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Advanced Wireless & 5G Networks

Prof. Dr. Ir. Michael Peeters — 2023–2024

Topics for today

- **3. From 2 to 5G**
  - We jump 2 generations.

Planning

Session	Date	Topic
1	20231006	~~Introduction, history, market, industry, bands, licensed vs. unlicensed, …~~
2	20231013	~~Technology baselining (a.k.a. refreshing what you should have known): 2G, WiFi, …~~
	20231020	~~Cancelled~~
3	20231027	~~Shannon/Friis continued. 2G as a ”low-complexity” example~~
4	~~20231110~~	~~L 2G~~
~~5~~	~~20231117~~	~~L 3GPP 2G-3G-4G-5G architecture evolution. 5G~~
~~6~~	~~20231124~~	~~L 5G~~
7	20231201-08 (ill)	L 5G
8	**20231215 – 3h**	U IEEE Wifi Network Architecture: 802.11 abgn
9	**20231222 – 2h + 3h (extra session)**	U QoS, 802.11 ac,ax and 802.11 ad,ay short range 802.15.4: Zigbee, BLE, and UWB
10.5		U Specials: LoRa, Sigfox (perhaps), proprietary, 802.11p
(12)	TBD	Extra: Technology enablers and acronyms you need to be aware of: ADC, FEM, PA, LSA, and other key analog and digital HW blocks, mMIMO, Beam management, 802.11be, AI, 6G, THz and their implications to the network

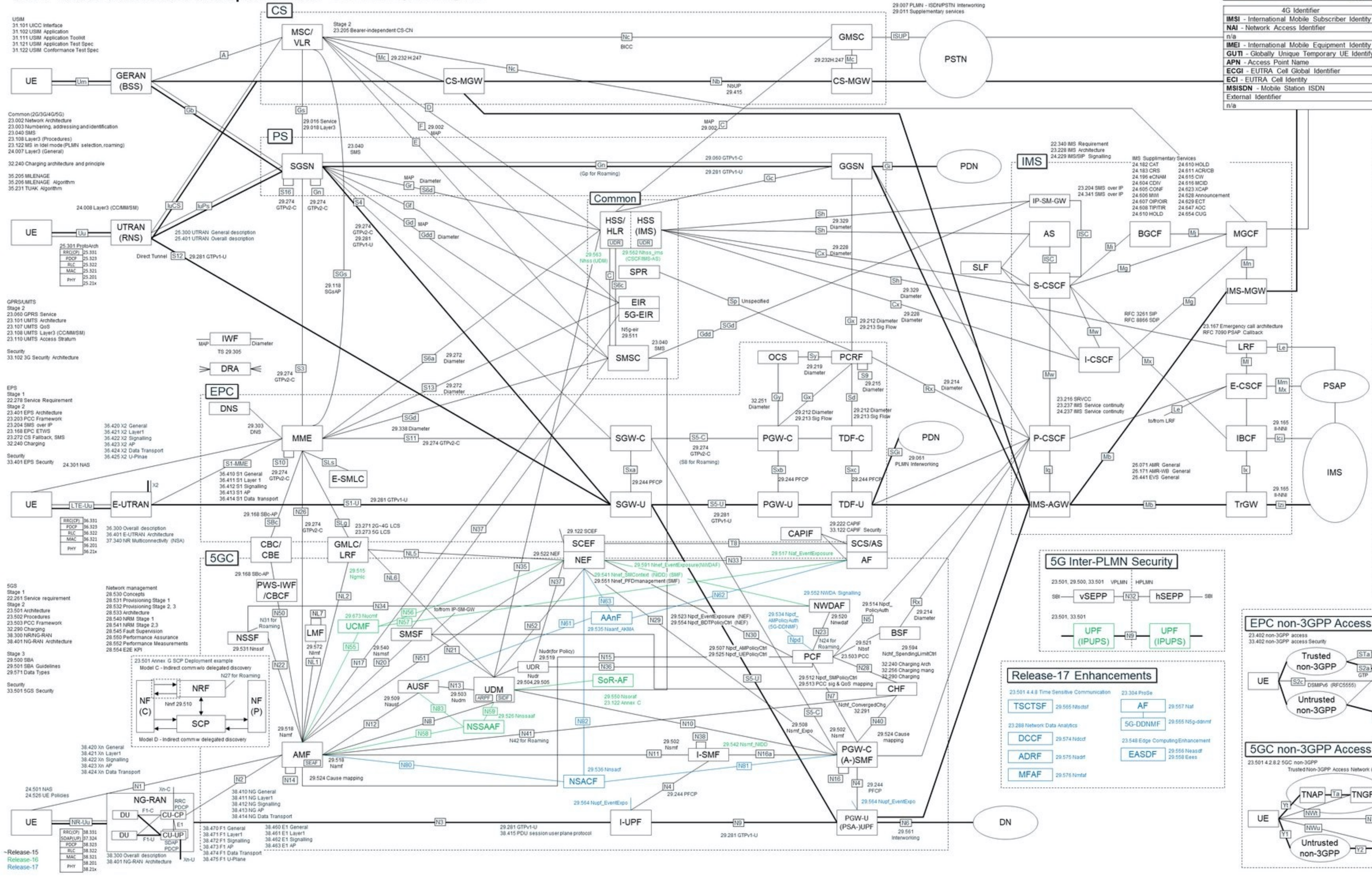
Your expectations

- How it is possible that, in a world where the number of devices continue to grow, every device can get mobile wireless connectivity with the internet without saturating the network.
- ~~How do 4G/5G/… technologies actually work.~~
- How do you go about designing a good WiFi network, both on the physical end (devices, access point locations, …) and on the configuration end.
- What are the technologies behind the current advancement in Cellular and Wi-Fi networks?
- Be able to understand the need for improved and efficient networking technologies, and how to approach solving the drawbacks of current technologies.
- What are the limitations of 5G in regard to the latest trends in Ai, AR/VR and technologies that require very low latency.
- What is next?
- Wifi 6 & 7 – new features.
- Link to cloud.
- ~~How do modern mobile networks work and how have they changed from the previous ones?~~
- What are the main problems or limitations faced by different types of networks? If it is possible, what are the best ways to solve them?
- How will wireless and mobile networks possibly evolve in the near future?
- ~~To better understand historical challenges in wireless that companies such as blackberry faced.~~
- To better understand wireless technologies such as Zigbee and LoRaWan and their use in IOT projects.
- What role data science could have in this field?
- Can networks be perfected to the point where we don't need to keep on creating new ones or upgrade the existing ones?
- ~~Can governments stop the development of networks?~~
- ~~Will connectivity ever be available underwater or underground?~~
- Security of wireless networks.

3. 2G to 5G

(concepts & toy examples)

3GPP Overall Architecture and Specifications



4G and 5G Identifier mapping

4G Identifier	5G Identifier
IMSI - International Mobile Subscriber Identity	**SUPI** - Subscription Permanent Identifier
NAI - Network Access Identifier	**SUPI** - Subscription Permanent Identifier
n/a	**SUCI** - Subscription Concealed Identifier
IMEI - International Mobile Equipment Identity	**PEI** - Permanent Equipment Identifier
GUTI - Globally Unique Temporary UE Identify	**5G-GUTI** - 5G Globally Unique Temporary UE Identify
APN - Access Point Name	**DNN** - Data Network Name
ECGI - EUTRA Cell Global Identifier	**NCGI** - NR Cell Global Identity
ECI - EUTRA Cell Identity	**NCI** - NR Cell Identity
MSISDN - Mobile Station ISDN	**GPSI** - Generic Public Subscription Identifier
External Identifier	**GPSI** - Generic Public Subscription Identifier
n/a	**S-NSSAI** - Single-Network Slice Selection Assistance Information

5G Network Function Abbreviations

Release-15

5G-EIR - 5G-Equipment Identity Register
AAnF - AKMA(Authentication and Key Management for Applications) Anchor Function
AF - Application Function
AMF - Access and Mobility Management Function
AUSF - Authentication Server Function
ARPF - Authentication credential Repository and Processing Function
BSF - Binding Support Function
CAPIF - Common API Framework for 3GPP northbound APIs
CHF - Charging Function
I-SMF - Intermediate SMF
I-UPF - Intermediate UPF
LMF - Location Management Function
LRF - Location Retrieval Function
N3IWF - Non-3GPP InterWorking Function
NEF - Network Exposure Function
NRF - Network Repository Function
NSSF - Network Slice Selection Function
NWDAF - Network Data Analytics Function
PCF - Policy Control Function
SCP - Service Communication Proxy
SEAF - SEcurity Anchor Function.
SEPP - Security Edge Protection Proxy
SIDF - Subscription Identifier De-concealing Function;
SMF - Session Management Function
SMSF - Short Message Service Function
TNAP - Trusted Non-3GPP Access Point
TNGF - Trusted Non-3GPP Gateway Function
TWIF - Trusted WLAN Interworking Function
UDM - Unified Data Management
UDR - Unified Data Repository
UDSF - Unstructured Data Storage Function
UPF - User Plane Function

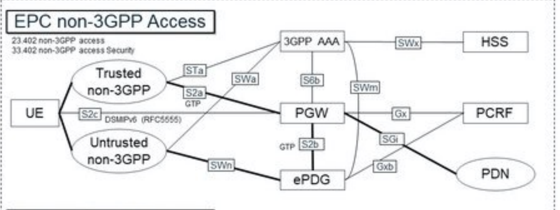
Release-16

IPUPS - Inter PLMN UP Security
NSSAAF - Network Slice-specific and SNPN Authentication and Authorization Function
UCMF - UE radio Capability Management Function
SoR-AF – Steering of Roaming Application Function

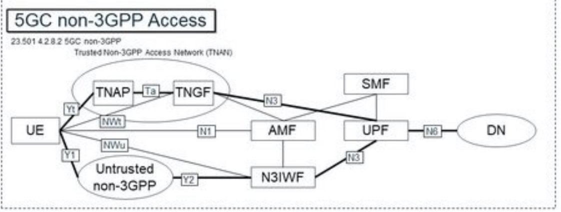
Release-17

5G DDNMF - 5G Direct Discovery Name Management Function
ADRF - Analytics Data Repository Function
MFAF - Messaging Framework Adaptor Function
DCCF - Data Collection Coordination Function
NSACF - Network Slice Admission Control Function
TSCTSF - Time Sensitive Communication and Time Synchronization function

EPC non-3GPP Access



5GC non-3GPP Access



What are the steps?

1. Switch on the mobile (& infrastructure)
2. Select a frequency band to receive & send
3. Pick a way to send and receive digital bits
4. Define how we are going to organize the bits for multiple users
5. Listen to synchronize and get system information
6. Random Access
7. Get a channel
8. Authenticate
9. Ask to send data (or get some data)
10. Ask to make a call
11. Move around
12. … (location update, release call, handover, etc …)

But what is the infrastructure?

- **Due to the time it took to standardize 5G, and the expectation of the market, the industry decide to take this in two steps:**
  1. Standardize a new RAN with an new air interface, **“New Radio” (NR),** and make sure it can work with the existing 4G core. This is called **Non-Stand-Alone (NSA)** as the 5G still needs a 4G network to get its act together. This is what most operators call 5G today.
  2. Standardize a new CORE that incorporates all of the new ideas of modern infrastructure, **5G Core network (5GC),** which is completely based on what is called a **Service-Based Architecture** (SBA), which implements IT network principles and a cloud-native design approach. **This is 5G Stand-Alone (SA).**
- **This however does mean we need to understand some 4G to talk about 5G… @#%&$(!!!**

What are the steps?

1. Switch on the mobile (& infrastructure)
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What are the steps?

1. ~~Switch on the mobile (& infrastructure)~~
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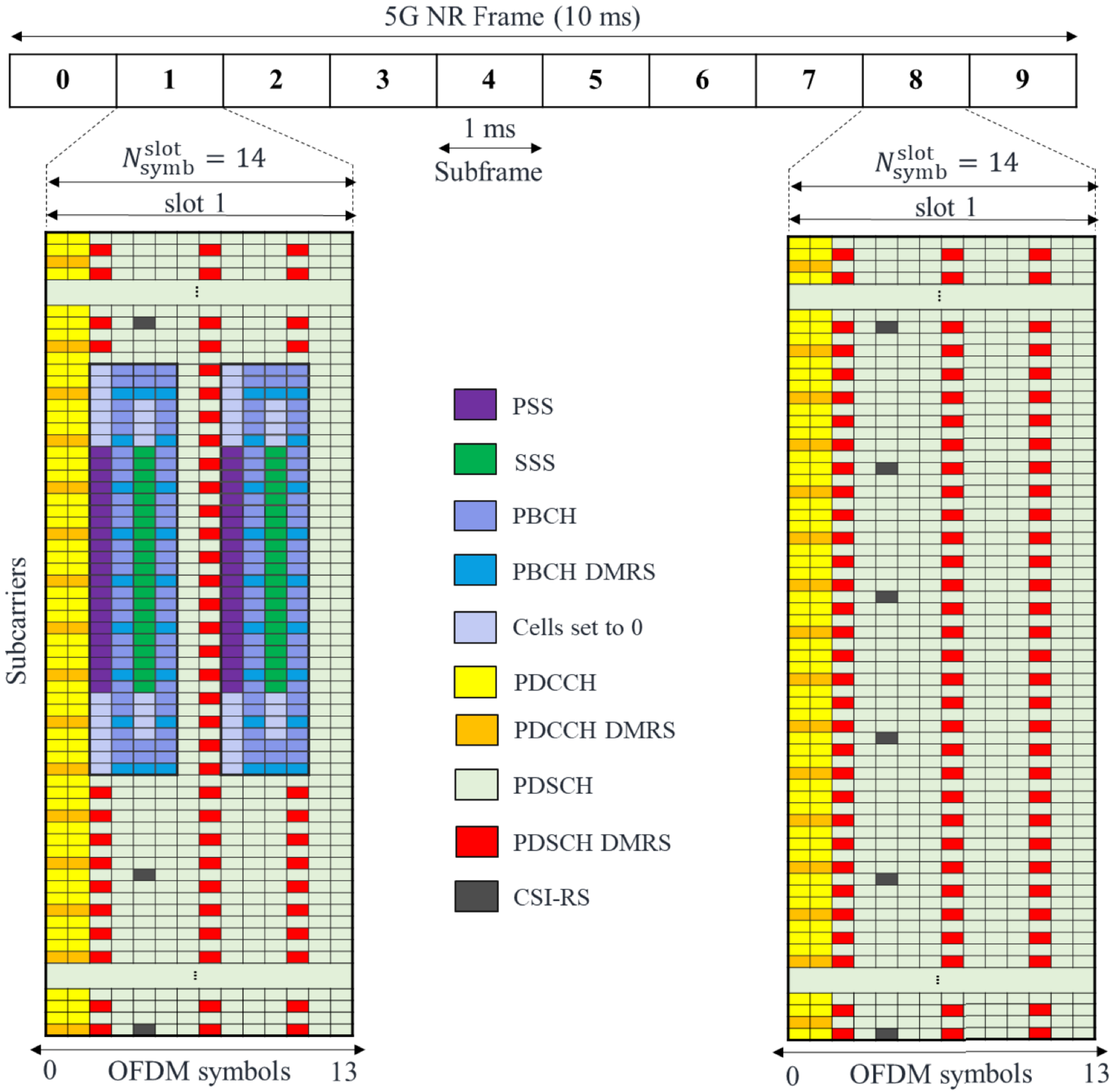
11. Move around
12. … (location update, release call, handover, etc …)

We create a time-frequency grid (like in GSM)

And we can distribute this to every user at the same time.



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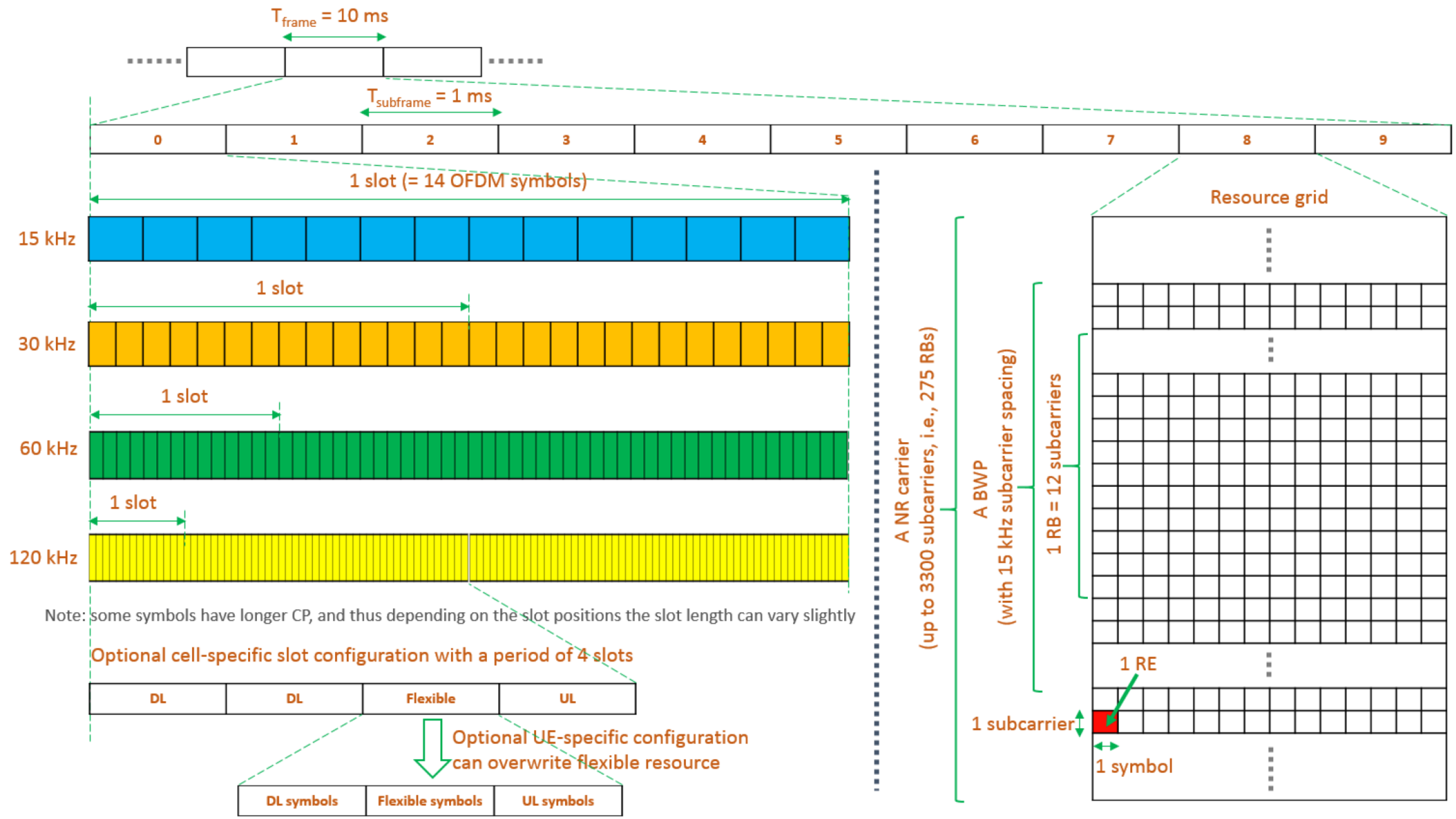
https://www.sharetechnote.com/html/5G/5G_FrameStructure.html

5G time-frequency grid

μ	Δ_f (kHz)	FR1	FR2	T_S (μs)	T_{CP} (μs)	$T_S + T_{CP}$ (μs)	N_{Slot}^{Frame}	T_{Slot} (ms)
0	15	✓	x	66.67	4.69	71.35	10	1
1	30	✓	x	33.33	2.34	35.68	20	0.5
2	60	✓	✓	16.67	1.17	17.84	40	0.25
3	120	x	✓	8.33	0.57	8.92	80	0.125
4	240	x	✓	4.17	0.29	4.46	160	0.0625



