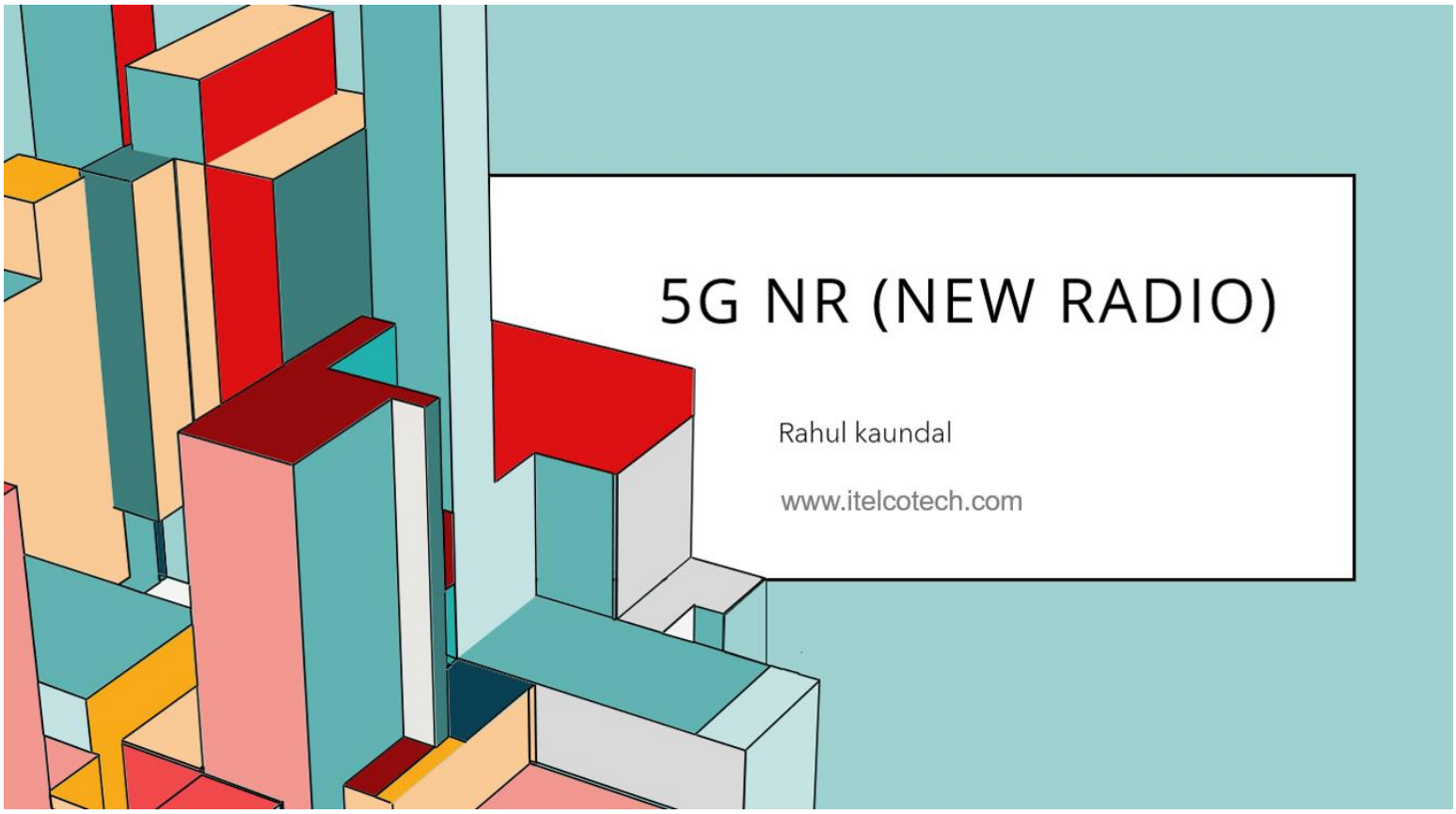
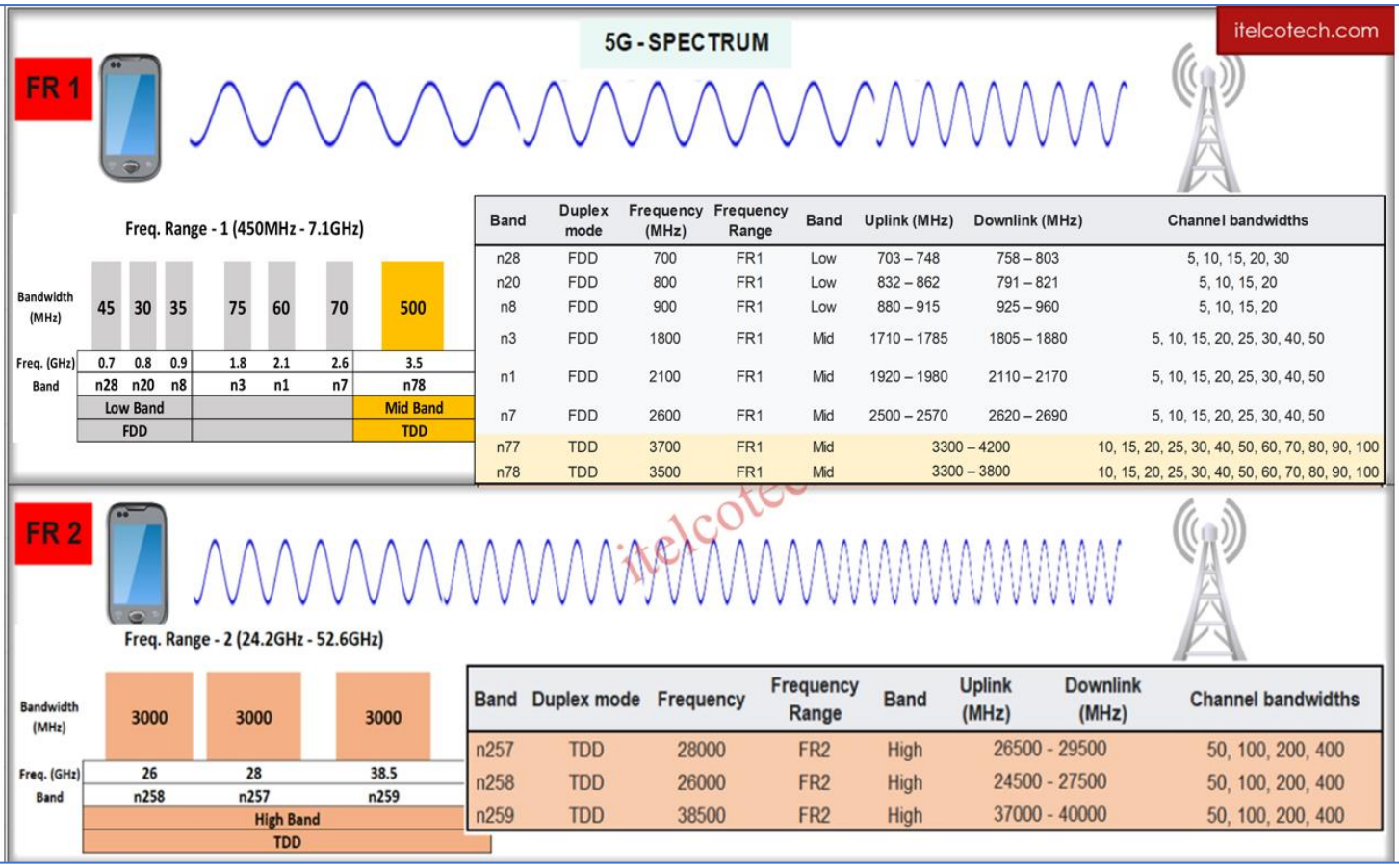


