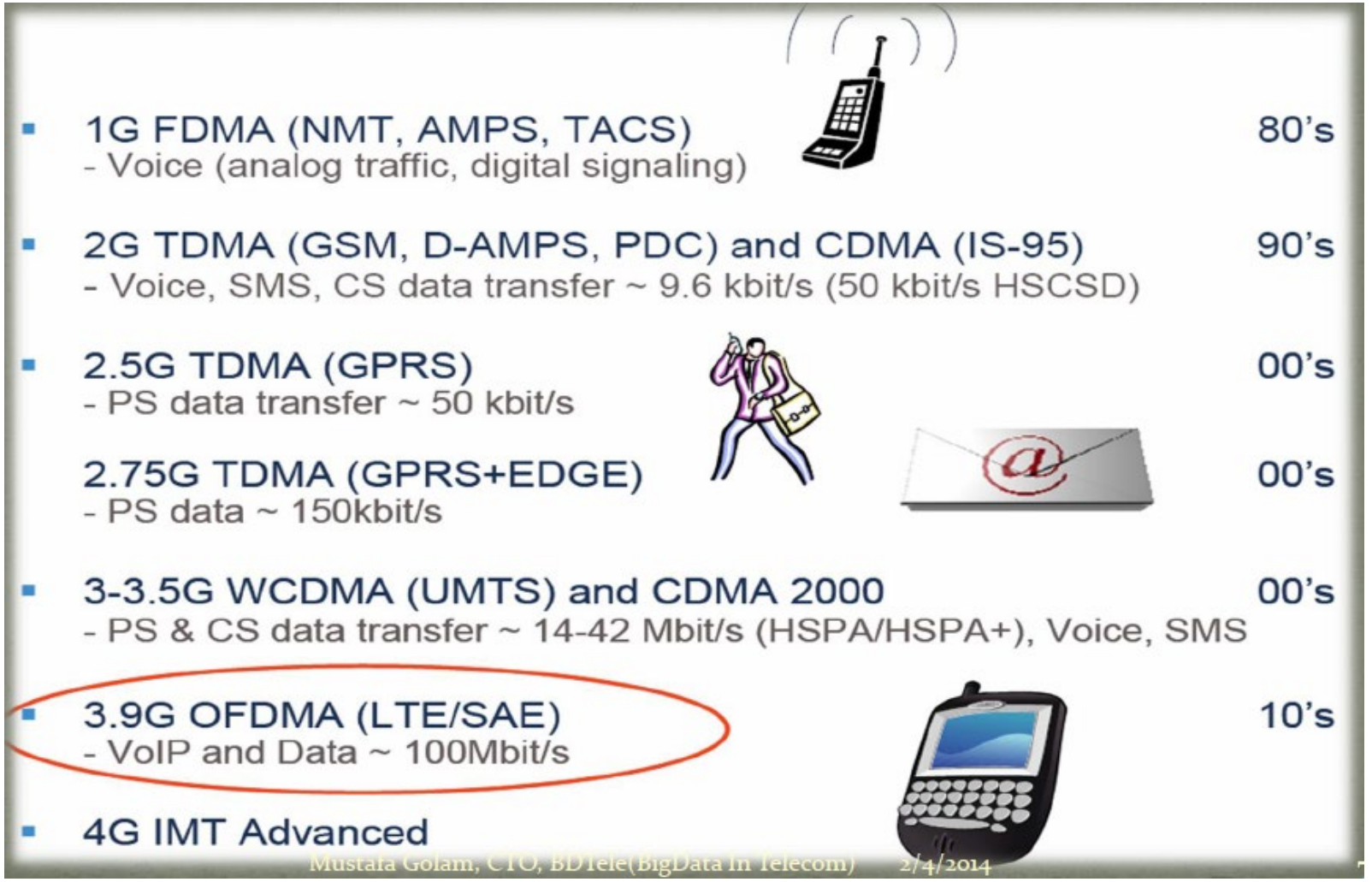
Introduction to Cellular Systems

Lecturer: Dr. Rui Wang

1st MOBILE RADIO TELEPHONE 1924

Courtesy of Rich Howard

History of Cellular Networks



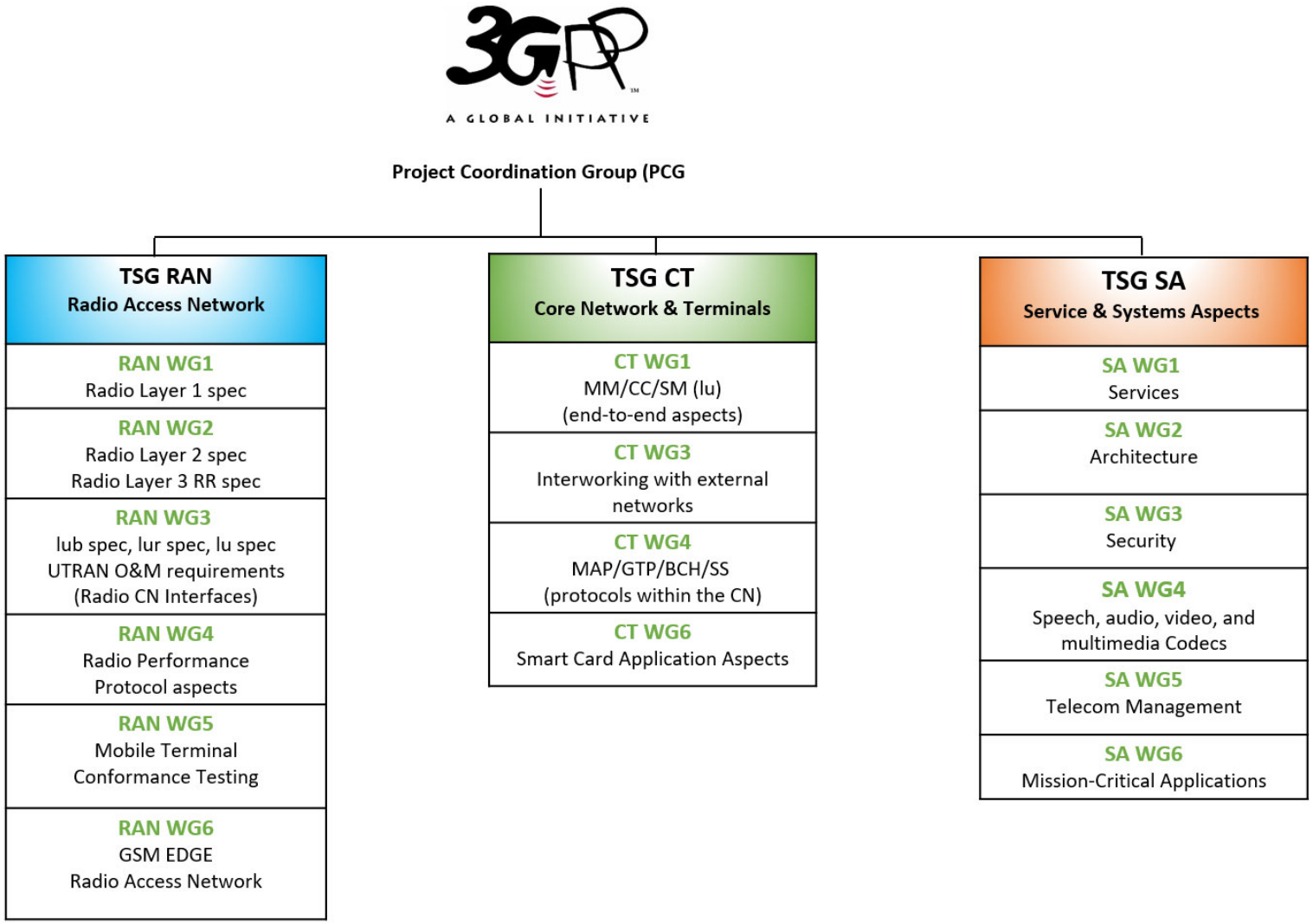
About 3GPP

- “The 3rd Generation Partnership Project (3GPP) unites [Seven] telecommunications standard development organizations (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC), known as “Organizational Partners” and provides their members with a stable environment to produce the Reports and Specifications that define 3GPP technologies.”
- “The project covers cellular telecommunications technologies, including **radio access, core network and service capabilities**, which provide a complete system description for mobile telecommunications.”
- “The 3GPP specifications also provide hooks for non-radio access to the core network, and for interworking with non-3GPP networks.”

--- https://www.3gpp.org/about-3gpp/about-3gpp

Organization of 3GPP

Three Technical Specification Groups (TSG) in 3GPP

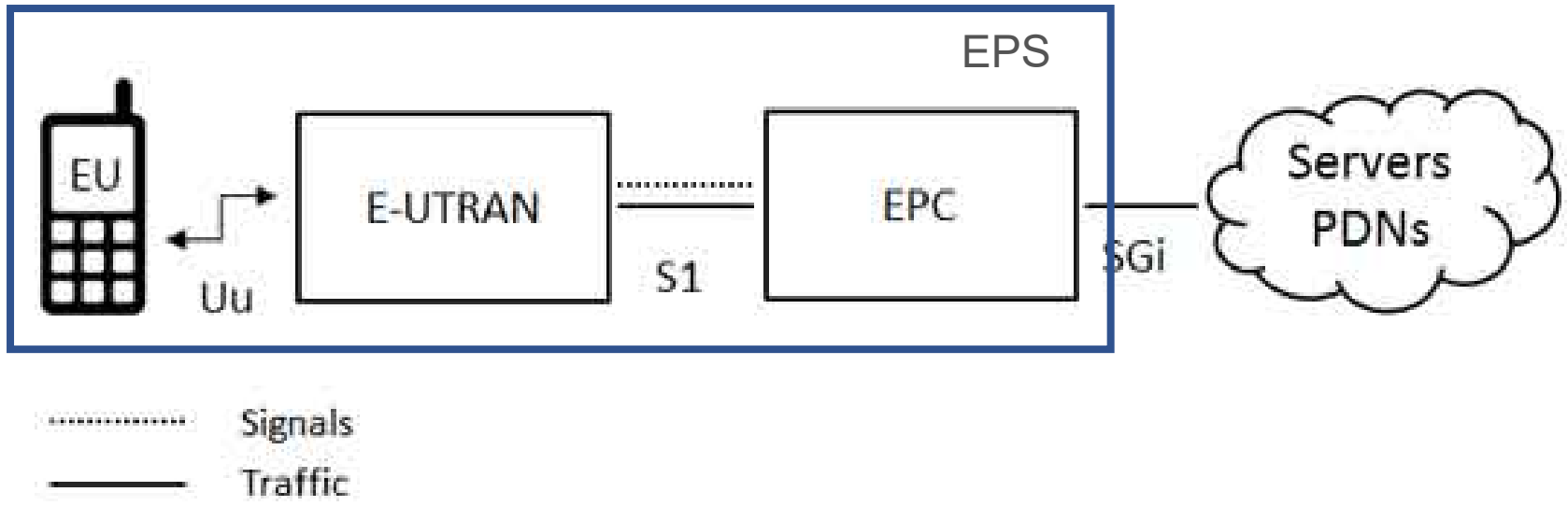


"**The TSG Service and System Aspects (TSG-SA)** is responsible for the overall architecture and service capabilities of systems based on 3GPP specifications and, as such, has a responsibility for cross TSG co-ordination."

"**The TSG Core Network and Terminals (TSG CT)** is responsible for specifying terminal interfaces (logical and physical), terminal capabilities (such as execution environments) and the Core network part of 3GPP systems."

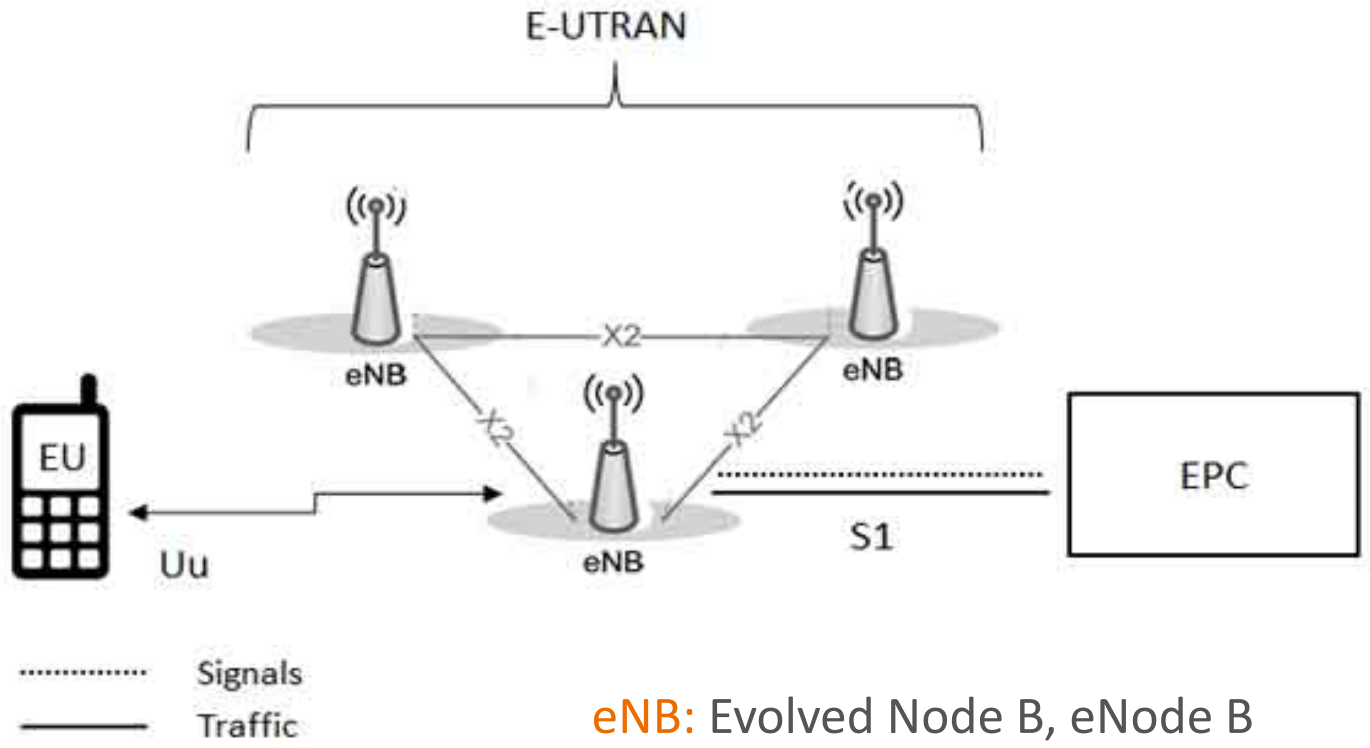
What are the major differences between cellular and Wi-Fi?