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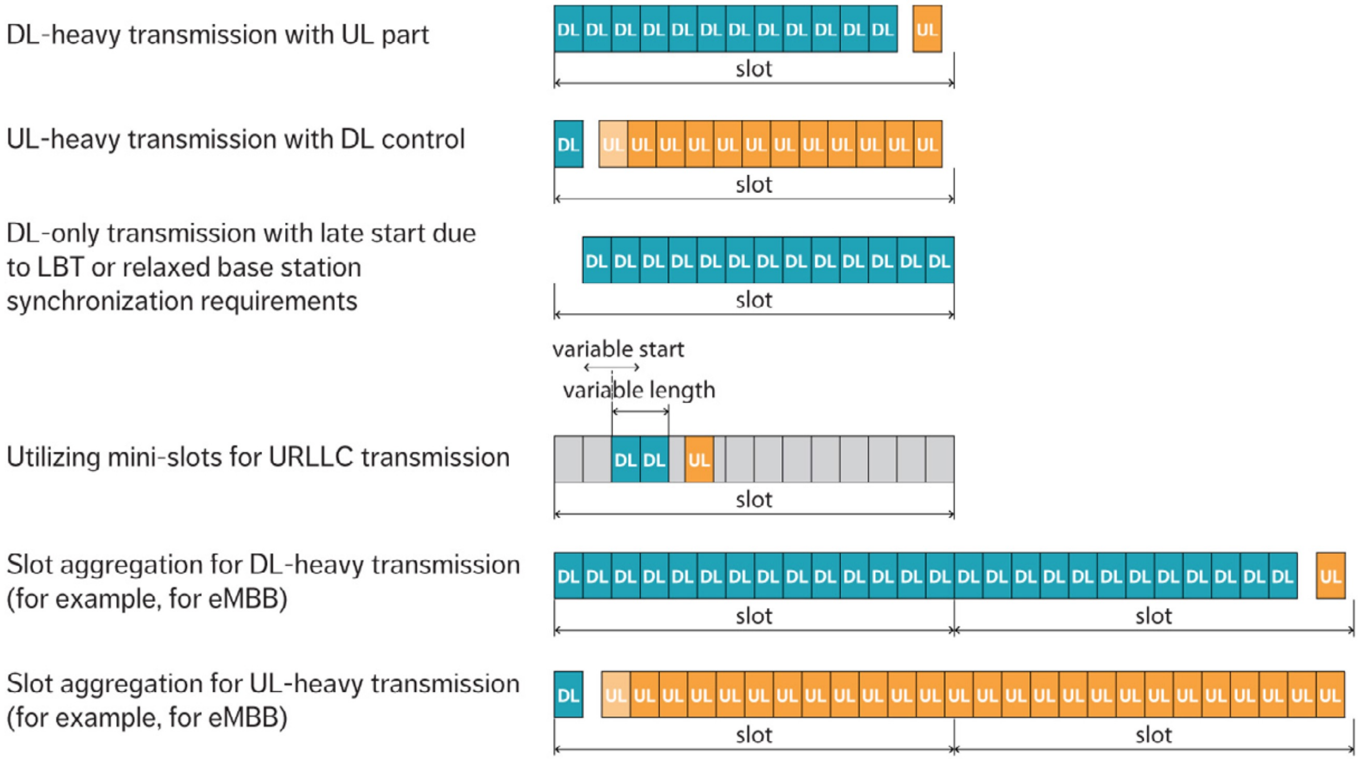
https://www.ericsson.com/49e9d0/assets/local/reports-papers/ericsson-technology-review/docs/2017/designing-for-the-future---the-5g-nr-physical-layer.pdf

5G slot types = flexibility



LBT=listen-before-talk for operation in unlicensed (wifi) spectrum

<38.213 v15.7 -Table 11.1.1-1: Slot formats for normal cyclic prefix>
D : Downlink, U : Uplink, F : Flexible

FDD

Format	Symbol Number in a slot													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	D	D	D	D	D	D	D	D	D	D	D	D	D	D
1	U	U	U	U	U	U	U	U	U	U	U	U	U	U
2	F	F	F	F	F	F	F	F	F	F	F	F	F	F
3	D	D	D	D	D	D	D	D	D	D	D	D	D	F
4	D	D	D	D	D	D	D	D	D	D	D	D	F	F
5	D	D	D	D	D	D	D	D	D	D	D	F	F	F
6	D	D	D	D	D	D	D	D	D	D	F	F	F	F
7	D	D	D	D	D	D	D	D	D	F	F	F	F	F
8	F	F	F	F	F	F	F	F	F	F	F	F	F	U
9	F	F	F	F	F	F	F	F	F	F	F	F	U	U
10	F	U	U	U	U	U	U	U	U	U	U	U	U	U
11	F	F	U	U	U	U	U	U	U	U	U	U	U	U
12	F	F	F	U	U	U	U	U	U	U	U	U	U	U
13	F	F	F	F	U	U	U	U	U	U	U	U	U	U
14	F	F	F	F	F	U	U	U	U	U	U	U	U	U
15	F	F	F	F	F	F	U	U	U	U	U	U	U	U
16	D	F	F	F	F	F	F	F	F	F	F	F	F	F
17	D	D	F	F	F	F	F	F	F	F	F	F	F	F
18	D	D	D	F	F	F	F	F	F	F	F	F	F	F
19	D	F	F	F	F	F	F	F	F	F	F	F	F	U
20	D	D	F	F	F	F	F	F	F	F	F	F	F	U
21	D	D	D	F	F	F	F	F	F	F	F	F	F	U
22	D	F	F	F	F	F	F	F	F	F	F	F	U	U
23	D	D	F	F	F	F	F	F	F	F	F	F	U	U
24	D	D	D	F	F	F	F	F	F	F	F	F	U	U
25	D	F	F	F	F	F	F	F	F	F	F	U	U	U
26	D	D	F	F	F	F	F	F	F	F	F	U	U	U
27	D	D	D	F	F	F	F	F	F	F	F	U	U	U
28	D	D	D	D	D	D	D	D	D	D	D	D	F	U
29	D	D	D	D	D	D	D	D	D	D	D	F	F	U
30	D	D	D	D	D	D	D	D	D	D	F	F	F	U
31	D	D	D	D	D	D	D	D	D	D	D	F	U	U
32	D	D	D	D	D	D	D	D	D	D	F	F	U	U
33	D	D	D	D	D	D	D	D	D	F	F	F	U	U
34	D	F	U	U	U	U	U	U	U	U	U	U	U	U
35	D	D	F	U	U	U	U	U	U	U	U	U	U	U
36	D	D	D	F	U	U	U	U	U	U	U	U	U	U
37	D	F	F	U	U	U	U	U	U	U	U	U	U	U
38	D	D	F	F	U	U	U	U	U	U	U	U	U	U
39	D	D	D	F	F	U	U	U	U	U	U	U	U	U
40	D	F	F	F	U	U	U	U	U	U	U	U	U	U
41	D	D	F	F	F	U	U	U	U	U	U	U	U	U
42	D	D	D	F	F	F	U	U	U	U	U	U	U	U
43	D	D	D	D	D	D	D	D	D	F	F	F	F	U
44	D	D	D	D	D	D	F	F	F	F	F	F	U	U
45	D	D	D	D	D	D	F	F	U	U	U	U	U	U
46	D	D	D	D	D	F	U	D	D	D	D	D	F	U

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3 types of channels

- **Physical Channels** : Define where is something transmitted over the air, e.g. first N symbols in the DL frame. Data and signalling messages are carried on physical channels between the different levels of the physical layer.
- **Logical Channels** : Define what type of information is transmitted over the air, e.g. traffic channels, control channels, system broadcast, etc. Data and signalling messages are carried on logical channels between the RLC and MAC protocols.

\+

- **Transport Channels** : Define how is something transmitted over the air, e.g. what are encoding, interleaving options used to transmit data. Data and signalling messages are carried on transport channels between the MAC and the physical layer.

Why so many?

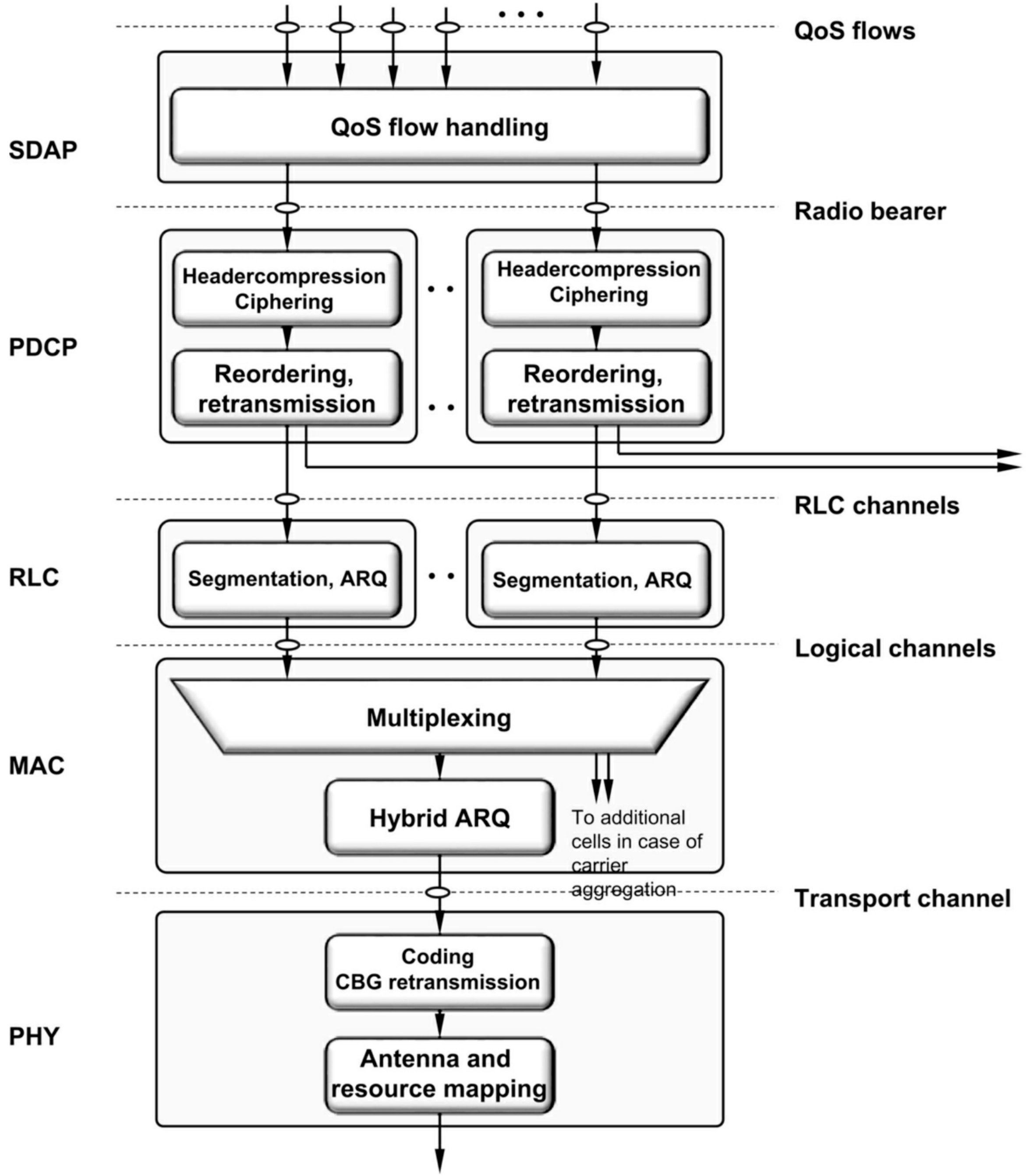
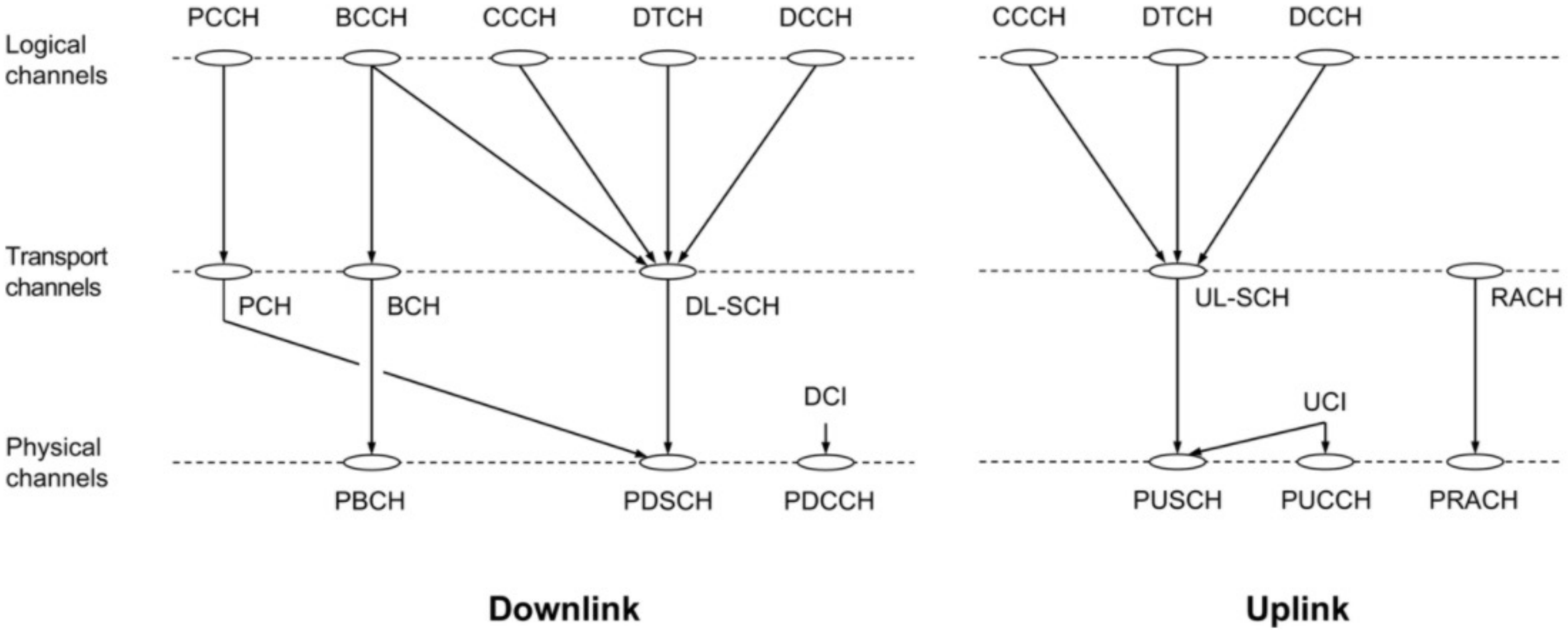


FIG. 6.7 NR downlink user-plane protocol architecture as seen from the device.

- Service Data Application Protocol (SDAP) is responsible for mapping QoS bearers to radio bearers according to their quality-of-service requirements. This protocol layer is not present in LTE but introduced in NR when connecting to the 5G core network due to the new quality-of-service handling.
- Packet Data Convergence Protocol (PDCP) performs IP header compression, ciphering, and integrity protection. It also handles retransmissions, in-sequence delivery, and duplicate removal3 in the case of handover. For dual connectivity with split bearers, PDCP can provide routing and duplication. Duplication and transmission from different cells can be used to provide diversity for services requiring very high reliability. There is one PDCP entity per radio bearer configured for a device.
- Radio-Link Control (RLC) is responsible for segmentation and retransmission handling. The RLC provides services to the PDCP in the form of RLC channels. There is one RLC entity per RLC channel (and hence per radio bearer) configured for a device. Compared to LTE, the NR RLC does not support in-sequence delivery of data to higher protocol layers, a change motivated by the reduced delays as discussed below.
- Medium-Access Control (MAC) handles multiplexing of logical channels, hybrid-ARQ retransmissions, and scheduling and scheduling-related functions. The scheduling functionality is located in the gNB for both uplink and downlink. The MAC provides services to the RLC in the form of logical channels. The header structure in the MAC layer has been changed in NR to allow for more efficient support of low-latency processing than in LTE.
- Physical Layer (PHY) handles coding/decoding, modulation/demodulation, multiantenna mapping, and other typical physical-layer functions. The physical layer offers services to the MAC layer in the form of transport channels.

Approach: physical, transport and logical channels

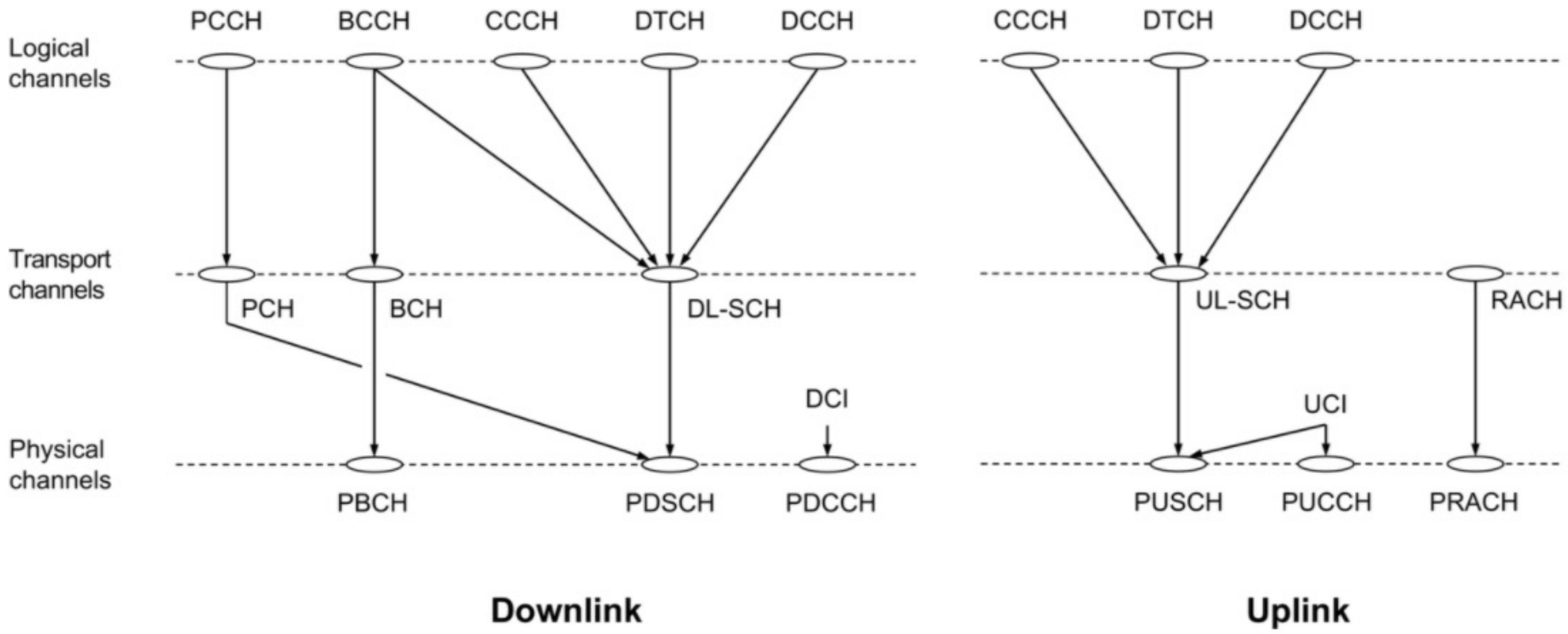


Note: same concept as in 2G, and almost identical to 4G

5G NR logical channels

- **Broadcast Control Channel, BCCH:** The BCCH is used within the downlink, and it is used for sending broadcast style information to the user equipments within that cell. The system information transmitted by the 5G NR BCCH is divided into different blocks:
  - Master Information Block, MIB: There is one MIB and this is mapped onto the BCH transport channel and then to the PBCH physical channel.
  - System Information Block, SIB: There are several system information blocks, SIBs. These are mapped onto the DL-SCH transport channel and then onto the PDSCH physical channel.
- **Paging Control Channel, PCCH**: This is only a downlink channel. It is used to page the UEs whose location at cell level is not known to the network. As a result the paging message needs to be transmitted in multiple cells. The PCCH is mapped to the PCH transport channel and then to the PDSCH physical channel.
- **Common Control Channel, CCCH:** This 5G channel is used on both the downlink and uplink for transmitting control information to and from the user equipments or mobiles. The channel is used for initial access, i.e. those mobiles that do not have a radio resource control, RRC connection.
- **Dedicated Control Channel, DCCH:** The DCCH is used within the uplink and downlink to carry dedicated control information between the UE or mobile and the network. It is used by the UE and the network after a radio resource control, RRC connection has been established.
- **Dedicated Traffic Channel, DTCH:** This 5G channel is present in both the uplink and downlink. It is dedicated to one UE and is used for carrying user information to and from a specific UE and the network.

