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NTN Architecture and Network Protocols

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3GPP over satellite

- **3G (UMTS-2001)**
  BGAN-Inmarsat system implemented the core network of Rel. 3 of 3GPP.
  Qualcomm developed 3G CDMA chipset that was possible to connect with Globalstar constellation but not integrated with terrestrial core networks.

- **4G (LTE-2010)**
  Modifications to the standard to incorporate LEO were studied.
  Connectivity to unmodified terminals: no standard-compliant gNB.
  A. Guidotti, A. Vanelli Coralli, D. Tarchi, "Satellite-enabled LTE systems in LEO Constellations", ICC2017.

- **5G (NR-2019)**
  In 2021, cellular and satellite stakeholders reach an agreement in a standard.
  Frequency bands (like the L-band (1-2 GHz) and S-band (2-4 GHz)) are harmonized (MSS).

3 GPP NTN

- With the recent publication of 3GPP technical specifications for Non-Terrestrial Networks (NTN), a comprehensive global standard for satellite systems has been established. This standard is designed to support any orbit, any frequency band, and any device.

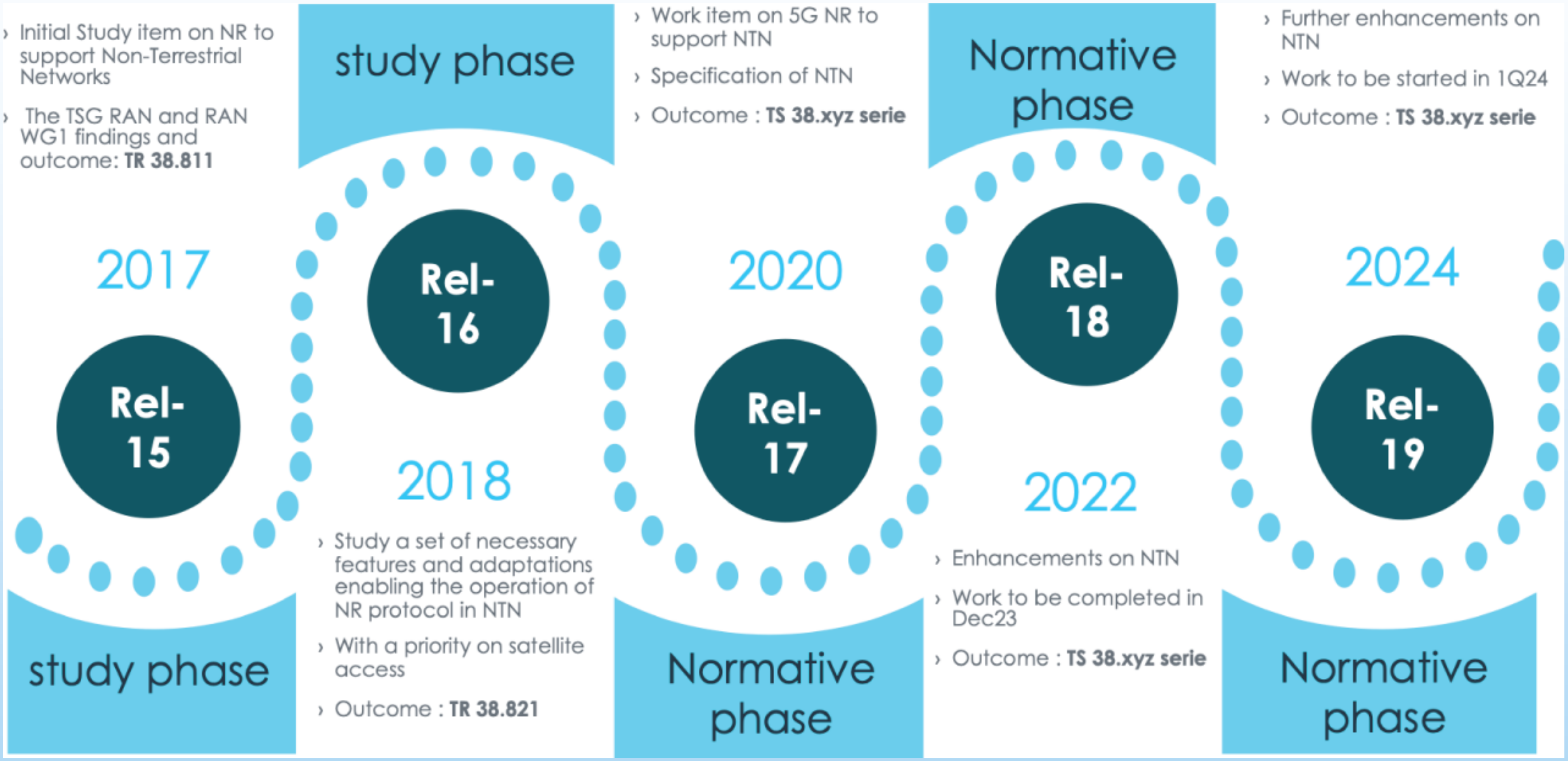
- Such specifications open the door for the seamless integration of airborne and spaceborne network components in the 5G system (5GS) and beyond (including 5G-Advanced and the upcoming 6G), delivering the promise of a ubiquitous mobile system that can support new use cases.

3 GPP NTN

- To support a hybrid terrestrial-satellite1 systems enabling New Radio (NR) and Internet of Things (IoT) services through satellites, the 3GPP work started with Study Items (SIs) on NTN in Releases 15 and 16; the necessary features for the support of the NTN component have been then specified as part of the 3GPP, Release-17.

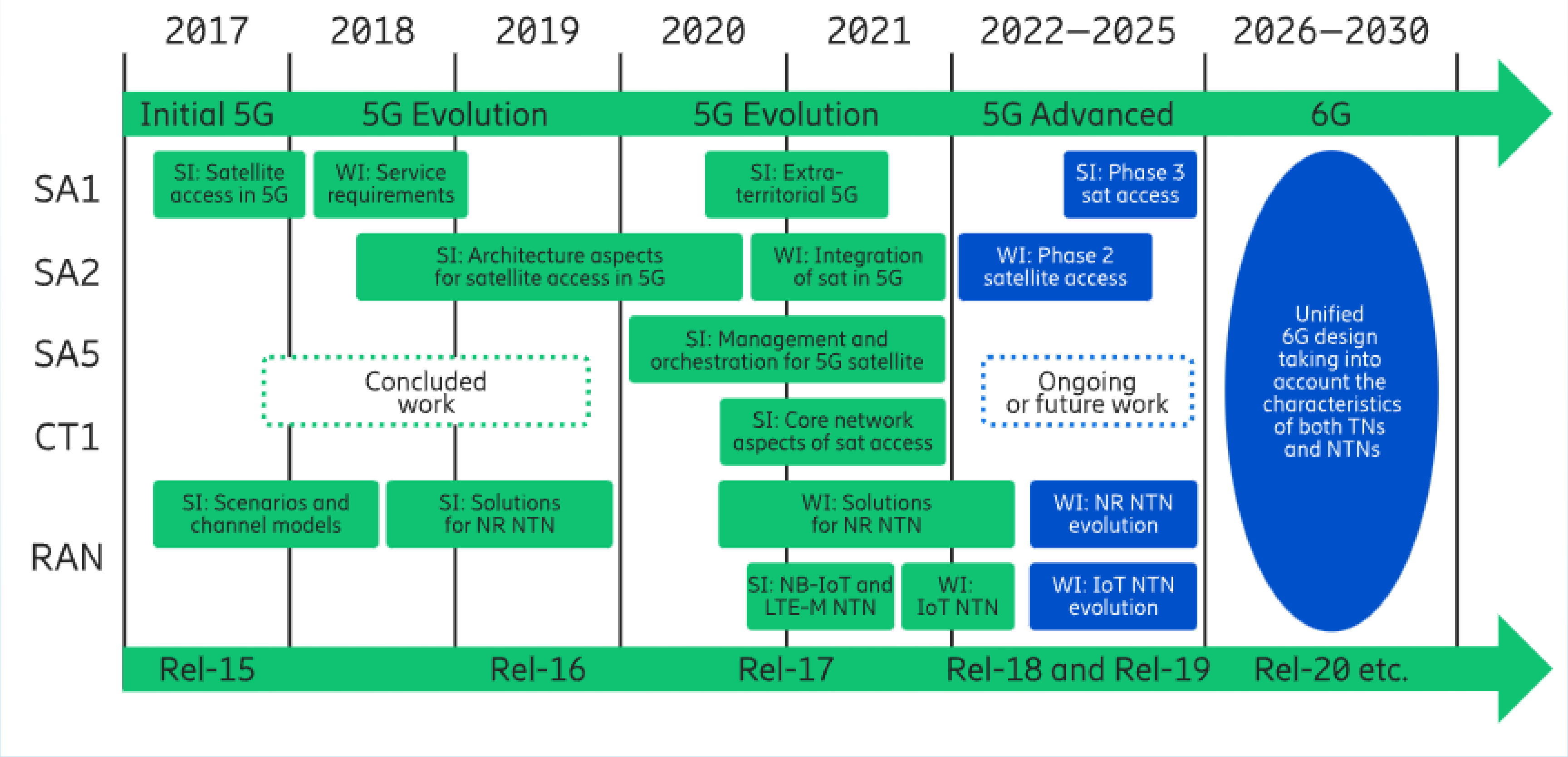
- In the same release, NTN support for Enhanced Universal Terrestrial RAN (E-UTRAN) Internet of Things (IoT) and Long Term Evolution (LTE) Cat-M (LTE-M) is also added, taking as baseline the same NTN architecture and signaling introduced in New Radio (NR). Specifications of NR IoT are foreseen for Rel-18, to be based on the same NTN architecture and signaling.

Road Map



- M. El Jaafari, N. Chuberre, S. Anjuere, L. Combelles, “Introduction to the 3GPP-defined NTN standard: a comprehensive view on the 3GPP work on NTN”, International Journal of Satellite Communications and Networking, vol. 41, no. 3, pp. 220–238, 2023. doi: 10.1002/sat.1471.

3GPP over satellite



3GPP Requirements for 5G via Satellite

- A 5GS providing service with satellite access shall be able to support LEO, MEO, and GEO-based satellite access with up to 35, 95, and 285 ms end-to-end latency, respectively.
- To optimize the Quality of Experience (QoE) for the UE, a 5GS shall support negotiation on quality of service (QoS) taking into account the latency penalty.
- The 5GS with satellite access shall support communication service availabilities of at least 99.99%.
- The 5GS with satellite access shall support high uplink and downlink data rates for 5G satellite Ues.
- For details see table 7.4.2-1 in 3GPP TS 22.261: “Service Requirements for the 5G System”, June 2023

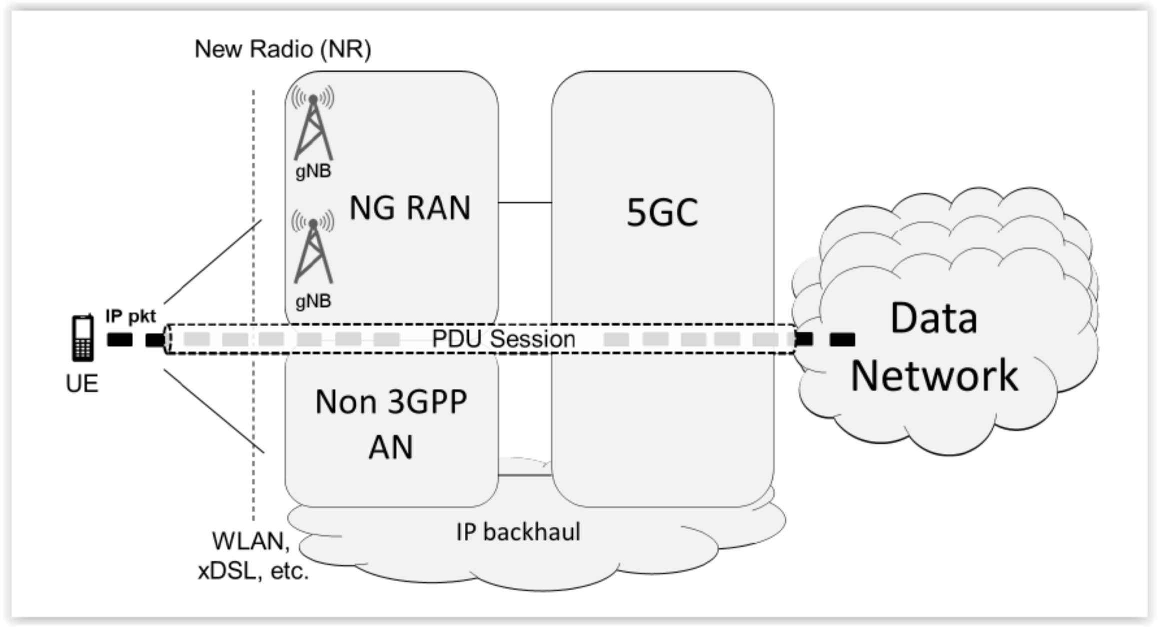
A 5G summary

References

- ETSI TS 138 211 V16.7.0 (2021-10), 5G; NR; Physical channels and modulation, (3GPP TS 38.211 version 16.7.0 Release 16)

5G Network Architecture (1)

- The 5G network is composed of an Access Network (AN) and a Core Network (5GC) (3GPP TS 23.501). AN includes the New-Generation Radio Access Network (NG-RAN) (3GPP TS 38.401), which uses the 5G New Radio (NR) interface (3GPP TS 38.300), and the access networks not belonging to the 3GPP standards (WiFi, xDSL, …) and used to access the Core Network.
- The various network entities are connected via IP, and support different levels of quality of service (QoS).

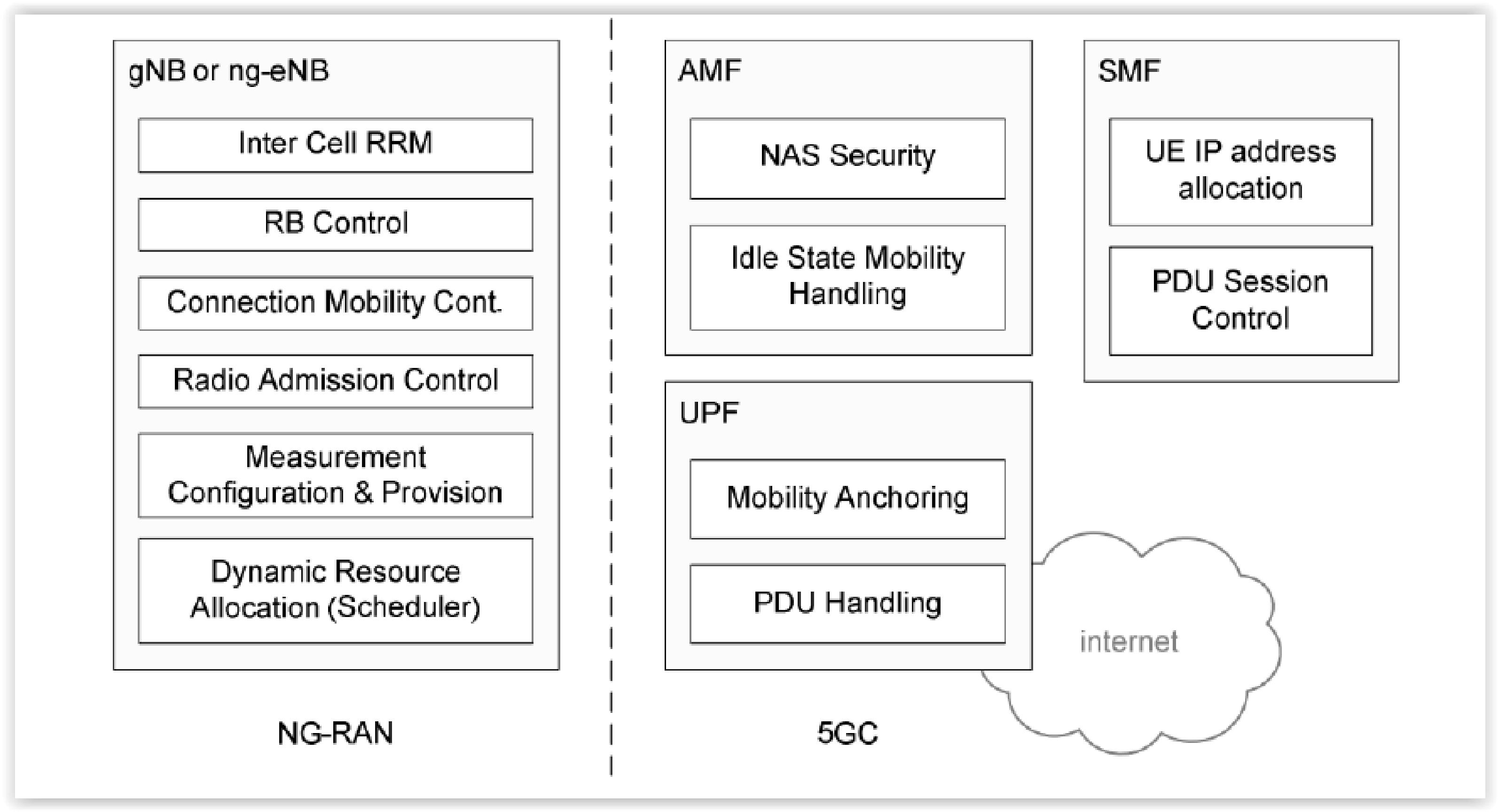


5G Network Architecture (2)

- The connection service between the mobile (UE) and the network is called PDU Session. Each PDU Session consists of a sequence of New Generation (NG) tunnels (over UDP/IP) in 5GC, and one or more radio bearers on the radio interface.
- The main task of the mobile network is to initialize, manage and terminate tunnels and bearers dynamically, following the user's movements.
- A session can transport IP packets, or packets from other sources (Ethernet and frames of other structures), allowing a dialogue at the data link layer level.
- Management is divided between NG-RAN and 5G Core.
  - NG-RAN establishes, manages and terminates sessions, taking care of physical layer issues (fading, interference, power control). NG-RN's task is to manage handover operations within node B (inter-gNB), as well as multiplexing between sessions (scheduling).
  - The other functions, not associated with radio access (mobility management, security, IP address assignment, ...) are the responsibility of the 5G Core Network.

5G Network Architecture (3)

- ng-eNB (Next Generation e-NodeB): connects a 5G terminal to the 5G Core Network using the 4G LTE radio interface.
- gNB: uses the 5G radio interface.



