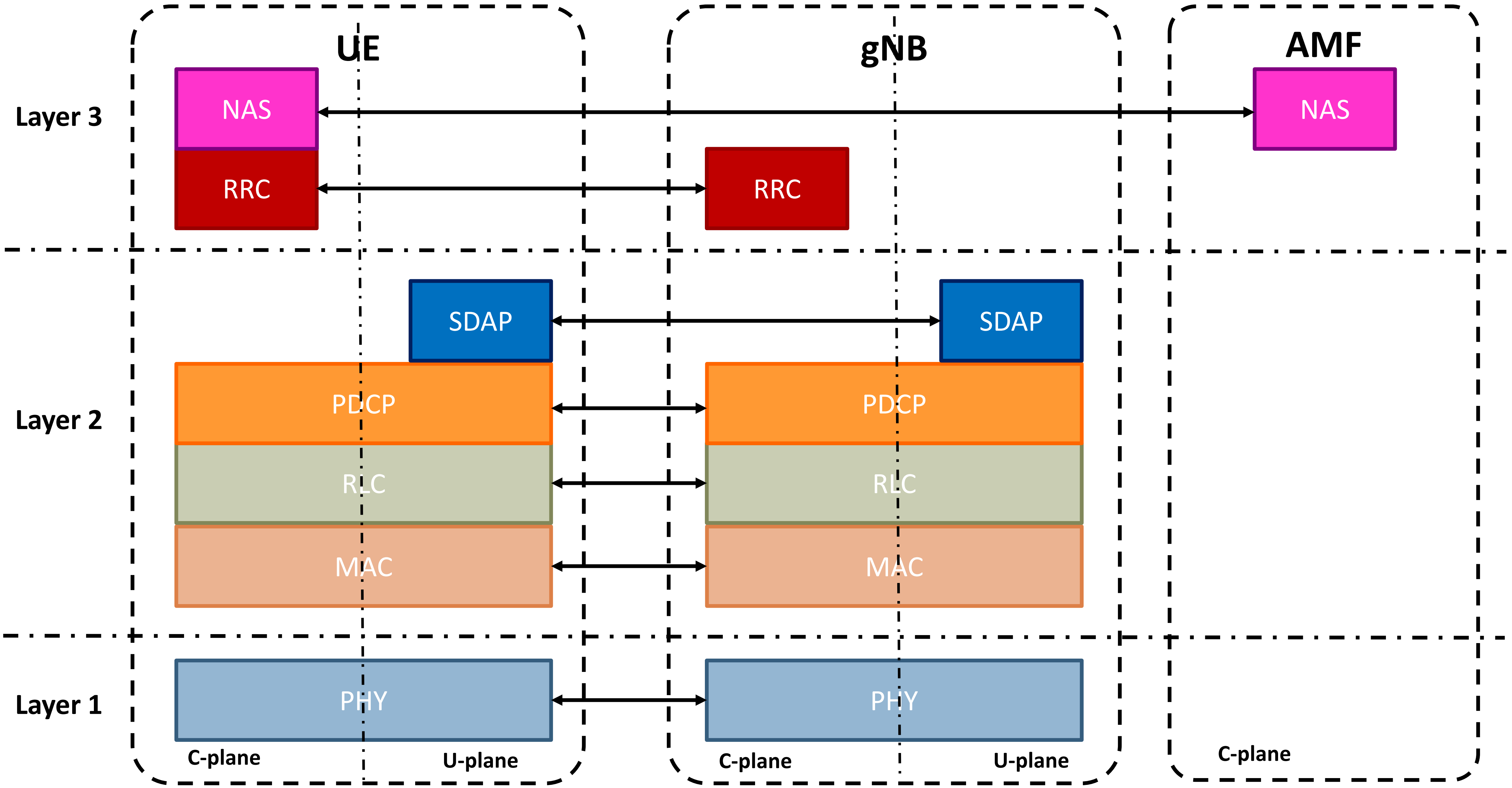
Source: 3 Ways Nokia is Using Machine Learning in 5G Networks, IEEE Spectrum, June 2018

Massive MIMO: Theory and Practice

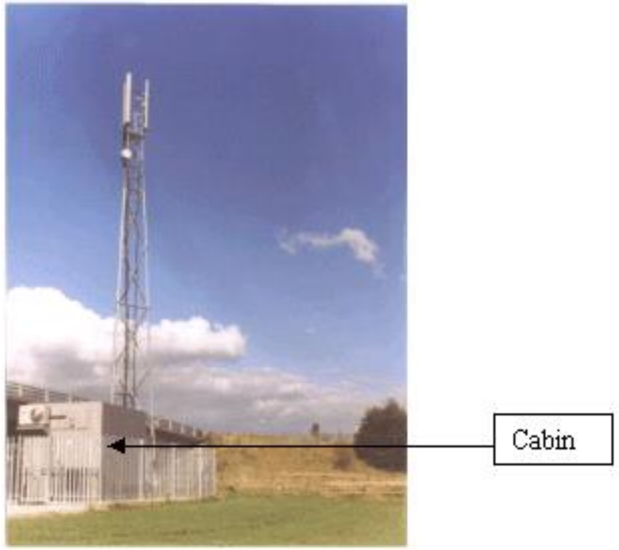


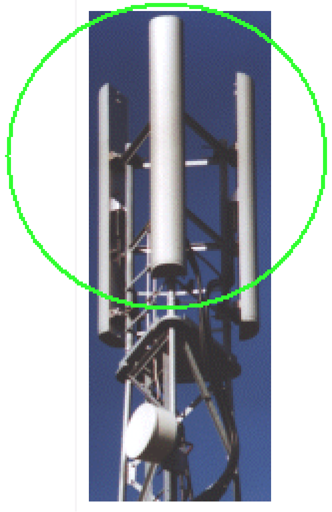


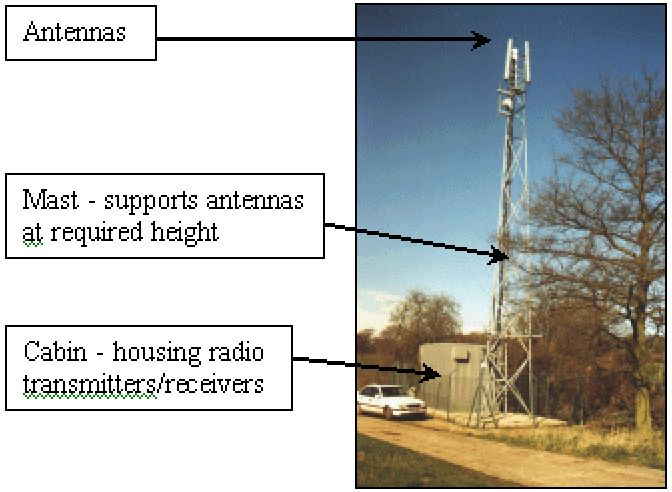
Source: Dr. Chih-Lin I.


UE
gNB
AMF
Layer 3
Layer 2
Layer 1
NAS
RRC
RRC
NAS
SDAP
SDAP
PDCP
PDCP
RLC
RLC
MAC
MAC
PHY
PHY
C-plane
U-plane
C-plane
U-plane
C-plane

Mobile Towers in Real Life



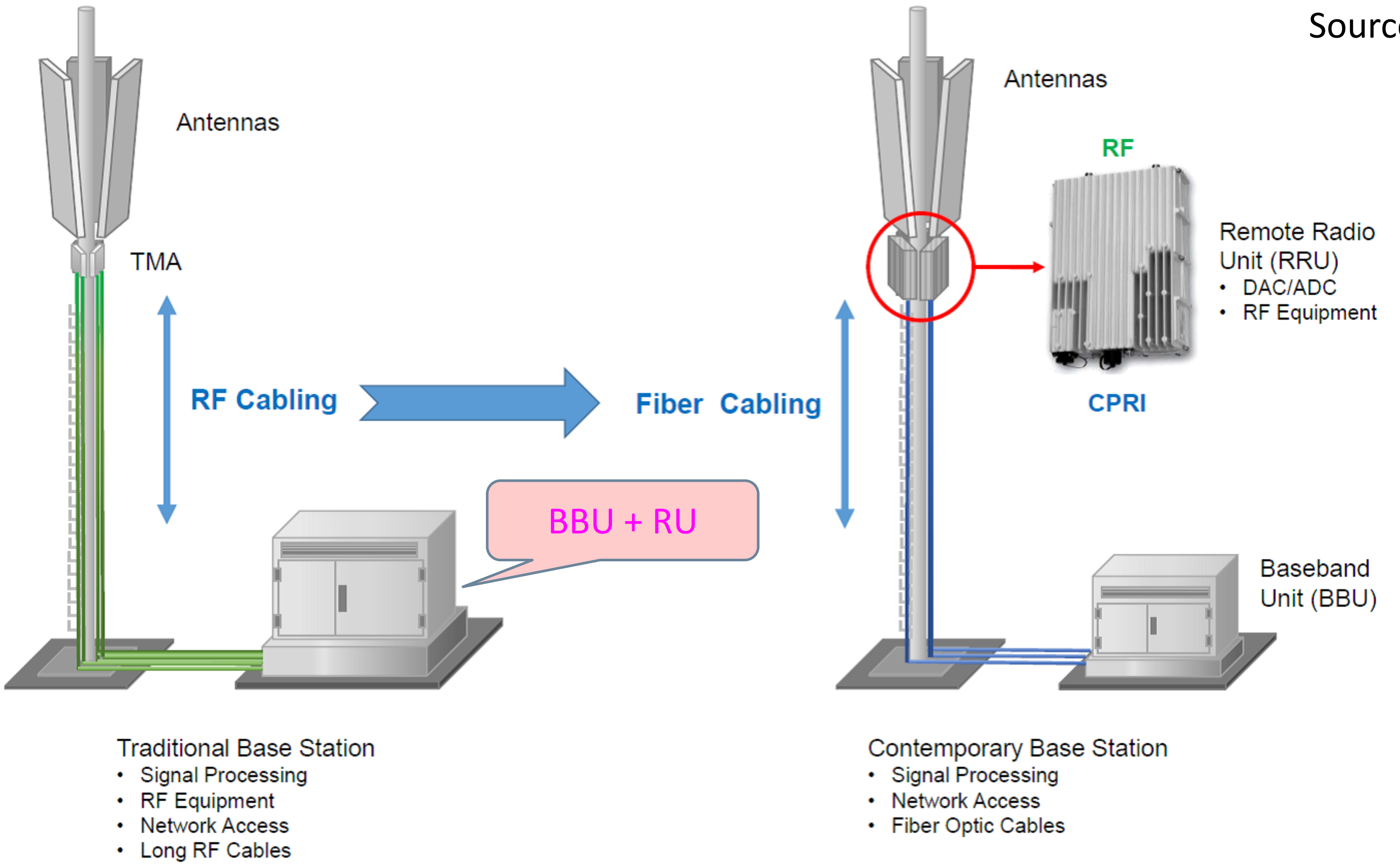




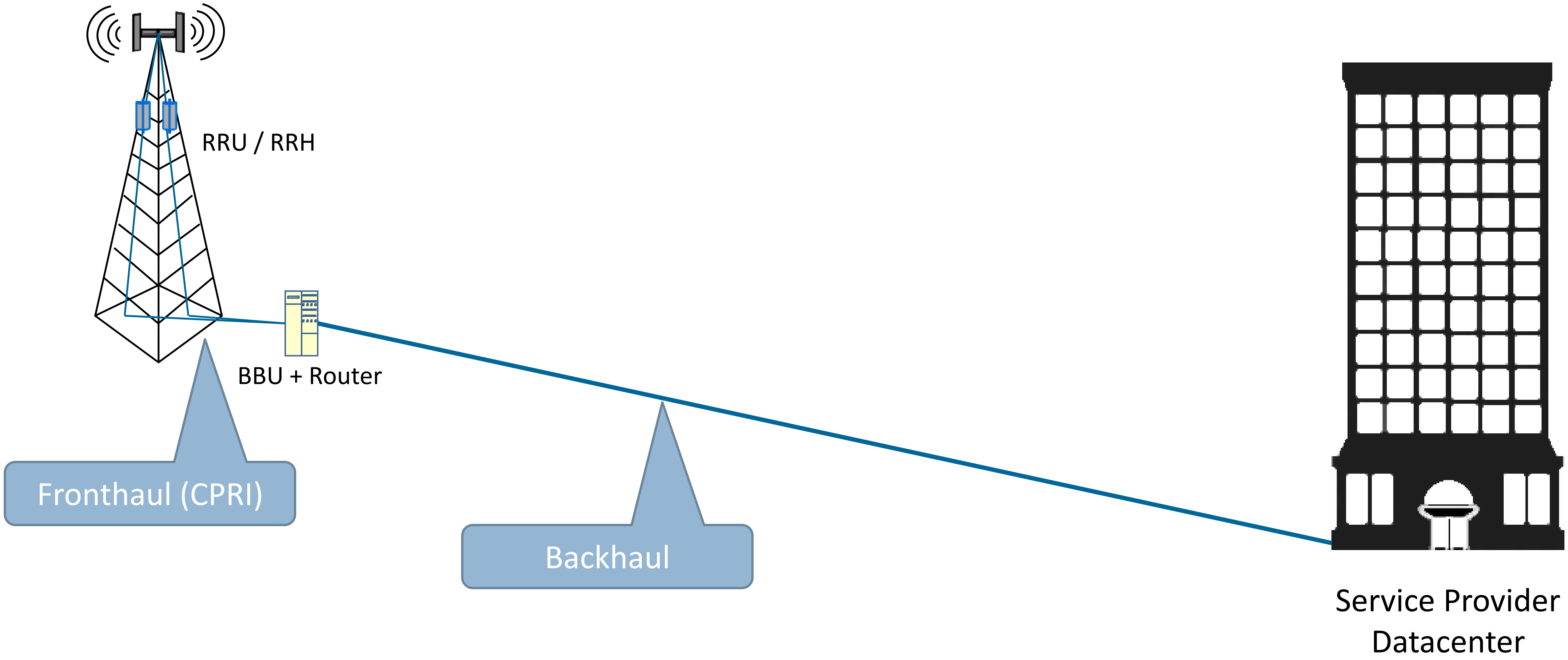
Source: [Ofcom]

Mobile Towers in Real Life

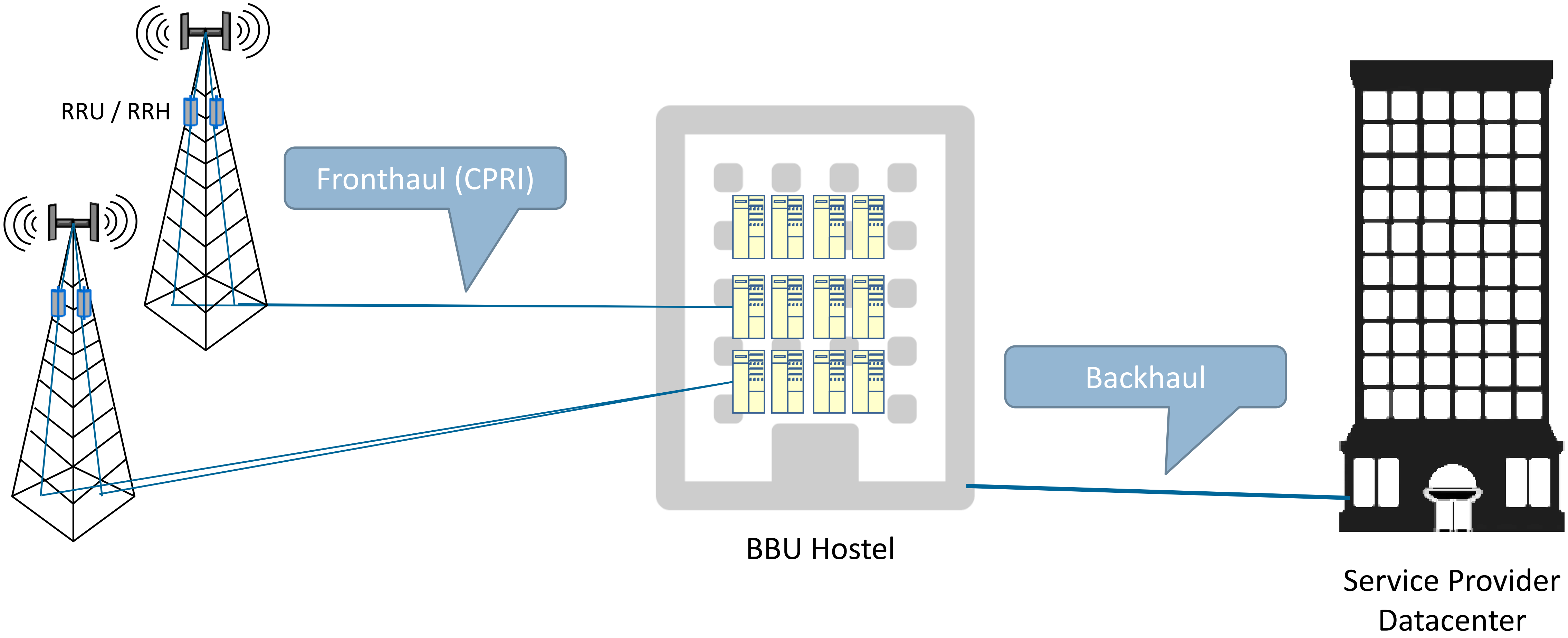
Source: National Instruments



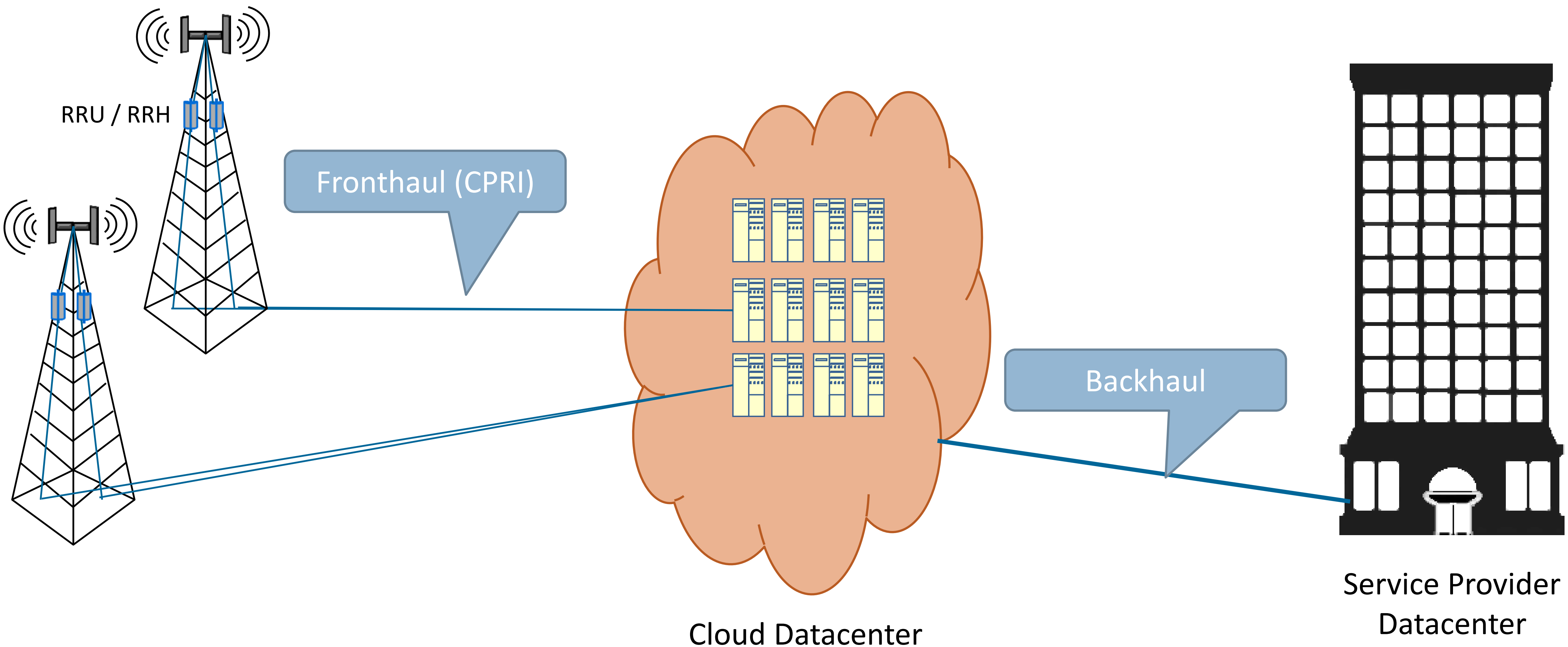
Macrocell Connections & Terminology



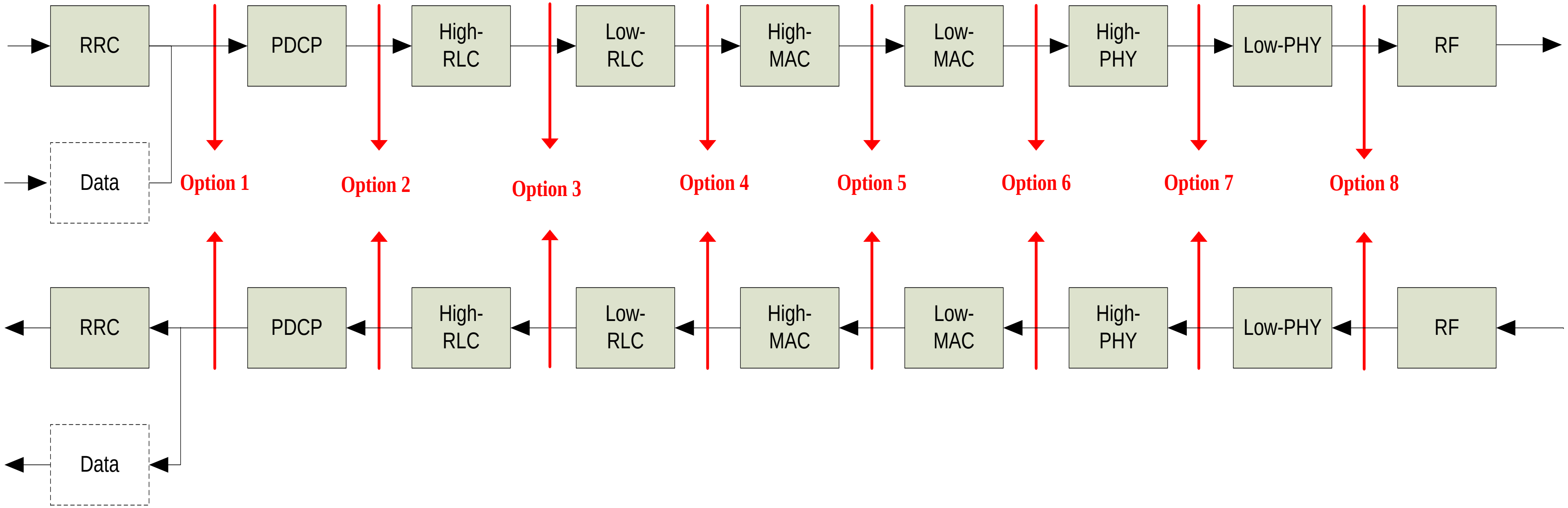
Centralized RAN (C-RAN) / BBU Hostelling



Cloud RAN (C-RAN)