AGENDA

- 5G Spectrum
- 5G NR Frame Structure
- 5G NR Initial Access - Channels/Signals
- Bandwidth Parts (BWP)
- Resource Grid
- Modulation and coding
- OFDMA
- Duplex Schemes
- Scheduler – Resource Allocation
- Carrier Aggregation



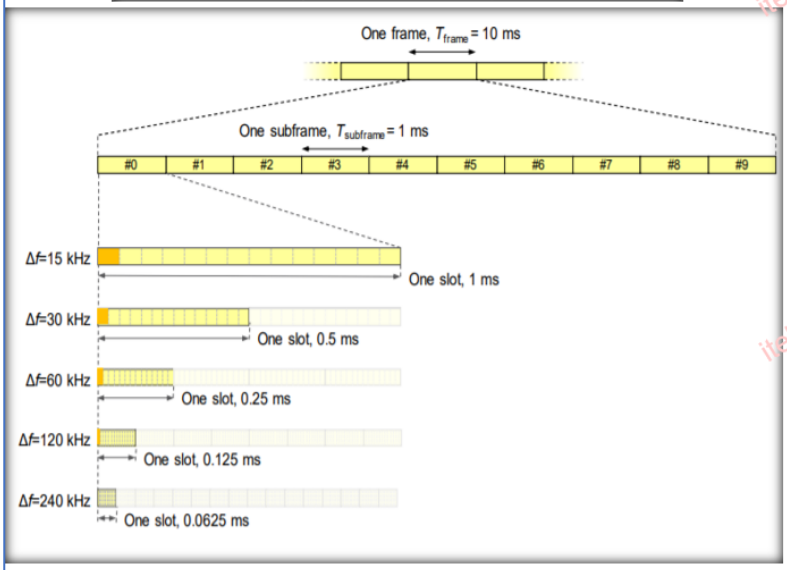
Band	Duplex mode	Frequency (MHz)	Frequency Range	Band	Uplink (MHz)	Downlink (MHz)	Channel bandwidths
n28	FDD	700	FR1	Low	703 – 748	758 – 803	5, 10, 15, 20, 30
n20	FDD	800	FR1	Low	832 – 862	791 – 821	5, 10, 15, 20
n8	FDD	900	FR1	Low	880 – 915	925 – 960	5, 10, 15, 20
n3	FDD	1800	FR1	Mid	1710 – 1785	1805 – 1880	5, 10, 15, 20, 25, 30, 40, 50
n1	FDD	2100	FR1	Mid	1920 – 1980	2110 – 2170	5, 10, 15, 20, 25, 30, 40, 50
n7	FDD	2600	FR1	Mid	2500 – 2570	2620 – 2690	5, 10, 15, 20, 25, 30, 40, 50
n77	TDD	3700	FR1	Mid	3300 – 4200		10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100
n78	TDD	3500	FR1	Mid	3300 – 3800		10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100

Band	Duplex mode	Frequency	Frequency Range	Band	Uplink (MHz)	Downlink (MHz)	Channel bandwidths
n257	TDD	28000	FR2	High	26500 - 29500		50, 100, 200, 400
n258	TDD	26000	FR2	High	24500 - 27500		50, 100, 200, 400
n259	TDD	38500	FR2	High	37000 - 40000		50, 100, 200, 400