4G: EPS Architecture



E-UTRAN: Evolved UMTS Terrestrial Radio Access Network (LTE)
EPC: Evolved Packet Core
PDN: Public Data Network
EPS: Evolved Packet System

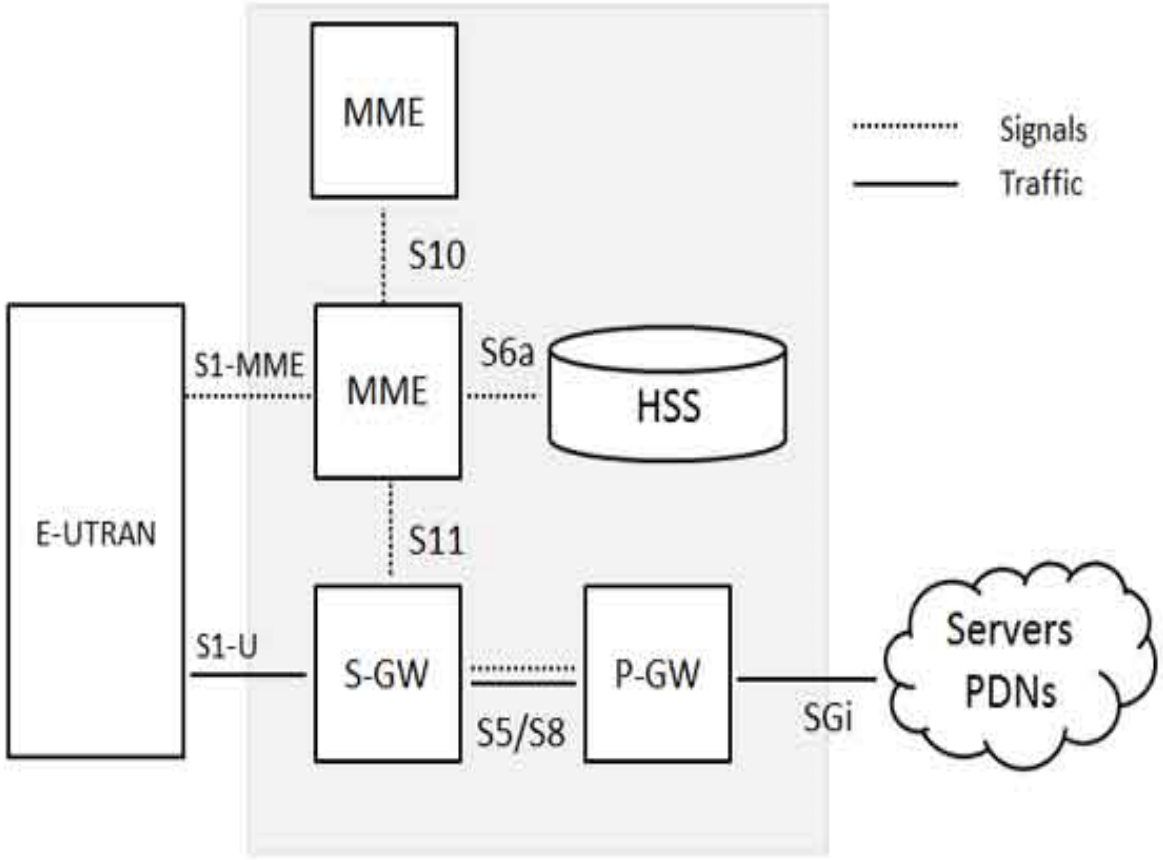
E-UTRAN



eNB: Evolved Node B, eNode B

- The eNB sends and receives radio transmissions to all the mobiles.
- The eNB controls the low-level operation of all its mobiles, such as handover commands.

EPC



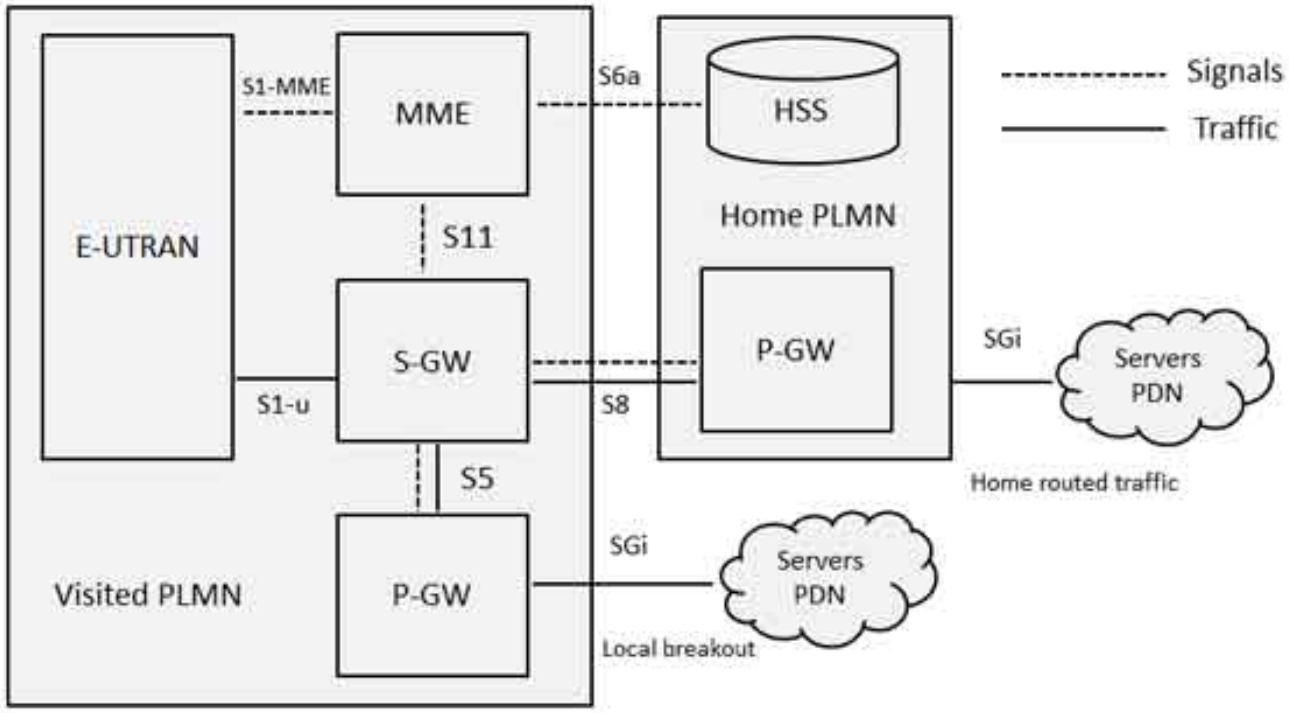
The Home Subscriber Server (HSS) contains information about all the network operator's subscribers.

The Packet Data Network (PDN) Gateway (P-GW) communicates with the outside world, i.e. packet data networks PDN, using SGi interface.

The serving gateway (S-GW) acts as a router, and forwards data between the base station and the PDN gateway.

The mobility management entity (MME) controls the high-level operation of the mobile by means of signalling messages and Home Subscriber Server (HSS).

Roaming

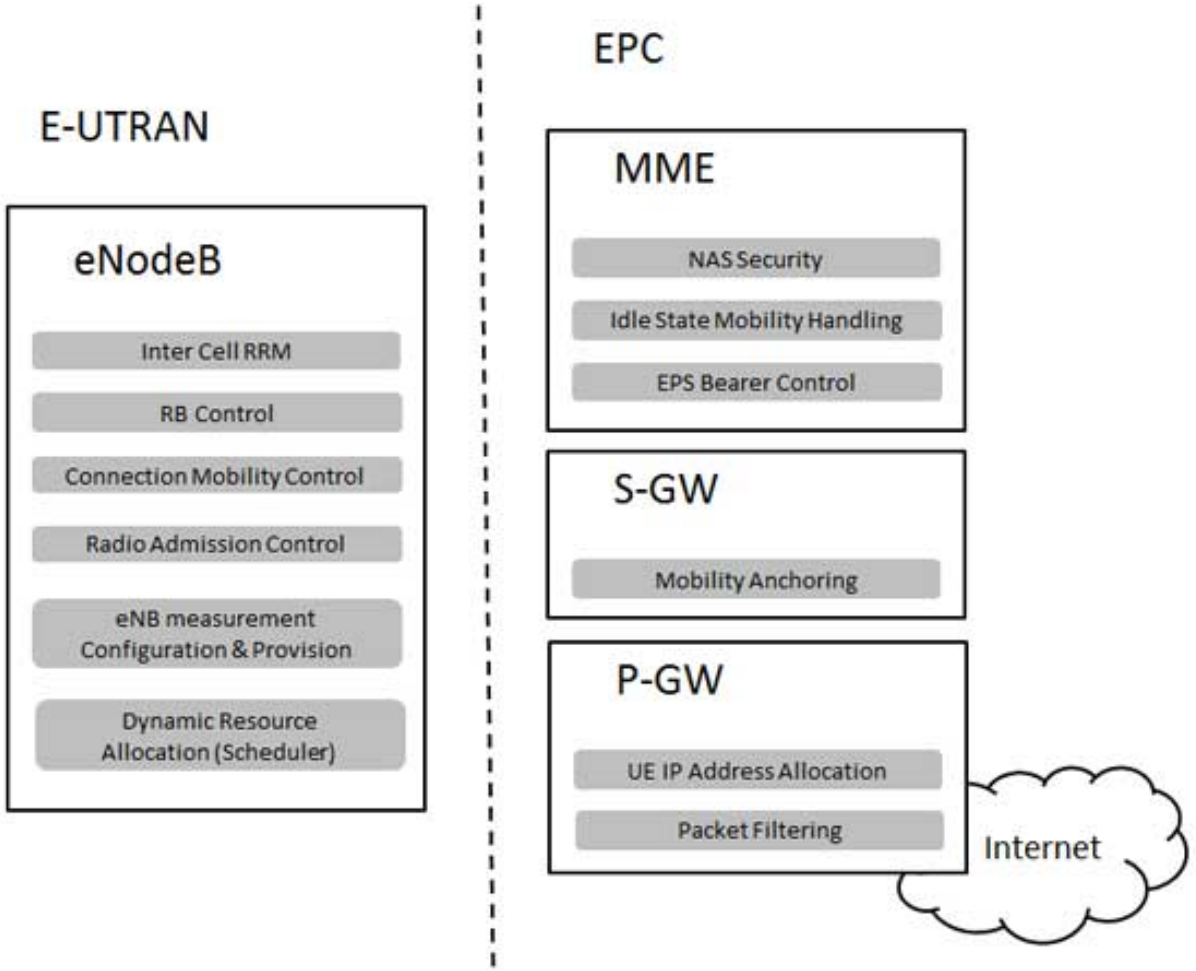


A network run by one operator in one country is known as a Public Land Mobile Network (PLMN)

When a subscribed user uses his operator's PLMN then it is said Home-PLMN

Roaming allows users to move outside their home network and using the resources from other operator's network. This other network is called Visited-PLMN.