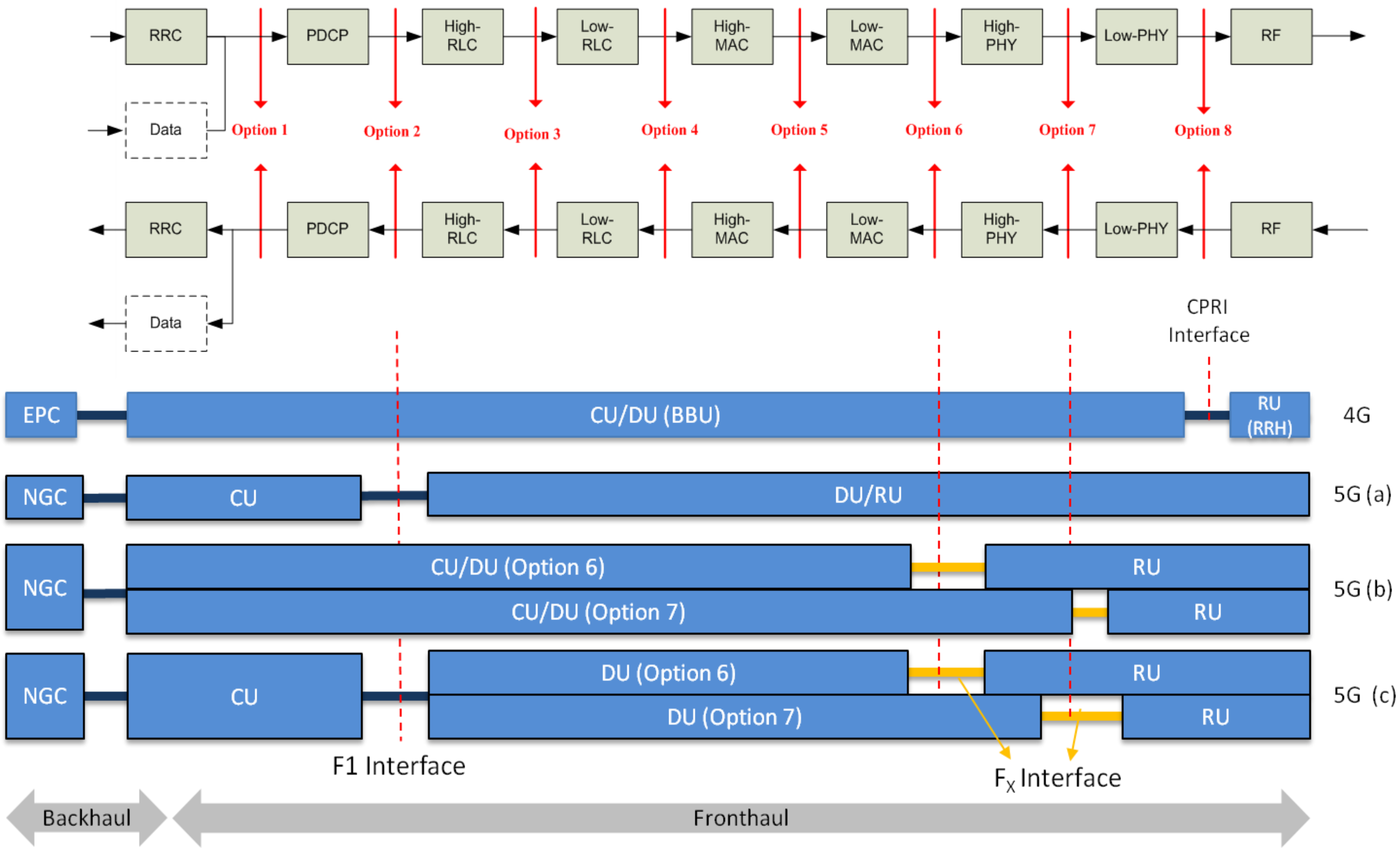


5G Split Point Options



Further details: 3GPP TR 38.801

Mapping of CU and DU functions according to the split points



CU – Central Unit

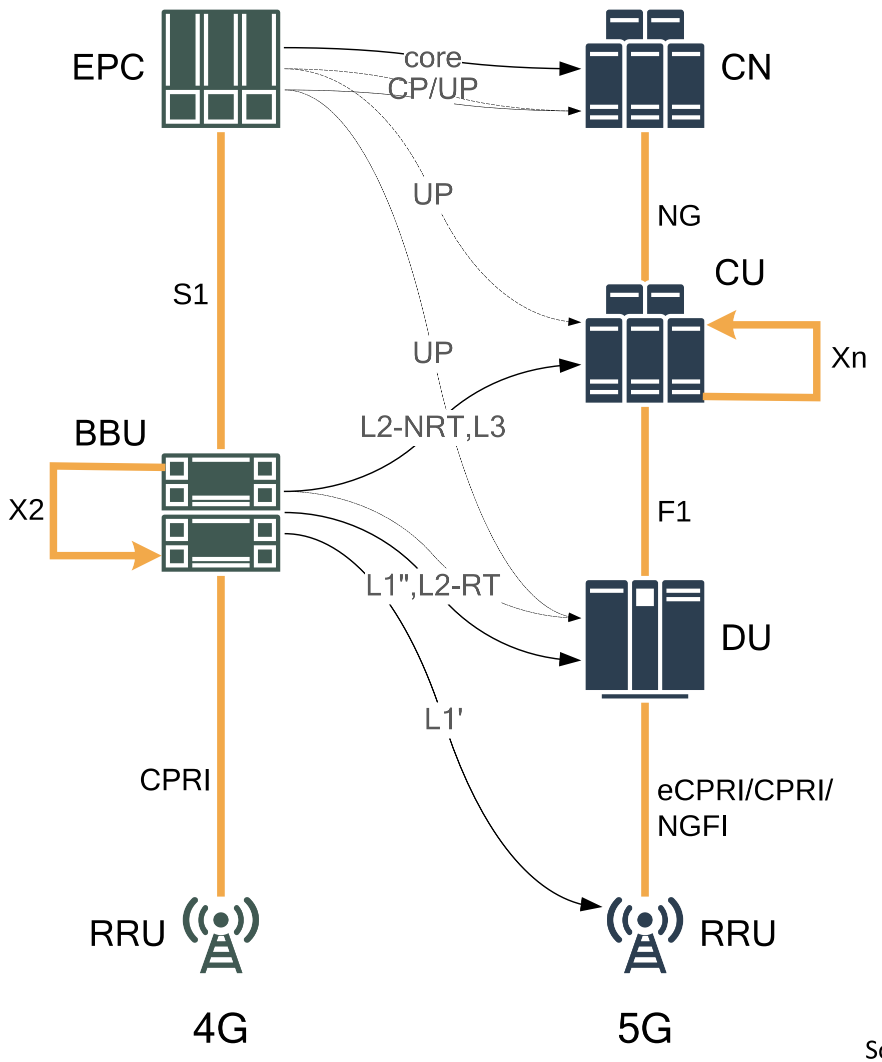
DU – Distributed Unit

RU – Remote Unit

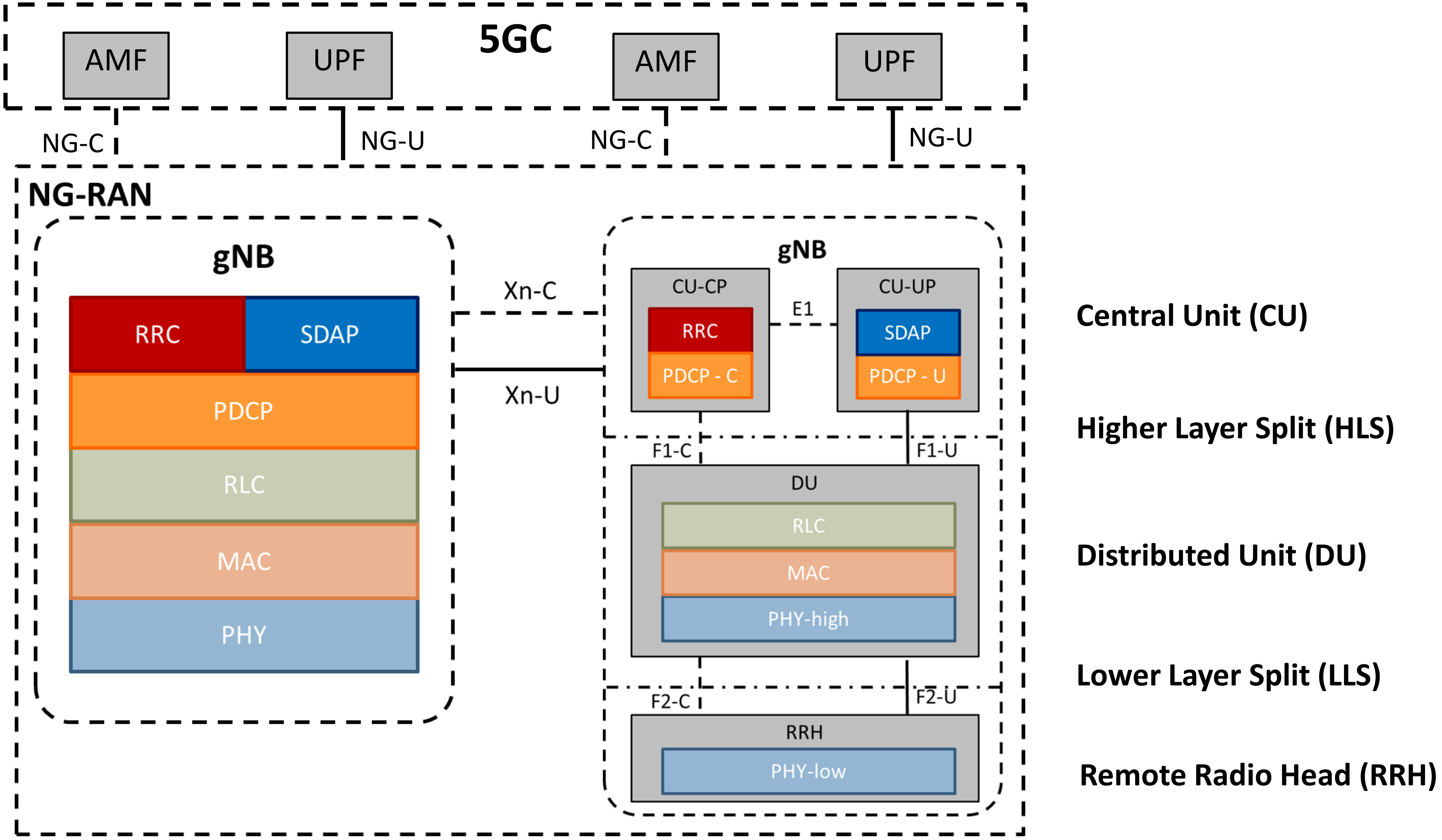
RRH – Remote Radio Head

NGC – Next-generation Core

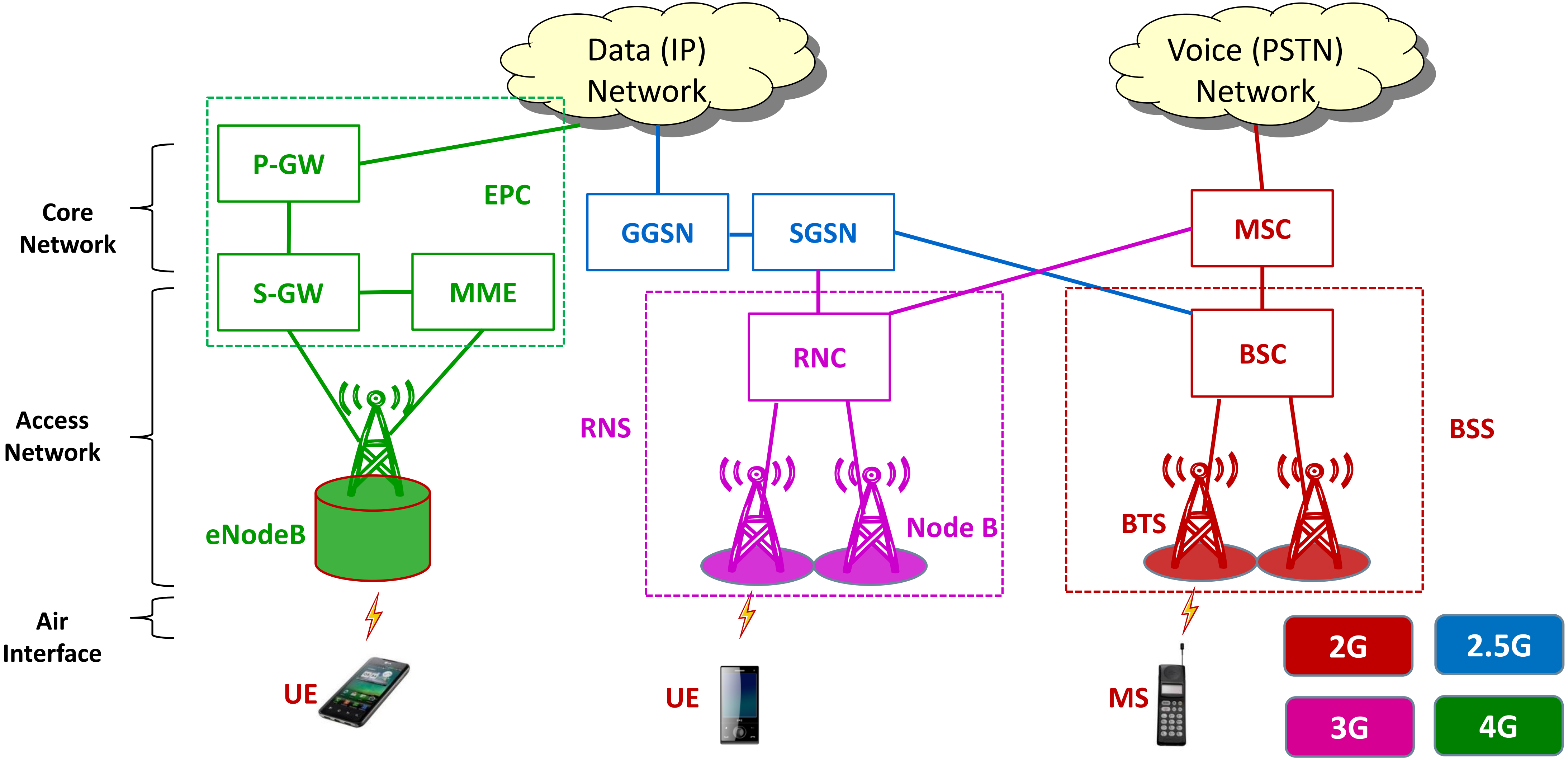
Evolving from single-node in 4G to split function architecture in 5G



Source: ITU-T GSTR-TN5G Transport network support of IMT-2020/5G


5GC
AMF
UPF
AMF
UPF
NG-C
NG-U
NG-C
NG-U
NG-RAN
gNB
RRC
SDAP
PDCP
RLC
MAC
PHY
Xn-C
Xn-U
gNB
CU-CP
RRC
PDCP - C
E1
CU-UP
SDAP
PDCP - U
F1-C
F1-U
DU
RLC
MAC
PHY-high
F2-C
F2-U
RRH
PHY-low
Central Unit (CU)
Higher Layer Split (HLS)
Distributed Unit (DU)
Lower Layer Split (LLS)
Remote Radio Head (RRH)

2G – 4G Reference Point Network Architecture



5GS Reference Point Representation

Release 15 3GPP TS 23.501 V15.0.0 (2017-12)

Figure 4.2.3-2 depicts the 5G System architecture in the non-roaming case, using the reference point representation showing how various network functions interact with each other.

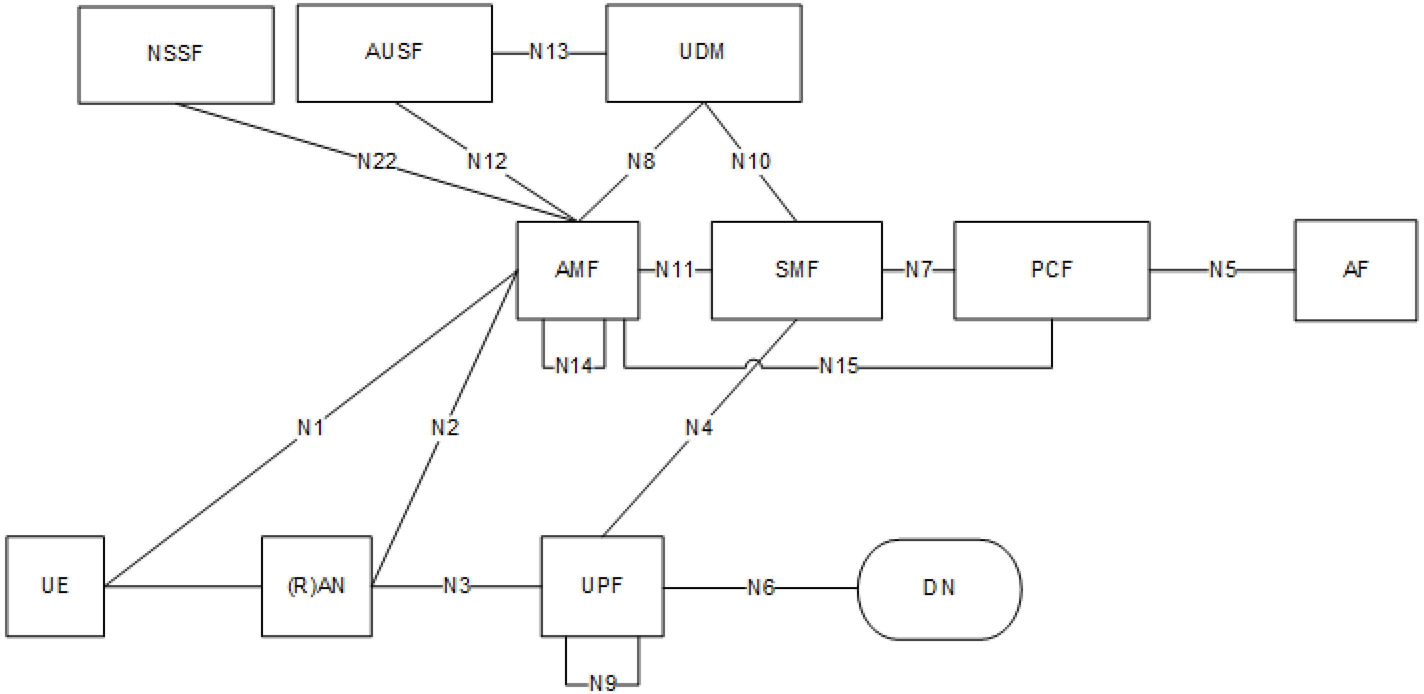


Figure 4.2.3-2: Non-Roaming 5G System Architecture in reference point representation

5GS Service Based Architecture (SBA)

Release 15 3GPP TS 23.501 V15.0.0 (2017-12)

4.2.3 Non-roaming reference architecture

Figure 4.2.3-1 depicts the non-roaming reference architecture. Service-based interfaces are used within the Control Plane.

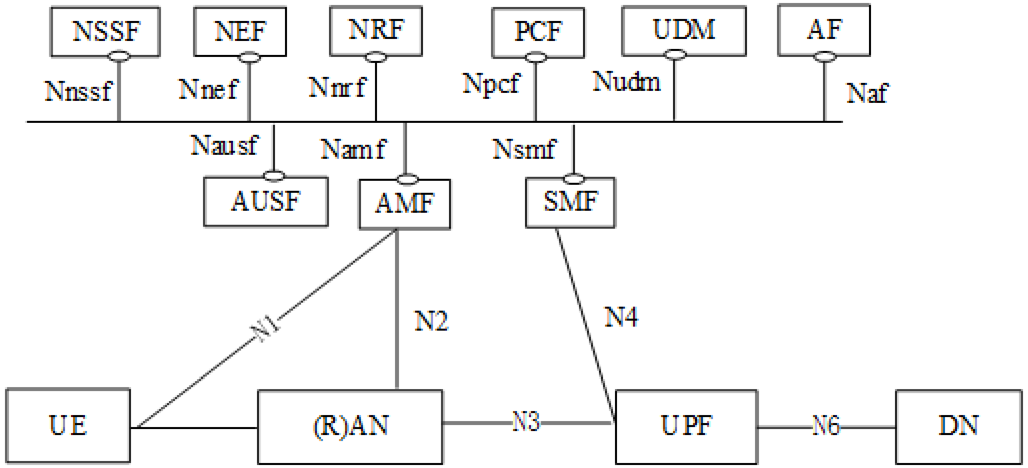
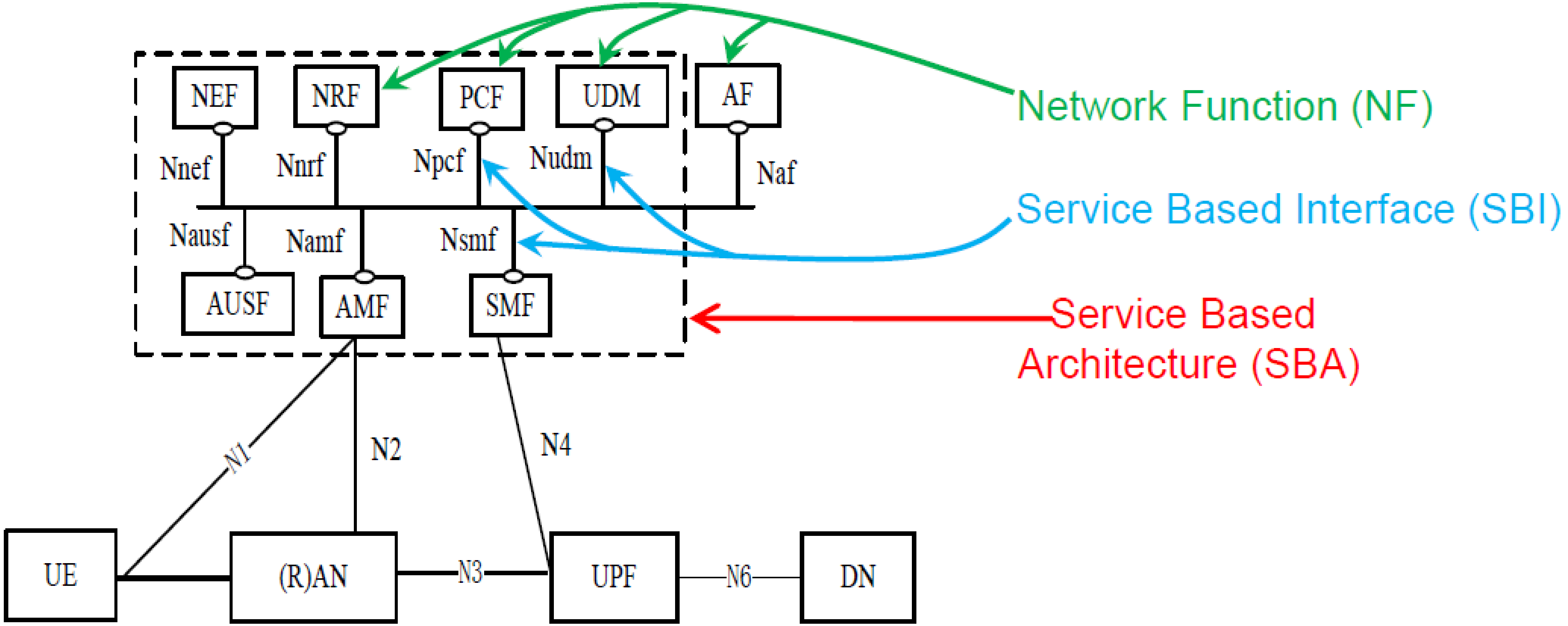


