3GPP 5G RAN architecture

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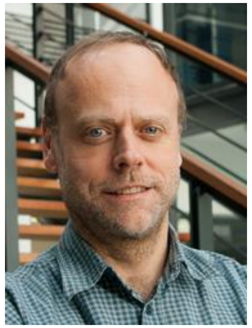

Raymond Knopp

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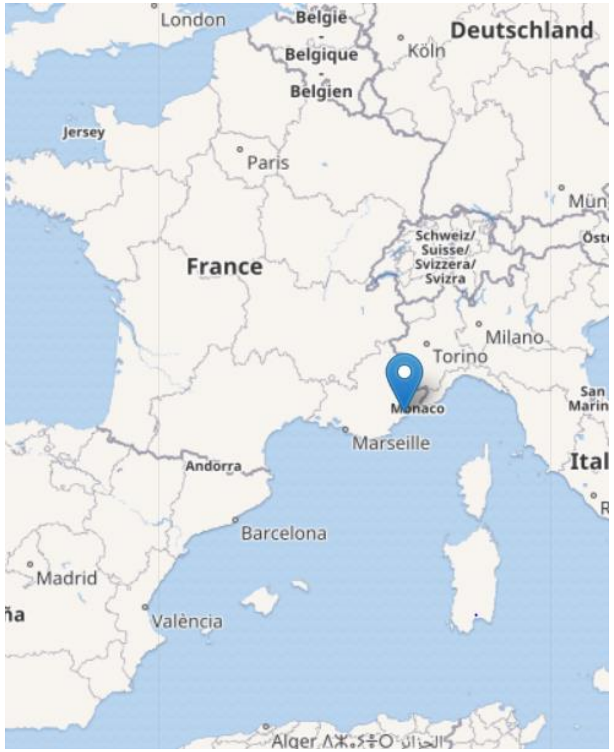
- President of the OpenAirInterface Software Alliance
- Long-time SDR and RAN enthusiast



Introduction

- This presentation is part of a EURECOM masters' level course (Mobile Systems, years 4 or 5), some PhD students take it too.
  - Created for 2G/3G/4G by Christian BONNET
  - Usually covers 3GPP RAN and Core
  - Currently has a network focus, other courses (Digital Communications) are more UE processing oriented covering some of the basic signal processing aspects
  - Current 5G version by A. Ksentini, N. Nikaein, R. Knopp (we share it), 42 hours
- How we want this to evolve via SLICES-RI
  - 3GPP architecture is very dry without lab sessions
  - Aim to integrate SLICES-RI infrastructure / OAI / Mosaic5G into the course to allow students to explore 3GPP through experimentation
    - "See" the protocol exchanges, build a disaggregated network
    - Play with real tools and equipment

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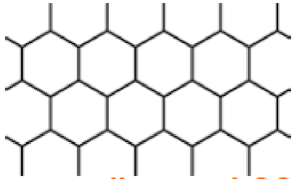
EUROPE Spectrum

Existing physical sites can be reused for 5G except for spectrum above 10 GHz

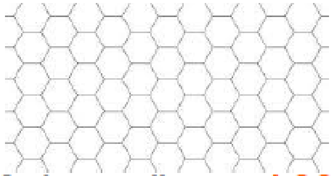
<1 GHz
macro coverage grid
territory and deep indoor coverage



Large cells, non-LOS*
deep indoor coverage
Mobile and fixed wireless
low capacity

900 MHz – 2G/3G
800 MHz – 4G
700 MHz – 5G

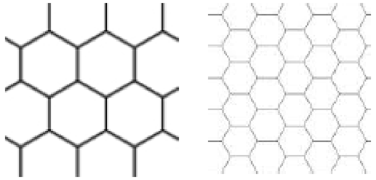
1 to 4 GHz
macro capacity grid
additional capacity for cities



Medium cells, non-LOS*
light indoor coverage
Mobile and fixed wireless
medium capacity

1800 MHz – 2G/4G
2100 MHz – 3G
2600 MHz – 4G
3500 MHz – 5G with massive MIMO

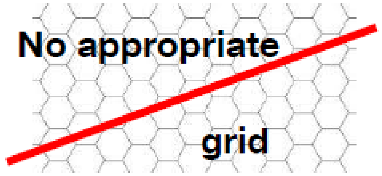
6-10 GHz
can reuse macro coverage and capacity grids with limitation



large & medium, near-LOS
window coverage
Fixed wireless
large capacity

5G with massive MIMO frequency band(s) not secured

>10 GHz
Flexible network partitioning & functionality.



only LOS*
outdoor coverage
Fixed wireless
very large capacity

5G with massive MIMO frequency band(s) not secured

*LOS = Line of sight

6 Orange Restricted

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Main Objectives of 5G/5G-Advanced

- Ultra-flexible radio-access configurations
  - Higher bandwidth
  - Higher spectral efficiency (bits/s/Hz/m^2)
  - Bandwidth parts
    - Tailor bandwidth to UE class (like eMTC narrowbands/widebands)
  - New abstractions for service classification down to L1 (slicing)
- Compatibility with 4G/5G core network
  - 5G dual-connectivity (non-standalone operation)
  - Interconnection of evolved 4G eNodeB (ng-eNB) with 5G core
- 5G core cloud-native architecture

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Vertical Use-cases (Rel 15/16)

- Public Networks
  - Mobile broadband
    - Gbit/s to mobile device
    - IMS-based voice services
    - New low-latency services (gaming)
  - Fixed broadband
    - Especially USA for now (mmWave acces)
  - NR-V2X
    - Non-critical
- Professional Networks
  - Surveillance
    - Security (low-latency), dense networks (stadium)
    - Smart Agriculture/Aquaculture
  - Industrial Networks
    - Control of machines (tooling, farming equipment)

Rel17/18 extensions

- Rel17
  - NR-V2X
    - Critical services
    - Public-safety
  - Massive machine-type communications
    - Coverage enhancement (CovEnh)
    - Reduced Capacity Devices (RedCap)
  - Further URLLC for Industrial IoT
    - Time-sensitive networking
  - Non puglic Networks
  - Non-terrestrial networks
- Rel 18 (5G advanced)
  - Evolution of DL MIMO
  - Study on AI/ML approaches in the air interface
  - Further Enhancements for coverage
  - Sidelink enhancements + relaying
  - Wakeup signals and network power saving
  - Support for UAV
  - Non-terrestrial network extenstions

A LOOK AT CURRENT 5G STANDARDIZATION

About the IMT/3GPP/NGMN/SCF/ORAN

- IMT = International Mobile Telecommunications
  - UN (Internation Telecommunications Union - ITU) standardization body to produce specifications for networking requirements. A big specification release ~ every 10 years
- 3GPP = Third Generation Parternship Project
  - Created at the onset of 3G to federate the standardization process to generate a system
    - Core Network
    - Radio-Access Network
    - Service Architecture
    - Testing Architecture
- NGMN = Next Generation Mobile Networks
  - Operator-driven consortium to produce “recommendations” for implementation of mobile communication systems
  - Example: famous “white-paper” in 2015 to help define 5G from the operator perspective.
- SCF = Small-Cell Forum
  - Produce functional specifications for non-3GPP interfaces tailored to “small-cell” network topologies
- O-RAN = Operator Defined Next Generation RAN Architecture and Interfaces
  - Produce functional specifications for non-3GPP interfaces aiding the deployment of disaggregated 3GPP network

IMT 2020 Requirements for 5G

Capability	Description	5G requirement	Usage scenario
Downlink peak data rate	Minimum maximum data rate technology must support	20 Gbit/s	eMBB
Uplink peak data rate		10 Gbit/s	eMBB
User experienced downlink data rate	Data rate in dense urban test environment 95% of time	100 Mbit/s	eMBB
User experienced uplink data rate		50 Mbit/s	eMBB
Latency	Radio network contribution to packet travel time	4 ms	eMBB
		1 ms	URLLC
Mobility	Maximum speed for handoff and QoS requirements	500 km/h	eMBB/URLLC
Connection density	Total number of devices per unit area	10^6/km^2	mMTC
Energy efficiency	Data sent/received per unit energy consumption (by device or network)	Equal to 4G	eMBB
Area traffic capacity	Total traffic across coverage area	10 Mbps/m^2	eMBB
Peak downlink spectrum efficiency	Throughput per unit wireless bandwidth and per network cell	30 bit/s/Hz	eMBB

- IMT-2030 has started!
- Expect a new slide soon ☺

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3GPP

- 3GPP is a consortium with seven national or regional telecommunication standards organizations as primary members ("organizational partners")
- variety of other organizations as associate members ("market representation partners"), like 4G Americas, 5G Infrastructure Association (5GIA), NGMN, etc.

Organization	Country/region	Website
Association of Radio Industries and Businesses (ARIB)	Japan	ARIB
Alliance for Telecommunications Industry Solutions (ATIS)	USA	ATIS
China Communications Standards Association (CCSA)	China	CCSA
European Telecommunications Standards Institute (ETSI)	Europe	ETSI
Telecommunications Standards Development Society (TSDSI)	India	TSDSI
Telecommunications Technology Association (TTA)	South Korea	TTA
Telecommunication Technology Committee (TTC)	Japan	TTC

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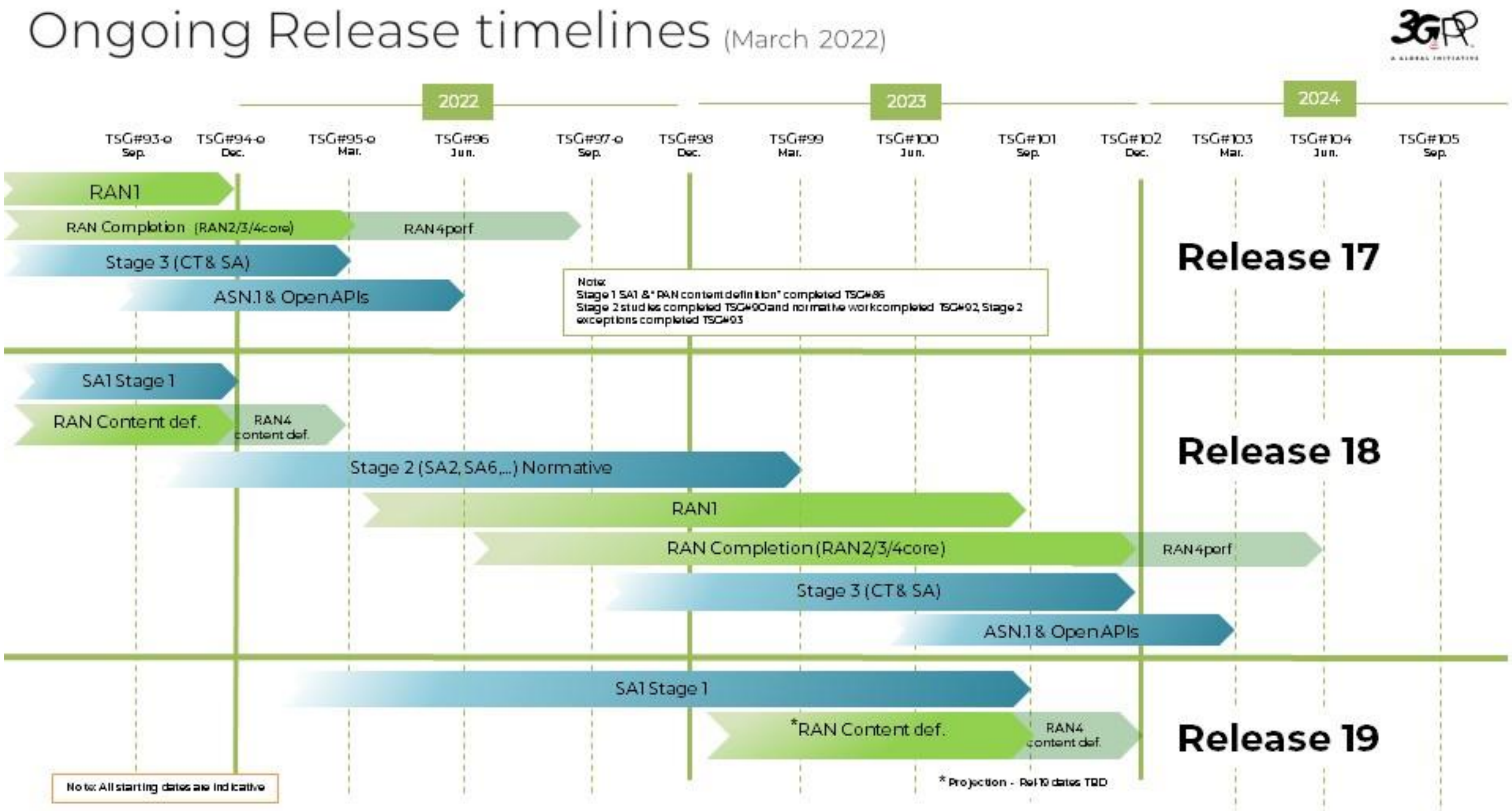
3GPP

- The 3GPP organizes its work into three different streams:
  - Radio Access Networks (RAN)
  - Services and Systems Aspects (SA)
  - Core Network and Terminals (CT)
- The three groups produce documents ultimately resulting in specifications.
- 3GPP standards are structured as Releases which represent an evolving set of functionalities.

3GPP Release Timeline (today’s)



Key RAN specifications (L2)

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

3GPP TS 38.401: "NG-RAN; Architecture description".

3GPP TS 33.501: "Security Architecture and Procedures for 5G System".

3GPP TS 37.340: "NR; Multi-connectivity; Overall description; Stage-2".

3GPP TS 38.321: "NR; Medium Access Control (MAC) protocol specification".

3GPP TS 38.322: "NR; Radio Link Control (RLC) protocol specification".