Frame Structure

a. Time Domain Structure

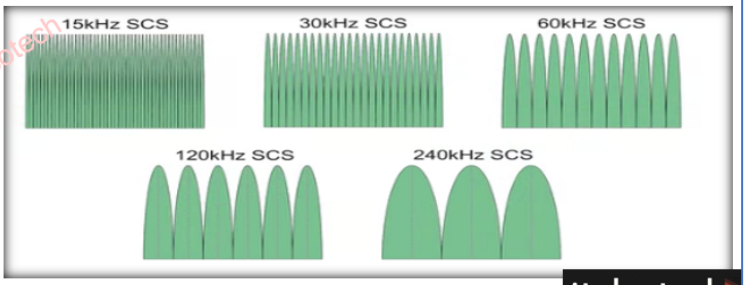
Structure Element	Length (ms)	Description
Frame	10	
Subframe	1	1 frame =10 subframes
Slot	$1/2^{\mu}$	1 subframe = 2^{μ} slots
OFDM symbol	$1/(14\times2^{\mu})$	1 slot = 14 symbols



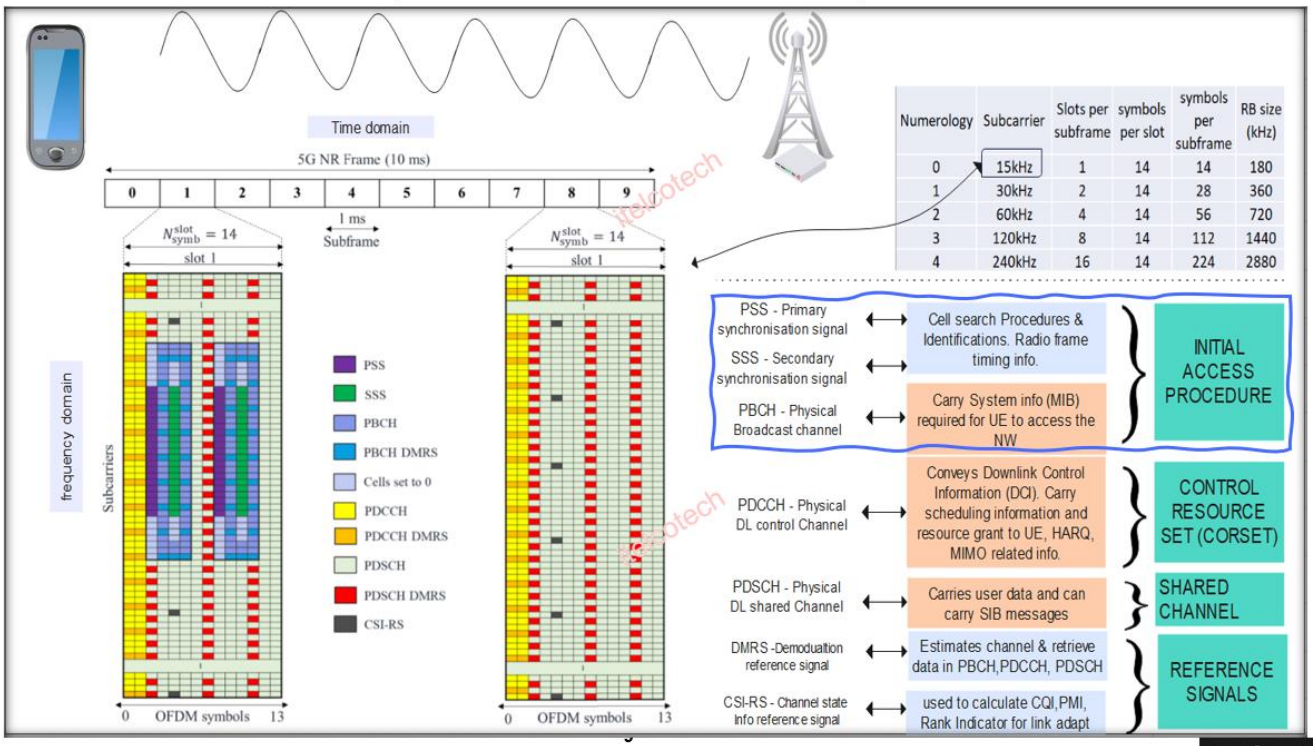
b. Frequency Domain Structure

μ	$\Delta f = 2^{\mu} \times 15$ [kHz]
0	15
1	30
2	60
3	120
4	240

Numerology	SCS	Slots per subframe	symbols per slot	symbols per subframe	RB size (kHz)
0	15kHz	1	14	14	180
1	30kHz	2	14	28	360
2	60kHz	4	14	56	720
3	120kHz	8	14	112	1440
4	240kHz	16	14	224	2880