Approach: physical, transport and logical channels

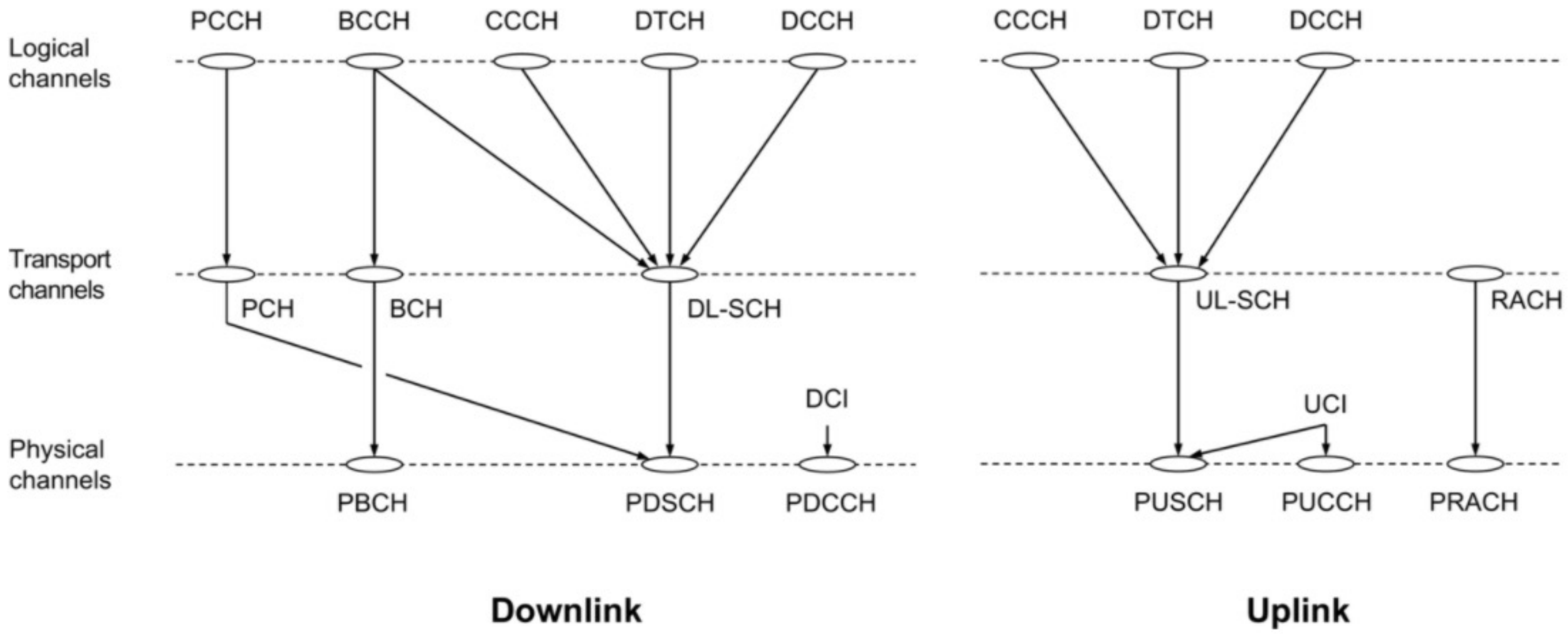


Note: same concept as in 2G, and almost identical to 4G

5G NR transport channels

- **Broadcast Channel, BCH:** The BCH 5G channel is used in the downlink only for transmitting the BCCH system information and specifically the Master Information Block, MIB, information. In order that the data can be utilised, it has a specific format.
- **Paging Channel, PCH:** The PCH is used for carrying paging information from the PCCH logical channel. The PCH supports discontinuous reception, DRX, to enable the UE to save battery power by waking up at a specific time to receive the PCH. In order that the PCH is received by all mobiles / UEs in the cell, the PCH must be broadcast over the entire cell as a single message, or where beam forming is used, this can be done using several different PCH instances.
- **Downlink Shared Channel, DL-SCH:** As the name indicates, this is a downlink only channel. It is the main transport channel used for transmitting downlink data and it supports all the key 5G NR features. These include: dynamic rate adaptation; HARQ, channel aware scheduling, and spatial multiplexing. The DL-SCH is also used for transmitting some parts of the BCCH system information, specifically the SIB. Each UE has a DL-SCH for each cell it is connected to.
- **Uplink Shared Channel, UL-SCH**: This is the uplink counterpart to the DLSCH that is, the uplink transport channel used for transmission of uplink data.
- **Random-Access Channel, RACH:** The RACH is a transport channel, which carries the random access preamble which is used to overcome the message collisions that can occur when UEs access the system simultaneously.

Approach: physical, transport and logical channels



Note: same concept as in 2G, and almost identical to 4G

5G NR physical channels - downlink

- **Physical downlink shared channel, PDSCH:** The 5G NR physical downlink shared channel, PDSCH carries data sharing the capacity on a time and frequency basis. The PDSCH physical channel carries a variety of items of data: user data; UE-specific higher layer control messages mapped down from higher channels; system information blocks (SIBs); & paging.
  - The PDSCH uses an adaptive modulation format dependent upon the link conditions, i.e. signal to noise ratio. It also uses a flexible coding scheme. The combination of these means that there is a flexible coding and data rate.
- **Physical downlink control channel, PDCCH:** As the name implies, the 5G physical downlink control channel carries downlink control data. Its primary function is scheduling the downlink transmissions on the PDSCH and also the uplink data transmissions on the PUSCH.
  - The PDCCH uses QPSK as its modulation format and polar coding as the coding scheme, except for small packets of data.
- **Physical broadcast channel, PBCH:** This 5G channel forms part of the synchronisation signal block. Its function is to provide UEs with the Master Information Block, MIB. A further function of the PBCH in conjunction with the control channel is to support the synchronisation of time and frequency. This aids with cell acquisition, selection and re-selection.
  - The PBCH uses a fixed data format and there is one block that extends over a TTI of 80 ms.
  - The PBCH uses QPSK modulation and it transmits a cell specific demodulation reference signal, DMRS pattern that can be used aid with beam-forming.

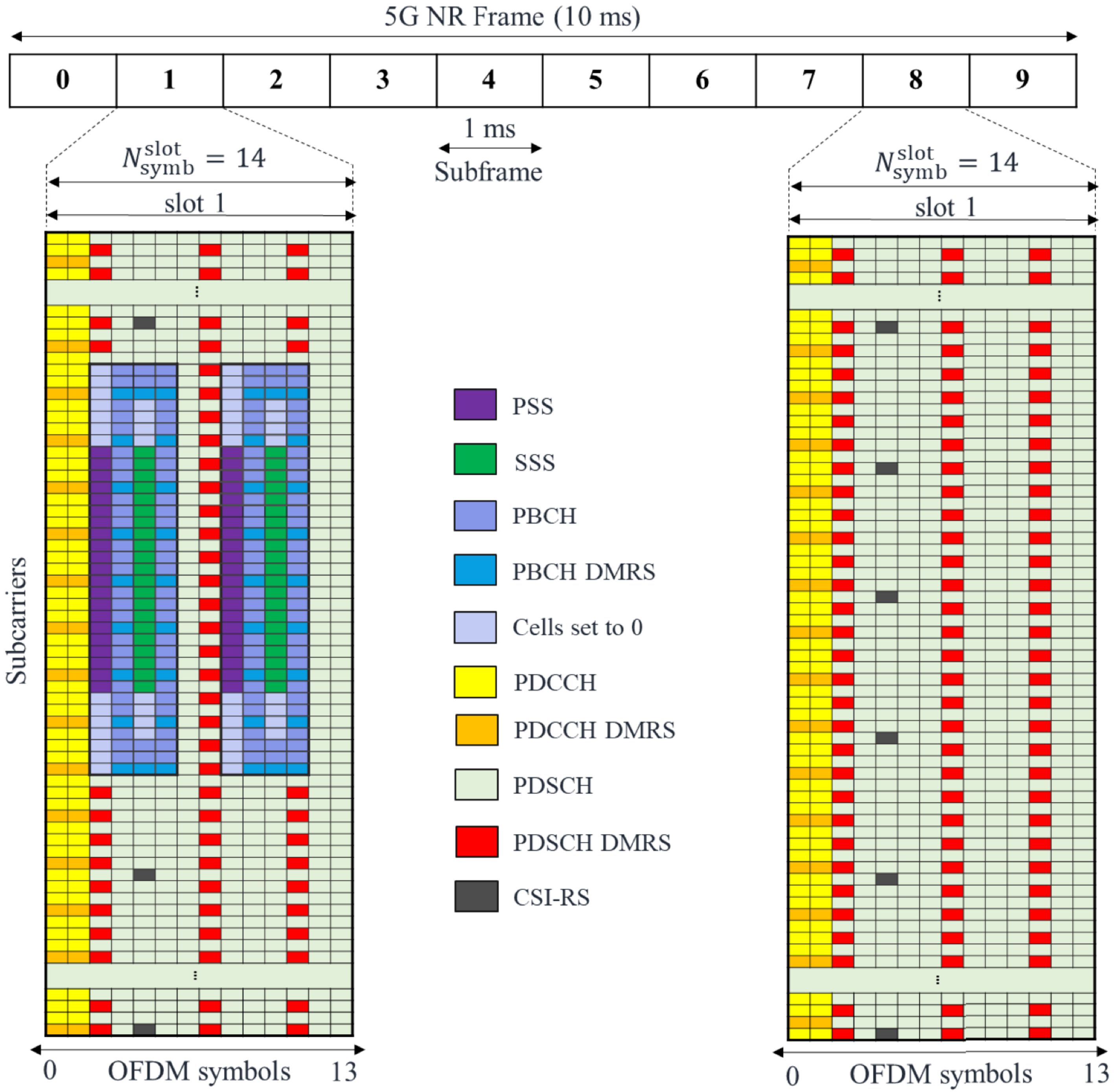
5G NR physical channels - uplink

- **Physical random access channel, PRACH:** This 5G channel - the physical random access channel, PRACH, is used for channel access. It transmits an initial random access pre-amble consisting of sequences which may be of two different lengths:
  - A long sequence is 839 which is applied to the subcarrier spacings of 1.25kHz and 5 kHz
  - Short sequence lengths of 139 are applied to subcarrier spacings of 15 kHz and 30 kHz (FR1 bands) and 60 kHz and 120 kHz (FR2 bands).
- **Physical uplink shared channel, PUSCH:** The 5G physical uplink shared channel, PUSCH, is the counterpart of the PDSCH. It is used to carry data from the UL-SCH and its higher mapped channels on a frequency and time-shared basis.
  - Like the PDSCH, The PUSCH also has a very flexible format. The allocation of frequency resources is undertaken using resource blocks along with a flexible modulation and coding scheme dependent upon the link signal to noise ratio.
  - To support the channel link estimation and demodulation, the PUSCH contains DMRS signals.
- **Physical uplink control channel, PUCCH:** The 5G physical uplink control channel, PUCCH, carries the uplink control data. It is also possible that dependent upon the resource allocation the uplink control information or data may also be sent on the PUSCH, even though in the downlink direction, control information is always sent on the PDCCH.

We create a time-frequency grid: NR frame structure

Visualize:
https://www.sqimway.com/nr_frame.php

Actually, the entire site is pretty good.

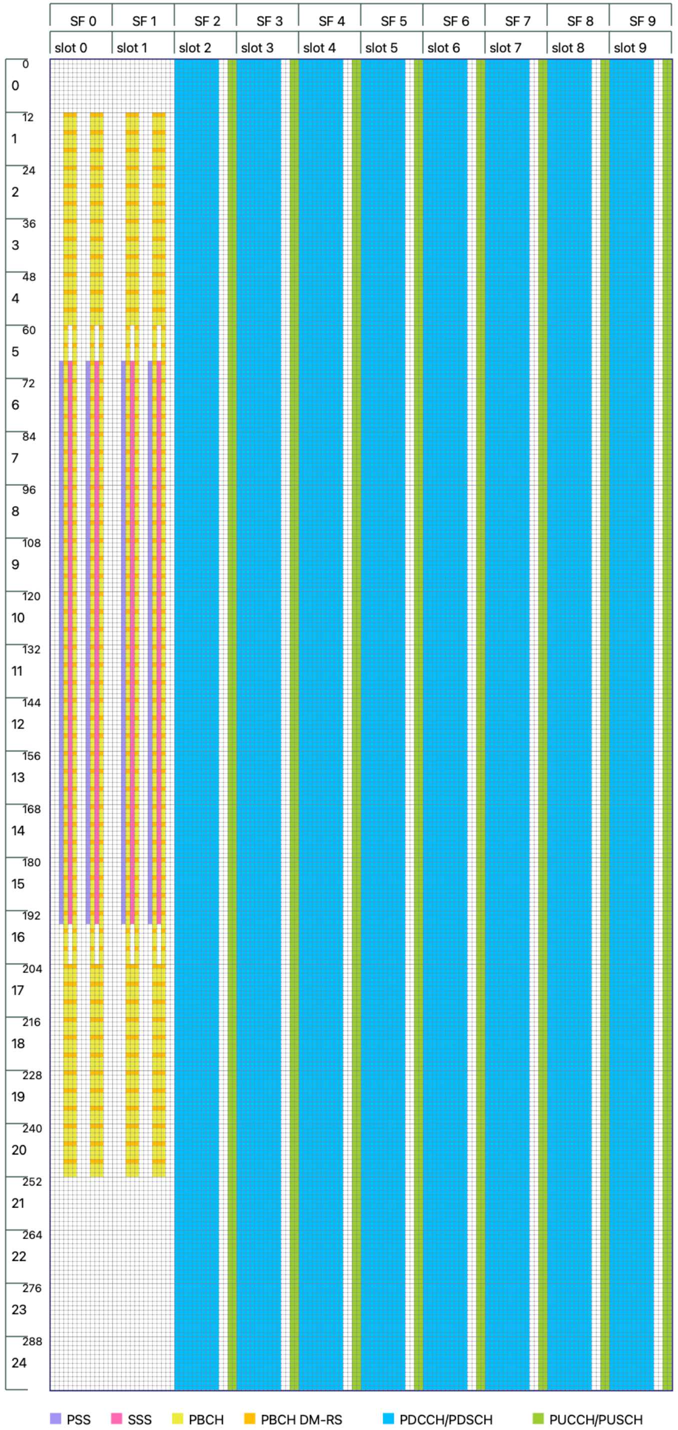


5G NR, ”4G-like”:
5 MHz TDD in 700MHz

Frequency band = n67
PDCCH subcarrier spacing = 15 KHz
SS/PBCH subcarrier spacing = 15 KHz -- pattern A
Bandwidth = 5 MHz
NRB max = 25
Slot format = 32

<38.213 v15.7 -Table 11.1.1-1: Slot formats for normal cyclic prefix>
D : Downlink, U : Uplink, F : Flexible

Format	Symbol Number in a slot													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	D	D	D	D	D	D	D	D	D	D	D	D	D	D
1	U	U	U	U	U	U	U	U	U	U	U	U	U	U
2	F	F	F	F	F	F	F	F	F	F	F	F	F	F
3	D	D	D	D	D	D	D	D	D	D	D	D	D	F
4	D	D	D	D	D	D	D	D	D	D	D	D	F	F
5	D	D	D	D	D	D	D	D	D	D	D	F	F	F
6	D	D	D	D	D	D	D	D	D	D	F	F	F	F
7	D	D	D	D	D	D	D	D	D	F	F	F	F	F
8	F	F	F	F	F	F	F	F	F	F	F	F	F	U
9	F	F	F	F	F	F	F	F	F	F	F	F	U	U
10	F	U	U	U	U	U	U	U	U	U	U	U	U	U
11	F	F	U	U	U	U	U	U	U	U	U	U	U	U
12	F	F	F	U	U	U	U	U	U	U	U	U	U	U
13	F	F	F	F	U	U	U	U	U	U	U	U	U	U
14	F	F	F	F	F	U	U	U	U	U	U	U	U	U
15	F	F	F	F	F	F	U	U	U	U	U	U	U	U
16	D	F	F	F	F	F	F	F	F	F	F	F	F	F
17	D	D	F	F	F	F	F	F	F	F	F	F	F	F
18	D	D	D	F	F	F	F	F	F	F	F	F	F	F
19	D	F	F	F	F	F	F	F	F	F	F	F	F	U
20	D	D	F	F	F	F	F	F	F	F	F	F	F	U
21	D	D	D	F	F	F	F	F	F	F	F	F	F	U
22	D	F	F	F	F	F	F	F	F	F	F	F	U	U
23	D	D	F	F	F	F	F	F	F	F	F	F	U	U
24	D	D	D	F	F	F	F	F	F	F	F	F	U	U
25	D	F	F	F	F	F	F	F	F	F	F	U	U	U
26	D	D	F	F	F	F	F	F	F	F	F	U	U	U
27	D	D	D	F	F	F	F	F	F	F	F	U	U	U
28	D	D	D	D	D	D	D	D	D	D	D	D	F	U
29	D	D	D	D	D	D	D	D	D	D	D	F	F	U
30	D	D	D	D	D	D	D	D	D	D	F	F	F	U
31	D	D	D	D	D	D	D	D	D	D	D	F	U	U
32	D	D	D	D	D	D	D	D	D	D	F	F	U	U
33	D	D	D	D	D	D	D	D	D	F	F	F	U	U
34	D	F	U	U	U	U	U	U	U	U	U	U	U	U



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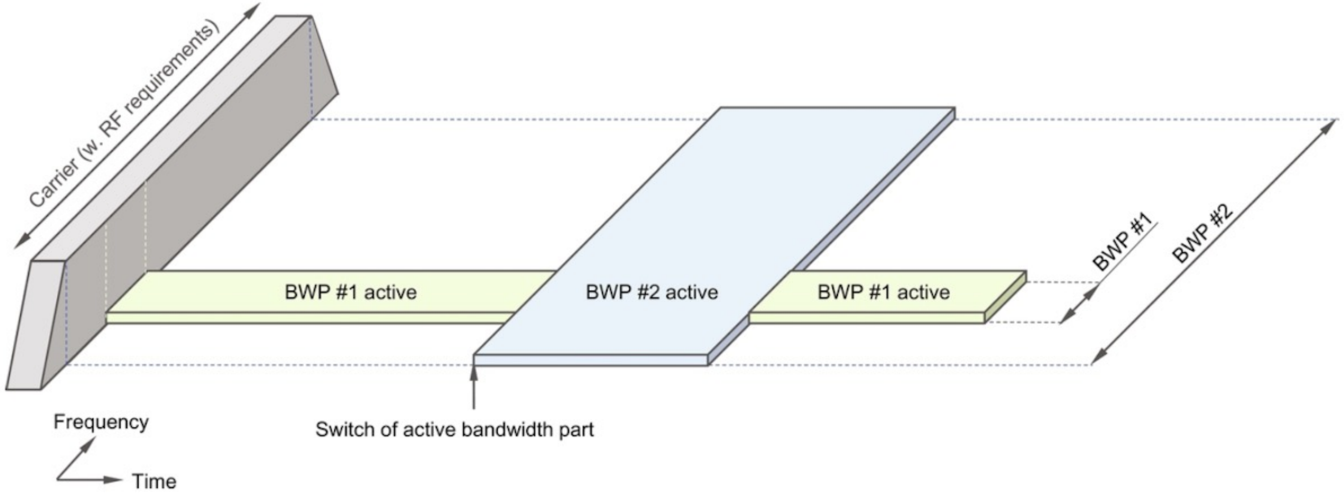
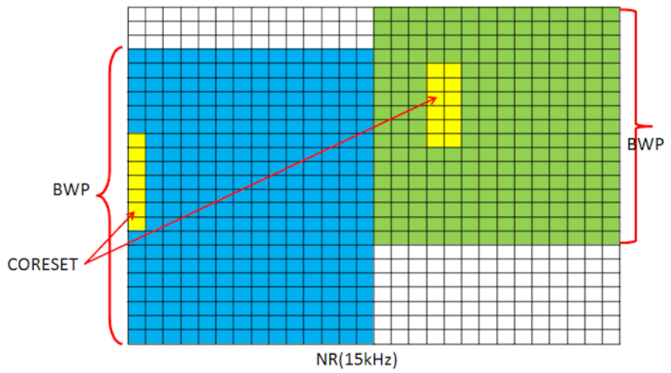
Bandwidth Part

- 4G assumed all devices being able to receive **the full carrier bandwidth.**
- This is not reasonable for 5G NR, given the very wide carrier bandwidth supported. Furthermore, reception of a very wide bandwidth can be costly in terms of device **energy consumption** compared to receiving a narrower bandwidth.
- 5G has use receiver-bandwidth adaptation such that the device can use a narrower bandwidth for monitoring control channels and to receive small-to-medium-sized data transmissions and to open the full bandwidth when a large amount of data is scheduled. To handle these two aspects—support for devices not capable of receiving the full carrier bandwidth and receiver-side bandwidth adaptation— **NR defines bandwidth parts (BWPs)**

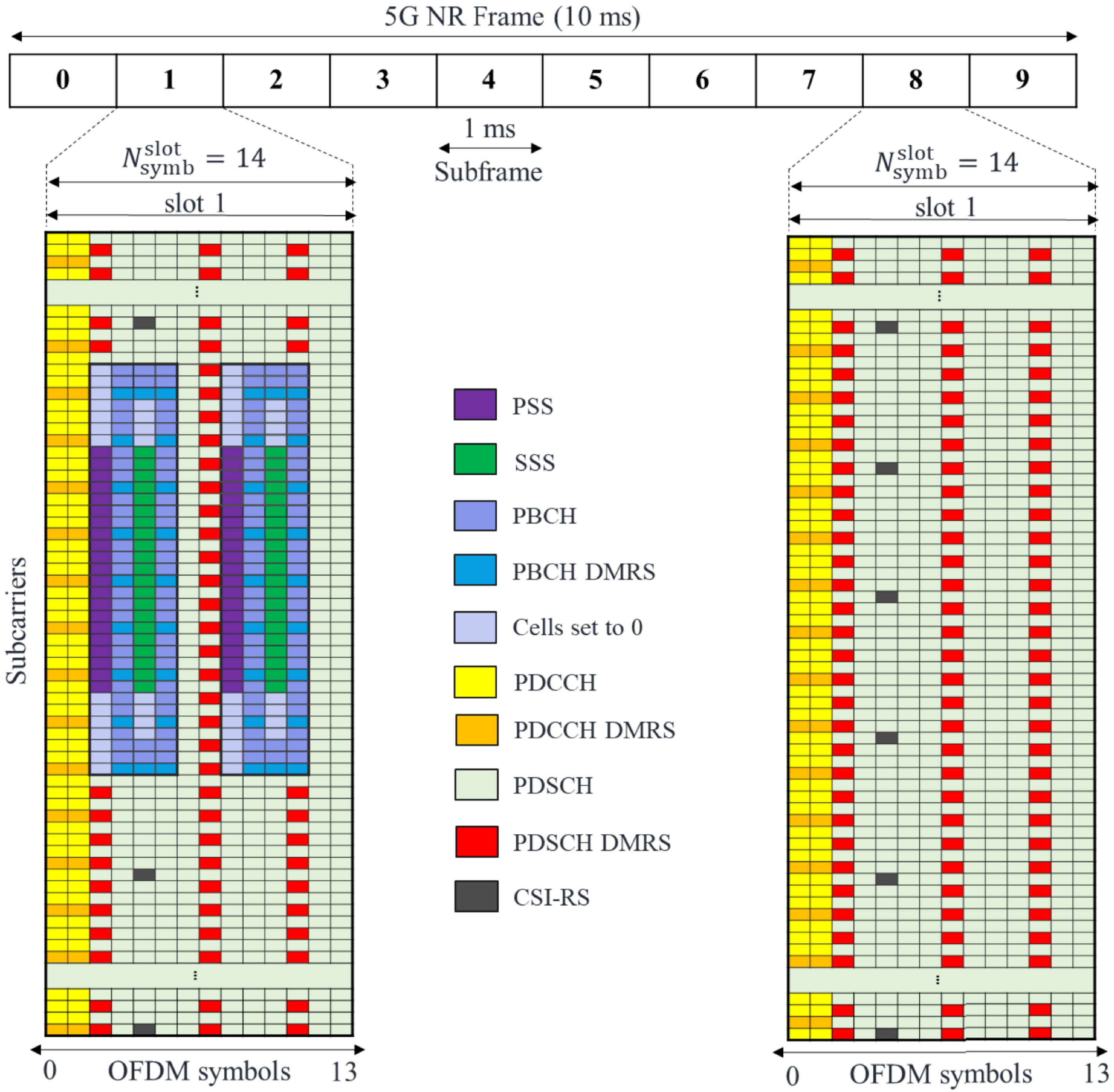


Time-Frequency Grid & CORESET

CORESET
The set of physical resources that is time frequency resource in which device tries to decode candidate control channels using one or more search spaces is called as the control resource set (CORESET).