5G Network Architecture (4)

- In addition to traditional communication (downlink and uplink), 5G also provides device-to-device communication (sidelink), independent of connectivity via the cellular infrastructure (usable for automotive communication - V2X Communication, TS 23.287, IoT, …).
- Device-to-device communication was first introduced in LTE advanced (3GPP Rel-12/13) evolving in versions 14 and 15 for new verticals such as (automotive).
- 5G Sidelink improves on the features of 4G (lower latency, wider bandwidth and greater reliability).
- In Rel-16, 5G NR sidelink was introduced, while in Rel-17, advanced features were included to improve resource allocation, energy savings and coverage.
- 5G Advanced (Rel-18) aims to further increase efficiency, and enable access to unlicensed spectrum.

Protocol stack

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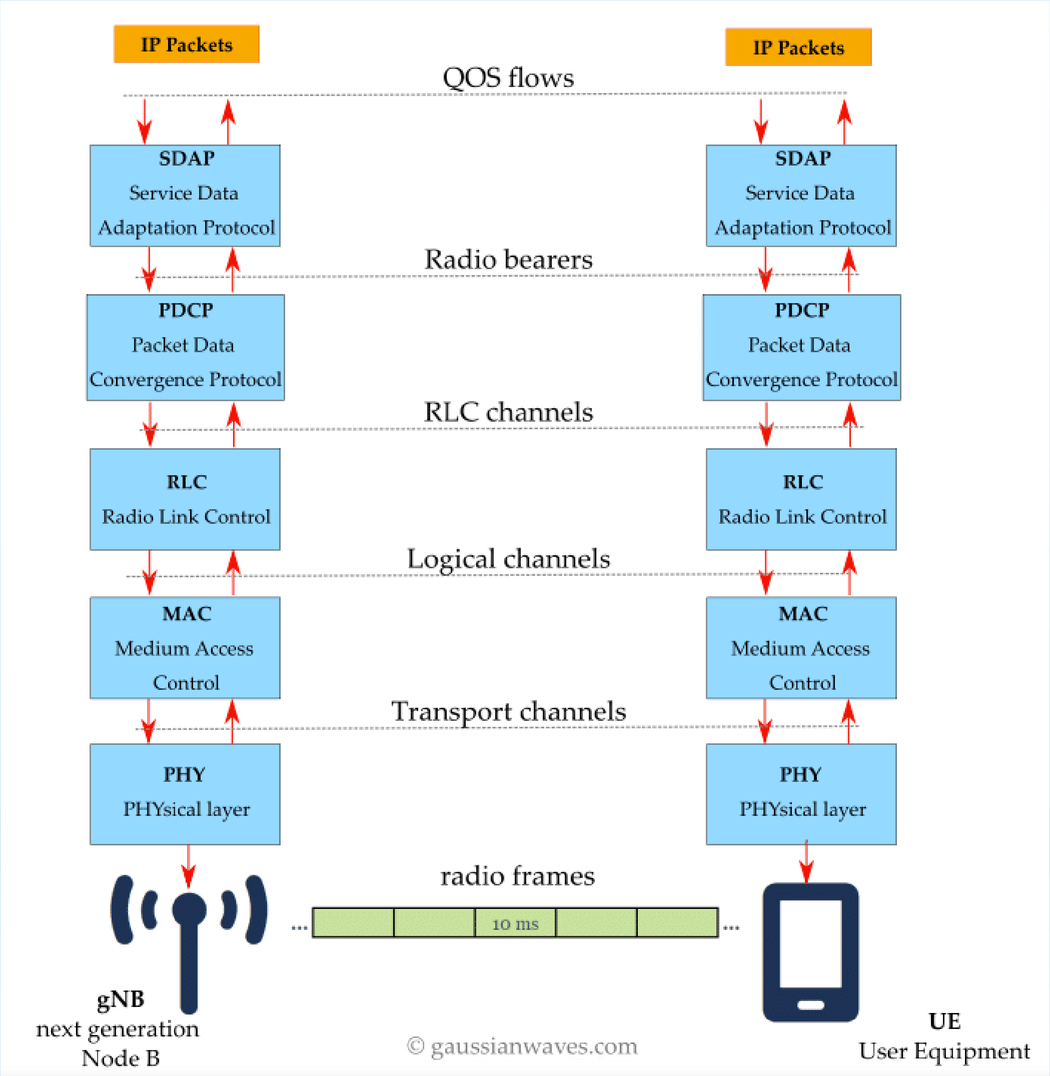

Services and Frequency Range

	5G
Services	eMBB, mMTC, URLLC
Latency	1 ms
Frequencies	Lower than 60 gHz
Bandwidth	Up to 100 MHz (< 6GHz) Up to 400 MHz (> 6GHz)
Carrier spacing	Variable
Frequency Allocation	Use fractions of bandwidth

Frequency range	Frequency	Duplex Mode
FR1	410 MHz -7.125 GHz	TDD and FDD
FR2	24.25 -52.6 GHz	TDD

Bands 5G FR1 (I)

Table 5.2-1: NR *operating bands* in FR1

NR *operating band*	Uplink (UL) *operating band* BS receive / UE transmit $F_{UL,low}$ – $F_{UL,high}$	Downlink (DL) *operating band* BS transmit / UE receive $F_{DL,low}$ – $F_{DL,high}$	Duplex mode
n1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
n2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
n3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
n5	824 MHz – 849 MHz	869 MHz – 894 MHz	FDD
n7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
n8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
n12	699 MHz – 716 MHz	729 MHz – 746 MHz	FDD
n14	788 MHz – 798 MHz	758 MHz – 768 MHz	FDD
n18	815 MHz – 830 MHz	860 MHz – 875 MHz	FDD
n20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
n25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz	FDD
n26	814 MHz – 849 MHz	859 MHz – 894 MHz	FDD
n28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
n29	N/A	717 MHz – 728 MHz	SDL
n30	2305 MHz – 2315 MHz	2350 MHz – 2360 MHz	FDD
n34	2010 MHz – 2025 MHz	2010 MHz – 2025 MHz	TDD
n38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
n39	1880 MHz – 1920 MHz	1880 MHz – 1920 MHz	TDD
n40	2300 MHz – 2400 MHz	2300 MHz – 2400 MHz	TDD
n41	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD
n48	3550 MHz – 3700 MHz	3550 MHz – 3700 MHz	TDD
n50	1432 MHz – 1517 MHz	1432 MHz – 1517 MHz	TDD
n51	1427 MHz – 1432 MHz	1427 MHz – 1432 MHz	TDD
n53	2483.5 MHz – 2495 MHz	2483.5 MHz – 2495 MHz	TDD

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Bands 5G FR1 (II)

n65	1920 MHz – 2010 MHz	2110 MHz – 2200 MHz	FDD
n66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
n70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD
n71	663 MHz – 698 MHz	617 MHz – 652 MHz	FDD
n74	1427 MHz – 1470 MHz	1475 MHz – 1518 MHz	FDD
n75	N/A	1432 MHz – 1517 MHz	SDL
n76	N/A	1427 MHz – 1432 MHz	SDL
n77	3300 MHz – 4200 MHz	3300 MHz – 4200 MHz	TDD
n78	3300 MHz – 3800 MHz	3300 MHz – 3800 MHz	TDD
n79	4400 MHz – 5000 MHz	4400 MHz – 5000 MHz	TDD
n80	1710 MHz – 1785 MHz	N/A	SUL
n81	880 MHz – 915 MHz	N/A	SUL
n82	832 MHz – 862 MHz	N/A	SUL
n83	703 MHz – 748 MHz	N/A	SUL
n84	1920 MHz – 1980 MHz	N/A	SUL
n86	1710 MHz – 1780 MHz	N/A	SUL
n89	824 MHz – 849 MHz	N/A	SUL
n90	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD
n91	832 MHz – 862 MHz	1427 MHz – 1432 MHz	FDD[2]
n92	832 MHz – 862 MHz	1432 MHz – 1517 MHz	FDD[2]
n93	880 MHz – 915 MHz	1427 MHz – 1432 MHz	FDD[2]
n94	880 MHz – 915 MHz	1432 MHz – 1517 MHz	FDD[2]
n95[1]	2010 MHz – 2025 MHz	N/A	SUL

NOTE 1: This band is applicable in China only.
NOTE 2: Variable duplex operation does not enable dynamic variable duplex configuration by the network, and is used such that DL and UL frequency ranges are supported independently in any valid frequency range for the band.

SDL, SUL: Supplementary Downlink, Uplink

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Bands 5G FR2

Table 5.2-2: NR *operating bands* in FR2

NR *operating band*	Uplink (UL) and Downlink (DL) *operating band* BS transmit/receive UE transmit/receive $F_{UL,low}$ – $F_{UL,high}$ $F_{DL,low}$ – $F_{DL,high}$	Duplex mode
n257	26500 MHz – 29500 MHz	TDD
n258	24250 MHz – 27500 MHz	TDD
n259	39500 MHz – 43500 MHz	TDD
n260	37000 MHz – 40000 MHz	TDD
n261	27500 MHz – 28350 MHz	TDD

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Frame structure

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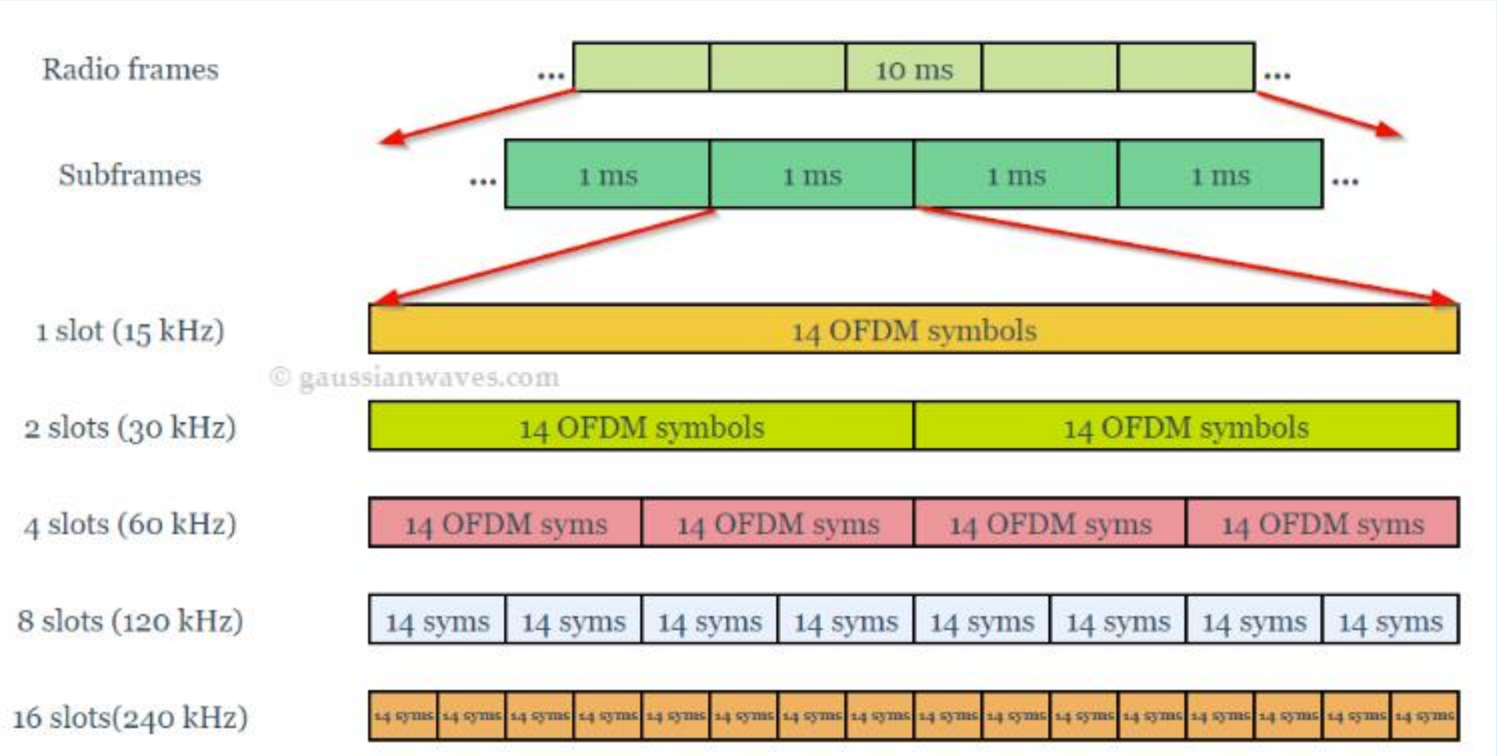

Carrier spacing

	Slot configuration					
Index (μ)	0	1	2		3	4
Carrier spacing Δ_f (kHz)	15	30	60		120	240
Resource Block Bandwidth (MHz)	0.18	0.36	0.72		1.44	2.88
Frame slots (10 ms)	10	20	40		80	160
Subframe slots(1 ms)	1	2	4		8	16
Slot duration (μs)	1000	500	250		125	62.25
Slot symbols	14	14	14	12	14	14
Subframe symbols	14	28	56	48	112	224
Symbol duration ($1/\Delta_f$) (μs)	66.7	33.3	16.7	16.7	8.33	4.17
Long cyclic prefix (μs)	5.21	2.86	1.69	4.17	1.11	0.81
Short cyclic prefix (μs)	4.69	2.34	1.17	4.17	0.59	0.29
Efficiency (%)	93%	93%	93%	80%	93%	93%

Cyclic prefix duration

- Let's define two basic times.

$$T_s = \frac{1}{15 \cdot 2048} 10^6 = 32.55 \text{ ns}$$ Sampling interval LTE.

$$T_c = \frac{1}{480 \cdot 4096} 10^6 = 0.51 \text{ ns}$$ Sampling interval 5G con Δ_f=480 kHz.

Be $K = \dfrac{T_s}{T_c} = 64$

- We have $$N_{CP,l}^{\mu} = \begin{cases} 512K \cdot 2^{-\mu} & \text{extended CP} \\ K\left(144 \cdot 2^{-\mu} + 16\right) & \text{normal CP, } l = 0 \text{ or } l = 7 \cdot 2^{\mu} \\ K144 \cdot 2^{-\mu} & \text{normal CP, } l \neq 0 \text{ and } l \neq 7 \cdot 2^{\mu} \end{cases}$$

being $T_{CP} = N_{CP,l}^{\mu} T_c$.

5G Resource Blocks (FR1)

W [Mhz]

Δ_f (kHz)	5	10	15	20	25	30	35	40
15	25	52	79	106	133	160	188	216
30	11	24	38	51	65	78	92	106
60	-	11	18	24	31	38	44	51

Δ_f (kHz)	45	50	60	70	80	90	100
15	242	270	-	-	-	-	-
30	119	133	162	189	217	245	273
60	58	65	79	93	107	121	135

3GPP TS 38.101-1 version 16.5.0 Release 16

5G Channel Bandwidth

- The overall frequency range is determined by adding appropriate margins.
- The minimum margins are obtained from the formula : $G_b = \left[W - \left(12 N_{\mathrm{RB}} + 1\right)\Delta_f\right] / 2$
  Example: W=10 MHz, Δ_f=15 kHz, N_{RB}=52.
  You get it G_b=(10·10^3-(12·52+1)15)/2=312.5 kHz.
  The bandwidth actually occupied is therefore: $\Delta_f\, 12 N_{\mathrm{RB}}$+2 G_b =9.985 MHz.

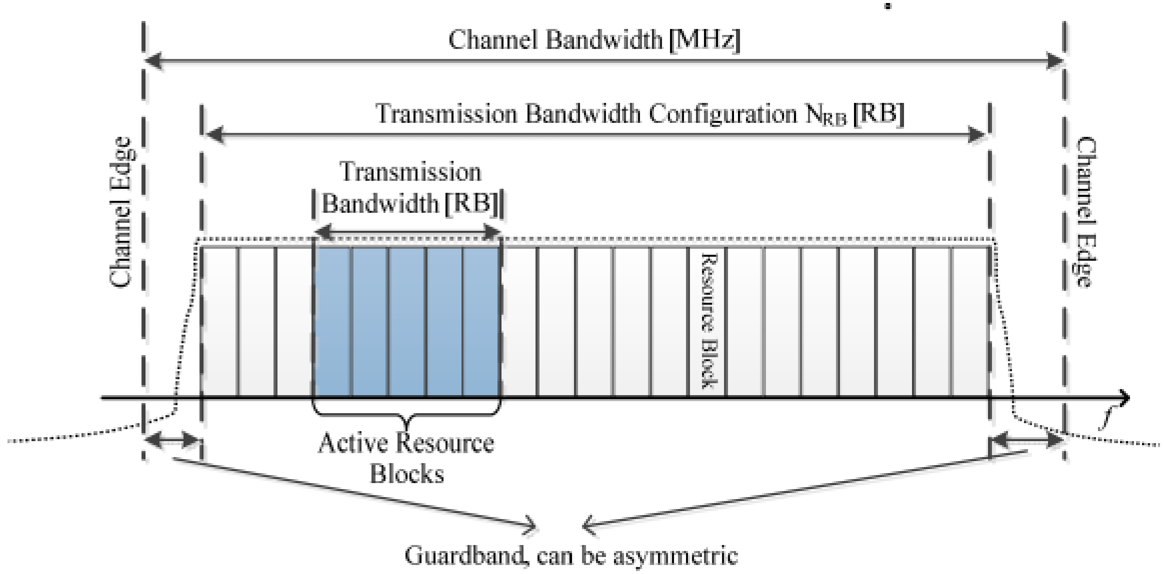

Figure 5.3.1-1: Definition of channel bandwidth and transmission bandwidth configuration for one NR channel

5G Resource Blocks (FR2)

W [Mhz]

Δ_f (kHz)	50	100	200	400	800	1600	2000
60	66	132	264	-	-	-	-
120	32	66	132	264	-	-	-
480	-	-	-	66	124	248	-
960	-	-	-	33	62	124	148