3GPP TS 38.323: "NR; Packet Data Convergence Protocol (PDCP) specification".

3GPP TS 37.324: "NR; Service Data Protocol (SDAP) specification".

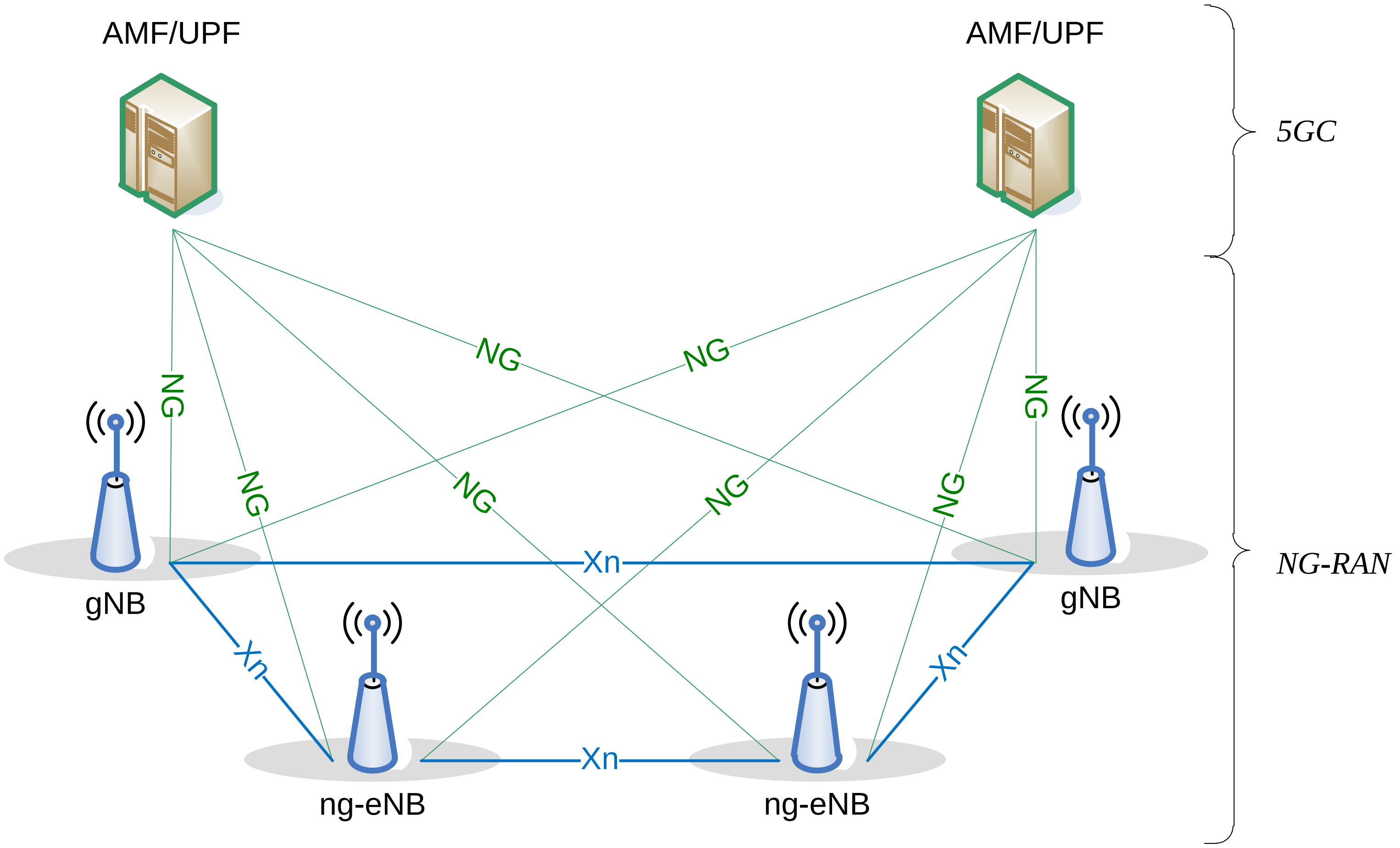
3GPP TS 38.304: "NR; User Equipment (UE) procedures in idle mode".

3GPP TS 38.306: "NR; User Equipment (UE) radio access capabilities".

3GPP TS 38.331: "NR; Radio Resource Control (RRC); Protocol specification".

3GPP TS 38.133: "NR; Requirements for support of radio resource management".

Overall Architecture (with 5G core)



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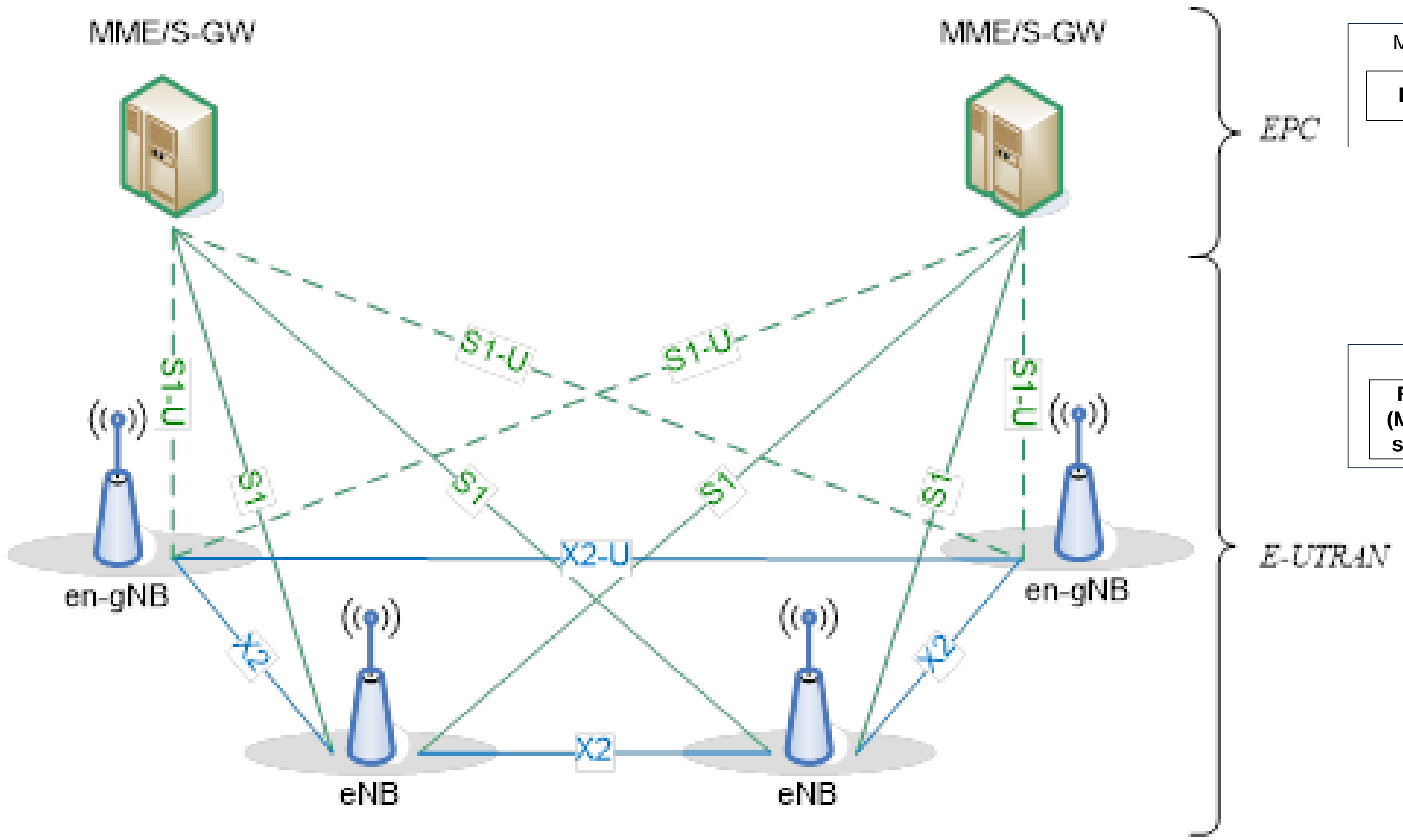
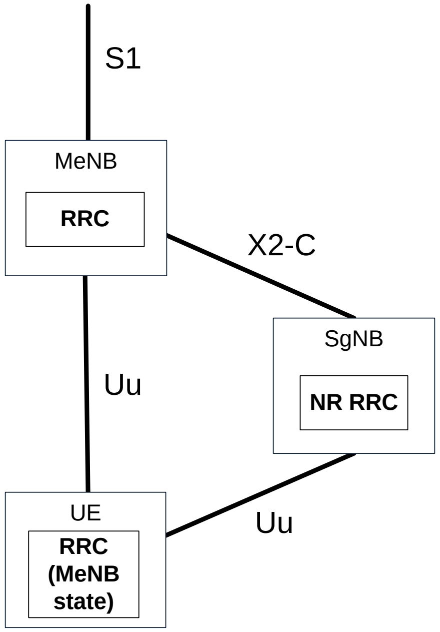
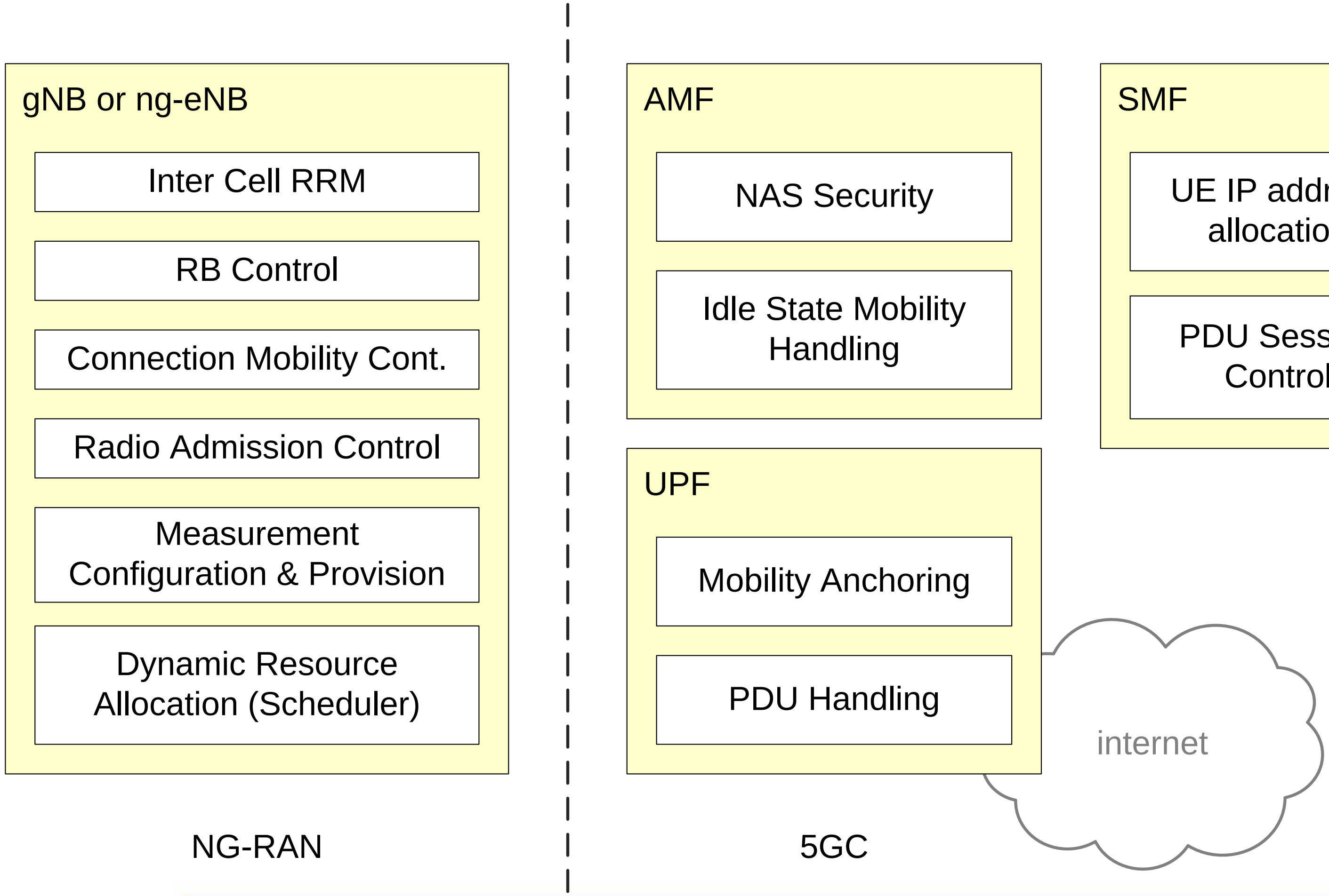
Overall Architecture (with 4G core) – EN-DC





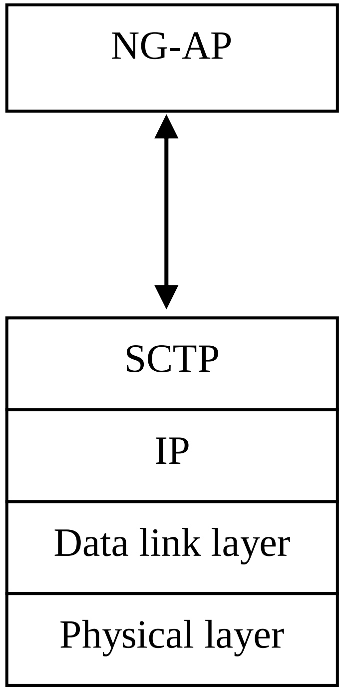
Functional Split between RAN and 5G Core



Functional Split (gNB, ng-eNB)

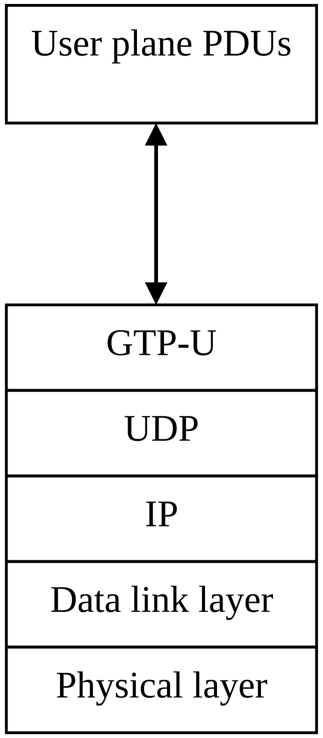
- The gNB and ng-eNB host the following functions:
  - Functions for Radio Resource Management: Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Dynamic allocation of resources to UEs in both uplink and downlink (scheduling);
  - IP header compression, encryption and integrity protection of data;
  - Selection of an AMF at UE attachment when no routing to an AMF can be determined from the information provided by the UE;
  - Routing of User Plane data towards UPF(s);
  - Routing of Control Plane information towards AMF;
  - Connection setup and release;
  - Scheduling and transmission of paging messages (originated from the AMF);
  - Scheduling and transmission of system broadcast information (originated from the AMF or O&M);Measurement and measurement reporting configuration for mobility and scheduling;
  - Transport level packet marking in the uplink;
  - Session Management;
  - Support of Network Slicing;
  - QoS Flow management and mapping to data radio bearers;
  - Support of UEs in RRC_INACTIVE state;
  - Distribution function for NAS messages;
  - Radio access network sharing;
  - Dual Connectivity;
  - Tight interworking between NR and E-UTRA.