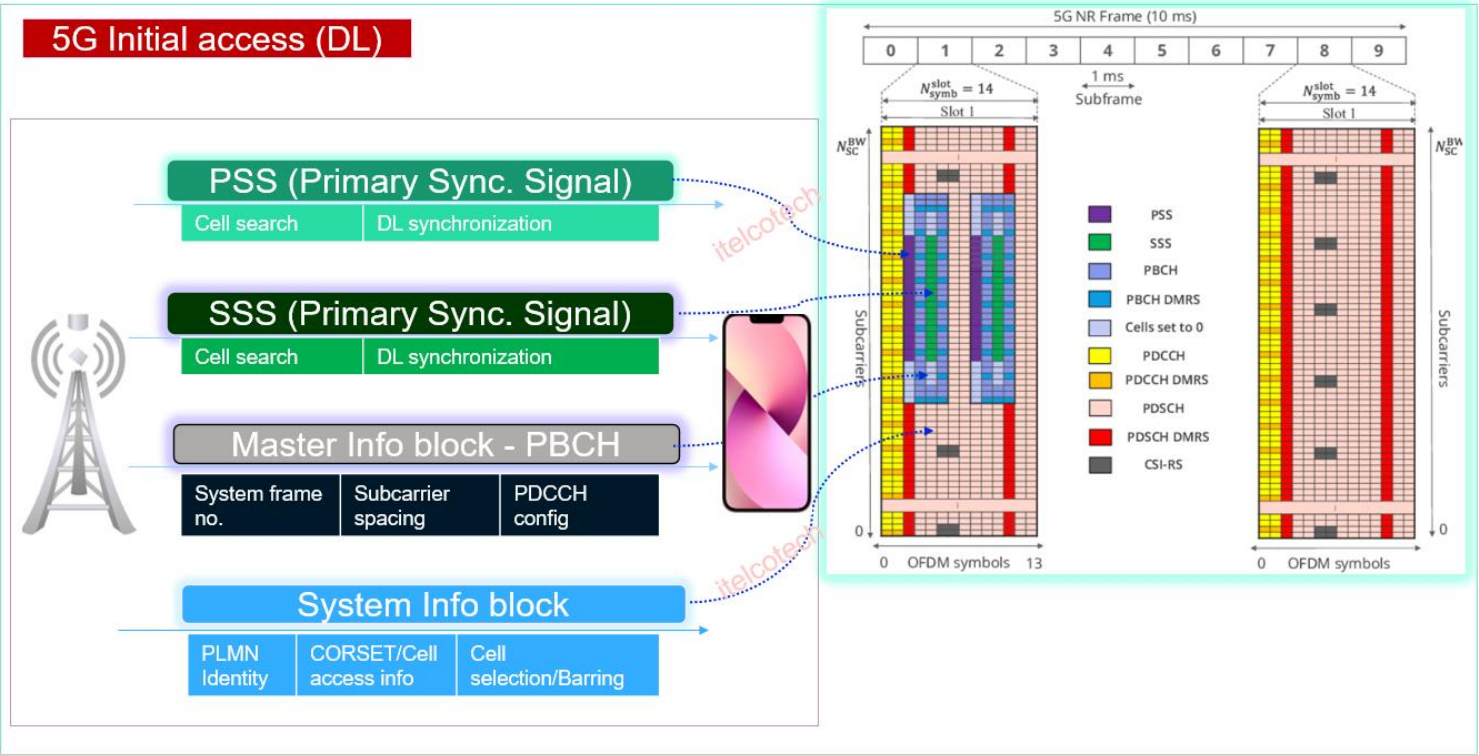


5G NR Frame and DL Channels



Numerology	Subcarrier	Slots per subframe	symbols per slot	symbols per subframe	RB size (kHz)
0	15kHz	1	14	14	180
1	30kHz	2	14	28	360
2	60kHz	4	14	56	720
3	120kHz	8	14	112	1440
4	240kHz	16	14	224	2880

5G Initial access (DL)



5G NR Frame and DL Channels (Initial Access)

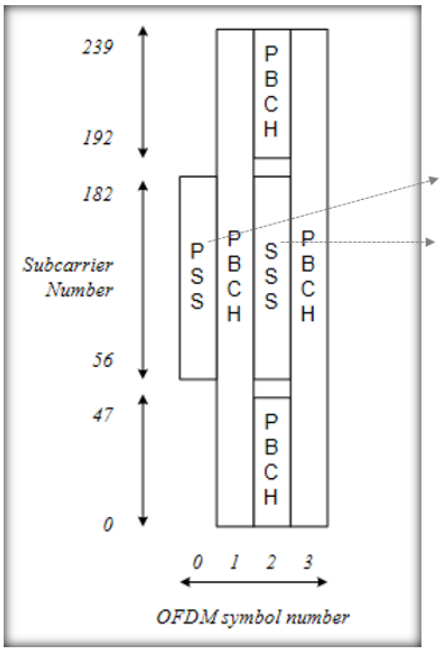
Synchronization Signal Block (**SSB**)–

Synchronization Signal plus PBCH block

Physical Broadcast Channel (**PBCH**)–

carries system information required by the UE to access the network

PBCH spanning across 3 OFDM symbols and 240 subcarriers, but on one symbol leaving an unused part in the middle for SSS



Primary and Secondary Synchronization Signals (**PSS/SSS)-**

Used for cell-search procedures and cell identification.