TS 138 101-2 - V17.6.0 - 5G

Carrier Spacing (SCS) and Frequencies

Table 5.3.5-1: *BS channel bandwidths* and SCS per *operating band* in FR1

NR band / SCS / *BS channel bandwidth*														
NR Band	**SCS kHz**	**5 MHz**	**10 MHz**	**15 MHz**	**20 MHz**	**25 MHz**	**30 MHz**	**40 MHz**	**50 MHz**	**60 MHz**	**70 MHz**	**80 MHz**	**90 MHz**	**100 MHz**
n1	15	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes					
	30		Yes	Yes	Yes	Yes	Yes	Yes	Yes					
	60		Yes	Yes	Yes	Yes	Yes	Yes	Yes					
n2	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60		Yes	Yes	Yes									
n3	15	Yes	Yes	Yes	Yes	Yes	Yes	Yes						
	30		Yes	Yes	Yes	Yes	Yes	Yes						
	60		Yes	Yes	Yes	Yes	Yes	Yes						
n5	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60													
n7	15	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes					
	30		Yes	Yes	Yes	Yes	Yes	Yes	Yes					
	60		Yes	Yes	Yes	Yes	Yes	Yes	Yes					
n8	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60													
n12	15	Yes	Yes	Yes										
	30		Yes	Yes										
	60													
n14	15	Yes	Yes											
	30		Yes											
	60													
n18	15	Yes	Yes	Yes										
	30		Yes	Yes										
	60													
n20	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60													
n25	15	Yes	Yes	Yes	Yes	Yes	Yes	Yes						
	30		Yes	Yes	Yes	Yes	Yes	Yes						
	60		Yes	Yes	Yes	Yes	Yes	Yes						
n26	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									

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Carrier Spacing (SCS) and Frequencies in FR2

Table 5.3.5-2: *BS channel bandwidths* and SCS per *operating band* in FR2

NR band / SCS / *BS channel bandwidth*					
NR Band	SCS kHz	50 MHz	100 MHz	200 MHz	400 MHz
n257	60	Yes	Yes	Yes	
	120	Yes	Yes	Yes	Yes
n258	60	Yes	Yes	Yes	
	120	Yes	Yes	Yes	Yes
n259	60	Yes	Yes	Yes	
	120	Yes	Yes	Yes	Yes
n260	60	Yes	Yes	Yes	
	120	Yes	Yes	Yes	Yes
n261	60	Yes	Yes	Yes	
	120	Yes	Yes	Yes	Yes

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5G MAC Layer

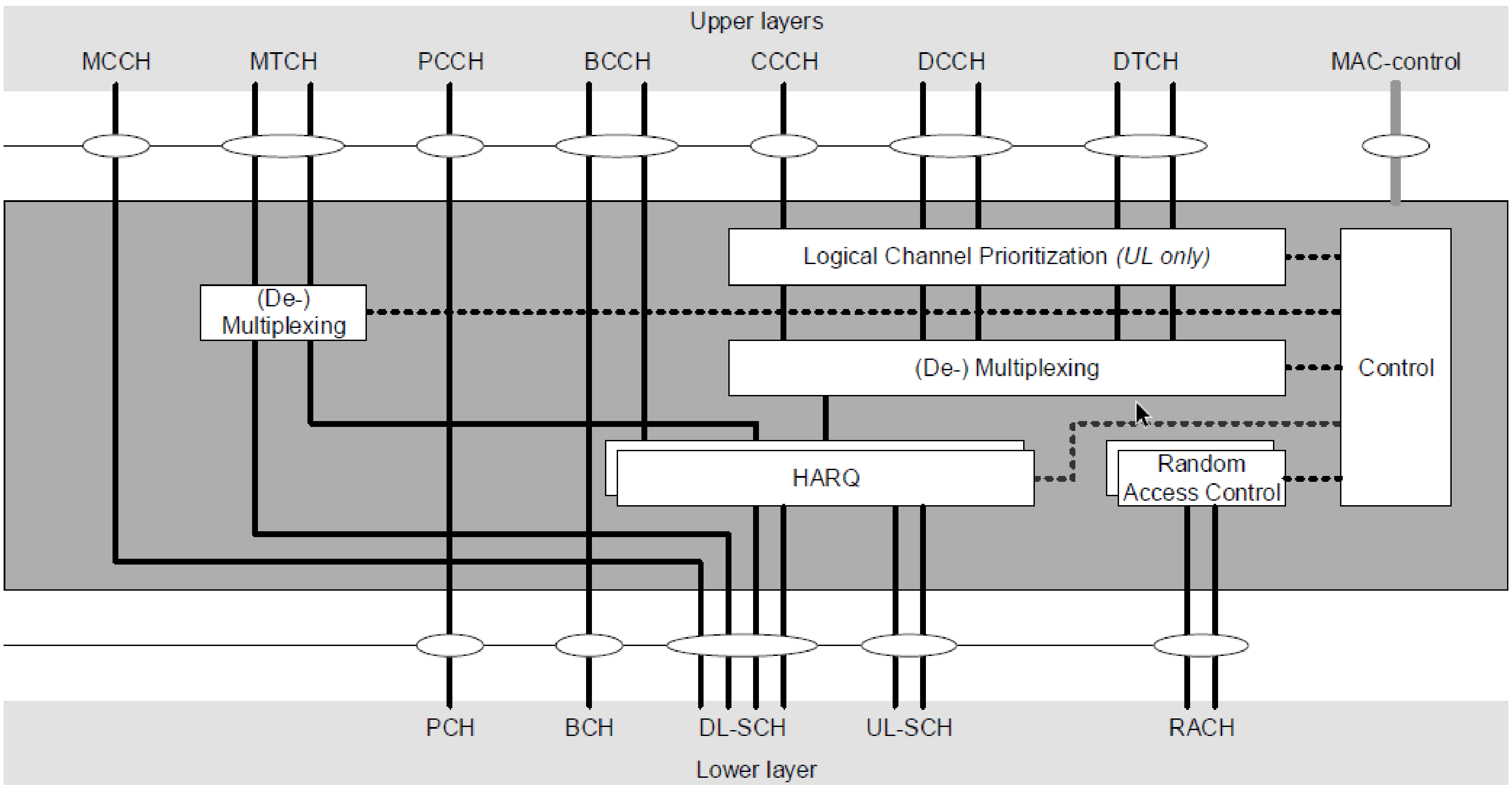

Figure 4.2.2-1: MAC structure overview

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5G MAC Layer (sidelink)

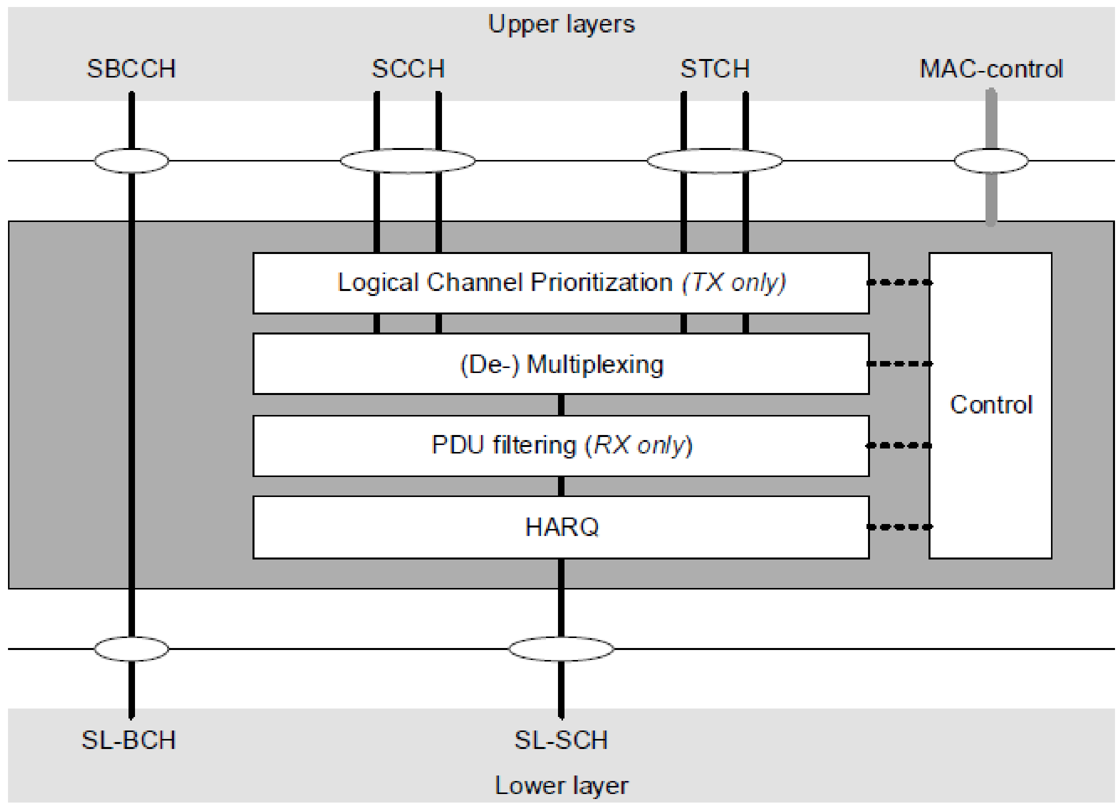

Figure 4.2.2-3: MAC structure overview for sidelink

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5G MAC Functions

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Table 4.4-1: The link direction association of MAC functions.

MAC function	Downlink	Uplink	Sidelink TX	Sidelink RX
Mapping between logical channels and transport channels	X	X	X	X
Multiplexing		X	X	
Demultiplexing	X			X
Scheduling information reporting		X	X	
Error correction through HARQ	X	X	X	X
Logical Channel prioritization		X	X	
Radio resource selection			X	

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5G MAC channels

Table 4.5.2-1: Transport channels used by MAC

Transport channel name	Acronym	Downlink	Uplink	Sidelink
Broadcast Channel	BCH	X		
Downlink Shared Channel	DL-SCH	X		
Paging Channel	PCH	X		
Uplink Shared Channel	UL-SCH		X	
Random Access Channel	RACH		X	
Sidelink Broadcast Channel	SL-BCH			X
Sidelink Shared Channel	SL-SCH			X

Table 4.5.3-1: Logical channels provided by MAC.

Logical channel name	Acronym	Control channel	Traffic channel
Broadcast Control Channel	BCCH	X	
Paging Control Channel	PCCH	X	
Common Control Channel	CCCH	X	
Dedicated Control Channel	DCCH	X	
Dedicated Traffic Channel	DTCH		X
MBS Control Channel	MCCH	X	
MBS Traffic Channel	MTCH		X
Sidelink Broadcast Control Channel	SBCCH	X	
Sidelink Control Channel	SCCH	X	
Sidelink Traffic Channel	STCH		X

MBS: Multicast/Broadcast Services

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5G MAC Channels Mapping

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Table 4.5.4.2-1: Uplink channel mapping.

Logical channel \ Transport channel	UL-SCH	RACH
CCCH	X	
DCCH	X	
DTCH	X	

Table 4.5.4.3-1: Downlink channel mapping.

Logical channel \ Transport channel	BCH	PCH	DL-SCH
BCCH	X		X
PCCH		X	
CCCH			X
DCCH			X
DTCH			X
MCCH			X
MTCH			X

Table 4.5.4.4-1: Sidelink channel mapping.

Logical channel \ Transport channel	SL-BCH	SL-SCH
SBCCH	X	
SCCH		X
STCH		X

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5G MAC PDU

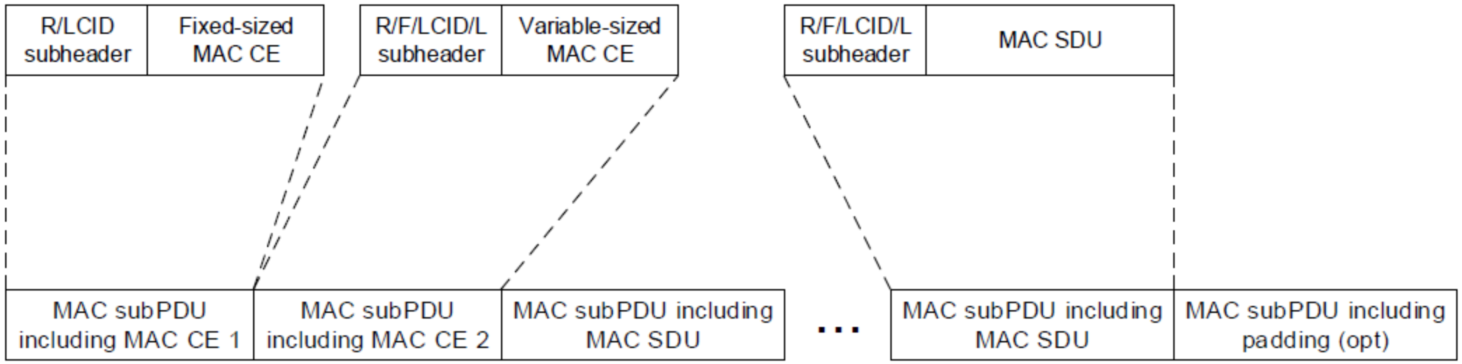

Figure 6.1.2-4: Example of a DL MAC PDU

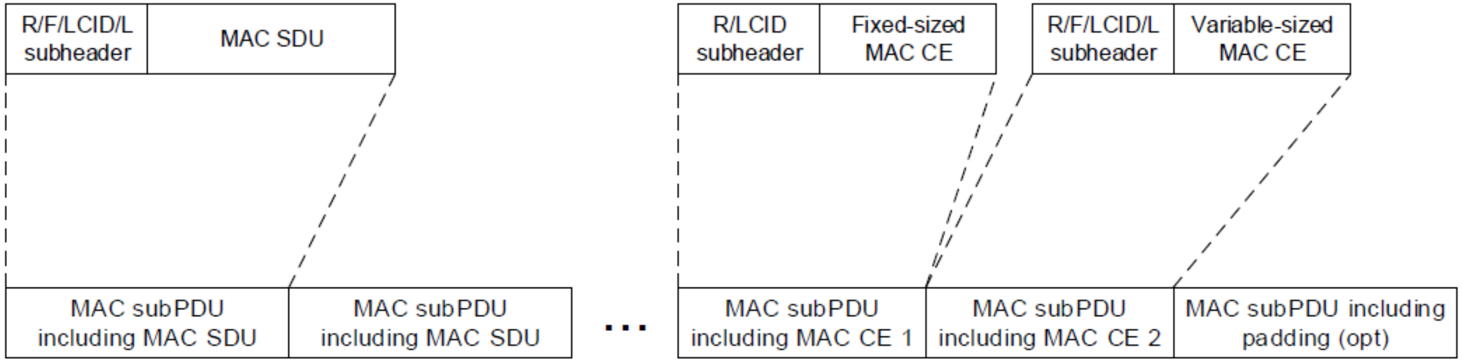

Figure 6.1.2-5: Example of a UL MAC PDU

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5G MAC subheader

LCID (Logical Channel ID). Identifies the logical channel of the MAC SDU or the type of MAC CE (Control Element). The LCID field has a size of 6 bits.

eLCID (extended Logical Channel ID). Extends the range of the LCID field. Its size is 1 byte if LCID=34, 2 bytes if LCID=3.

L (8 or 16 bits): indicates the length in bytes of the corresponding MAC SDU or MAC CE (not present for example for fixed size CE).

F: size of the L field (1 indicates 16-bit L).

R: Reserved bit, set to zero.

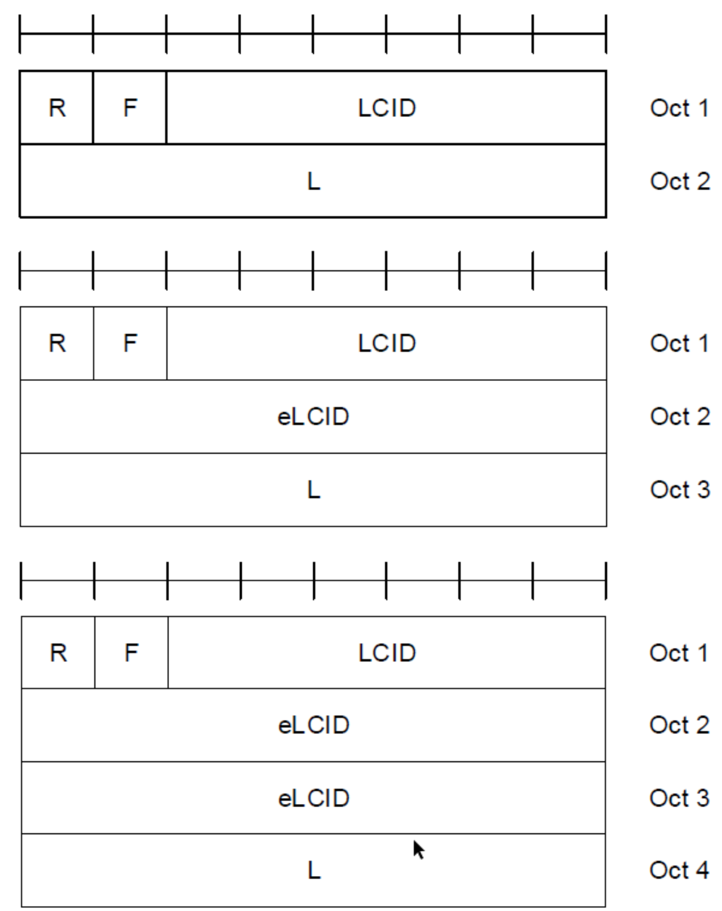

Figure 6.1.2-1: R/F/LCID/(eLCID)/L MAC subheader with 8-bit L field

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5G NTN Architecture

- High-level viewpoint: a NTN architecture needs radio access from the terrestrial UE to the satellite, referred to as the "service link", and in a second step, the satellite needs to be connected to a terrestrial gateway, referred to as the "feeder link".
- The service link is described as the NR Uu interface, so the well-known 5G RAT and the feeder link is described as satellite radio interface (SRI).
- This SRI can either be the 5G NR waveform or another proprietary or standardized waveform.
- The mmWave, in the range from 30 GHz to 300 GHz, is considered for Gbps data rate connections. The advantage in addition to the wide bandwidth and therefore very high throughput is the resilience to clouds and bad weather.
- Future networks will also implement free space optical (FSO) feeder links with frequencies beyond 190 THz that provide data rates up to Tbps and distances up to 1000 km. The key advantage is that these optical frequencies do not fall under international regulation control, but the major disadvantage is the propagation aspect. FSO links do not propagate through clouds.

