IEE2620: System Aspects in Communications

Muhammad Mahtab Alam, Professor

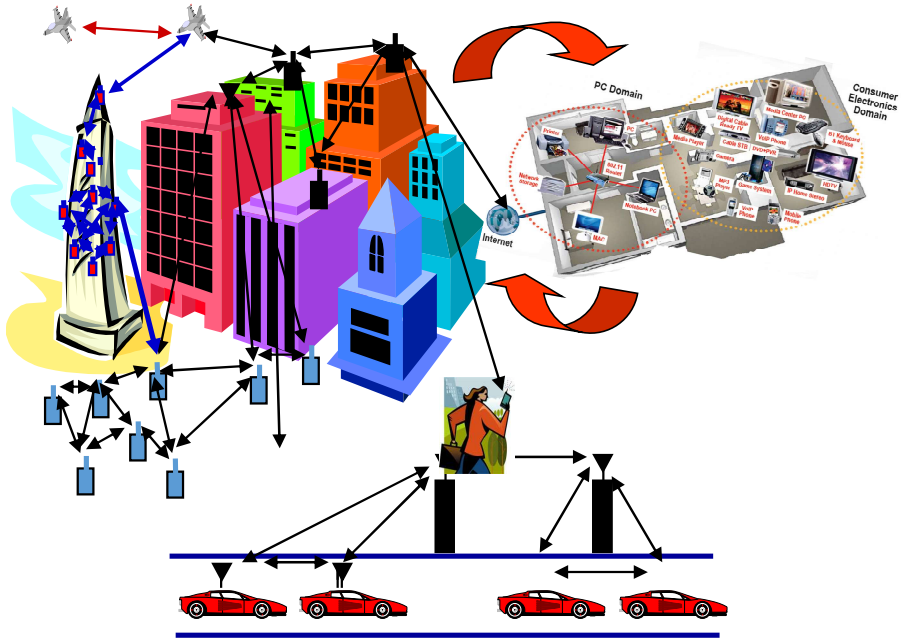
Timetable | Timetable calendar | 2024/2025 Spring

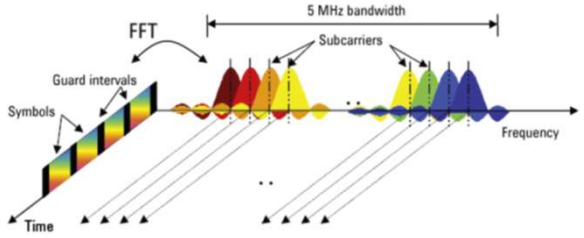
Muhammad Mahtab Alam (Study week 1-16)

Week view | Dates view | Copy URL | Export iCalendar file

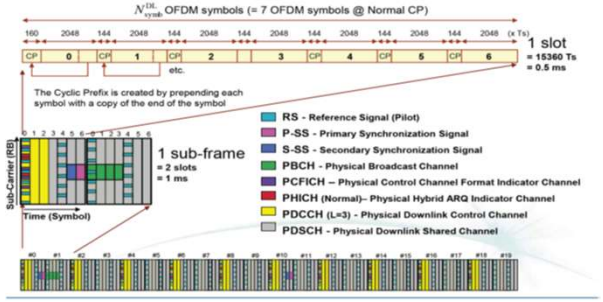
Other | Even | Odd | 1 - 16 | *Student group italicized* - subject is elective | Student group not italicized - subject is compulsory

Time	Course	Language	Type	Teacher	Room	Study weeks	Student groups	Syllabus	Comment
Monday									
12:00 - 13:30	IEE2620 - System Aspects in Communication	estonian	lecture	Muhammad Mahtab Alam (Tenured Full Professor)	Distance learning	1-16	*IAVM21*	View	





Downlink Frame Structure Type 1



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3GPP Protocol Architecture for 5G

5G NR Physical Resource

5G NR Channels and Signals
on 18B Application

Contents


3GPP Protocol Architecture for 5G


5G NR Physical Resource


5G NR Channels and Signals on 18B Application

5G NR Physical Resource

1 5G Numerology

2 Time-Domain Resources

3 Frequency-Domain Resources

4 Space-Domain Resources

SCS(SubCarrier Spacing)