Figure 4.2.3-1: 5G System architecture

SBA Terminology



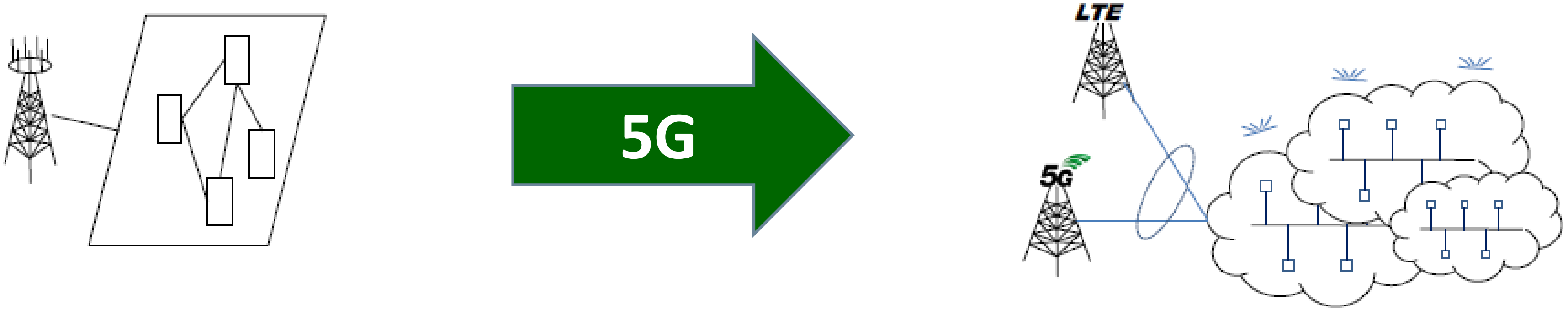
NF – Network Function

SBI – Service Based Interface

SBA – Service Based Architecture

Source: Georg Mayer

Core Network Architecture Evolution in 5G

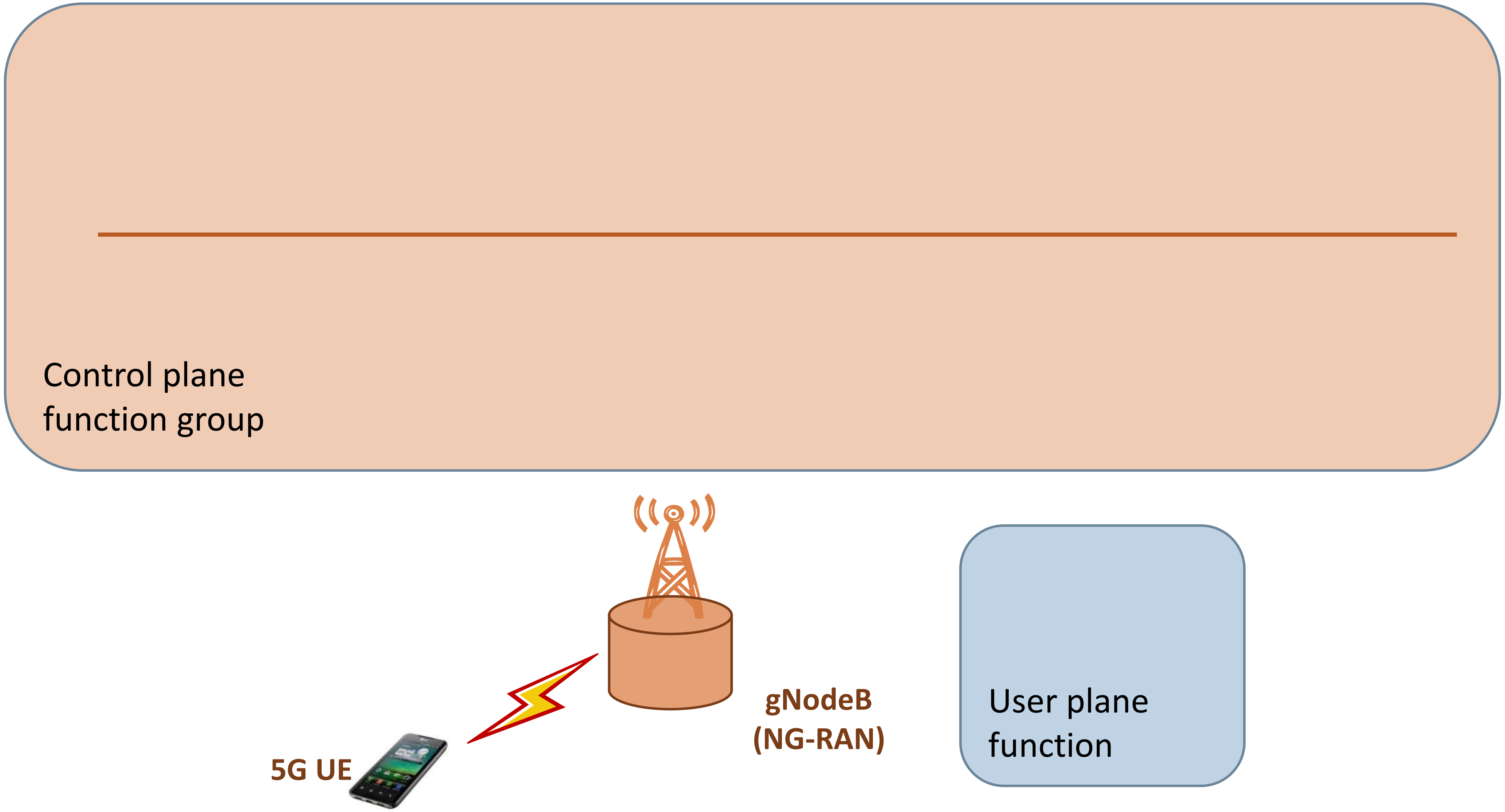


- Functional entities
- Single Core
- Dedicated protocols

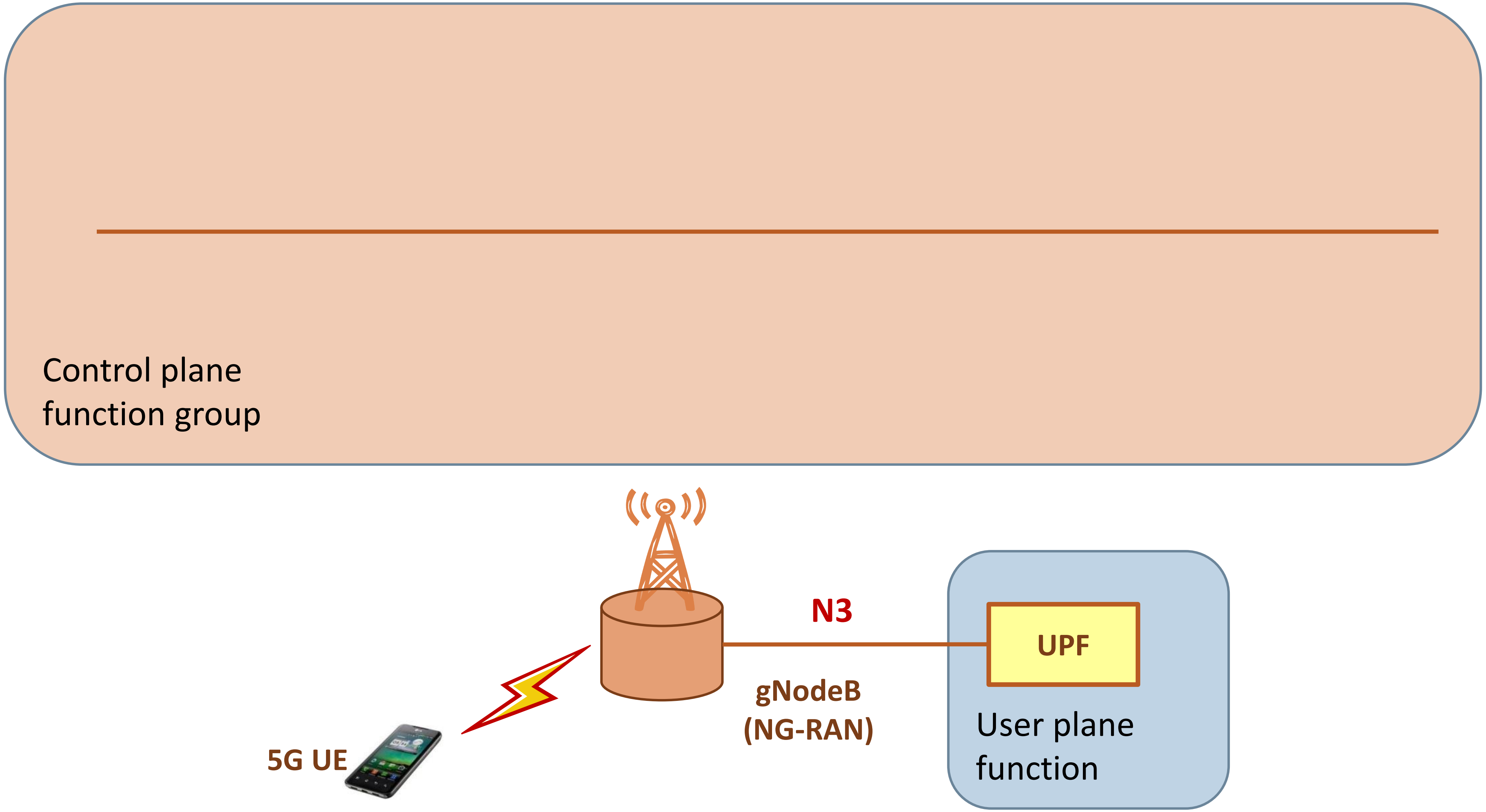
- Service Based (SBA/SBI/NAPS)
- Virtualization & Slicing
- Softwarization/ Cloudification
- Application Programming Interfaces
- Harmonized protocols (HTTP …)
- Exposure to 3rdParties
- Backward & Forward Compatibility

Source: Georg Mayer

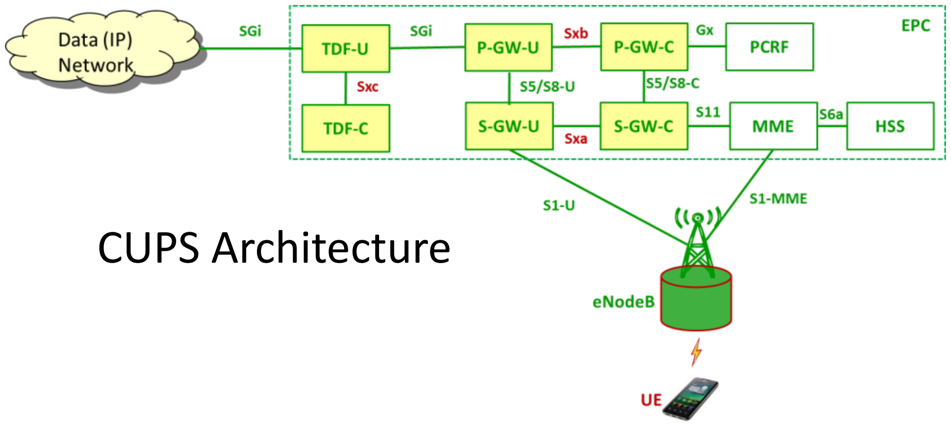
5GS Service Based Architecture (SBA)



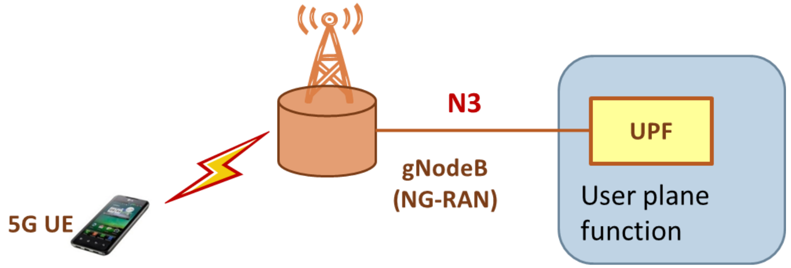
5GS Service Based Architecture (SBA)



User Plane Function (UPF)



CUPS Architecture



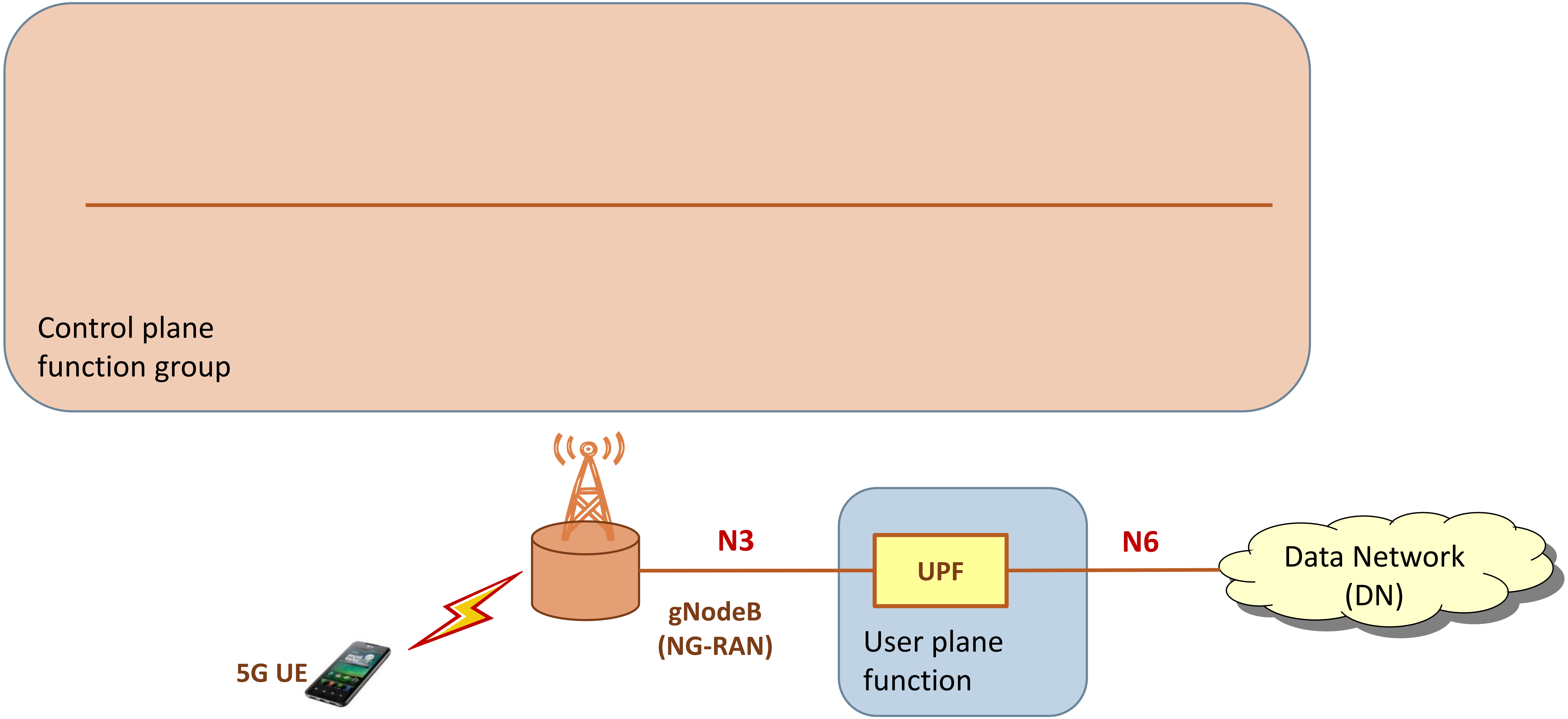
- The U-plane function (UPF) in the 5G core network provides functions specific to U-plane processing the same as S-GW-U and P-GW-U in CUPS.
- See section 6.2.3 of TS 23.501 for more details on functionality of UPF

User Plane Function (UPF)

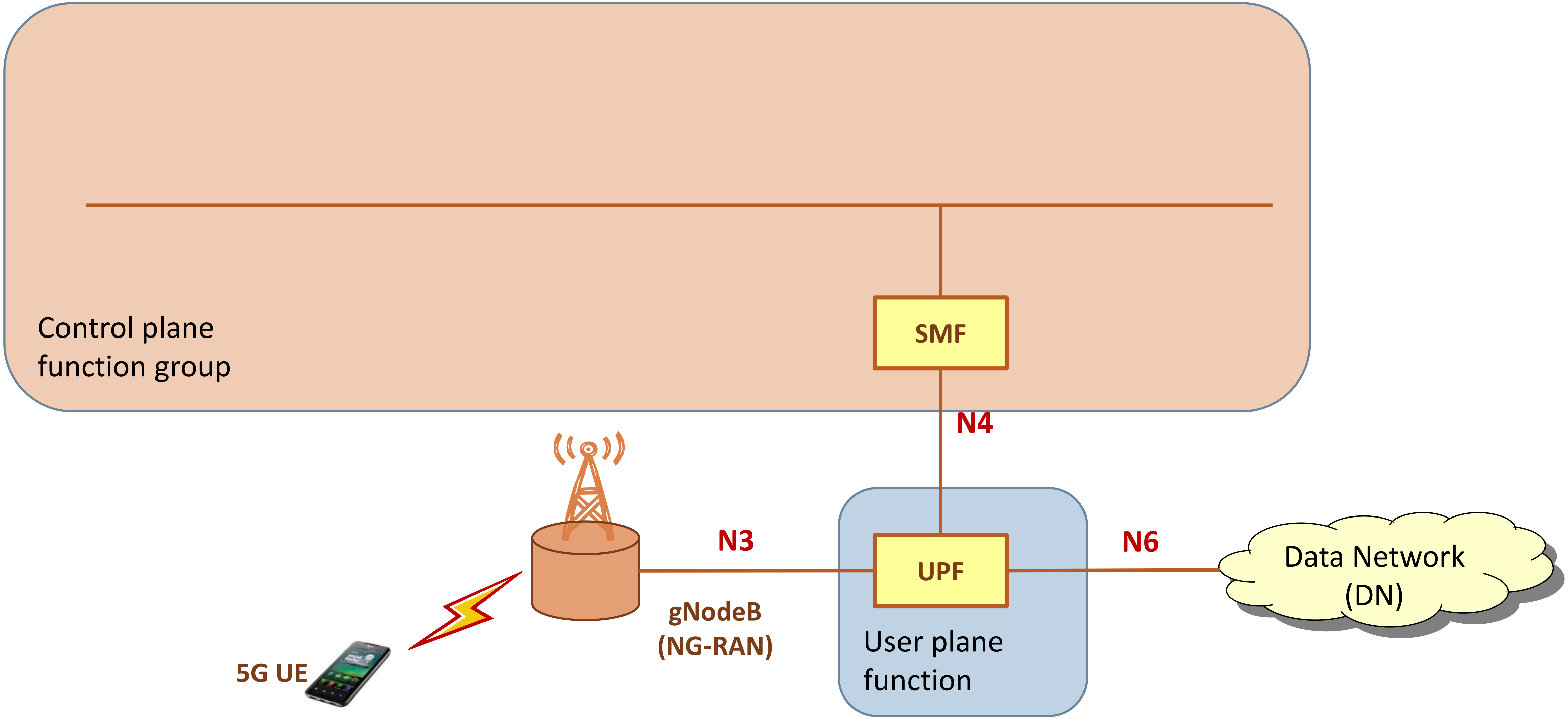
- Section 6.2.3 of TS 23.501 - The User plane function (UPF) includes the following functionality. Some or all of the UPF functionalities may be supported in a single instance of a UPF:
    - Anchor point for Intra-/Inter-RAT mobility (when applicable).
    - External PDU Session point of interconnect to Data Network.
    - Packet routing & forwarding (e.g. support of Uplink classifier to route traffic flows to an instance of a data network, support of Branching point to support multi-homed PDU session).
    - Packet inspection (e.g. Application detection based on service data flow template and the optional PFDs received from the SMF in addition).
    - User Plane part of policy rule enforcement, e.g. Gating, Redirection, Traffic steering).
    - Lawful intercept (UP collection).
    - Traffic usage reporting.
    - QoS handling for user plane, e.g. UL/DL rate enforcement, Reflective QoS marking in DL.
    - Uplink Traffic verification (SDF to QoS Flow mapping).
    - Transport level packet marking in the uplink and downlink.
    - Downlink packet buffering and downlink data notification triggering.
    - Sending and forwarding of one or more "end marker" to the source NG-RAN node.
    - ARP proxying as specified in IETF RFC 1027 and / or IPv6 Neighbour Solicitation Proxying as specified in IETF RFC 4861 functionality for the Ethernet PDUs. The UPF responds to the ARP and / or the IPv6 Neighbour Solicitation Request by providing the MAC address corresponding to the IP address sent in the request.

  NOTE:Not all of the UPF functionalities are required to be supported in an instance of user plane function of a Network Slice.

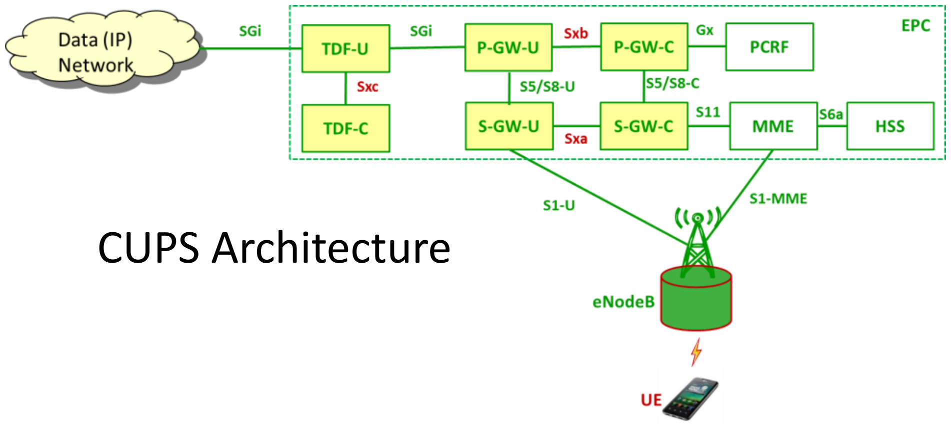
5GS Service Based Architecture (SBA)



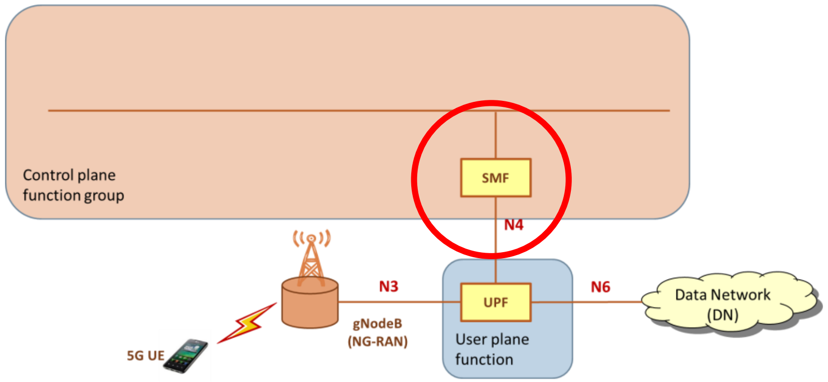
5GS Service Based Architecture (SBA)



Session Management Function (SMF)



CUPS Architecture



- The control plane functionality has been slightly re-organized in 5G core network. Instead of MME, S-GW-C & P-GW-C in EPC, the functionality has been divided between Session Management Function (SMF) and Access & Mobility management Function.
- There can be multiple SMFs associated with the UE. One for each slice.
- See section 6.2.2 of TS 23.501 for more details on functionality of SMF

Session Management Function (SMF)

- Section 6.2.2 of TS 23.501 - The Session Management function (SMF) includes the following functionality. Some or all of the SMF functionalities may be supported in a single instance of a SMF:
  - Session Management e.g. Session establishment, modify and release, including tunnel maintain between UPF and AN node.
  - UE IP address allocation & management (including optional Authorization).
  - DHCPv4 (server and client) and DHCPv6 (server and client) functions.
  - ARP proxying as specified in IETF RFC 1027 [53] and / or IPv6 Neighbour Solicitation Proxying as specified in IETF RFC 4861 [54] functionality for the Ethernet PDUs. The SMF responds to the ARP and / or the IPv6 Neighbour Solicitation Request by providing the MAC address corresponding to the IP address sent in the request.
  - Selection and control of UP function, including controlling the UPF to proxy ARP or IPv6 Neighbour Discovery, or to forward all ARP/IPv6 Neighbour Solicitation traffic to the SMF, for Ethernet PDU Sessions.
  - Configures traffic steering at UPF to route traffic to proper destination.
  - Termination of interfaces towards Policy control functions.
  - Lawful intercept (for SM events and interface to LI System).
  - Charging data collection and support of charging interfaces.
  - Control and coordination of charging data collection at UPF.
  - Termination of SM parts of NAS messages.
  - Downlink Data Notification.
  - Initiator of AN specific SM information, sent via AMF over N2 to AN.
  - Determine SSC mode of a session.

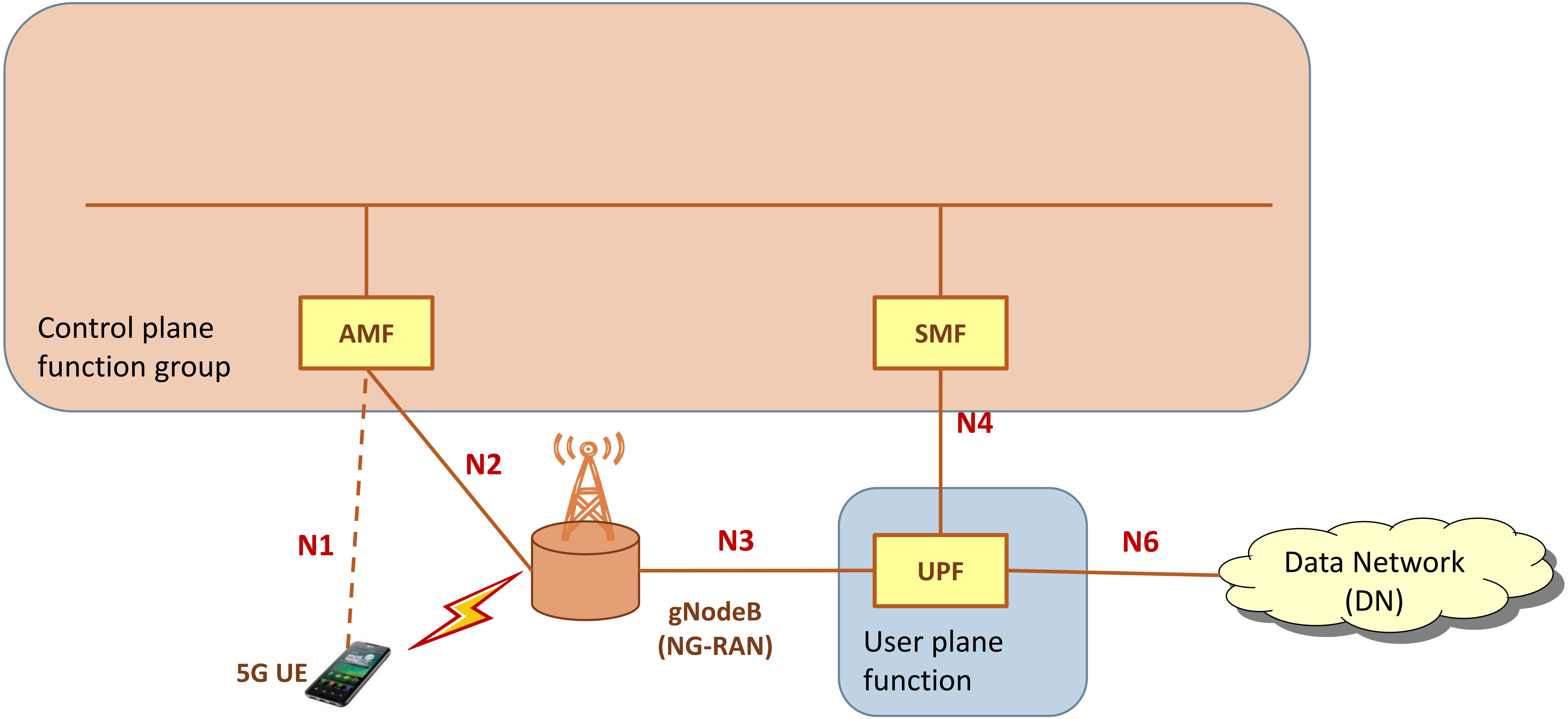
Session Management Function (SMF)

- Roaming functionality:
- Handle local enforcement to apply QoS SLAs (VPLMN).
- Charging data collection and charging interface (VPLMN).
- Lawful intercept (in VPLMN for SM events and interface to LI System).
- Support for interaction with external DN for transport of signalling for PDU Session authorization/authentication by external DN.

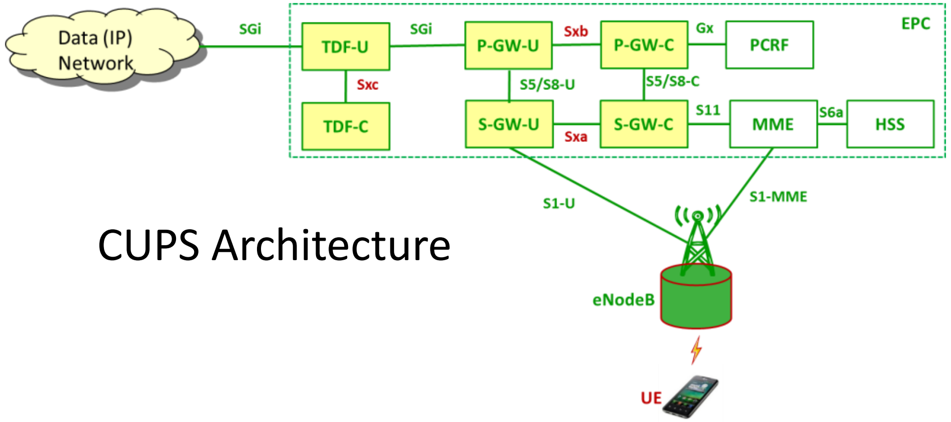
NOTE: Not all of the functionalities are required to be supported in a instance of a Network Slice.

In addition to the functionalities of the SMF described above, the SMF may include policy related functionalities as described in clause 6.2.2 in TS 23.503.