NG-C (N1/N2) Interface



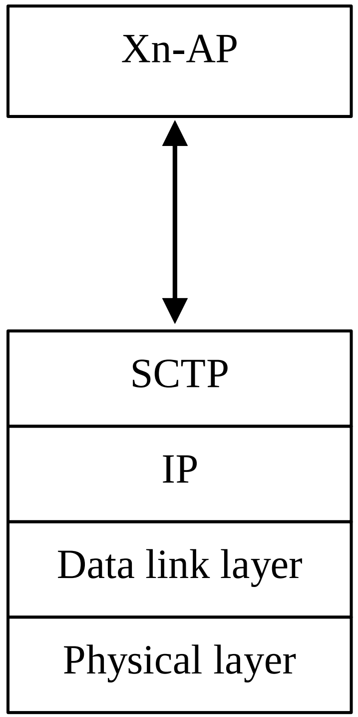
- NG-C provides the following functions:
  - NG interface management;
  - UE context management;
  - UE mobility management;
  - Transport of NAS messages (N1);
  - Paging;
  - PDU Session Management;
  - Configuration Transfer;
  - Warning Message Transmission.

NG-U (N3) Interface



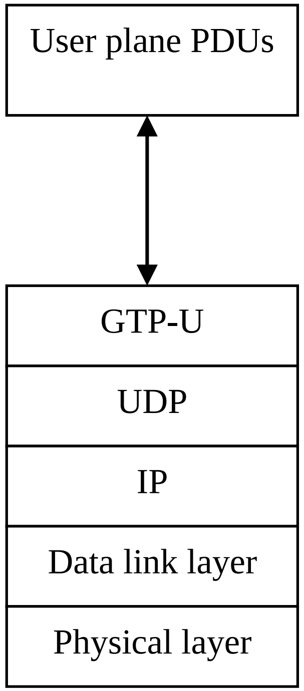
- NG-U (N3) delivery of user plane PDUs between the NG-RAN node and the UPF.

Xn-C Interface



- The Xn-C interface supports the following functions:
  - Xn interface management;
  - UE mobility management, including context transfer and RAN paging:
  - Dual connectivity;

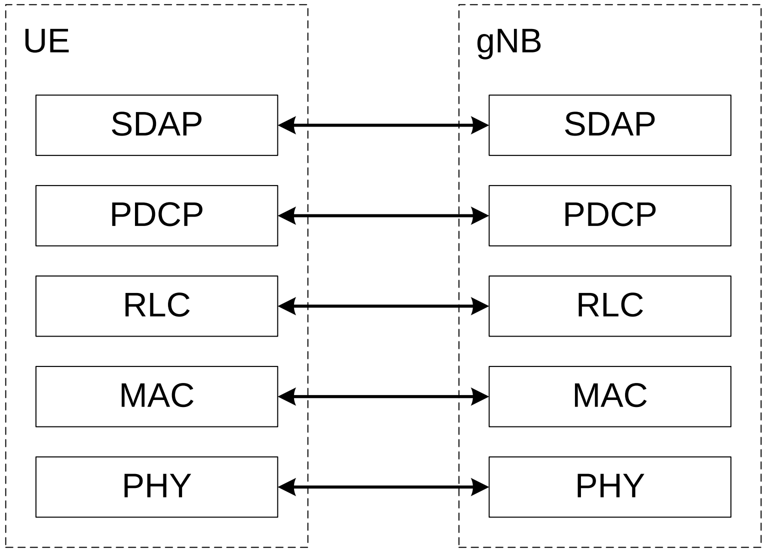
Xn-U Interface

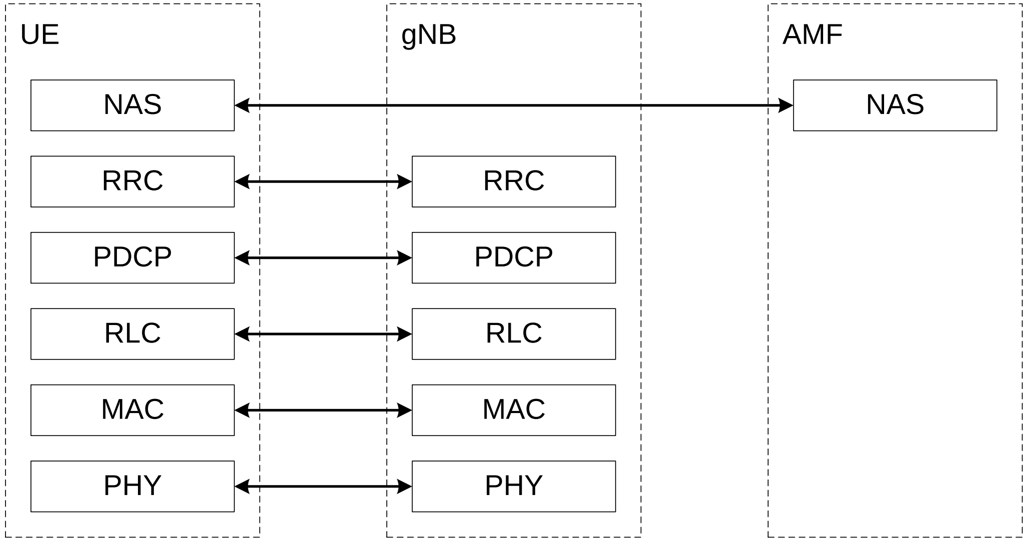


- Xn-U provides non-guaranteed delivery of user plane PDUs and supports the following functions:
  - Data forwarding;
  - Flow control.