- **Numerologies supported by 3GPP Release 15 (TS 38.211)**

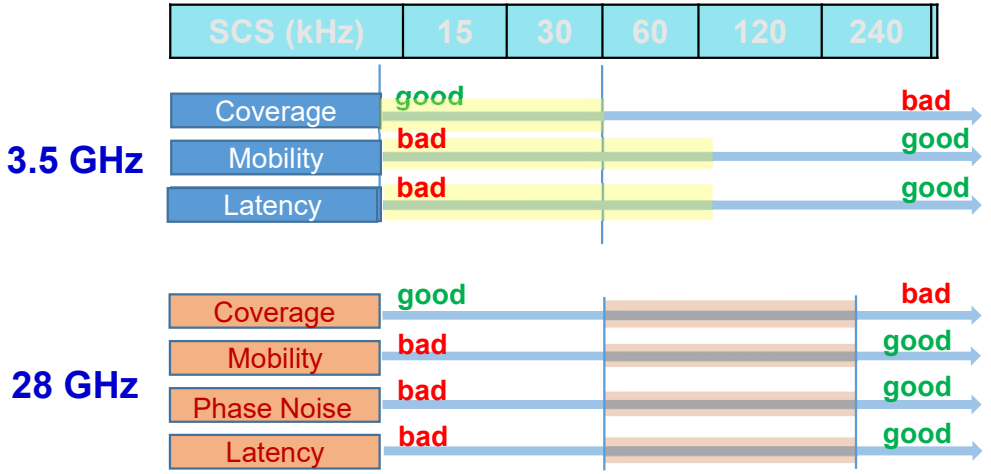
μ	SCS	CP
0	15 kHz	Normal
1	30 kHz	Normal
2	60 kHz	Normal, extended
3	120 kHz	Normal
4	240 kHz	Normal

- **Application scenarios:**

Scalable Numerology		
	Flexibility	**Example**
Case 1	Different spectrum	Sub-6 GHz, mmWave
Case 2	Multiple services	eMBB, URLLC, mMTC
Case 3	Multiple scenarios	Low/high Speed

- **3GPP TS 38.104 (RAN4) defines SCS for different frequency bands.**
  - SCS for bands below 1GHz: 15 kHz, 30 kHz
  - SCS for bands btw 1GHz and 6GHz: 15 kHz, 30 kHz, 60 kHz
  - SCS for band 24GHz to 52.6GHz: 60 kHz, 120 kHz
  - In Release 15, 240 kHz for data is not considered.

- **Recommended SCS for different frequency bands (eMBB services):**



5G NR Physical Resource

1 Numerology

2 Time-Domain Resources: CP, Symbol, Slot, Frame Structure

3 Frequency-Domain Resources

4 Space-Domain Resources

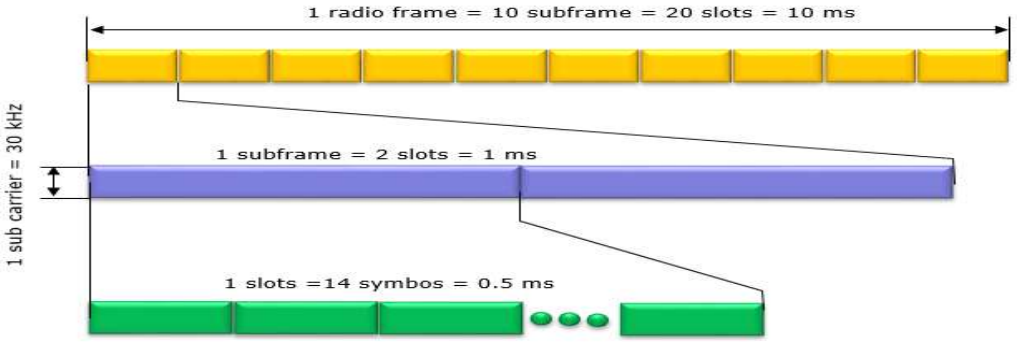
Frame Structure Architecture

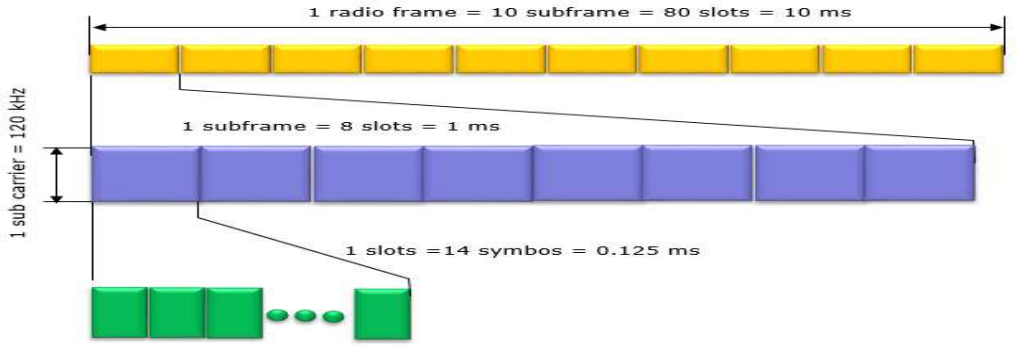
- **Frame length: 10ms**
  - SFN (System Frame Number) range: 0 to 1023
- **Subframe length: 1ms**
  - Subframe index per system frame: 0 to 9
- **Slot length: 14 symbols**