5G NTN Architecture

- There is also the possibility of an inter-satellite link (ISL). This is required particularly in LEO constellations because the satellite may not always have connectivity to the earth based gateway, especially when you consider the satellite being over a maritime region.
- In addition, the ISL may be used for control message exchange like mobility or handover scenario control, for traffic management purposes and for satellite flight control independently of 3GPP.
- Satellite constellations like LEO or GEO have the advantage of a known or predictable trajectory, which facilitates the routing of the connection to the ground station.
- Airborne stations like low or high altitude platform systems (LAPS or HAPS) may not be on a predictive flight route and therefore require some control of the feeder link routing and steering.

5G NTN Architecture

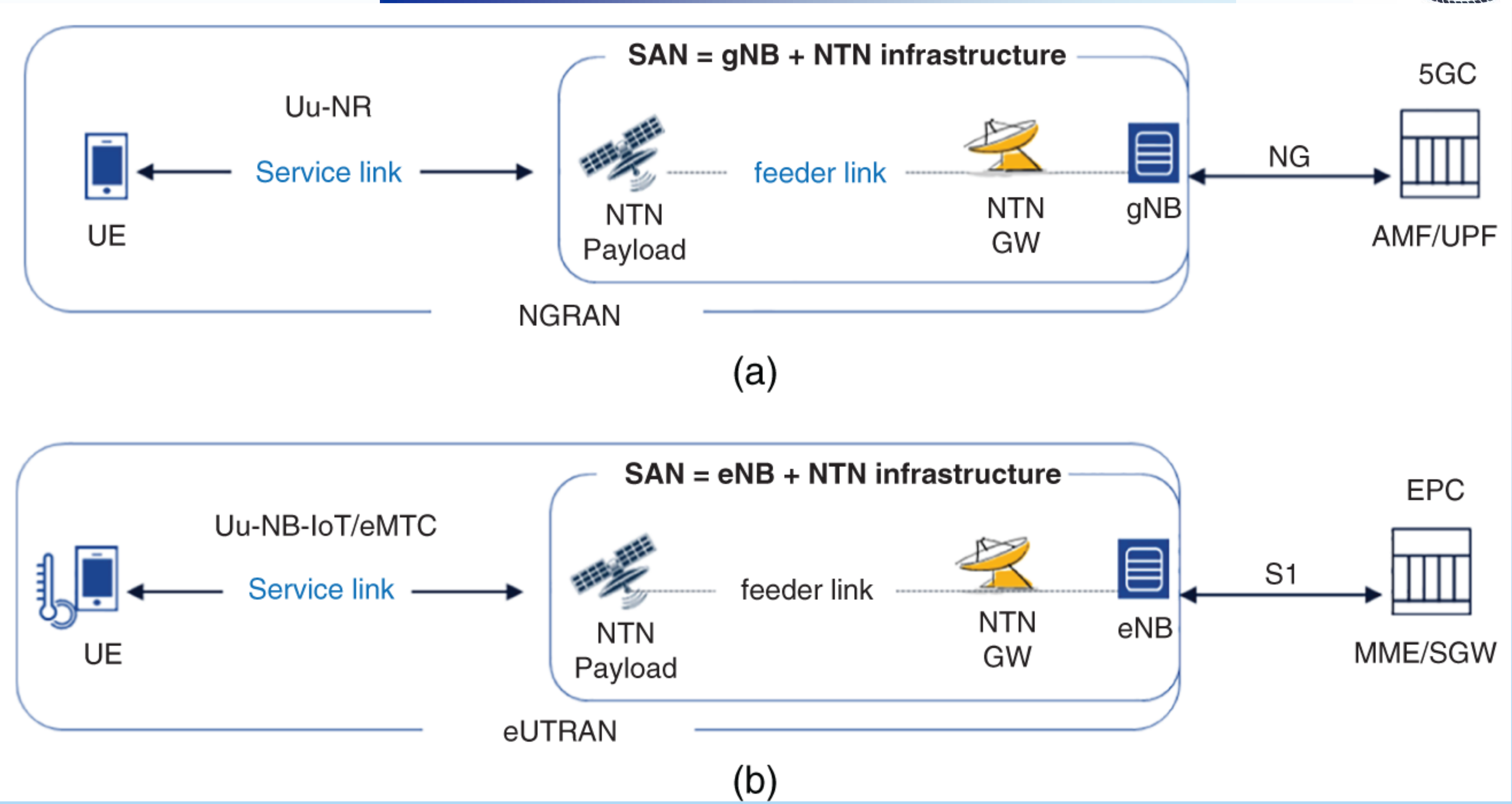
- Targeting an NTN-capable RAN deployment, two possible architecture options are discussed within 3GPP:
- the transparent mode (chapter 3.10.2) and the regenerative mode (chapter 3.10.3).
- Release 17 deals primarily with the transparent mode architecture.
- In the 5G system architecture, the major impact due to the introduction of NTN is considered to occur in the RAN where possible architecture models support transparent or regenerative architectures.

QoS support

- One notifiable aspect of 5G is the strong and sophisticated quality of service (QoS) framework that defines different QoS flows and introduces a specific protocol (SDAP) to leverage, maintain and manage the QoS support.

Parameter	**Value**
5QI value	10
Resource type	non-guaranteed bit ratio (non-GBR)
Default priority level	90
Packet delay budget	1100 ms
Packet error rate	10^{-8}
Example services	Video (buffered streaming), TCP-based (e.g. WWW, email, chat, FTP, P2P file sharing, progressive video) and any service that can be used over satellite access type with these characteristics

NTN based RAN architecture with transparent satellite



- (a) NTN NG-RAN architecture and (b) IoT NTN EUTRAN architecture.
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Transparent NTN NG-RAN architecture

- The major aspect in the transparent architecture is the disaggregation of the legacy term "base station" into the components satellite, ground gateway and gNB functions.
- The satellite functions implement RF filtering, frequency conversion, RF amplification and RF transmission and reception in both the uplink and downlink direction.
- A pivotal characteristic is that the waveform or RAT is repeated between the serving and feeder link by an unchanged payload. By way of analogy and simplification, the functions of the satellite station correspond to the analog RF repeater concept.
- A frequency carrier change is applied to avoid interferences between the serving and feeder link, but this is up to the manufacturer and the operator. The document [TR 23.737] defines the functionality of the transparent payload as the electromagnetic waves that are transmitted from the earth's surface and converted by a satellite receive antenna into an electric signal, which is channel-filtered and amplified by a low-noise amplifier (LNA).

Transparent NTN NG-RAN architecture

- The signal is then frequency-converted. A high-power amplifier (HPA) finally delivers the signal to a transmitting antenna generating a reconditioned electromagnetic wave towards the earth’s surface where the receive gateway is located.
- The advantage of the transparent architecture is the independency on the radio waveform, so any amendments here do not require changes in the spaceborne station. The disadvantages are the amplification of noise because the satellite does not perform any channel equalization or noise cancellation, the vulnerability against jamming attacks and the lack of ISL connections for traffic steering.
- The termination of the 5G NR air interface (Uu) with respect to the protocol anchor is in the terrestrial gNB function.
- The gateway adopts a parabolic antenna or antenna array with beamforming capabilities to steer the feeder link heading towards the satellite station, avoiding interference between satellites.

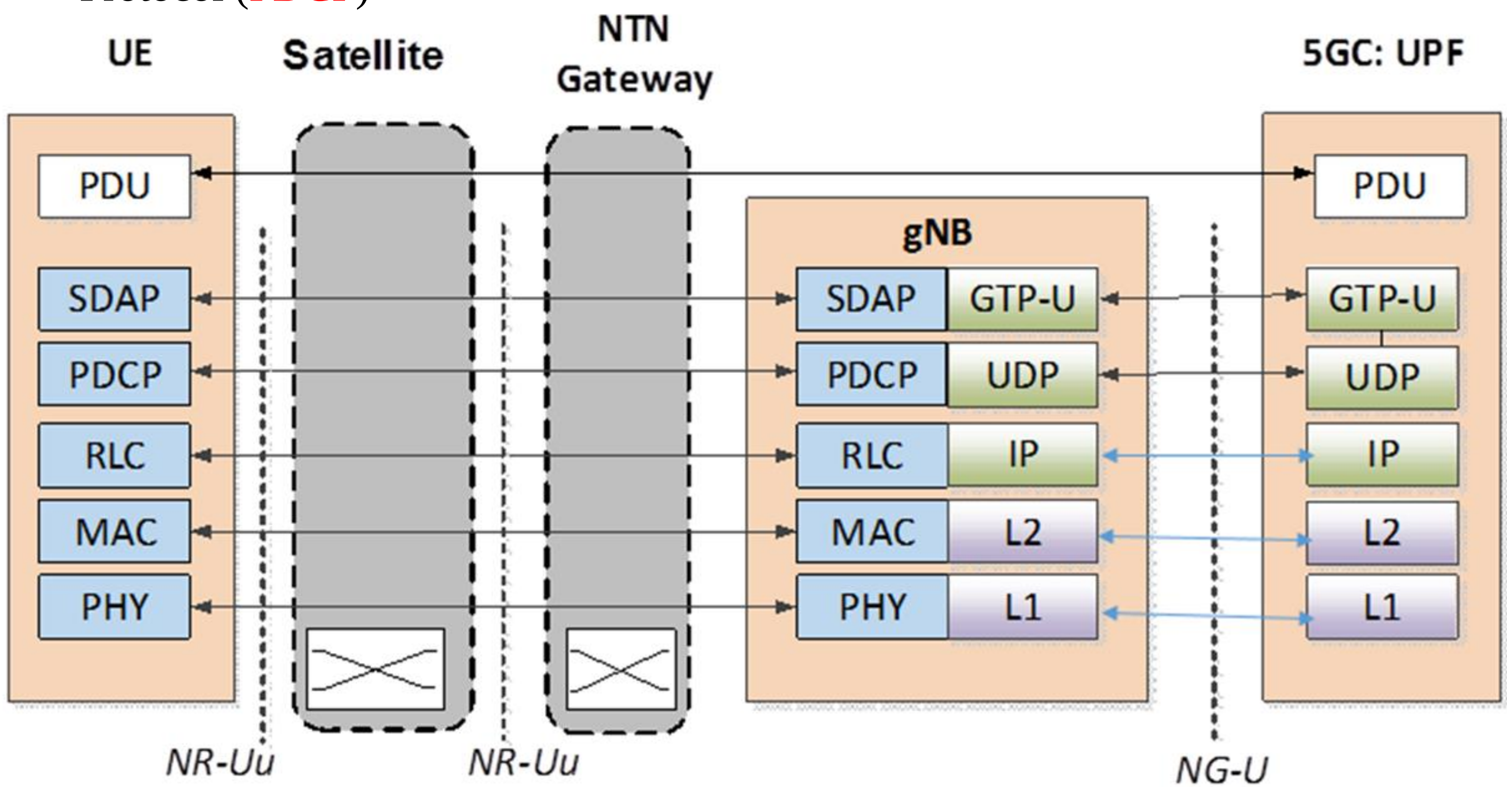
Transparent NTN NG-RAN architecture

- The gateway and the gNB can be incorporated into the same hardware cabinet or the gNB functions are offered to several satellites.
- Only in the opposite view, a satellite is only connected to a single gNB to clarify the protocol termination point.
- It is possible for a satellite to be connected to multiple gateways or gNBs, but in such cases, the payload is logically split.
- From the perspective from the UE, one specific UE data connection to the 5GC is routed via a single gateway or gNB. Exceptions are the multi connectivity scenarios.
- The connection between the UE and the terrestrial gNB includes at least the serving and the feeder link, but also several ISLs in between are possible in future extensions.

Transparent Mode: User plane

- TR 38.821
  - Service Data Adaptation Protocol (SDAP)
  - Packet Data Convergence Protocol (PDCP)

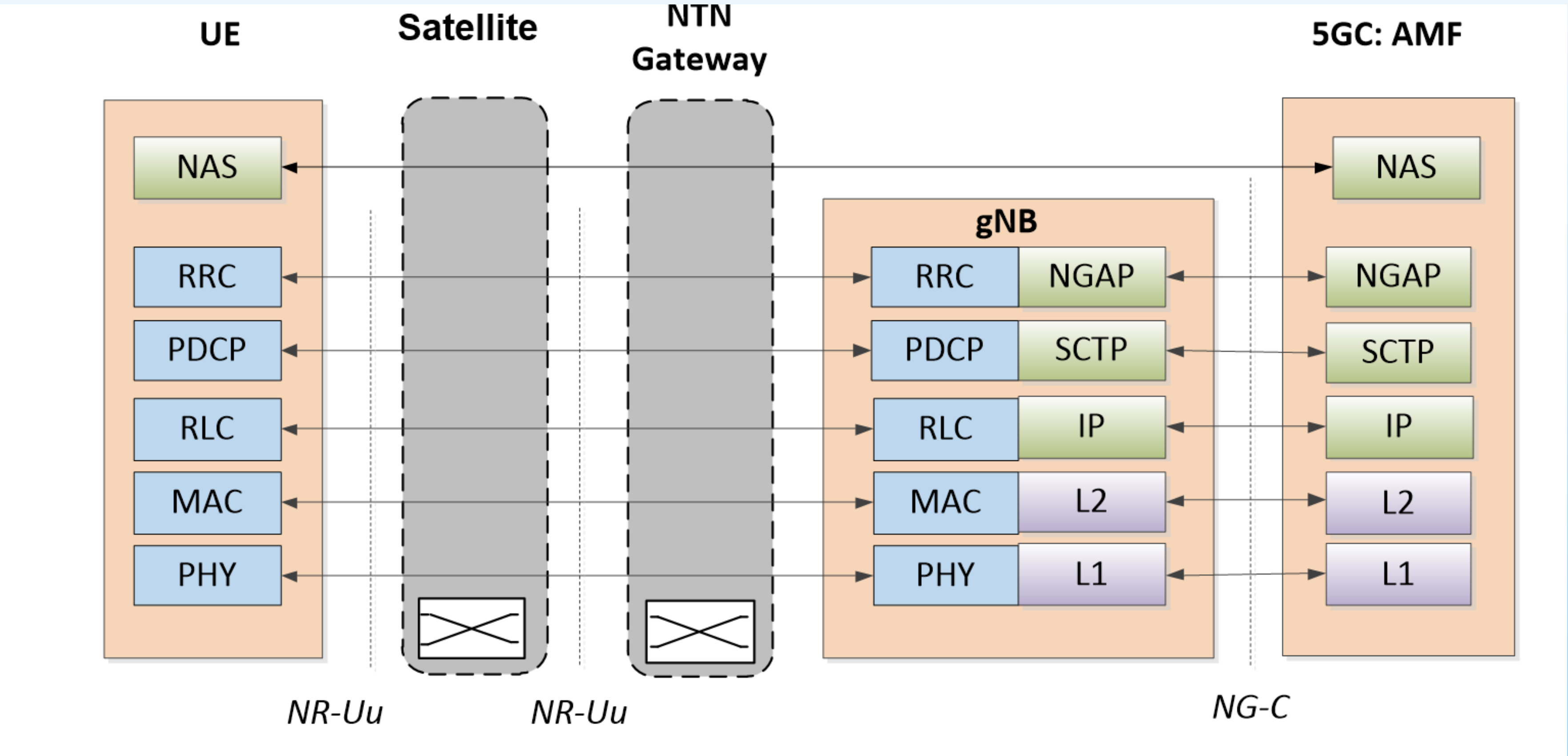
gNB (gNodeB) provides connectivity between user equipment (UE) and the evolved packet core (EPC)
User Plane Function (UPF)
GTP-U (GPRS Tunneling Protocol for the User Plane)



Transparent Mode: Control plane

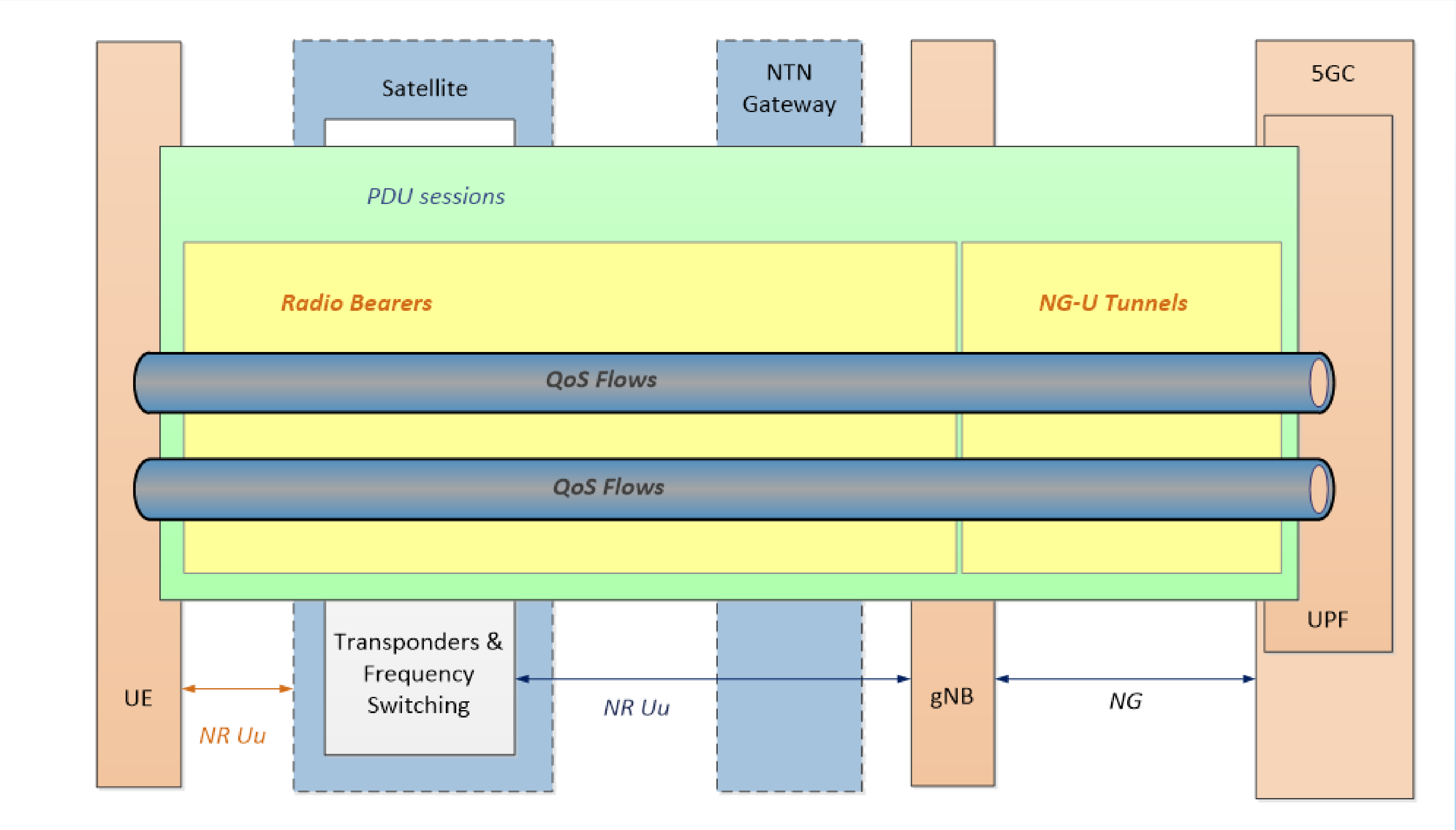
- TR 38.821
  - NAS (Non-Access Stratum).