Radio Protocol

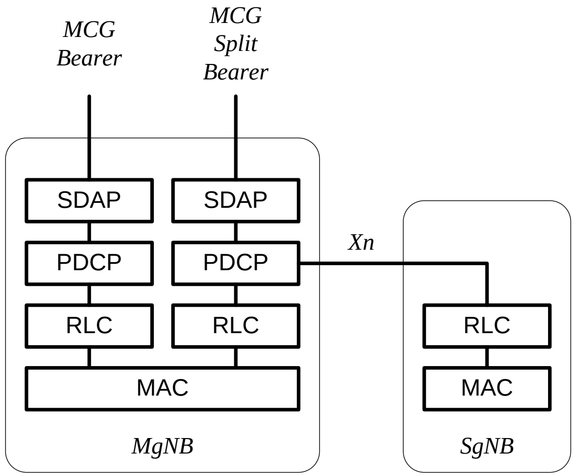
User-plane

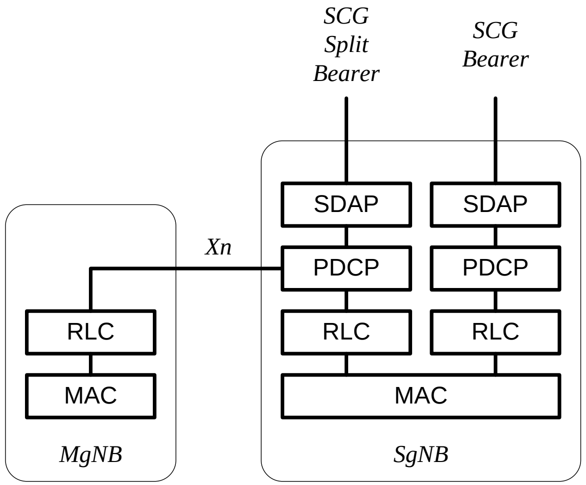




Control plane

Dual connectivity User-plane





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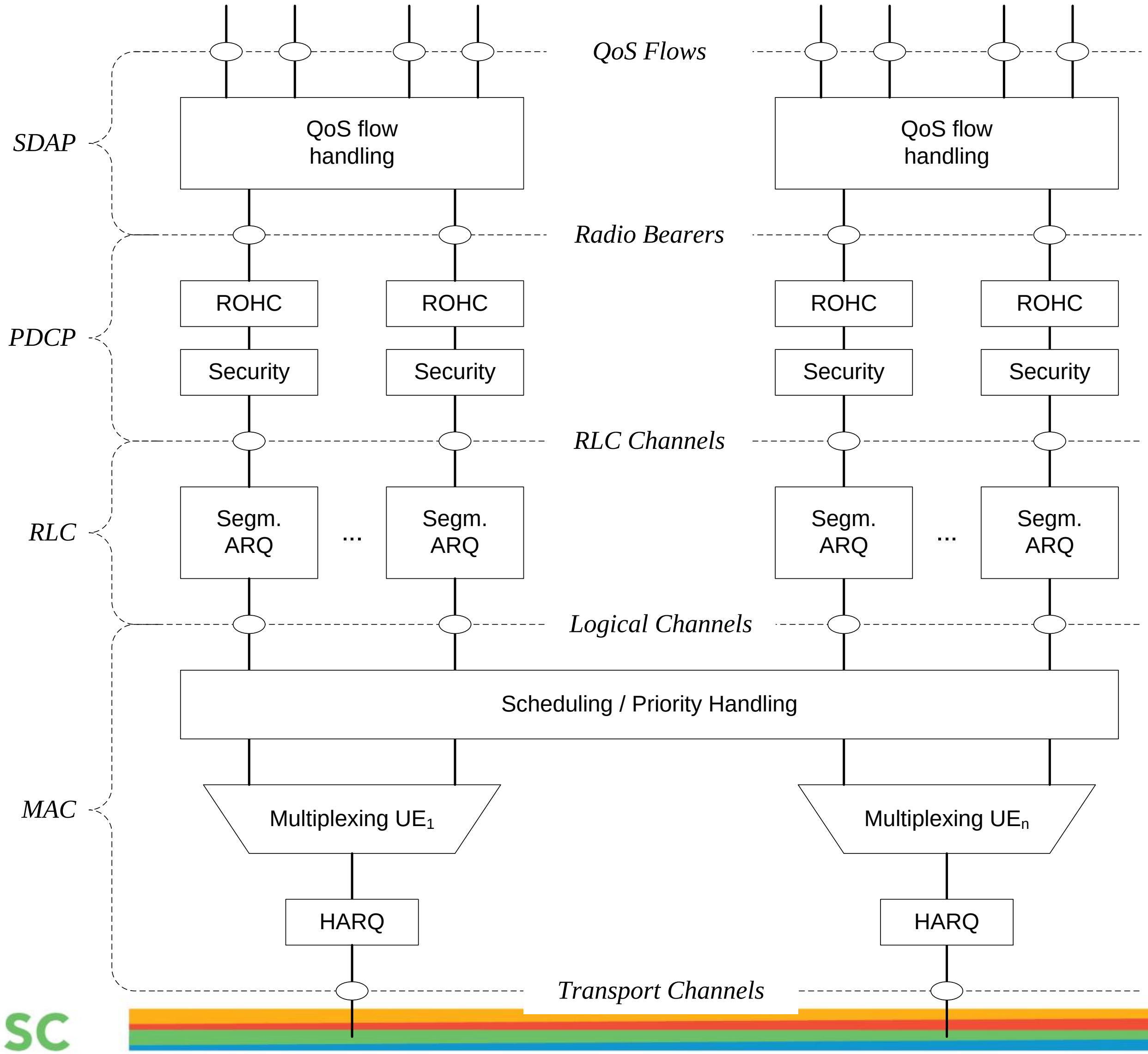
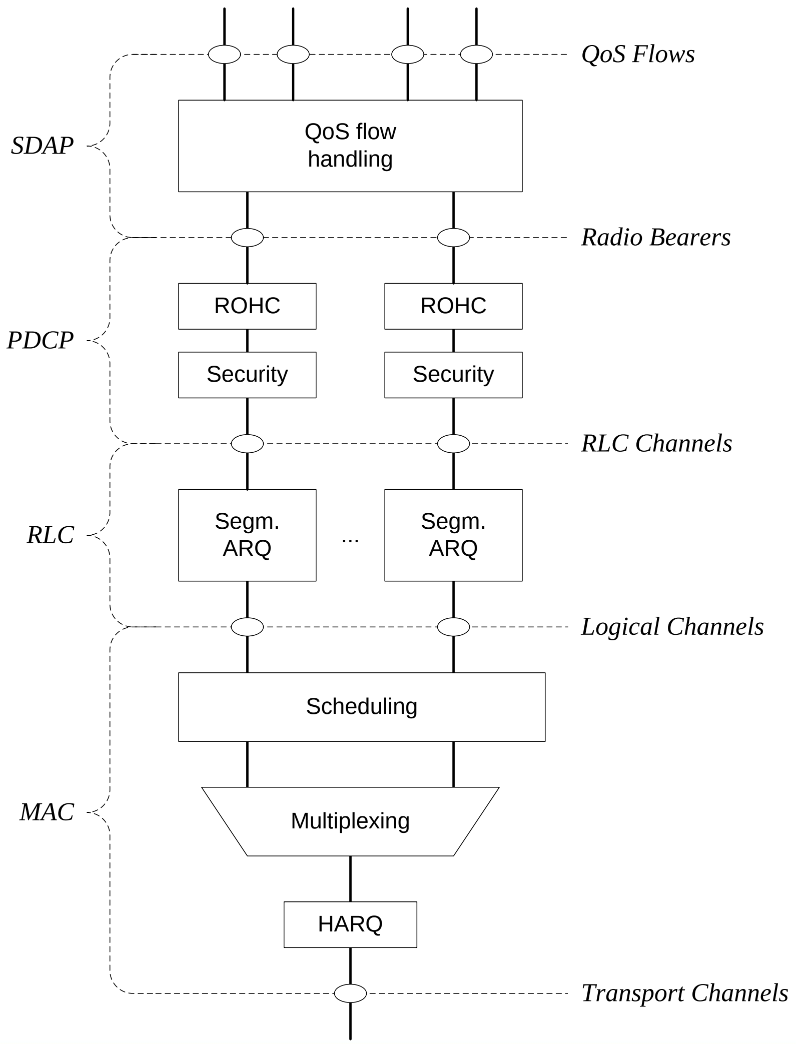
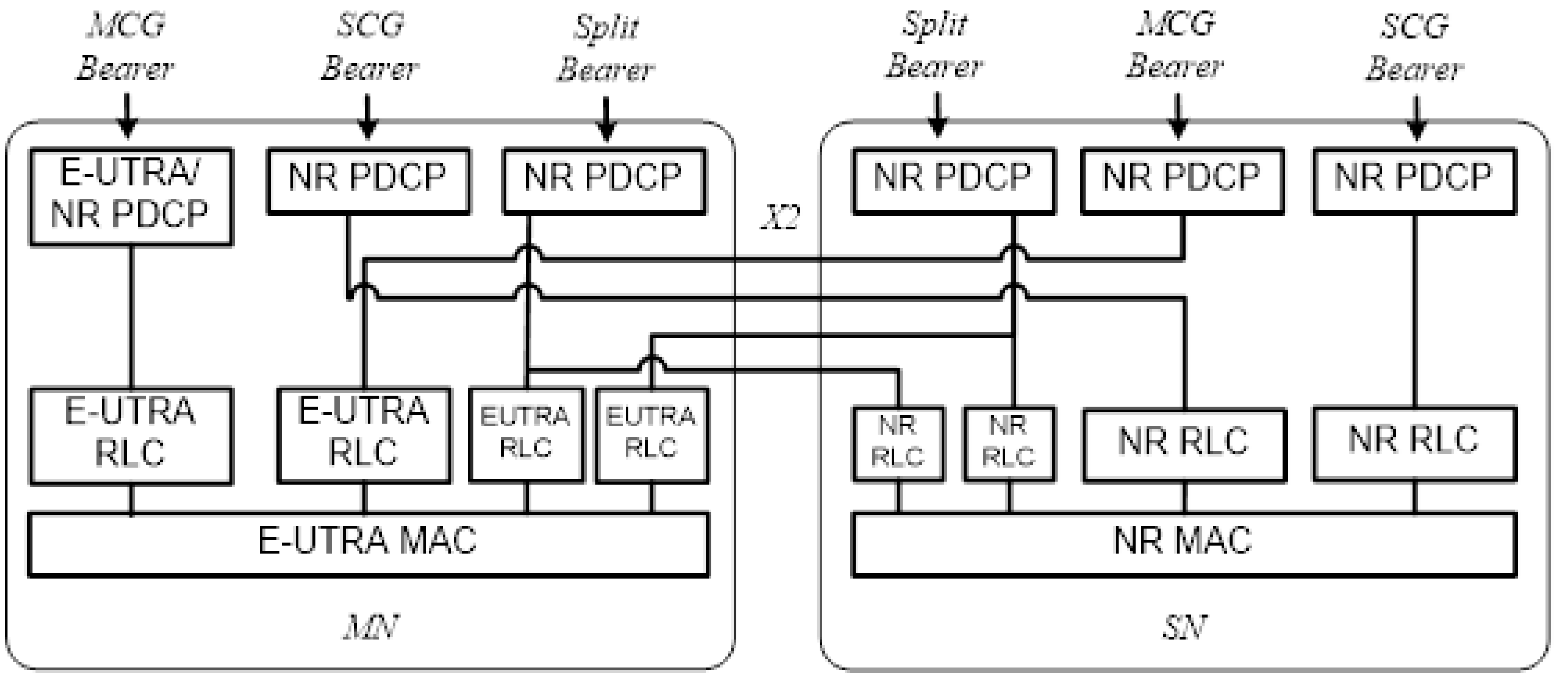
Layer 2 Architecture (Downlink)



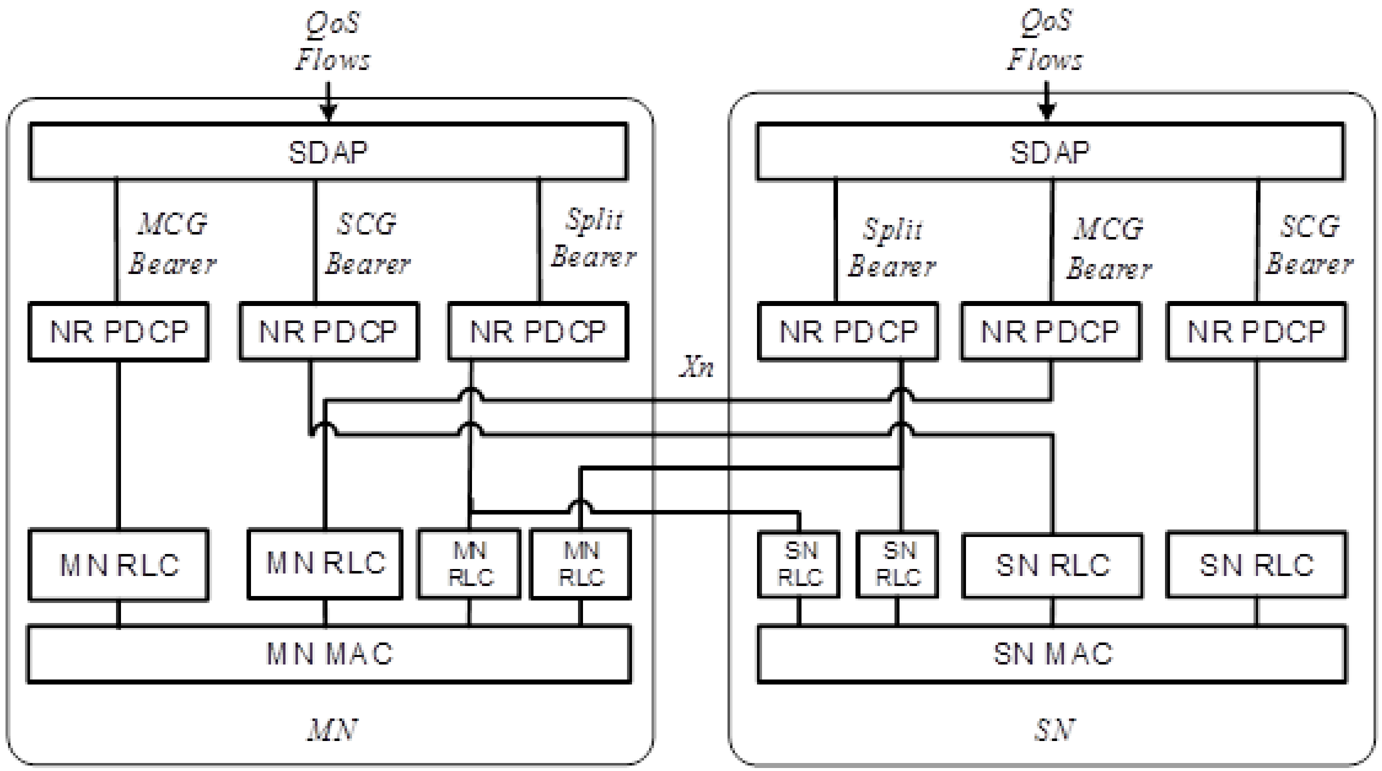
Layer 2 (Uplink)



Overall dual-connectivity Architecture (with 4G core)



Overall dual-connectivity Architecture (with 5G core)



MAC Layer

- The main services and functions of the MAC sublayer include:
  - Mapping between logical channels and transport channels;
  - Multiplexing/demultiplexing of MAC SDUs belonging to one or different logical channels into/from transport blocks (TB) delivered to/from the physical layer on transport channels;
  - Scheduling information reporting;
  - Error correction through HARQ (one HARQ entity per carrier in case of CA);
  - Priority handling between UEs by means of dynamic scheduling;
  - Priority handling between logical channels of one UE by means of logical channel prioritisation;
  - Padding.

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Logical Channels

- **Broadcast Control Channel (BCCH)**: a downlink channel for broadcasting system control information.
- **Paging Control Channel (PCCH):** a downlink channel that transfers paging information and system information change notifications.
- **Common Control Channel (CCCH):** channel for transmitting control information between UEs and network. This channel is used for UEs having no RRC connection with the network.
- **Dedicated Control Channel (DCCH):** a point-to-point bi-directional channel that transmits dedicated control information between a UE and the network. Used by UEs having an RRC connection.
- **Traffic channels** are used for the transfer of user plane information only:
- **Dedicated Traffic Channel (DTCH):** point-to-point channel, dedicated to one UE, for the transfer of user information. A DTCH can exist in both uplink and downlink.

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Mapping of Logical to Transport/Physical Channels

- In Downlink, the following connections between logical channels and transport channels exist:
  - BCCH can be mapped to BCH;
  - BCCH can be mapped to DL-SCH;
  - PCCH can be mapped to PCH;
  - CCCH can be mapped to DL-SCH;
  - DCCH can be mapped to DL-SCH;
  - DTCH can be mapped to DL-SCH.
- In Uplink, the following connections between logical channels and transport channels exist:
  - CCCH can be mapped to UL-SCH;
  - DCCH can be mapped to UL- SCH;
  - DTCH can be mapped to UL-SCH.

RLC (Radio-Link Control)

- The RLC sublayer supports three transmission modes:
  - Transparent Mode (TM);
  - Unacknowledged Mode (UM);
  - Acknowledged Mode (AM).
- The main services and functions of the RLC sublayer depend on the transmission mode and include:
  - Transfer of upper layer PDUs;
  - Sequence numbering independent of the one in PDCP (UM and AM);
  - Error Correction through ARQ (AM only);
  - Segmentation (AM and UM) and re-segmentation (AM only) of RLC SDUs;
  - Reassembly of SDU (AM and UM);
  - Duplicate Detection (AM only);
  - RLC SDU discard (AM and UM);
  - RLC re-establishment;
  - Protocol error detection (AM only).

PDCP (Packet Data Convergence Protocol)

- The main services and functions of the PDCP sublayer for the user plane include:
  - Sequence Numbering;
  - Header compression and decompression: ROHC only;
  - Transfer of user data;
  - Reordering and duplicate detection;
  - PDCP PDU routing (in case of split bearers);
  - Retransmission of PDCP SDUs;
  - Ciphering, deciphering and integrity protection;
  - PDCP SDU discard;
  - PDCP re-establishment and data recovery for RLC AM;
  - Duplication of PDCP PDUs.
- The main services and functions of the PDCP sublayer for the control plane include:
  - Sequence Numbering;
  - Ciphering, deciphering and integrity protection;
  - Transfer of control plane data;
  - Reordering and duplicate detection;
  - Duplication of PDCP PDUs (see subclause 16.1.3).

SDAP (Service Data Adaptation Protocol)

- New entity w.r.t. 4G
- The main services and functions of SDAP include:
  - Mapping between a QoS flow and a data radio bearer;
  - Marking QoS flow ID (QFI) in both DL and UL packets.