SCS (kHz)	Slot Configuration (Normal CP)		
	Number of Symbols/Slot	Number of Slots/Subframe	Number of Slots /Frame
15	14	1	10
30	14	2	20
60	14	4	40
120	14	8	80
240	14	16	160
480	14	32	320

	Slot Configuration (Extended CP)		
60	12	4	40

- **Frame structure architecture:**
  - Example: SCS = 30 kHz/120 kHz





Time Units for the Physical Layer

- **Time units for the NR system: Ts and Tc**
  Tc = 0.509 ns: sampling interval for the SCS of 480 kHz

$$T_c = 1/(\Delta f_{max} \cdot N_f) = 0.509 \text{ ns}$$

($\Delta f_{max} = 480 \times 10^3$, $N_f = 4096$)

  - **Ts = 32.552 ns: s**ampling interval for the SCS of 15 kHz

$$T_s = 1/(\Delta f_{ref} \cdot N_{f,ref}) = 32.552 \text{ ns}$$

($\Delta f_{ref} = 15 \times 10^3$, $N_f = 2048$)

  - **K = 64**: auxiliary parameter

$$\kappa = \frac{T_s}{T_c} = 64$$

- **Frame and subframe length: Tf and Tsf**
  - **Tf = 10 ms** (frame length)

$$T_f = \left(\Delta f_{max} \cdot N_f / 100\right) T_c = 10 ms$$

($\Delta f_{max} = 480 \times 10^3$, $N_f = 4096$, $T_c = 0.509 ns$)

  - **Tsf = 1 ms** (subframe length)

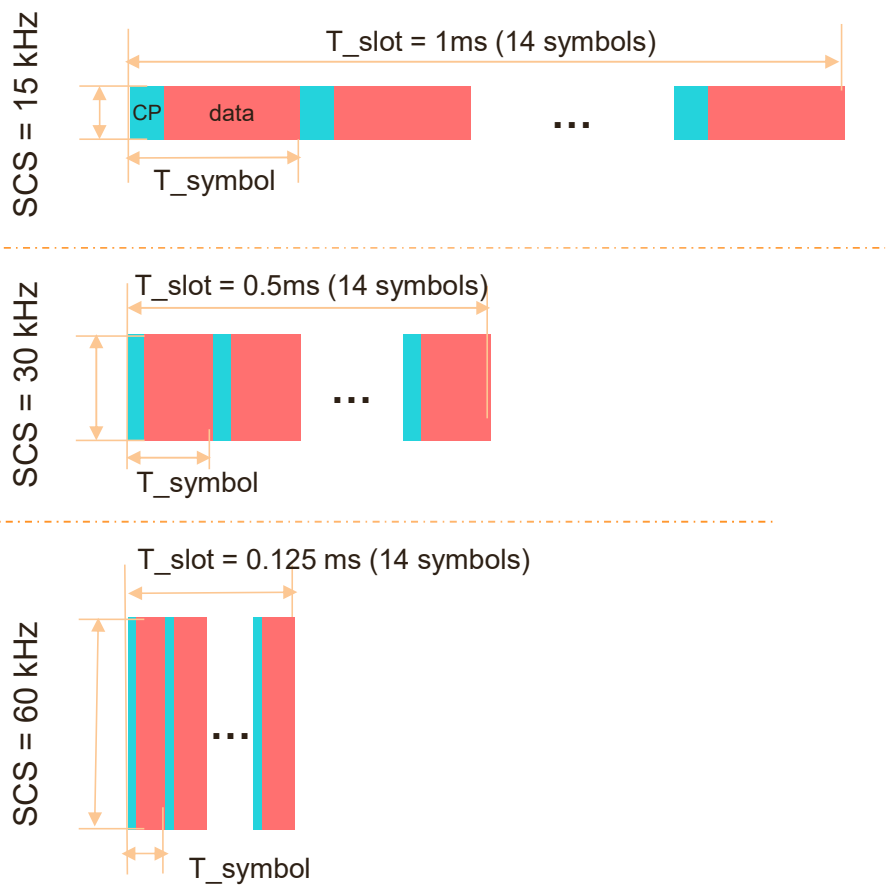
$$T_{sf} = \left(\Delta f_{max} \cdot N_f / 1000\right) T_c = 1 ms$$