Mobility Management Function (AMF)
NGAP (NG Application Protocol)
Stream Control Transmission Protocol (SCTP)



Transparent Mode: mapping QoS flows

- TR 38.821



Transparent NTN NG-RAN architecture

- Summarizing, the transparent payload architecture does not require many modifications to the existing 5G NG-RAN architecture model.
- Some changes are required, particularly some physical layer timers to adapt to the long delay of the feeder and service link.

Regenerative NTN NG-RAN architecture

- The regenerative architecture deals with the three components satellite, gateway and gNB (Radio base station in 5G networks), but allows some combinations.
- The gNB functions are incorporated into the satellite itself.
- The regenerative architecture model raises the complexity of the satellite hardware and computing power and is discussed within 3GPP at a lower priority in Release 17 and envisaged for later releases.
- Further separations are made in the optional disaggregation of the gNB functions into the distributed unit (DU) and the centralized unit (CU).
- The regenerative payload architecture supports two architecture models:

  a) the satellite node can directly incorporate the DU and CU, and via the feeder link to the gateway there is a direct connection to the 5G core network (5GC).

  b) the satellite can only host the DU functions of the gNB and therefore the feeder link to the terrestrial gateway carries the F1 interface over the SRI and the CU is terrestrial based.

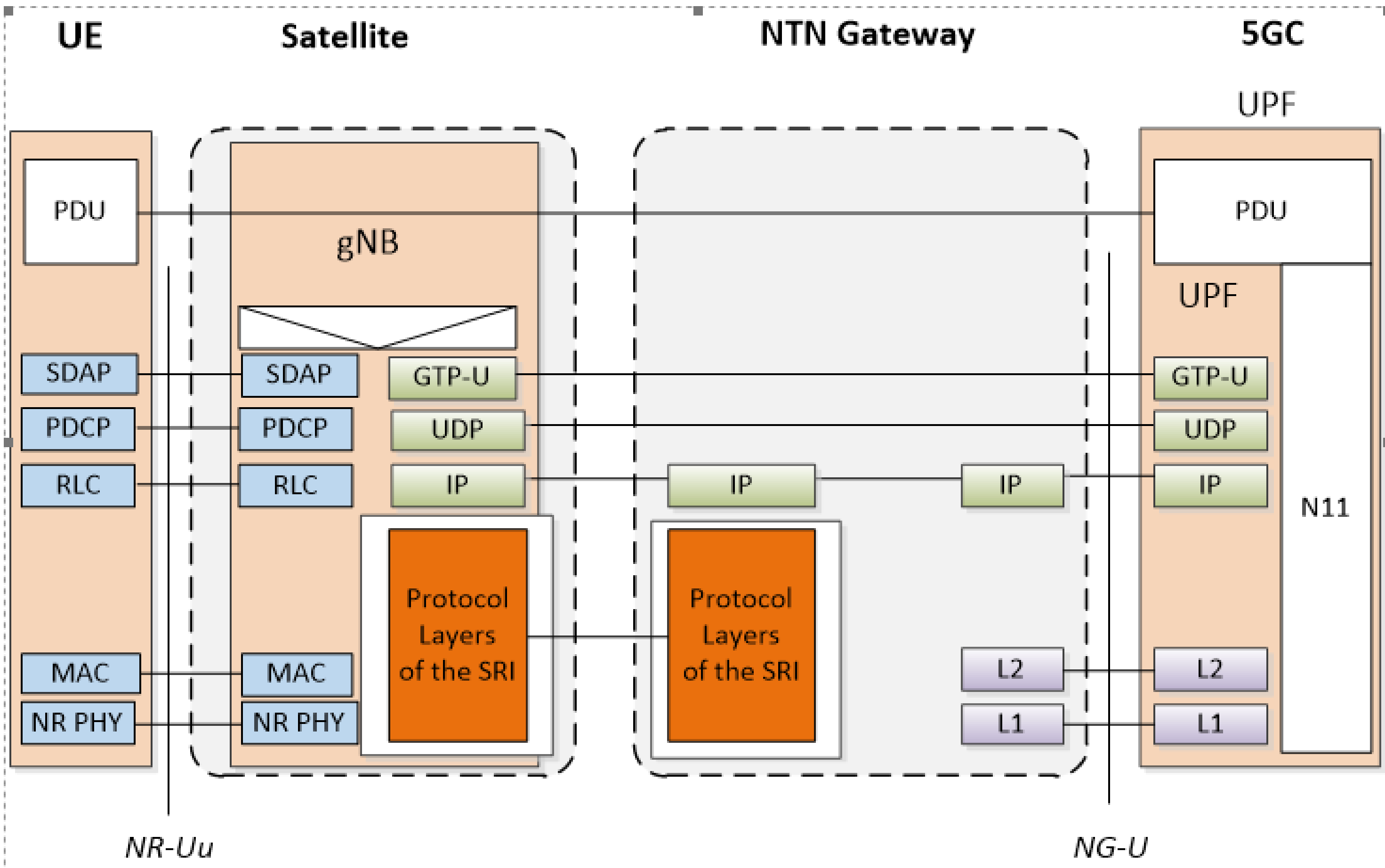
Regenerative NTN NG-RAN architecture

- The document [TR 23.737] defines the regenerative payload functionality as the implementation, where an on-board processor (OBP) is inserted between the LNA (Low Noise Amplifier) and the HPA (High-Power Amplifier).
- This OBP allows conversion of the air interface between the uplink and the downlink. It allows bits or packet errors to be corrected before they are retransmitted, or packets to be routed between beams.
- Ultimately any network function can be implemented, at the expense of power and mass, thanks to an OBP (including gNB CUs or DUs, or any function attached to a 5GC).
- One advantage of the regenerative architecture is the reduction of latency as the Uu interface terminates in the satellite that incorporates the entire NTN gNB functionality, thus the single-way latency only includes the service link. Buffer management, link control or retransmissions need to be implemented in the regenerative mode satellite and this increases the afore-mentioned complexity aspect.

Regenerative NTN NG-RAN architecture

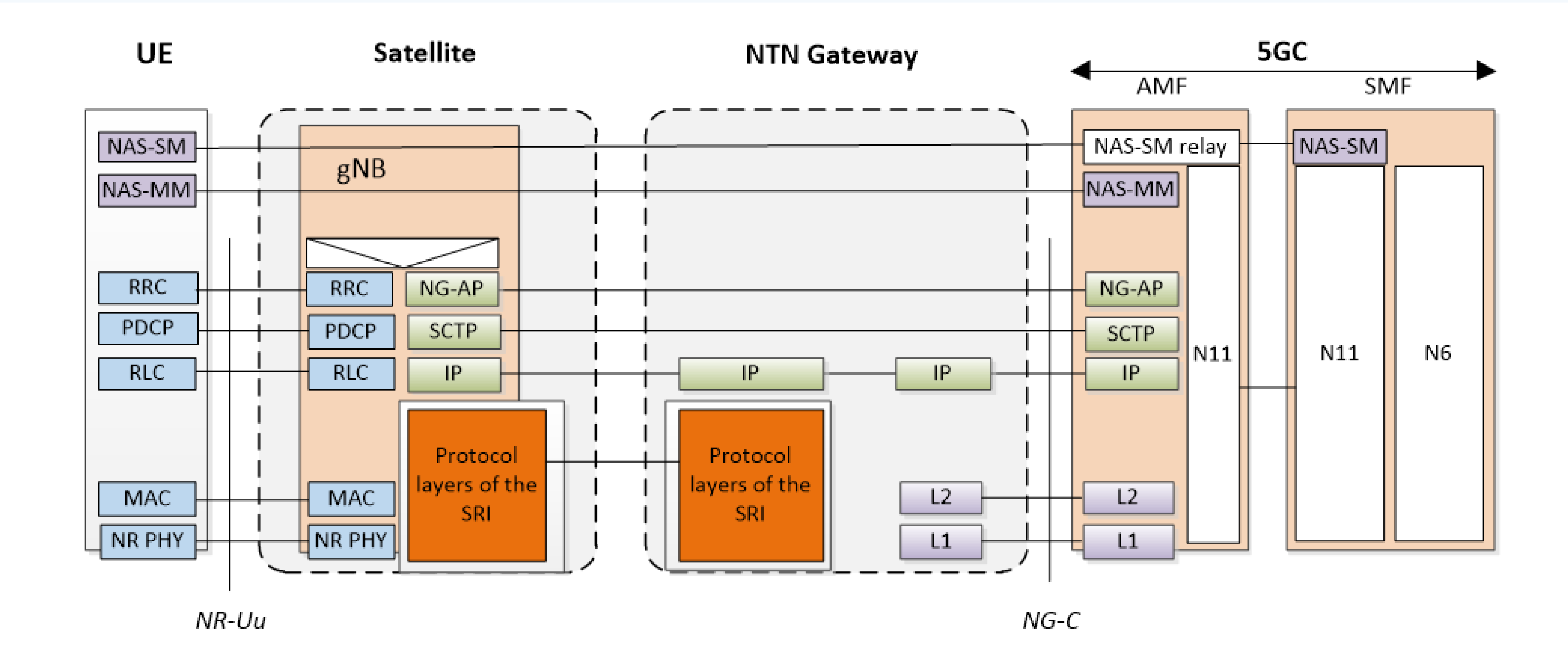
- A second advantage is the possible deployment of an NTN with multiple ISL connections between the satellites, especially a swarm LEO constellation where only a few LEO satellites have access to the gateway.
- The implementation of DU and probably CU functionality into the satellite give them a better autonomy, but at the expense of higher complexity. Sophisticated ISL traffic steering methods leverage ubiquitous coverage and allow intelligent and efficient traffic management in future deployments.
- Lastly, as a third advantage, with the regenerative architecture we obtain an independency between the service and feeder link, possibly allowing the usage of mmWave or FSO feeder links with very high throughput.

Regenerative mode: user plane

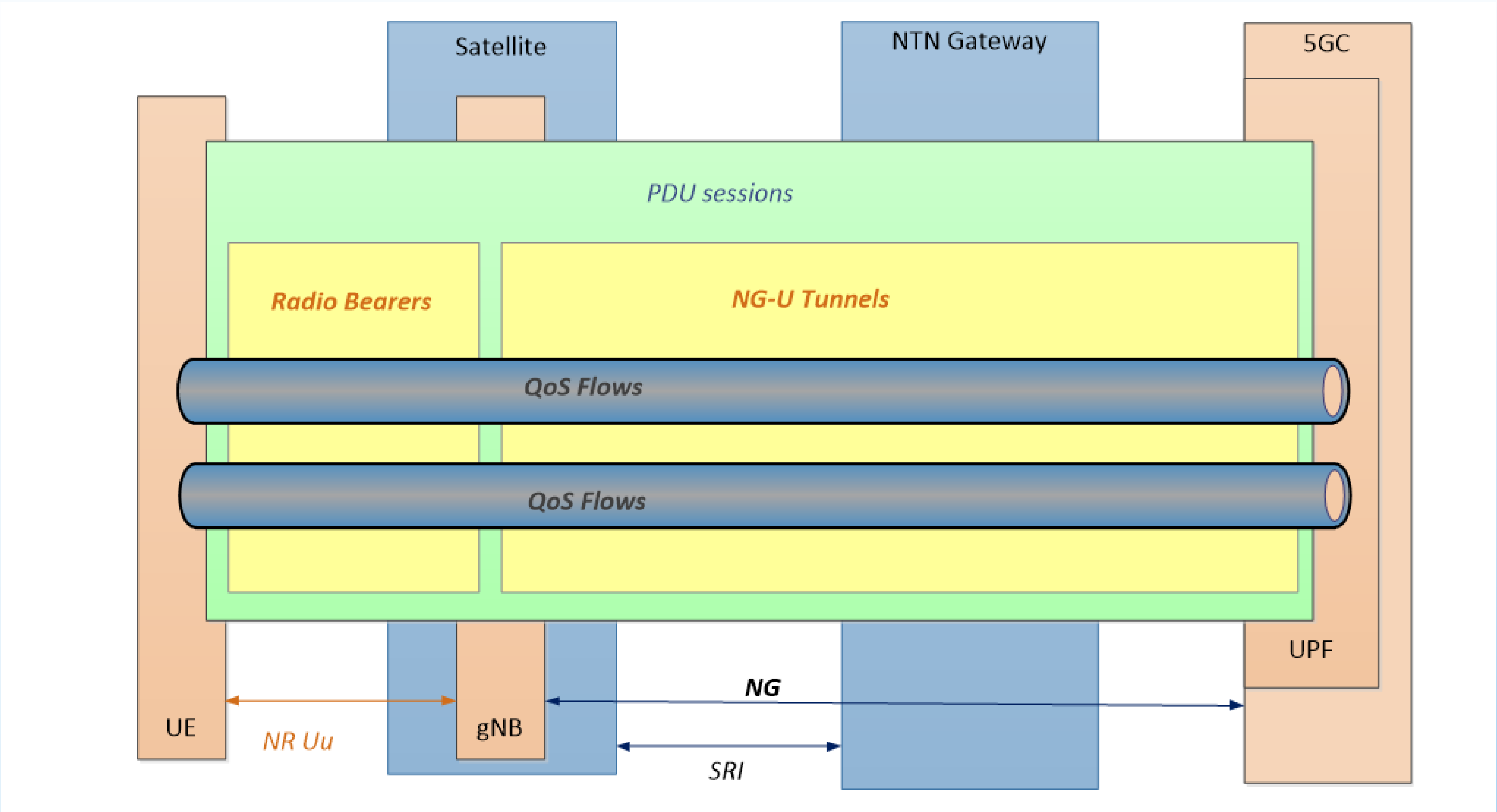


Regenerative mode: control plane

Session Management Function (SMF)



Regenerative mode: QoS flows



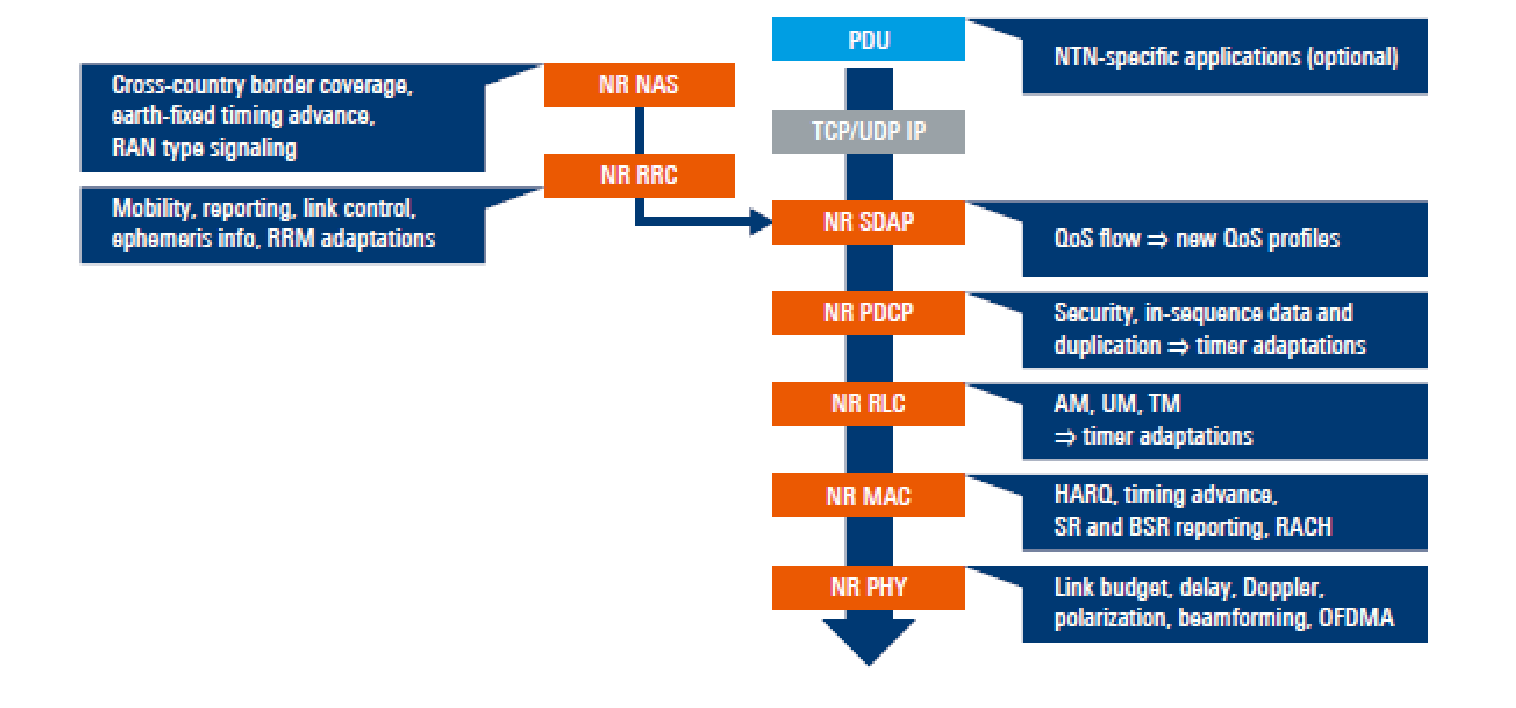
Regenerative NTN NG-RAN architecture

- The Uu interface terminates in the satellite containing all the NTN gNB functions and that there is the SRI (Satellite Radio Interface) link to transport the user and control plane data from the regenerative mode satellite via the gateway to the 5GC. To enable transparent user plane data transport, the user PDUs are transported over the GTP-U protocol in a tunnel procedure between the satellite containing all the gNB functions and the 5GC.