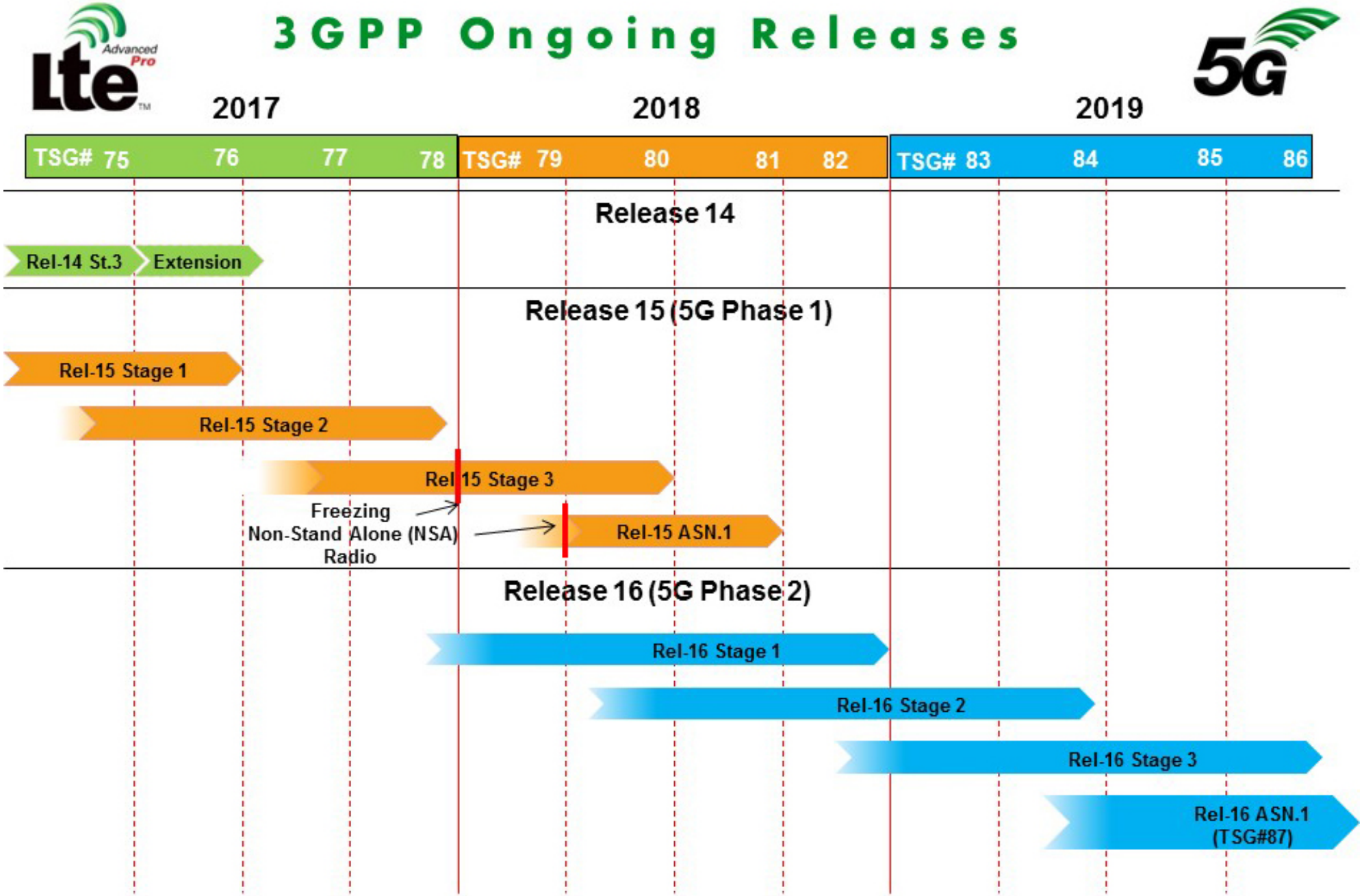
Functional Split

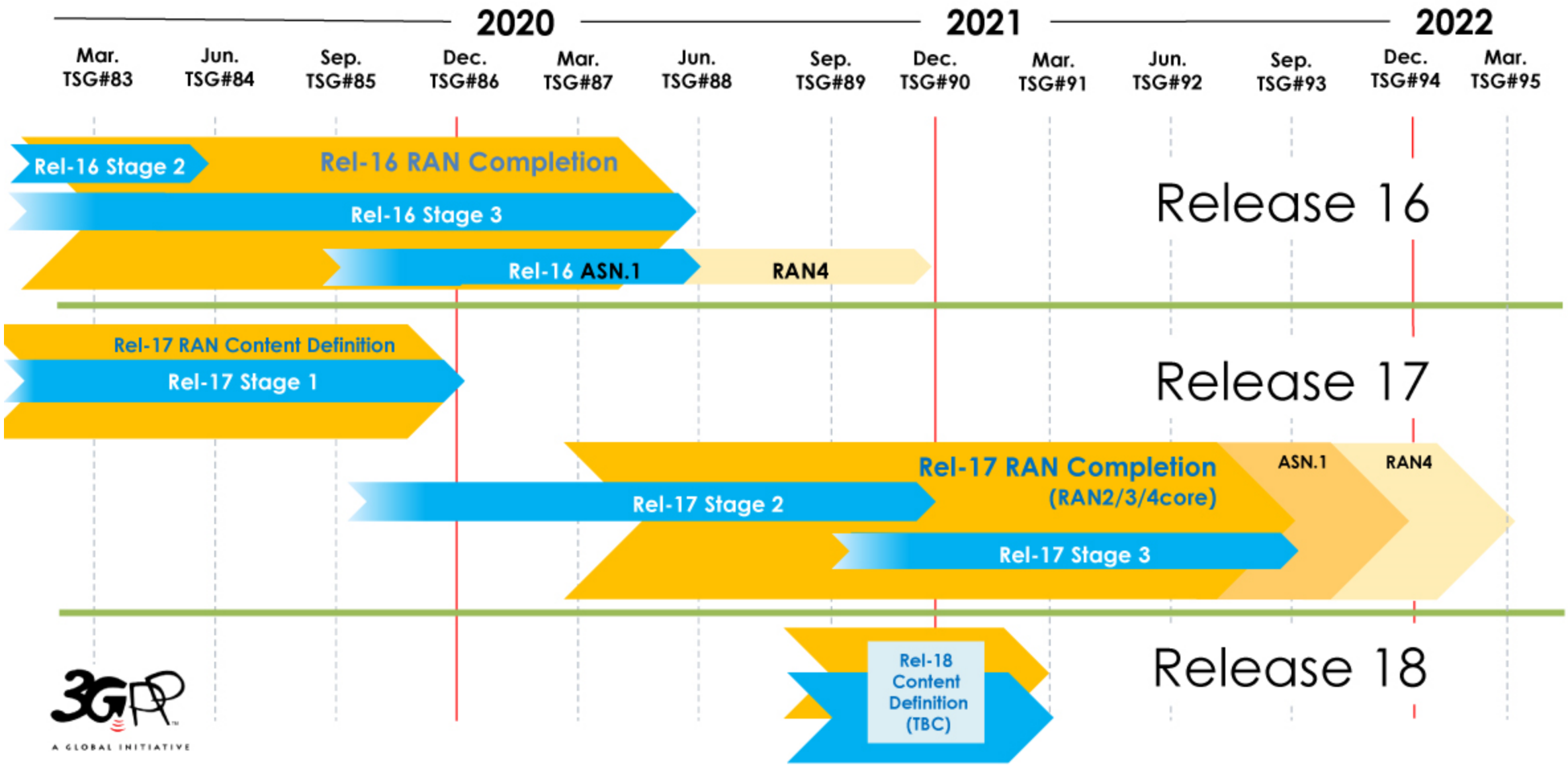


3GPP Releases on 4G

Release Number	Description	Date of Frozen
8	**LTE Introduced**	2008
9	**Enhancement to LTE**	2009
10	**LTE Advanced**	2011
11	**Enhancement to LTE Advanced**	2012
12	**Further enhancement to LTE Advanced**	2014
13	**Meeting the growing throughput demand**	2015
14	**Start of 5G**	2016

3GPP Ongoing Releases





Source: 3GPP TSG SA#87e, 17-20 March 2020, e-meeting document SP-200222

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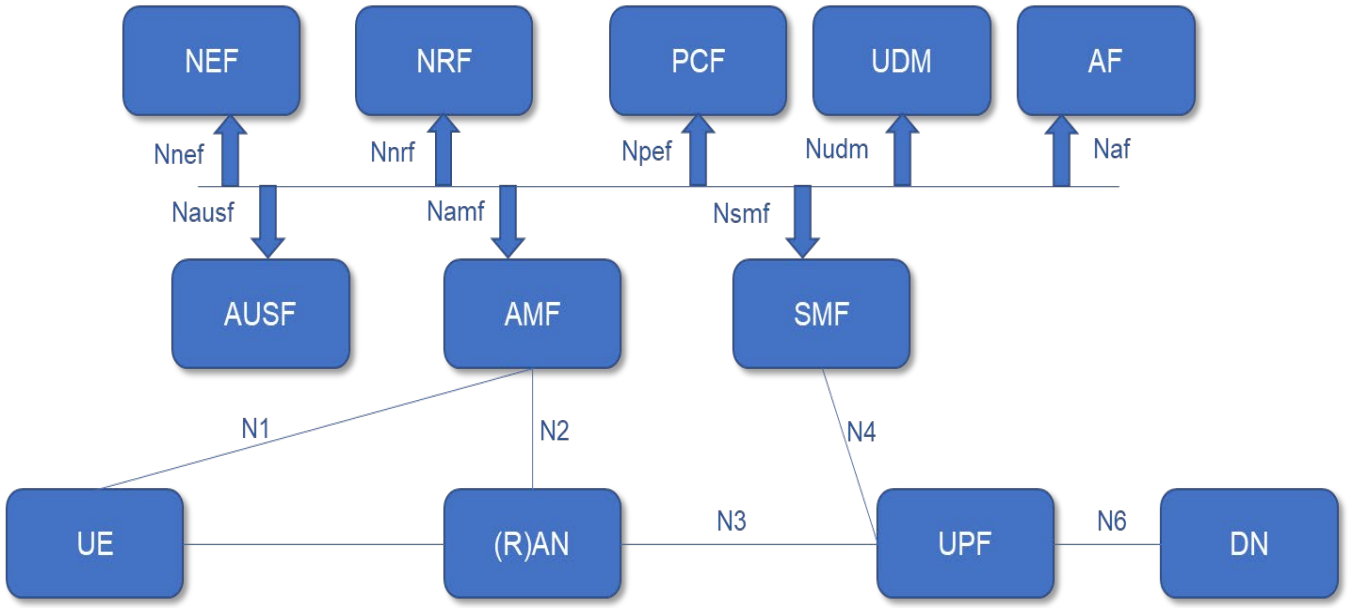
Architecture of 5G Systems



The 5G System (5GS) will have three main components:

- 5G Access Network (5G-AN)
- 5G Core Network (5GC)
- Use Equipment (UE)

Authentication Server Function (AUSF)

Core Access and Mobility Management Function (AMF)

Data network (DN)

Network Exposure Function (NEF)

NF Repository Function (NRF)

Policy Control function (PCF)

Session Management Function (SMF)

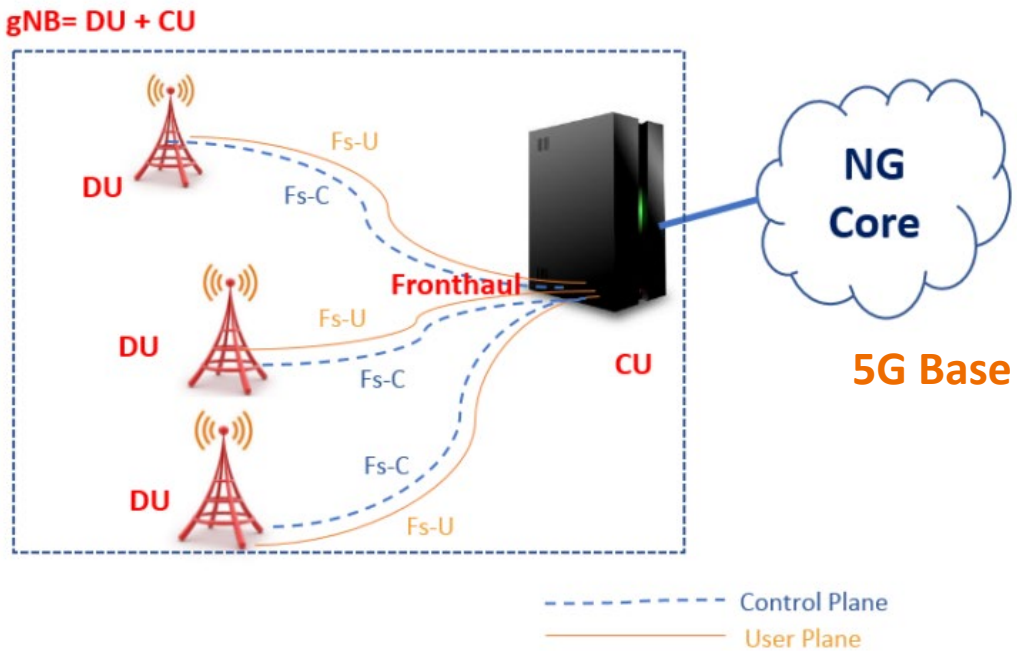
Unified Data Management (UDM)

User plane Function (UPF)

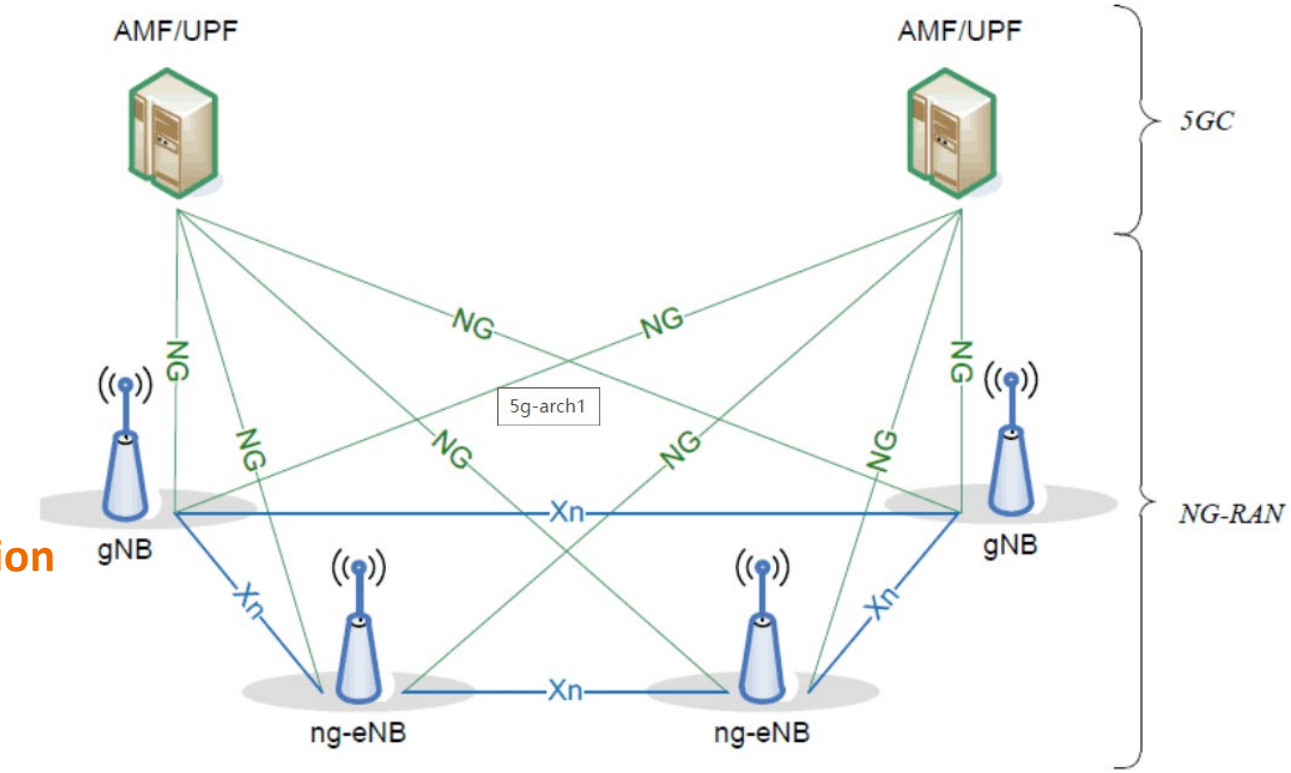
Application Function (AF)

User Equipment (UE)

(Radio) Access Network ((R)AN)



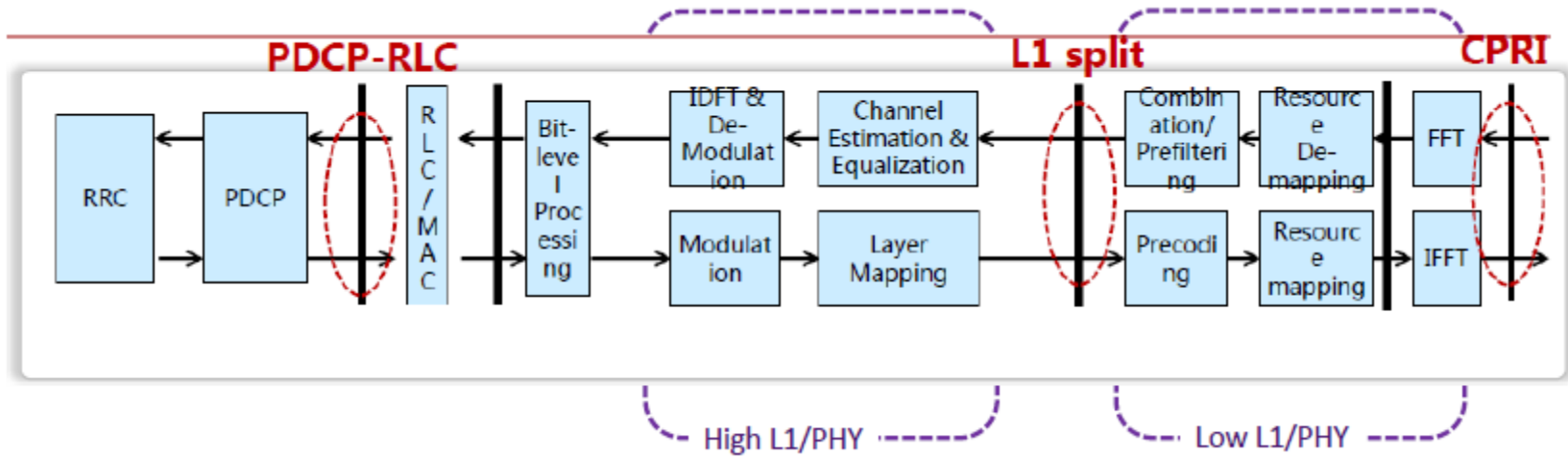
5G Base Station



4G Base Station connected to 5G Core

Traditional BS is divided into RRH+DU+CU structure

- RRH: Radio transmission and receiving
- DU: baseband close to RRH
- CU: baseband in cloud center



Specification Numbering

- “All 3GPP specifications have a specification number consisting of 4 or 5 digits. (e.g. 09.02 or 29.002).”
- “The first two digits define the series, followed by 2 further digits for the 01 to 13 series or 3 further digits for the 21 to 55 series.”