($\Delta f_{max} = 480 \times 10^3$, $N_f = 4096$, $T_c = 0.509 ns$)

Relationship btw SCS and Symbol Length

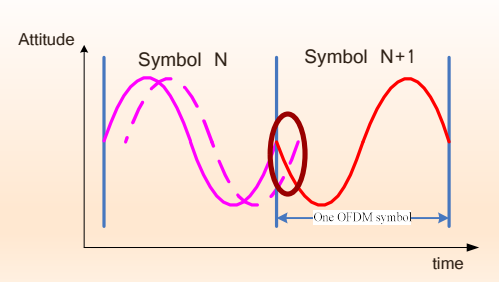
- **SCS and Symbol length/ CP length /Slot length**

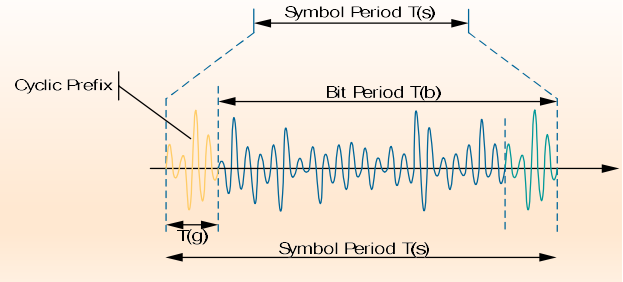
Parameter/Numerology (μ)	0	1	2	3	4
SCS (kHz): **SCS = 15 x 2^(μ)**	15	30	60	120	240
OFDM symbol for data duration (us): **T_data = 1/SCS**	66.67	33.33	16.67	8.33	4.17
CP Duration (μs): **T_cp = 144/2048*T_data**	4.69	2.34	1.17	0.59	0.29
OFDM symbol duration(μs): **T_symbol = T_data + T_cp**	71.35	35.68	17.84	8.92	4.46
Slot Length (ms): **T_slot = 1/2^(μ)**	1	0.5	0.25	0.125	0.0625



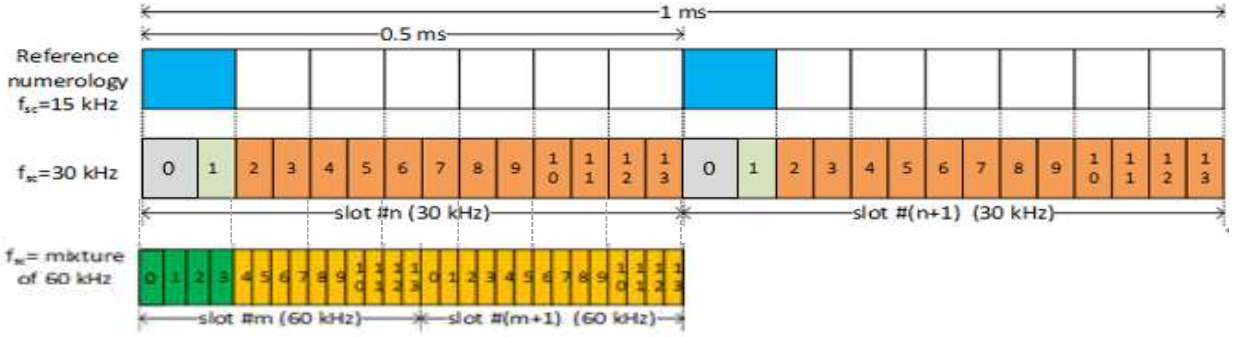
Cyclic Prefix (CP)

- **CP function:**
  - To eliminate inter-channel interference (ICI) caused by multipath propagation.





- **NR CP design principle:**
  - Same overhead as that in LTE, ensuring aligned symbols btw different SCS values and the reference numerology (15 kHz).