- The control plane architecture is similar to the user plane. The RRC terminates within the satellite gNB function, so here too we assume a shorter reaction time for RRC-specific radio link control procedures at the expense of higher computation power being required within the satellite itself. In the case of the alternative disaggregated architecture where the satellite carries the DU functions and the CU is still on ground, the control plane like the RRC protocol layer also terminates on ground, hence the long delay like that in the transparent architecture prevails. To transport NAS messages between the gNB and the 5GC functions AMF or SMF, the NG-AP protocol establishes a tunnel between them across the gateway and the SRI link.

NTN procedures and protocol stack

- The introduction of NTN requires an update and amendment of certain procedures to tackle the previously described challenges, e.g. latency, Doppler shift and others



- 5G NTN takes flight: technical overview of 5g non-terrestrial networks, RS

Physical Layer (1)

- The major impacts of NTN on the physical layer is the long delays, the Doppler shift, the high path attenuation and the polarization rotation.
- The physical waveform does not require a specific amendment due to NTN, which is a compromise between complexity, timeline and feasibility.
- It is decided by 3GPP to maintain OFDMA as the primary waveform because it is in 5G NR, also for NTN connections, despite the high peak-to-average-power ratio (PAPR).
- Another challenging parameter is the sensitivity of OFDMA to Doppler shifts, thus a pre-adjustment and carrier frequency correction is needed.
- Given the expected future dual connectivity scenarios between terrestrial and non-terrestrial, the reuse of OFDM for satellite based connectivity will provide advantages as the impact is lowest.
- New frequency bands are possible in the 5G system and slight changes like a higher transmit power, circular polarization introduction or sophisticated beamforming methodologies do not require an intensive specification update. 5G NTN will reuse the existing reference signals and physical channel structure.

Physical Layer (2)

- The flexibility is kept on the physical layer with respect to the spectrum used as NTN may use the FR1 and FR2 range.
- The complexity increases as the Ka-band discussed for NTN defines an uplink region that is in the gap between FR1 and FR2, or in other words it would then be in a spectrum undefined by 3GPP. This is one reason why FR2 for NTN is postponed. The second reason is the duplex mode FDD applied for NTN. A TDD system needs the definition of a guard period between the TX and RX switch. Due to the long delays in NTN, such a guard period would need to be very long and result in inefficient spectrum use. Consequently, 3GPP decided on FDD for the FR2 frequencies in NTN, which is a novelty as the current FR2 bands are all TDD.
- With respect to synchronization and initial network acquisition, the currently specified concept using synchronization signals and channels (e.g. the SSB block) stays the same in NTN. It is assumed that the UE will follow the S-criterion, determining the best cell by measuring power (e.g. RSRP -reference signal received power) and signal quality (e.g. RSRQ - quality).

Physical Layer (3)

- For cell reselection purposes too, the ephemeris information and the UE location can be considered. The specifications contain the definition for the SSB (Synchronization Signal Blocks) based RRM measurement timing configuration window known as SMTC (SS/PBCH Block Measurement Timing Configuration), and it is up to the network to update the SMTC configuration of the UE to accommodate the different propagation delays between terrestrial and non-terrestrial cells or to mitigate the relative time change between two SANs. For Release 17, one or more SMTC configurations associated with one frequency can be configured and optionally linked to a set of cells. Different offsets in addition to the legacy SMTC configuration are possible.

Physical Layer (4)

- 5G NR already applies adaptive modulation and coding which will remain in NTN with preferred choices of phase-shift key modulations schemes up to the order of 16. UE and satellite support QPSK and 16QAM, optionally 64QAM, can be used. Due to the longer RTT, a possible link quality feedback (e.g. CQI) arrives delayed at the gNB scheduler, but with NTN, the greatest impairment of the SNR is the free space path loss (FSPL), which can be predicted from the constellation geometry. At high satellite velocity and longer packet durations, the path loss may fluctuate, thus, depending on the QoS profile, a more robust MCS scheme is then selected.

Physical Layer (5)

- Spectral efficiency improvements based on multiple antenna technologies (MIMO) suffer from the dominant LOS and long distance resulting in a delayed rank indicator feedback and it is assumed that NTN MIMO will be left for future enhancements. The absence of scatterers near the satellite antenna tends to make the fading among all the channels between the satellite and UE spatially correlated.

MAC Layer

- The impact of longer latency affects procedures controlled by the MAC layer. Agreed conclusions are the MAC enhancements for procedures like random access (RACH), power saving or discontinuous reception (DRX), timing advance (TA), scheduling request (SR) and hybrid automatic repeat request (HARQ) [R2-1818511].
- A possible elision of HARQ feedback causing an impact on reliability results in the recommendation to tackle reliability issues by a more robust MCS selection and support by higher layers like RLC and PDCP.
- RACH extensions ensure proper functioning under circumstances resulting from longer delays. Timing advance updates deal with not only the absolute value of the longer RTT but also mitigate affects like time-variant and floating RTT due to the elliptic nature of the beam footprint and satellite motion.

RLC layer (1)

- The RLC too has to cope with the major challenge of extended RTT.
- An RLC entity offers the three different transport modes
  - unacknowledged (UM),
  - acknowledged (AM)
  - transparent mode (TM).
- With extensive delays, the difficulty is to meet the requirements of the AM, especially as the RLC AM is the default mode for signaling radio bearers. The MAC layer may operate in HARQ disabled mode and the RLC AM should then ensure reliable data transfer. This may lead to a special configuration of the maxRetxThreshold parameter that sets the number of maximum retransmissions and bridges between the latency and reliability aspect in the QoS profile.
- In the acknowledged mode, the RLC layer uses a polling mechanism. The TX entity sends a PDU containing a poll request and starts the timer t-PollRetransmit. The RX entity replies with a status report and, in the case of timer expiry, the poll is repeated. The current configurable maximum time of the t-PollRetransmit timer is 4000 ms, which is considered to be long enough even for NTN GEO RTT.

RLC layer (2)

- The flow control of received data units is controlled by the t-Reassembly timer, with a maximum of 200 ms. This timer detects a possible loss of RLC PDUs at lower layers. In cases where the HARQ is enabled on the MAC layer, an extension will be beneficial because a running t-Reassembly timer also includes HARQ retransmissions. 3GPP working group RAN2 suggests an extension up to 2200 ms for this reassembly timer and to be future proof an additional t-ReassemblyExt information element is part of Release 17.
- This also applies to the t-statusProhibit timer whose length of 2400 ms is considered to be long enough, also for NTN. A proposal suggests consideration of a possible extension of the RLC sequence number field, which currently has a maximum length of 18 bits, and extension of the AM_Window_Size describing the buffer status. These two values are considered to fulfill the requirements for NTN as well, but future technology evolutions may support larger subcarrier spacing (e.g. 120 kHz) and therefore shorter slot durations as well as methodologies like carrier aggregation or dual connectivity which could then lead to a stalling situation as the buffer will be exceeded [R2-1818512].

PDCP layer

- The user plane protocol layer supports data transmission with in-sequence provisioning, discard functions, dispatching, ciphering and duplication. It is assumed that there is no need to update the ciphering function of the PDCP layer due to NTN introduction.
- The PDCP layer needs to cope with longer RTT and it provides the QoS support in close cooperation with the RLC layer. The PDCP parameter discardTimer sets the maximum time before a discard notification is sent to the TX RLC entity and, in the case of extended retransmissions, there is a suggestion to extend this timer as a beneficial amendment. To be future proof, a new information element discardTimerExt with length 2000 ms is introduced in Release 17 with the option of future extension.
- At the RX entity, the t-Reordering timer influences the reordering function. The maximum duration of currently 3000 ms is surely sufficient for RLC UM mode, but assuming a larger number of RLC AM retransmissions a probable extension of this timer value could be beneficial. As with the RLC layer, a potential extension of the PDCP sequence number, currently max. 18 bit, and the buffer size given as Window_Size would be beneficial to NTN.

HARQ (1)

- The drawback of a HARQ process is its stop-and-wait nature: the transmitter needs to wait until a positive acknowledgment is received before it can send the next data packet, otherwise a retransmission occurs.
- To overcome a stall situation, several HARQ processes operate in multi-tasking mode. In 5G NR Release 15, up to 16 HARQ processes operate simultaneously per UE and several timers control behavior such as the periods between RX and acknowledgment and retransmissions. As NTN causes much longer delays, an adaptation of the current HARQ mechanisms is needed and 3GPP discusses three possible adaptations:
  - Extending the number of existing HARQ processes to 32 processes.
  - Disabling HARQ feedback and shifting the retransmission to higher layers (RLC AM).
  - Configuration of automatic retransmission, e.g. TTI bundling features.
- A simple linear increase in the number of HARQ processes is unfeasible due to memory restrictions and the maximum number of possible parallel channels. For example, a GEO constellation with 544 ms RTT would then require such a number of HARQ processes. For a LEO constellation, 3GPP agreed to increase the overall number up to 32 HARQ processes, depending on the UE capability.

HARQ (2)

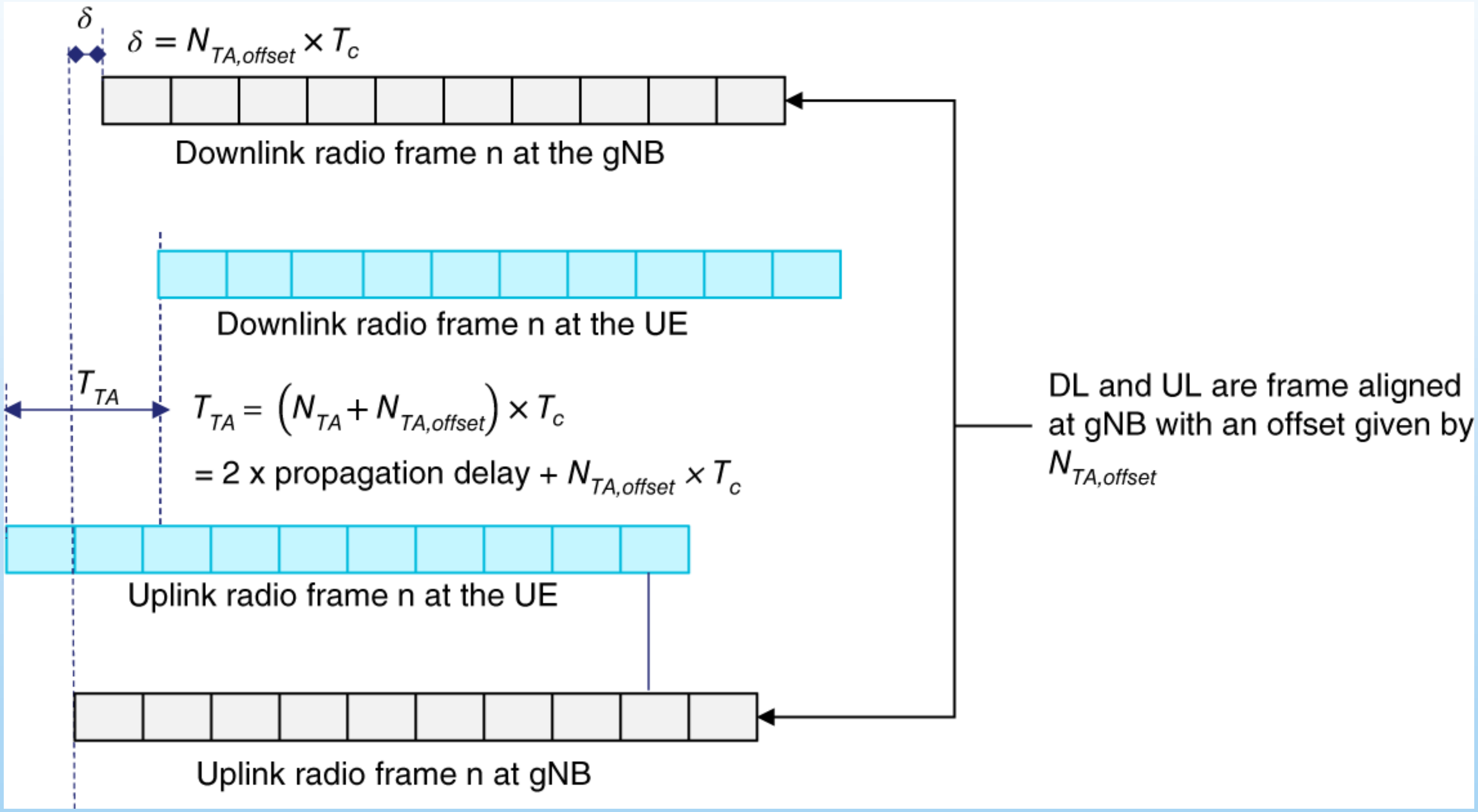
- This entails updating the scheduling message DCI HARQ ID field to a size of 5 bits. As this is optional, the RRC parameter harq-ProcessNumberSizeDCI indicates whether the DCI field HARQ process number is extended to 5 bits. To support NTN without excessive requirements with regard to processing power and UE memory, 3GPP agreed to permit the disabling of the HARQ feedback, configurable via RRC parameter HARQ-feedbackEnabling-disablingperHARQprocess for each HARQ process. This allows the transmitter to use the HARQ process for successive data transmission without being forced to wait for feedback and causing a stall situation. Optionally, the RRC can enable automatic retransmission of PDUs to improve the reliability of the connection. This blind retransmission which is not related to any feedback is similar to features such as TTI bundling that are already permitted in legacy wireless communications.

HARQ (3)

- In summary, the network can choose one of these three scheduling options:
  - Disable, i.e. no HARQ retransmissions,
  - blind retransmissions
  - extended HARQ feedback.
- To avoid excessive monitoring of the PDSCH by the UE, such automatic retransmissions are only allowed within a certain time window following the first transmission of a PDSCH PDU. The possible impact on the scheduling mechanism is then a lower target BER for the MCS selection, and the reliability of the connection can also be influenced by the RLC operating in acknowledged mode (AM) and by the process for counting the PDCP layer sequence number.
- To adjust for longer delays, the response time for HARQ feedback is extended. The PUCCH carrying the HARQ ACK/NACK is deferred by the HARQ timer K1 and the additional NTN timer Koffset. The large RTT requires some updates of HARQ timers in DRX situations.

Timing Advance in TN (1)

- The Timing Advance (TA) refers to the negative offset between the start of a given DL frame as observed by the UE and



Timing Advance in TN (2)

- The TA applied by the UE is given by the following formula:

$$T_{TA} = \left(N_{TA} + N_{TA,offset}\right) T_c$$

$$Tc = (480 \cdot 4096)^{-1} \quad \text{ms}$$

For initial access, random-access procedure is used in order for UE to achieve Uplink synchronization and obtain the resource for RRC Connection Request message. Initial access procedure is triggered by the UE by transmitting a random access PRACH preamble with $N_{TA} = 0$, then the UE receives its first Timing Advance Command (TAC) within the Random Access Response (RAR) message. Within the TAC, a set of 12 bits is used to indicate a TA value from 0 to 3846. The UE uses this value to calculate N_{TA} as follows:

$$N_{TA} = T_A \cdot 16 \cdot \frac{64}{2^{\mu}}$$

where μ is the Numerology SubCarrier Separation (SCS) index.

Timing advance (1)

- The random access time alignment procedure in terrestrial networks is divided into two steps. First, the UE sends a non-synchronized PRACH signal that presumably arrives with a delay that is two times the propagation delay at the base station antenna. A long guard time as a characteristic of the PRACH preamble defined within the PRACH slot protects against such delays, i.e. using the SIB indication as to which preamble format should be applied, the network indirectly indicates its maximum cell range.
- In a second step during the random access, the base station measures the delay and controls in its response message (Msg2) the timing advance adjustments.
- The drawback of large delays in NTN situations is that they would require PRACH guard intervals, by defining new preamble formats with such long guard times that the entire system would become inefficient.

Timing advance (2)

- The second impact is not only the long RTT due to the UE-to-satellite distance, but also the high differential delay due to a large beam footprint. These issues require permanent maintenance of the time alignment during a connection, which is similar to terrestrial networks, but this time alignment needs to cope with longer absolute timing advance times. There have been several discussions on the best mechanism to update the timing advance and allow longer times or larger values for TA update.
- [TR 38.811] discusses the aspect of an alignment between the downlink and uplink at the gNB, which would lead to a large offset between RX and TX at the UE side.
- Another proposal discussed a more relaxed time alignment between the uplink and downlink at the gNB side. For example, a gNB could apply a system frame number shift as time offset.