---https://www.3gpp.org/specifications/specification-numbering

- Each specification defines a component of 3GPP systems. With the development of new releases, the specification version will be updated

Spec no.	Title	Rel-12	Rel-13
36.211	Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation	12.9.0	13.5.0
36.321	Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification	12.9.0	13.5.0
36.423	Evolved Universal Terrestrial Radio Access Network (E-UTRAN); X2 Application Protocol (X2AP)	12.9.0	13.6.0

How to find the specification

- Specification Release version matrix: http://www.3gpp.org/DynaReport/SpecReleaseMatrix.htm
- TR: technical report (e.g. TR25.996)
- TS: technical specification
- Locate the specification by number and version

Spec no.	Title	WG	Ph1	Ph1-DCS	Ph1-EXT	UMTS	Ph2	R96	R97	R98	R99	R00	Rel-4	Rel-5	Rel-6	Rel-7	Rel-8	Rel-9	Rel-10	Rel-11	Rel-12	Rel-13	Rel-14	Rel-15	Rel-16	Rel-17
00.01U	Work programme for the standardization of Universal Mobile Telecommunications System (UMTS) spec withdrawn	SMG5				*none*																				
00.02	Voice group call service study (UIC project) spec withdrawn	-	*none*																							
00.02U	Coordination guideline for SMG on UMTS with respect to ITU and European research programmes spec withdrawn	SMG5				*none*																				
01.00	Working Procedures for SMG and PT SMG spec withdrawn	SP					*none*	*none*	*none*	*none*	*none*															

23.501	System architecture for the 5G System (5GS)	S2																				15.9.0	16.4.0

General | Versions | Responsibility | Related

Specification #: 23.501

Release 16(Spec is UCC for this Release) **Latest Remark:**

Meetings	Version	Upload date	Comment
SA#87-E	16.4.0	2020-03-27	Version updated with TSG SA#8...
SA#86	16.3.0	2019-12-22	Version updated with TSG SA#8...
SA#85	16.2.0	2019-09-24	Version updated with TSG SA#8...
SA#84	16.1.0	2019-06-11	Version updated with TSG SA#8...
SA#83	16.0.2	2019-04-01	MCC correction swapping claus...
SA#83	16.0.1	2019-04-01	MCC correction of clause 5.29...
SA#83	16.0.0	2019-03-28	Rel-16 Version created with T...

Release 15(Spec is UCC for this Release) **Latest Remark:**

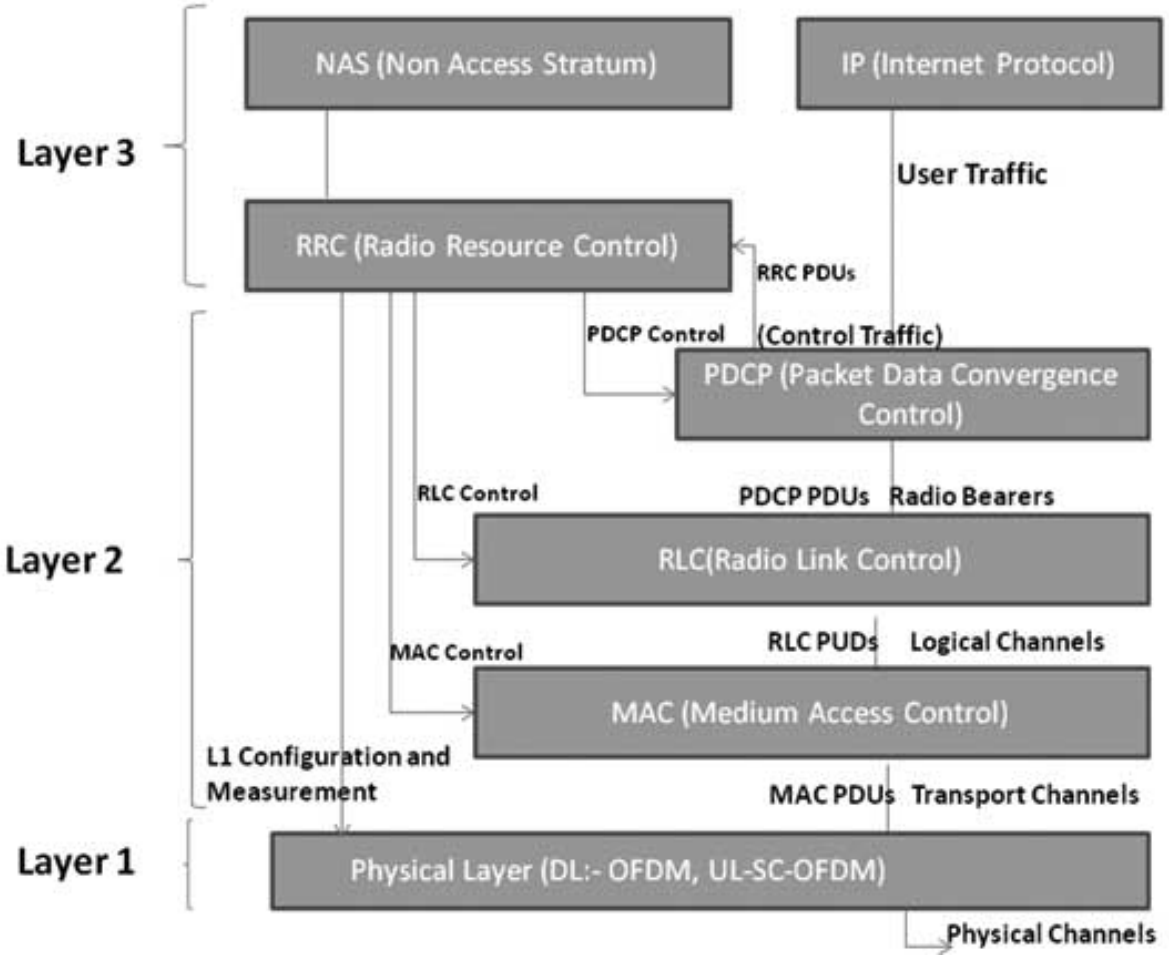
Meetings	Version	Upload date	Comment
SA#87-E	15.9.0	2020-03-27	Version updated with TSG SA#8...
SA#86	15.8.0	2019-12-22	Version updated with TSG SA#8...
SA#85	15.7.0	2019-09-24	Version updated with TSG SA#8...
SA#84	15.6.0	2019-10-09	Version updated with TSG SA#8...
SA#83	15.5.0	2019-03-25	Version updated with TSG SA#8...
SA#82	15.4.0	2018-12-18	Version updated with TSG SA#8...
SA#81	15.3.0	2018-09-17	Version updated with TSG SA#8...
SA#80	15.2.0	2018-06-19	Version updated with TSG SA...

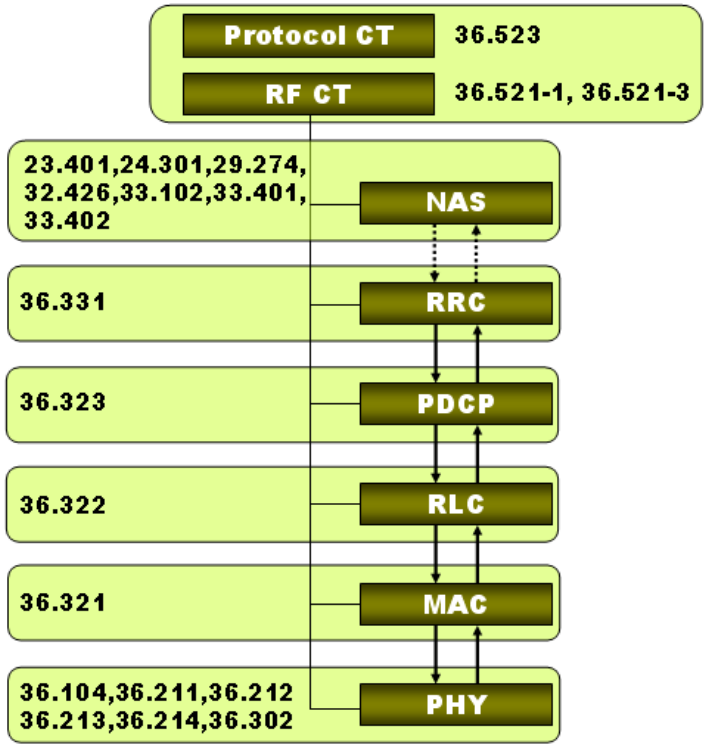
3GPP TS 23.501 V16.4.0 (2020-03)

Technical Specification

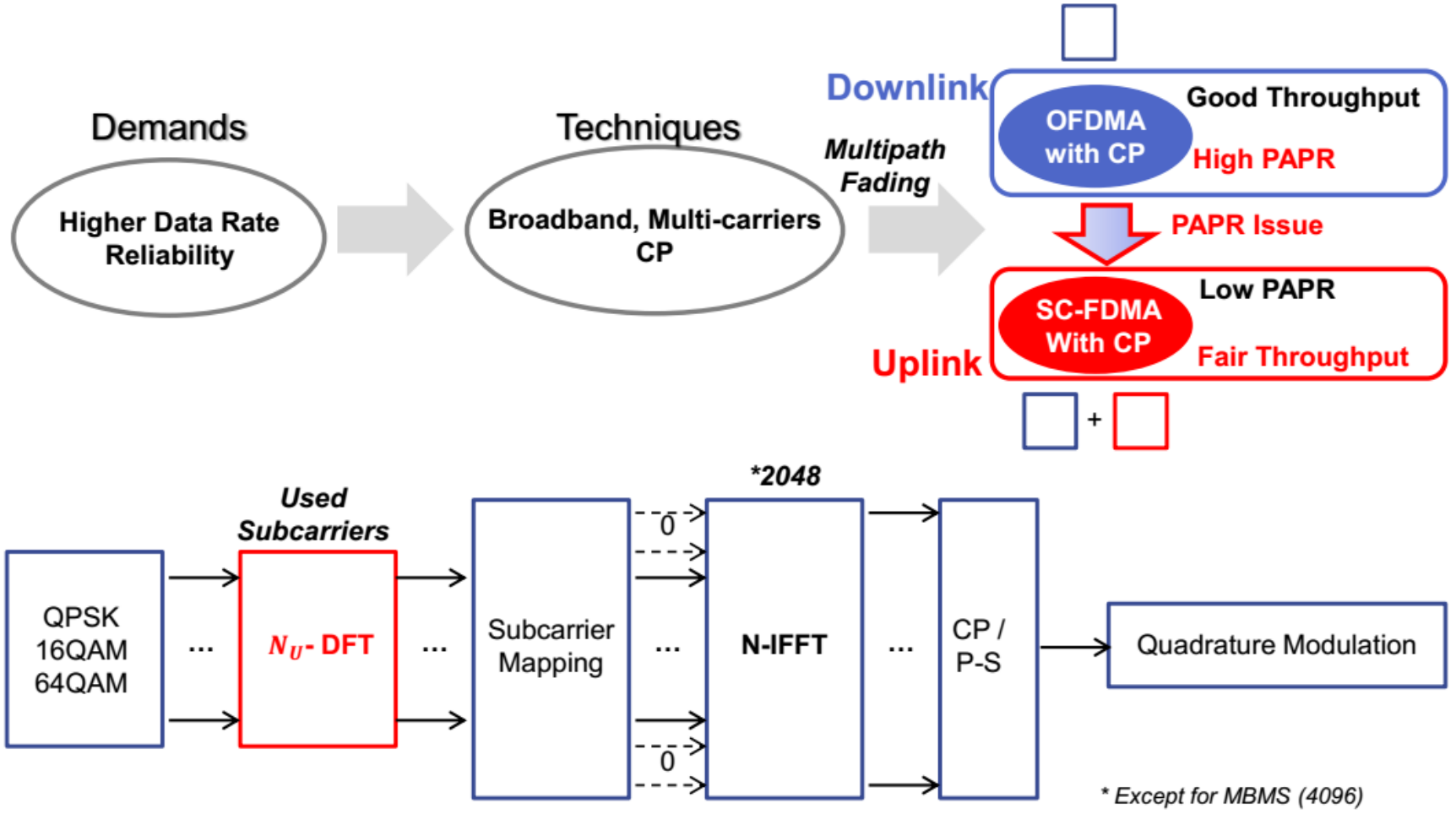
3rd Generation Partnership Project;
Technical Specification Group Services and System Aspects;
System architecture for the 5G System (5GS);
Stage 2
(Release 16)

LTE Protocol Architecture





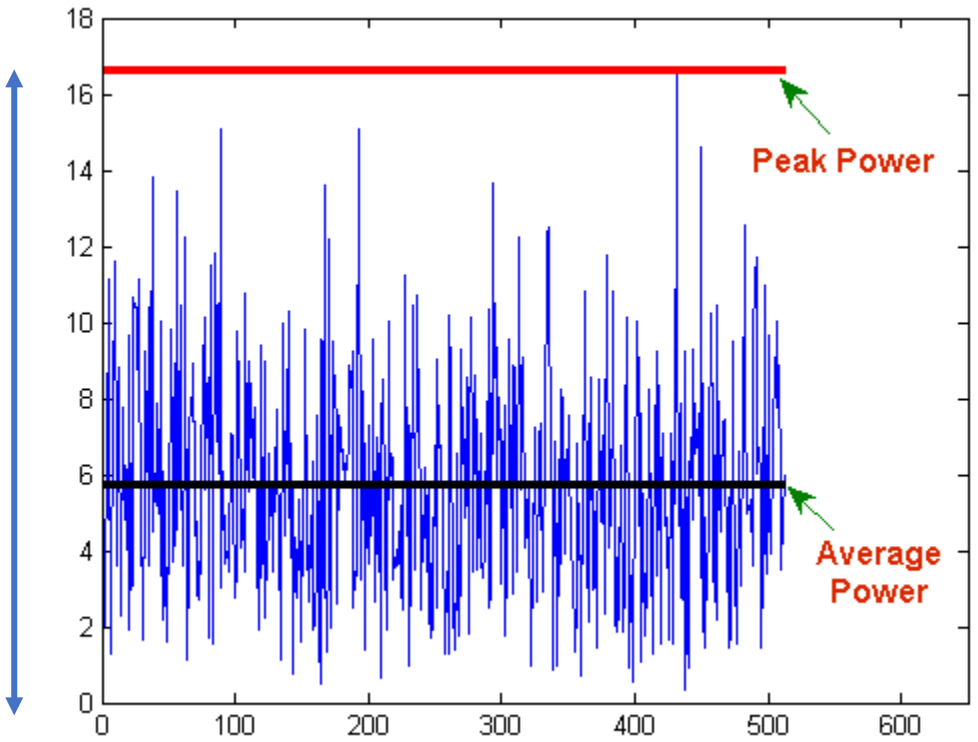
LTE Signals – OFDM



Peak-to-Average Power Ratio (PAPR)