- **CP length for different SCS values:**

$$N^{\mu}_{\mathrm{CP},l} = \begin{cases} 512\kappa \cdot 2^{-\mu} & \text{extended cyclic prefix} \\ 144\kappa \cdot 2^{-\mu} + 16\kappa & \text{normal cyclic prefix, } l = 0 \text{ or } l = 7 \cdot 2^{\mu} \\ 144\kappa \cdot 2^{-\mu} & \text{normal cyclic prefix, } l \neq 0 \text{ and } l \neq 7 \cdot 2^{\mu} \end{cases}$$

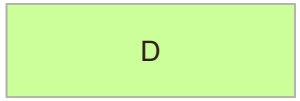
$$T_{cp} = N_{cp} \cdot T_c$$

Parameter μ	SCS (kHz)	CP (μs)
0	15	T_{CP}: 5.2 μs for l = 0 or 7; **4.69 μs** for others
1	30	T_{CP}: 2.86 μs for l = 0 or 14; **2.34 μs** for others
2	60	T_{CP}: 1.69 μs for l = 0 or 28; **1.17 μs** for others **Extended T_{CP}: 4.17 μs**
3	120	T_{CP}: 1.11 μs for l = 0 or 56; **0.59 μs** for others
4	240	T_{CP}: 0.81 μs for l = 0 or 112; **0.29 μs** for others

Slot Format and Type

- **Slot structure** (*section 4.3.2 in 3GPP TS 38.211*)
  - Downlink, denoted as D, for downlink transmission
  - Flexible, denoted as X, for flexibly usage.
  - Uplink, denoted as U, for uplink transmission

- **Main slot types**
  - Type 1: DL-only slot



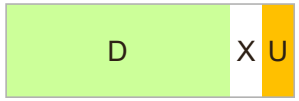
  - Type 2: UL-only slot

  - Type 3: flexible-only slot

  - Type 4: mixed slot

Type4-1

Type4-2



Type4-3

Type4-4

Type4-5

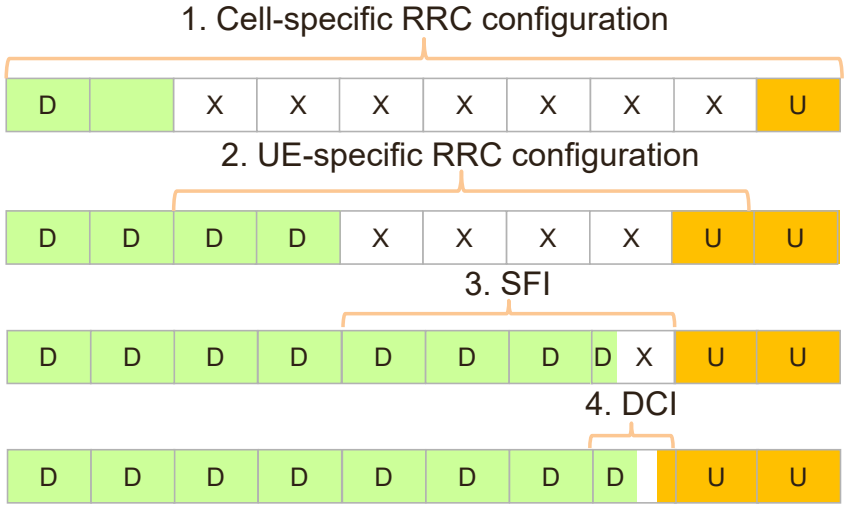
- **Compared with LTE slot format, NR features:**
  - Flexibility: symbol-level uplink/downlink adaptation in NR while subframe-level in LTE
  - Diversity: More kinds of uplink/downlink configurations are supported in NR to cope with more scenarios and service types.

UL/DL Slot Configuration

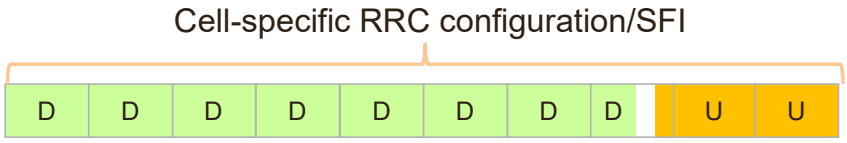
- **Configuration (*section 11.1 in 3GPP TS 38.213*)**
  - Layer 1: semi-static configuration through cell-specific RRC signaling
  - Layer 2: semi-static configuration through UE-specific RRC signaling
  - Layer 3: dynamic configuration through UE-group SFI
  - Layer 4: dynamic configuration through UE-specific DCI

- **Main characteristics: hierarchical configuration or separate configuration of each layer**
  - Different from LTE, the NR system supports UE-specific configuration, which delivers high flexibility and high resource utilization
  - Support for symbol-level dynamic TDD