Timing advance (3)

- Summarizing the timing advance aspects, the NTN UE will pre-compensate the delay (and the Doppler shift) when accessing the network. This is performed in four major steps:
  - 1. The UE determines its terrestrial position, e.g. via GNSS or RAT positioning
  - 2. The satellite provides orbit information, velocity information and common parameters in the SIB (System Information Block) broadcast
  - 3. Based on the estimated UE and satellite position, a calculation of the propagation delay is executed by the UE
  - 4. Finally, the UE derives the initial timing advance and frequency shift for initial radio access. Depending on the SIB setting, the UE reports the timing advance during the RACH procedure

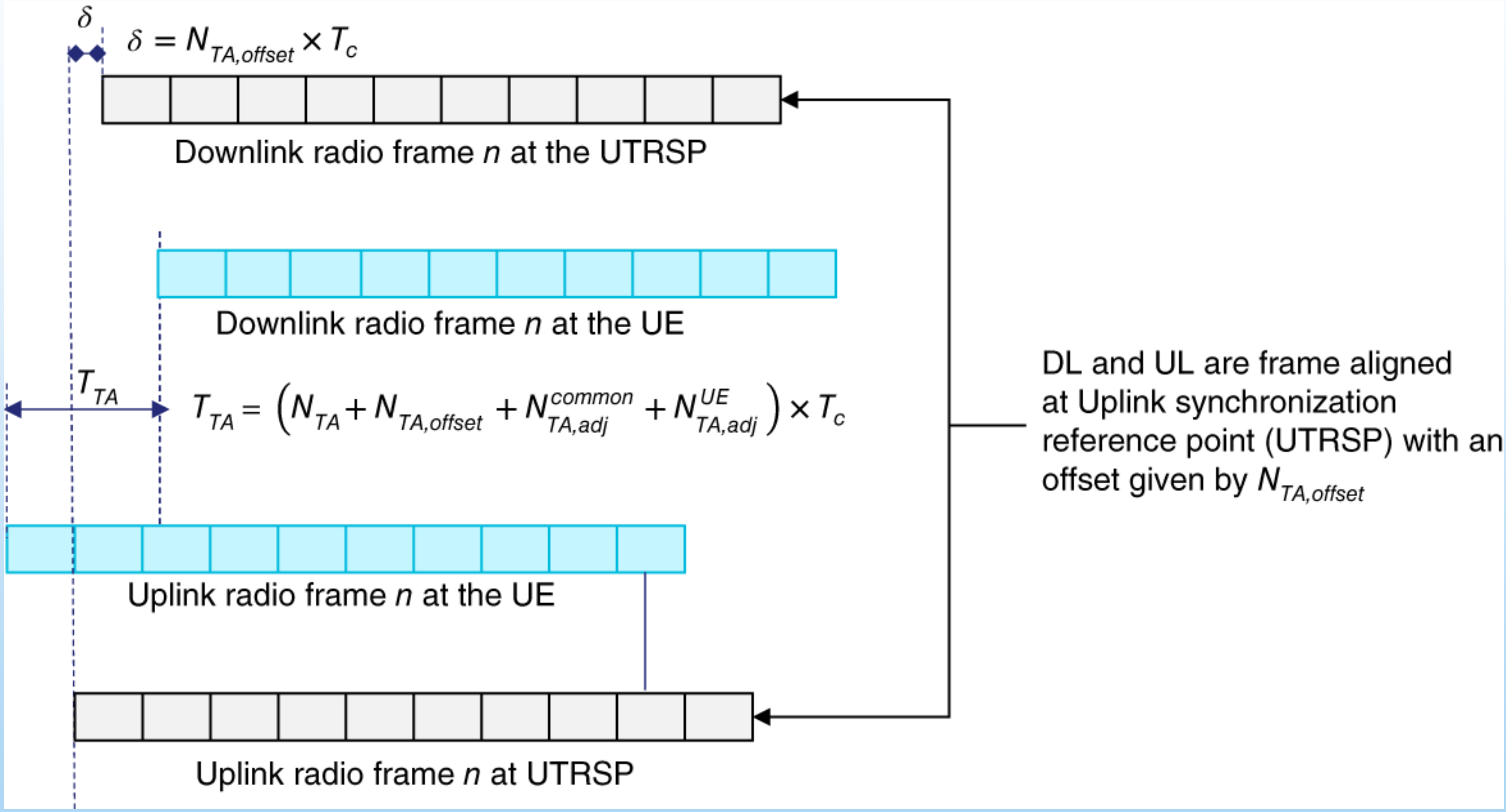
Timing Advance (4)

- The timing advance is given by [TS 38.213]:

$$T_{TA} = \left(N_{TA} + N_{TA,offset} + N_{TA,adj}^{common} + N_{TA,adj}^{UE}\right)T_c$$

- where:
  - N_{TA} and $N_{TA,offset}$ are specified in 3GPP TS 38.213 and 3GPP TS 38.211 as part of the existing TA Control.
  - $N_{TA,adj}^{common}$ is a network-controlled common *TA*, and may include any timing offset deemed necessary by the network (e.g. feeder link delay). It is derived from the higher-layer parameters ta-Common, ta-CommonDrift, and ta-CommonDriftVariation if configured, otherwise $N_{TA,adj}^{common} = 0$
  - $N_{TA,adj}^{UE}$ is UE self-estimated TA to pre-compensate for the service link delay. It is computed by the UE based on UE position and serving satellite-ephemeris-related higher-layers parameters if configured, otherwise $N_{TA,adj}^{UE} = 0$.
  - T_c is the NR basic time unit $Tc = (480 \cdot 4096)^{-1}$ ms. Uplink and Downlink radio frame timing at the gNB and at the UE in NTN is illustrated in the Figure.

Timing Advance (4)



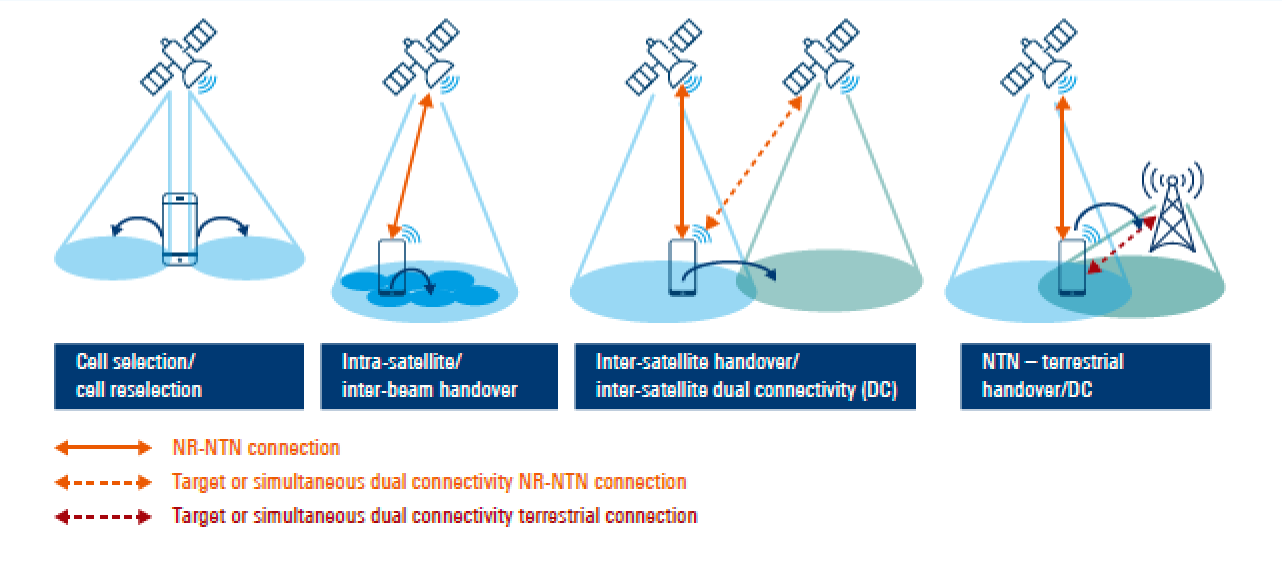
- Vanelli-Coralli

Mobility scenarios

- Several mobility procedures need to be considered:
  - Mobility procedure while the UE is in idle mode, also known as cell reselection, or in a more general situation also described as PLMN reselection
  - Mobility procedure to handover a connection from one satellite to another satellite, i.e. inter-satellite handover
  - Mobility procedure between spaceborne sNB and terrestrial gNB
  - Mobility procedure to handover a connection from one beam within a satellite to another beam, i.e. intra-satellite handover
  - Reconfiguration procedure to modify allocated radio resources, i.e. change of the bandwidth part (BWP) or frequency channel

Mobility scenarios

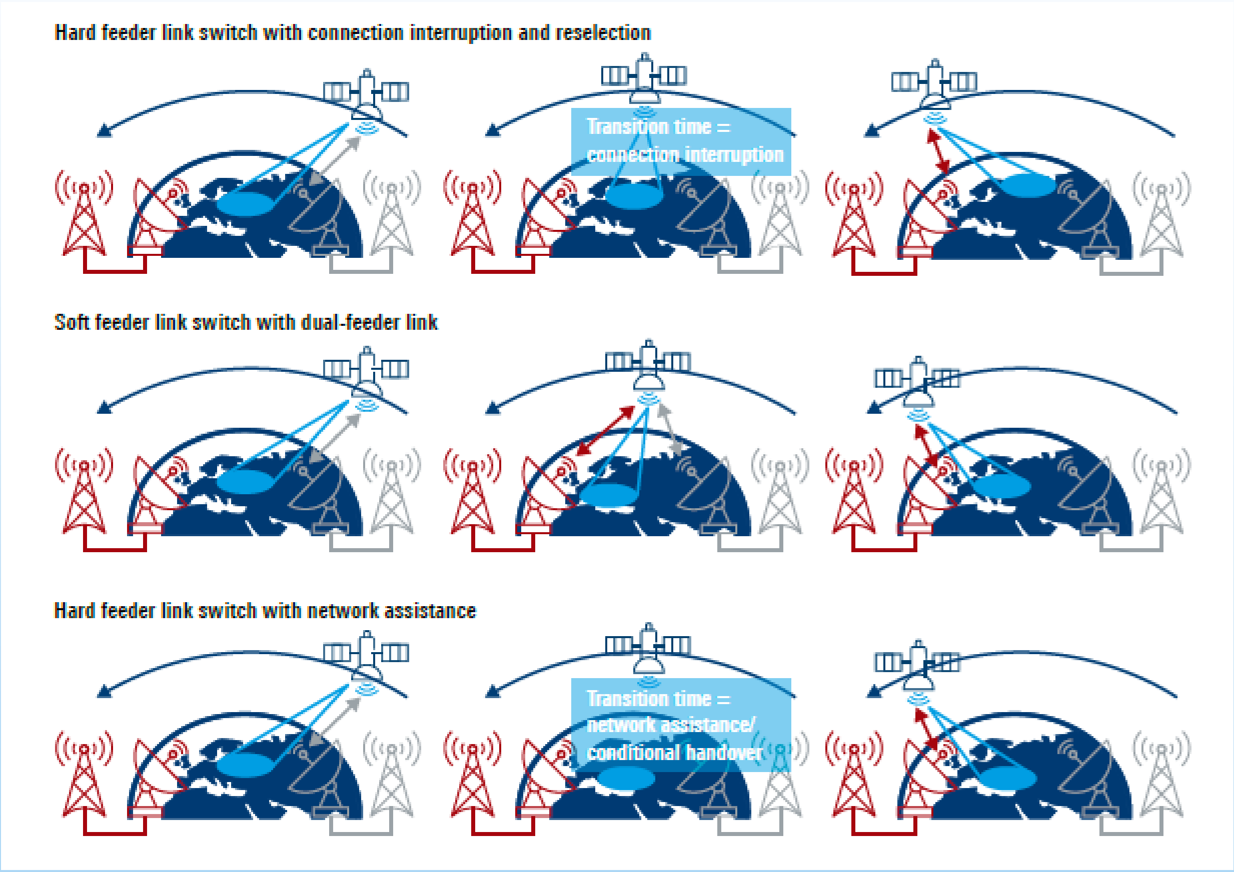
- Examples



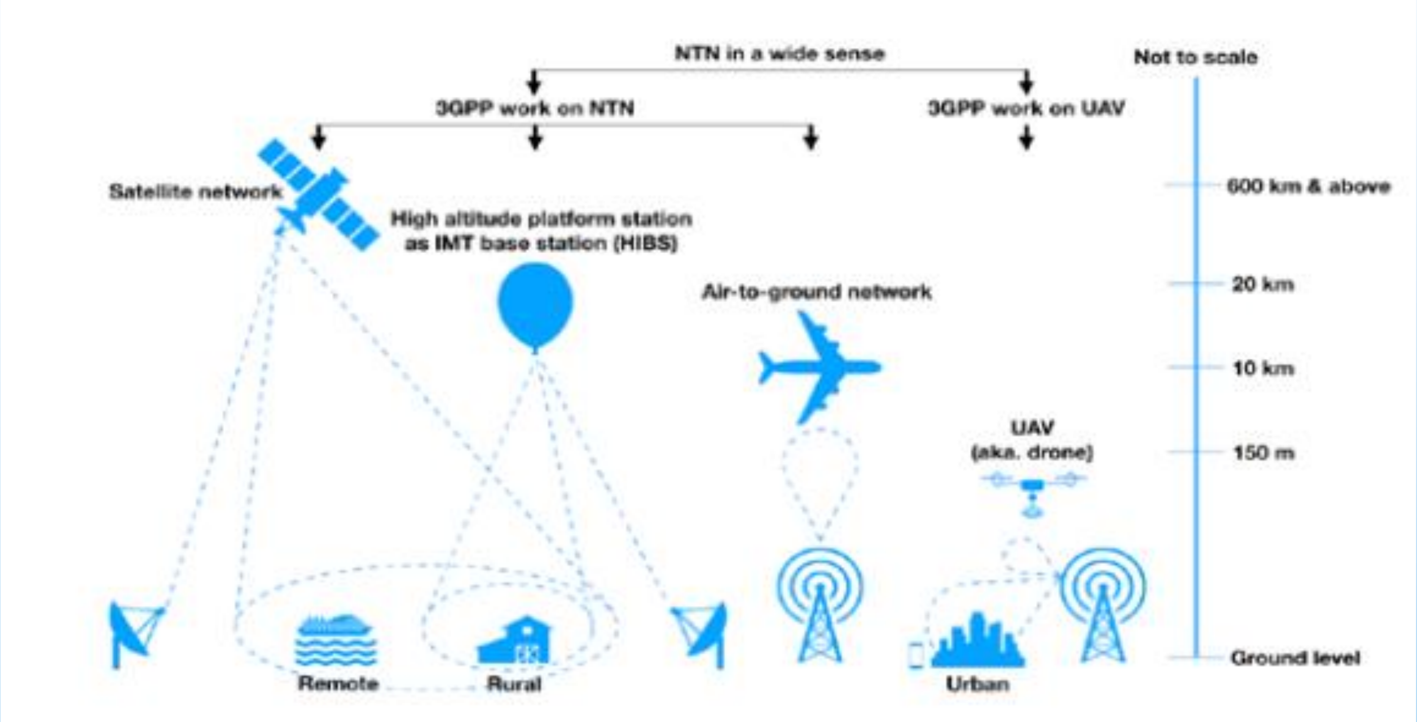
Feeder link switch

- In a transparent mode the link between the satellite and the ground station is referred to as the feeder link. In the case of non-GEO, switching of the feeder link may become necessary. A major challenge is that the feeder link switch may result in transferring multiple established connections for all affected UEs.
- For a soft feeder link switch, an NTN payload connection is able to cope with more than one gateway during a given period, i.e. a temporary overlap can be ensured during the transition between the feeder links. This requires the capability within the satellite to maintain at least two feeder link connections in parallel. Higher layers in the core network architecture are required to tackle duplication and packet loss.
- For a hard feeder link switch, an NTN payload connection is established to one gateway at any given time, i.e. a radio link interruption may occur during the transition period between the feeder links. This requires some enhancement of the existing handover procedures and several possibilities exist.

Feeder link switch



Different types of non-terrestrial networks



NTN Use Cases Evaluation (1)

5G Service enabler	5G Use case	5G Use case description	Satellite service
eMBB	Multi connectivity	Users in underserved areas (home or in Small Offices, big events in ad-hoc built-up facilities) are connected to the 5G network via multiple network technologies and benefit from high data rates. Delay sensitive traffic may routed over the long latency links.	Broadband connectivity to cells or relay node in underserved areas in combination with terrestrial wireless/cellular or wire line access featuring limited user throughput.
eMBB	Fixed cell connectivity	Users in isolated villages or industry premises (mining, offshore platforms) access 5G services and benefits from high data rates.	Broadband connectivity between the core network and the cells in unserved areas (isolated areas).

NTN Use Cases Evaluation (2)

5G Service enabler	5G Use case	5G Use case description	Satellite service
eMBB	Mobile cell connectivity	Passengers on board of vessels or aircraft access 5G services and benefit from high data rates.	Broadband connectivity between the core network and the cells on board a moving platform (e.g. aircraft or vessels).
eMBB	Network Resilience	Some critical network links require high availability which can be achieved through the aggregation of two or several network connections on parallel. The intent is to prevent complete network connection outage	Secondary/backup connection (although potentially limited in capability compared to the primary network connection).

NTN Use Cases Evaluation (3)

5G Ser. en.	5G Use case	5G Use case description	Satellite service
eMBB	Trunking	A network operator may want to deploy or restore (disaster relief) 5G service in an isolated area (not connected to public data network). A network operator may want to interconnect various 5G local access network islands not otherwise connected.	Broadband connectivity between the public data network and a mobile network anchor point or between the anchor points of two mobile networks.
eMBB	Edge eMBB network Delivery	Media and entertainment content such as live broadcasts, ad-hoc broadcast/multicast streams, group communications, Mobile Edge Computing's Virtual Network Function updates are transmitted in multicast mode to a RAN equipment at the network edge where it may be stored in a local cache or further distributed to the User Equipment. The intent is to off load popular content from the mobile network infrastructure (especially at backhaul level).	Broadcast channel to support Multicast delivery to 5G network edges.

NTN Use Cases Evaluation (4)

5G Ser. en.	5G Use case	5G Use case description	Satellite service
eMBB	Mobile eMBB cell hybrid Connectivity	Passengers on board public transport vehicles (e.g., high speed/regular trains, buses, river boats) access reliable 5G services. They are served by a base station which is connected by a hybrid cellular/satellite connection. The cellular connectivity may be intermittent and/or support limited user throughput.	Broadband connectivity between the core network and the cells in un-served areas (isolated areas).
eMBB	Direct eMBB To Node broadcast	TV or multimedia service delivery to home premises or on board a moving platform	Broadcast/Multicast service to access points in homes or on-board moving platforms.
eMBB	Wide area public safety	Emergency responders, such as police, fire brigade and medical personnel can exchange messaging and voice services in outdoor conditions anywhere they are and achieve continuity of service whatever mobility scenarios.	Access to User Equipment (handset or vehicle mounted).

NTN Use Cases Evaluation (5)

5G Ser. en.	5G Use case	5G Use case description	Satellite service
eMBB	Direct to mobile broadcast	Public safety authorities want to be able to instantaneously alert/warn the public (or specific subsets thereof) of catastrophic events and provide guidance to them during the disaster relief while the terrestrial network might be down. Automotive industry players are interested to provide instantaneously Firmware/Software Over The Air services (FOTA/SOTA) to their customers wherever they are. This will include information updates such as map information including points of interest (POI), real-time traffic, weather, and early warning broadcasts (e.g., floods, earthquakes, and other extreme weather situations, as well as terror attacks), parking availability, infotainment, etc. Media and entertainment industry can provide entertainment services in vehicles (cars, buses, trucks).	Broadcast/Multicast service directly to User Equipment whether handheld or vehicle mounted.