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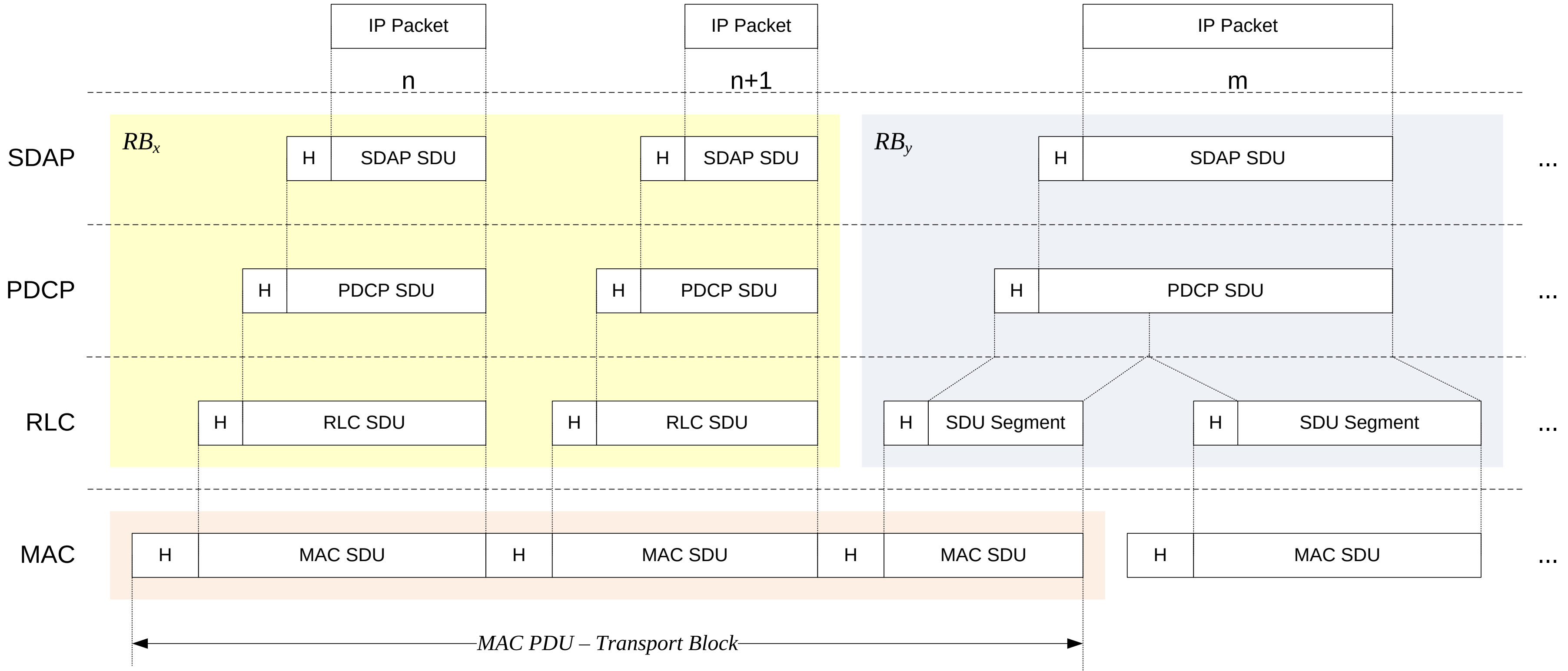
Example L2 Data Flow



An example of the Layer 2 Data Flow is depicted on Figure 6.6-1, where a transport block is generated by MAC by concatenating two RLC PDUs from RB_x and one RLC PDU from RB_y. The two RLC PDUs from RB_x each corresponds to one IP packet (*n* and *n+1*) while the RLC PDU from RB_y is a segment of an IP packet (*m*).

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RRC (5G)

- The main services and functions of the RRC sublayer include:
  - Broadcast of System Information related to AS and NAS;
  - Paging initiated by 5GC or NG-RAN;
  - Establishment, maintenance and release of an RRC connection between the UE and NG-RAN including:
    - Addition, modification and release of carrier aggregation;
    - Addition, modification and release of Dual Connectivity in NR or between E-UTRA and NR.
  - Security functions including key management;
  - Establishment, configuration, maintenance and release of Signalling Radio Bearers (SRBs) and Data Radio Bearers (DRBs);
  - Mobility functions including:
    - Handover and context transfer;
    - UE cell selection and reselection and control of cell selection and reselection;
    - Inter-RAT mobility.
  - QoS management functions;
  - UE measurement reporting and control of the reporting;
  - Detection of and recovery from radio link failure;
  - NAS message transfer to/from NAS from/to UE.

RRC States

- RRC supports the following states which can be characterised as follows:
  - **RRC_IDLE:**
    - PLMN selection;
    - Broadcast of system information;
    - Cell re-selection mobility;
    - Paging for mobile terminated data is initiated by 5GC;
    - Paging for mobile terminated data area is managed by 5GC;
    - DRX for CN paging configured by NAS.
  - **RRC_INACTIVE:**
    - Broadcast of system information;
    - Cell re-selection mobility;
    - Paging is initiated by NG-RAN (RAN paging);
    - RAN-based notification area (RNA) is managed by NG- RAN;
    - DRX for RAN paging configured by NG-RAN;
    - 5GC - NG-RAN connection (both C/U-planes) is established for UE;
    - The UE AS context is stored in NG-RAN and the UE;
    - NG-RAN knows the RNA which the UE belongs to.
  - **RRC_CONNECTED:**
    - 5GC - NG-RAN connection (both C/U-planes) is established for UE;
    - The UE AS context is stored in NG-RAN and the UE;
    - NG-RAN knows the cell which the UE belongs to;
    - Transfer of unicast data to/from the UE;
    - Network controlled mobility including measurements.

RAN/Core Disaggregation

- Different deployment topologies for the RAN (and Core) are proposed in 3GPP driven by operators and vertical industries
  - Allow for optimizing geographic distribution of processing
  - Allow for multi-vendor solutions (end-to-end networking equipment from more than one vendor)
  - Allow tailoring solutions to specific vertical industry use-cases (industrial IoT, automotive, public-safety, etc.)

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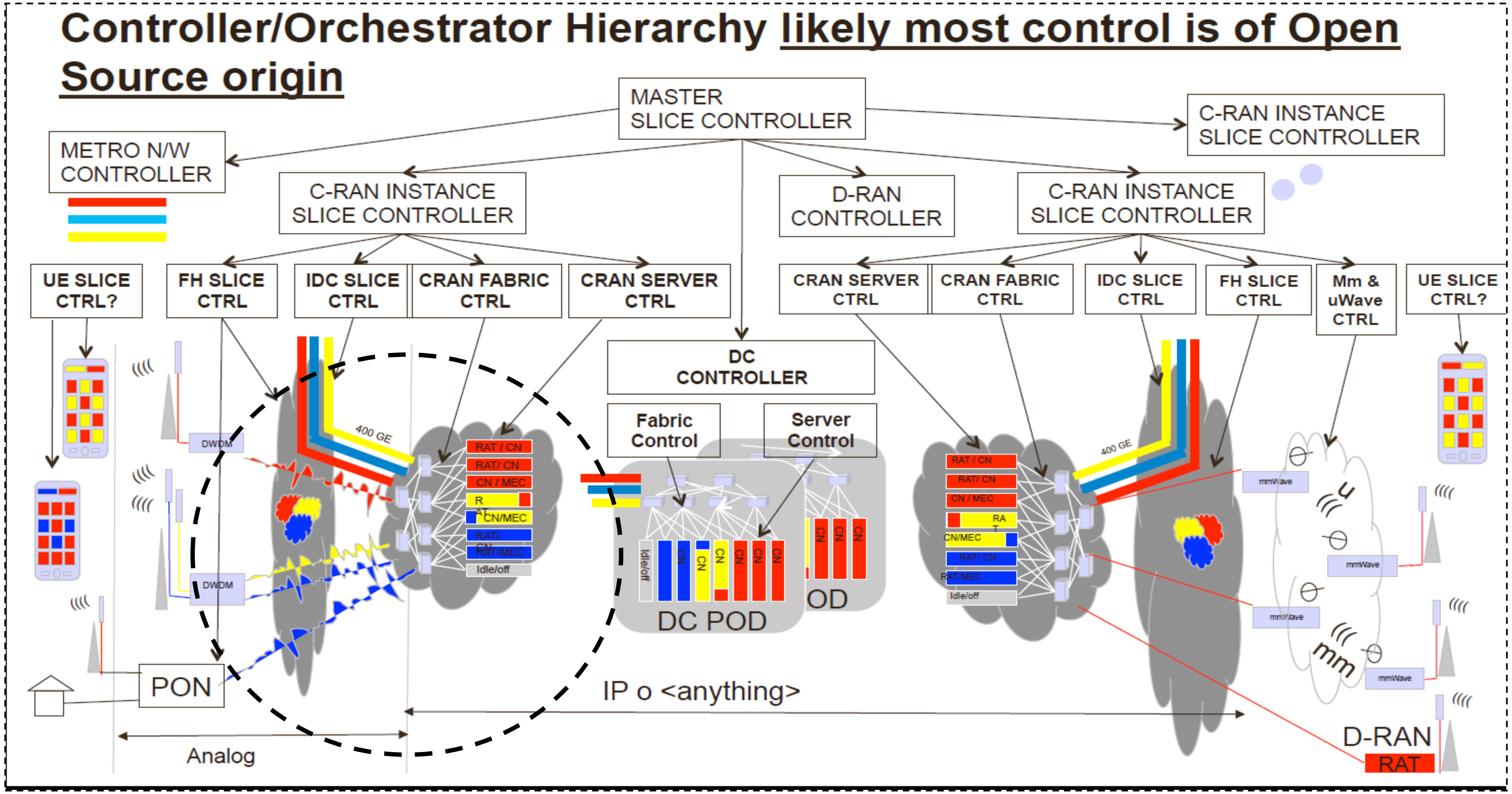
ITU IMT2020 FG Vision (primary networks)



Source: https://www.itu.int/en/ITU-T/Workshops-and-Seminars/itu-ngmn/Documents/Abstracts_and_Presentations/Peter-Ashwood-Smithv2.pdf

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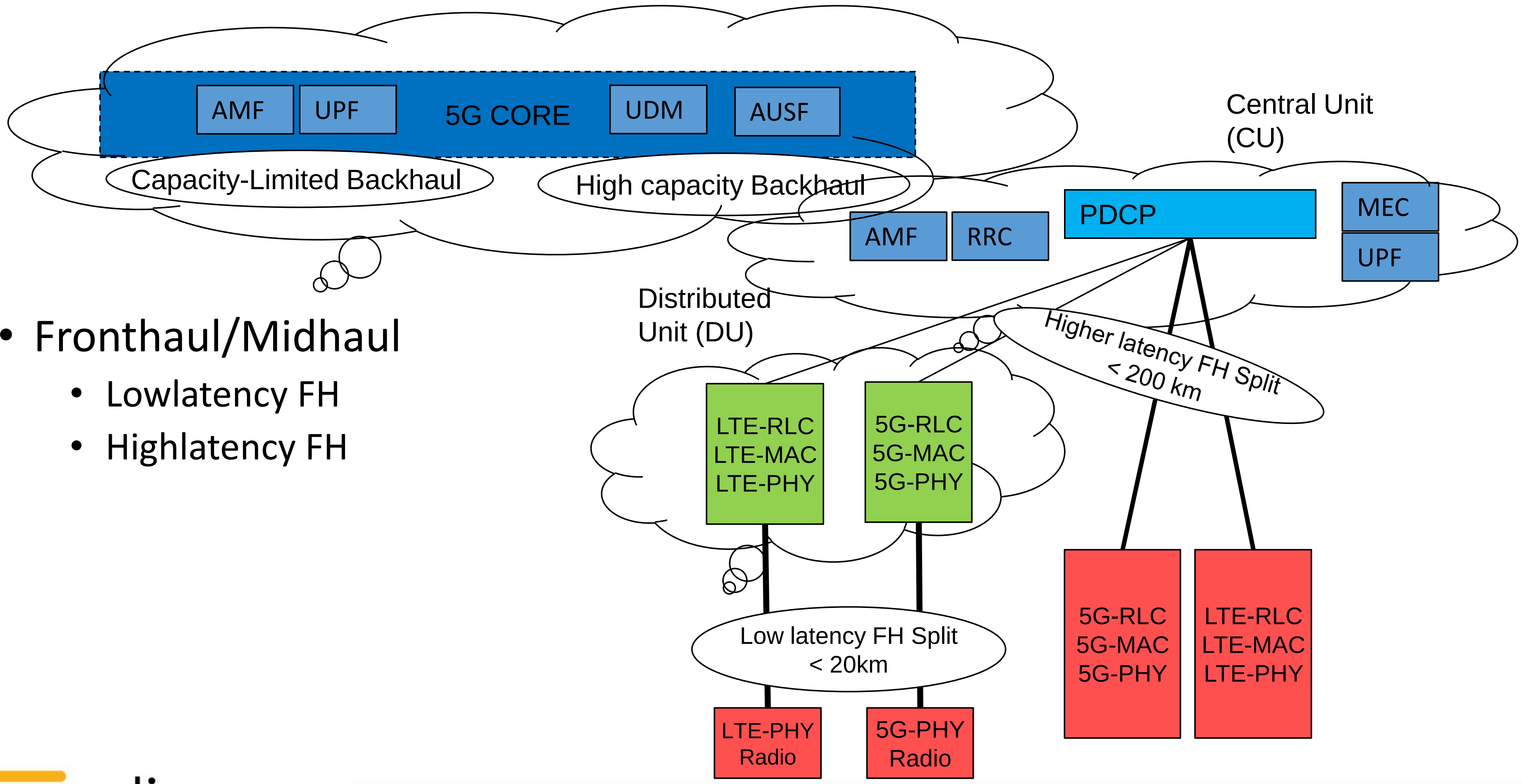
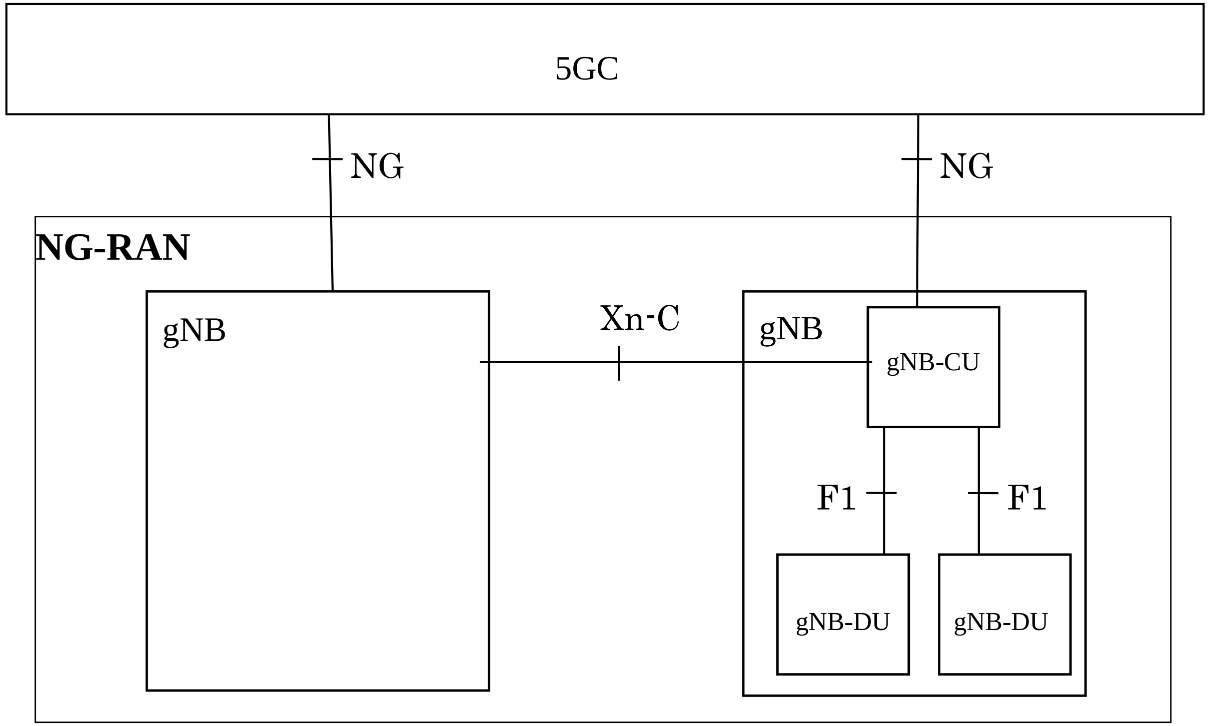
Considered RAN Splits in 3GPP evolution