- **Hierarchical configuration**



- **Separate layer configuration**



1 Numerology

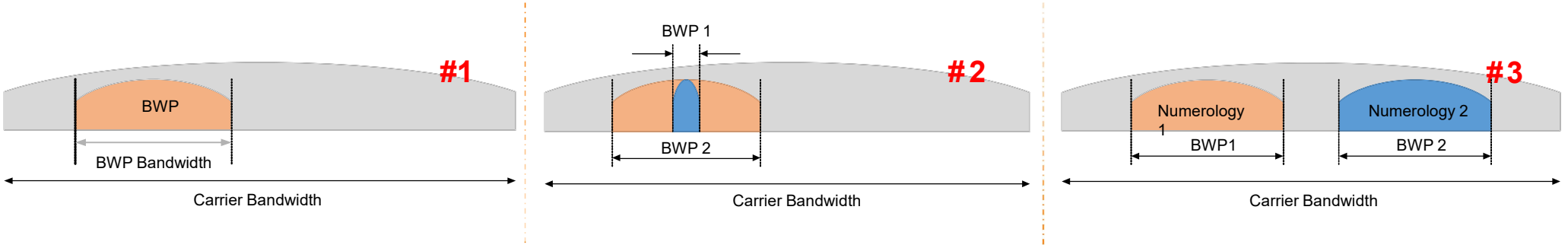
2 Time-Domain Resources

3 **Frequency-Domain Resources:** RB, RBG, REG, CCE, BWP

4 Space-Domain Resources

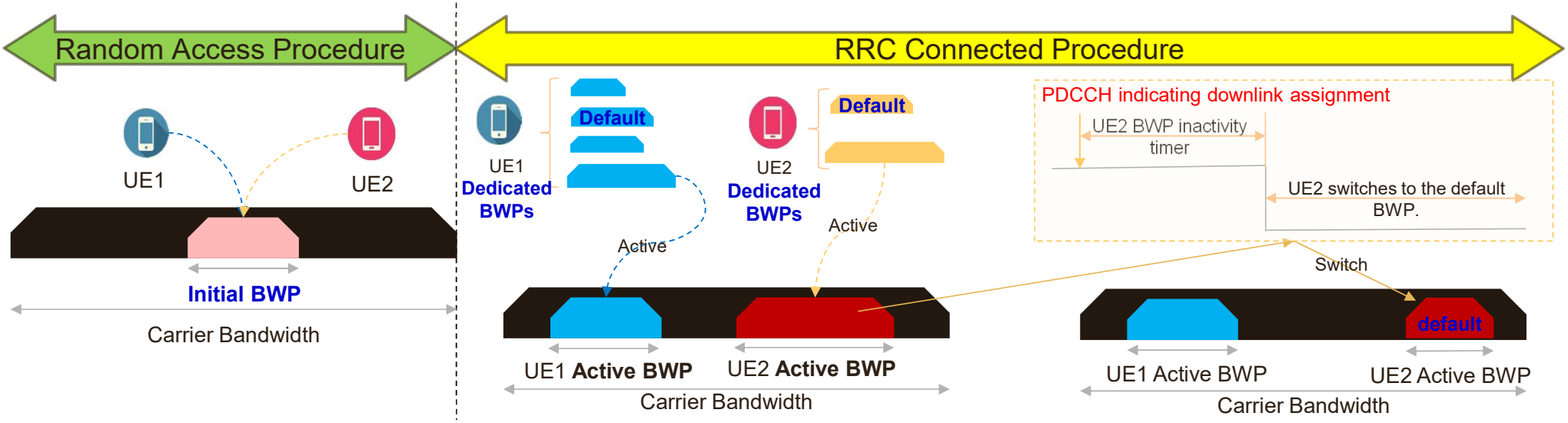
BWP Definition and Application Scenarios

- **Definition and characteristics**
  - The BWP is a new concept introduced in the NR system. It is a set of contiguous bandwidth resources allocated by the gNodeB to UEs. Its configuration is **mandatory** for 5G service access.
  - It is a UE-level concept (BWP configurations vary with UEs). All channel resources allocated to UEs or to be scheduled are within the BWP range.
- **Application scenarios**
  - Scenario#1: UEs with a small bandwidth access a large-bandwidth network.
  - Scenario#2: UEs switch between small and large BWPs to save battery power.
  - Scenario#3: The numerology is unique for each BWP and service-specific.