Note: BWP enables multiplexing of different services on a given carrier. In Above example two BWP shown for 15kHz Numerology. Coreset Size and position depends on as per configuration.

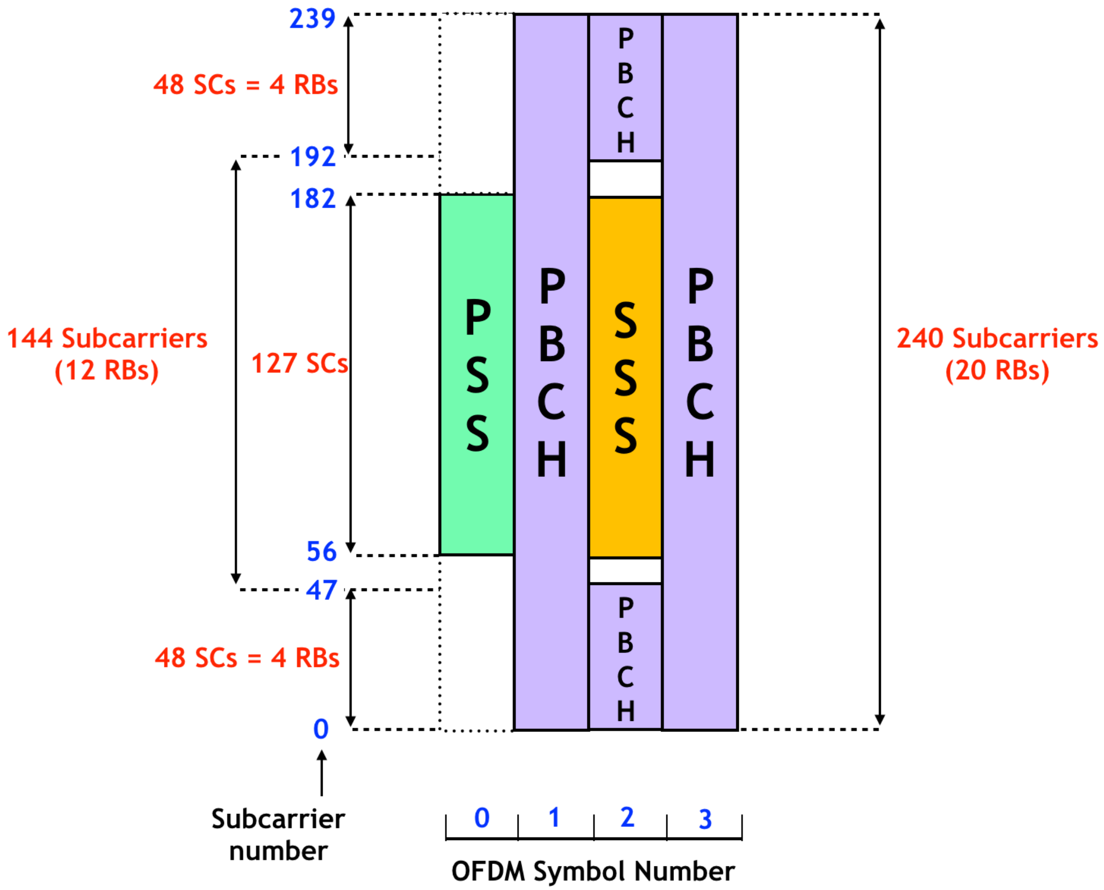


What are the steps?

1. ~~Switch on the mobile (& infrastructure)~~
2. ~~Select a frequency band to receive & send~~
3. ~~Pick a way to send and receive digital bits~~
4. ~~Define how we are going to organize the bits for multiple users~~
5. Listen to synchronize and get system information
6. Random Access
7. Get a channel
8. Authenticate
9. Ask to send data (or get some data)
10. Ask to make a call
11. Move around
12. … (location update, release call, handover, etc …)

Synchronization

- **The Synchronization Signal Block (SSB)**
  - Cell search is the procedure for a UE to acquire time and frequency synchronization with a cell and to detect Physical layer Cell ID (PCI) of the cell.
  - During cell search operations which are carried out when a UE is powered ON, mobility in connected mode, idle mode mobility (e.g. reselections), inter-RAT mobility to NR system etc., the UE uses NR synchronization signals and PBCH to derive the necessary information required to access the cell.
  - Similar to LTE, two types of synchronization signals are defined for NR; Primary Synchronization Signal (PSS) and the Secondary Synchronization Signal (SSS). The Synchronization Signal/PBCH block (SSB) consists of PSS, SSS and Physical Broadcast Channel (PBCH).

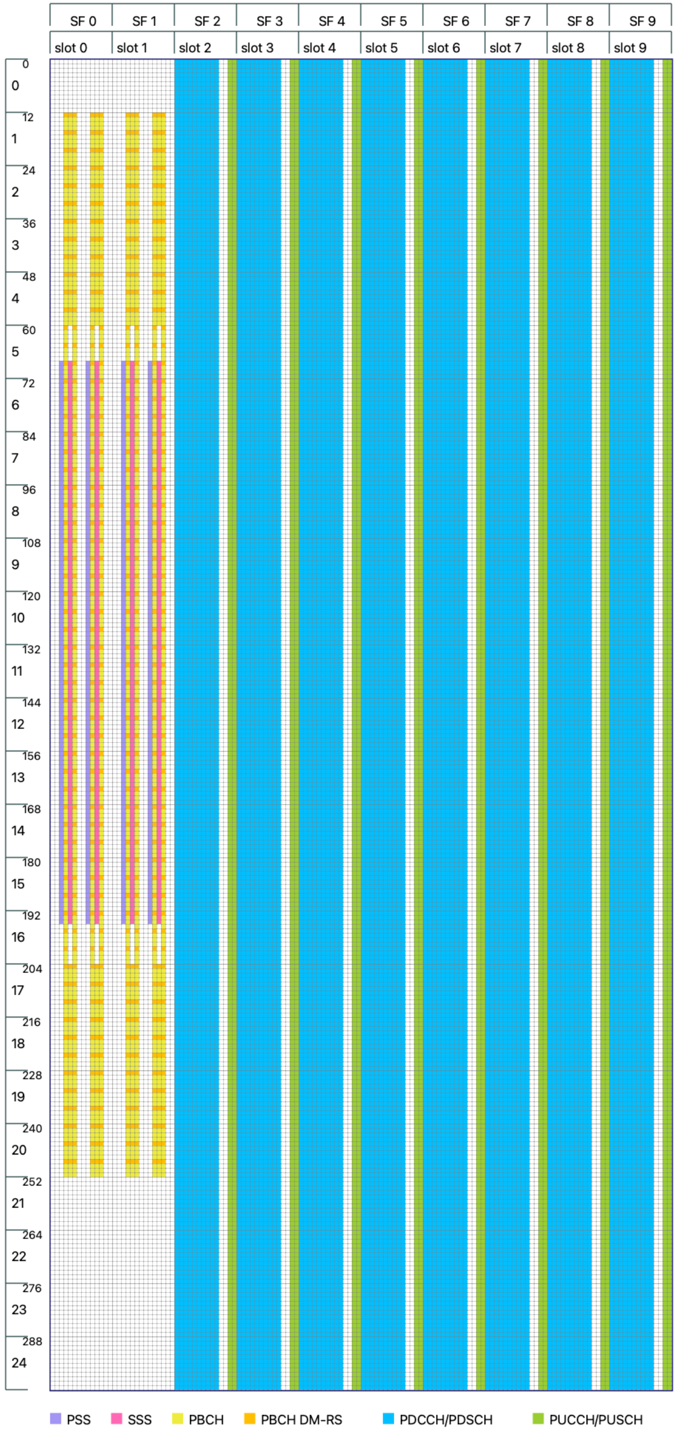


5G NR, ”4G-like”:
5 MHz TDD in 700MHz

Frequency band = n67
PDCCH subcarrier spacing = 15 KHz
SS/PBCH subcarrier spacing = 15 KHz -- pattern A
Bandwidth = 5 MHz
NRB max = 25
Slot format = 32

<38.213 v15.7 -Table 11.1.1-1: Slot formats for normal cyclic prefix>
D : Downlink, U : Uplink, F : Flexible

Format	Symbol Number in a slot													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	D	D	D	D	D	D	D	D	D	D	D	D	D	D
1	U	U	U	U	U	U	U	U	U	U	U	U	U	U
2	F	F	F	F	F	F	F	F	F	F	F	F	F	F
3	D	D	D	D	D	D	D	D	D	D	D	D	D	F
4	D	D	D	D	D	D	D	D	D	D	D	D	F	F
5	D	D	D	D	D	D	D	D	D	D	D	F	F	F
6	D	D	D	D	D	D	D	D	D	D	F	F	F	F
7	D	D	D	D	D	D	D	D	D	F	F	F	F	F
8	F	F	F	F	F	F	F	F	F	F	F	F	F	U
9	F	F	F	F	F	F	F	F	F	F	F	F	U	U
10	F	U	U	U	U	U	U	U	U	U	U	U	U	U
11	F	F	U	U	U	U	U	U	U	U	U	U	U	U
12	F	F	F	U	U	U	U	U	U	U	U	U	U	U
13	F	F	F	F	U	U	U	U	U	U	U	U	U	U
14	F	F	F	F	F	U	U	U	U	U	U	U	U	U
15	F	F	F	F	F	F	U	U	U	U	U	U	U	U
16	D	F	F	F	F	F	F	F	F	F	F	F	F	F
17	D	D	F	F	F	F	F	F	F	F	F	F	F	F
18	D	D	D	F	F	F	F	F	F	F	F	F	F	F
19	D	F	F	F	F	F	F	F	F	F	F	F	F	U
20	D	D	F	F	F	F	F	F	F	F	F	F	F	U
21	D	D	D	F	F	F	F	F	F	F	F	F	F	U
22	D	F	F	F	F	F	F	F	F	F	F	F	U	U
23	D	D	F	F	F	F	F	F	F	F	F	F	U	U
24	D	D	D	F	F	F	F	F	F	F	F	F	U	U
25	D	F	F	F	F	F	F	F	F	F	F	U	U	U
26	D	D	F	F	F	F	F	F	F	F	F	U	U	U
27	D	D	D	F	F	F	F	F	F	F	F	U	U	U
28	D	D	D	D	D	D	D	D	D	D	D	D	F	U
29	D	D	D	D	D	D	D	D	D	D	D	F	F	U
30	D	D	D	D	D	D	D	D	D	D	F	F	F	U
31	D	D	D	D	D	D	D	D	D	D	D	F	U	U
32	D	D	D	D	D	D	D	D	D	D	F	F	U	U
33	D	D	D	D	D	D	D	D	D	F	F	F	U	U
34	D	F	U	U	U	U	U	U	U	U	U	U	U	U



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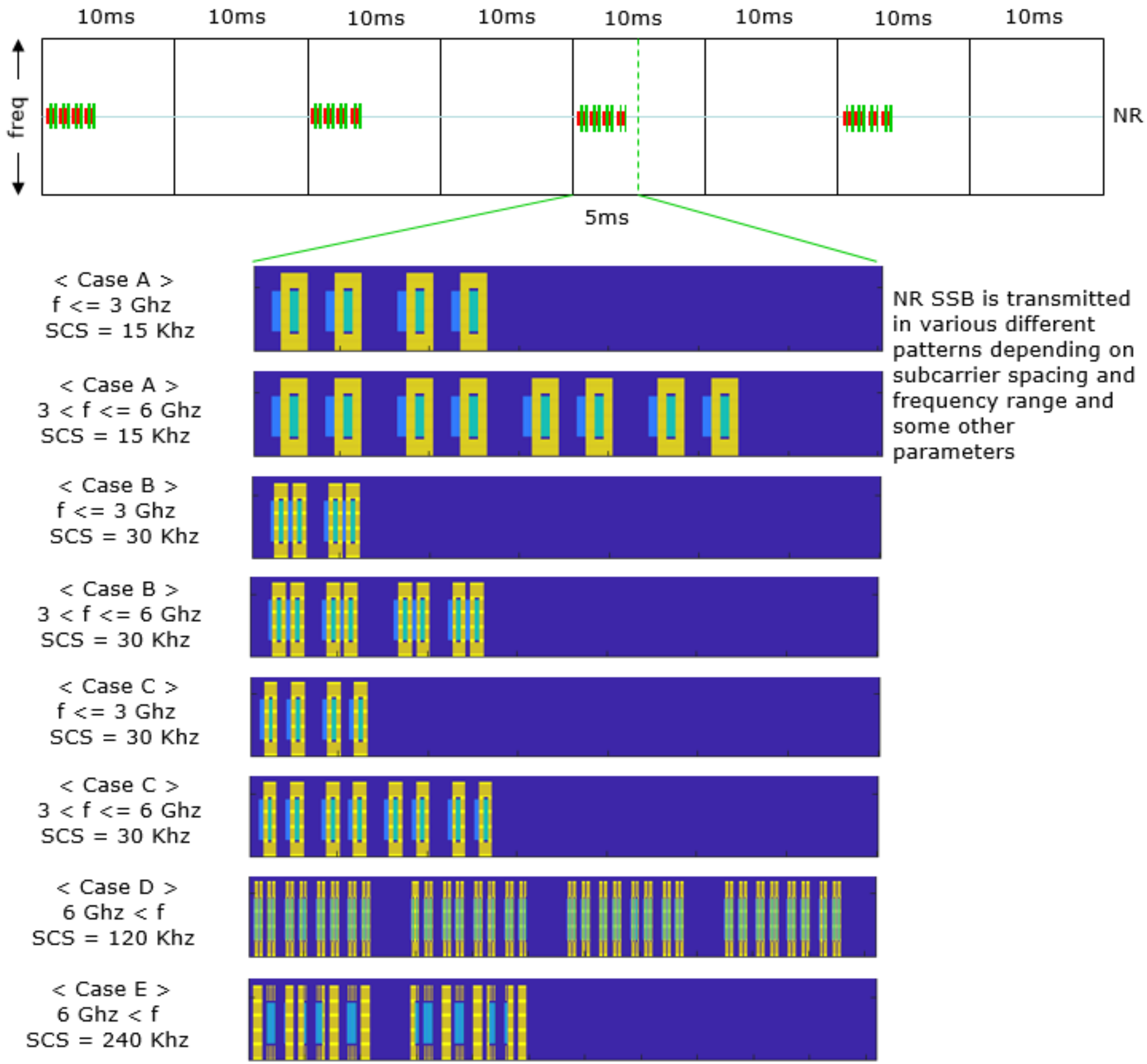
SSB can have different configurations.



It carries the PBSCH, with MIB

- **Master Information Block**

Cell not allowed <-

How to figure out
System Information Block 1

Common Resource Block <-

Information Carried Within the PBCH

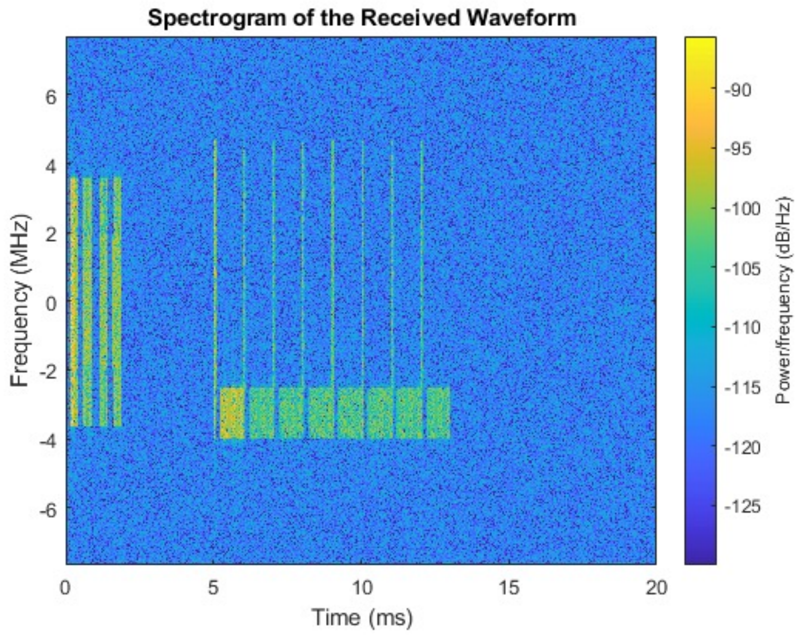
Information	Number of Bits
SS-block time index	0 (FR1)/3 (FR2)
CellBarred flag	2
1st PDSCH DMRS position	1
SIB1 numerology	1
SIB1 Configuration	8
CRB grid offset	5 (FR1)/4 (FR2)
Half-frame bit	1
System Frame Number (SFN)	10
Cyclic Redundancy Check (CRC)	24

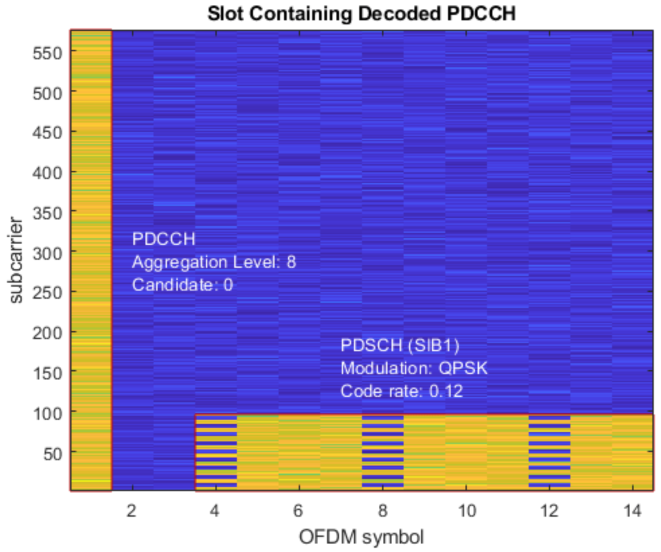
System Information

- **System information** is a joint name for all the common (non-device-specific) information that a device needs in order to properly operate within the network. In general, the system information is carried within different System Information Blocks (SIBs), each consisting of different types of system information.
  - In 4G, all system information is periodically broadcast over the entire cell area making it always available but also implying that it is transmitted even if there is no device within the cell. For NR, a different approach has been adopted where the system information, beyond the very limited information carried within the MIB, has been divided into two parts.
- **SIB1**, sometimes also referred to as the remaining minimum system information (RMSI), consists of the system information that a device needs to know before it can access the system. SIB1 is always periodically broadcast over the entire cell area. One important task of SIB1 is to provide the information the device needs in order to carry out an initial random access.
  - The remaining SIBs, not including SIB1, consist of the system information that a device does not need to know before accessing the system. These SIBs can also be periodically broadcast similar to SIB1. Alternatively, these SIBs can be transmitted on demand, that is, only transmitted when explicitly requested by a connected device.

SIB1

- Cell Selection Information
- Cell Access Related Information
- Connection Establishment Failure Control
- SI Scheduling Information
- Serving Cell Common Configuration
- IMS Emergency Support Flag
- eCall Over IMS Support Flag
- UE -Timer and Constants
- UAC-Barring Information
- Use Full Resume ID Flag





ASN.1

- ASN. 1 is used by protocol developers to represent data structures which are defined as a part of a standards document. The main advantage of using ASN. 1 to represent data structures is that it is independent of programming language or platform as well as it is both human and machine readable.