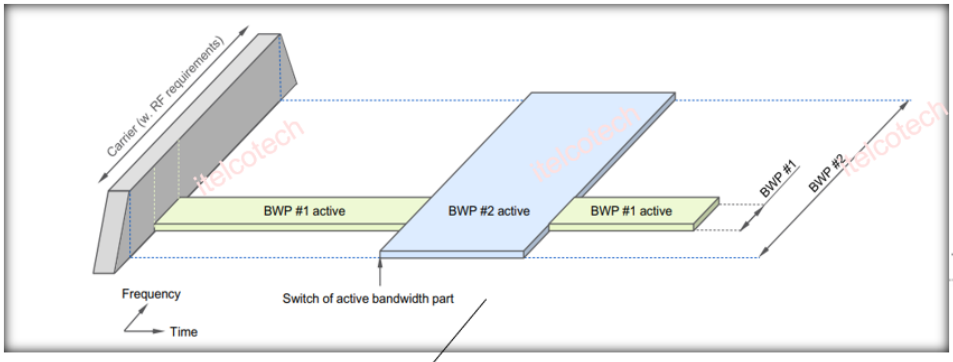
PSS sends one of three orthogonal sequences and SSS sends one of 336 binary sequences. 1008 unique PCIs.

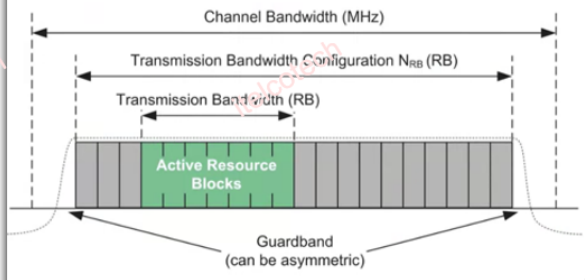
Occupies 127 subcarriers

Bandwidth Part (BWP)

4G : Downlink control channels occupy the full carrier bandwidth - significantly increase the power consumption of device.

5G : bandwidth adaptation - narrower bandwidth for monitoring control channels/ small-to-medium-sized data transmissions,
full bandwidth for scheduling large amount of data





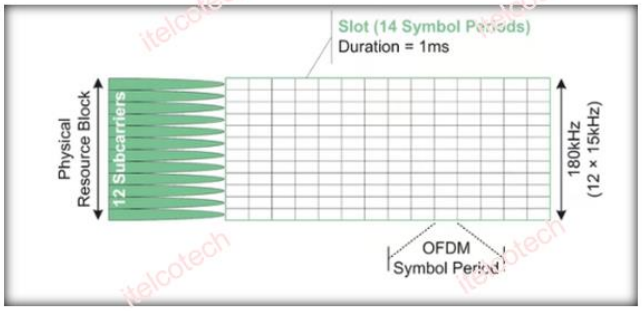
BWP switched by DCI

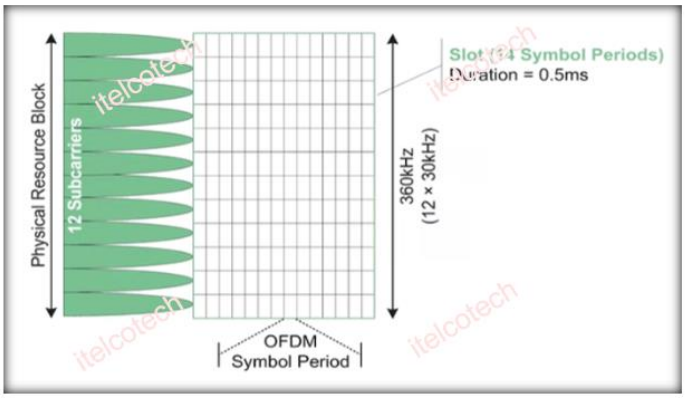
Bandwidth part is characterized by a numerology and a set of consecutive resource blocks in the numerology of the BWP