Linear Region of Power Amplifier

High PAPR implies high cost on the PAs



Peak-to-Average Power Ratio

- Inverse DFT: $\mathrm{x_n} = \frac{1}{N}\sum_{k=0}^{N-1} X_k e^{j\frac{2\pi kn}{N}}$
- For the simplicity of analysis, suppose the signal is 1, then $\mathrm{x_n} = [1,0,0,0, \dots]$
- Maximum signal power is 1
- Average signal power is 1/N
- PAPR = N increases w.r.t. the number of subcarriers
- SC-FDMA can reduce the PAPR

UL/DL Parameters

Channel bandwidth [MHz]	1.4	3	5	10	15	20
Number of resource blocks (N_{RB})	6	15	25	50	75	100
Number of occupied subcarriers	72	180	300	600	900	1200
IDFT(Tx)/DFT(Rx) size	128	256	512	1024	1536	2048
Sample rate [MHz]	1.92	3.84	7.68	15.36	23.04	30.72
Samples per slot	960	1920	3840	7680	11520	15360

Some Calculations

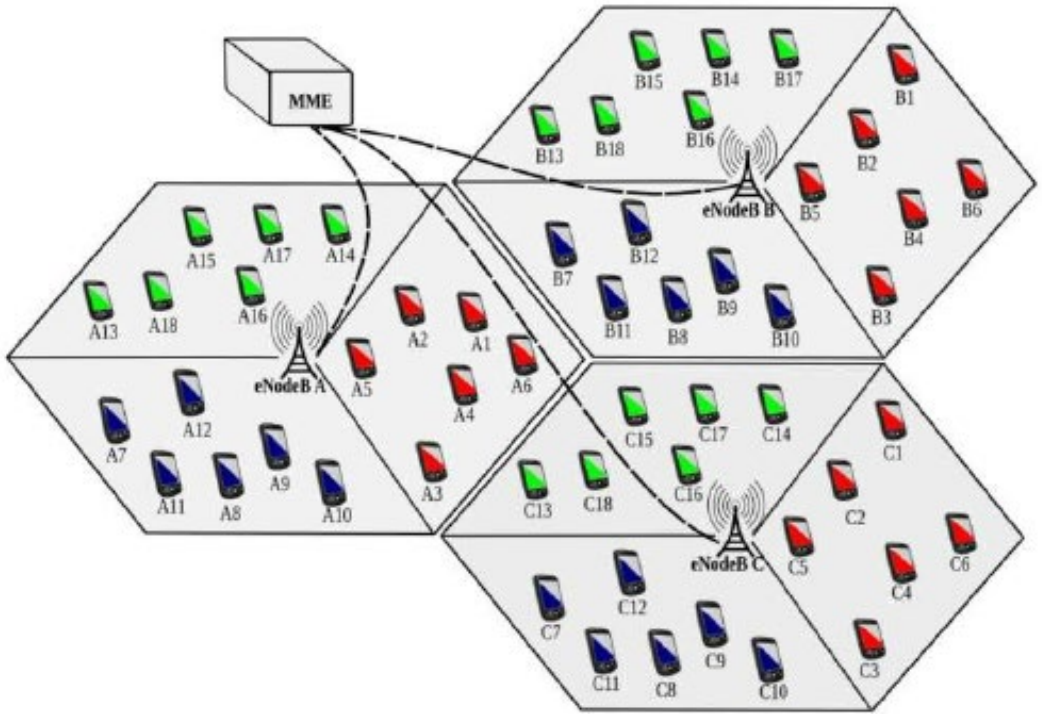
- Bandwidth = Sample Rate * # of occupied subcarriers / # of subcarriers
- E.g., 1.92M*72/128 = 1.08MHz < 1.4MHz

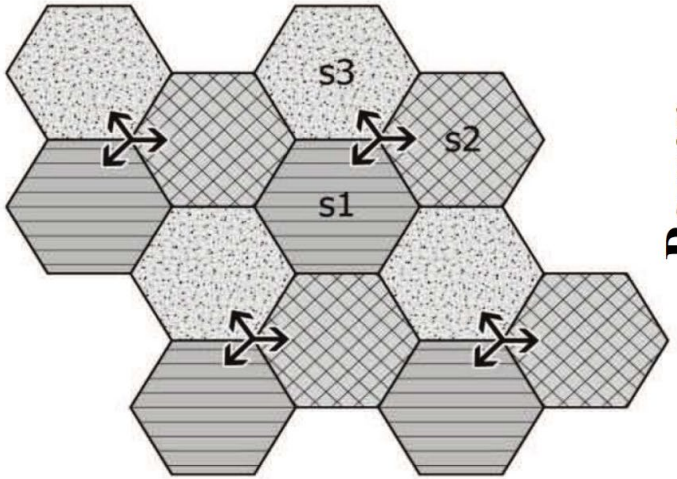
- Subcarrier Spacing = Sample Rate / # of subcarriers
- E.g., 1.92M/128 = 3.84M/256 = … = 15KHz

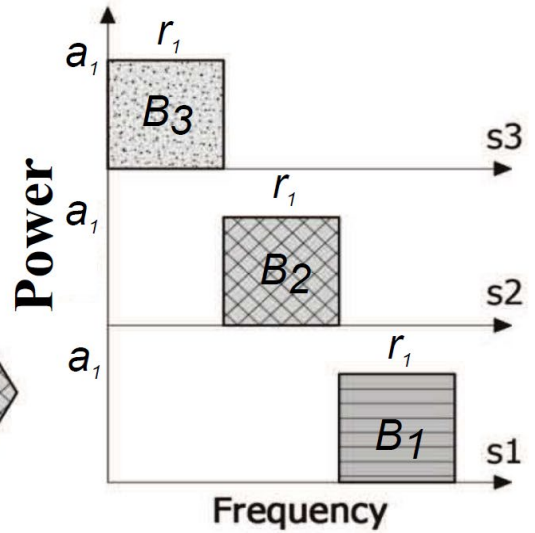
- OFDM Symbol Duration = # of subcarriers / Sample Rate = 1 / Subcarrier Spacing
- E.g., 1/15KHz