Introduction to ASN.1

YOU ARE HERE ITU > HOME > ITU-T > ASN.1 PROJECT

- Project
- Introduction to ASN.1
- Short introduction
- Myths about ASN.1
- Application fields of ASN.1
- Defects and Technical Corrigenda on ASN.1 2015 Edition
- Tools
- The Encoding control notation
  - Tutorial
  - ECN specification for Bluetooth SDP
  - ECN specification for UMTS RRC protocol

MAIN CONCEPTS

ASN.1 is a formal notation used for describing data transmitted by telecommunications protocols, regardless of language implementation and physical representation of these data, whatever the application, whether complex or very simple.

Abstract Syntax Notation number One
is a standard that defines a formalism
for the specification of abstract data types.

The notation provides a certain number of pre-defined basic types such as:

- integers (INTEGER),
- booleans (BOOLEAN),
- character strings (IA5String, UniversalString...),
- bit strings (BIT STRING),
- etc.,

and makes it possible to define constructed types such as:

- structures (SEQUENCE),
- lists (SEQUENCE OF),
- choice between types (CHOICE),
- etc.

Remember the MIB?

–MIB

The MIB includes the system information transmitted on BCH.

```
-- ASN1START
-- TAG-MIB-START
MIB ::=                          SEQUENCE {
    systemFrameNumber                BIT STRING (SIZE (6)),
    subCarrierSpacingCommon          ENUMERATED {scs15or60, scs30or120},
    ssb-SubcarrierOffset             INTEGER (0..15),
    dmrs-TypeA-Position              ENUMERATED {pos2, pos3},
    pdcch-ConfigSIB1                 PDCCH-ConfigSIB1,
    cellBarred                       ENUMERATED {barred, notBarred},
    intraFreqReselection             ENUMERATED {allowed, notAllowed},
    spare                            BIT STRING (SIZE (1))
}
-- TAG-MIB-STOP
-- ASN1STOP
```

SIB1

Note: many OPTIONAL !

–SIB1

SIB1 contains information relevant when evaluating if a UE is allowed to access a cell and defines the scheduling of other system information. It also contains radio resource configuration information that is common for all UEs and barring information applied to the unified access control.

```
-- ASN1START
-- TAG-SIB1-START
SIB1 ::=          SEQUENCE {
    cellSelectionInfo               SEQUENCE {
        q-RxLevMin                      Q-RxLevMin,
        q-RxLevMinOffset                INTEGER (1..8)                          OPTIONAL,   -- Need S
        q-RxLevMinSUL                   Q-RxLevMin                              OPTIONAL,   -- Need R
        q-QualMin                       Q-QualMin                               OPTIONAL,   -- Need S
        q-QualMinOffset                 INTEGER (1..8)                          OPTIONAL    -- Need S
    }                                                                           OPTIONAL,   -- Cond Standalone
    cellAccessRelatedInfo           CellAccessRelatedInfo,
    connEstFailureControl           ConnEstFailureControl                       OPTIONAL,   -- Need R
    si-SchedulingInfo               SI-SchedulingInfo                           OPTIONAL,   -- Need R
    servingCellConfigCommon         ServingCellConfigCommonSIB                  OPTIONAL,   -- Need R
    ims-EmergencySupport            ENUMERATED {true}                           OPTIONAL,   -- Need R
    eCallOverIMS-Support            ENUMERATED {true}                           OPTIONAL,   -- Need R
    ue-TimersAndConstants           UE-TimersAndConstants                       OPTIONAL,   -- Need R
    uac-BarringInfo                 SEQUENCE {
        uac-BarringForCommon            UAC-BarringPerCatList                   OPTIONAL,   -- Need S
        uac-BarringPerPLMN-List         UAC-BarringPerPLMN-List                 OPTIONAL,   -- Need S
        uac-BarringInfoSetList          UAC-BarringInfoSetList,
        uac-AccessCategory1-SelectionAssistanceInfo CHOICE {
            plmnCommon                      UAC-AccessCategory1-SelectionAssistanceInfo,
            individualPLMNList              SEQUENCE (SIZE (2..maxPLMN)) OF UAC-AccessCategory1-SelectionAssistanceInfo
        }                                                                       OPTIONAL    -- Need S
    }                                                                           OPTIONAL,   -- Need R
    useFullResumeID                 ENUMERATED {true}                           OPTIONAL,   -- Need R
    lateNonCriticalExtension        OCTET STRING OPTIONAL,
    nonCriticalExtension            SIB1-v1610-IEs                              OPTIONAL
}
SIB1-v1610-IEs ::=              SEQUENCE {
    idleModeMeasurementsEUTRA-r16   ENUMERATED{true}                            OPTIONAL,   -- Need R
    idleModeMeasurementsNR-r16      ENUMERATED{true}                            OPTIONAL,   -- Need R
    posSI-SchedulingInfo-r16        PosSI-SchedulingInfo-r16                    OPTIONAL,   -- Need R
    nonCriticalExtension            SIB1-v1630-IEs OPTIONAL
}
SIB1-v1630-IEs ::=              SEQUENCE {
    uac-BarringInfo-v1630 SEQUENCE {
        uac-AC1-SelectAssistInfo-r16    SEQUENCE (SIZE (2..maxPLMN)) OF UAC-AC1-SelectAssistInfo-r16
    }                                                                           OPTIONAL,   -- Need R
    nonCriticalExtension            SEQUENCE {}                                 OPTIONAL
}
UAC-AccessCategory1-SelectionAssistanceInfo ::=    ENUMERATED {a, b, c}
UAC-AC1-SelectAssistInfo-r16 ::=      ENUMERATED {a, b, c, notConfigured}
-- TAG-SIB1-STOP
-- ASN1STOP
```

cellAccessRelatedInfo drill down example

```
-- ASN1START
-- TAG-CELLACCESSRELATEDINFO-START
CellAccessRelatedInfo   ::=        SEQUENCE {
    plmn-IdentityList                   PLMN-IdentityInfoList,
    cellReservedForOtherUse               ENUMERATED {true}             OPTIONAL,    -- Need R
    ...,
    [[
    cellReservedForF
    npn-IdentityInfoL
    ]]
}
-- TAG-CELLACCESSRE
-- ASN1STOP
```

–PLMN-IdentityInfoList

The IE PLMN-IdentityInfoList includes a list of PLMN identity information.

```
-- ASN1START
-- TAG-PLMN-IDENTITYINFOLIST-START
PLMN-IdentityInfoList ::=          SEQUENCE (SIZE (1..maxPLMN)) OF PLMN-IdentityInfo
PLMN-IdentityInfo ::=              SEQUENCE {
    plmn-IdentityList                  SEQUENCE (SIZE (1..maxPLMN)) OF PLMN-Identity,
    trackingAreaCode                   TrackingAreaCode                          OPTIONAL,      -- Need R
    ranac                              RAN-AreaCode                              OPTIONAL,      -- Need R
    cellIdentity
    cellReservedForOperatorUse
    ...,
    [[
    iab-Support-r16
    ]]
}
-- TAG-PLMN-IDENTITYINFOLIST-STOP
-- ASN1STOP
```

–PLMN-Identity

The IE PLMN-Identity identifies a Public Land Mobile Network. Further information regarding how to set the IE is specified in TS 23.003 [21].

```
-- ASN1START
-- TAG-PLMN-IDENTITY-START
PLMN-Identity ::=                  SEQUENCE {
    mcc                                MCC                  OPTIONAL,                -- Cond MCC
    mnc                                MNC
}
MCC ::=                            SEQUENCE (SIZE (3)) OF MCC-MNC-Digit
MNC ::=                            SEQUENCE (SIZE (2..3)) OF MCC-MNC-Digit
MCC-MNC-Digit ::=                  INTEGER (0..9)
-- TAG-PLMN-IDENTITY-STOP
-- ASN1STOP
```

Only one not OPTIONAL

ServingCellConfigCommonSIB

–ServingCellConfigCommonSIB

The IE ServingCellConfigCommonSIB is used to configure cell specific parameters of a UE's serving cell in SIB1.

```
-- ASN1START
-- TAG-SERVINGCELLCONFIGCOMMONSIB-START
ServingCellConfigCommonSIB ::=      SEQUENCE {
    downlinkConfigCommon                DownlinkConfigCommonSIB,
    uplinkConfigCommon                  UplinkConfigCommonSIB
    supplementaryUplink                 UplinkConfigCommonSIB
    n-TimingAdvanceOffset               ENUMERATED { n0, n25600, n39936
    ssb-PositionsInBurst               SEQUENCE {
        inOneGroup                          BIT STRING (SIZE (8)),
        groupPresence                       BIT STRING (SIZE (8))
    },
    ssb-PeriodicityServingCell          ENUMERATED {ms5, ms10, ms20, ms4
    tdd-UL-DL-ConfigurationCommon       TDD-UL-DL-ConfigCommon                                    OPTIONAL, -- Cond TDD
    ss-PBCH-BlockPower                  INTEGER (-60..50),
    ...,
    [[
    channelAccessMode-r16               CHOICE {
        dynamic                             NULL,
        semiStatic                          SemiStaticChannelAccessConf
    }
    discoveryBurstWindowLength-r16      ENUMERATED {ms0dot5, ms1, ms2, m
    highSpeedConfig-r16                 HighSpeedConfig-r16
    ]]
}
-- TAG-SERVINGCELLCONFIGCOMMONSIB-STOP
-- ASN1STOP
```

–UplinkConfigCommon

The IE UplinkConfigCommon provides common uplink parameters of a cell.

```
-- ASN1START
-- TAG-UPLINKCONFIGCOMMON-START
UplinkConfigCommon ::=              SEQUENCE {
    frequencyInfoUL                     FrequencyInfoUL                         OPTIONAL,   -- Cond InterFreqHOAndServCellAd
    initialUplinkBWP                    BWP-UplinkCommon                        OPTIONAL,   -- Cond ServCellAdd
    dummy                               TimeAlignmentTimer
}
-- TAG-UPLINKCONFIGCOMMON-STOP
-- ASN1STOP
```

–BWP-UplinkCommon

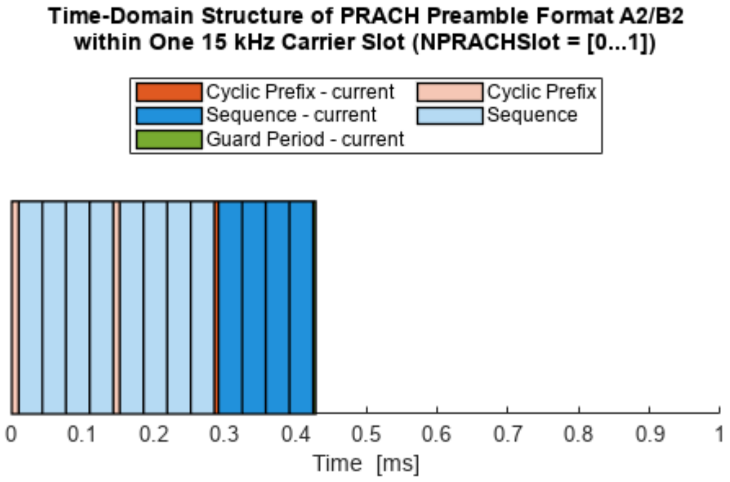
The IE BWP-UplinkCommon is used to configure the common parameters of an uplink BWP. They are "cell specific" and the network ensures the necessary alignment with corresponding parameters of the initial bandwidth part of the PCell are also provided via system information. For all other serving cells, the network provides the common parameters via dedicated signa

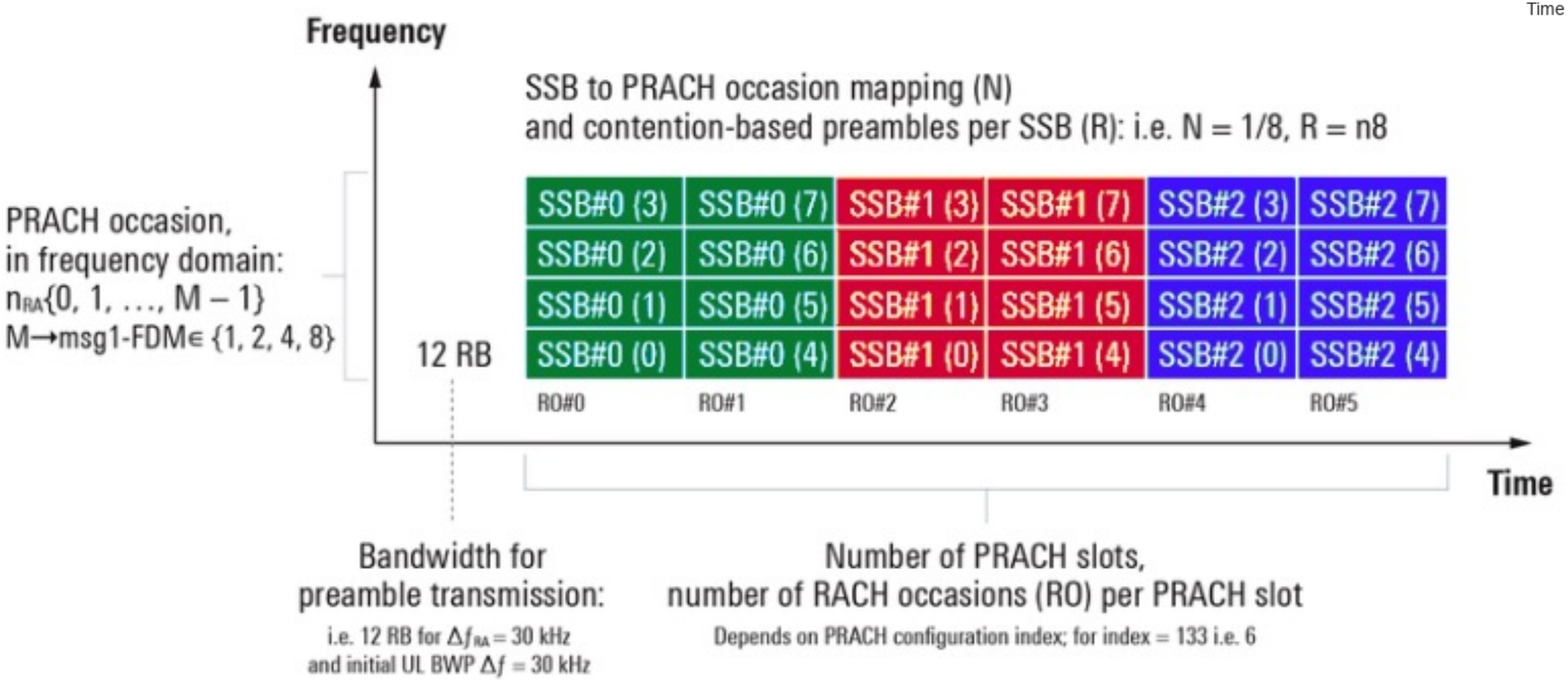
```
-- ASN1START
-- TAG-BWP-UPLINKCOMMON-START
BWP-UplinkCommon ::=                SEQUENCE {
    genericParameters                   BWP,
    rach-ConfigCommon                   SetupRelease { RACH-ConfigCommon }       OPTIONAL,   -- Need M
    pusch-ConfigCommon                  SetupRelease { PUSCH-ConfigCommon }      OPTIONAL,   -- Need M
    pucch-ConfigCommon                  SetupRelease { PUCCH-ConfigCommon }      OPTIONAL,   -- Need M
    ...,
    [[
    rach-ConfigCommonIAB-r16            SetupRelease { RACH-ConfigCommon }       OPTIONAL,   -- Need M
    useInterlacePUCCH-PUSCH-r16         ENUMERATED {enabled}                     OPTIONAL,   -- Need R
    msgA-ConfigCommon-r16               SetupRelease { MsgA-ConfigCommon-r16 }   OPTIONAL    -- Cond SpCellOnly2
    ]]
}
-- TAG-BWP-UPLINKCOMMON-STOP
-- ASN1STOP
```

What are the steps?

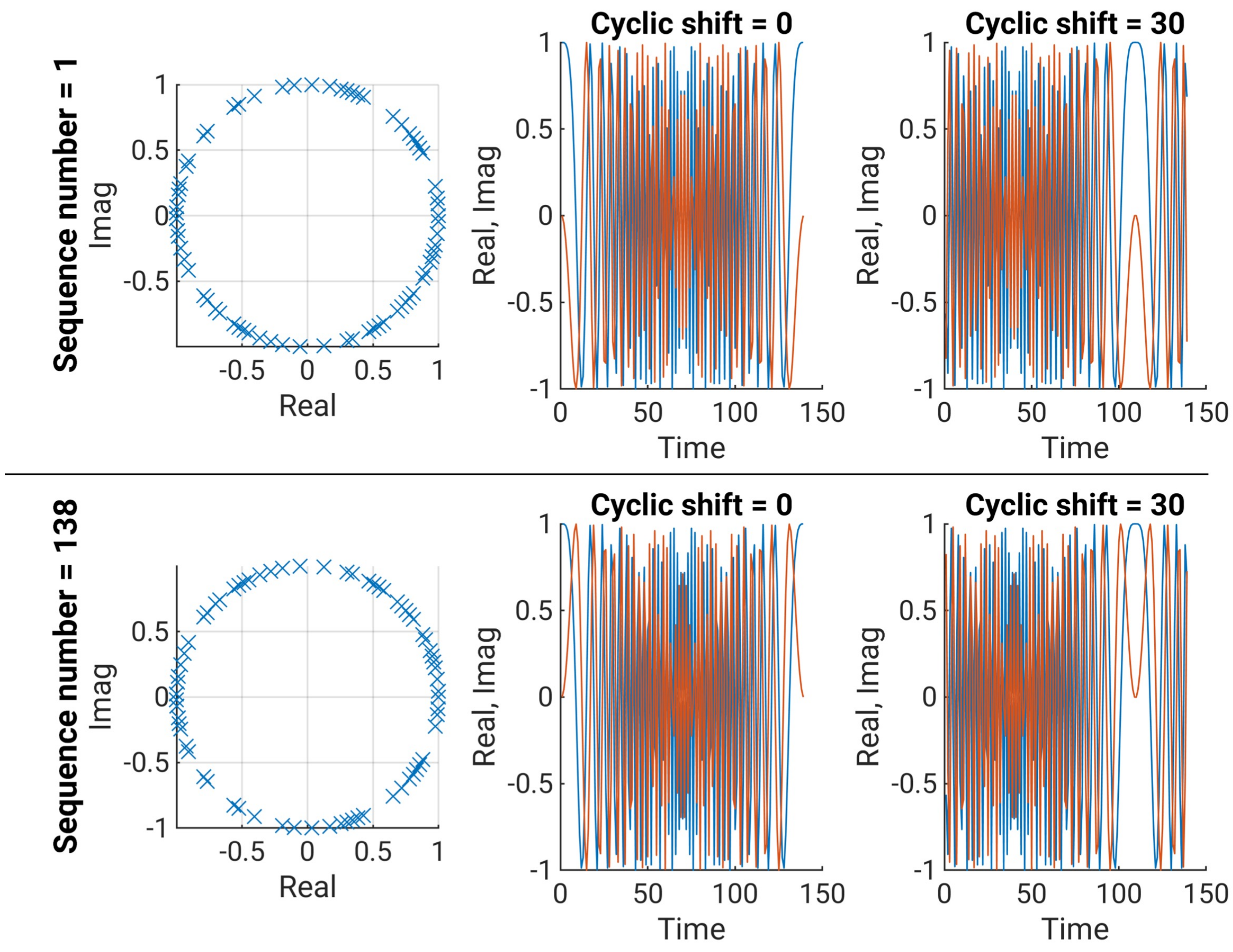
1. ~~Switch on the mobile (& infrastructure)~~
2. ~~Select a frequency band to receive & send~~
3. ~~Pick a way to send and receive digital bits~~
4. ~~Define how we are going to organize the bits for multiple users~~
5. ~~Listen to synchronize and get system information~~
6. Random Access
7. Get a channel
8. Authenticate
9. Ask to send data (or get some data)
10. Ask to make a call
11. Move around
12. … (location update, release call, handover, etc …)