- Fronthaul/Midhaul
  - Lowlatency FH
  - Highlatency FH

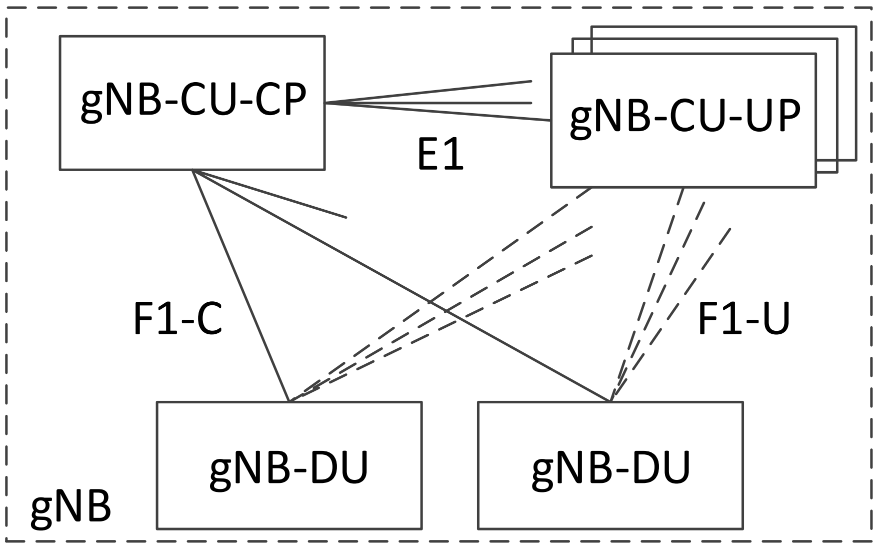
3GPP NG-RAN Functional Split



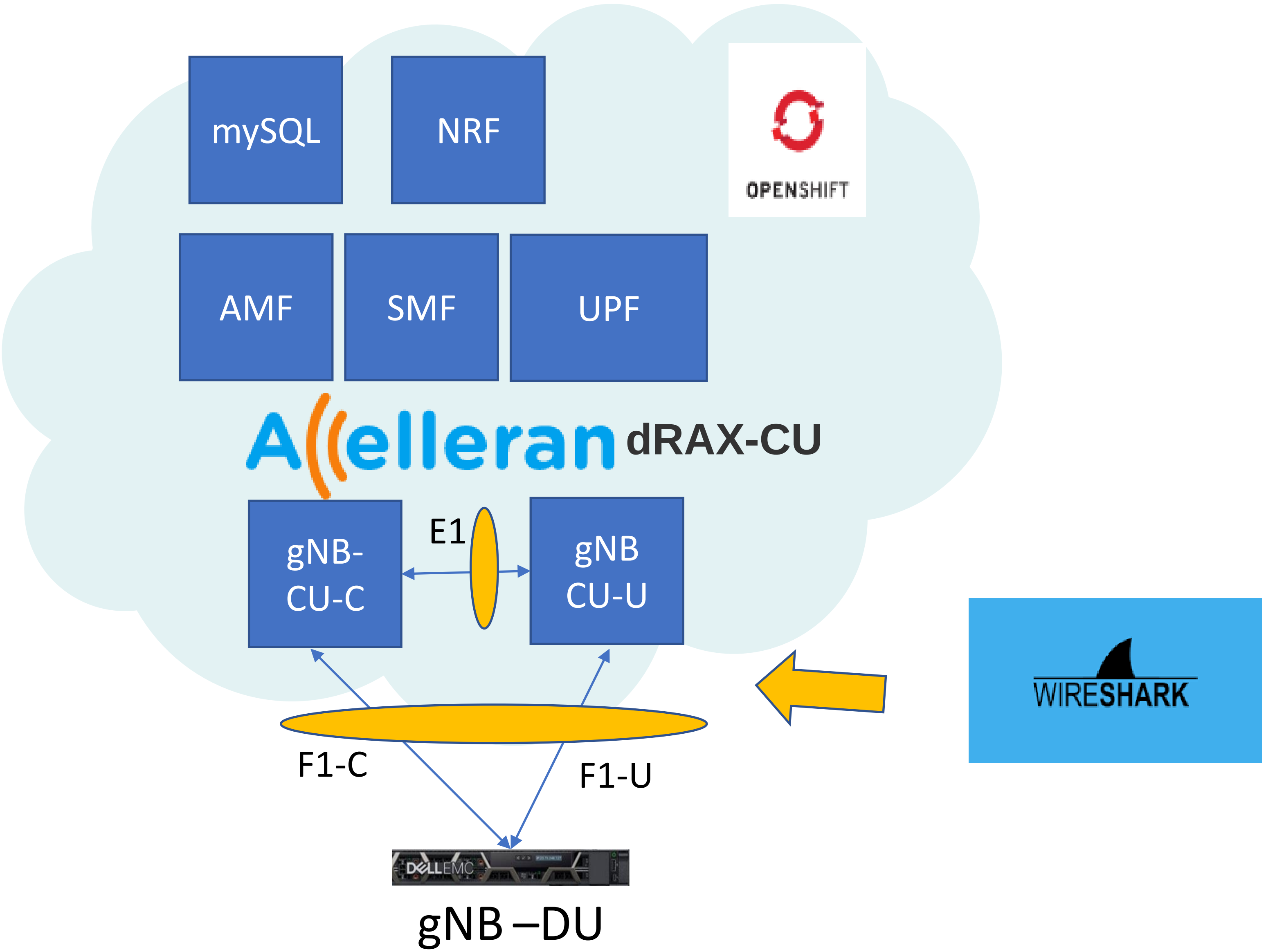
Introduction of F1 interface to split the RAN (gNodeB) in to two logical entities : gNB-CU, gNB-DU

Further split of gNB-CU (for breakout)

- An additional control-plane interface (E1) allows for gNB-CU to be split between C-plane and U-plane segments

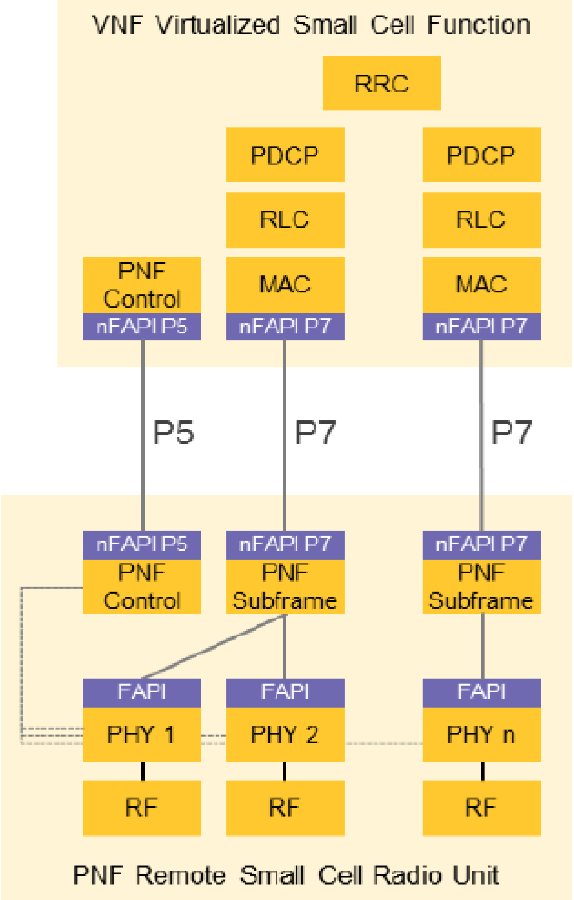


Example



mySQL
NRF
OPENSHIFT
AMF
SMF
UPF
Acceleran dRAX-CU
gNB-CU-C
E1
gNB CU-U
WIRESHARK
F1-C
F1-U
DELLEMC
gNB –DU

Small Cell Forum Functional Split



- (N)FAPI
  - N if networked. Uses TLV-formatted PDUs
- Interface for “simple” gNB devices (small-cells)
- P5 = configuration of PNF (SCTP for “N”)
- P7 = control and user-plane information (UDP for “N”)
  - Control is to configure physical/transport channels on UL/DL
  - User-plane contains the payload of different physical/transport channels
- Originally designed for 4G as an interface for disaggregated RAN
  - Issues with HARQ because of latency
- Can be used inside the “RAN cloud” between containers

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Fronthaul interfaces

- (yesterday's lecture)
- Used to interconnect radio-units and gNodeB processing over long-distances
- CPRI/ECPRI is mainstream and uses proprietary user-plane and control plane formats, along with analog radio-over-fiber.
  - Not interoperable among vendors in general
  - Not specified by 3GPP
- O-RAN Open Fronthaul Interface (FHI)
  - Aims for interoperability between vendors

Bands, Channels, Bandwidth Parts

- Band = indicator of range of potential frequencies for the network

Frequency range designation	Corresponding frequency range
FR1	450 MHz – 6000 MHz
FR2	24250 MHz – 52600 MHz

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

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
n46	5150 MHz – 5925 MHz	5150 MHz – 5925 MHz	TDD[3]
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
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
n96[4]	5925 MHz – 7125 MHz	5925 MHz – 7125 MHz	TDD[3]

Break to talk about RAN for SLICES-RI

- Who will really deploy 5G/5G-Adv radio sites in SLICES-RI?
- Bands
  - In France (EURECOM allocations)
    - **n38/41 40 MHz** (2.575-2.615), next 2 years. Already operational outdoor.
    - **n78 30 MHz (3.46-3.49 GHz),** in the formal request process, renewable every 6 months (incumbant SFR starts at 3.49 GHz, so power and direction will be limited). Used at very low-power indoor now. From 3.49-3.8 GHz, forget it, even indoor at low power. Interference is high because commercial 5G is everywhere and massive-MIMO arrays seem to penetrate very well, even at 3.5 GHz (better coverage indoor at 3.5 GHz than 2.6 GHz 4G)
    - **n77 (3.8-4.0 GHz),** should be ok for 2 years with 100 MHz. Difficult to get RRU, AW2S TBD or Mavenir O-RU maybe if they sell it to us. Used indoors and wired at EURECOM today. UEs are functional.
    - **N258 (somewhere in 25-26 GHz)**, should be ok for a few years. Really uncertain for SLICES-RI services. Many difficulties for “reliable” experimentation. HW issues (RRU, UE) even if we can get OAI to work properly in mmWave.

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Target RAN/Core Architecture for Slices V0

- E1/F1 interface over what distances?
- One central RAN/Core C-plane for all radio sites (e.g. in Paris?)
- Local CU-U/UPF for low-latency services
  - If we have a long-distance F1 interface (F1-C everything, F1-U for eMBB only), we will need local breakout for low-latency services. Paris<->Nice is 15ms RTT.

Is this it?