- Define Ts= OFDM Symbol Duration / 2048, which is basic time unit in LTE

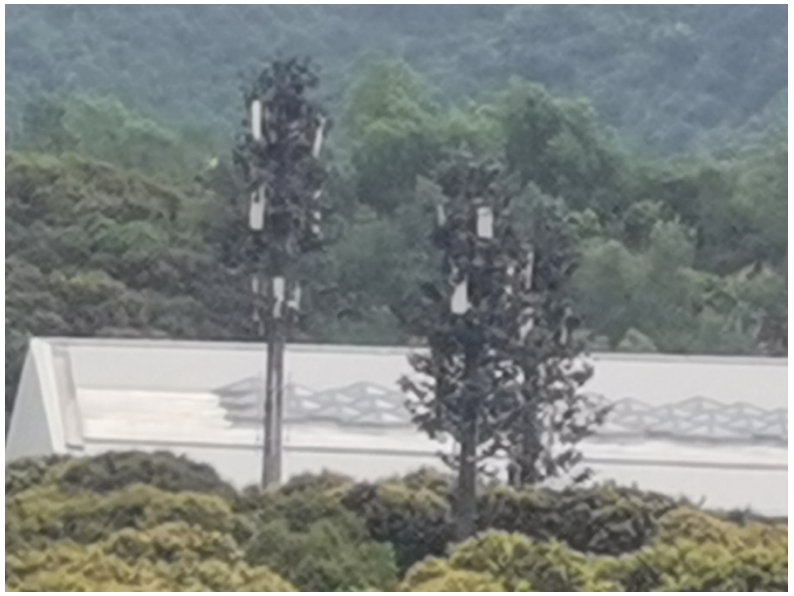
Sectors and Frequency Reuse

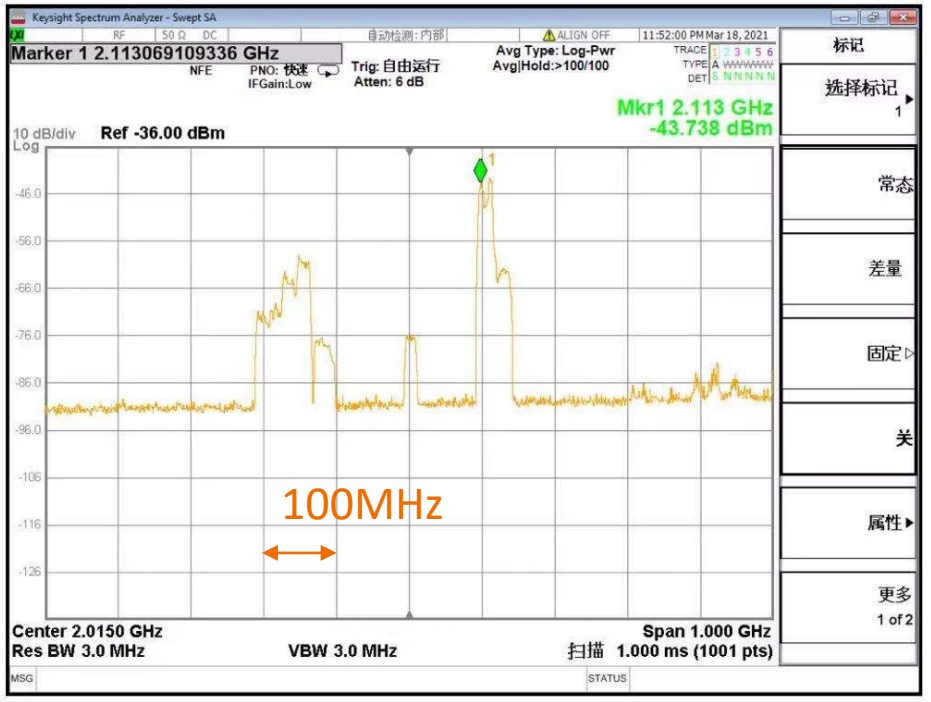




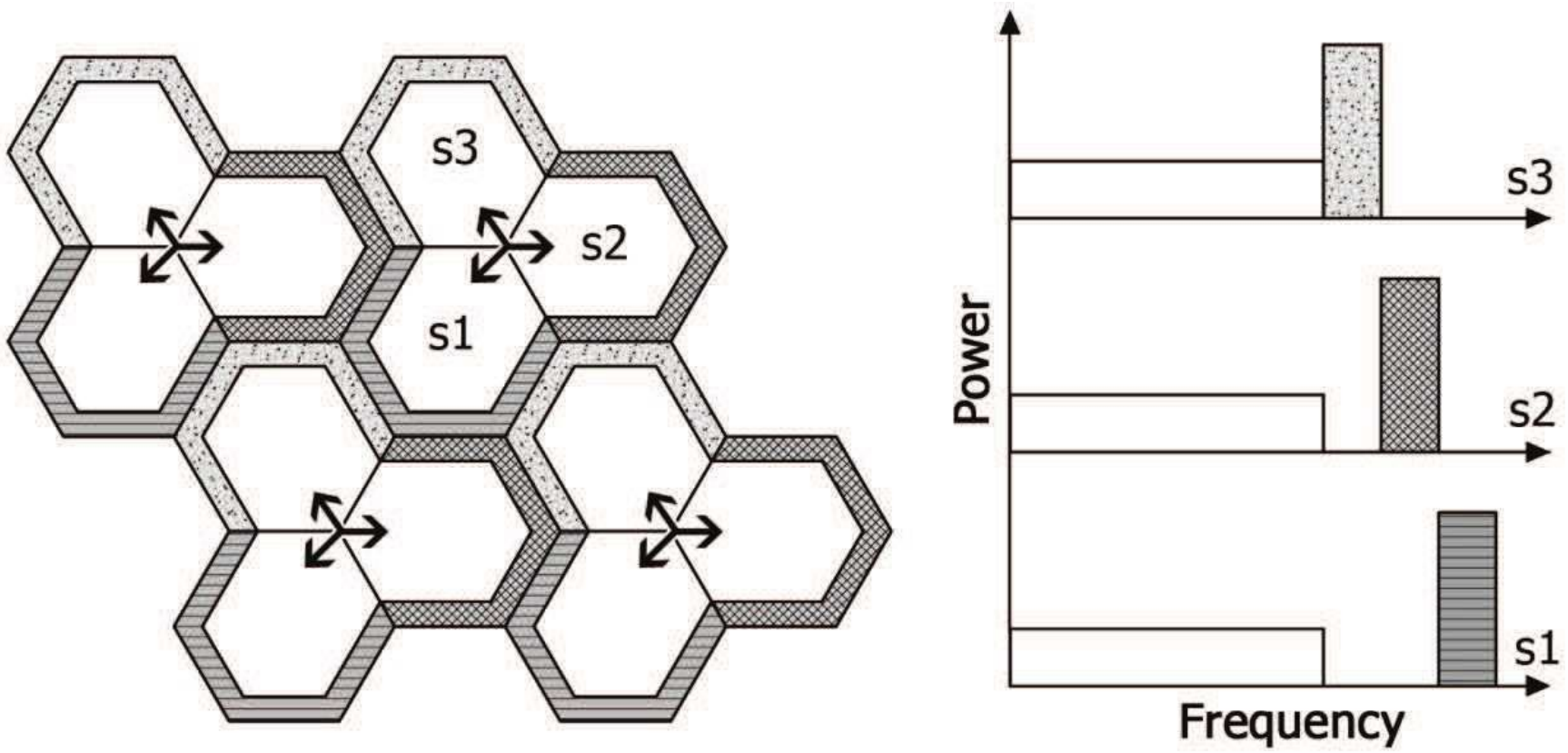


Sectors and Frequency Reuse

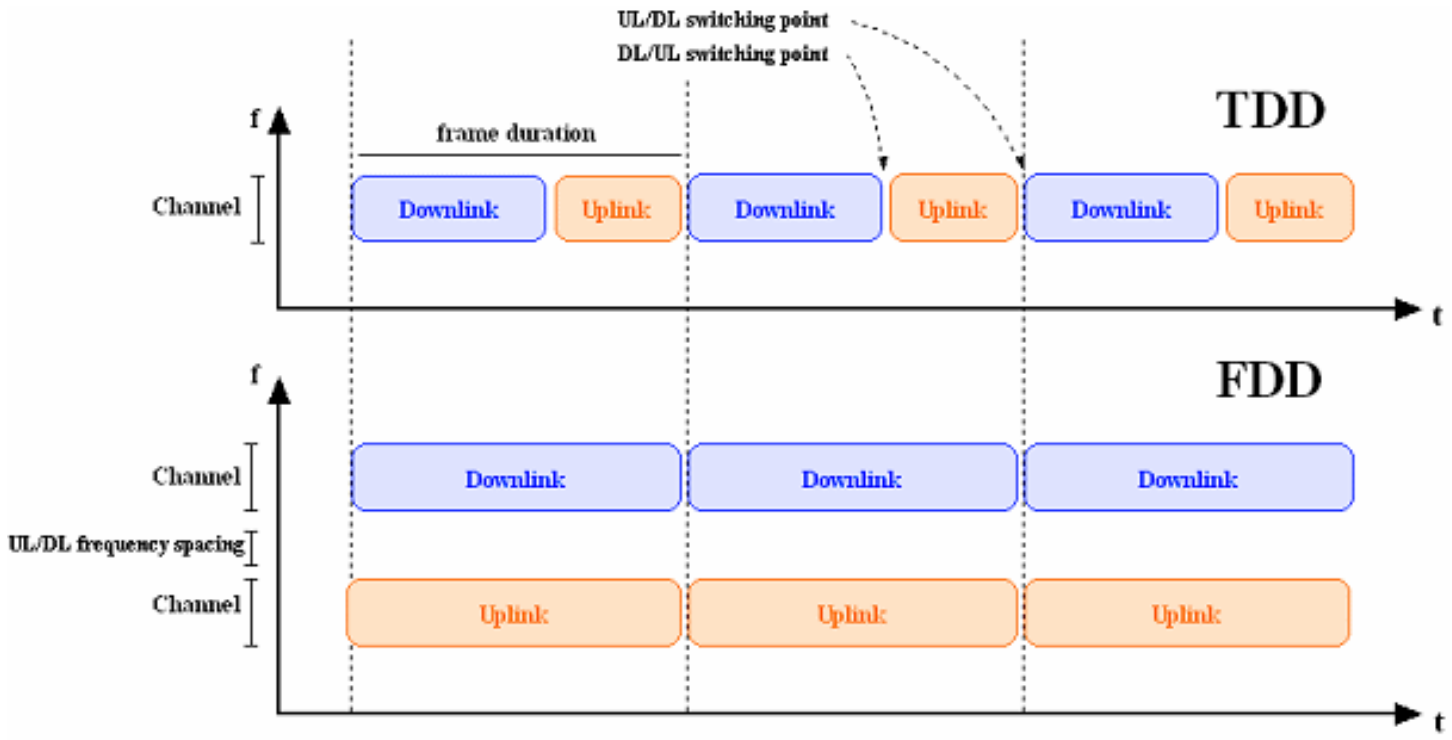




Soft/Fractional Frequency Reuse



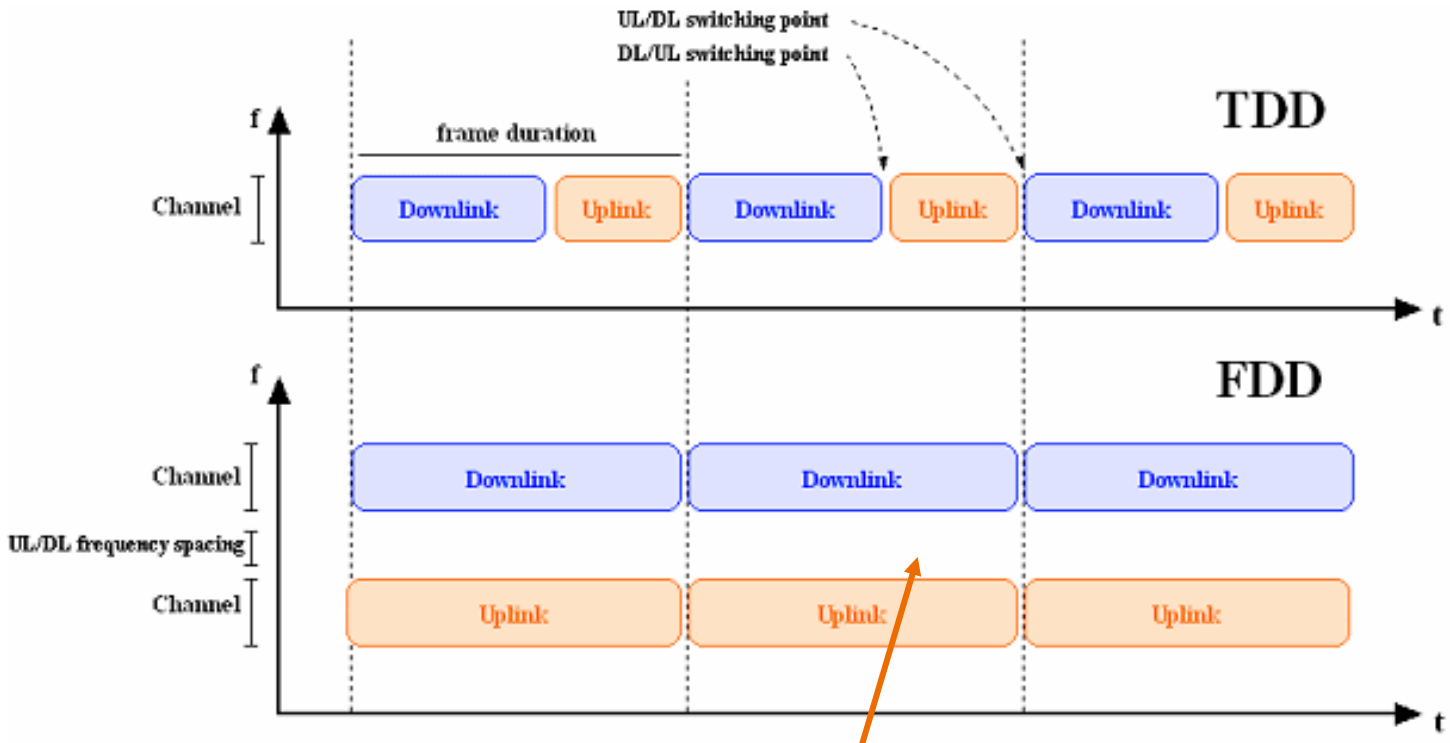
Duplexing Modes: TDD and FDD



Time-Division Duplex: same spectrum different time

Frequency-Division Duplex: same time different spectrum

Duplexing Modes: TDD and FDD



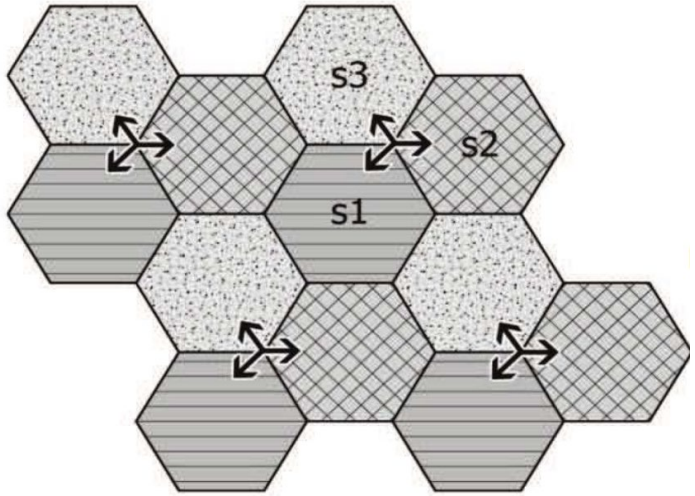
Time-Division Duplex: **same spectrum different time**

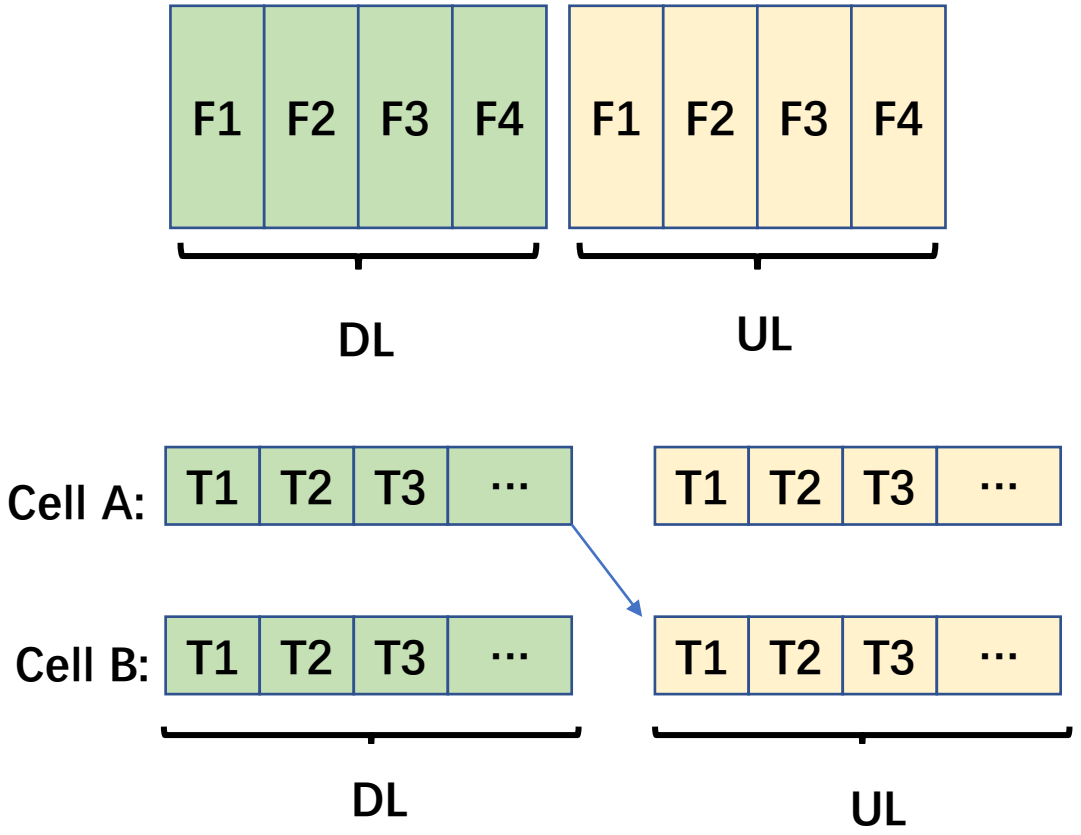
Frequency-Division Duplex: **same time different spectrum**

Guard band is required to isolated the mutual interference between downlink and uplink

TDD or FDD?

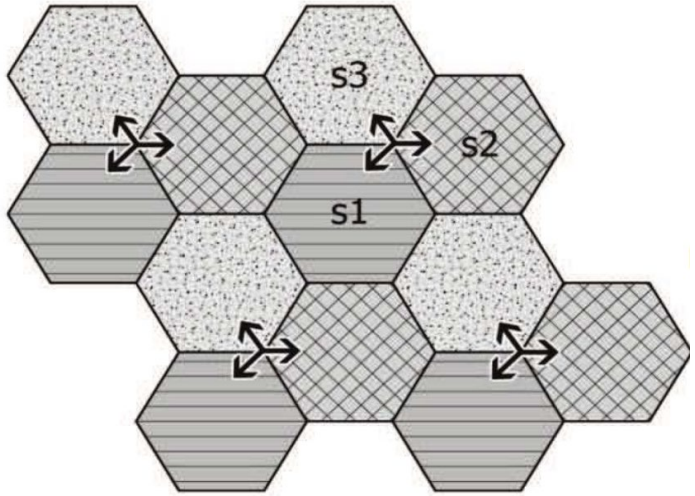
- TDD can dynamically adjust the UL and DL resource, however