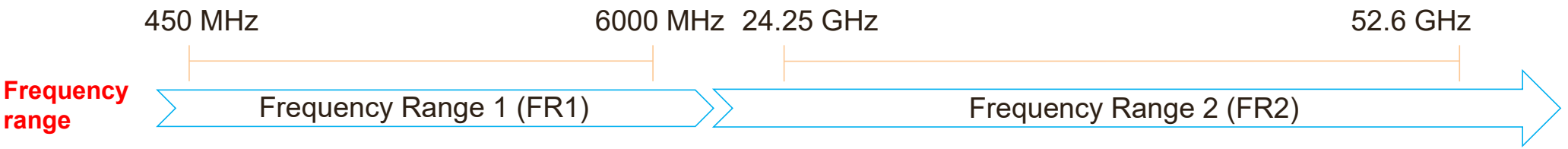


BWP Types

- **Initial BWP**: used in the initial access phase
- **Dedicated BWP**: configured for UEs in RRC_CONNECTED mode.
  -- According to 3GPP specifications, a maximum of **4** dedicated BWPs can be configured for a UE.
- **Active BWP**: one of the dedicated BWPs activated by a UE in RRC_CONNECTED mode.
  -- According to 3GPP specifications, a UE in RRC_CONNECTED mode can activate only **1** dedicated BWP at a given time.
- **Default BWP**: one of the dedicated BWPs used by the UE in RRC_CONNECTED mode after the BWP inactivity timer expires.



3GPP-defined 5G Frequency Ranges and Bands



NR Operating Band	Uplink (UL) operating band BS receive UE transmit F_{UL_low} – F_{UL_high}	Downlink (DL) operating band BS transmit UE receive F_{DL_low} – F_{DL_high}	Duplex Mode
n1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
n2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
n3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
n5	824 MHz – 849 MHz	869 MHz – 894MHz	FDD
n7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
n8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
n20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
n28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
n38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
n41	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD
n50	1432 MHz – 1517 MHz	1432 MHz – 1517 MHz	TDD
n51	1427 MHz – 1432 MHz	1427 MHz – 1432 MHz	TDD
n66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
n70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD
n71	663 MHz – 698 MHz	617 MHz – 652 MHz	FDD
n74	1427 MHz – 1470 MHz	1475 MHz – 1518 MHz	FDD
n75	N/A	1432 MHz – 1517 MHz	SDL
n76	N/A	1427 MHz – 1432 MHz	SDL
n78	3300 MHz – 3800 MHz	3300 MHz – 3800 MHz	TDD
n77	3300 MHz – 4200 MHz	3300 MHz – 4200 MHz	TDD
n79	4400 MHz – 5000 MHz	4400 MHz – 5000 MHz	TDD
n80	1710 MHz – 1785 MHz	N/A	SUL
n81	880 MHz – 915 MHz	N/A	SUL
n82	832 MHz – 862 MHz	N/A	SUL
n83	703 MHz – 748 MHz	N/A	SUL
n84	1920 MHz – 1980 MHz	N/A	SUL

NR Operating Band	Uplink (UL) operating band BS receive UE transmit F_{UL_low} – F_{UL_high}	Downlink (DL) operating band BS transmit UE receive F_{DL_low} – F_{DL_high}	Duplex Mode
n257	26500 MHz – 29500 MHz	26500 MHz – 29500 MHz	TDD
n258	24250 MHz – 27500 MHz	24250 MHz – 27500 MHz	TDD
n260	37000 MHz – 40000 MHz	37000 MHz – 40000 MHz	TDD

- Frequency range (MHz)
  - 3GPP TS 38.101-2 defines 2 NR frequency ranges: FR1 and FR2. **FR1 is often called sub-6 GHz while FR2 is often referred to as millimeter wave.**
- 5G frequency band
  - 3GPP TS 38.101 mainly defines NR frequency bands.
  - NR and LTE have some frequency bands in same but the frequencies are represented in different ways.