NTN Use Cases Evaluation (6)

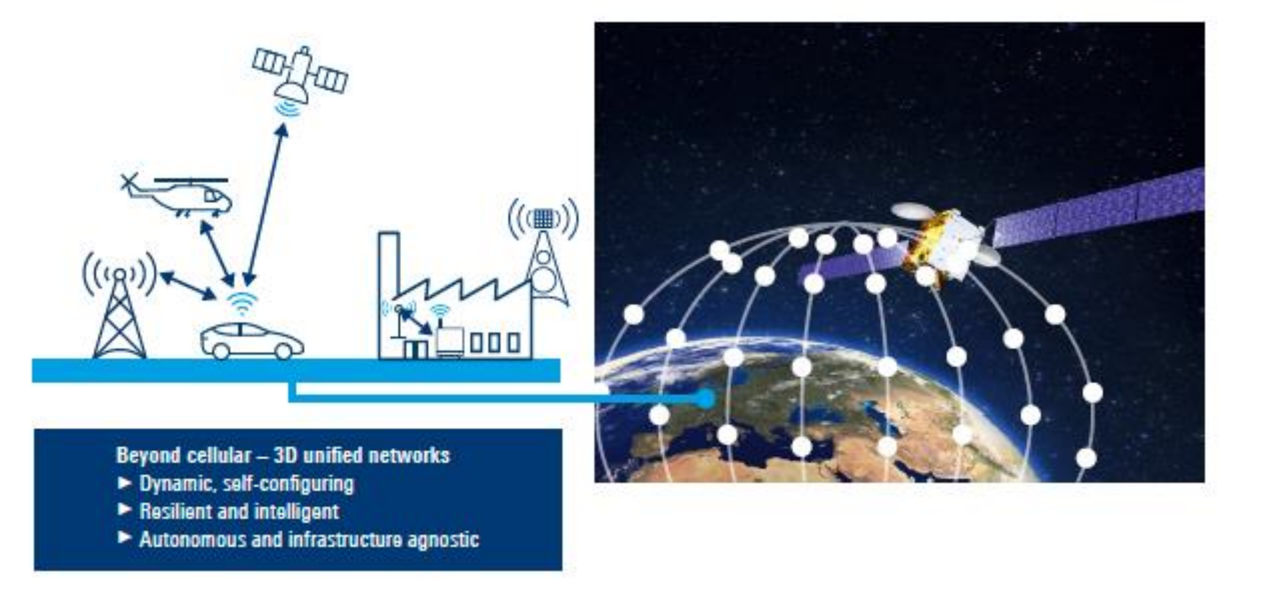
5G Ser. en.	5G Use case	5G Use case description	Satellite service
eMBB	Local area public safety	Emergency responders, such as police, fire brigade, and medical personnel can set up a tactical cell wherever they need to operate. This cell can be connected to the 5G system via satellite to exchange data, voice and video-based services between the public safety users within a tactical cell or with the remote coordination center.	Broadband connectivity between the core network and the tactical cells.
mMTC	Local area IoT services	Group of sensors that collect local information, connect to each other and report to a central point. The central point may also command a set of actuators to take local actions such as on-off activities or far more complex actions. The sensors/actuators served by a local area network may be in a smart grid sub-system (Advanced Metering) or on board a moving platform (e.g., container on board a vessel, a truck or a train).	Connectivity between mobile core network and base station serving loT devices in a cell or a group of cells.

NTN Use Cases Evaluation (7)

5G Ser. en.	5G Use case	5G Use case description	Satellite service
mMTC	Wide area IoT services	Global continuity of service for telematic applications based on a group of sensors/actuators (loT devices, battery activated or not) scattered over or moving around a wide area and reporting information to or controlled by a central server. These sensors and/or actuators may be used for example the following telematics applications: Automotive and road transport: high density platooning, HD map updates, Traffic flow optimization, vehicle software updates, automotive diagnostic reporting, user base insurance information (e.g., speed limit, driving behavior), safety status reporting (e.g., air-bag deployment reporting), advertising-based revenue, context awareness information (e.g., neighboring bargain opportunities based on revenue), remote access functions (e.g., remote door unlocking). Energy: Critical surveillance of oil/ gas infrastructures (e.g., pipeline status) Transport: fleet management, asset tracking, digital signage, remote road alerts Agriculture: livestock management, Farming	Connectivity between loT devices (battery activated sensors/ actuators or not) and spaceborne platform. Continuity of service across spaceborne platforms and terrestrial base stations is needed.

Long-term outlook regarding NTN evolution – path towards 6G

- 3D unified network



Path towards 6G (1)

- Research activities:
  - Network nodes are dynamic, they can enter the network or leave on the fly, coordination between neighbor cells is done automatically
  - Network nodes will become autarchic; even without connection to the core network, they can provide communication services. A buzzword talks about resilient networks and digital sovereignty
  - Unified networks, i.e. enhancement of network slicing by offering multiple access technologies, i.e. the user service selects the best RAT for specific use cases to obtain optimized QoS
  - AI methods incorporated in the network to coordinate inter-node signaling and traffic routing and dynamic network constellations on the one hand. The objective is node autonomy to enable real-time satellite decisions and seamless control. On the other hand, AI methods will be used to route traffic, provide services with best QoS (network slicing using intelligent nodes, i.e. MEC mechanisms)

Path towards 6G (2)

- Research activities:
  - Multi-access edge computing (MEC) is much more than just a data cloud. It means onboard computing power, i.e. scheduling decisions, slice selection, QoS profiles negotiation and inter-node coordination
  - Enhancements on the random access channel to avoid RACH capacity overloading of a single satellite by introducing non-orthogonal medium access (NOMA) with successive interference cancellation (SIC) methods
  - Joint communication techniques for spectrum efficiency improvement, applying multiple satellites, e.g. MIMO transmission using two satellites as TX points to overcome the dominant LOS influence and create link de-correlation
  - Enhanced and sophisticated methods for spectrum coordination, inter-node signaling procedures for handover and mobility scenarios and agile methods leaving the static architecture of legacy networks
  - Architecture evolution by connecting UAV based gNBs via satellite backhaul to terrestrial core network functions

Path towards 6G (3)

- Research activities:
  - Security aspects require a redesign because nodes may enter and leave the network and devices possess different shape and form factors. Envisagement of new security concepts on top of the current symmetric authentication mechanism needs to be put into place.
  - Architecture evolution of NTN: In Release 17, 3GPP discusses a transparent mode architecture, e.g. the gNB is on the ground and connected via a gateway to the satellite and the satellite provides radio access. Both the feeder and service link are 5G NR. In later releases, the regenerative mode will be introduced, i.e. the satellite has onboard processing and behaves as entire gNB, but is still connected to the ground based core. In the long term, a node will inherit further core network functions and operate independently and autonomously.
  - Holographic radio to control the physical space through intelligent surfaces with the objective of improving spectral efficiency and network capacity,
  - Free space optical (FSO) or laser based non-RF radio to compensate for atmospheric distortion and to offer ultra-low latency services. Potentially realized as hybrid architecture providing RF and FSO connectivity.

Release 18

- SA2 led - System Architecture & Services
  - XR (Extended Reality) & media services
  - Edge Computing Phase 2
  - System Support for AI/ML-based Services
  - Enablers for Network Automation for 5G Phase 3
  - Enh. support of Non-Public Networks Phase 2
  - Network Slicing Phase 3
  - 5GC LoCation Services Phase 3
  - 5G multicast-broadcast services Phase 2
  - Satellite access Phase 2
  - 5G System with Satellite Backhaul
  - 5G Timing Resiliency and TSC & URLLC enh.
  - Evolution of IMS multimedia telephony service
  - Personal IoT Networks
  - Vehicle Mounted Relays support in the 5G system architecture Phase 3

Release 18

- SA2 led - System Architecture & Services
  - Proximity-based Services in 5GS Phase 2
  - UPF enh. for Exposure & SBA
  - Ranging based services & Sidelink positioning
  - Generic group management, exposure & communication enh.
  - 5G UE Policy Phase 2
  - UAS, UAV & UAM Phase 2
  - 5G AM Policy Phase 2
  - RedCap Phase 2
  - Support for 5WWC Phase 2
  - System Enabler for Service Function Chaining
  - Extensions to TSC Framework to support DetNet
  - Seamless UE context recovery
  - MPS when access to EPC/5GC is WLAN

Release 18

- SA3 led - Security & Privacy
  - SECAM and SCAS for 3GPP virtualized network products and Management Function (MnF)
  - Mission critical security enhancements Phase 3
  - Security and privacy aspects of RAN & SA features
- SA4 led - Multimedia Codecs, Systems and Services
  - Systems & Media Architecture:
    - 5G Media, Service Enablers
    - Split-Rendering
    - 5G AR Experiences Architecture
  - Media:
    - Video codec for 5G
    - Media Capabilities for Augmented Reality Glasses
    - AI / ML Study
  - Real-Time Communications:
    - XR conversational services
    - WebRTC-based services and collaboration models

Release 18

- SA4 led - Multimedia Codecs, Systems and Services
  - Immersive Voice & Audio:
    - EVS Codec Extension for Immersive Voice and
    - Audio Services (IVAS_Codec)
    - Terminal Audio quality performance and Test methods for Immersive Audio Services (ATIAS)
  - Streaming & Broadcast Services:
    - 5GMS Enh. (Network slicing, Low latency, Background traffic)
    - Further MBS Enh. (Free to air, Hybrid unicast/broadcast).

Release 18

- SA5 led - Management, Orchestration & Charging
  - Intelligence and Automation:
    - Self configuration of RAN Nes, Enh. and evaluation of of autonomous network levels, Enh. intent driven management services,
    - AI/ ML management, Enh. of the management aspects related to NWDAF, Enh. of MDA, Fault supervision volution, Management support of RAN intelligence
  - Management Architecture and Mechanisms:
    - Network slicing provisioning rules, Enh. service based management architecture, URLLC/5GLAN/
    - Cloud native VNF/MOCN/IOT NTN/Edge computing management, 5G PM and KPIs; QoE,
    - MDT/Trace, Data collection management

Release 18

- SA5 led - Management, Orchestration & Charging
  - Support of New Services:
    - Enh. Energy Efficiency for 5G Phase 2 Network slice management capability exposure, Enh. management of Non-Public Networks, Network and Service Operations for Energy Utilities, Key
    - Quality Indicators (KQIs) for 5G service experience,
    - Deterministic Communication Service Assurance
  - Charging Management:
    - Enhancement of Network Slicing Phase 2, Nchf charging services phase 2, 5G roaming charging architecture for wholesale and retail scenarios,
    - Enhanced support of Non-Public Networks,
    - Time Sensitive Networking

Release 18

- SA6 led - Application Enablement & Critical Communication Applications
  - Critical Communications:
    - MCX Enhancements – MC over 5GS (5MBS, ProSe)
    - Adhoc group comm., MCPTT Enh.
    - Railways - Gateway UE, Interworking
  - Service Frameworks:
    - Edge App Architecture Enh., SEAL Enh., SubscriberAware API (CAPIF Enh.)
    - Fused location, Application Data Analytics, App Layer NW Slicing
  - Enablers for Vertical Applications:
    - Enhancements to V2X, UAS applicationenablement, 5G Messaging, Future Factories,
    - Personal IoT networks, Capability exposure for IoT platforms

Release 18

- RAN1 led - Radio Layer 1 (Physical layer)
  - MIMO Evolution for Downlink and Uplink
  - Learning (ML) for NR Air Interface
  - Study on Evolution of NR Duplex Operation
  - NR sidelink evolution
  - Study on expanded and improved NR positioning
  - Further NR RedCap UE complexity/cost reduction
  - Study on network energy savings
  - Further NR coverage enhancements
  - NR Network-Controlled Repeaters
  - Enh. of NR Dynamic spectrum sharing (DSS)
  - Study on low-power Wake-up Signal and Receiver for NR
  - Multi-carrier enhancements for NR

Release 18

- RAN2 led - Radio Layer 2 & Layer 3 Radio Resource Control
  - NR Mobility Enh.
  - Study on XR Enh. for NR
  - NR sidelink relay enh.
  - NR NTN (Non-Terrestrial Networks) enh.
  - IoT NTN enh.
  - NR Support for UAV
  - Dual Tx/Rx MUSIM
  - In-Device Co-existence (IDC) enh. for NR and MRDC
  - Mobile Terminated-Small Data Transmission (MTSDT) for NR Enh. of NR Multicast and Broadcast Services

Release 18

- RAN3 led - UTRAN/E-UTRAN/NG-RAN Architecture & Related Network Interfaces
  - Mobile IAB
  - AI/ML for NG-RAN Further enh. of data collection for SON
  - (Self-Organising Networks)/MDT (Minimization of Drive Tests) in NR and EN-DC
  - Enh. on NR QoE management and optimizations for diverse services
  - Study on enh. for resiliency of gNB-CU
- RAN4 led - Radio Performance & Protocol Aspects*
  - Further RF requirements enh. for NR Frequency Range 1 (FR1)
  - NR RF requirements enh. for Frequency Range 2 (FR2), Phase 3
  - Req. for NR Frequency Range 2 (FR2) multi-Rx chain

Release 18

- RAN4 led - Radio Performance & Protocol Aspects*
  - DL reception RRM enh. for NR and MR-DC
  - Enh.on NR and MR-DC Measurement Gaps and Measurements without Gaps
  - NR demodulation performance evolution
  - Study on enh. for 700/800/900MHz band combinations
  - NR BS RF requirement evolution
  - Study on NR Frequency Range 2 (FR2) Over-the-Air (OTA) testing enh.
  - Support of intra-band non-collocated EN-DC/NRCA deployment
  - Enh. NR support for high-speed train scenario in frequency range 2 (FR2)
  - BS/UE EMC enh.
  - Air-to-ground network for NR
  - NR support for dedicated spectrum less than 5MHz for FR1

Release 19

- To provide a balanced evolution in terms of:
  - Mobile broadband evolution and further vertical expansion, enhancing mobile experiences and extending 5G’s reach into new areas
  - Addressing immediate and longer-term commercial needs, to drive new value in commercialization efforts and to efficiently enable advanced deployments
  - Supporting new and enhanced devices and network evolution, so as to focus on the end-to-end 5G technology progression & new levels of performance

- This steady and balanced evolution is of particular importance as 6G will start from Rel-20, putting Rel-19 in place as the foundation stone for the bridge to 6G.

Release 19

- Among the approved Rel-19 projects, we have the “traditional” ones such as enhancing MIMO, mobility, topology, and self-organized networks (SON)/minimization of drive testing (MDT). We also have the continued evolution for non-terrestrial networks (NTN), and eXtended Reality (XR).

- A new area worth highlighting is a study called ‘Solutions for Ambient IoT in NR’, with the possibility of being converted into a work item in TSG RAN#106 (December 2024). Ambient IoT aims for a harmonized design for low-end tags with backscattered (up to ~1μW) and active transmissions (≤ a few hundred μW) in a licensed frequency-division-duplex (FDD) spectrum in frequency range 1 (FR1). Two topologies are considered, one is where a base station (BS) is connected directly to a tag and the other one is where a user equipment (UE) can serve an intermediate node under the network control.

Release 19

- Energy efficiency has always been a focus of 3GPP standardization. Rel-19 takes this a step further, with enhancements introduced to improve network energy savings. Based on the outcome of the study in Rel-18, we will see specifications for the support of low-power wake-up signal/receiver (LP-WUS/WUR) in Rel-19.

- Artificial intelligence (AI)/machine learning (ML) is taking the main stage across TSG RAN in Rel-19. WG RAN1 is leading an AI/ML project focusing on specifying use cases for CSI prediction, beam management and positioning, as a continuation of the study in Rel-18. The group (RAN1) also continues to study the use case of CSI compression (started in Rel-18). In parallel, WG RAN2 is leading a study of AI/ML for mobility management, focusing on network triggered layer 3 mobility, while WG RAN3 continues its work on AI/ML for NG (next generation)-RAN and WG RAN4 investigates all the necessary aspects related to performance and the requirements for AI/ML in the RAN.

Release 19

- Another Rel-19 project worth emphasizing is the specification of sub-band full-duplex (SBFD) in a time-division duplex (TDD) system, which enables the conversion of some frequency portion of a downlink slot into an uplink subband, orthogonal to the remaining subbands for downlink. This is a continuation of Rel-18 study, and is expected to bring benefits such as improved uplink coverage and reduced latency for TDD.

- Two studies in Rel-19 provide a direct bridge to 6G topics: Channel modeling for integrated sensing and communications (ISAC), and Channel modeling for higher mid-band spectrum (e.g., 7-24 GHz). These two Rel-19 projects are critical in laying the necessary foundation for further technical study and specification work, at a later stage.

Release 19 and beyond

Verso il 6G – ipotesi di piano di lavoro

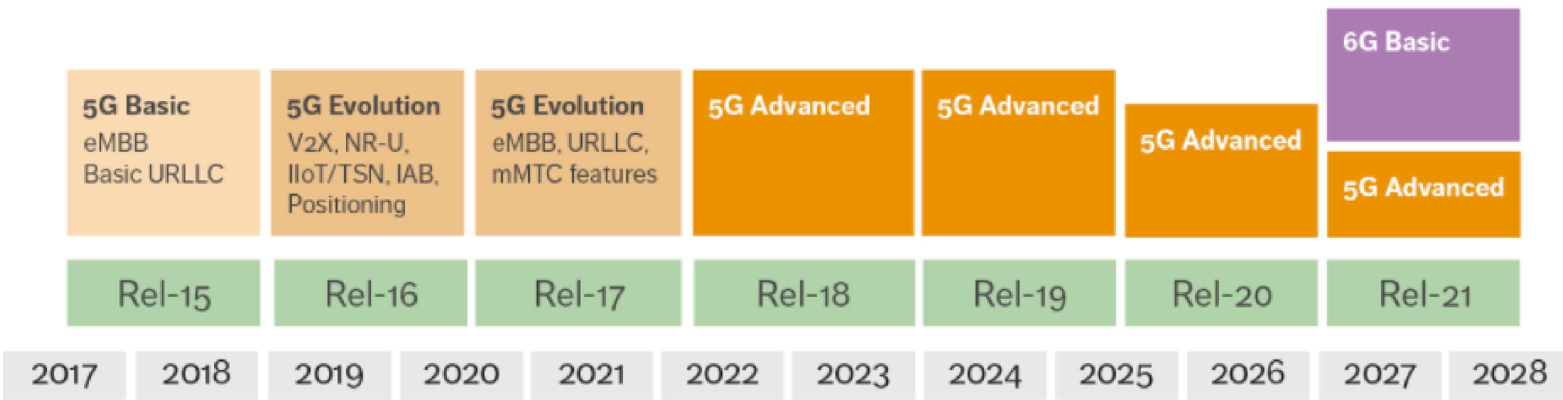


Figure 1 : 3GPP's 5G evolution tentative time plan