PRACH region flexible





Zadoff Chu Sequences



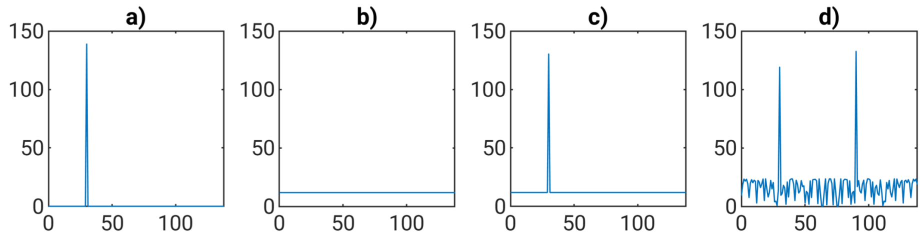
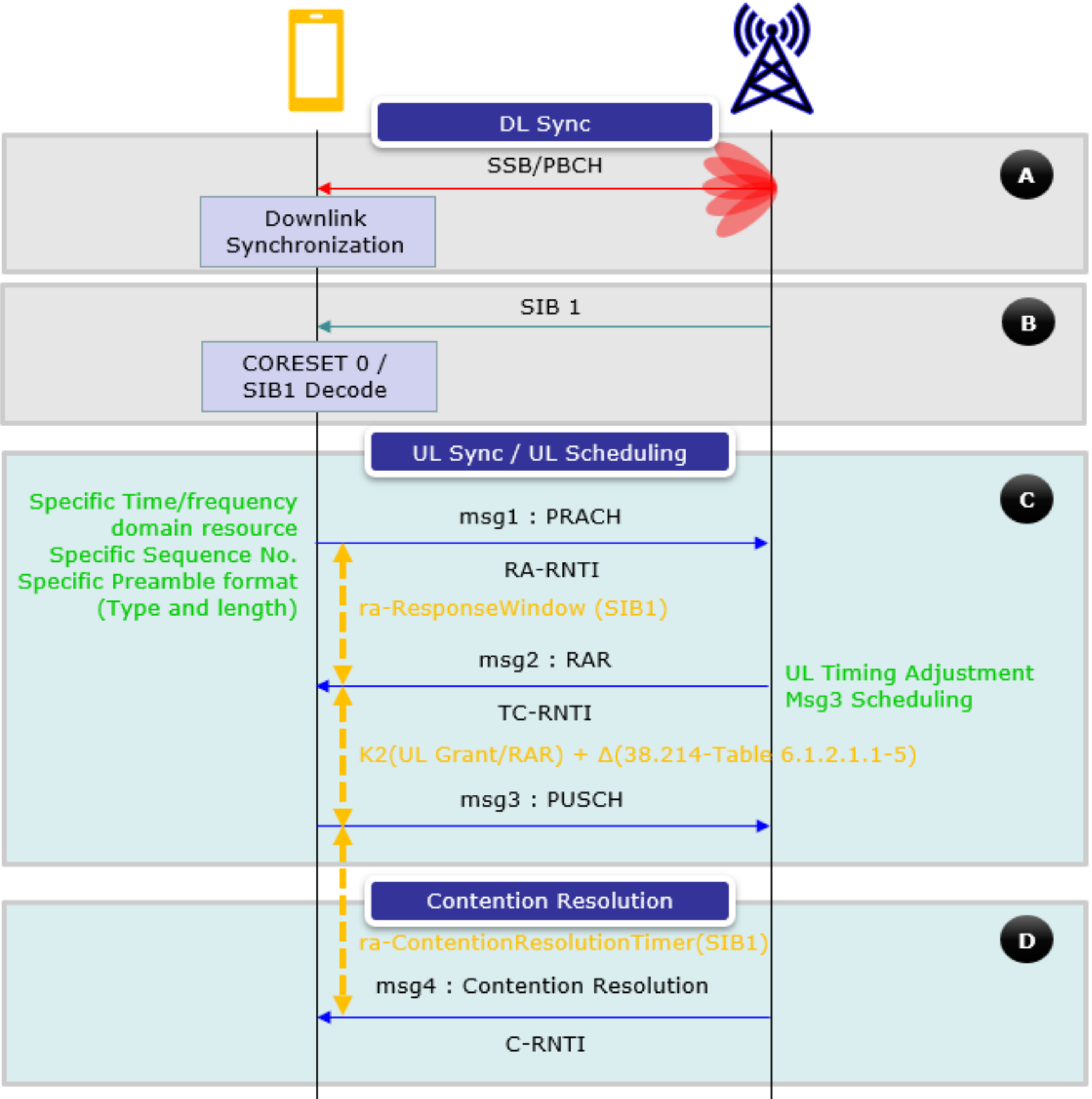


Figure 7: Comparison of correlations between a sequence and
a) a cyclically shifted sequence,
b) a sequence with different sequence number,
c) a cyclically shifted sequence and a sequence with different sequence number,
d) two cyclically shifted sequences and two sequences with different sequence numbers.

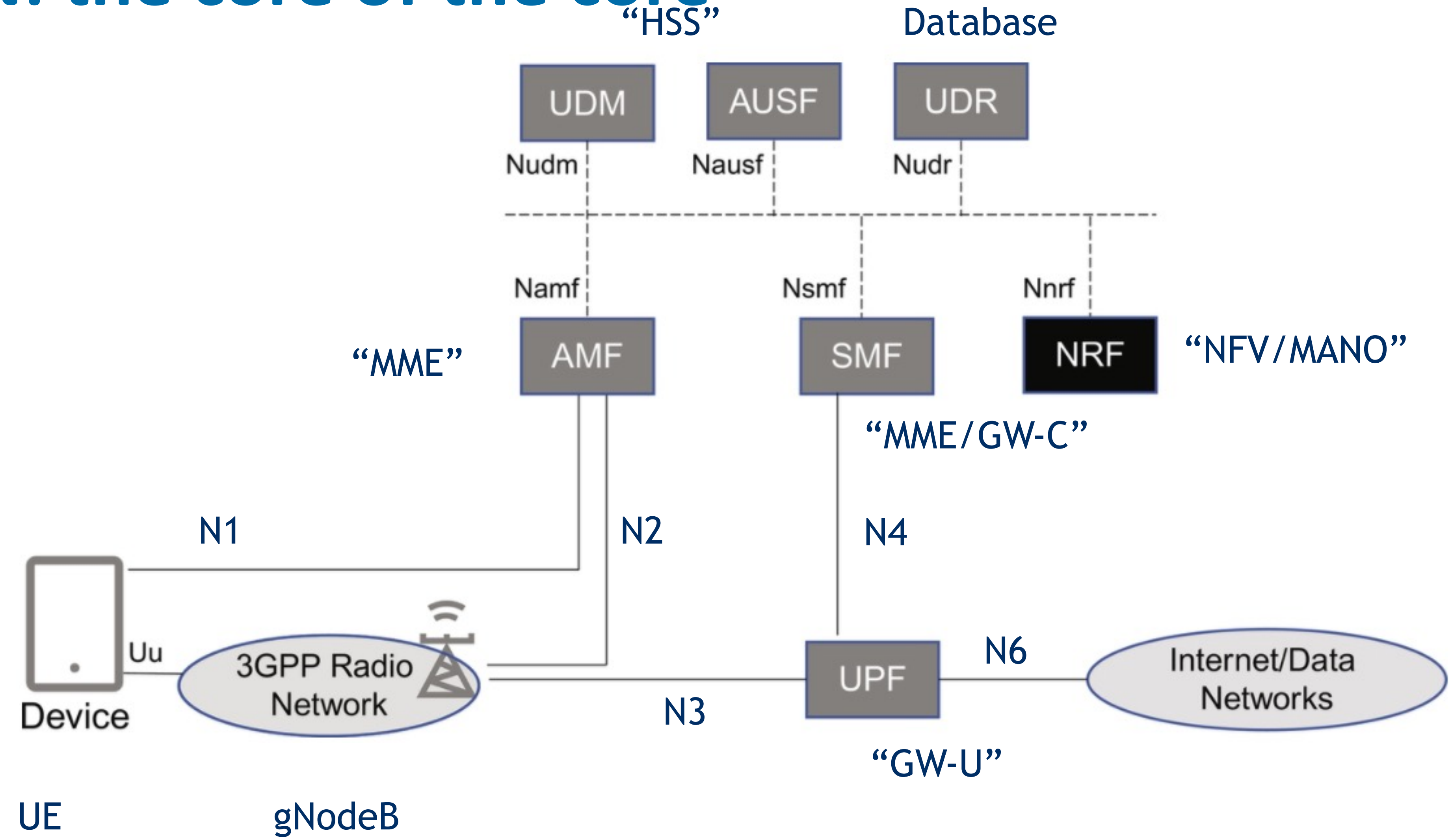
RACH High Level Flow

- **Msg1 (Preamble Transmission):** The UE selects a random access preamble from a set of predefined preambles. These preambles can be of roughly two categories: Short Preamble and Long Preamble Format . The UE also selects a random sequence number for the preamble. After choosing the preamble and sequence number, the UE transmits the preamble on the PRACH.
- **Msg2 (Random Access Response):** Upon receiving Msg1, the gNB (5G base station) sends a response called Msg2. Msg2 consists of several critical pieces of information, such as the Time Advance (TA) command for timing adjustment, the RAPID (Random Access Preamble ID) matching the preamble sent by the UE, and an initial uplink grant for the UE. The gNB also assigns a temporary identifier called RA-RNTI (Random Access Radio Network Temporary Identifier) to the UE.
- **Msg3 :** Using the initial uplink grant provided in Msg2, the UE transmits Msg3 on the PUSCH (Physical Uplink Shared Channel). Msg3 is a PUSCH which may carry a certain RRC message(e.g, RrcRequest) or just be pure PHY data.
- **Msg4 (Contention Resolution):** After processing Msg3, the gNB sends Msg4 to the UE. Msg4 is a MAC data which is for Contention Resolution. The Contention Resolution message contains the UE's identity, confirming that the gNB has correctly identified the UE, and contention has been resolved. At this step, network provide UE with C-RNTI(Cell Radio Network Temporary Identifier)

- There is a faster 2-step process as well.



5G CN: the core of the core



A little more detail

- See: https://www.eventhelix.com/5G/standalone-access-registration/5g-standalone-access-registration.pdf
- Switch to pdf.
- **NOTE:**
  - we will be using different RNTI = 'Radio Network Temporary Identifier' and is used to differentiate/identify a connected mode UE in the cell, a specific radio channel, a group of UEs in case of paging, a group of UEs for which power control is issued by the gNB, system information transmitted for all the UEs by the gNB etc…

RNTI	Usage	Transport Channel	Logical Channel	Value (he
P-RNTI	Paging and System Information change notification	PCH	PCCH	FFFE
SI-RNTI	Broadcast of System Information	DL-SCH	BCCH	FFFF
RA-RNTI	Random Access Response	DL-SCH	N/A	
Temporary C-RNTI	Contention Resolution (when no valid C-RNTI is available)	DL-SCH	CCCH DCCH	
Temporary C-RNTI	Msg3 transmission	UL-SCH	CCCH, DCCH, DTCH	
C-RNTI MCS-C-RNTI	Dynamically scheduled unicast transmission	UL-SCH	DCCH, DTCH	
C-RNTI	Dynamically scheduled unicast transmission	DL-SCH	CCCH, DCCH, DTCH	
MCS-C-RNTI	Dynamically scheduled unicast transmission	DL-SCH	DCCH, DTCH	
C-RNTI	Triggering of PDCCH ordered random access	N/A	N/A	
CS-RNTI	Configured scheduled unicast transmission (activation, reactivation and retransmission)	DL-SCH UL-SCH	DCCH, DTCH	0001-FFE
CS-RNTI	Configured scheduled unicast transmission (deactivation)	N/A	N/A	
TPC-PUCCH-RNTI	PUCCH power control	N/A	N/A	
TPC-PUSCH-RNTI	PUSCH power control	N/A	N/A	
TPC-SRS-RNTI	SRS trigger and power control	N/A	N/A	
INT-RNTI	Indication pre-emption in DL	N/A	N/A	
SFI-RNTI	Slot Format Indication on the given cell	N/A	N/A	
SP-CSI-RNTI	Activation of Semi-persistent CSI reporting on PUSCH	N/A	N/A	

RRCSetupComplete.

RRCSetupComplete

UE ➔ gNB

38.331

The UE sends the RRC Setup Complete message with a Registration Request in the dedicatedNAS-Message field.

```
RRCSetupComplete ::=                SEQUENCE {
    rrc-TransactionIdentifier           RRC-TransactionIdentifier,
    criticalExtensions                  CHOICE {
        rrcSetupComplete                    RRCSetupComplete-IEs,
        criticalExtensionsFuture            SEQUENCE {}
    }
}

RRCSetupComplete-IEs ::=            SEQUENCE {
    selectedPLMN-Identity               INTEGER (1..maxPLMN),
    registeredAMF                       RegisteredAMF                               OPTIONAL,
    guami-Type                          ENUMERATED {native, mapped}                 OPTIONAL,
    s-nssai-List                        SEQUENCE (SIZE (1..maxNrofS-NSSAI)) OF S-NSSAI  OPTIONAL,
    dedicatedNAS-Message                DedicatedNAS-Message,
    ng-5G-S-TMSI-Value                  CHOICE {
        ng-5G-S-TMSI                        NG-5G-S-TMSI,
        ng-5G-S-TMSI-Part2                  BIT STRING (SIZE (9))
    }                       OPTIONAL,
    lateNonCriticalExtension            OCTET STRING                                OPTIONAL,
    nonCriticalExtension                SEQUENCE{}                                  OPTIONAL
}

RegisteredAMF ::=                   SEQUENCE {
    plmn-Identity                       PLMN-Identity                               OPTIONAL,
    amf-Identifier                      AMF-Identifier
}
```

Registration Request

Field	Type
Extended protocol discriminator	
Security header type	
Spare half octet	
Registration request message identity	Message type
5GS registration type	• initial registration • mobility registration updating • periodic registration updating • emergency registration
ngKSI	NAS key set identifier
Spare half octet	
5GS mobile identity	(optional, can be encrypted)
Non-current native NAS key set identifier	NAS key set identifier
5GMM capability	
UE security capability	
Requested NSSAI	NSSAI
Last visited registered TAI	5GS tracking area identity
S1 UE network capability	
Uplink data status	
PDU session status	
MICO indication	
UE status	
Additional GUTI	5GS mobile identity
Allowed PDU session status	
UE's usage setting	
Requested DRX parameters	DRX parameters
EPS NAS message container	
LADN indication	
Payload container	

What are the steps?

1. ~~Switch on the mobile (& infrastructure)~~
2. ~~Select a frequency band to receive & send~~
3. ~~Pick a way to send and receive digital bits~~
4. ~~Define how we are going to organize the bits for multiple users~~
5. ~~Listen to synchronize and get system information~~
6. ~~Random Access~~
7. ~~Get a channel~~
8. Authenticate
9. Ask to send data (or get some data)
10. Ask to make a call
11. Move around
12. … (location update, release call, handover, etc …)

Authenticate

- See: https://www.eventhelix.com/5G/standalone-access-registration/5g-standalone-access-registration.pdf
- Switch to pdf.

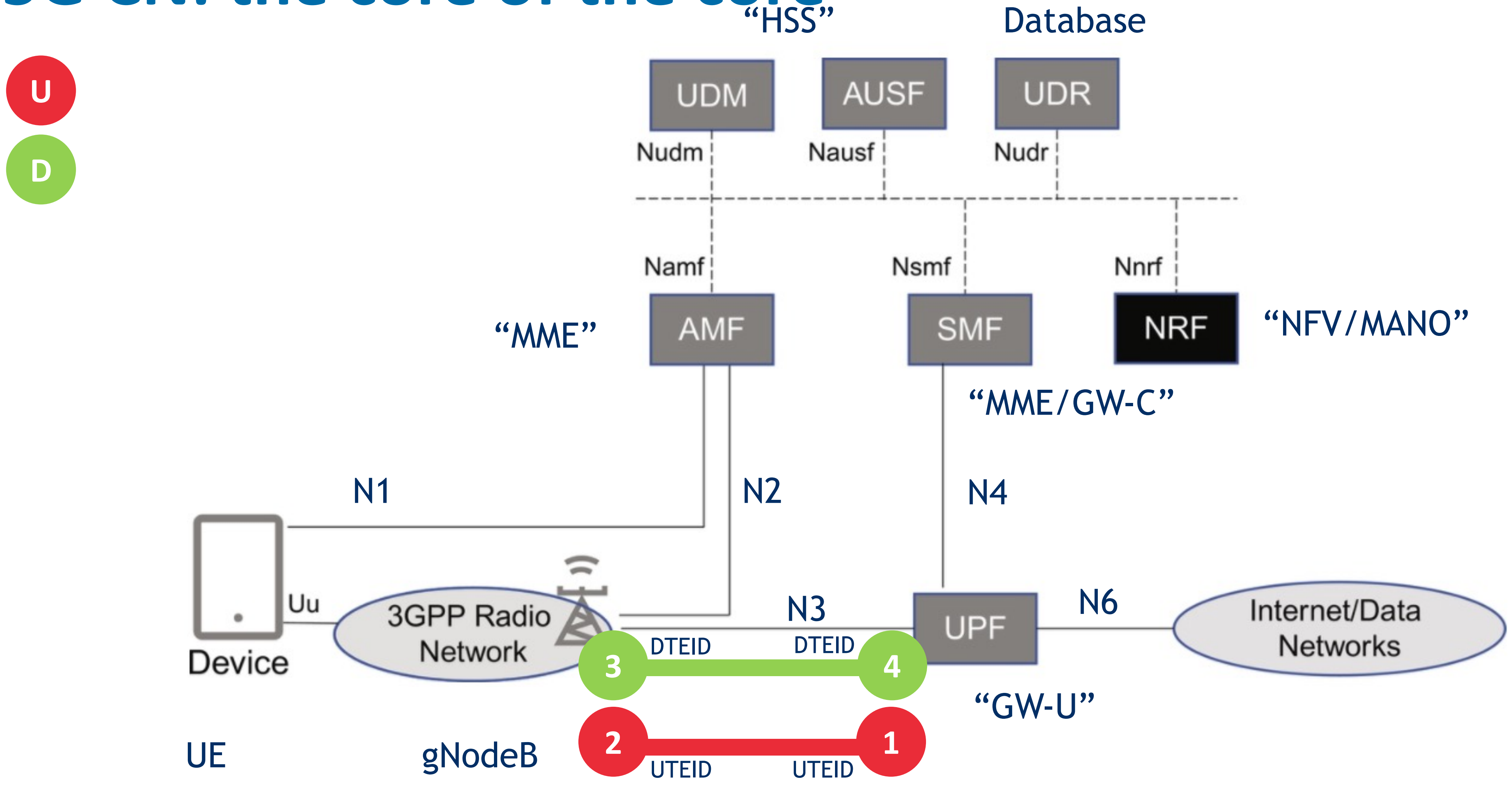
What are the steps?

1. ~~Switch on the mobile (& infrastructure)~~
2. ~~Select a frequency band to receive & send~~
3. ~~Pick a way to send and receive digital bits~~
4. ~~Define how we are going to organize the bits for multiple users~~
5. ~~Listen to synchronize and get system information~~
6. ~~Random Access~~
7. ~~Get a channel~~
8. ~~Authenticate~~
9. Ask to send data (or get some data)
10. Ask to make a call
11. Move around
12. … (location update, release call, handover, etc …)

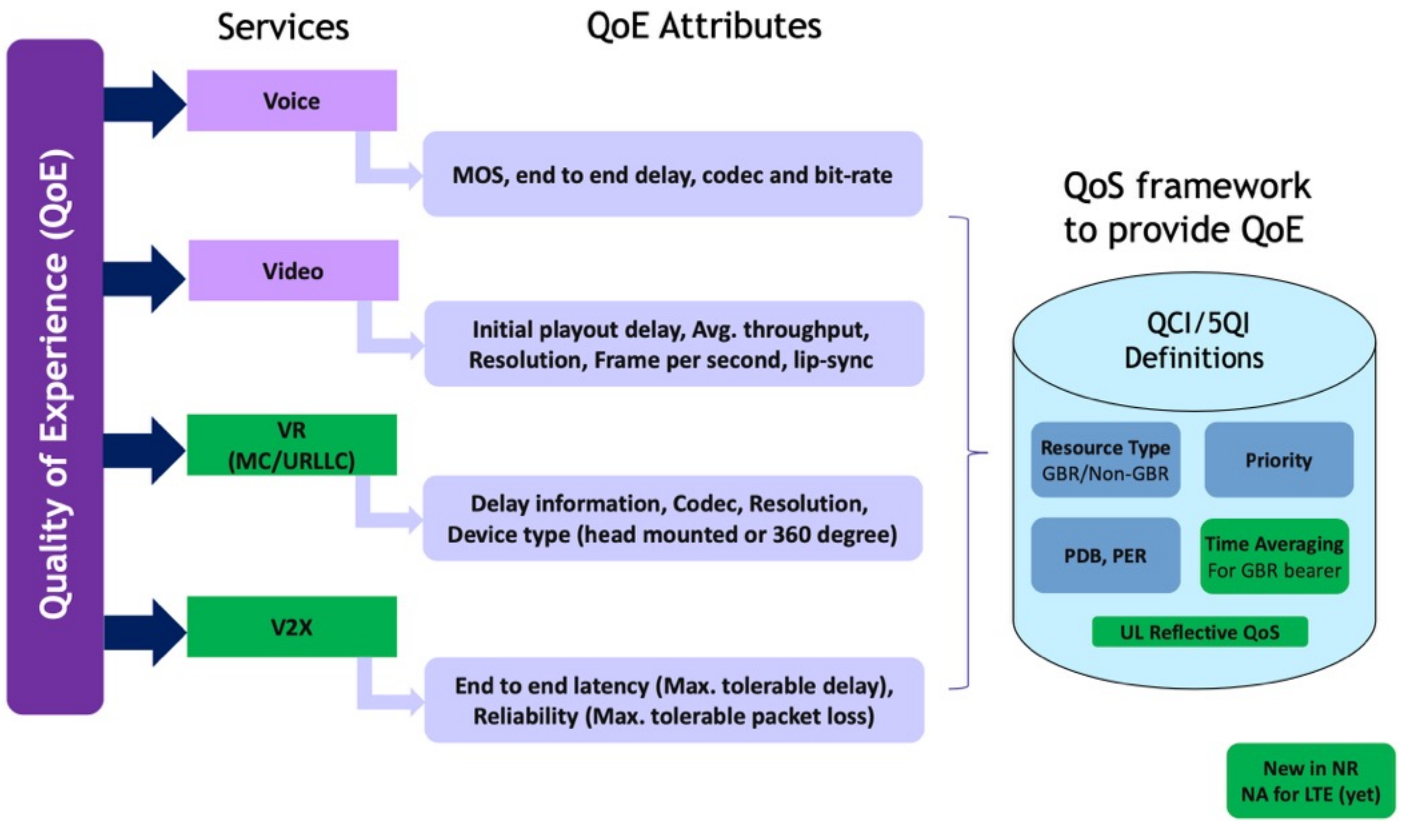
Ask to send data or get some data

- See: https://www.eventhelix.com/5G/standalone-access-registration/5g-standalone-access-registration.pdf
- Switch to pdf.