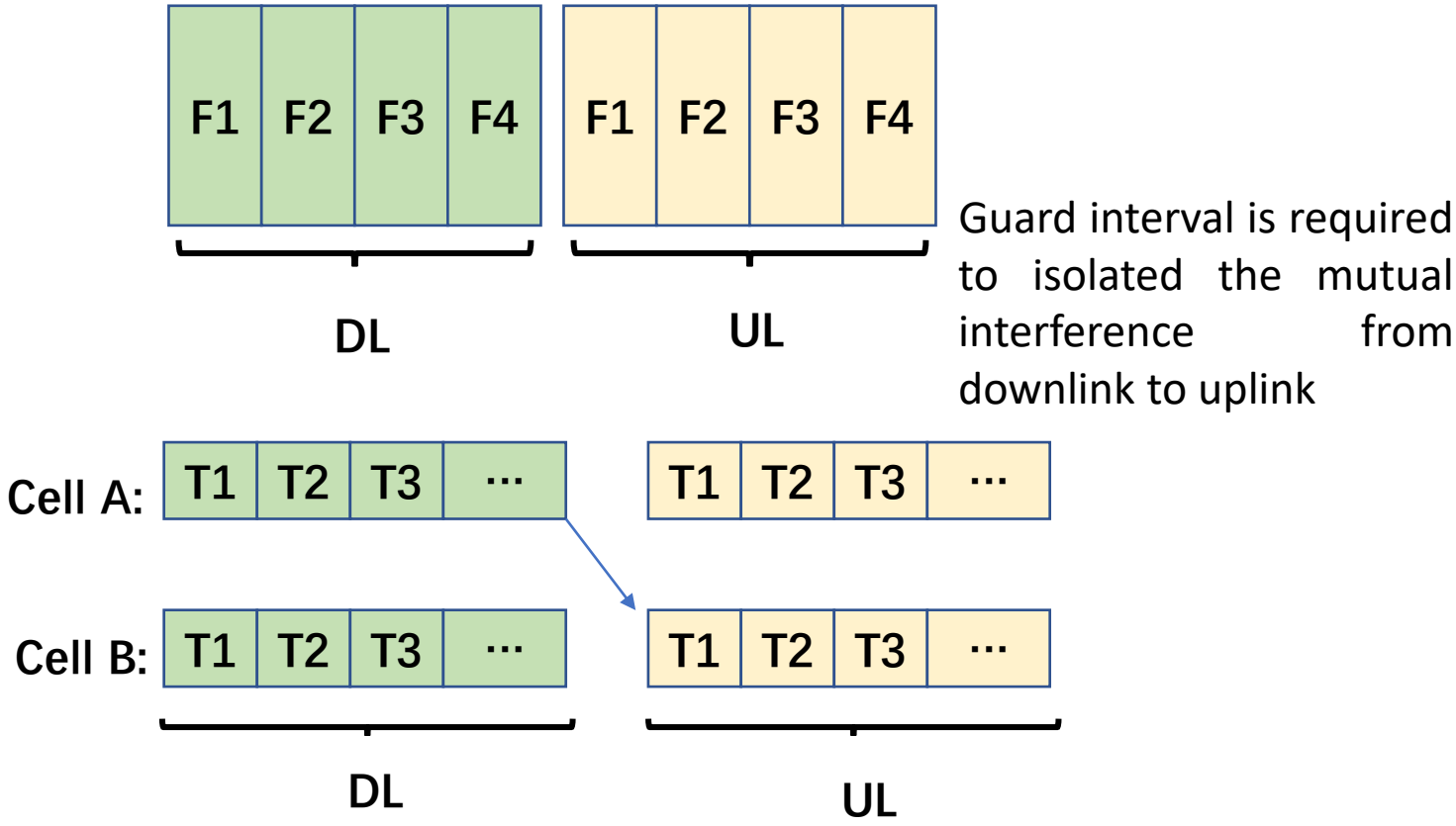




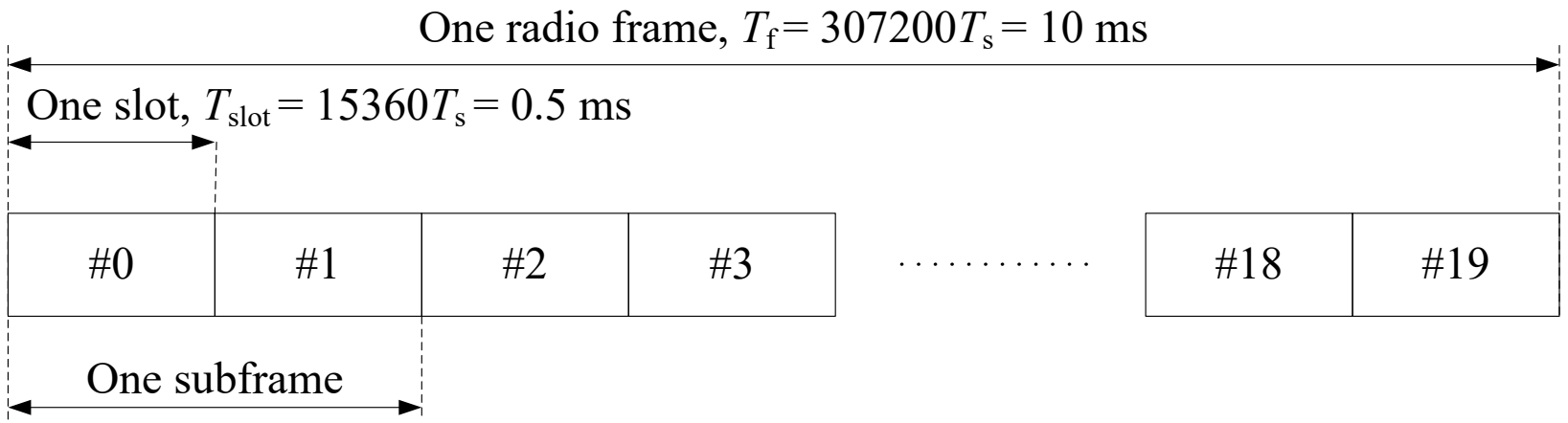
TDD or FDD?

- TDD can dynamically adjust the UL and DL resource, however





Frame Structure Type 1 (36.211, 4.1)

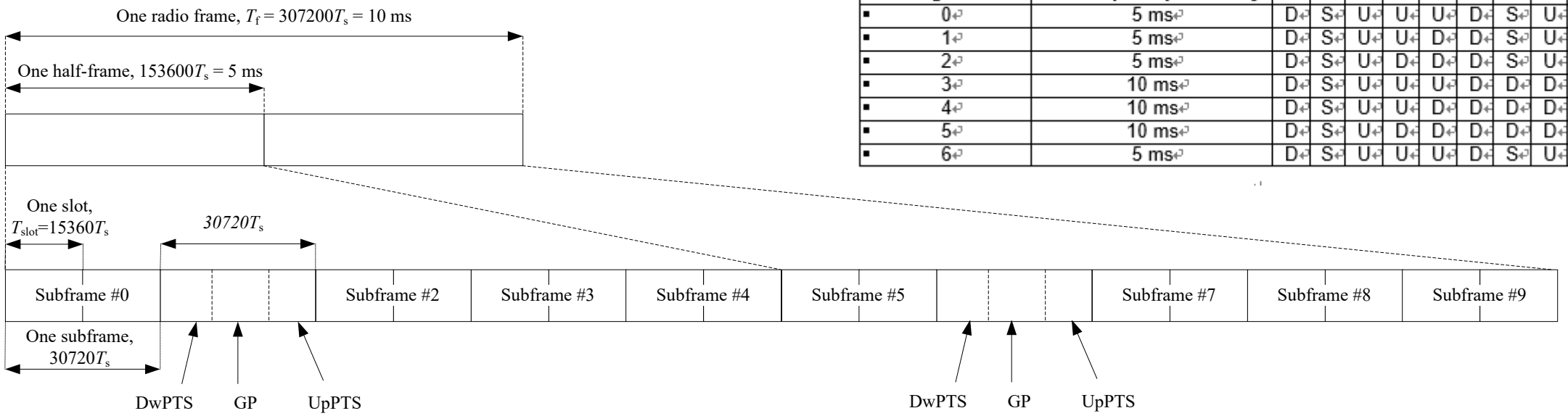


"Frame structure type 1 is applicable to both full duplex and half duplex **FDD** only. Each radio frame is $T_f = 307200 \cdot T_s = 10\,\text{ms}$ long and consists of **10 subframes** of length $30720 \cdot T_s = 1\,\text{ms}$, numbered from 0 to 9."

Each subframe is further divided into two slots, each with length $15360 \cdot T_s = 0.5$ ms

Frame Structure Type 2 (36.211, 4.1)

Uplink-downlink configuration	Downlink-to-Uplink Switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D



"Frame structure type 2 is applicable to **TDD** only. Each radio frame of length $T_f = 307200 \cdot T_s = 10ms$ consists of **two half-frames** of length $153600 \cdot T_s$ =5 ms each. Each half-frame consists of **five subframes** of length $30720 \cdot T_s$ =1 ms."

Each subframe is further divided into two slots, each with length $15360 \cdot T_s$ =0.5 ms

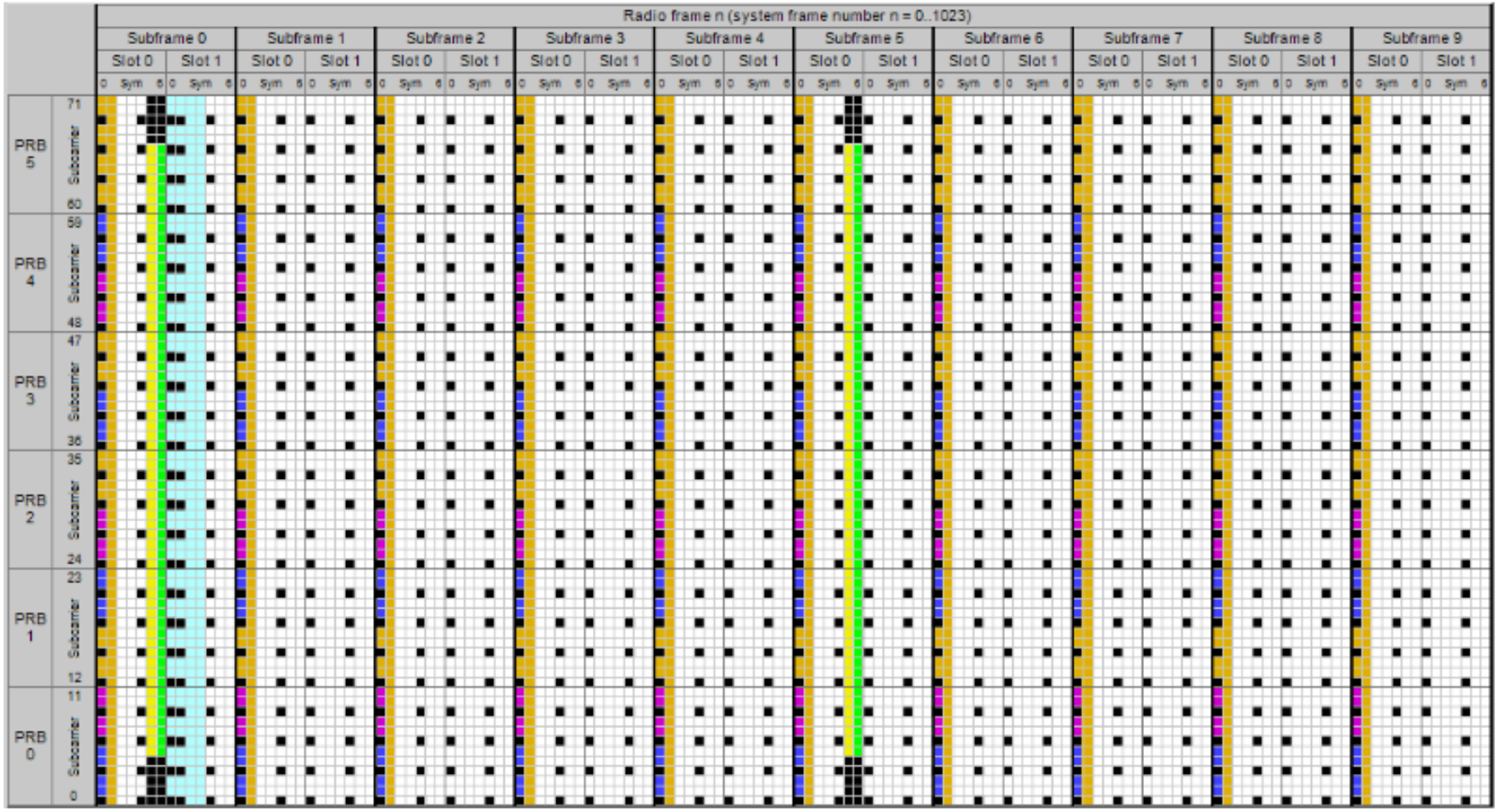
Cyclic Prefix

- Normal CP: **160Ts** first symbol and **144 Ts** the remaining symbols
- 7*2048+6*144+160 = 15360Ts = 0.5ms
- Light speed * CP = **1.4km**

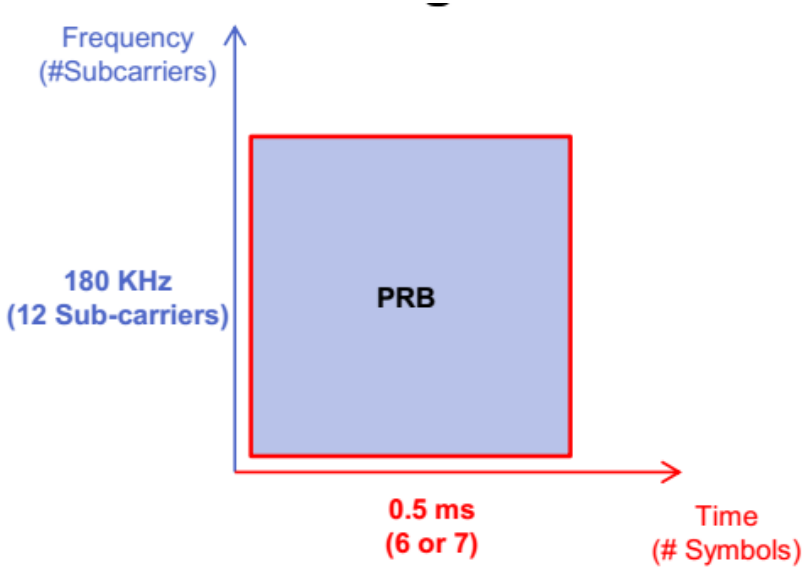
- Extended CP: **521Ts**
- 512*6+2048*6 = 15360Ts = 0.5ms
- Light speed * CP = **5km**

- With normal CP, there are **7** OFDM symbols per slot; with extended CP, there are **6** OFDM symbols per slot.

Resource Element

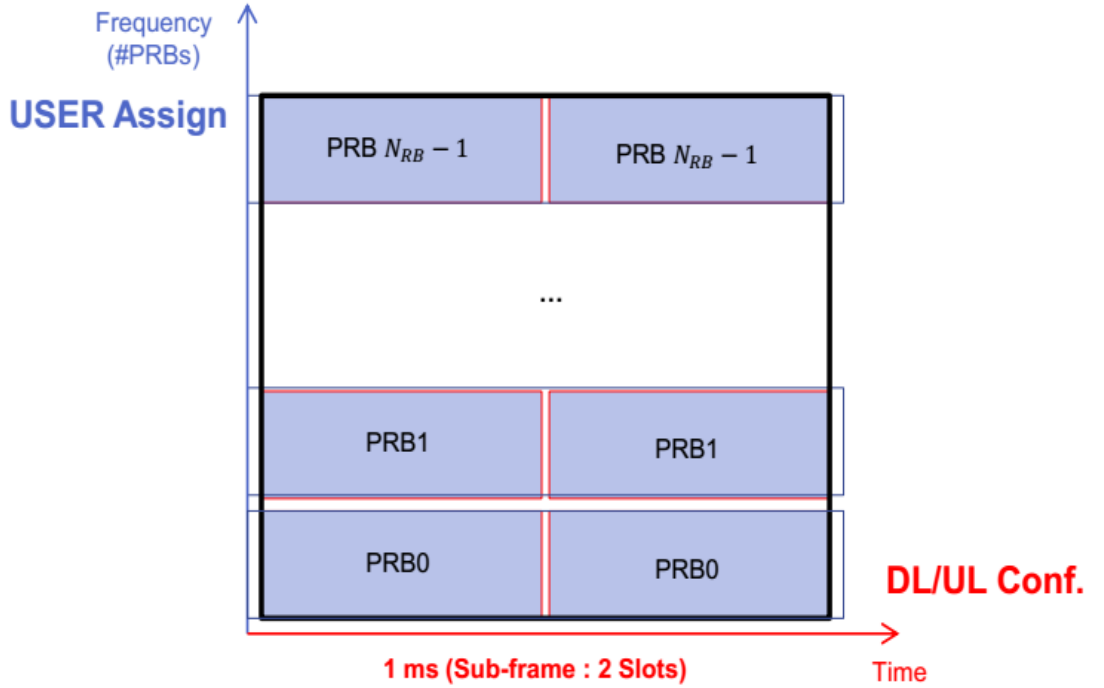


Physical Resource Block



Parameters (Except for MBMS)