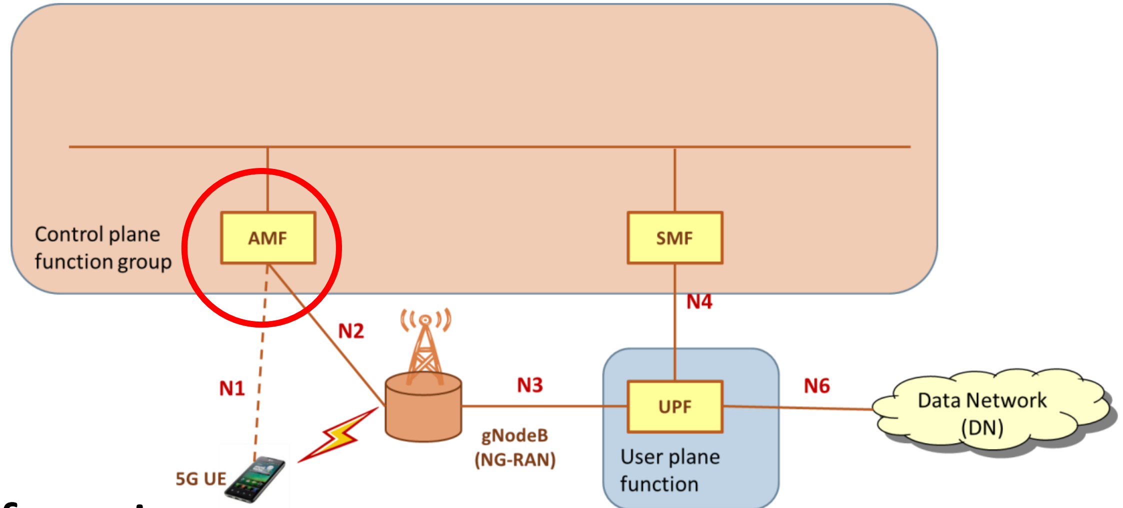
5GS Service Based Architecture (SBA)



Access & Mobility management Function (AMF)



CUPS Architecture



- AMF is a single node to manage all UE related functions.
- The EPC functionality of MME, S-GW-C & P-GW-C has been reallocated so that all access and mobility functionality is done by AMF
- See section 6.2.1 of TS 23.501 for more details on functionality of AMF

Access & Mobility management Function (AMF)

Section 6.2.1 of TS 23.501 - The Access and Mobility Management function (AMF) includes the following functionality. Some or all of the AMF functionalities may be supported in a single instance of an AMF:

- Termination of RAN CP interface (N2).
- Termination of NAS (N1), NAS ciphering and integrity protection.
- Registration management.
- Connection management.
- Reachability management.
- Mobility Management.
- Lawful intercept (for AMF events and interface to LI System).
- Provide transport for SM messages between UE and SMF.
- Transparent proxy for routing SM messages.
- Access Authentication.
- Access Authorization.
- Provide transport for SMS messages between UE and SMSF.
- Security Anchor Functionality (SEAF). It interacts with the AUSF and the UE, receives the intermediate key that was established as a result of the UE authentication process. In case of USIM based authentication, the AMF retrieves the security material from the AUSF.
- Security Context Management (SCM). The SCM receives a key from the SEAF that it uses to derive access-network specific keys.
- Location Services management for regulatory services.
- Provide transport for Location Services messages between UE and LMF as well as between RAN and LMF.
- EPS Bearer ID allocation for interworking with EPS.

NOTE 1: Regardless of the number of Network functions, there is only one NAS interface instance per access network between the UE and the CN, terminated at one of the Network functions that implements at least NAS security and Mobility Management.

Access & Mobility management Function (AMF)

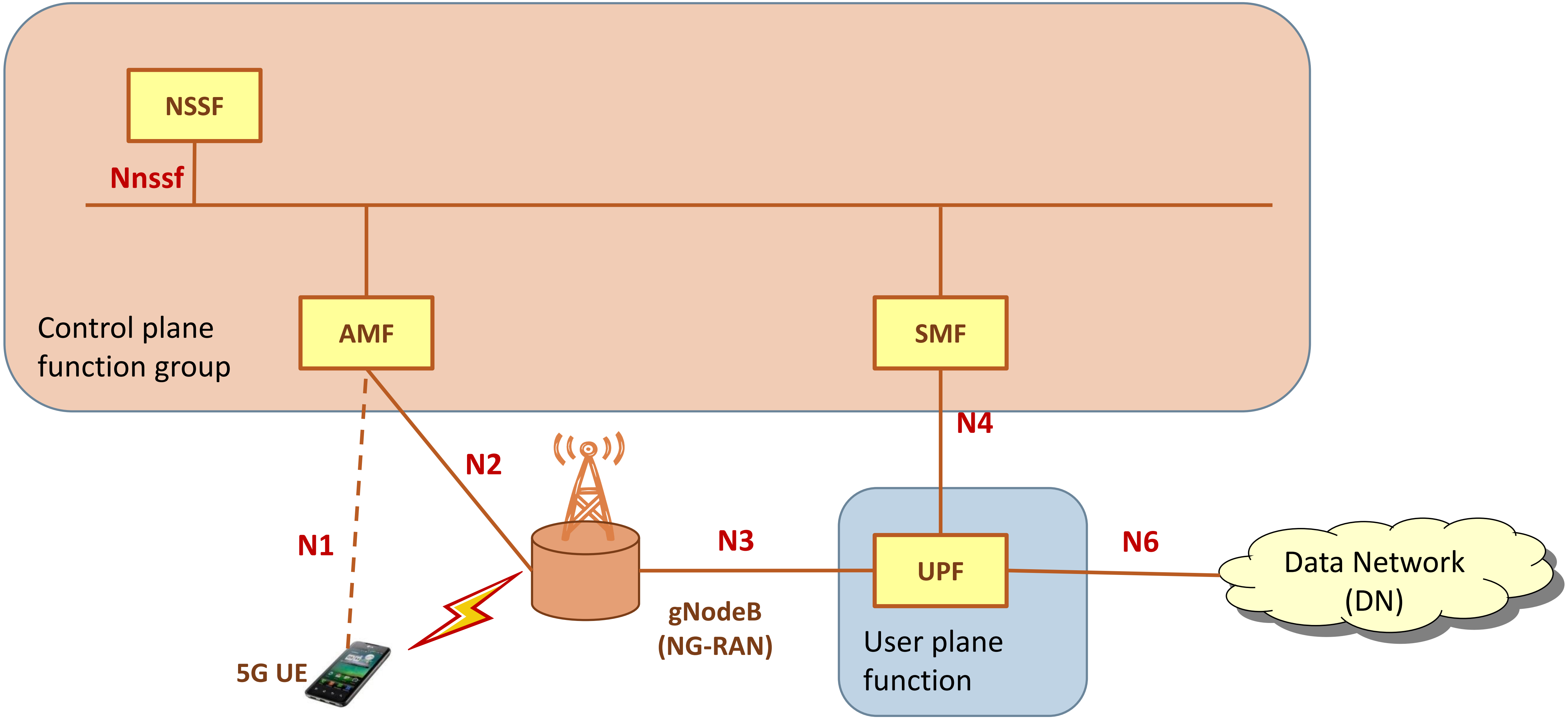
In addition to the functionalities of the AMF described above, the AMF may include the following functionality to support non-3GPP access networks:

- Support of N2 interface with N3IWF. Over this interface, some information (e.g. 3GPP cell Identification) and procedures (e.g. Hand-Over related) defined over 3GPP access may not apply, and non-3GPP access specific information may be applied that do not apply to 3GPP accesses.
- Support of NAS signalling with a UE over N3IWF. Some procedures supported by NAS signalling over 3GPP access may be not applicable to untrusted non-3GPP (e.g. Paging) access.
- Support of authentication of UEs connected over N3IWF.
- Management of mobility, authentication, and separate security context state(s) of a UE connected via non-3GPP access or connected via 3GPP and non-3GPP accesses simultaneously.
- Support as described in clause 5.3.2.3 a co-ordinated RM management context valid over 3GPP and Non 3GPP accesses.
- Support as described in clause 5.3.3.4 dedicated CM management contexts for the UE for connectivity over non-3GPP access.

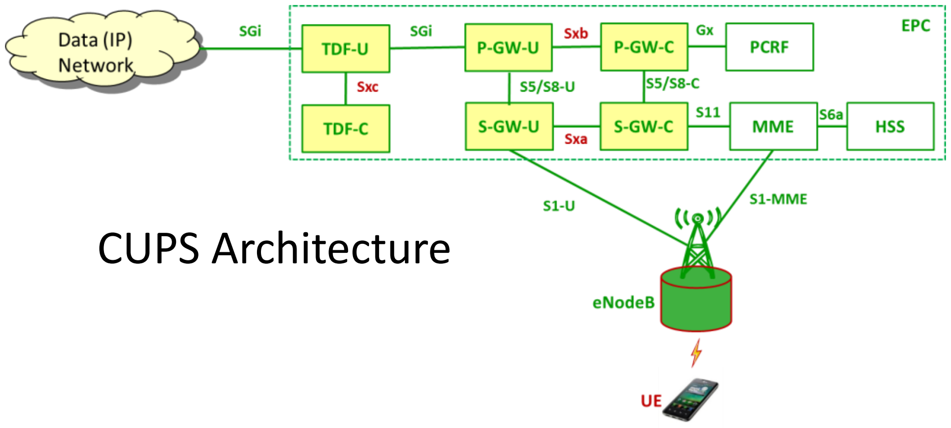
NOTE 2: Not all of the functionalities are required to be supported in an instance of a Network Slice.

In addition to the functionalities of the AMF described above, the AMF may include policy related functionalities as described in clause 6.2.8 in TS 23.503

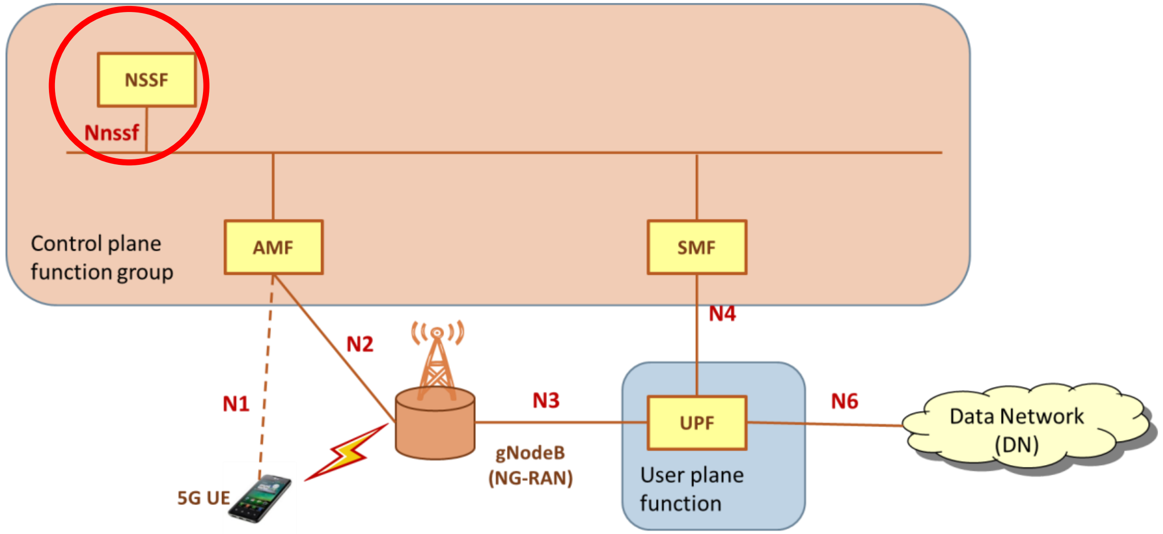
5GS Service Based Architecture (SBA)



Network Slice Selection Function (NSSF)



CUPS Architecture



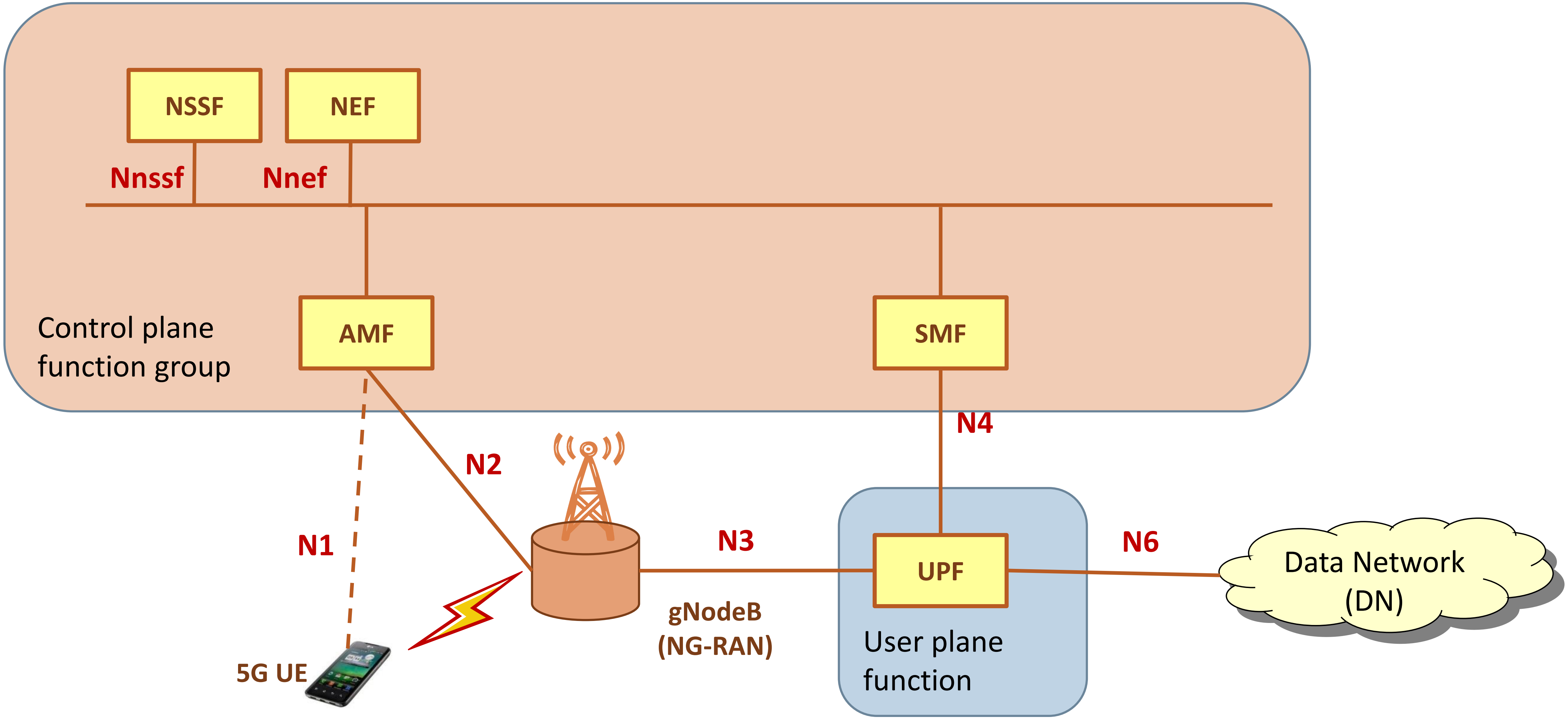
- NSSF supports the following functionality:
  - Selecting the set of Network Slice instances serving the UE,
  - Determining the Allowed NSSAI (Network Slice Selection Assistance Information) and, if needed, the mapping to the Subscribed S-NSSAIs,
  - Determining the AMF Set to be used to serve the UE, or, based on configuration, a list of candidate AMF(s), possibly by querying the NRF.

Network Slice Selection Function (NSSF)

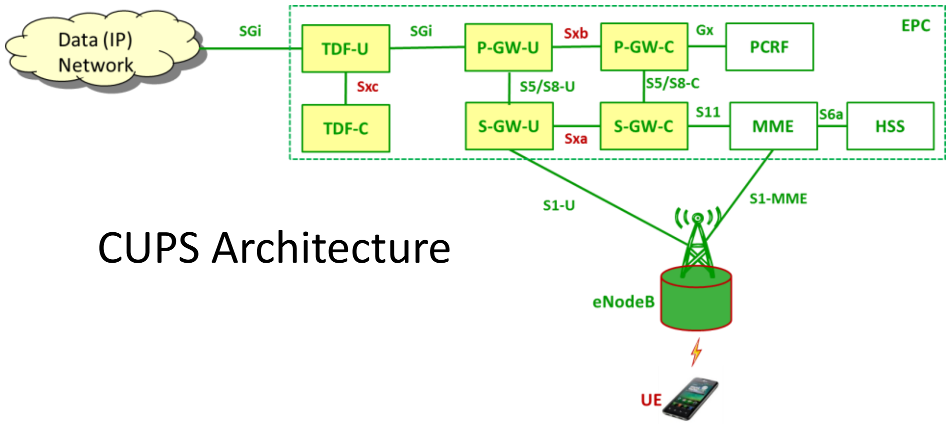
Section 6.2.14 of TS 23.501 - The Network Slice Selection Function (NSSF) supports the following functionality:

- Selecting the set of Network Slice instances serving the UE,
- Determining the Allowed NSSAI and, if needed, the mapping to the Subscribed S-NSSAIs,
- Determining the AMF Set to be used to serve the UE, or, based on configuration, a list of candidate AMF(s), possibly by querying the NRF.

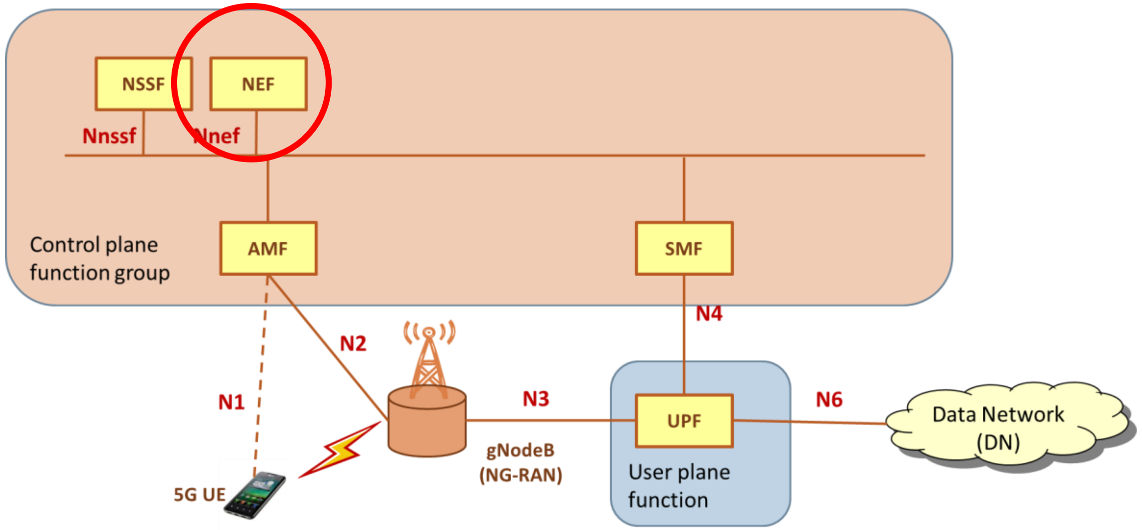
5GS Service Based Architecture (SBA)



Network Exposure Function (NEF)



CUPS Architecture



- A Network Exposure Function (NEF) having a function similar to the Service Capability Exposure Function (SCEF) in EPC.
- See section 6.2.5 of TS 23.501 for more details on functionality of NEF

Network Exposure Function (NEF)

Section 6.2.5 of TS 23.501 - The Network Exposure Function (NEF) supports the following independent functionality:

- Exposure of capabilities and events:
  3GPP NFs expose capabilities and events to other NFs via NEF. NF exposed capabilities and events may be securely exposed for e.g. 3rd party, Application Functions, Edge Computing as described in clause 5.13.
  NEF stores/retrieves information as structured data using a standardized interface (Nudr) to the Unified Data Repository (UDR).

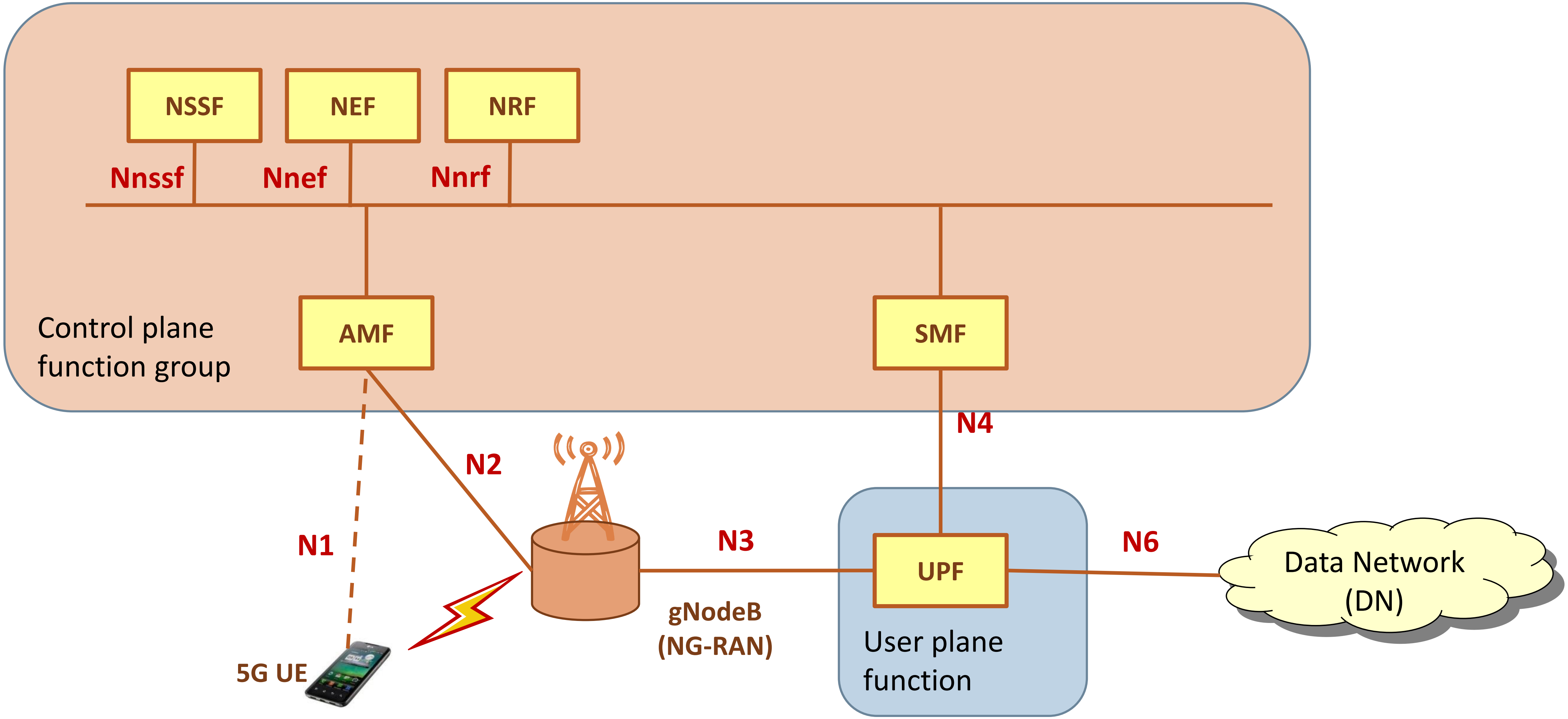
NOTE:The NEF can access the UDR located in the same PLMN as the NEF.

- Secure provision of information from external application to 3GPP network:
  It provides a means for the Application Functions to securely provide information to 3GPP network, e.g. Expected UE Behaviour. In that case the NEF may authenticate and authorize and assist in throttling the Application Functions.
- Translation of internal-external information:
  It translates between information exchanged with the AF and information exchanged with the internal network function. For example, it translates between an AF-Service-Identifier and internal 5G Core information such as DNN, S-NSSAI, as described in clause 5.6.7.
  In particular, NEF handles masking of network and user sensitive information to external AF's according to the network policy.
- The Network Exposure Function receives information from other network functions (based on exposed capabilities of other network functions). NEF stores the received information as structured data using a standardized interface to a Unified Data Repository (UDR) (interface to be defined by 3GPP). The stored information can be accessed and "re-exposed" by the NEF to other network functions and Application Functions, and used for other purposes such as analytics.
- A NEF may also support a PFD Function: The PFD Function in the NEF may store and retrieve PFD(s) in the UDR and shall provide PFD(s) to the SMF on the request of SMF (pull mode) or on the request of PFD management from NEF (push mode), as described in TS 23.503.

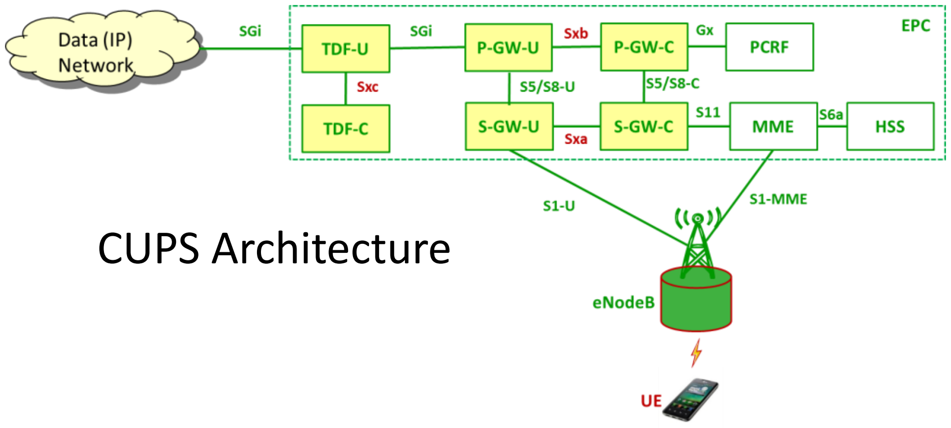
A specific NEF instance may support one or more of the functionalities described above and consequently an individual NEF may support a subset of the APIs specified for capability exposure.