5G CN: the core of the core

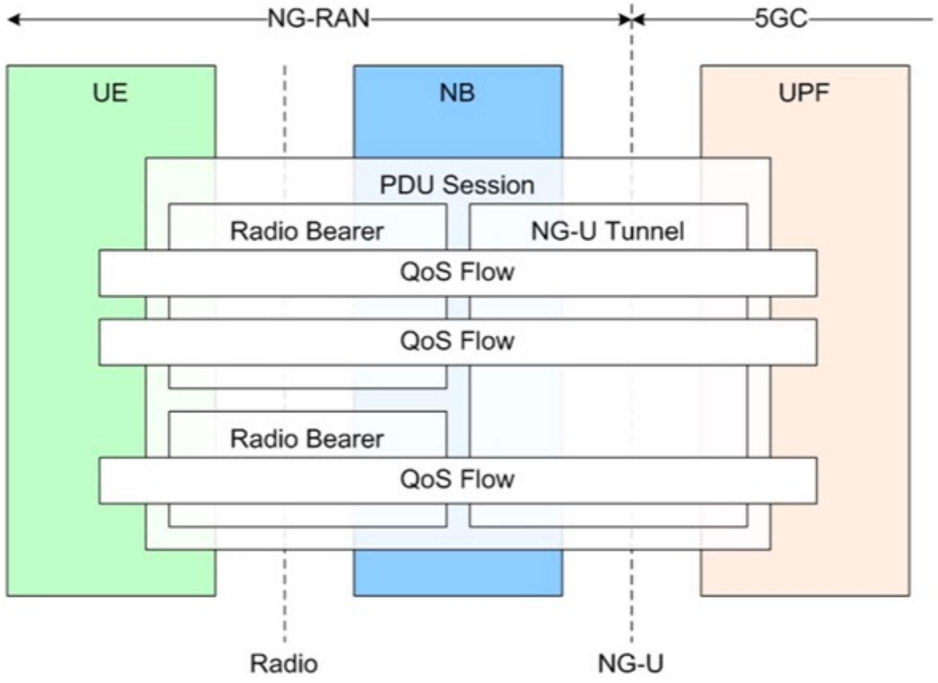


From QoS to QoE: new items



QoS in 5G

- The concept of QoS in 5G is flow based. Packets are classified and marked using QFI (QoS Flow Identifier). The 5G QoS flows are mapped in the AN (Access Network) to DRBs (Data Radio Bearers; unlike 4G LTE where mapping is one to one between EPC and radio bearers).



Protocol Flow

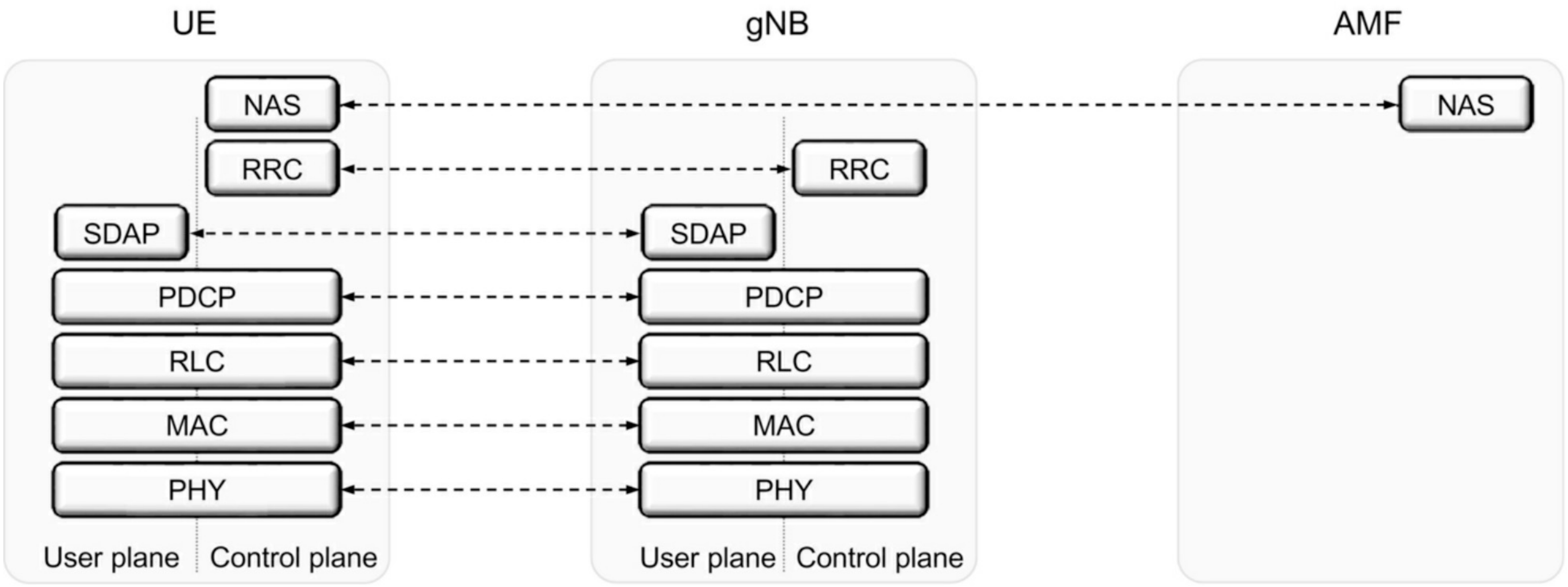
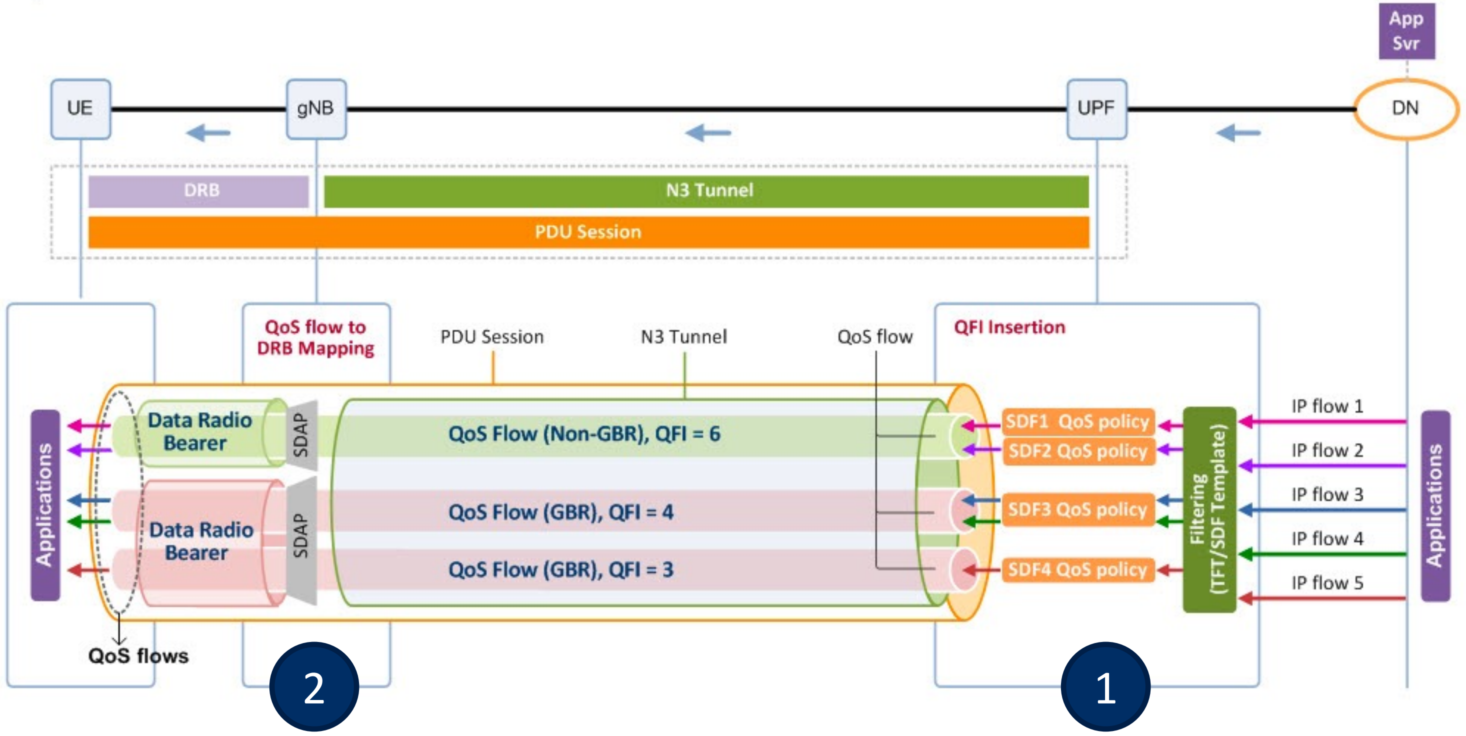


FIG. 6.6 User-plane and control-plane protocol stack.

SDAP = service data adaptation protocol flows (QoS)

Overall view: 2 step process

The QoS differentiation within a PDU session



5QI	: 5G QoS Identifier
ARP	: Allocation and Retention Priority
GFBR	: Guaranteed Flow Bit Rate
MFBR	: Maximum Flow Bit Rate
PDB	: Packet Delay Budget
PER	: Packet Error Rate
QFI	: QoS Flow Identifier
RQA	: Reflective QoS Attribute

QoS Flow type		QoS Flow parameters
GBR flow	Non-GBR flow	5QI
		ARP
		RQA
		GFBR
		MFBR
		Notification Control
		Maximum Packet Loss Rate

5QI

Resource Type*
Default Priority Level
PDB
PER
Default Maximum Data Burst Volume
Default Averaging Window

* GBR, non-GBR or delay critical GBR

University of Antwerp
Faculty of Science

QCI to 5QI

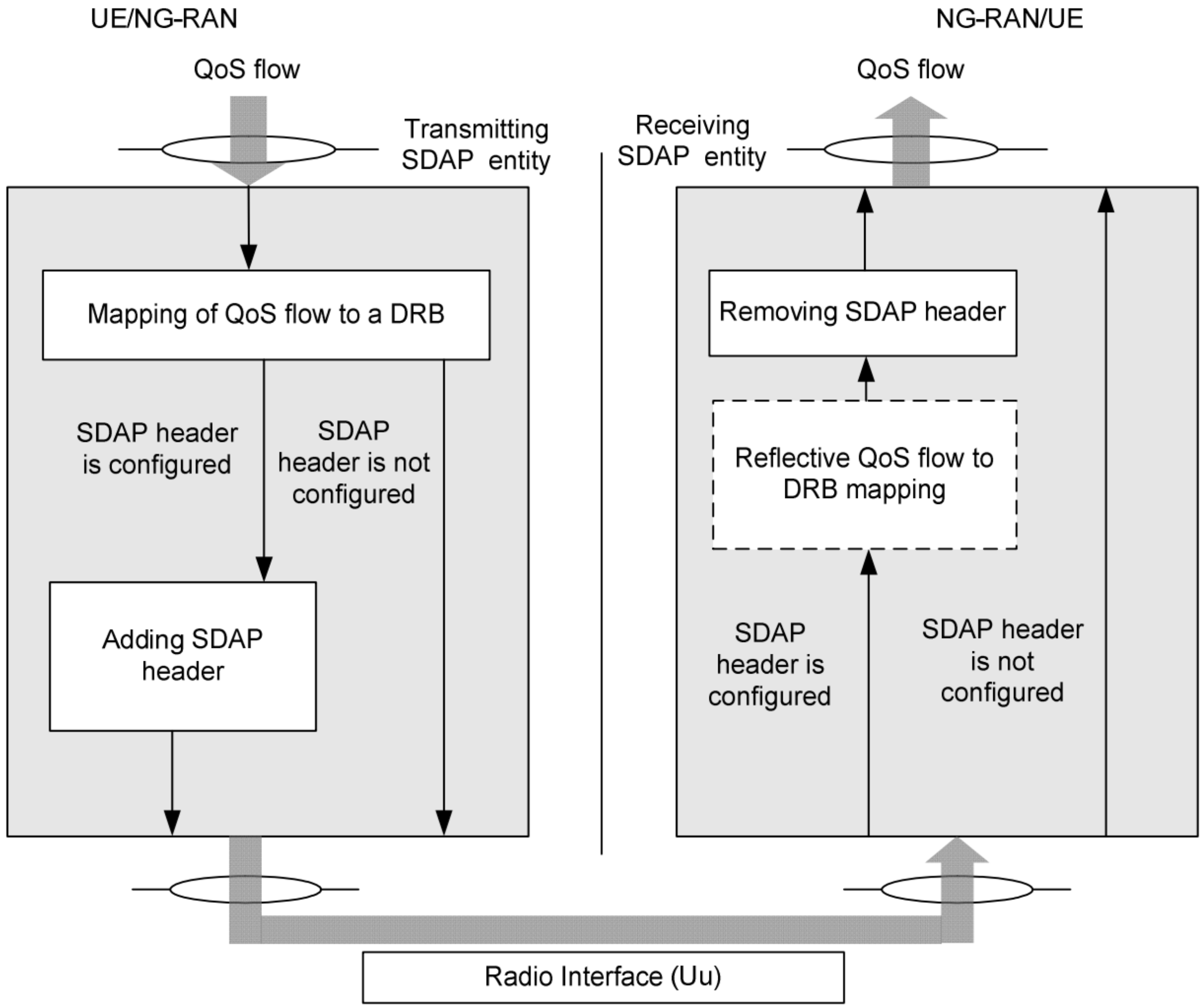
5QI - (5G QoS Indicators)							
5QI Value	ResourceType	DefaultPriorityLevel	PacketDelayBudget	PacketErrorRate	DefaultMaximumData BurstVolume	DefaultAveragingWindow	Example Services
1	GBR	20	100 ms	10^{-2}	N/A	2000 ms	Conversational Voice
2	GBR	40	150 ms	10^{-3}	N/A	2000 ms	Conversational Video(Live Streaming)
3	GBR	30	50 ms	10^{-3}	N/A	2000 ms	Real Time Gaming,V2X messagesElectricity distribution –medium voltage,Process automation -monitoring
4	GBR	50	300 ms	10^{-6}	N/A	2000 ms	Non-ConversationalVideo (BufferedStreaming)
65	GBR	7	75 ms	10^{-2}	N/A	2000 ms	Mission Critical userplane Push To Talkvoice (e.g., MCPTT)
66	GBR	20	100 ms	10^{-2}	N/A	2000 ms	Non-Mission-Criticaluser plane Push ToTalk voice
67	GBR	15	100 ms	10^{-3}	N/A	2000 ms	Mission Critical Videouser plane
75	GBR	This 5QI is not supported in this Release(16.4) of the specification as it is only used for transmission of V2X messagesover MBMS bearers as defined in TS 23.285 but the value is reserved for future use.					
71	GBR	56	150 ms	10^{-3}	N/A	2000 ms	Live" Uplink Streaming(e.g. TS 26.238)
72	GBR	56	300 ms	10^{-8}	N/A	2000 ms	Live" Uplink Streaming(e.g. TS 26.238)
73	GBR	56	300 ms	10^{-8}	N/A	2000 ms	Live" Uplink Streaming(e.g. TS 26.238)
74	GBR	56	500 ms	10^{-8}	N/A	2000 ms	Live" Uplink Streaming(e.g. TS 26.238)
76	GBR	56	500 ms	10^{-4}	N/A	2000 ms	Live" Uplink Streaming(e.g. TS 26.238)
5	Non-GBR	10	100 ms	10^{-6}	N/A	N/A	IMS Signalling
6	Non-GBR	60	300 ms	10^{-6}	N/A	N/A	Video (BufferedStreaming)TCP-based (e.g., www,e-mail, chat, ftp, p2pfile sharing, progressivevideo, etc.)
7	Non-GBR	70	100 ms	10^{-3}	N/A	N/A	Voice,Video (Live Streaming)Interactive Gaming
8	Non-GBR	80	300 ms	10^{-6}	N/A	N/A	Video (BufferedStreaming)TCP-based (e.g., www,e-mail, chat, ftp, p2pfile sharing, progressive video, etc.)
9	Non-GBR	90	300 ms	10^{-6}	N/A	N/A	Video (BufferedStreaming)TCP-based (e.g., www,e-mail, chat, ftp, p2pfile sharing, progressive video, etc.)
69	Non-GBR	5	60 ms	10^{-6}	N/A	N/A	Mission Critical delaysensitive signalling(e.g., MC-PTTsignalling)
70	Non-GBR	55	200 ms	10^{-6}	N/A	N/A	Mission Critical Data(e.g. example servicesare the same as 5QI6/8/9)
79	Non-GBR	65	50 ms	10^{-2}	N/A	N/A	V2X messages
80	Non-GBR	68	10 ms	10^{-6}	N/A	N/A	Low Latency eMBBapplicationsAugmented Reality
82	DelayCriticalGBR	19	10 ms	10^{-4}	255 Bytes	2000 ms	Discrete Automation(see TS 22.261)
83	DelayCriticalGBR	22	100 ms	10^{-4}	1354 Bytes	2000 ms	Discrete Automation(see TS 22.261)
84	DelayCriticalGBR	24	30 ms	10^{-5}	1354 Bytes	2000 ms	Intelligent transportsystems (TS 22.261)
85	DelayCriticalGBR	21	50 ms	10^{-5}	255 Bytes	2000 ms	Electricity Distributionhigh voltage (TS 22.261)
							By: Mohammed Ameen G S - 5G/LTE(RNO Engineer)

SDAP

- **Service Data Application Protocol (SDAP)** is responsible for mapping QoS bearers to radio bearers according to their quality-of-service requirements. This protocol layer is not present in LTE but introduced in NR when connecting to the 5G core network due to the new quality-of-service handling. It also tackles Reflective **QoS.**

Reflective QoS

- In the case of **reflective mapping**, which is a new feature in NR when connected to the 5G core network, the device observes the QFI in the downlink packets for the PDU session. This provides the device with knowledge about which IP flows are mapped to which QoS flow and radio bearer. The device then uses the same mapping for the uplink traffic.



http://www.techplayon.com/5g-nr-qos-architecture-qos-attribute-and-qos-flow/
http://5gblogs.com/5g-quality-of-services-qos/

Summarizing

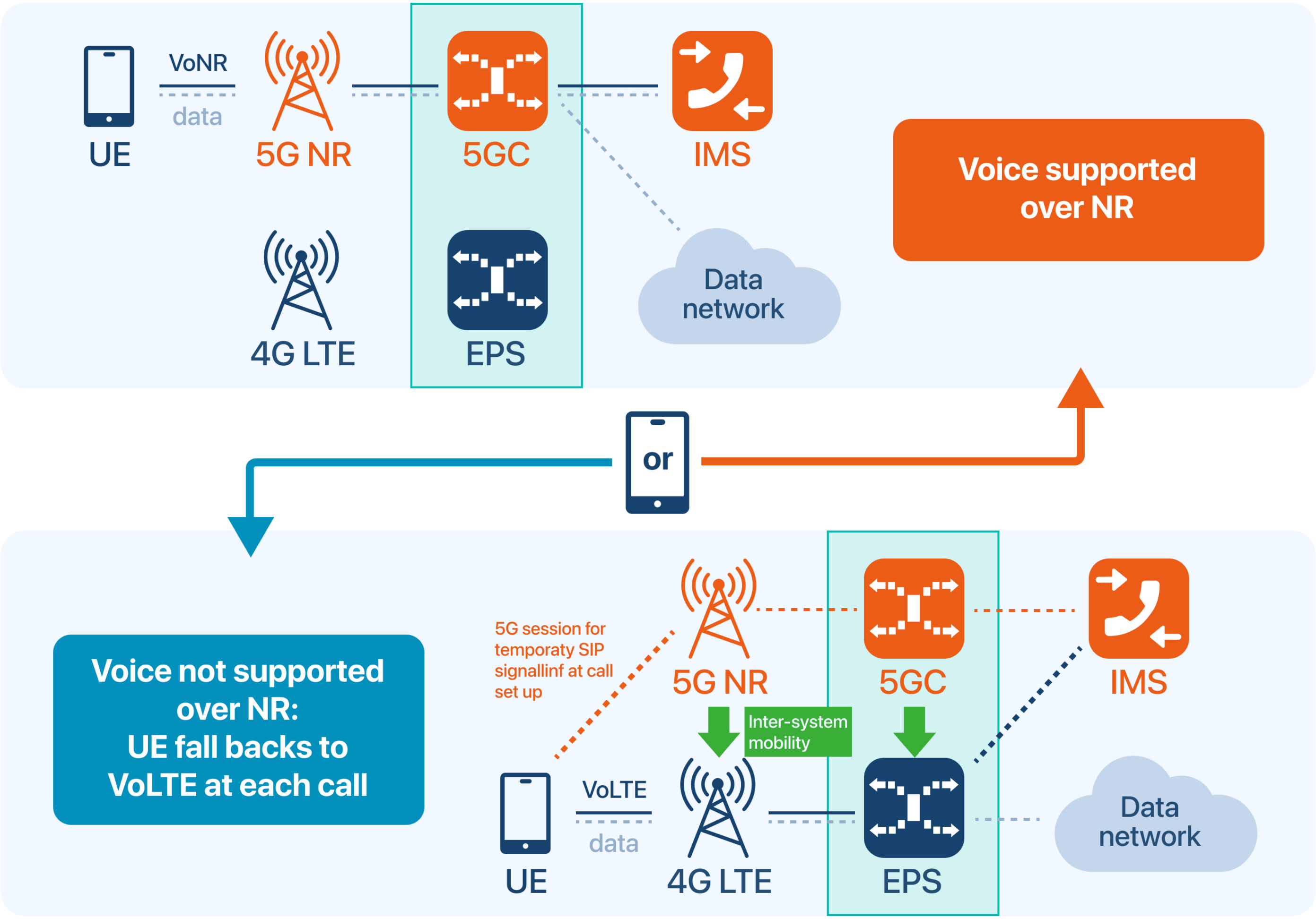
- In 5G, QoS is enforced at the **QoS flow level**.
- 5G uses QoS Flows, each identified by a **QoS Flow ID (QFI)**. Both **non-GBR flows and GBR** flows are supported in 5G, along with a new delay-critical GBR. 5G also introduces a new concept - **Reflective QoS.**
- The QoS flow is the lowest level granularity within the 5G system and is where policy and charging are enforced. One or more **Service Data Flows (SDFs)** can be transported in the same QoS flow, if they share the same policy and charging rules. All traffic within the same QoS flow receives the same treatment.
- 5G QoS to be assured on application basis, so we can create a QoS flow for each application and QoS flows are created dynamically without the need for E2E signaling. Also, short lived QoS flows (e.g., low latency requirements) can receive differentiated QoS treatment (without the overhead of establishing EPS bearers from E2E as in 4G).