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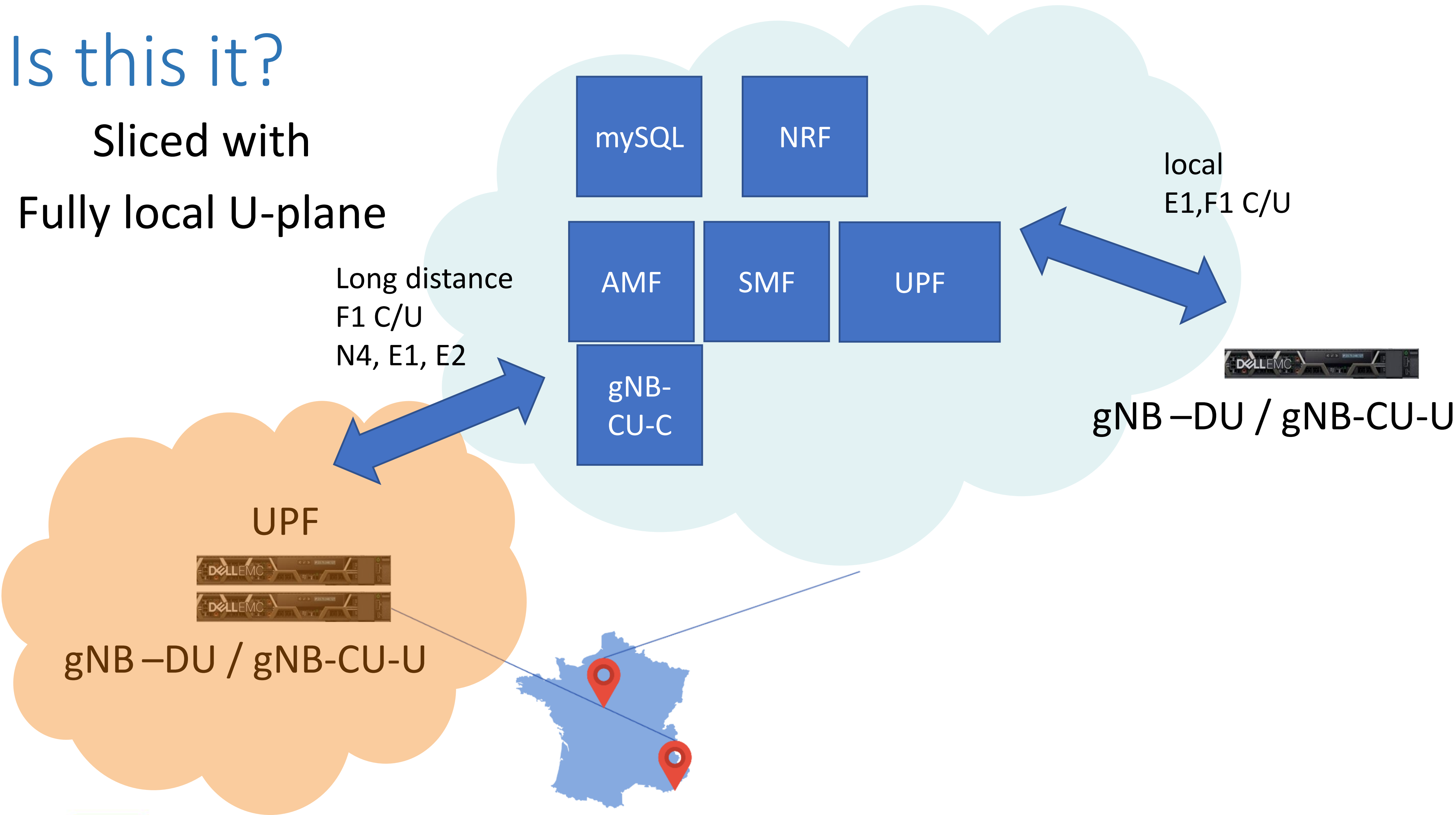
Fully local U-plane



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Frames, Subframe, Slots, Symbols, Resource Elements

- **Numerology** is a number $\mu = 0{,}1{,}2{,}3{,}4$
- **Frame** = 10 ms period (common to 3G/4G)
- **Subframe** = 1 ms period (common to 4G)
- **Slot** =$2^{-\mu}$ms period (1,.5,.25,.125,.0675)ms
  - Higher numerology means shorter slots => more slots per subframe
  - Slots per subframe is 2^{μ}
- 14 OFDM symbols / slot for all μ in *Normal Prefix Mode*
- 12 OFDM symbols / slot for $\mu = 2$ in *Extended Prefix Mode*

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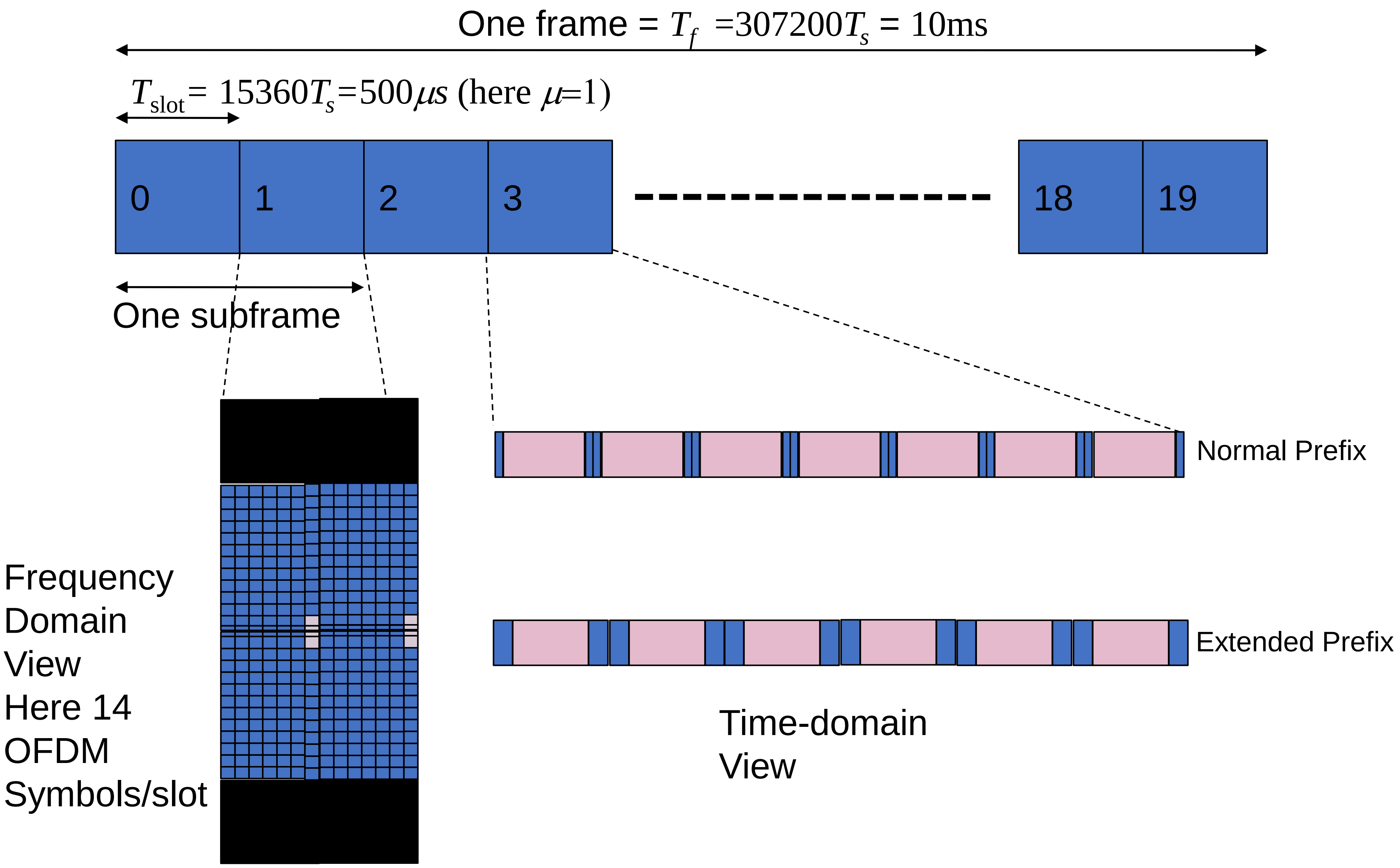
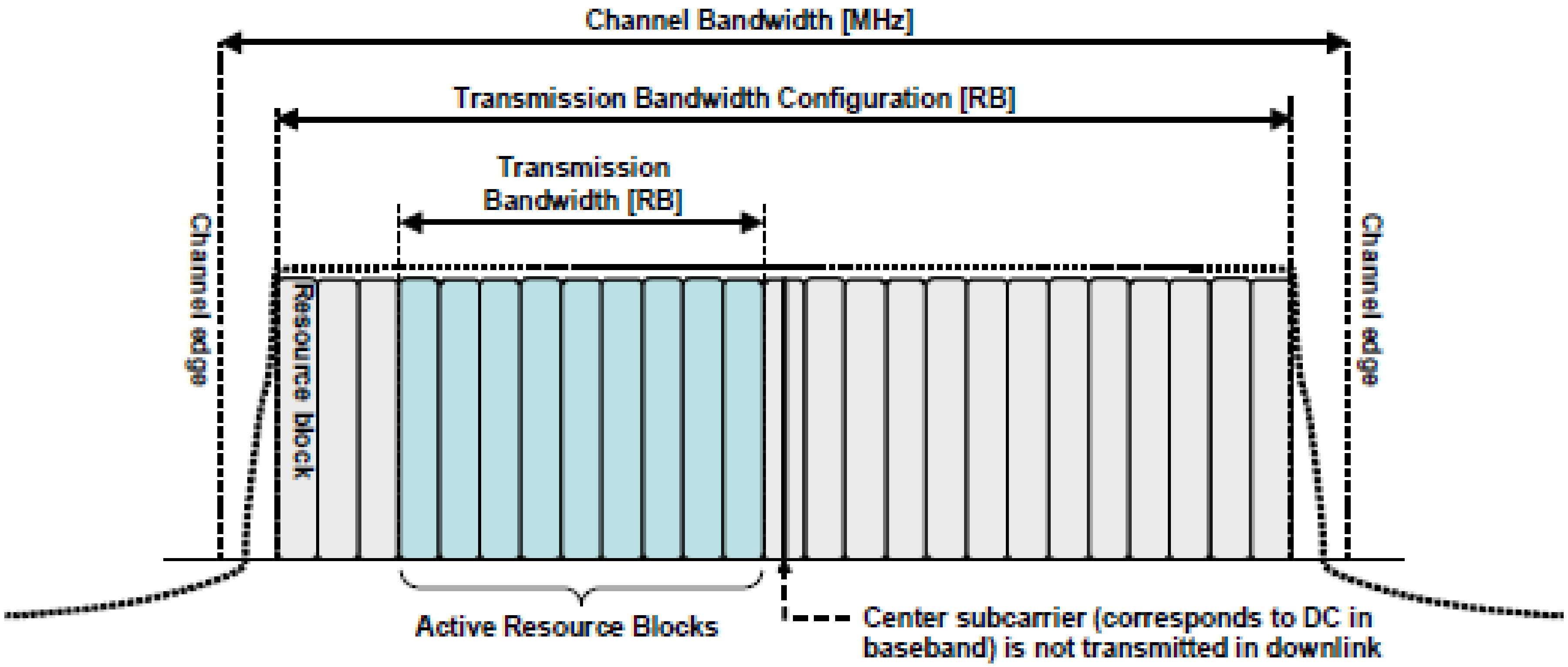
Frames, Subframe, Slots, Symbols, Resource Elements



Resource blocks



- **NR defines the notion of a <u>resource block</u> which represents the minimal scheduling resource for both uplink and downlink transmissions**
- **A <u>physical resource block</u>(PRB) corresponds to** $180 \cdot 2^{\mu}$ **kHz of spectrum**

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Subcarrier Spacing (SCS)

- **Subcarrier spacing is the bandwidth per resource element (OFDM subcarrier)**
- **The PRB is 12 subcarriers, so subcarrier spacing is** $180 \cdot 2^{\mu}/12$ **= 15,30,60,120,240 kHz**

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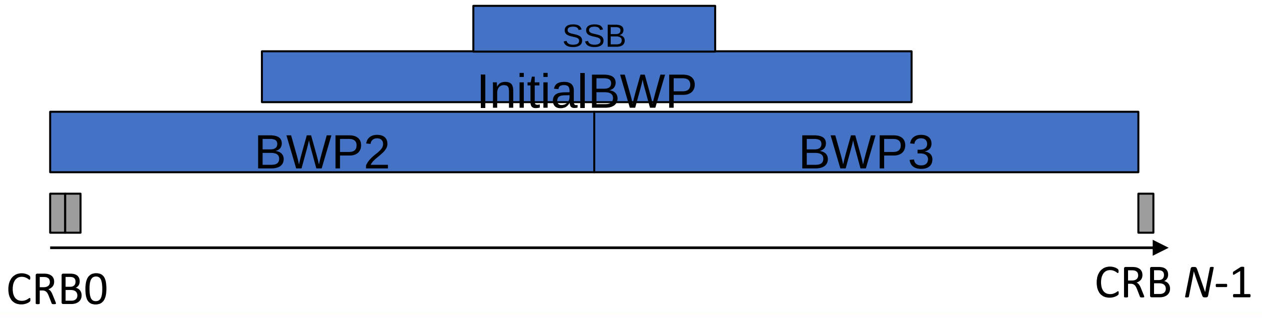
Common PRB Formats

Channel Bandwidth /SCS	Number PRB	Typical IDFT size	Number of Non-Zero Sub-carriers (REs)	Bandwidth
100MHz/30kHz	273	4096	3276	98.28 MHz
100MHz/120kHz	66	1024	792	95.04MHz
10MHz/15kHz	52	1024	624	9.36 MHz
40MHz/30kHz	106	1536 or 2048	1272	38.16 MHz
50MHz/30kHz	133	2048	1596	47.88 MHz

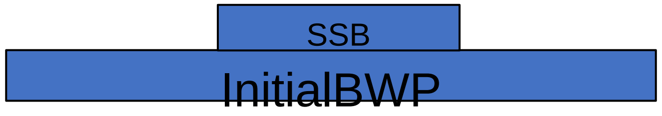
- PRBs are mapped onto contiguous OFDMA/SC-FDMA symbols in the time-domain with starting symbol in (1…14) and can have any length in (2…14). PRBs can be aggregated across slots when using *repetitions*
- Each PRB is chosen to be equivalent to 12 sub-carriers of an OFDMA symbol in the frequency-domain
- OFDMA/SC-FDMA Sub-carriers are termed "Resource Elements" (RE)
- high-frequencies are nulled
  - Spectral shaping
  - Half the bandwidth loss w.r.t. WCDMA (22%)