NOTE:The NEF can access the UDR located in the same PLMN as the NEF.

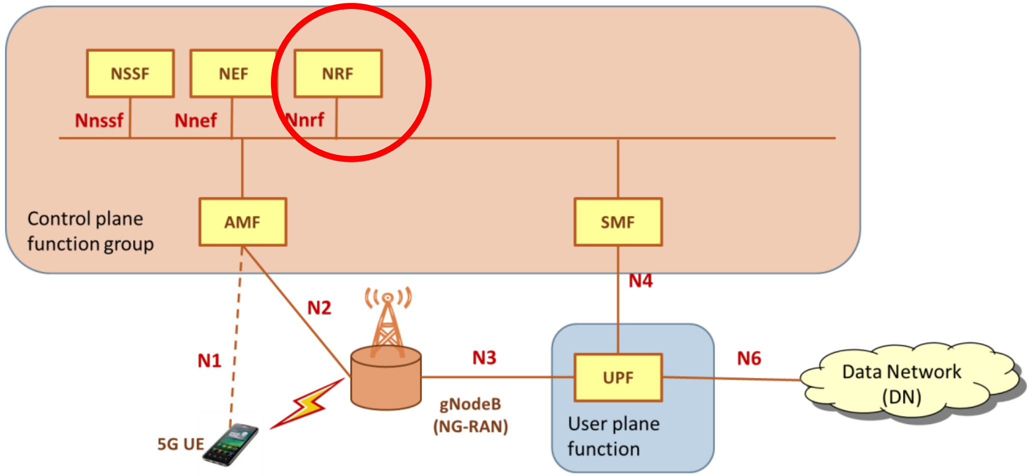
5GS Service Based Architecture (SBA)



Network Repository Function (NRF)



CUPS Architecture



- Different Network Functions (NFs) are connected together via a uniform interface called a service-based interface. In addition, an individual NF consists of smaller unit functions called NF services, and an NF service in a certain NF can directly access an NF service in another NF without having to pass through another node. A Network Repository Function (NRF) provides a discovery function for NF services.
- See section 6.2.6 of TS 23.501 for more details on functionality of NRF

Network Repository Function (NRF)

Section 6.2.6 of TS 23.501 - The NF Repository Function (NRF) supports the following functionality:

- Supports service discovery function. Receive NF Discovery Request from NF instance, and provides the information of the discovered NF instances (be discovered) to the NF instance.
- Maintains the NF profile of available NF instances and their supported services.

NF profile of NF instance maintained in an NRF includes the following information:

- NF instance ID
- NF type
- PLMN ID
- Network Slice related Identifier(s) e.g. S-NSSAI, NSI ID
- FQDN or IP address of NF
- NF capacity information
- NF Specific Service authorization information
- Names of supported services
- Endpoint information of instance(s) of each supported service
- Identification of stored data/information

NOTE 1: This is only applicable for a UDR profile. See applicable input parameters for Nnrf_NFManagement_NFRegister service operation in TS 23.502 clause 5.2.7.2.2. This information applicability to other NF profiles is implementation specific.

- Other service parameter, e.g., DNN, notification endpoint for each type of notification that the NF service is interested in receiving.

NOTE 2: It is expected service authorization information is usually provided by OA&M system, and it can also be included in the NF profile in case that e.g. an NF instance has an exceptional service authorization information.

Network Repository Function (NRF)

In the context of Network Slicing, based on network implementation, multiple NRFs can be deployed at different levels (see clause 5.15.5):

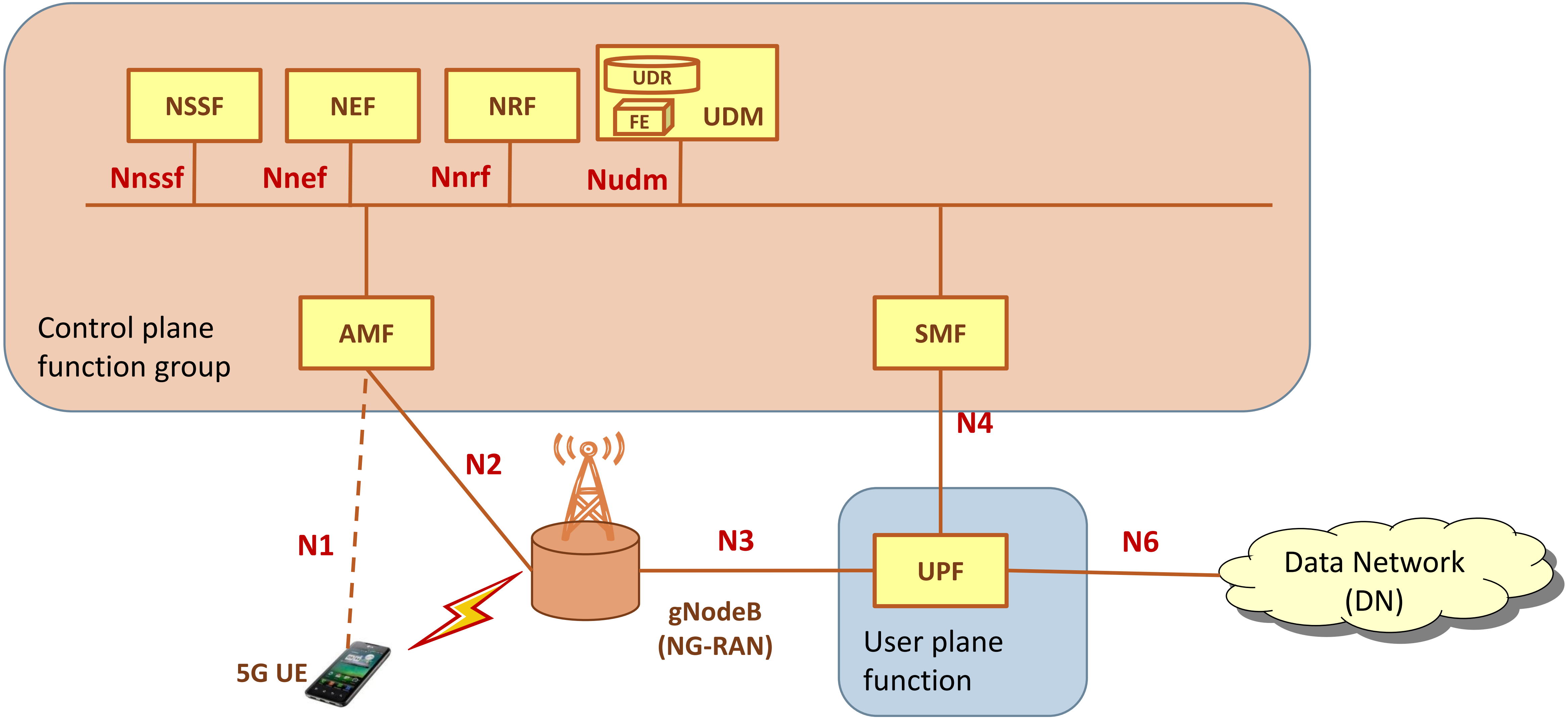
- PLMN level (the NRF is configured with information for the whole PLMN),
- shared-slice level (the NRF is configured with information belonging to a set of Network Slices),
- slice-specific level (the NRF is configured with information belonging to an S-NSSAI).

NOTE 3: Whether NRF is an enhancement of DNS server is to be determined during Stage 3.

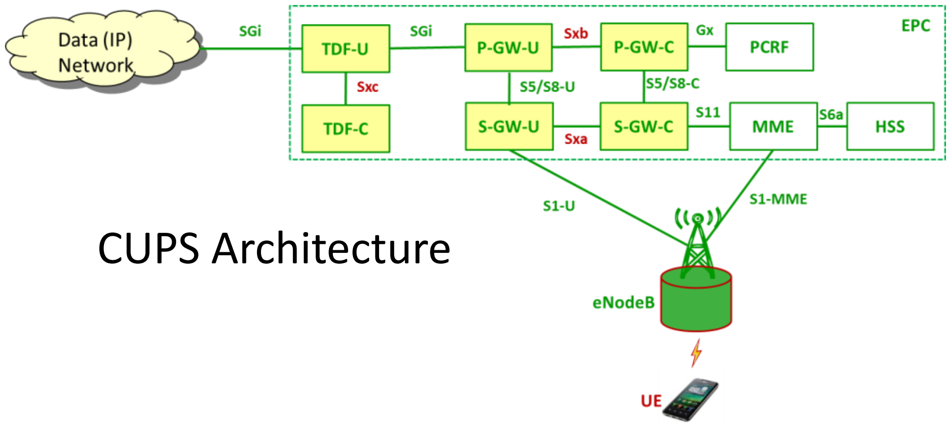
In the context of roaming, multiple NRFs may be deployed in the different networks (see clause 4.2.4):

- the NRF(s) in the Visited PLMN (known as the vNRF) configured with information for the visited PLMN.
- the NRF(s) in the Home PLMN (known as the hNRF) configured with information for the home PLMN, referenced by the vNRF via the N27 interface

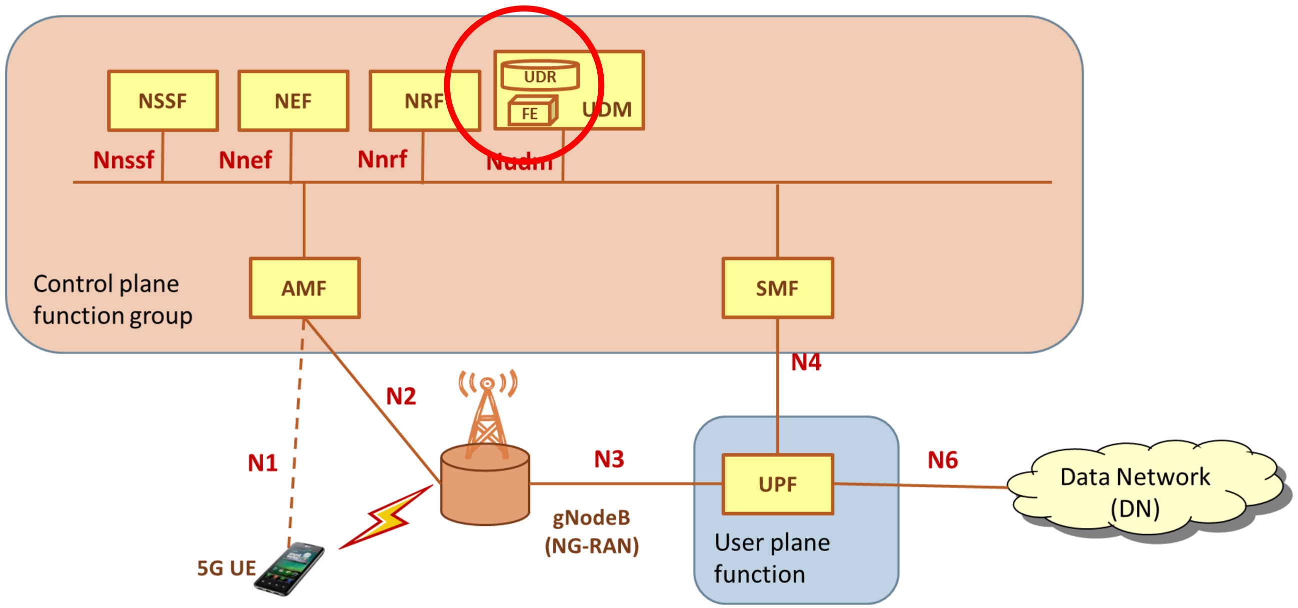
5GS Service Based Architecture (SBA)



Unified Data Repository (UDR)



CUPS Architecture



- UDR is a facility where user data can be accessed stored and managed in a common way.
- See section 6.2.11 of TS 23.501 for more details on functionality of UDR

Unified Data Repository (UDR)

Section 6.2.11 of TS 23.501 - The Unified Data Repository (UDR) supports the following functionality:

- Storage and retrieval of subscription data by the UDM.
- Storage and retrieval of policy data by the PCF.
- Storage and retrieval of structured data for exposure, and application data (including Packet Flow Descriptions (PFDs) for application detection, application request information for multiple UEs), by the NEF.

The Unified Data Repository is located in the same PLMN as the NF service consumers storing in and retrieving data from it using Nudr. Nudr is an intra-PLMN interface.

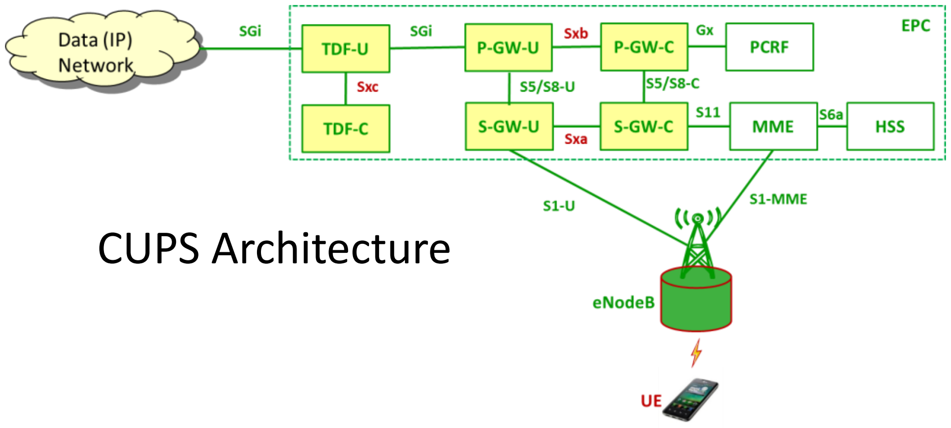
NOTE 1: Deployments can choose to collocate UDR with UDSF.

Section 6.2.12 of TS 23.501 - The UDSF (Unstructured Data Storage Function) is an optional function that supports the following functionality:

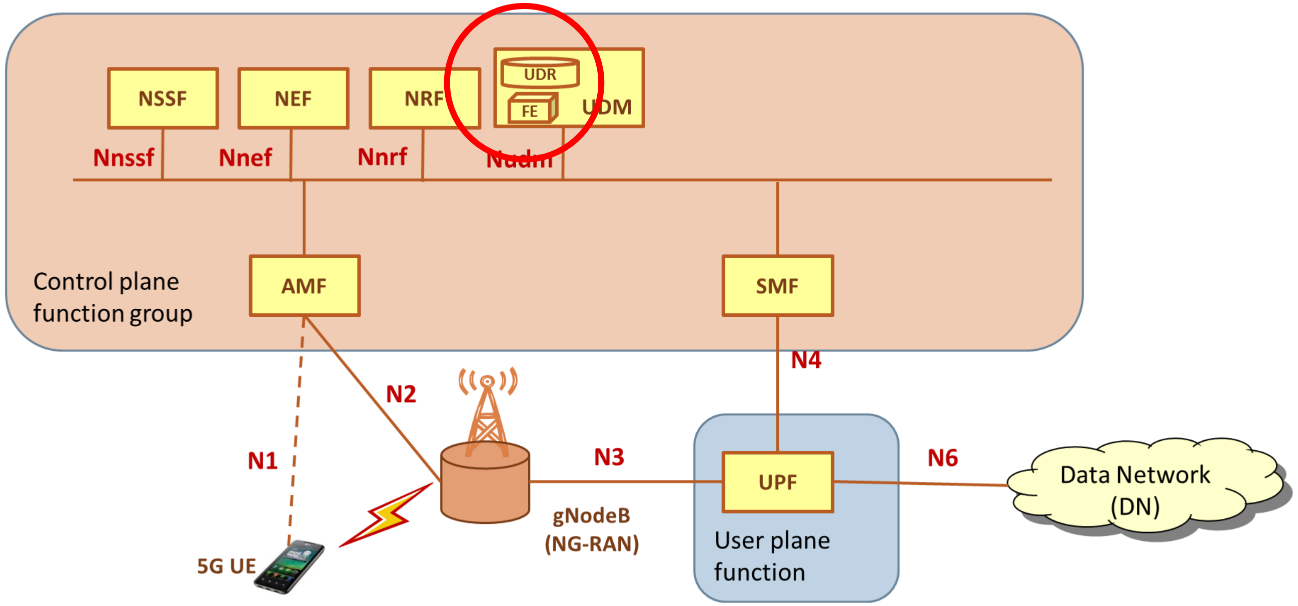
- Storage and retrieval of information as unstructured data by any NF.

NOTE: Deployments can choose to collocate UDSF with UDR.

Front End (FE)

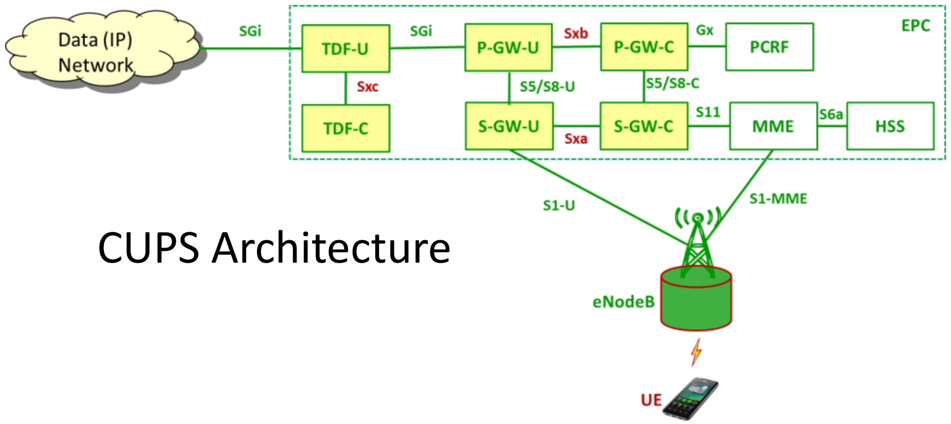


CUPS Architecture

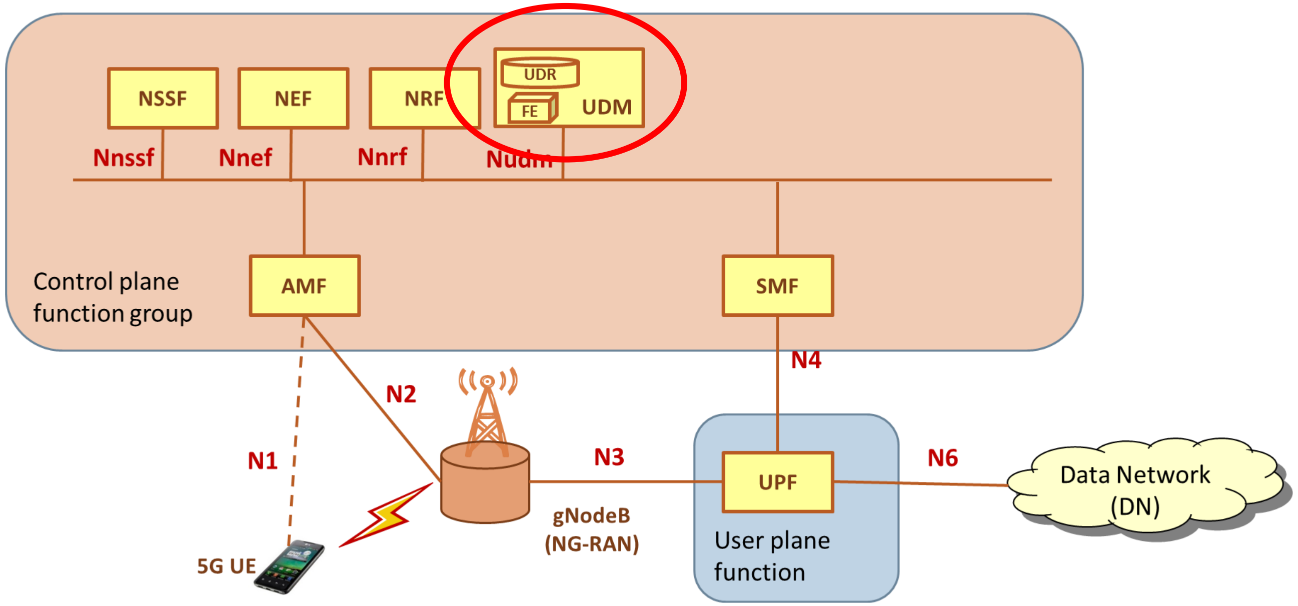


- Front End (FE) is a core network functional entity or service layer entity or provisioning entity that can access user data stored in a unique repository.
- Front End Identifier is defined as a name that uniquely identifies an FE within the set of all FEs accessing an UDR.

Unified Data Management (UDM)



CUPS Architecture



- Unified Data Management (UDM), is analogous to the Home Subscriber Server (HSS) in EPC architecture and introduces the concept of User Data Convergence (UDC) that separates the User Data Repository (UDR) storing and managing subscriber information from the front end processing subscriber information.
- See section 6.2.7 of TS 23.501 for more details on functionality of UDM

Unified Data Management (UDM)

Section 6.2.7 of TS 23.501 - The Unified Data Management (UDM) includes support for the following functionality:

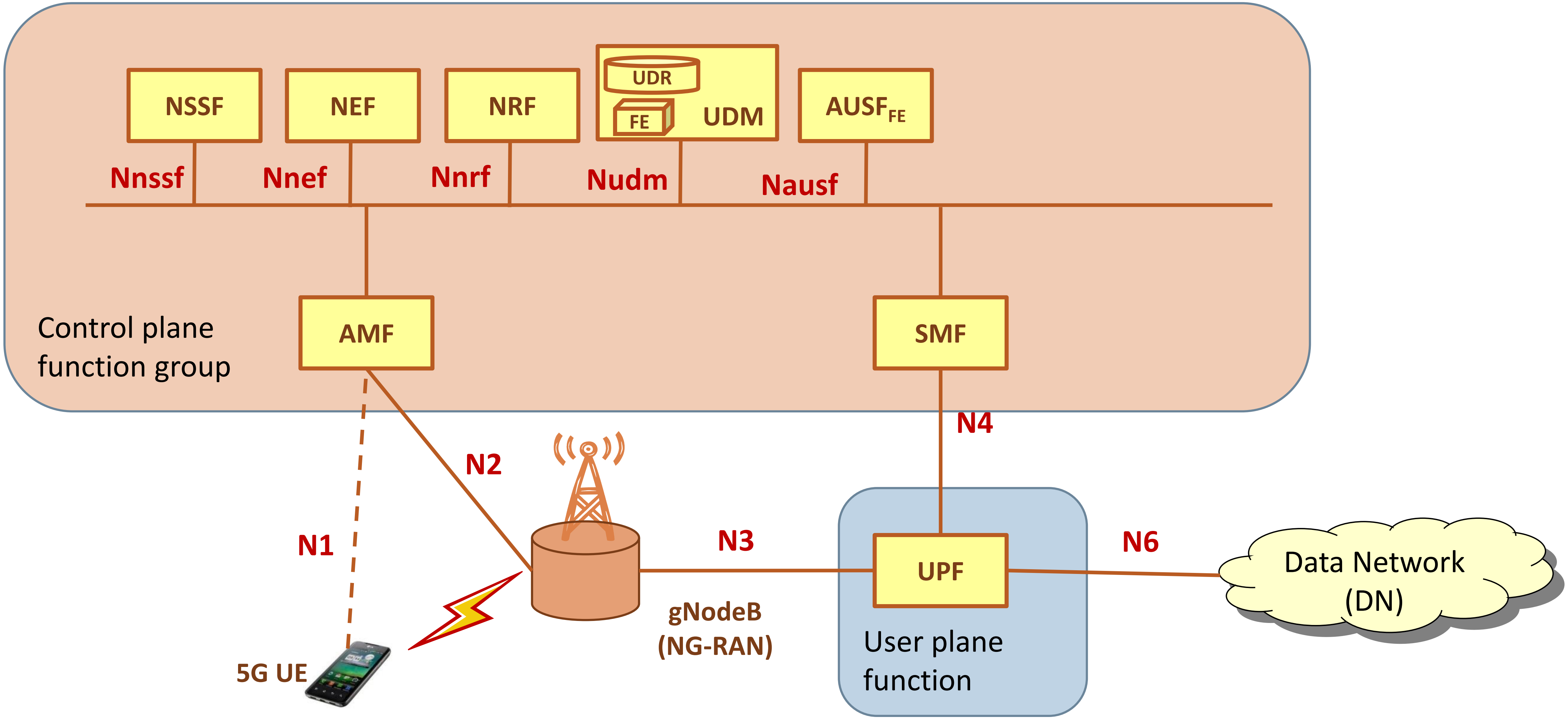
- Generation of 3GPP AKA Authentication Credentials.
- User Identification Handling (e.g. storage and management of SUPI for each subscriber in the 5G system).
- Access authorization based on subscription data (e.g. roaming restrictions).
- UE's Serving NF Registration Management (e.g. storing serving AMF for UE, storing serving SMF for UE's PDU Session).
- Support to service/session continuity e.g. by keeping SMF/DNN assignment of ongoing sessions.
- MT-SMS delivery support.
- Lawful Intercept Functionality (especially in outbound roaming case where UDM is the only point of contact for LI).
- Subscription management.
- SMS management.

To provide this functionality, the UDM uses subscription data (including authentication data) that may be stored in UDR, in which case a UDM implements the application logic and does not require an internal user data storage and then several different UDMs may serve the same user in different transactions.