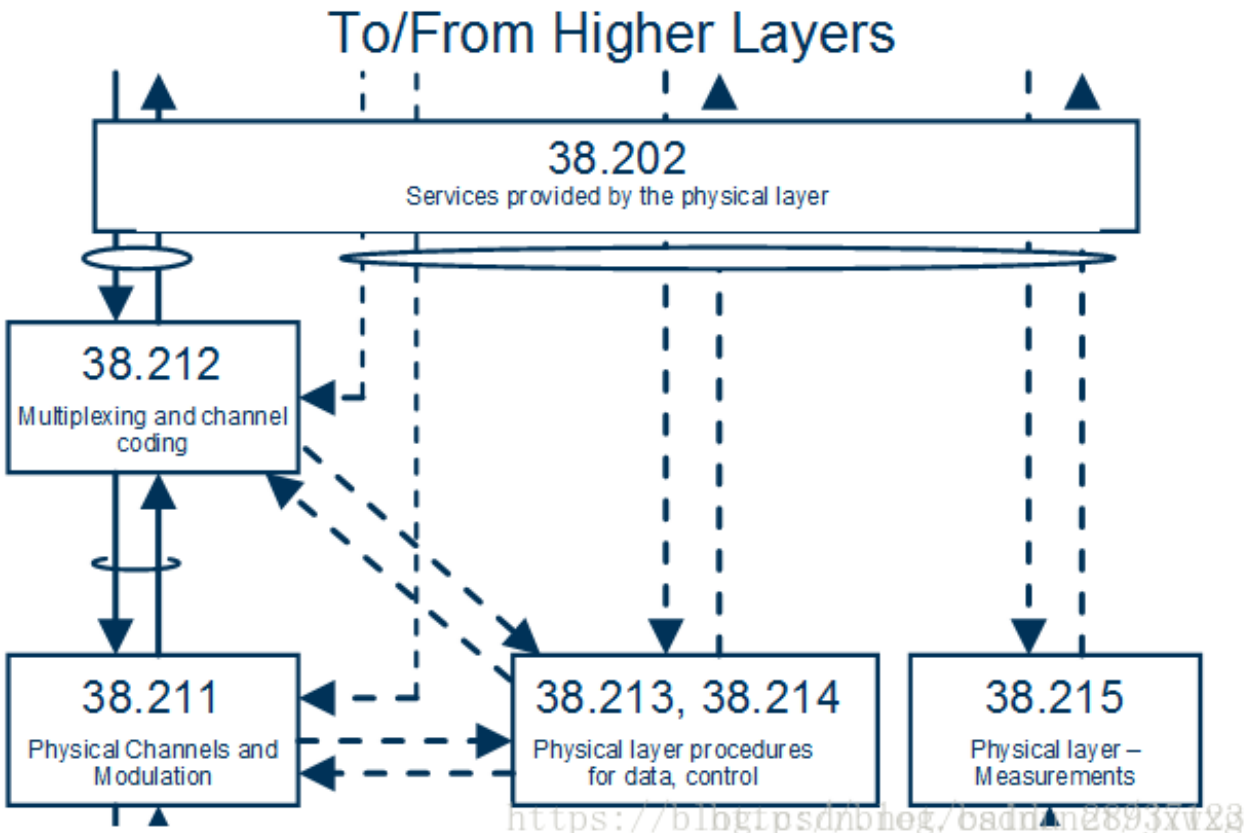
CP Type	# Symbols / Slot
Normal CP	7
Extended CP	6



Parameters (Except for MBMS)

System BW [MHz]	1.4	3	5	10	15	20
# PRBs N_{RB} (# Used Subcarriers N_u)	6 (72)	15 (180)	25 (300)	50 (600)	75 (900)	100 (1200)

5G PHY Specifications



5G Spectrum

600 MHz	LTE/5G	North America
700 MHz	LTE/5G	APAC, EMEA, LatAm
3.3-3.4	LTE/5G	APAC, Africa, LatAm
3.4-3.6	LTE/5G	Global
3.55-4.2	LTE/5G	US
3.6-3.8	5G	Europe
4.5	5G	Japan China
28	5G	US, Korea Japan
39	5G	US
24.25-27.5	5G	WRC-19 band
31.8-33.4	5G	WRC-19 band (Fra, UK)

Full coverage with <1 GHz

Dense urban high data rates at 3.5 – 4.5 GHz

Hotspot 10 Gbps at 28/39 GHz

Future mmwave options

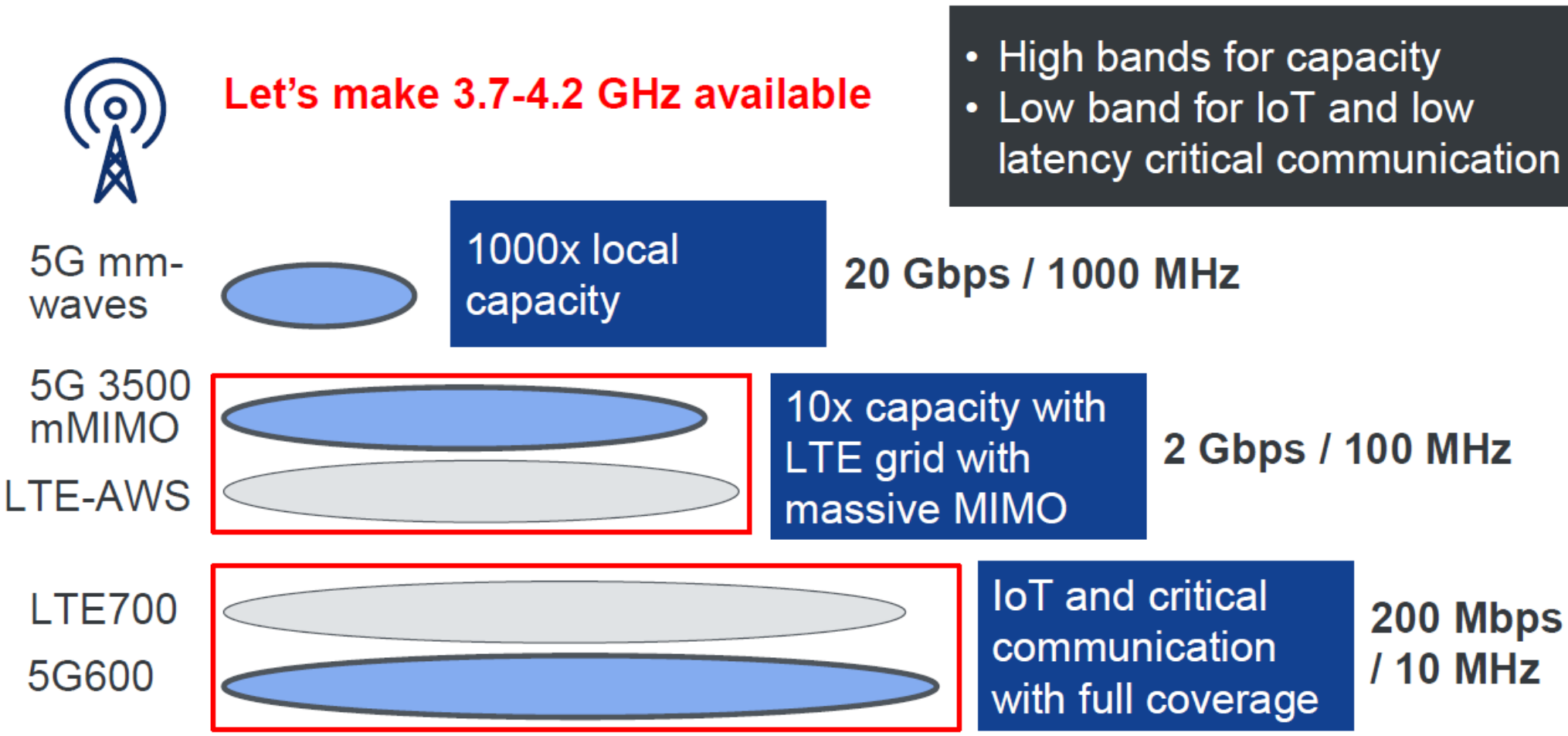
5G Spectrum

5G service
New Radio (NR)

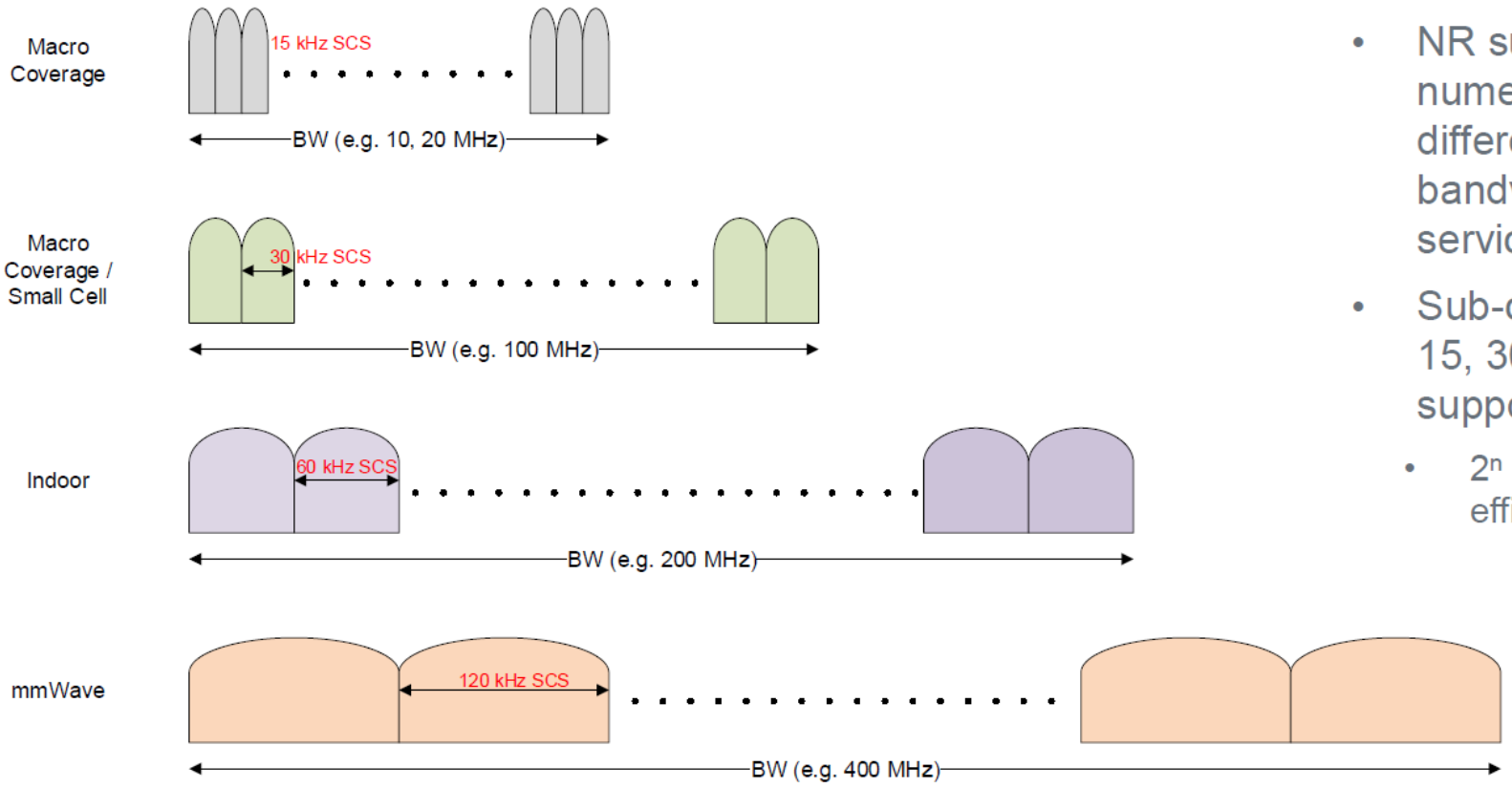
4G Band

TDD Mode

5G Heterogeneous Coverage

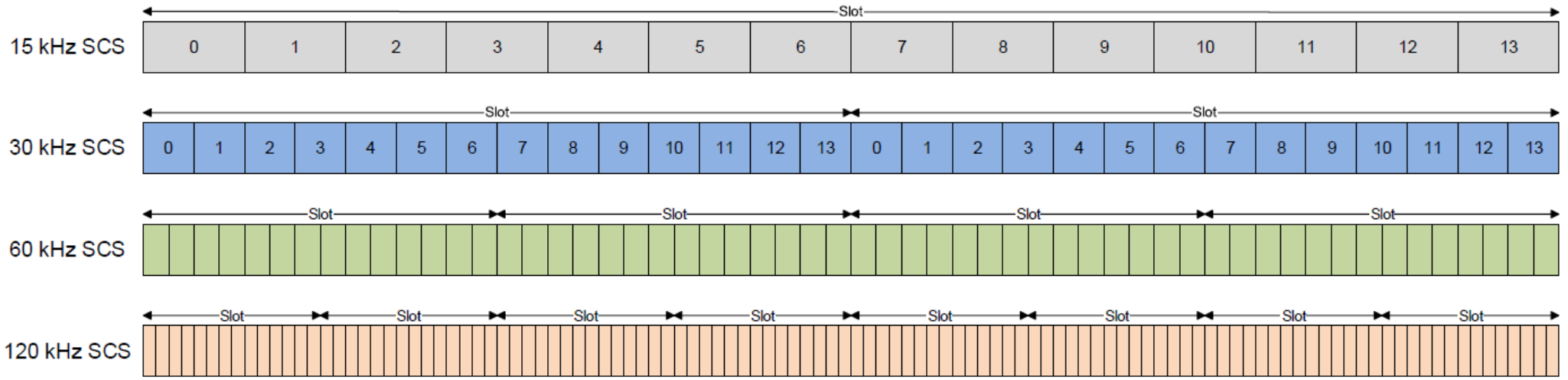


Scalable Numerology (38.211, 4.2)



- NR supports scalable numerology to address different spectrum, bandwidth, deployment and services
- Sub-carrier spacing (SCS) of 15, 30, 60, 120 kHz is supported for data channels
  - 2^n scaling of SCS allows for efficient FFT processing

Scalable Numerology



- One slot is comprised of 14 symbols
  - Slot length depends on SCS – 1ms for 15 kHz SCS to 0.125ms for 120 kHz SCS
- Mini-slot (2,4, or 7 symbols) can be allocated for shorter transmissions
- Slots can also be aggregated for longer transmissions

Reading (April 6th)

3GPP TS 36.211

- Section 4, 5.1, 5.2, 6.1, 6.2

3GPP TS 38.211

- Section 4