Bandwidth parts

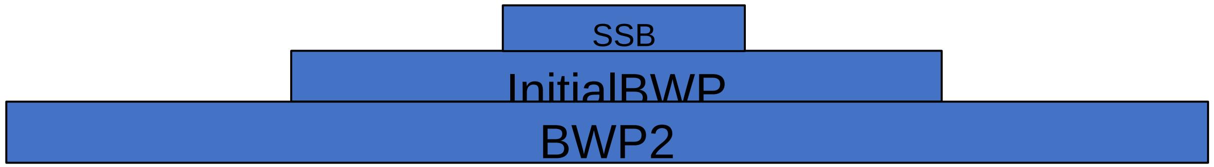
- Channel Bandwidth is partitioned into so-called *bandwidth parts (BWP)*
  - Defined by a starting PRB and size
  - Can be overlapping
  - Can have different numerologies (μ)
  - Are UE-dependent except index 0 which is gNB-dependent (i.e. common to all UEs connected to the gNB)
- One BWP is special – the SSB -
  - Subcarrier-spacing is not arbitrary (15 or 30 for FR1, 120 or 240 for FR2)
- Resource blocks in the grid are called the *Common Resource Block (CRB)*
  - *A BWP comprises a number of CRBs less than or equal to the total number of CRBs for the bandwidth configuration*



Formats in OAI

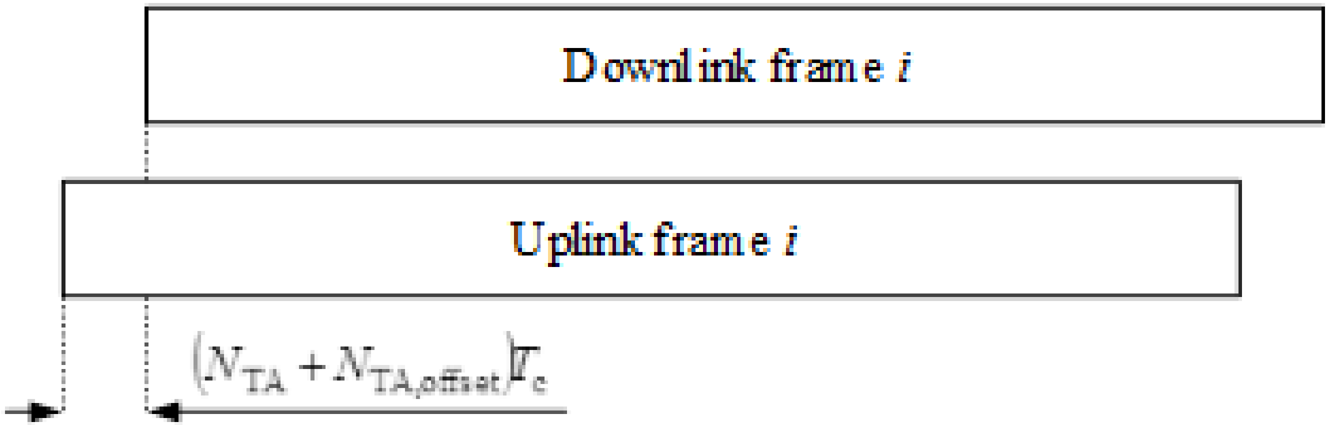


20,30,40,50,60 MHz
SSB+initalBWPs are the only BWP



80,100 MHz
nitalBWP of 20-60 MHz until UE is fully configured (PDUSession)
Dedicated BWP of 80/100 MHz with PDUSession

Timing Advance

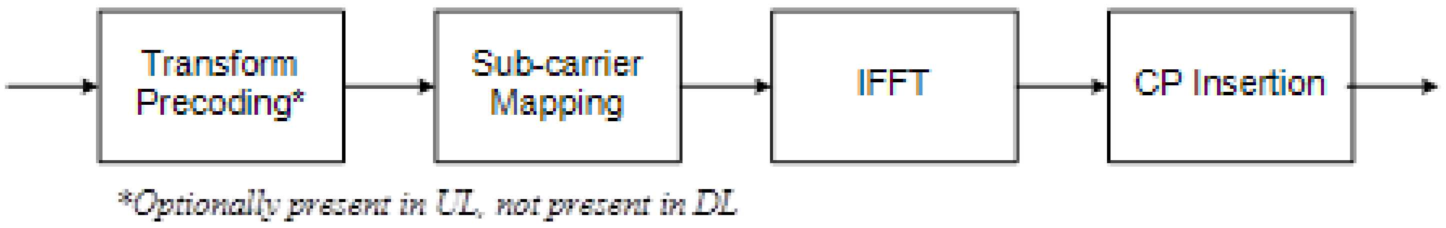


- Timing Advance (TA) is used to adjust the uplink frame timing relative to the downlink frame timing
- Constance part $N_{TA,offset}$, which is non-zero in TDD and variable and UE-specific part (N_{TA}), which is used to synchronize UEs at the gNodeB receiver

Antenna Ports

- An antenna port is defined such that the channel over which a symbol on the antenna port is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed.
  - Note: This is a purely "virtual" antenna port, also sometimes called *logical* antenna port
  - Symbol here is Resource Element
- A gNodeB can have any number of physical antenna ports
  - 64,128,192 are common sizes for so-called *"Massive-MIMO"* or *"Active"* Antenna arrays
  - Through spatial signal processing the UE is made to believe that the antenna has a certain (smaller) number of *logical* antenna ports
  - Each logical antenna port (which can be UE-specific) is associated with a signal that can be used to estimate the channel between the gNB and UE (or UE and gNB for the UL). This can be the SSB DMRS (Demodulation Reference Signal - later) or the PDSCH CSI-RS (Channel State Information Reference Signal – later)

Basic OFDM Transmission

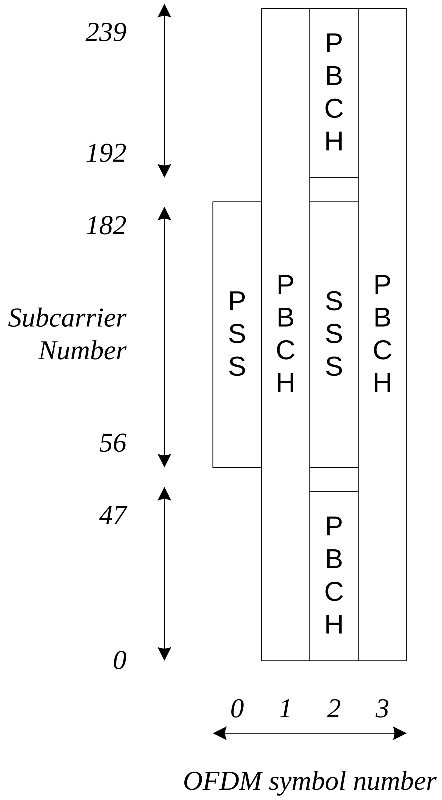


- DL is regular OFDM
- UL can have a transform precoder (SC-FDMA), this is UE-specific and even physical channel specific

Synchronization Signal Block (SSB)

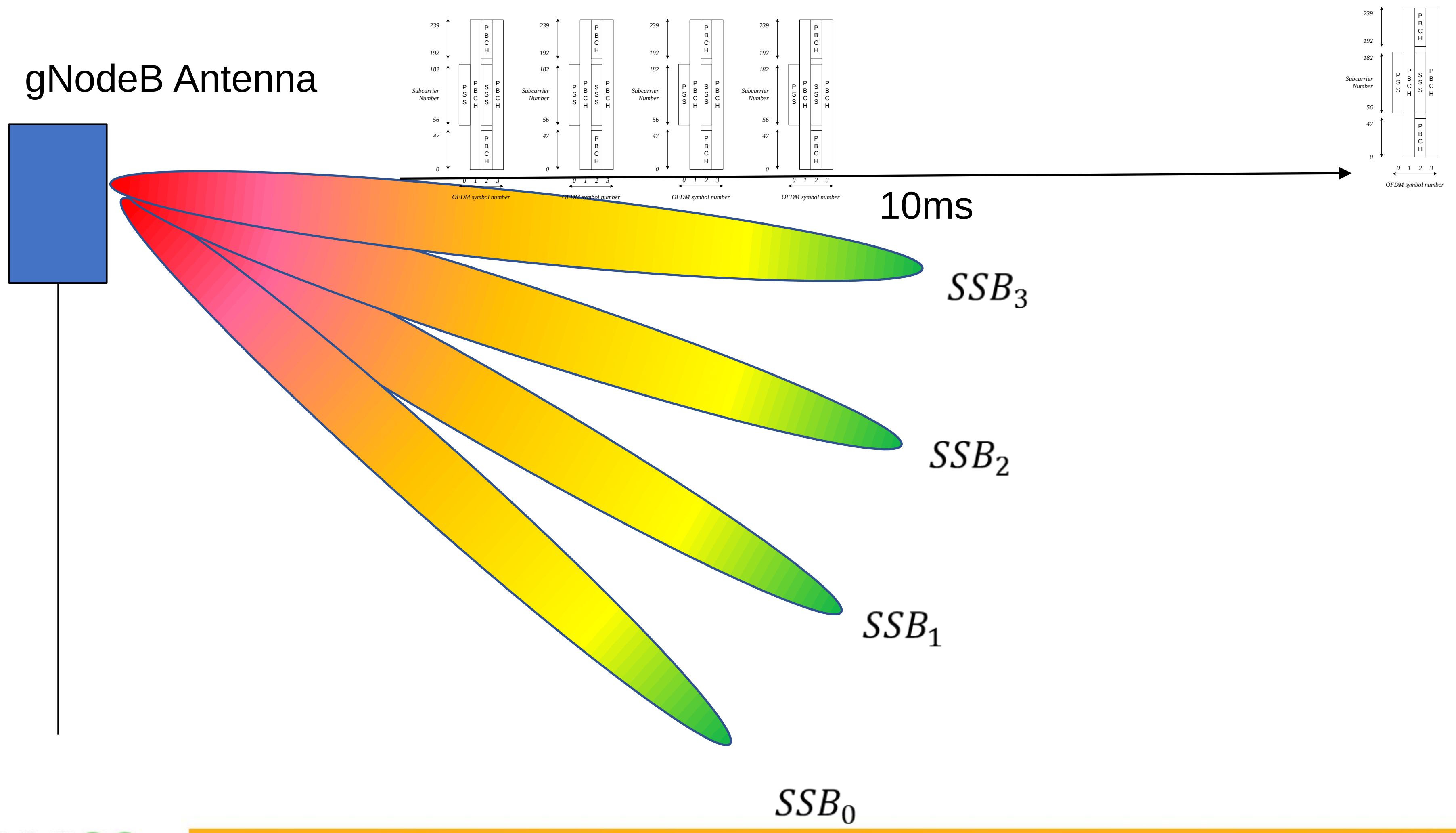
- Used in standalone and non-standalone
- Usually coincides with the initial BWP
- A UE finds the gNodeB by detecting the "Synchronization" Channels
  - Primary synchronization (PSS) channel gives initial timing and frequency measurements
  - Secondary synchronization (SSS) channel gives additional frequency measurements and carries a small payload which conveys the "physical cell identifier"
- Once timing/frequency/cell id are hypothesized
  - Detection of PBCH => first real amount of System Information (MIB) for the network (a piece of the particular gNB configuration in standalone mode, just time information frame/slot in non-standalone)

SSB allocations



- Contains 4 signals
  - PSS,SSS, PBCH, PBCH DMRS
  - Over 4 symbols
  - 240 resource elements (20 PRBs)
- This occurs in particular symbols in the first few slots of the first half-frame and repeats each frame
  - Each SSB is mapped to a particular beam index
  - A UE will try to measure multiple SSBs

SSB Beams and Time multiplexing



SSB Beams and Time multiplexing (2)

- UE determines the strongest SSB index (Beam) and camps on it, while doing measurements of the other ones in case beam pattern changes because of mobility or another reason
- SSB index is used later for transmission of the first uplink message to connect to the gNodeB (PRACH, later)

Physical Broadcast Channel (PBCH)

- The PBCH carries the MIB (24 bits), the first RRC protocol unit, called the **Master Information Block**, and some other dedicated bits for the PHY layer
- It is coded using
  - a binary polar code + rate-matching
  - 32-bit payload + 24-bit CRC

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System Information

- This is used only in Standalone operation
  - Non-standalone provides the full NR radio configuration via LTE link and can skip this step
  - In Standalone, UE has to receive radio configuration messages over NR link, in addition to the necessary protocol information
- System information (SIB1) uses 2 types of DL transmission
  - Physical Downlink Control Channel (PDCCH) carrying DCI (downlink control information)
  - Physical Downlink Shared Channel (PDSCH) carrying payload
- Initially, this information is conveyed over a special allocation before cell-specific information is known (it is in the payload of the first and only necessary one, SIB1
  - the allocation depends on parameters in the MIB which define
    - "Coreset0" which defines the resources of the PDCCH (starting PRB and length of PDCCH in PRBs and number of symbols, based on a lookup table)
  - The DCI contents define the allocation of SIB1

PDCCH

- This is a special signaling channel which provides
  - Scheduling information for DL traffic and signaling (PDSCH)
  - Scheduling information for UL traffic and signaling (PUSCH)
  - Power-control information
  - RAN and 5GC Paging-related information

Scheduling process (gNB perspective)

- Determine which UEs should be granted resources on the uplink (based on information from SRS and queuing feedback) and what resources to grant
- Determine which UEs should be granted resources on the downlink (based on CQI, RI, and local queuing information)
- Identify common control channel messages for format 2-x (TPC)
- For each message decide on PDCCH format (1,2,4 or 8, 16 CCEs), and any power offset to be applied
- Determine how much PDCCH resources (in terms of CCEs) will be required, how many OFDM symbols would be needed for these PDCCHs
- If any PDCCH cannot be mapped to a CCE location (no more room)
  - Increase OFDM symbol count for PDCCH (if possible)
  - Drop some DLSCH allocations (lowest priority)
- Allocate resources to PDCCHs
- Check powers
- Transmit

Outline

Scientific Large-scale Infrastructure for Computing Communication Experimental Studies

Starting Communities

Thank you

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