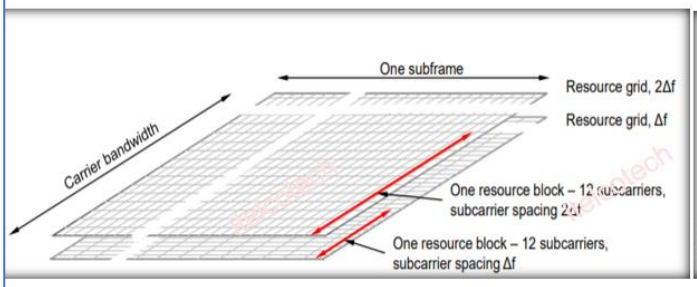
Resource Grid

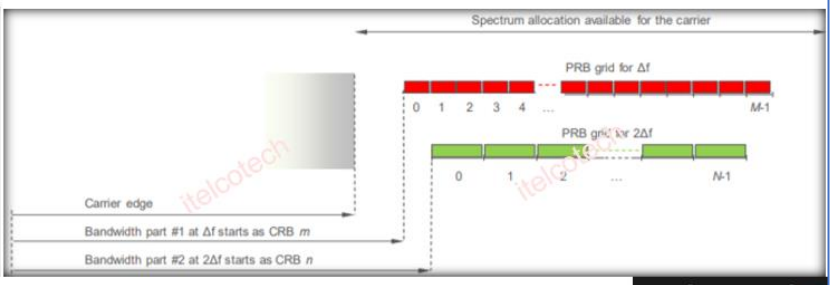
Resource block = 12 subcarriers

Resource element = 1 subcarrier in OFDM symbol



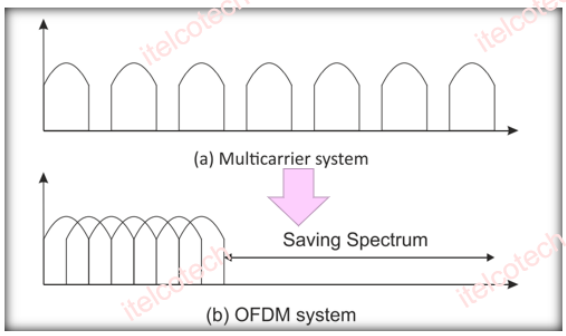


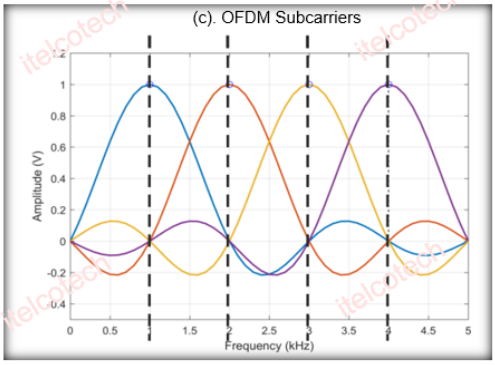




OFDMA

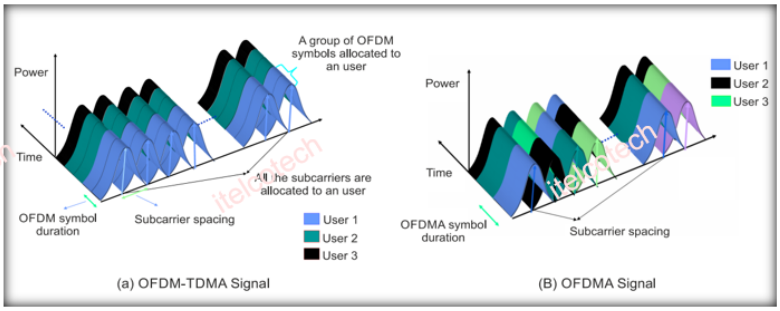
OFDM (Orthogonal frequency division multiplex) - Multicarrier transmission with overlapping and orthogonal narrowband subchannels.





No guard band between subcarriers are needed

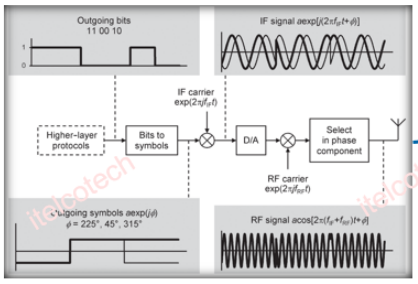
OFDMA is the “access” version of OFDM, where the access to resources is shared between users in both time and frequency domain

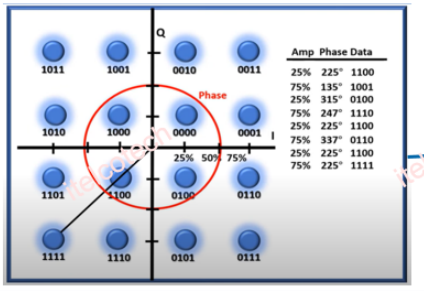


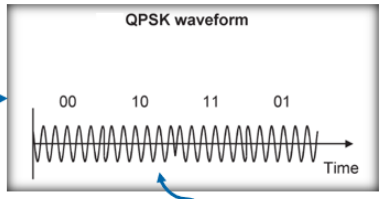
Modulation

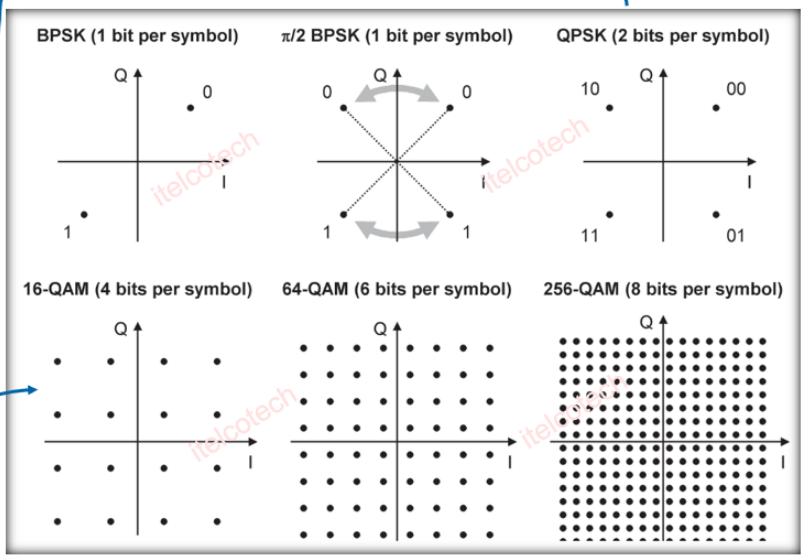
Baseband signals are transmitted using a high frequency periodic signal (carrier signals).
A *modulator* encodes a sequence of bits onto the carrier signal by adjusting the amplitude (a) or initial phase (ϕ) or frequency (f). It helps in –

a. Reducing size of antenna → Wavelength = speed of light / frequency
b. Reducing interference
c. Allow multiplexing of the signals









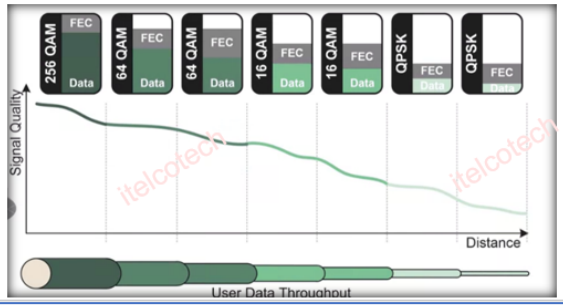
Modulation and Coding Scheme (MCS)

Modulation and Coding Scheme defines the modulation order (QPSK, 16QAM, 64 QAM, 256QAM) based on the channel quality index. If CQI is good, a higher number of bits can be transferred using high modulation, which in turn improves spectral efficiency.