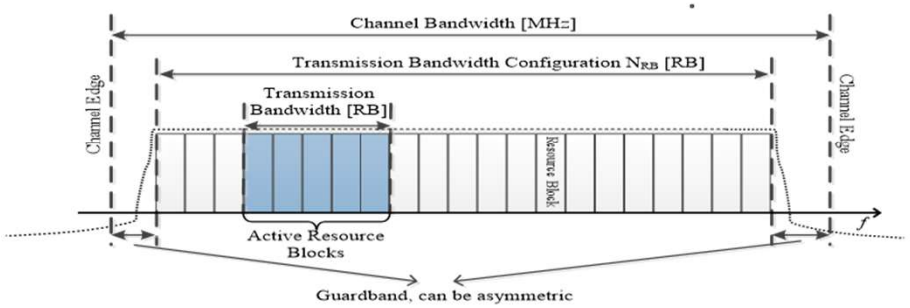
Source: 3GPP TS 38.101

Transmission Bandwidth and Spectrum Utilization

- **Transmission bandwidth varies with RG and SCS.**
  - Maximum transmission bandwidth on the gNodeB side (*Table 5.3.2-1 and 5.3.2-2 in 3GPP TS 38.104*)

SCS (kHz)	5 MHz	10 MHz	15 MHz	30 MHz	20 MHz	25 MHz	40 MHz	50 MHz	60 MHz	70 MHz	80 MHz	90 MHz	100 MHz
	N_{RB} and Spectrum Utilization (FR1: 400 MHz to 6000 MHz)												
15	25	52	79	[160]	106	133	216	270	-	-	-	-	-
	90%	93.6%	94.8%		95.4%	95.8%	97.2%	97.2%	\	\	\	\	\
30	11	24	38	[78]	51	65	106	133	162	[189]	217	[245]	273
	79.2%	86.4%	91.2%		91.8%	93.6%	95.4%	95.8%	97.2%		97.7%		98.3%
60	-	11	18	[38]	24	31	51	65	79	[93]	107	[121]	135
		79.2%	86.4%		86.4%	893%	91.8%	93.6%	94.8%		93.6%		97.2%

SCS (kHz)	50 MHz	100 MHz	200 MHz	400 MHz
	N_{RB} and Spectrum Utilization (FR2: 24 GHz to 52 GHz)			
60	66	132	264	N/A
	95%	95%	95%	\
120	32	66	132	264
	92.2%	95%	95%	95%



  - Maximum transmission bandwidth on the UE side (*3GPP TS 38.101-1 and TS 38.101-2*).
    - ✓ The number of RBs in the 30 MHz bandwidth is to be determined.
    - ✓ The 70 MHz and 90 MHz bandwidths are not supported.
    - ✓ Other values are the same as those on the gNodeB side.

1 Numerology

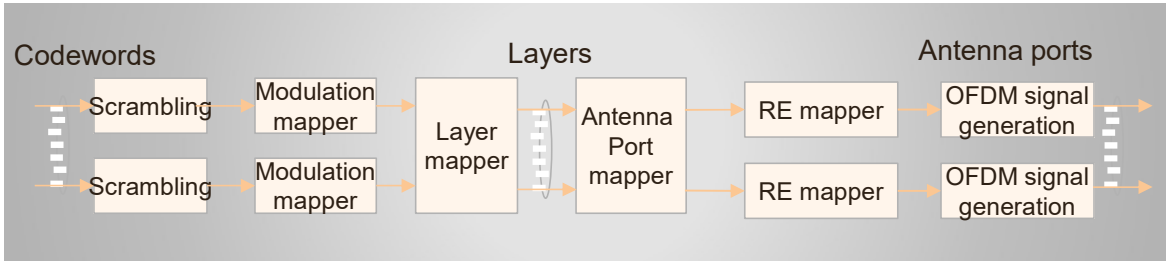
2 Time-Domain Resources

3 Frequency-Domain Resources

4 **Space-Domain Resources:** Layer, Antenna Port, QCL

Codeword and Antenna Ports

- **Basic concepts**
  - Codeword
    - Upper-layer service data on which channel coding applies.
    - Codewords uniquely identify data flow. By transmitting different data, MIMO implements spatial multiplexing.
    - The number of codewords depends on the rank of the channel matrix.
  - Layer
    - Used to define mapping relationship btw codewords and transmit antenna.
  - Antenna port
    - Antennas ports are defined based on reference signals.



Number of codewords ≤ Number of layers ≤ Number of antenna ports

- **Protocol-defined number of codewords**
  - 1 to 4 layers: 1 codeword
  - 5 to 8 layers: 2 codewords
- **Protocol-defined maximum number of layers**
  - For DL/User: 8@SU; 4@MU
  - For UL/User: 4@SU or MU
- **Protocol-defined number of antenna ports**

Channel/Signal		Maximum Number of Ports
UL	PUSCH with DMRS	8 or 12
	PUCCH	1
	PRACH	1
	SRS	4
DL	PDSCH with DMRS	8 or 12
	PDCCH	1
	CSI-RS	32
	SSB	1