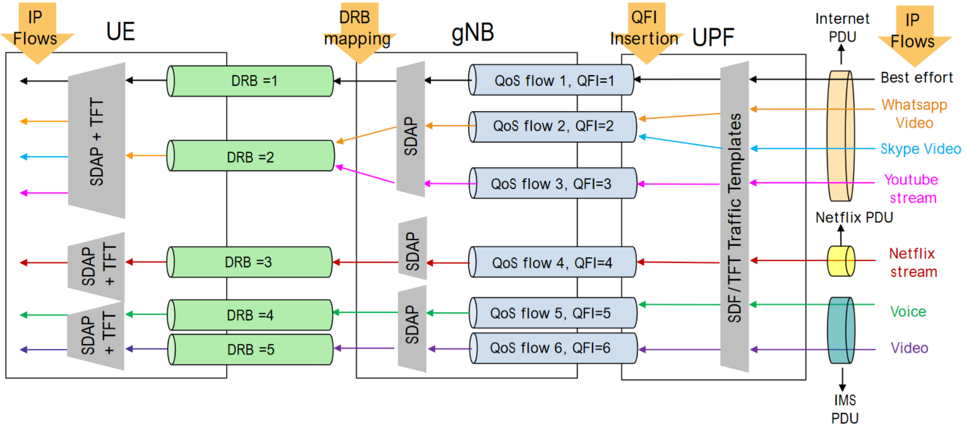
Parameter	5G	4G LTE
QoS Identifier	5G QoS Identifier - 5QI	Quality Class Indicator - QCI
IP Flow: UE to UPF/P-GW flow	QoS Flow	EPS Bearer
Flow/Bearer identifier	QoS Flow Identifier - QFI	EPS Bearer ID- EBI
Reflective QoS	Reflective QoS Indicator - RQI	N/A

What are the steps?

1. ~~Switch on the mobile (& infrastructure)~~
2. ~~Select a frequency band to receive & send~~
3. ~~Pick a way to send and receive digital bits~~
4. ~~Define how we are going to organize the bits for multiple users~~
5. ~~Listen to synchronize and get system information~~
6. ~~Random Access~~
7. ~~Get a channel~~
8. ~~Authenticate~~
9. ~~Ask to send data (or get some data)~~
10. Ask to make a call
11. Move around
12. … (location update, release call, handover, etc …)

A voice call… is data (over a different PDU)





Different Packet Data Unit session associated with each PDN (“APN”).

What are the steps?

1. ~~Switch on the mobile (& infrastructure)~~
2. ~~Select a frequency band to receive & send~~
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8. ~~Authenticate~~
9. ~~Ask to send data (or get some data)~~
10. Ask to make a call
11. Move around
12. … (location update, release call, handover, etc …)

Handover/handoff

- **Classification based on system**
  - Inter-system (vertical)
  - Intra-system (horizontal)
- **Classification based on cell**
  - Intra-cell = channel change vs.
  - Inter-cell = due to mobility
- **Classification based on action**
  - Hard = break-before-make
  - Soft = make-before-break
  - Dual connectivity = make-and-keep
- **Classification based on control**
  - Network-controlled
    - Mobile-assisted
  - Mobile-controlled

Handover procedures

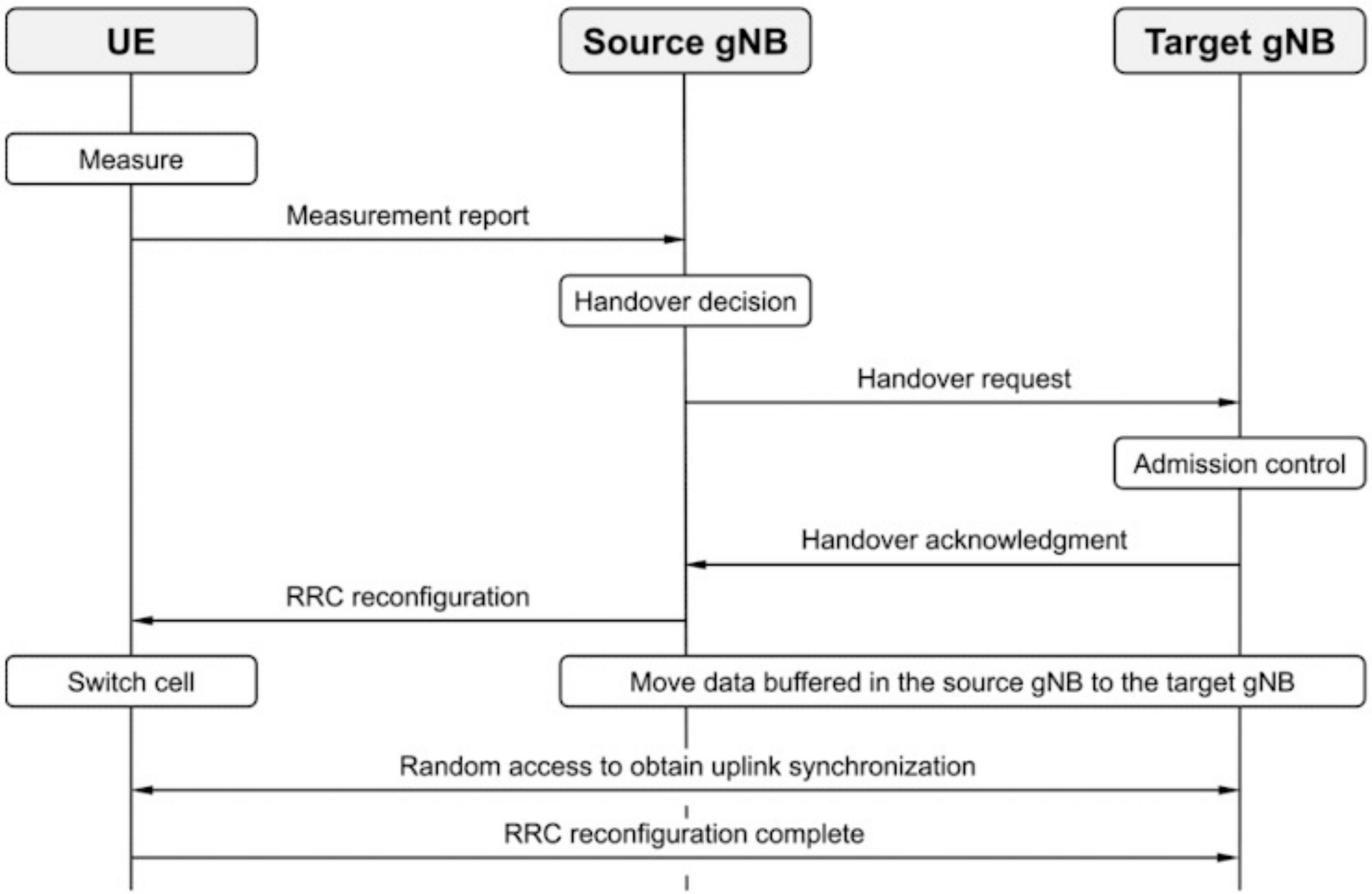
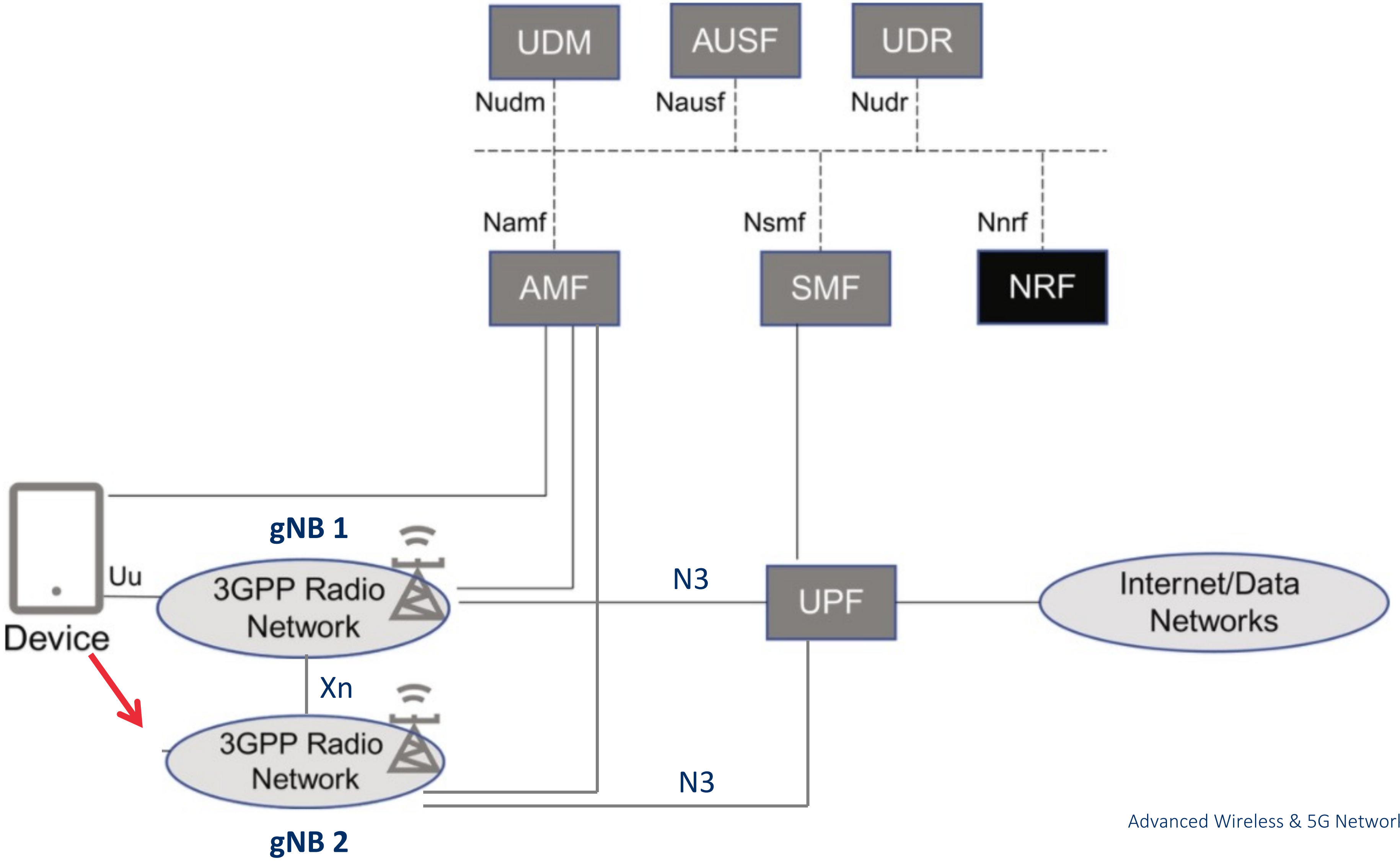


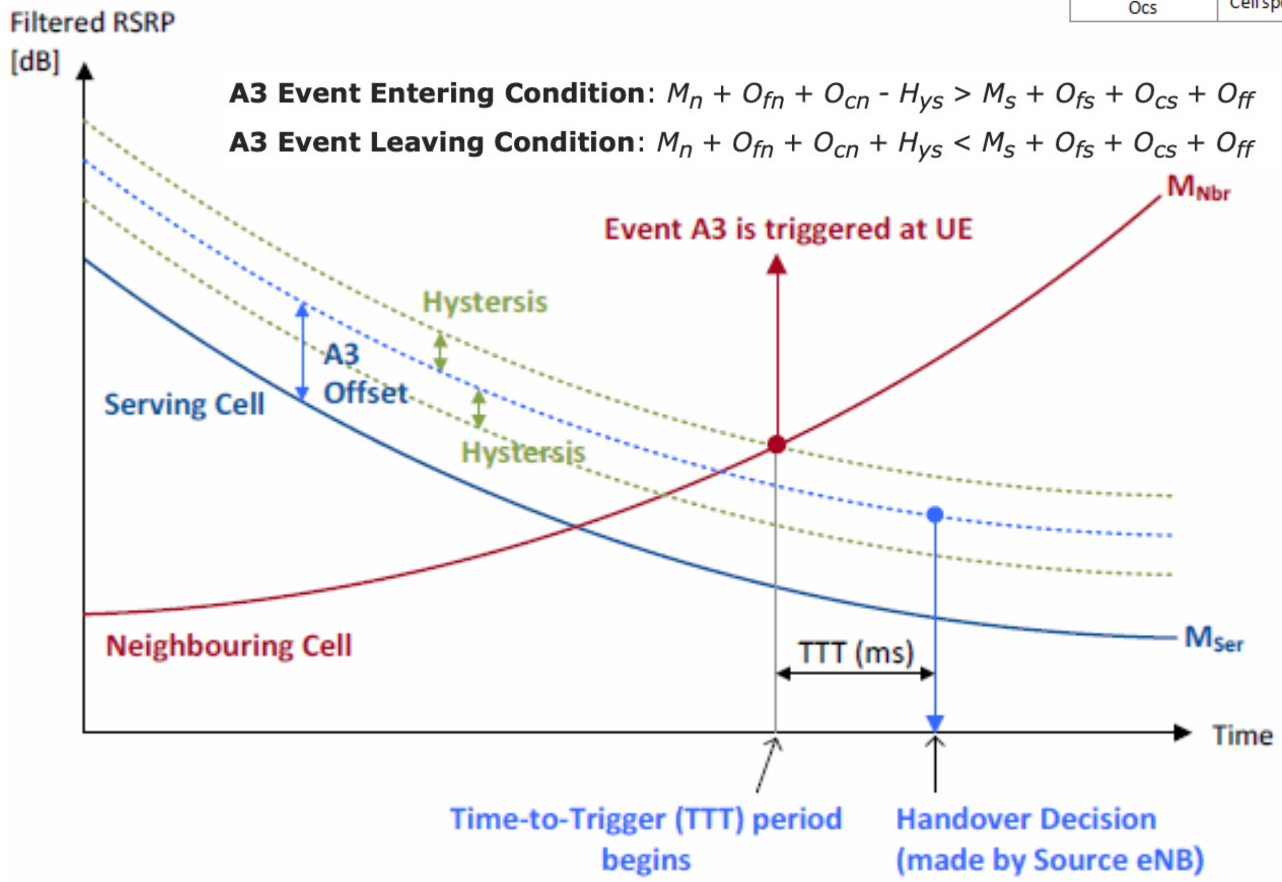
FIG. 6.18 Connected state handover (simplified view).

2 main types: Xn and NGAP HO

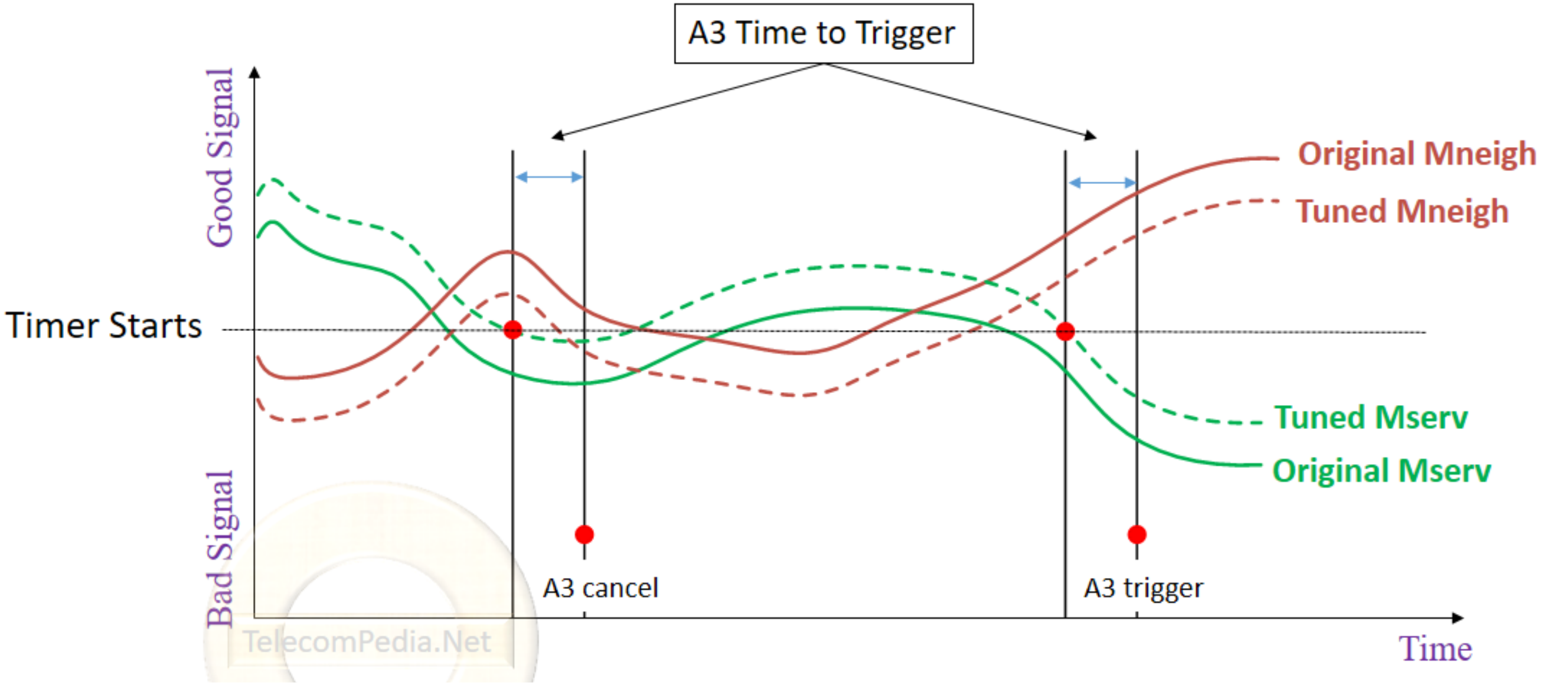


Example (algo is not specified)

Symbol	Definition
Mn	Measurement result of the neighbor cell
Ms	Measurement result of the serving cell
Hys	Hysteresis parameter for Event A3
Off	Offset parameter of Event A3
Ofn	Frequency specific offset of the frequency of the neighbor cell
Ocn	Cell specific offset of the neighbor cell
Ofs	Frequency specific offset of the serving frequency
Ocs	Cell specific offset of the serving cell



Example of Handover Algorithm (2)



What are the steps?

1. ~~Switch on the mobile (& infrastructure)~~
2. ~~Select a frequency band to receive & send~~
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10. ~~Ask to make a call~~
11. ~~Move around~~
12. ~~… (location update, release call, handover, etc …)~~

Next

- This was all for 5G SA, what about NSA
- 5G has a lot of fancier ways to send bits
- 5G Slicing

- Wifi