CQI is used by the mobile to indicate the channel quality to the gNB. This indicates the level of modulation and coding the UE could operate.

Code rate is defined as the ratio between information bits and total transmitted bits (Information + Redundant Bits).

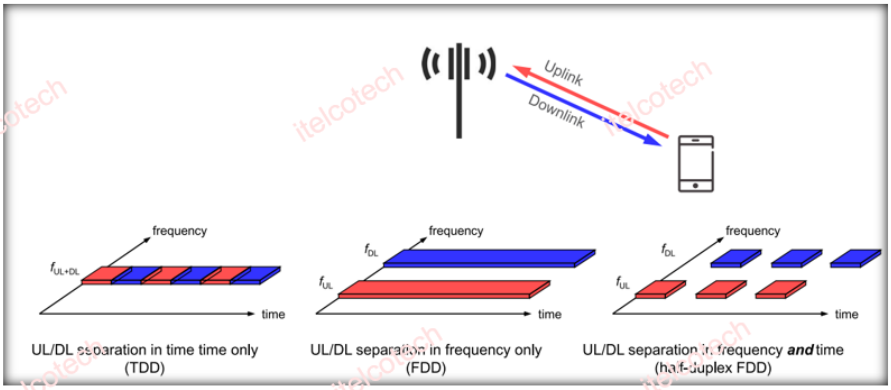
CQI index	modulation	code rate x 1024	efficiency
0	out of range		
1	QPSK	78	0.1523
2	QPSK	193	0.3770
3	QPSK	449	0.8770
4	16QAM	378	1.4766
5	16QAM	490	1.9141
6	16QAM	616	2.4063
7	64QAM	466	2.7305
8	64QAM	567	3.3223
9	64QAM	666	3.9023
10	64QAM	772	4.5234
11	64QAM	873	5.1152
12	256QAM	711	5.5547
13	256QAM	797	6.2266
14	256QAM	885	6.9141
15	256QAM	948	7.4063



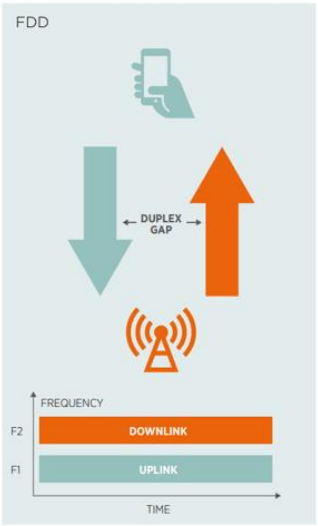
MCS Index I_{MCS}	Modulation Order Q_m	Target code Rate $R \times [1024]$	Spectral efficiency
0	2	120	0.2344
1	2	193	0.3770
2	2	308	0.6016
3	2	449	0.8770
4	2	602	1.1758
5	4	378	1.4766
6	4	434	1.6953
7	4	490	1.9141
8	4	553	2.1602
9	4	616	2.4063
10	4	658	2.5703
11	6	466	2.7305
12	6	517	3.0293
13	6	567	3.3223
14	6	616	3.6094
15	6	666	3.9023
16	6	719	4.2129
17	6	772	4.5234
18	6	822	4.8164
19	6	873	5.1152
20	8	682.5	5.3320
21	8	711	5.5547
22	8	754	5.8906
23	8	797	6.2266
24	8	841	6.5703
25	8	885	6.9141
26	8	916.5	7.1602
27	8	948	7.4063
28	2	reserved	
29	4	reserved	
30	6	reserved	
31	8	reserved	

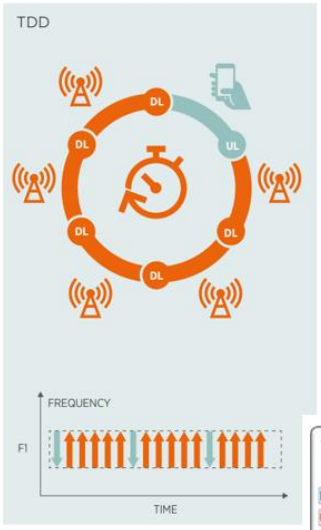
Duplex Schemes

- **TDD** — uplink and downlink transmissions use the same carrier frequency and are separated in time only
- **FDD** — uplink and downlink transmissions use different frequencies but can occur simultaneously
- Half-duplex FDD — uplink and downlink transmissions are separated in frequency and time, suitable for simpler devices operating in paired spectra