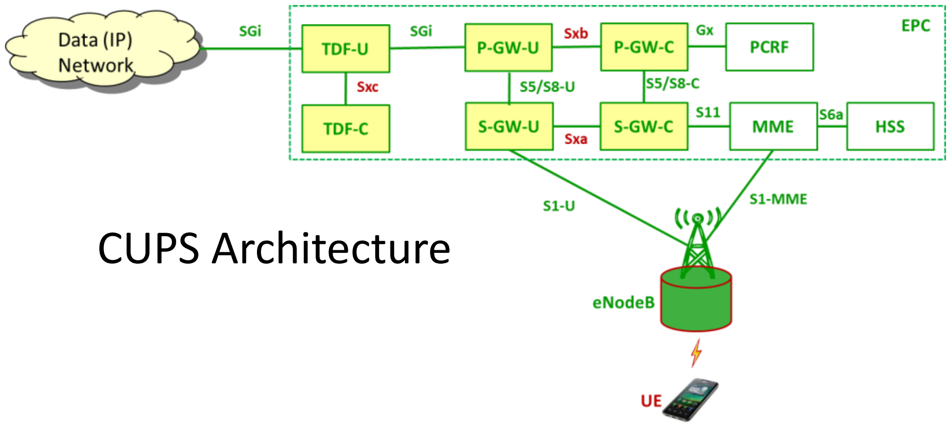
NOTE 1: The interaction between UDM and HSS is implementation specific.

NOTE 2: The UDM is located in the HPLMN of the subscribers it serves, and access the information of the UDR located in the same PLMN.

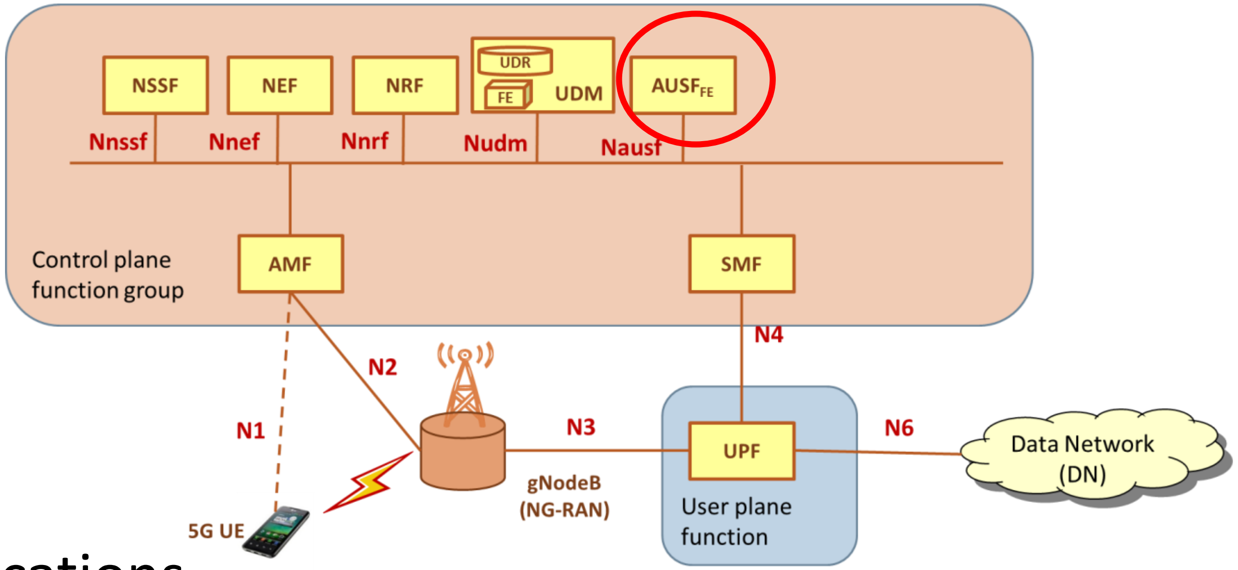
5GS Service Based Architecture (SBA)



Authentication Server Function (AUSF)



CUPS Architecture



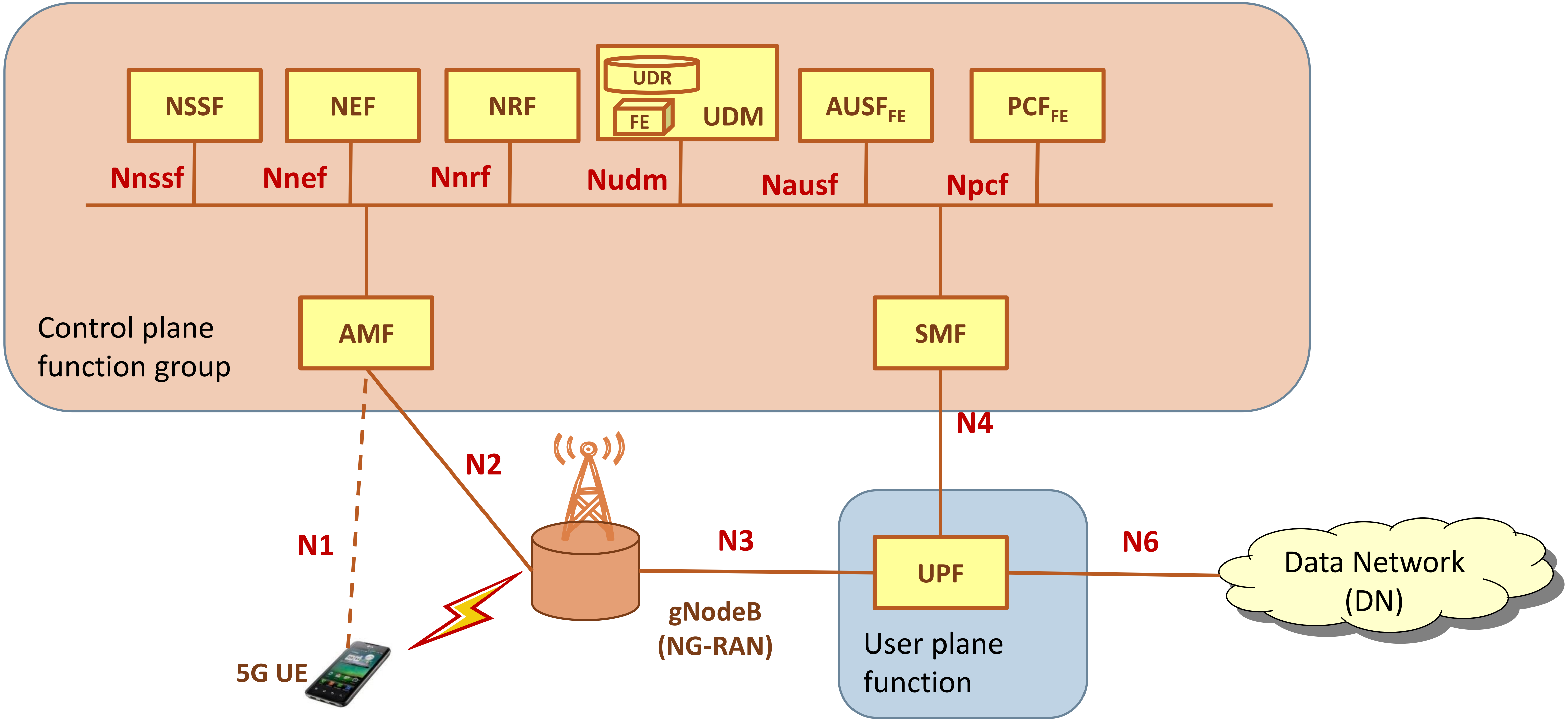
- The front-end section includes new specifications for an Authentication Server Function (AUSF) dedicated to authentication processing
- See section 6.2.8 of TS 23.501 for more details on functionality of AUSF

Authentication Server Function (AUSF)

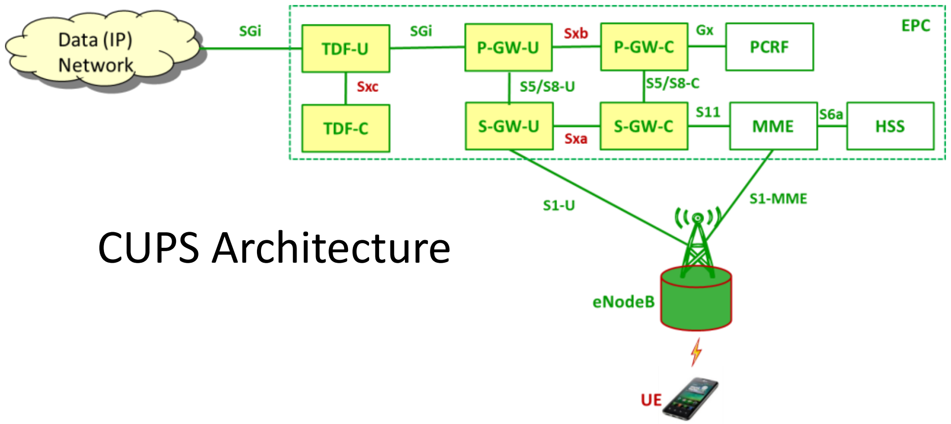
Section 6.2.8 of TS 23.501 - The AUSF supports the following functionality:

- Supports Authentication Server Function (AUSF) as specified by SA WG3.

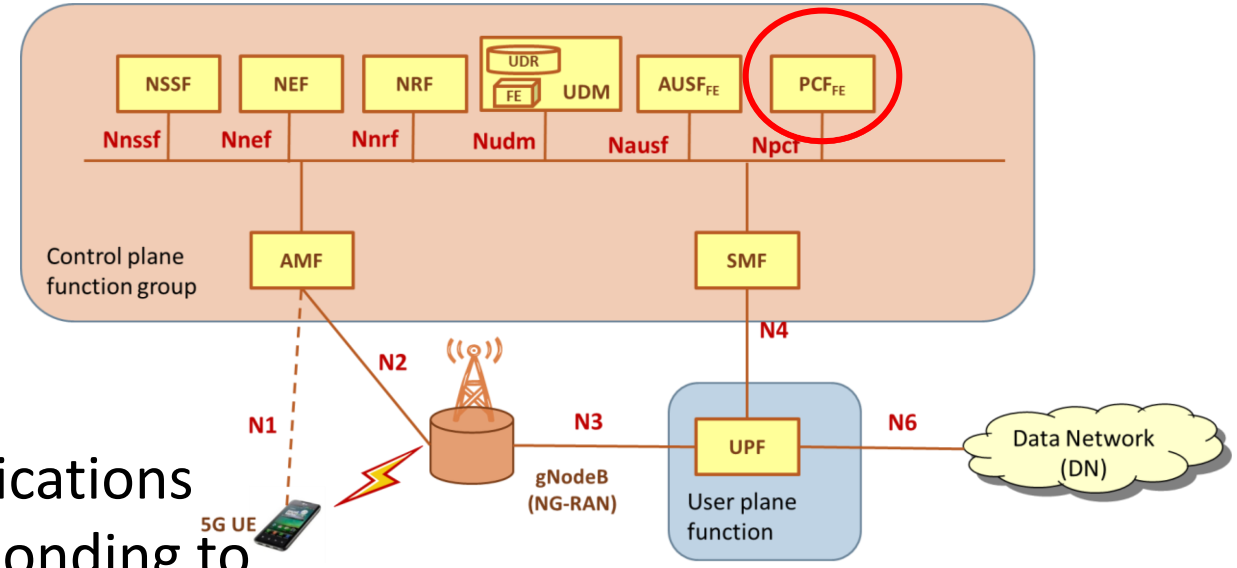
5GS Service Based Architecture (SBA)



Policy Control Function (PCF)



CUPS Architecture



- The front-end section includes new specifications for a Policy Control Function (PCF) corresponding to the Policy and Charging Rule control Function (PCRF) in EPC.
- See section 6.2.4 of TS 23.501 for more details on functionality of PCF

Policy Control Function (PCF)

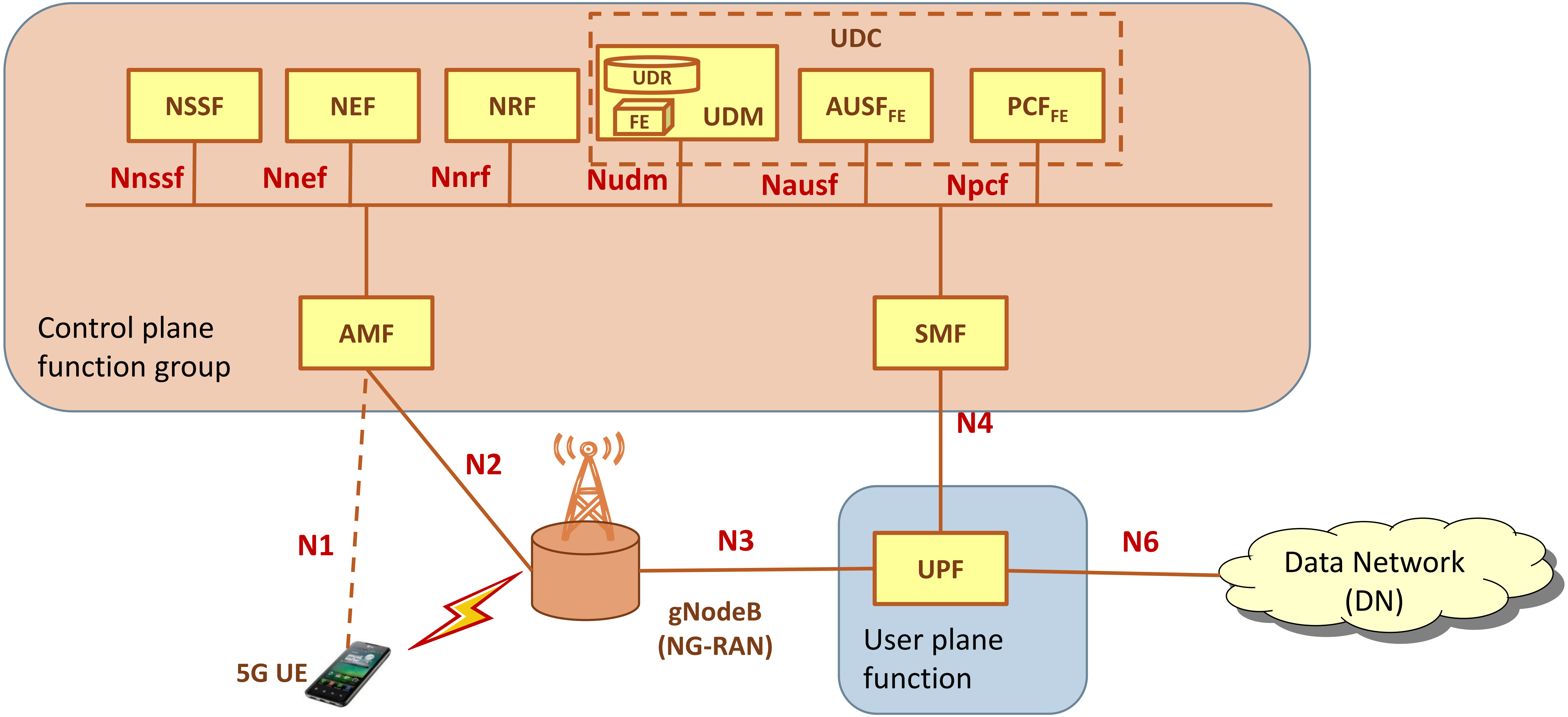
Section 6.2.4 of TS 23.501 - The Policy Control Function (PCF) includes the following functionality:

- Supports unified policy framework to govern network behaviour.
- Provides policy rules to Control Plane function(s) to enforce them.
- Accesses subscription information relevant for policy decisions in a Unified Data Repository (UDR).

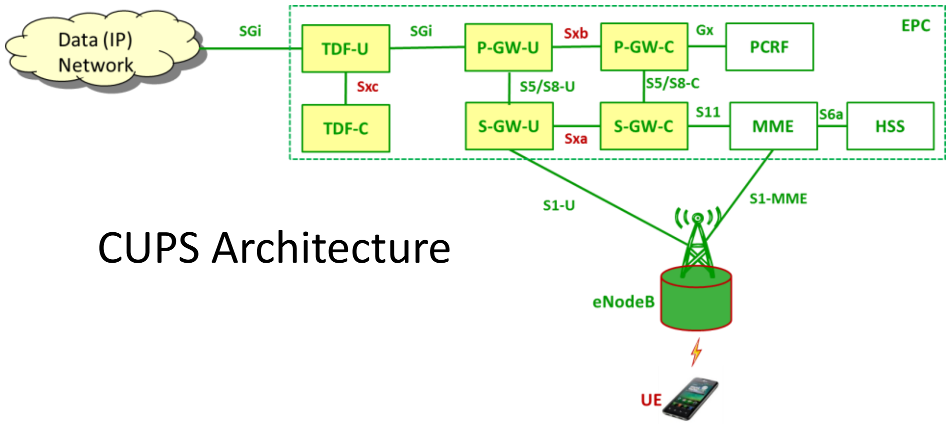
NOTE:The PCF accesses the UDR located in the same PLMN as the PCF.

The details of the PCF functionality are defined in clause 6.2.1 of TS 23.503.

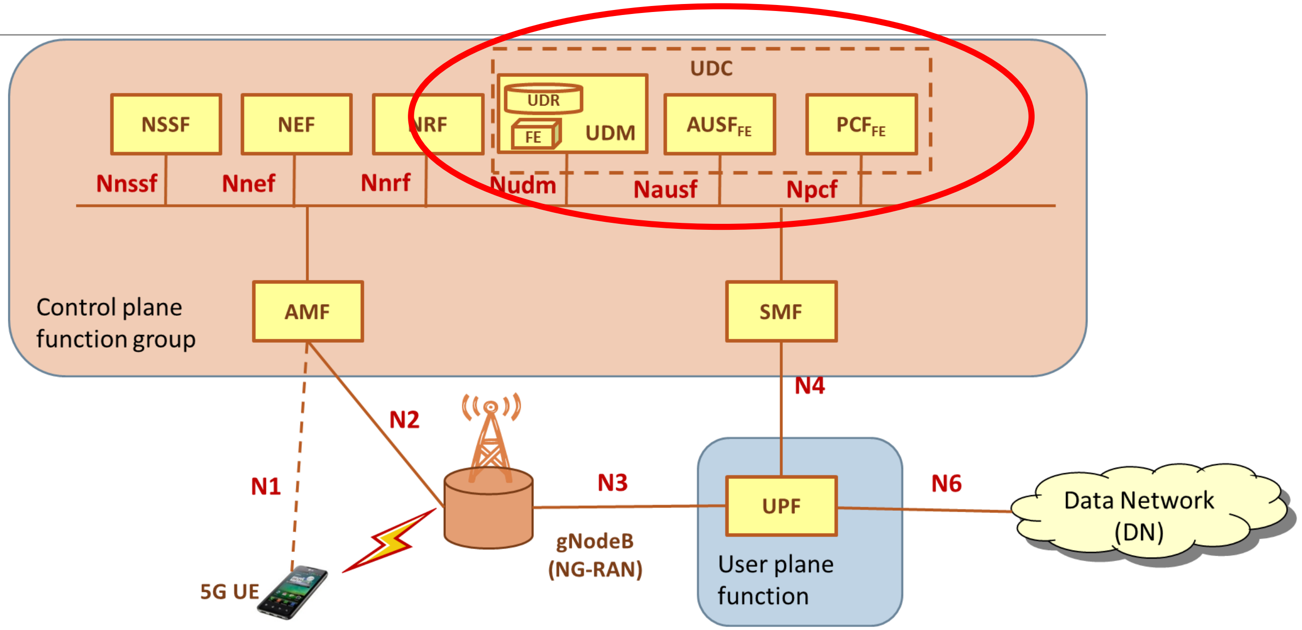
5GS Service Based Architecture (SBA)



User Data Convergence (UDC)



CUPS Architecture



- User data convergence is an optional concept to ensure data consistency and simplify creation of new services by providing easy access to the user data, as well as to ensure the consistency of storage and data models and to have minimum impact on traffic mechanisms, reference points and protocols of network elements.
- See 3GPP TS 23.335: User Data Convergence (UDC); Technical realization and information flows; Stage 2 for more details

UDC Reference Architecture

Release 14 3GPP TS 23.335 V14.0.0 (2017-03)

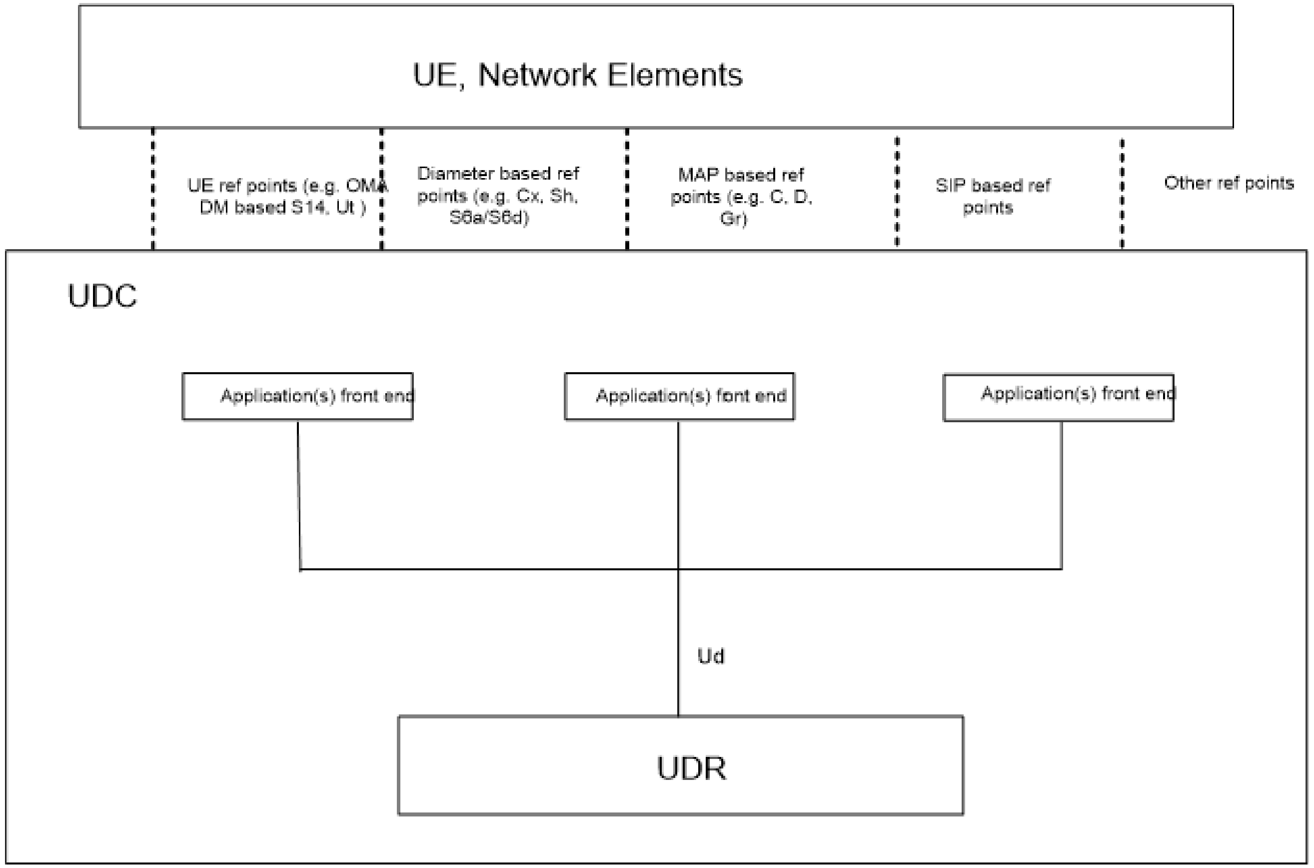
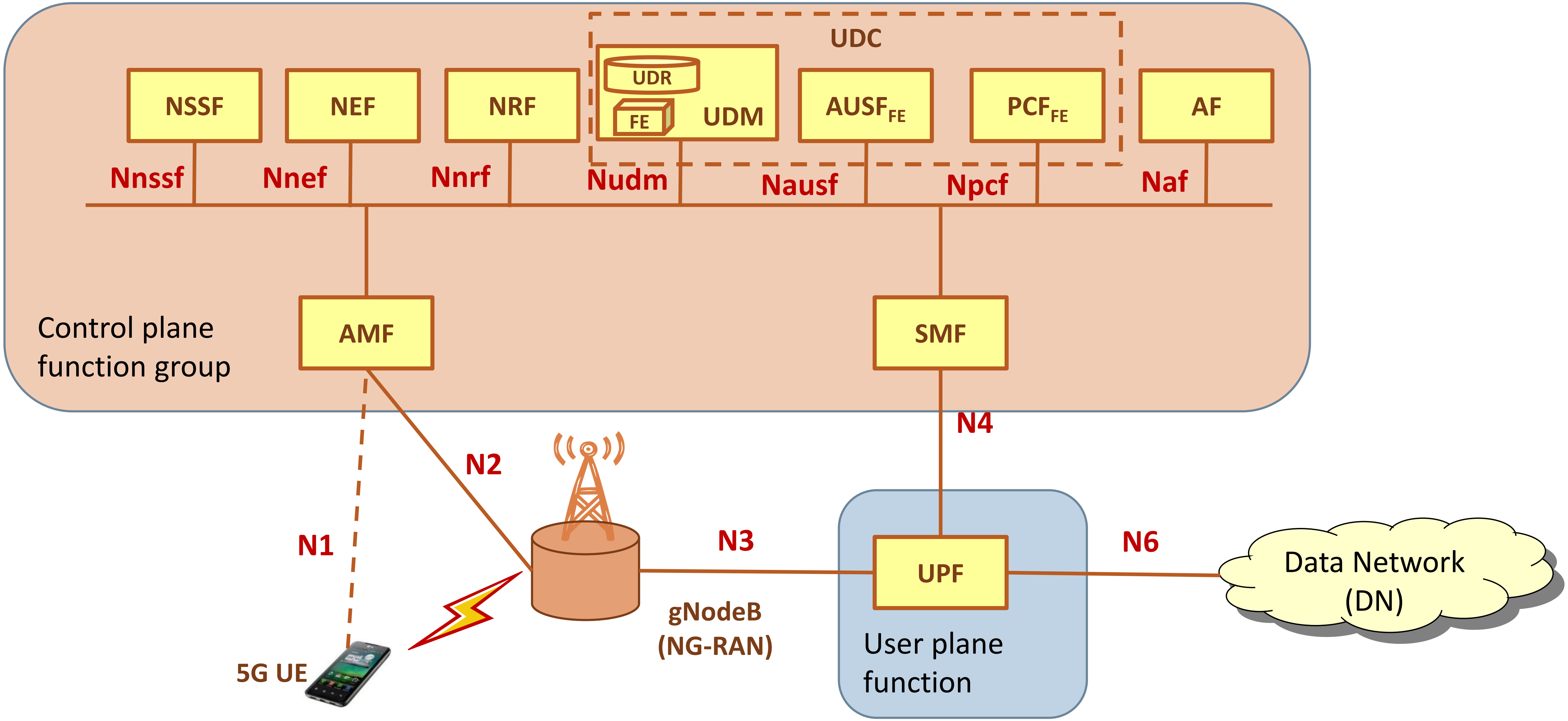


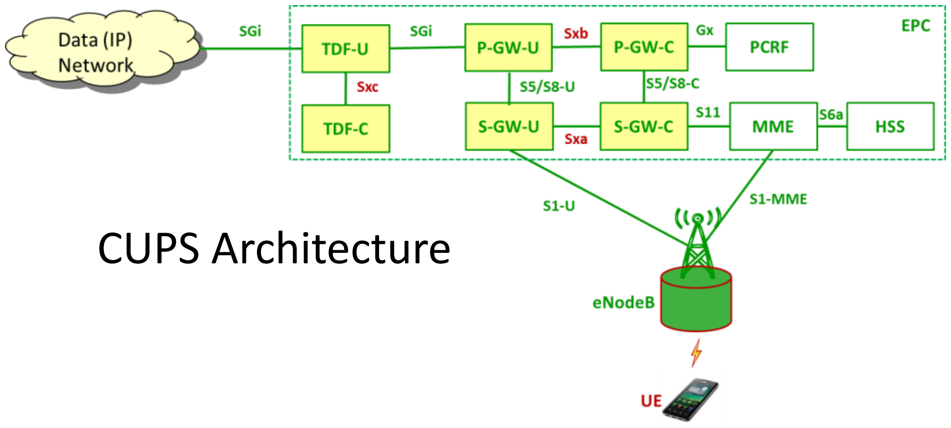
Figure 4.1-1: UDC reference architecture

- Standardization of the Data Model for the Ud interface between Front-Ends and the UDR is out of the scope of 3GPP.

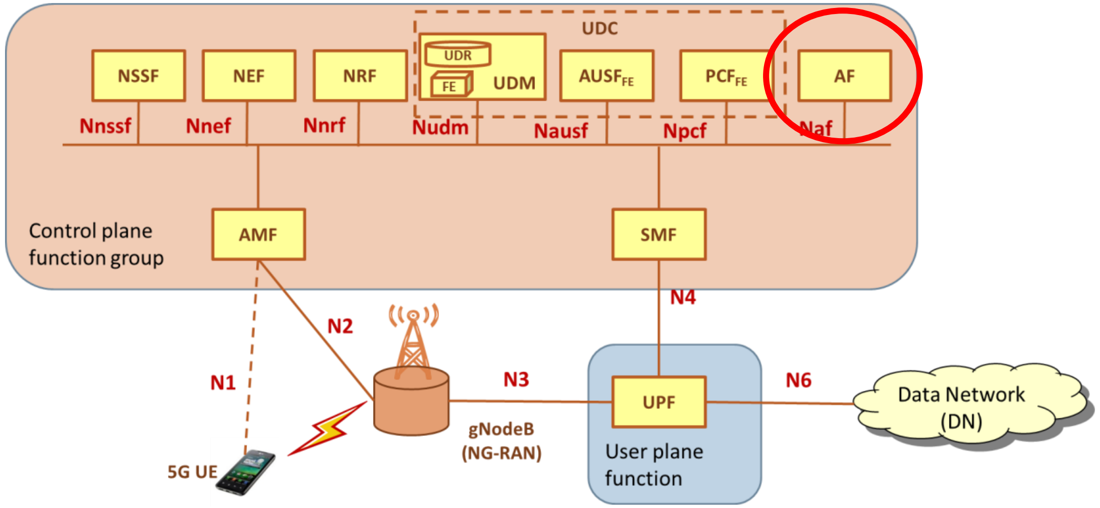
5GS Service Based Architecture (SBA)



Application Function (AF)



CUPS Architecture



- The Application Function (AF) fulfils the role of an application server. It interacts with the 3GPP Core Network in order to provide services
- See section 6.2.10 of TS 23.501 for more details on functionality of AF

Application Function (AF)

Section 6.2.10 of TS 23.501 - The Application Function (AF) interacts with the 3GPP Core Network in order to provide services, for example to support the following:

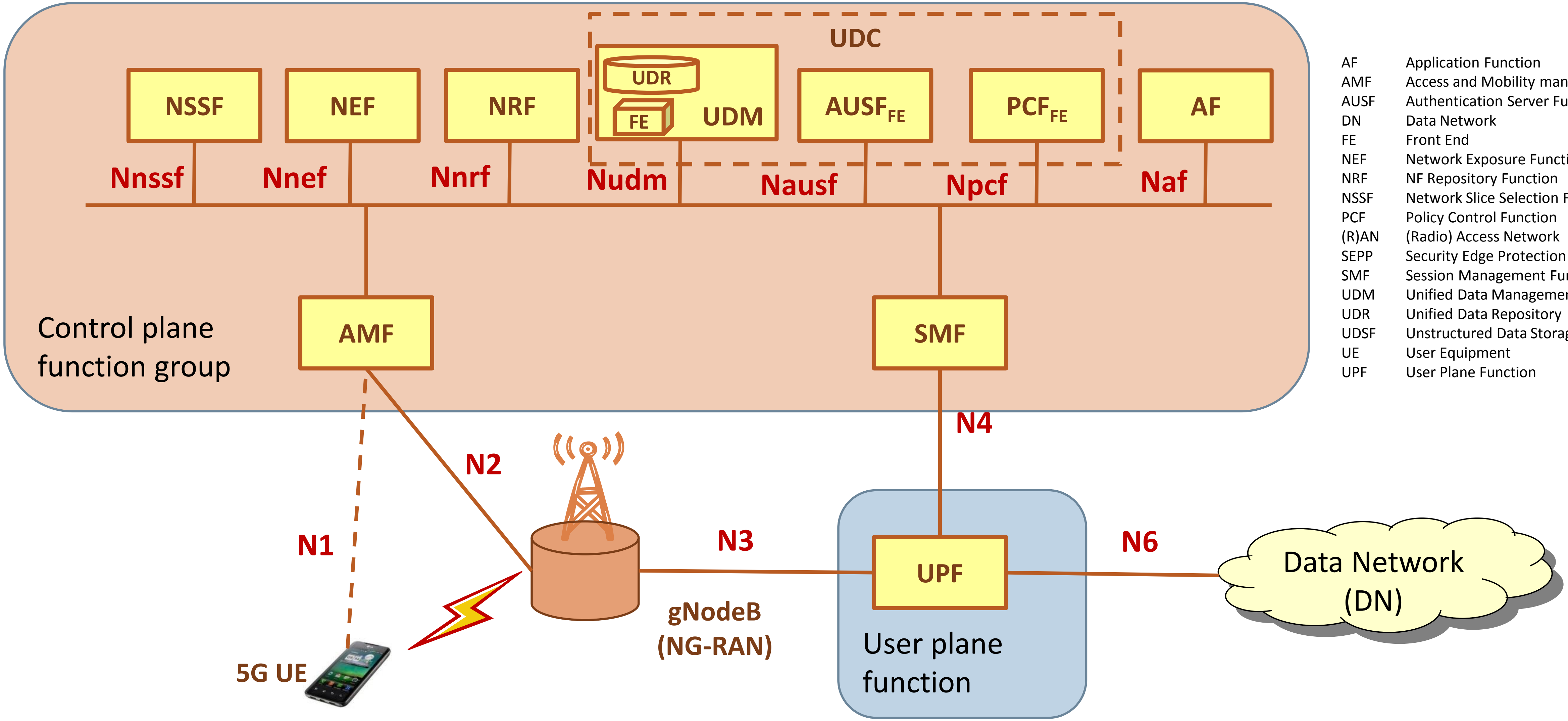
- Application influence on traffic routing (see clause 5.6.7),
- Accessing Network Exposure Function (see clause 5.20),
- Interacting with the Policy framework for policy control (see clause 5.14),

Based on operator deployment, Application Functions considered to be trusted by the operator can be allowed to interact directly with relevant Network Functions.

Application Functions not allowed by the operator to access directly the Network Functions shall use the external exposure framework (see clause 7.4) via the NEF to interact with relevant Network Functions.

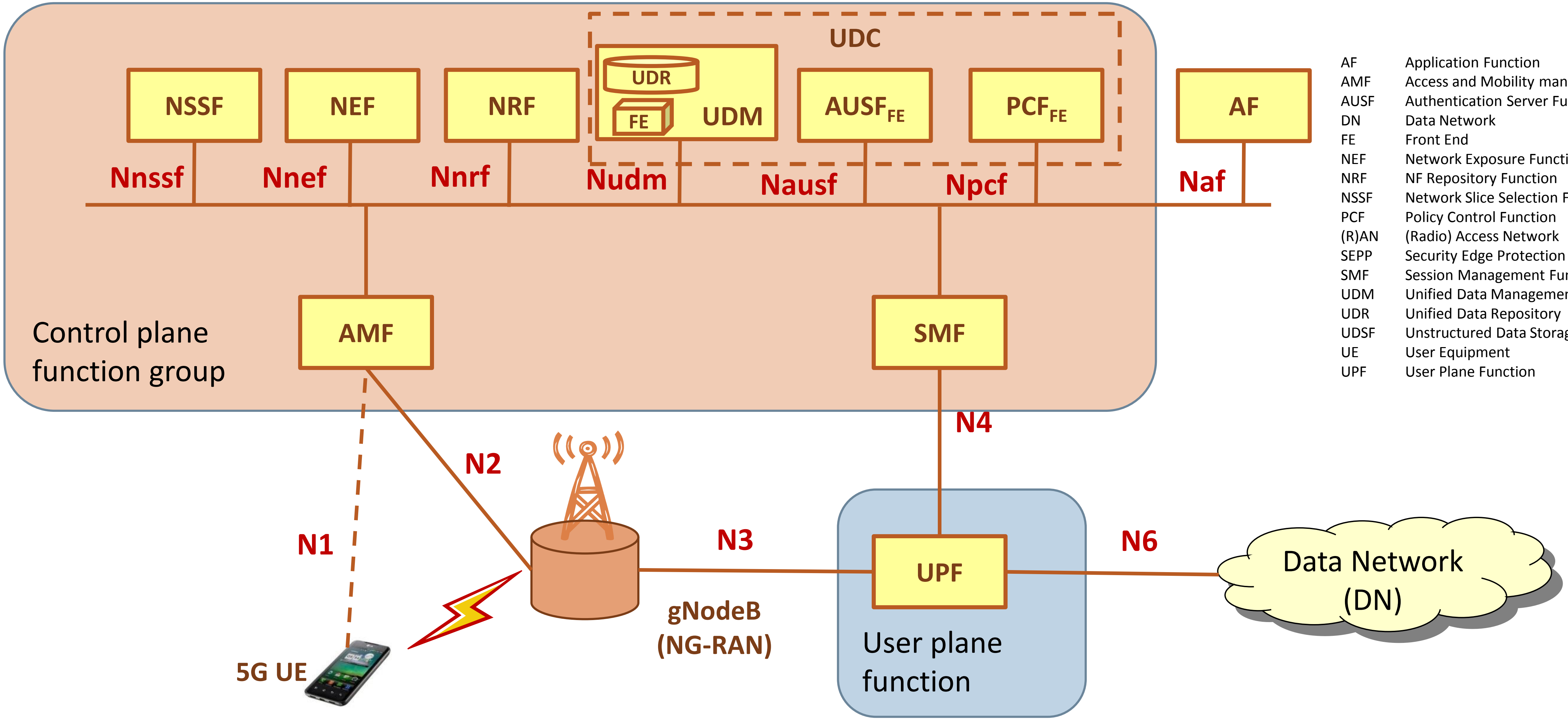
The functionality and purpose of Application Functions are only defined in this specification with respect to their interaction with the 3GPP Core Network.

5GS Service Based Architecture (SBA)



AF	Application Function
AMF	Access and Mobility management Function
AUSF	Authentication Server Function
DN	Data Network
FE	Front End
NEF	Network Exposure Function
NRF	NF Repository Function
NSSF	Network Slice Selection Function
PCF	Policy Control Function
(R)AN	(Radio) Access Network
SEPP	Security Edge Protection Proxy
SMF	Session Management Function
UDM	Unified Data Management
UDR	Unified Data Repository
UDSF	Unstructured Data Storage Function
UE	User Equipment
UPF	User Plane Function

5GS Service Based Architecture (SBA)



AF	Application Function
AMF	Access and Mobility management Function
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DN	Data Network
FE	Front End
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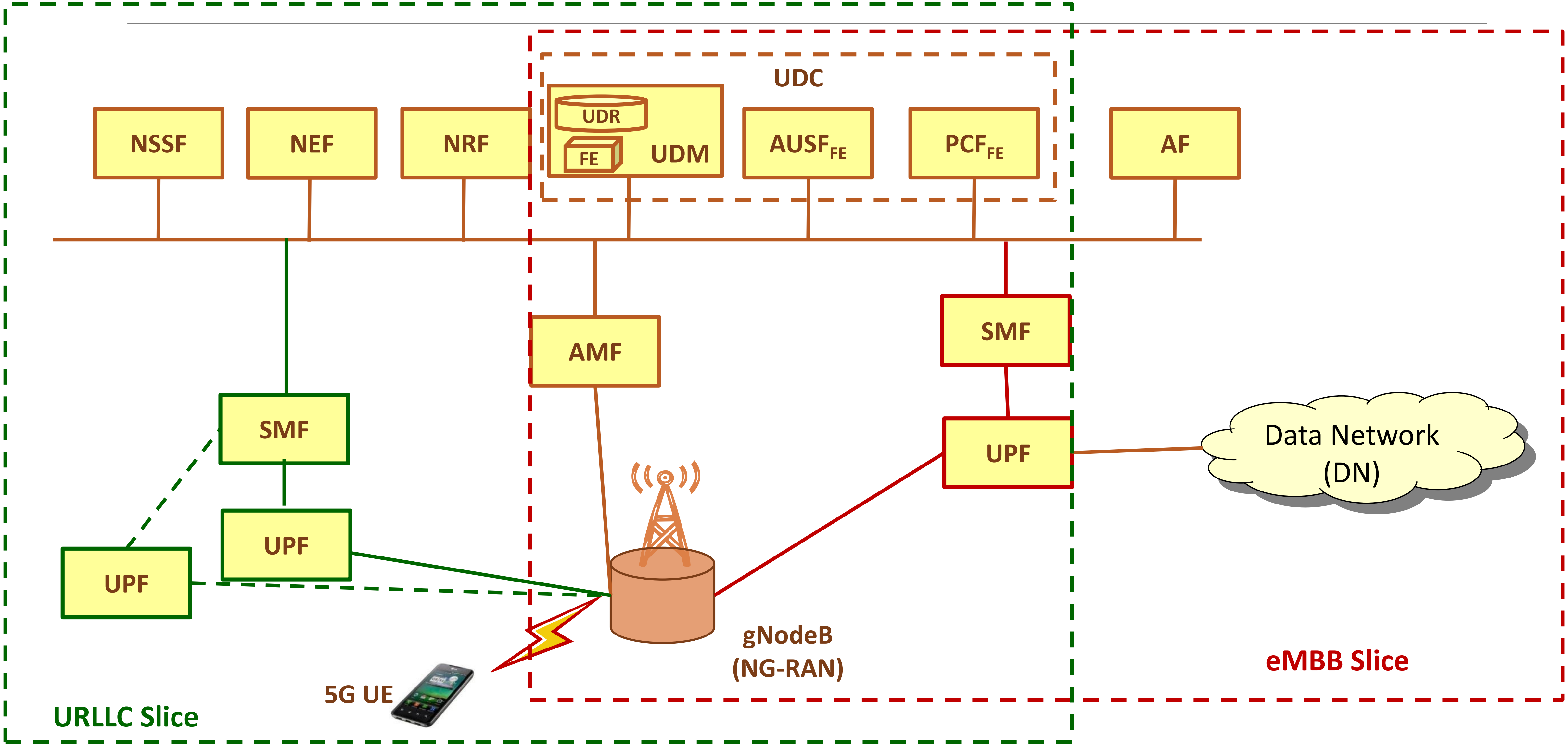
UDR	Unified Data Repository
UDSF	Unstructured Data Storage Function
UE	User Equipment
UPF	User Plane Function

5GS Service Based Architecture (SBA)



5GS Reference Point Architecture

Release 15 3GPP TS 23.501 V15.0.0 (2017-12)

Figure 4.2.3-2 depicts the 5G System architecture in the non-roaming case, using the reference point representation showing how various network functions interact with each other.

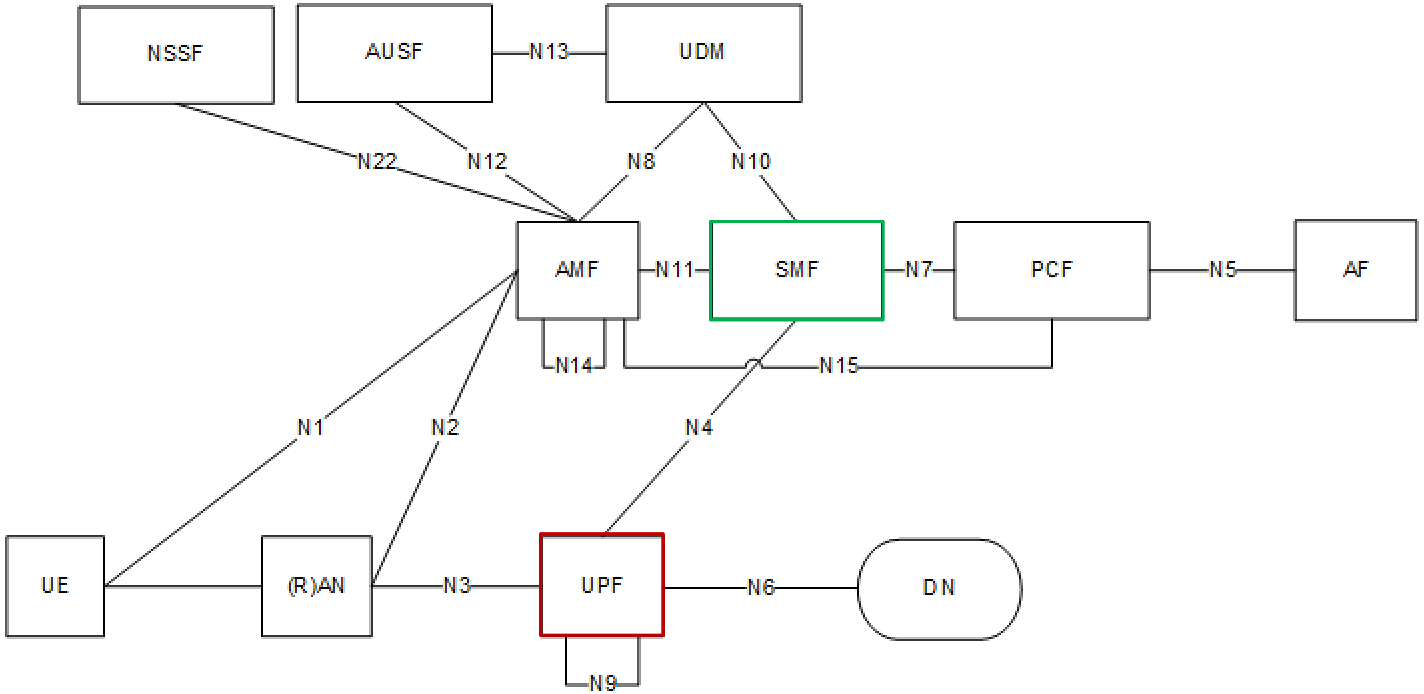


Figure 4.2.3-2: Non-Roaming 5G System Architecture in reference point representation

5GS Reference Point Architecture

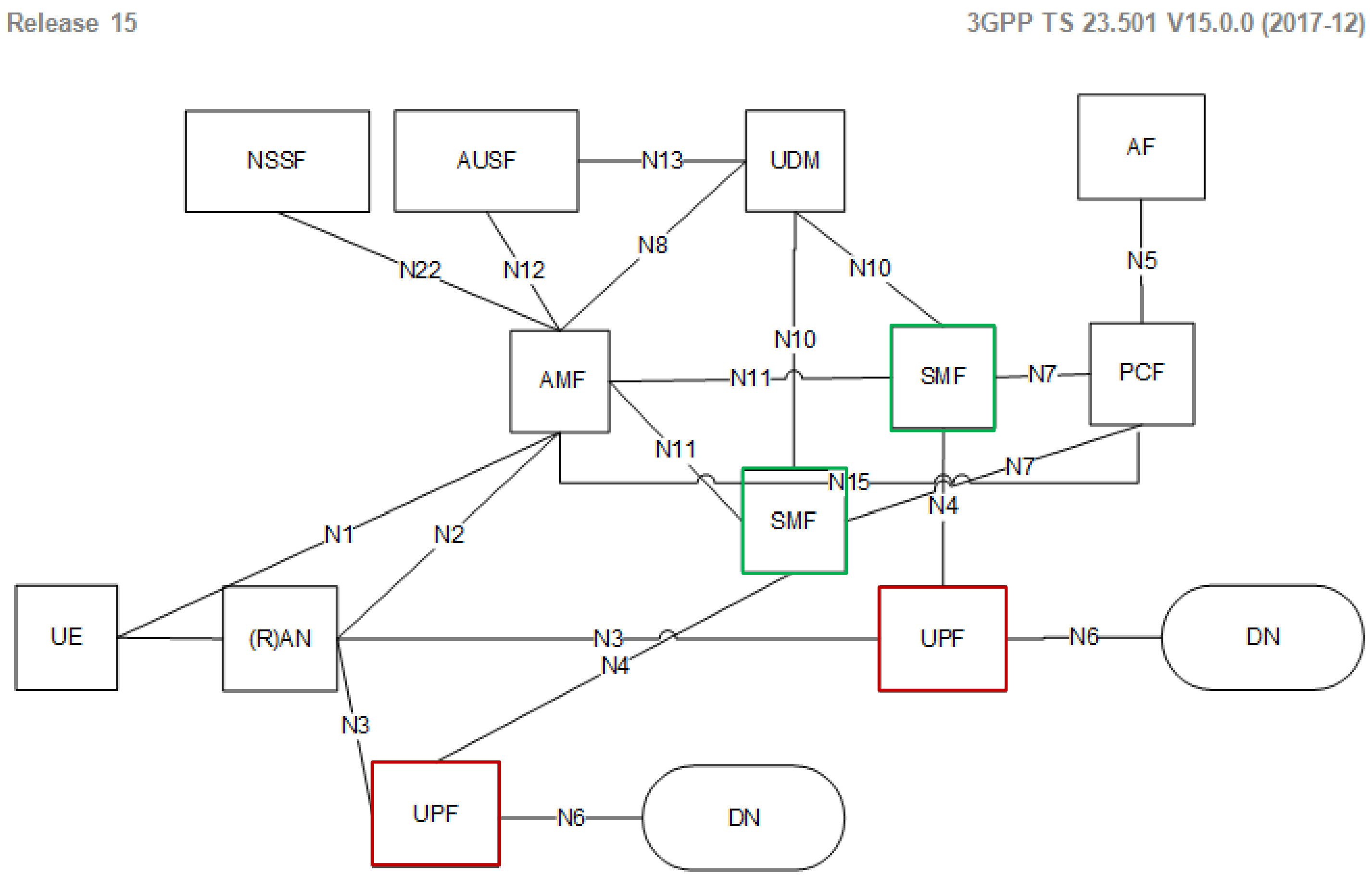


Figure 4.2.3-3: Applying non-roaming 5G System architecture for multiple PDU Session in reference point representation

5GS Reference Point Architecture

Release 15 3GPP TS 23.501 V15.0.0 (2017-12)

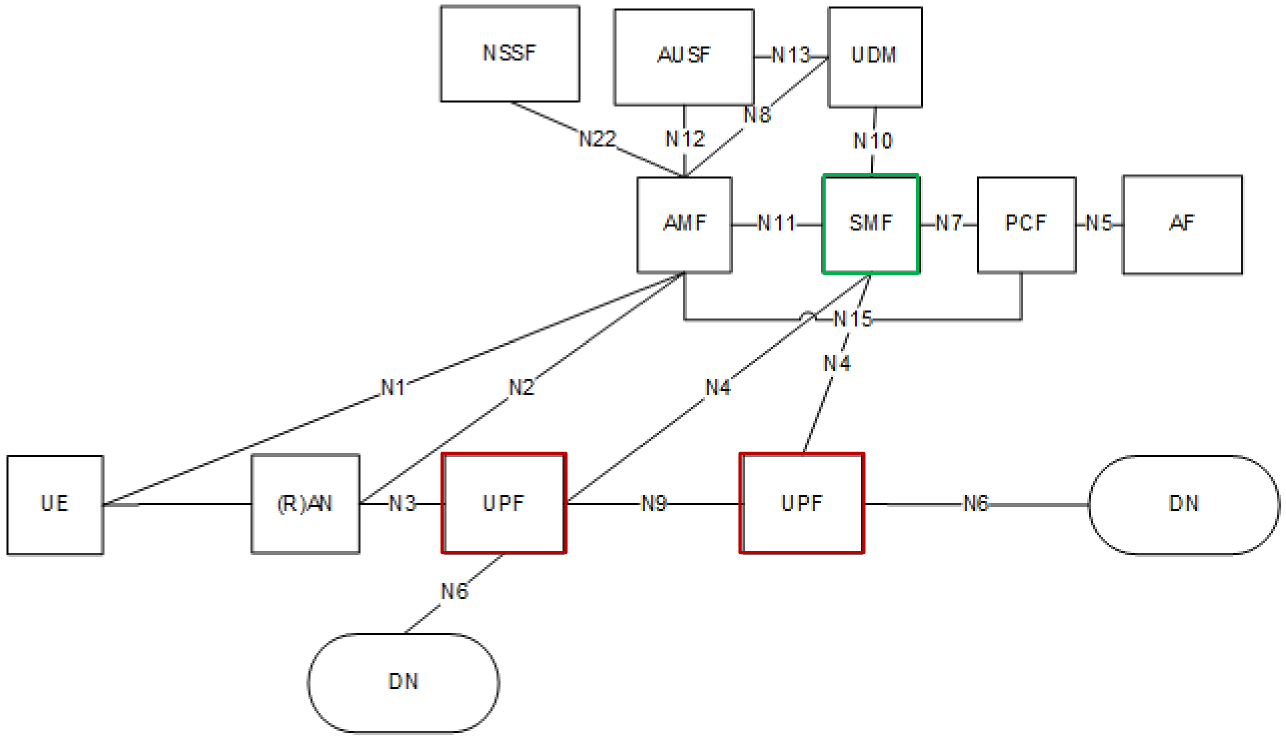
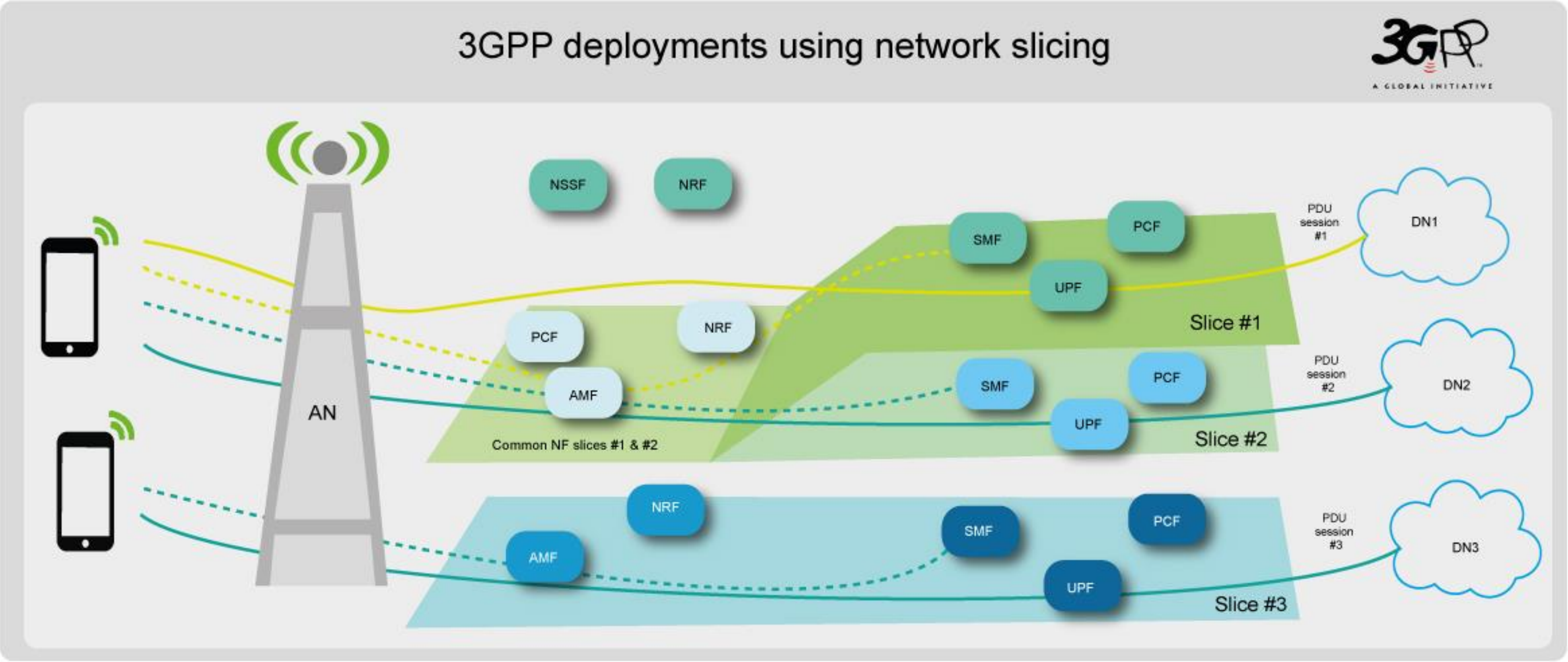


Figure 4.2.3-4: Applying non-roaming 5G System architecture for concurrent access to two (e.g. local and central) data networks (single PDU Session option) in reference point representation

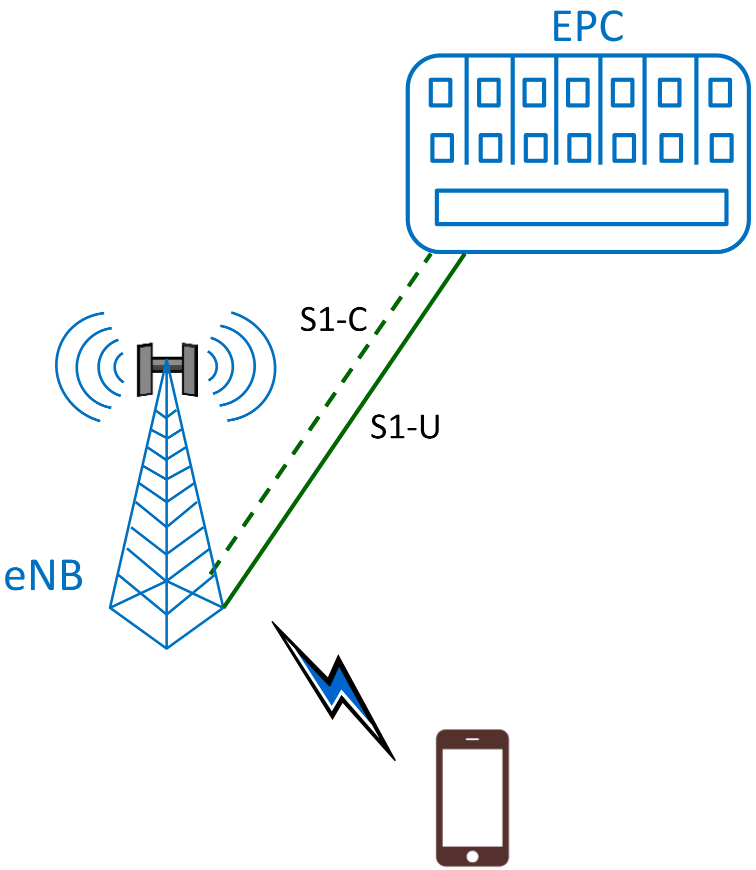
5GS using Network Slicing



Source: 3GPP

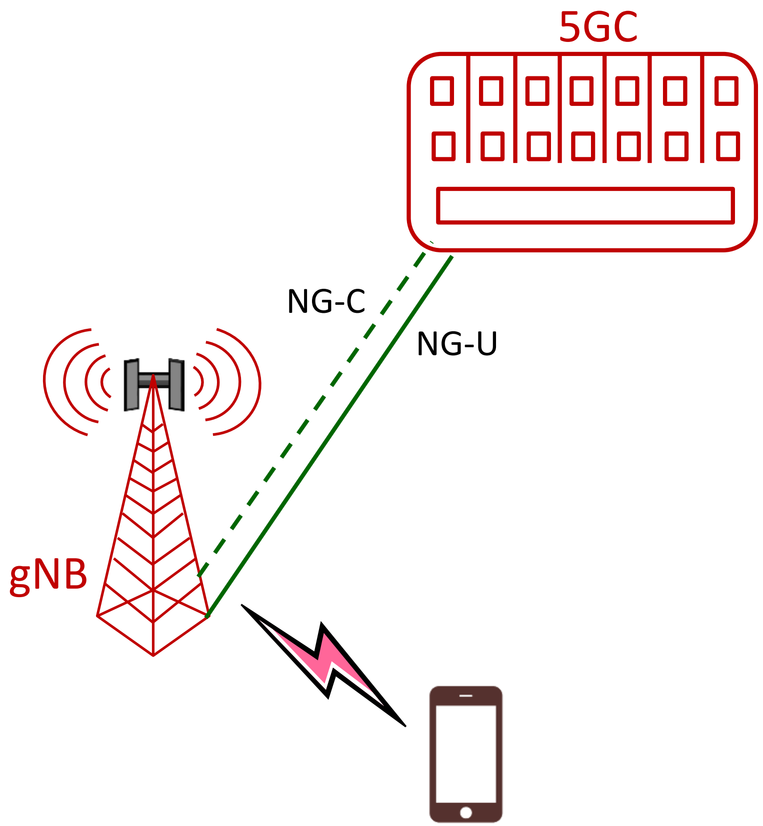
Option 1: SA LTE connected to EPC - Legacy

Option 1



Option 2: SA NR connected to 5GC

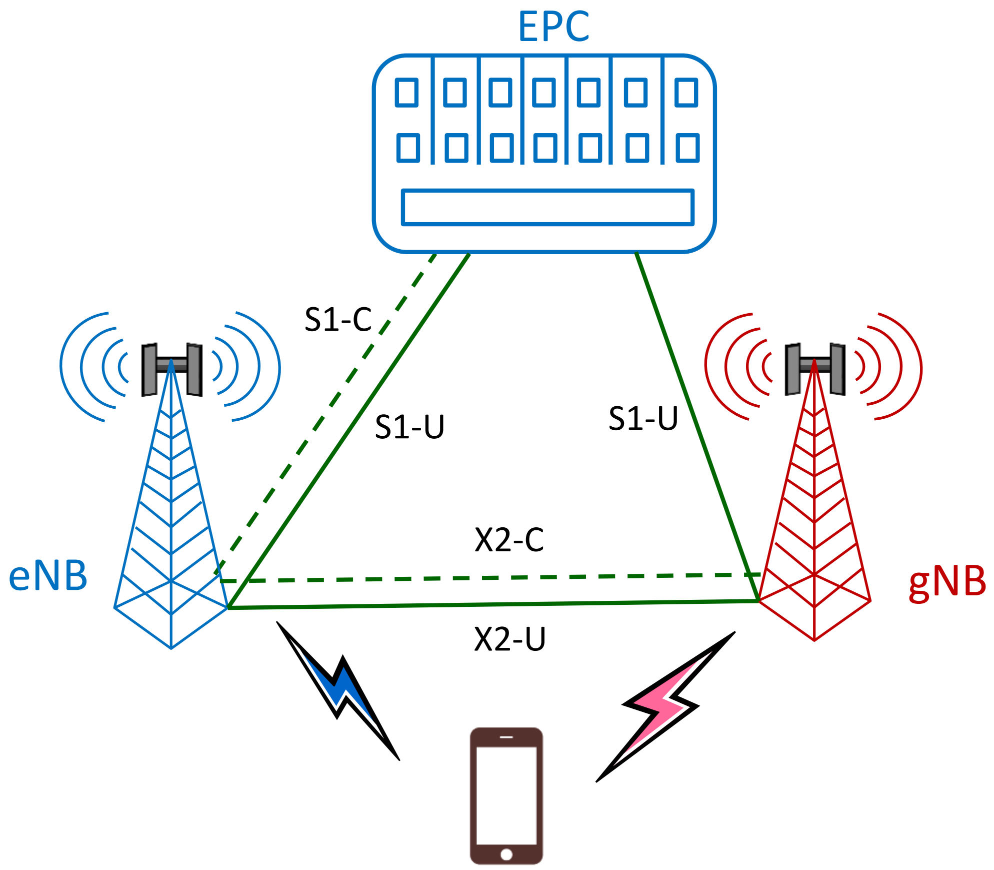
3GPP SA Option 2



- Only option for greenfield 5G operators
- Full support for new 5G applications and services including:
  - Enhanced Mobile Broadband (eMBB)
  - Massive Machine-Type Communications (mMTC)
  - Ultra-reliable and Low Latency Communications (URLLC)
- Needs multiple spectrum to provide all above cases and also to provide ubiquitous 5G coverage

Option 3: Non-Standalone (NSA) NR, LTE assisted, EPC connected

3GPP NSA / "LTE Assisted" Option 3 / 3A / 3X
a.k.a. EN-DC



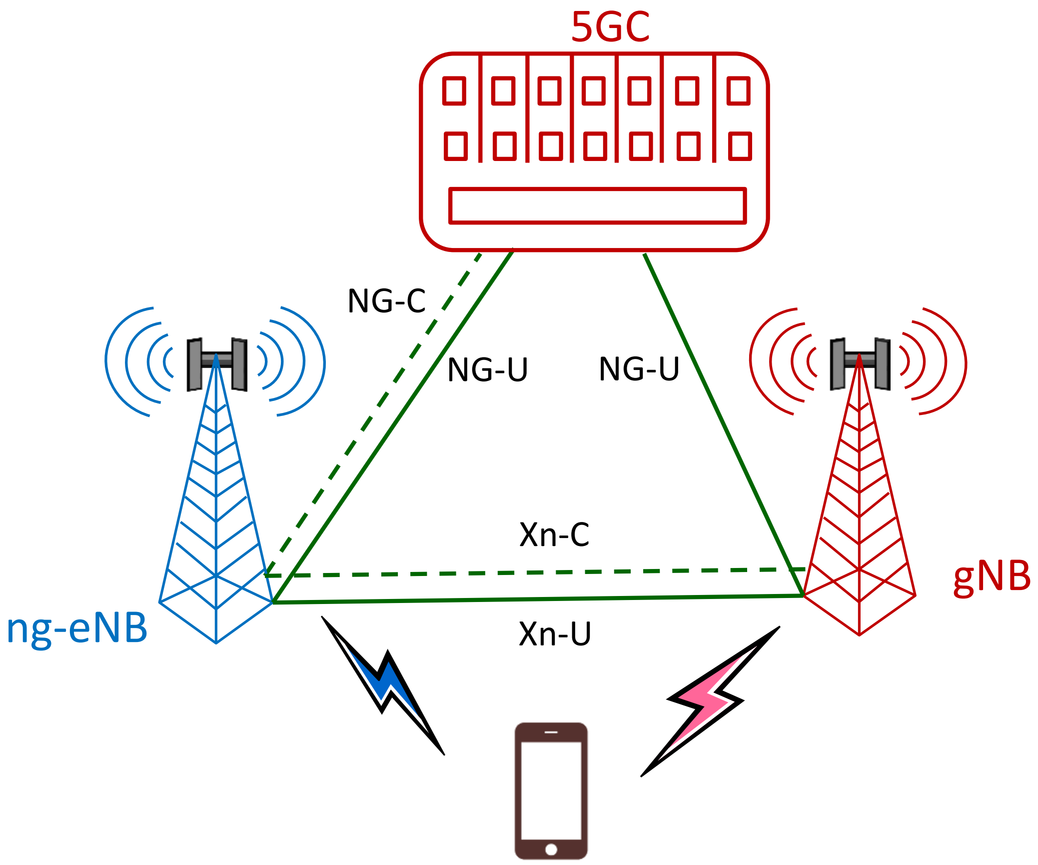
- Leverages existing 4G deployments
- Capable of creating 5G hotspots quickly
- No overloading of EPC with 5G signaling
- New 5G applications and services creation possible

<u>Difference between 3/3A/3X</u>

- In option 3, there is no connection from gNB to EPC – eNB hardware upgrade is probably required
- In option 3A, gNB has S1-U interface to EPC but no X2. New services can be handled by NR and X2 backhaul is easy to meet
- Option 3X is a combination of 3 & 3A. S1-U is available from gNB and X2 interface is available too

Option 7: NSA LTE assisted NR connected to 5GC

3GPP NSA / "NR Assisted" Option 7 / 7A / 7X



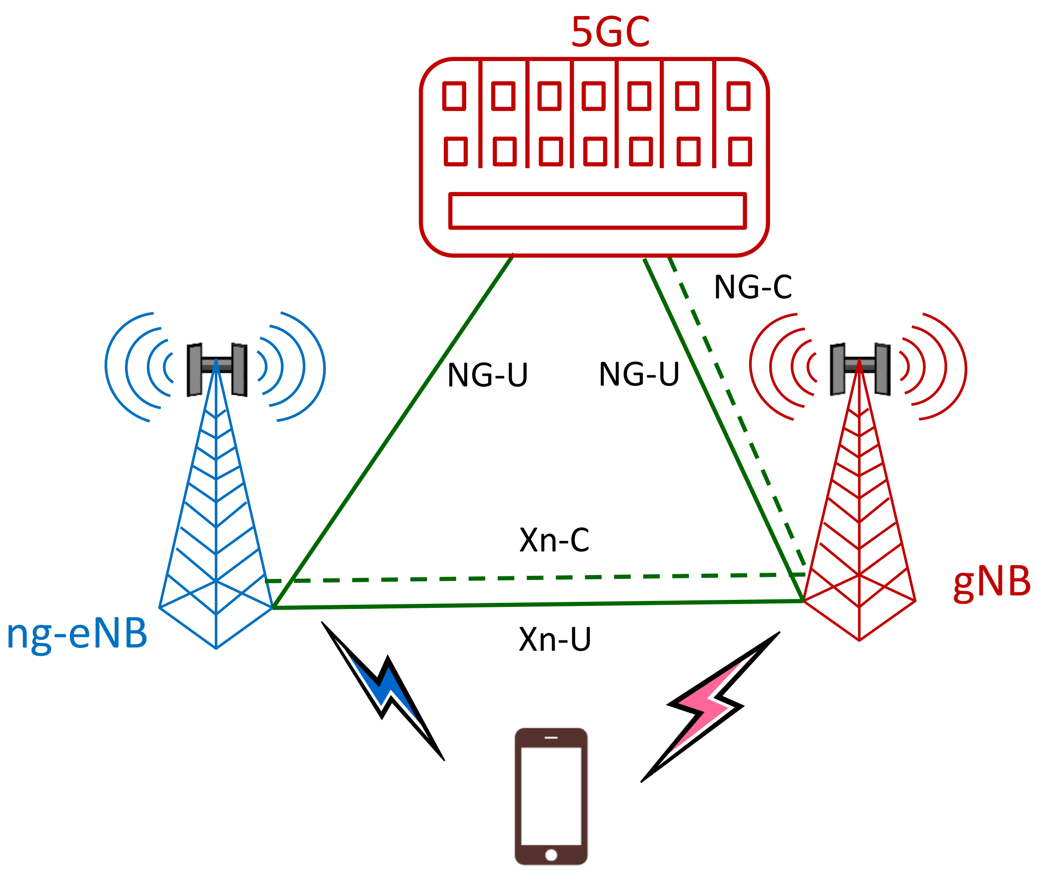
- In this case ng-eNB is the master and gNB is secondary node.
- Next Generation CN (NGCN) has replaced EPC
- Evolved eNB and gNB connect via Xn interface
- 5G driven by capacity needs, rather than just coverage
- New 5G applications and services creation possible

<u>Difference between Option 7 / 7A / 7X</u>

- In option 7, there is no interface between gNB and 5GC. Information flows via Xn
- In option 7A, there is no Xn interface and gNB is connected to 5GC via NG-U interface
- Option 7X is a combination of option 7 & 7A

Evolution Architecture: Non-Standalone (NSA)

3GPP NSA / "NR Assisted" Option 4 / 4A
a.k.a. NE-DC

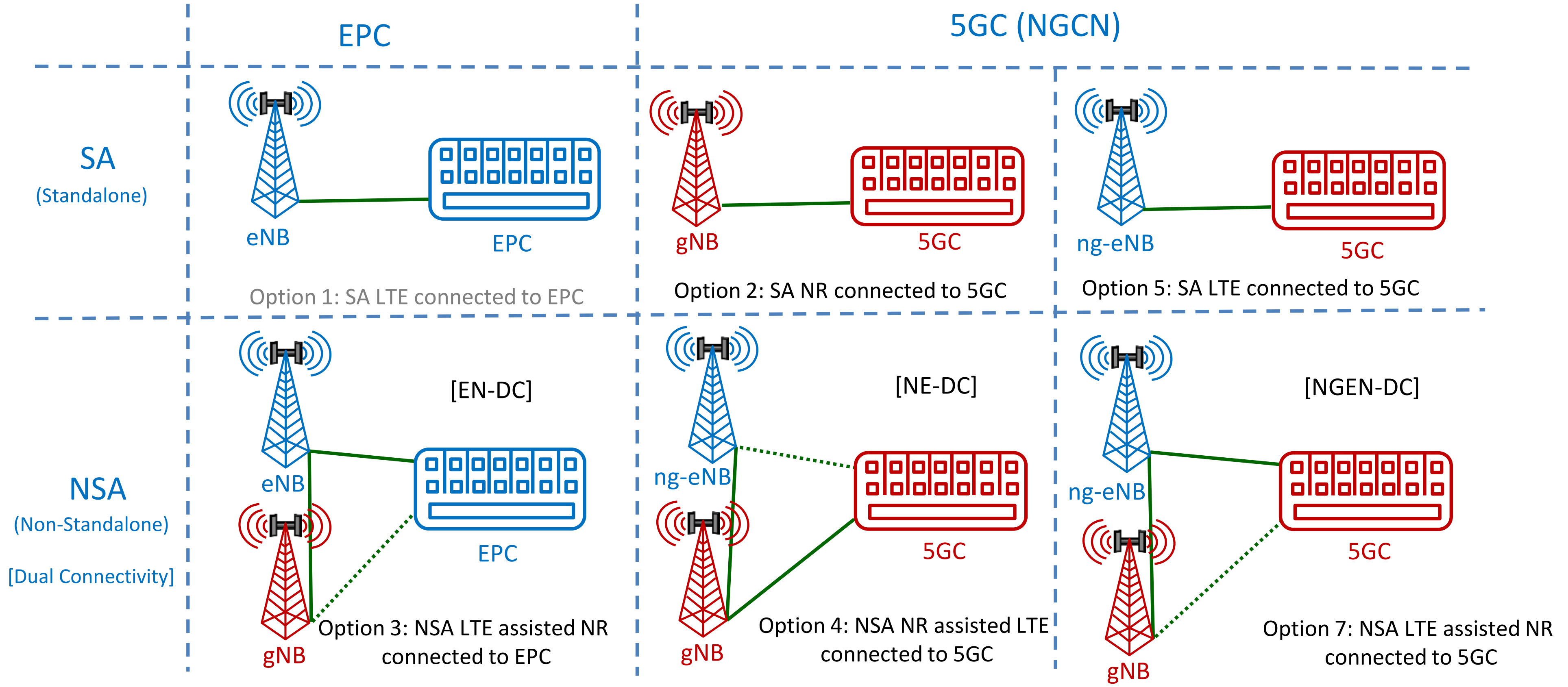


- Next Generation CN (NGCN) has replaced EPC
- 5G driven by capacity needs, rather than just coverage
- New 5G applications and services creation possible

<u>Difference between Option 4 & 4A</u>

- In Option 4, there is no direct connectivity between ng-eNB and 5GC. All information flows via Xn interface
- In Option 4A, there is no Xn interface between ng-eNB and gNB. ng-eNB is connected to 5GC via NG-U interface.

5G Deployment Options and Migration Strategy



Migration Strategy

- Option 1 ↗ Option 2 ↘ Option 3
- Option 3 ↗ Option 7 ↘ Option 5
- Option 3 ↗ Option 3 ↘ Option 2
- Option 3 ↗ Option 4 ↘ Option 2

Further Reading

- 3GPP 5G Specifications – 3G4G
- 5G Resources – 3G4G
- 5G – The 3G4G Blog
- Rel-15 announcement on Standalone NR – 3GPP, June 2018
- Working towards full 5G in Rel-16 – 3GPP Webinar, July 2018
- Submission of initial 5G description for IMT-2020 – 3GPP, Jan 2018
- NGMN Overview on 5G RAN Functional Decomposition, Feb 2018
- Andy Sutton: 5G Network Architecture, Design and Optimisation – 3G4G Blog, Jan 2018
- 5G NR Resources, Qualcomm
- UK5G Innovation Network

3G4G

Further Reading – Magazines & Whitepapers

- NGMN 5G Whitepaper, Feb. 2015 – This paper lays the foundation on the 5G vision.
- 5G Americas: 5G Services & Use Cases, Nov. 2017 – Even though this is US centric, it looks at lots of verticals for the application of 5G
- Nokia: Translating 5G use cases into viable business cases, April 2017
- 5G Americas: LTE to 5G – Cellular and Broadband Innovation, August 2017
- GSMA: The 5G era: Age of boundless connectivity and intelligent automation, Feb 2017
- Special Issue on 5G – Journal of ICT Standardization. Articles contributed by 3GPP colleagues, delegates & chairs.
- GTI 5G Network Architecture White Paper, Feb 2018
- Deloitte/DCMS: The impacts of mobile broadband and 5G, June 2018
- NTT Docomo: 5G RAN Standardization Trends, Jan 2018

Thank You

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