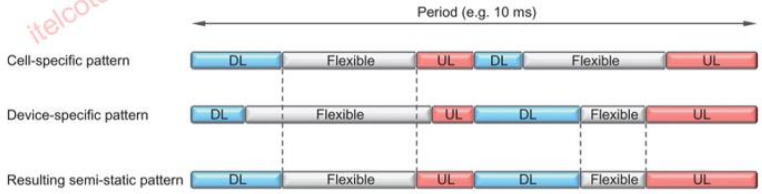


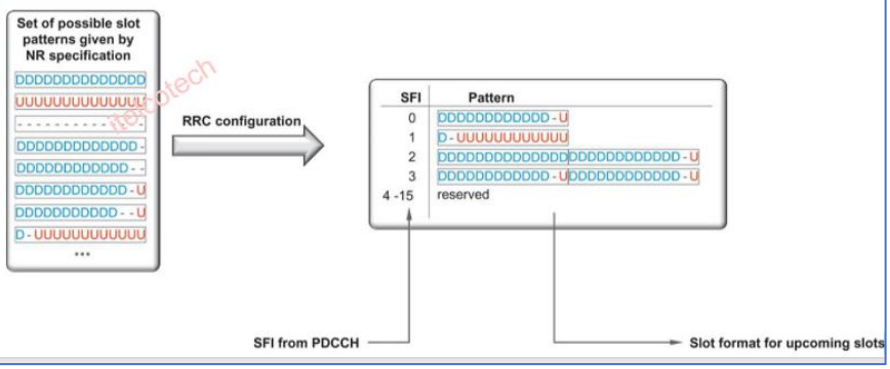
Duplex Schemes





In TDD, synchronization is required to avoid interference





SFI - dynamically signal the current uplink–downlink allocation to a group of devices monitoring a special downlink control message known as the slot-format indicator (SFI)

Scheduler – Resource Allocation

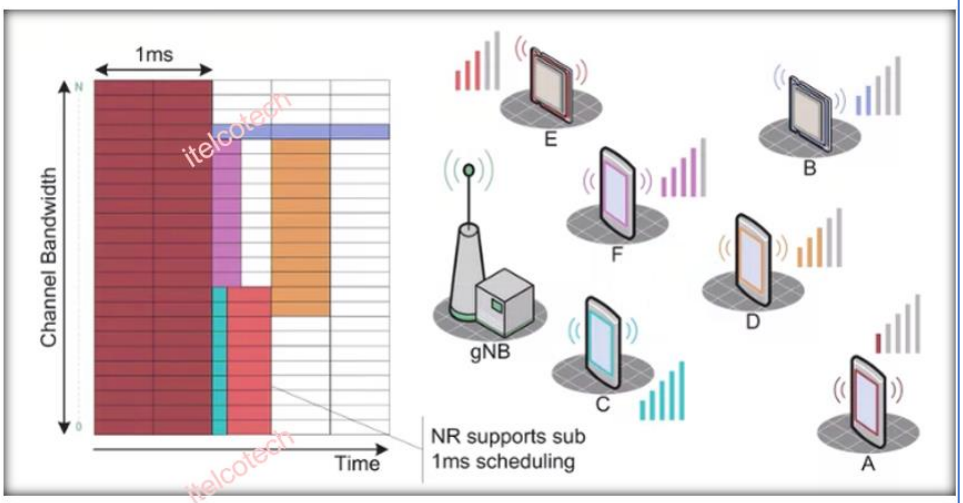
In NR, the ***downlink scheduler*** is responsible for dynamically controlling the device(s) to transmit to.

Each of the scheduled devices is provided with a *scheduling assignment* including information on the set of time–frequency resources upon which the device's DL-SCH is transmitted.

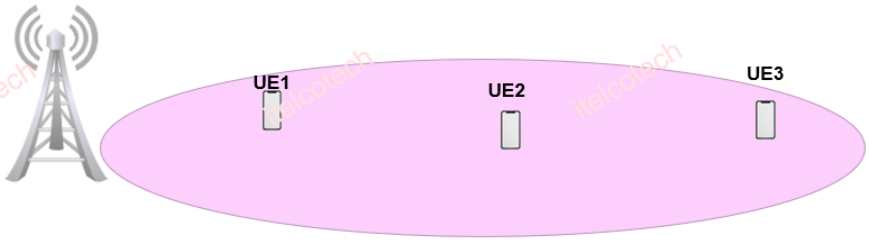
Scheduler depends on the specific scheduling strategy -

- Channel conditions at the device, including spatial-domain properties
- Buffer status of the different data flows
- Priorities of the different data flows, including the amount of data pending retransmission

gNB use CSI reports to measure the channel quality in the time, frequency, and spatial domains.



Scheduler – Resource Allocation



Choice of the scheduler has a significant impact on network performance such as **throughput, delay and fairness index**

Schedule Mode	THP(Mbps)			RSRP(dBm)			Avg SINR(dB)			RANK2 SINR(dB)			QCI/Priority Weight		
	UE 1	UE 2	UE 3	UE 1	UE 2	UE 3	UE 1	UE 2	UE 3	UE 1	UE 2	UE 3	UE 1	UE 2	UE 3
MAX C by I	33.3	0.66	0.209	-100	-107	-123	25.76	15.99	2.26	15.9	7.27	-0.79	9/1	8/5	6/10
RR	11.5	5.2	1.9	-101	-108	-119	22.58	16.63	4.26	15.11	7.68	-0.2			
PF	11.9	5.3	2.5	-101	-108	-121	21.49	16.35	2.67	13.82	7.35	-0.52			
EPF	7.3	5	4.9	-99	-107	-121	26.4	17.36	3.5	16.94	10.94	-0.52			

round-robin principle - each UE gets an equal share of something in turn

objective is to maintain the balance between getting high total throughput and guarantee all UEs getting a proportionally level of service

Carrier Aggregation

Carrier Aggregation is a technique to combine multiple carriers - **to achieve multi-Gigabit 5G data rates**

- **Inter-band carrier aggregation**:

- **Intra-band contiguous carrier aggregation**:

- **Intra-band non-contiguous carrier aggregation**: