IEE2650: Cellular Communication Technologies

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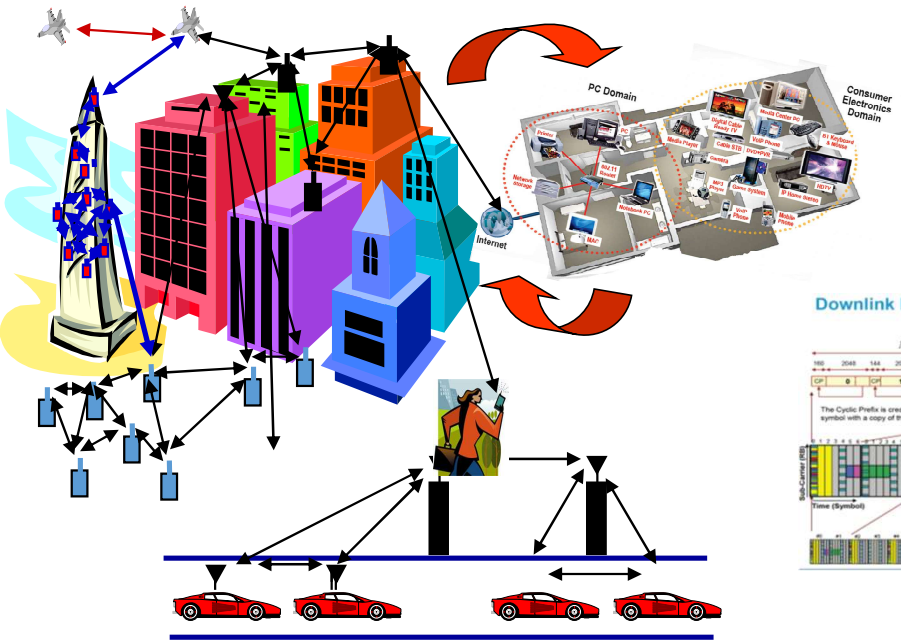
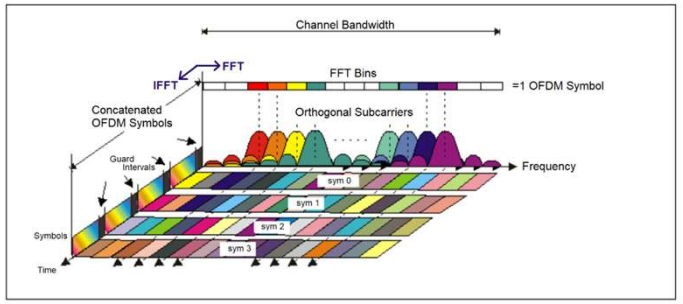
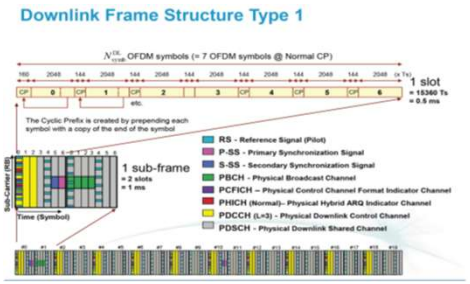
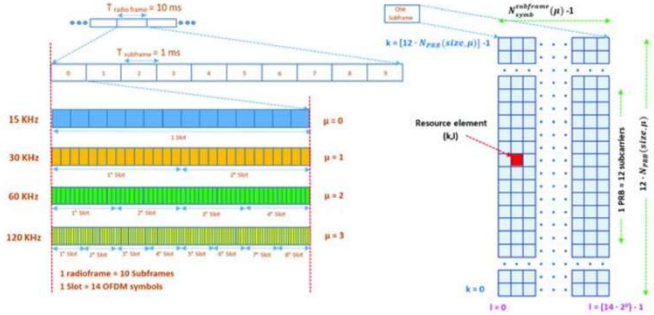




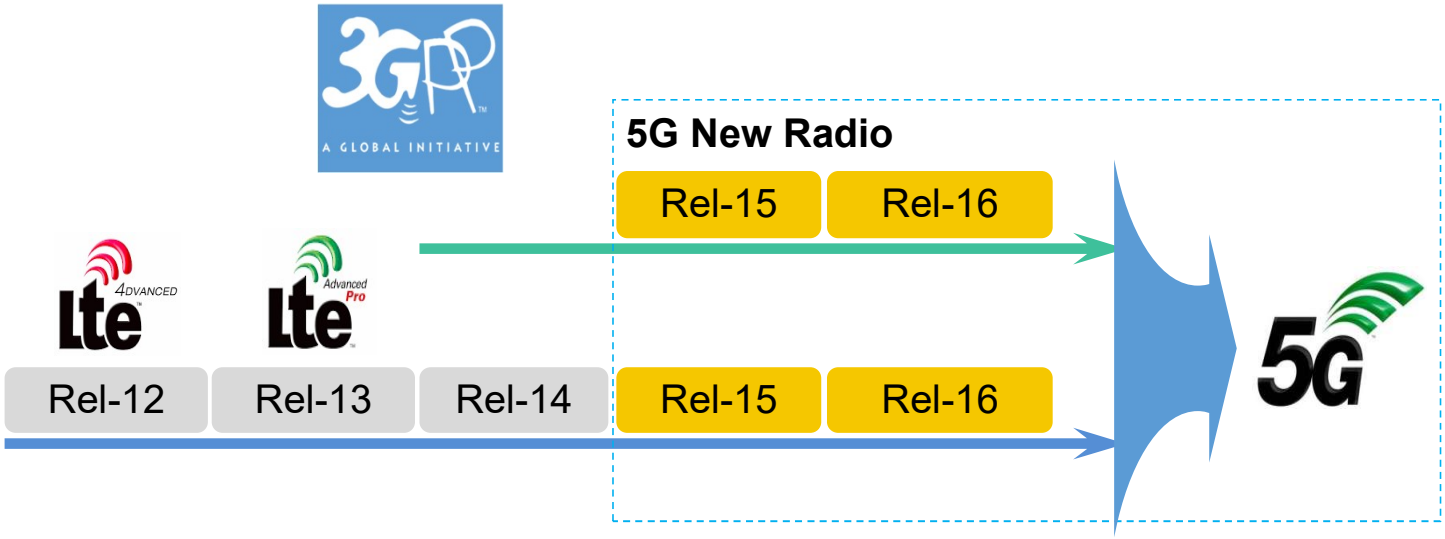
Frequency-Time Representative of an OFDM signal





5G Air Interface

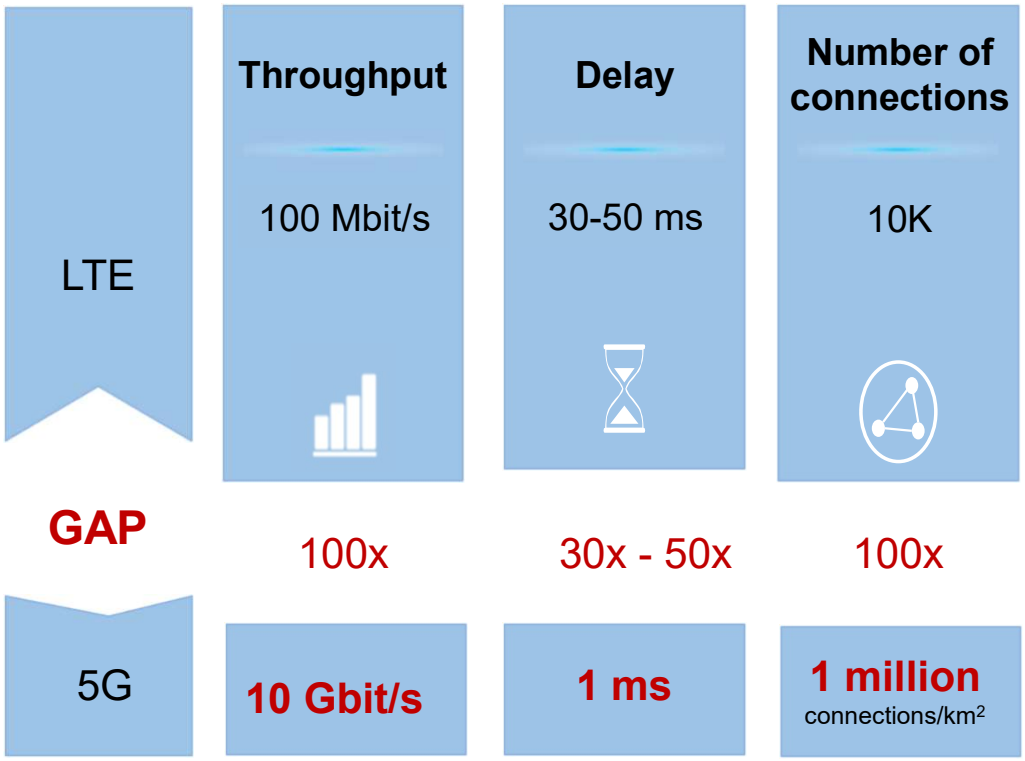
5G Starts from 3GPP Release 15



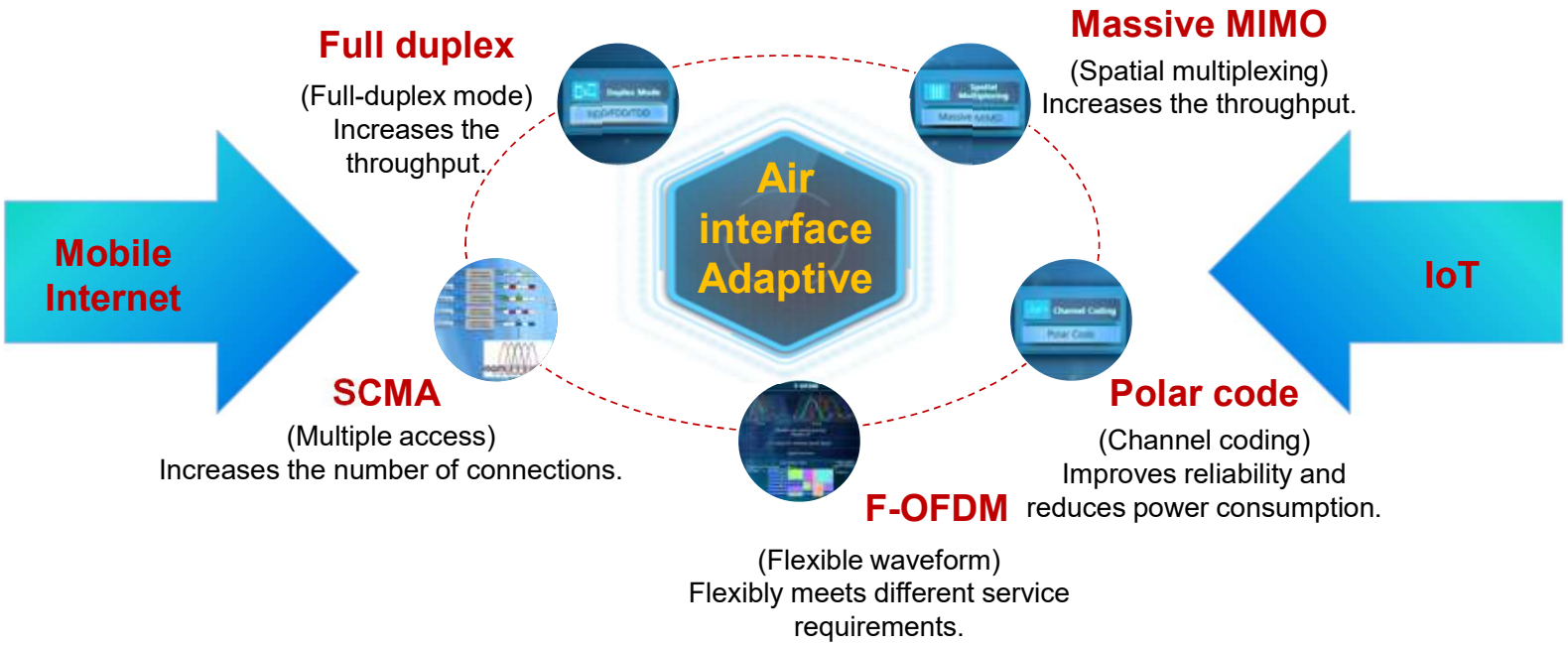
5G includes:

- New Radio
- LTE Advanced Pro evolution
- Next-generation core network
- EPC evolution

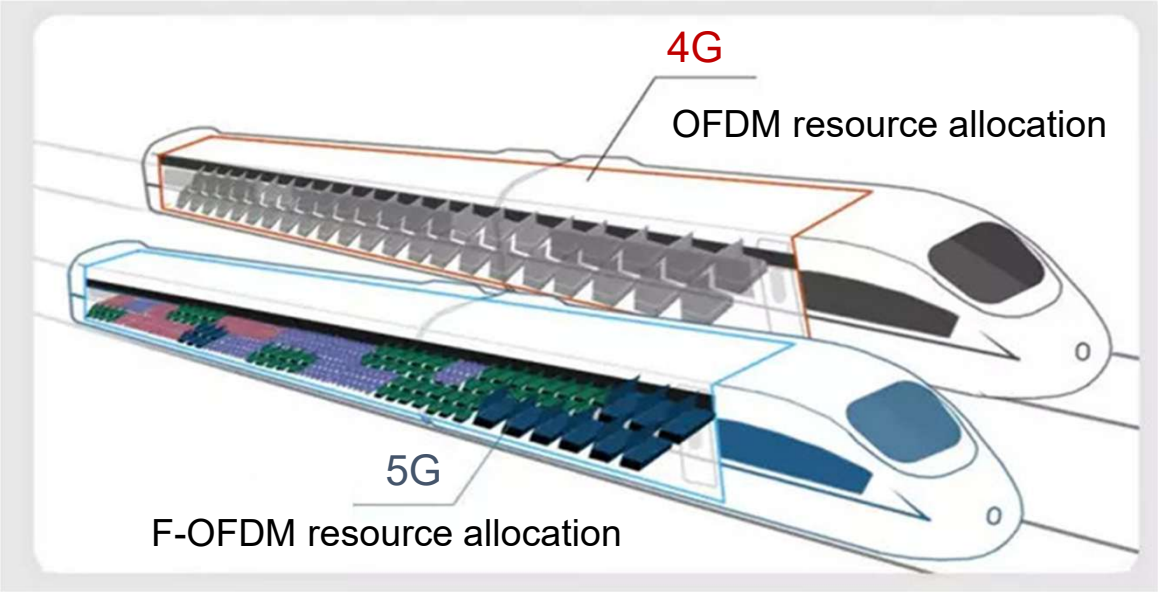
Key Performance Comparison Between 4G and 5G



New Air Interface Technologies



F-OFDM: Adaptive Waveform for Air Interface



4G (OFDM): fixed subcarrier bandwidth of 15 kHz.

5G (F-OFDM): Subcarrier bandwidth can flexibly adapt to the packet sizes of different QoE applications.

	OFDM	F-OFDM
Service adaptation	Fixed subcarrier spacing (SCS) Fixed cyclic prefix (CP)	Flexible SCS Flexible CP
High spectral efficiency	10% of guard bandwidth	Minimum guard bandwidth of one subcarrier

Contents

3 Main TSGs (Technical Specification Group)

Project Co-ordination Group (PCG)

TSG RAN Radio Access Network	TSG SA Service & Systems Aspects	TSG CT Core Network & Terminals
RAN WG1 Radio Layer 1 spec	**SA WG1** Services	CT WG1
RAN WG2 Radio Layer 2 spec Radio Layer 3 RR spec	**SA WG2** Architecture	CT WG3 Interworking with external networks, policy and billing control
RAN WG3 Iub spec, Iur spec, Iu spec UTRAN O&M requirements (transmission interfaces)	**SA WG3** Security	CT WG4 Core Network Protocols
RAN WG4 Radio Performance Protocol aspects	SA WG4 Codec	CT WG6 Smart Card Application Aspects
RAN WG5 Mobile Terminal Conformance Testing	SA WG5 Telecom Management	
RAN WG6 Legacy RAN radio and protocol	SA WG6 Mission-critical applications	

TSGs are responsible for 3GPP standard finalization.

TSG SA Protocol Architecture

- **TR：Technical Report**

SA WG1

TR 22.891: Study on New Services and Markets Technology Enablers (New service study)
TR 22.861: FS_SMARTER - massive Internet of Things (Massive IoT)
TR 22.862: Feasibility study on new services and markets technology enablers for critical communications; Stage 1 (Critical Communication)
TR 22.863: Feasibility study on new services and markets technology enablers for enhanced mobile broadband; Stage 1 (eMBB)
TR 22.864: Feasibility study on new services and markets technology enablers for network operation; Stage 1 (Network operation)

SA WG2

TR 23.799: Study on Architecture for Next Generation System

SA WG3

TR 33.899: Study on the security aspects of the next generation system

TS 22.261: Service requirements for next generation new services and markets

TS 23.501: System architecture for the 5G system
TS 23.502: Procedure for the 5G system

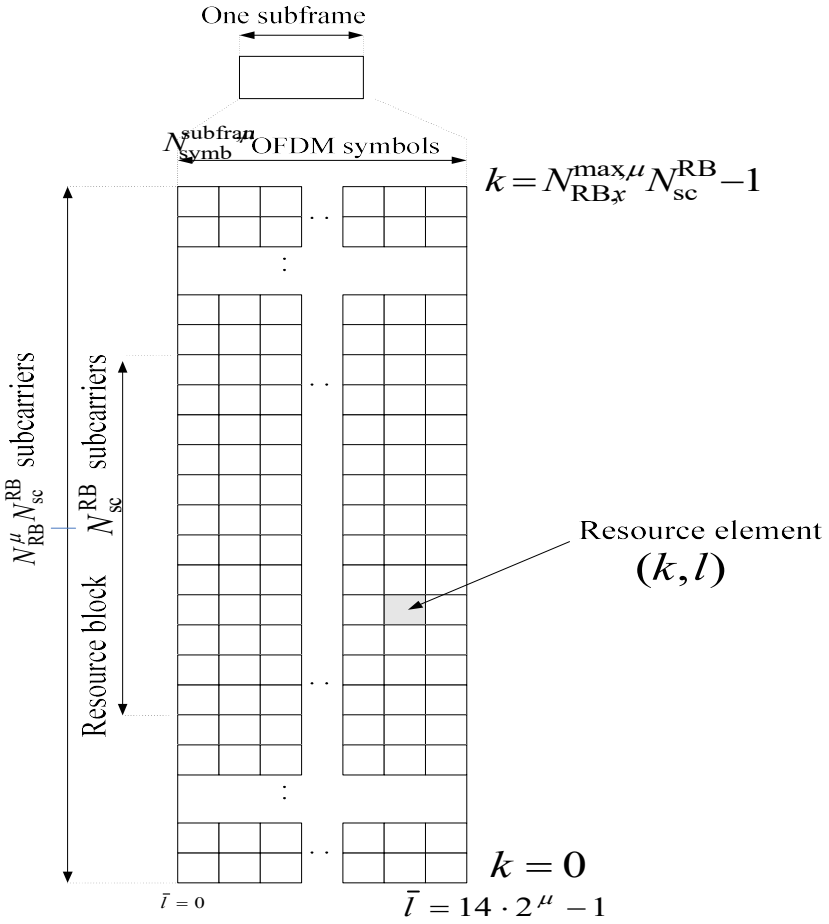
- **TS：Technical Specification**

Contents

5G NR Physical Resource

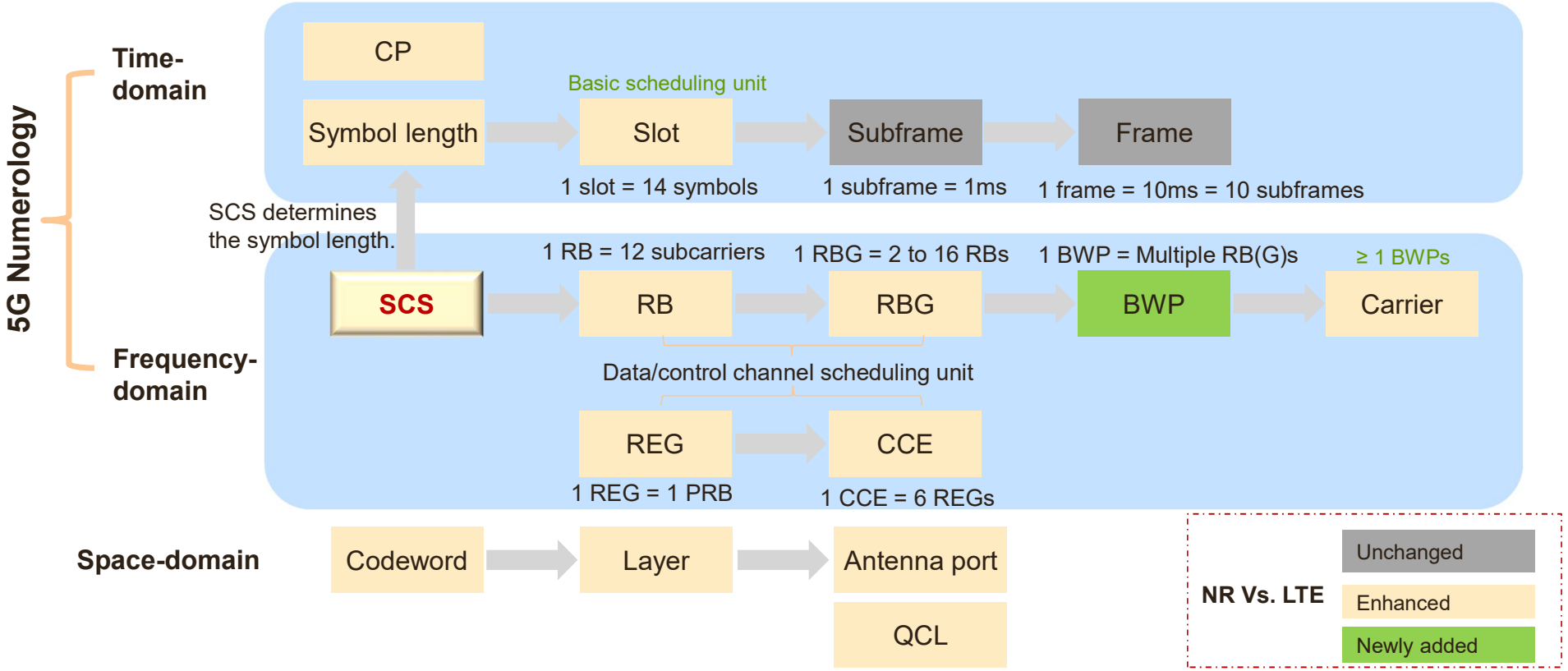
Basic Concepts of Frequency-Domain Resources

- **Resource Grid (RG)**
  - Resource group at the physical layer to define bandwidth
  - Frequency domain: available RB resources within the transmission bandwidth
- **Resource Element (RE)**
  - Smallest unit of physical-layer resources
  - Time domain: 1 symbol, frequency domain: 1 subcarrier
- **Resource Block (RB)**
  - Basic scheduling unit for data channel
  - Frequency domain: 12 contiguous subcarriers
- **Resource Block Group (RBG)**
  - Basic scheduling unit for data channel, to reduce control channel overheads
  - Frequency domain: {2, 4, 8, 16} RBs
- **Resource Element Group (REG)**
  - Basic unit involved in control channel resource allocation
  - Time domain: 1 symbol, frequency domain: 12 subcarriers (1 PRB)
- **Control Channel Element (CCE)**
  - Basic scheduling unit involved in control channel resource allocation
  - Frequency domain: 1 CCE = 6 REGs = 6 PRBs
  - CCE aggregation level: 1, 2, 4, 8, 16



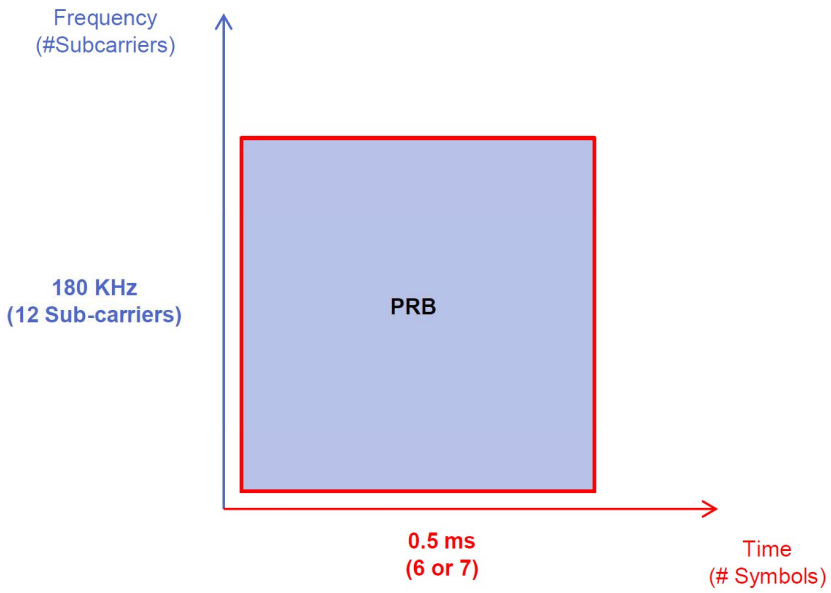
NR Air Interface Resources Overview

5G Numerology: refers to SubCarrier Spacing (SCS) and related parameters such as the symbol length and CP length of the NR system

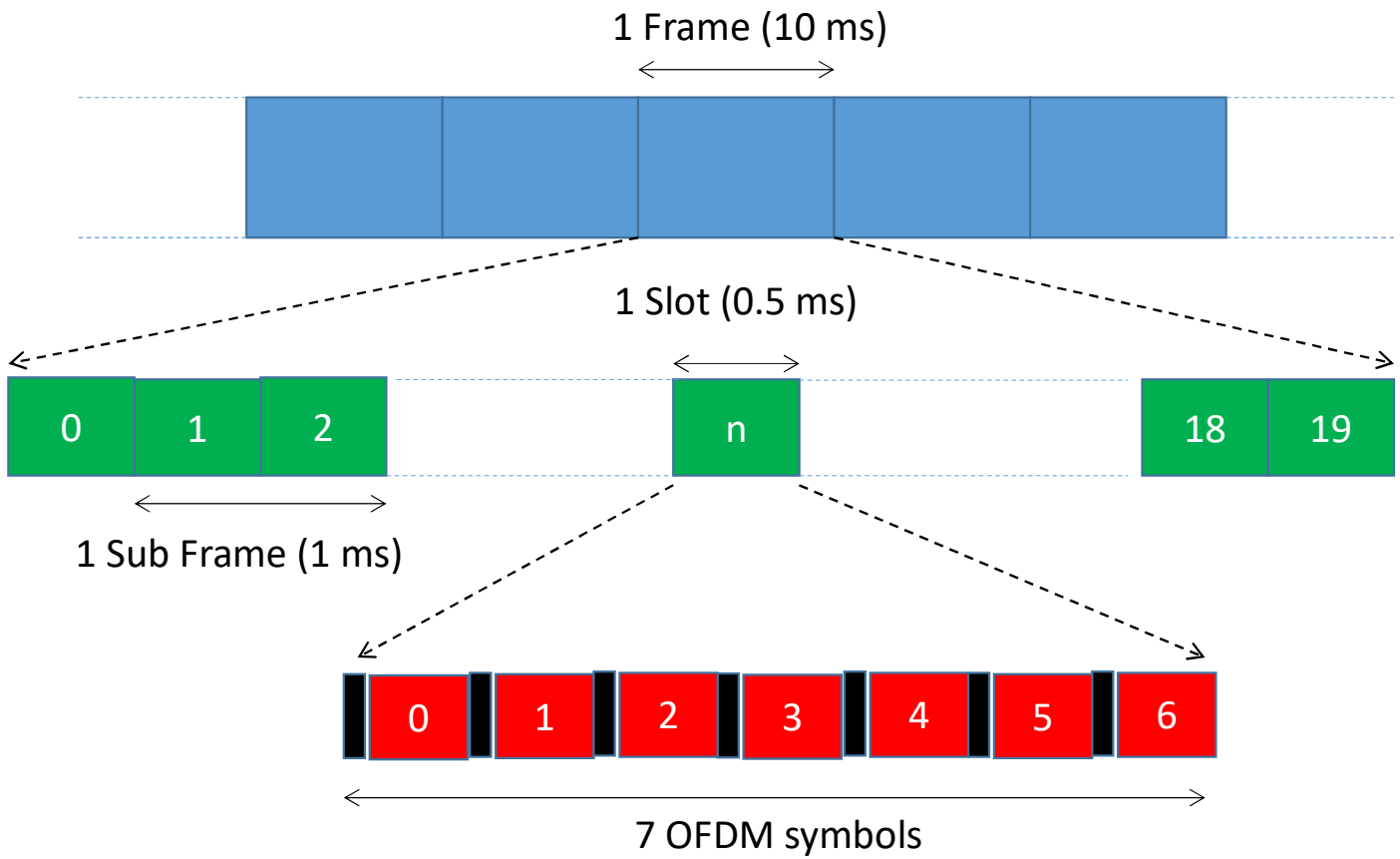


LTE Resource

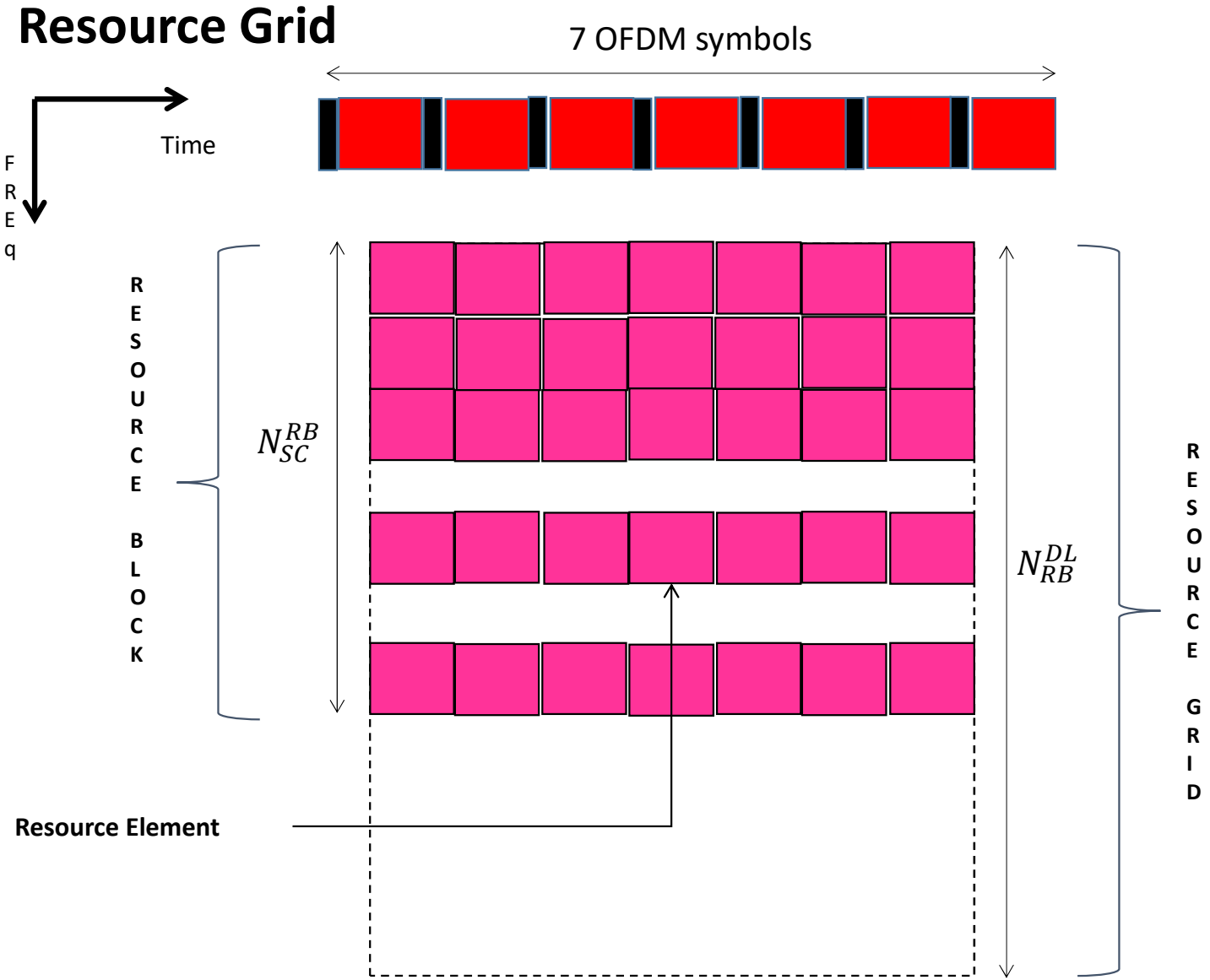
- **Physical Resource Block (PRB)**
  - ✓ **The Smallest User Assignment Resource Unit (12 Sub-carriers)**



Generic Frame Structure – Type 1



Resource Grid



SCS(SubCarrier Spacing)

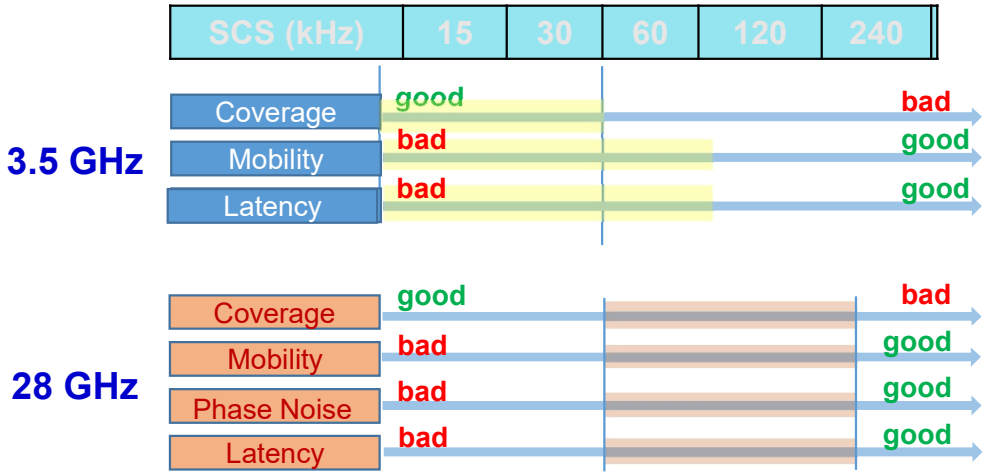
- **Numerologies supported by 3GPP Release 15 (TS 38.211)**

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

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)

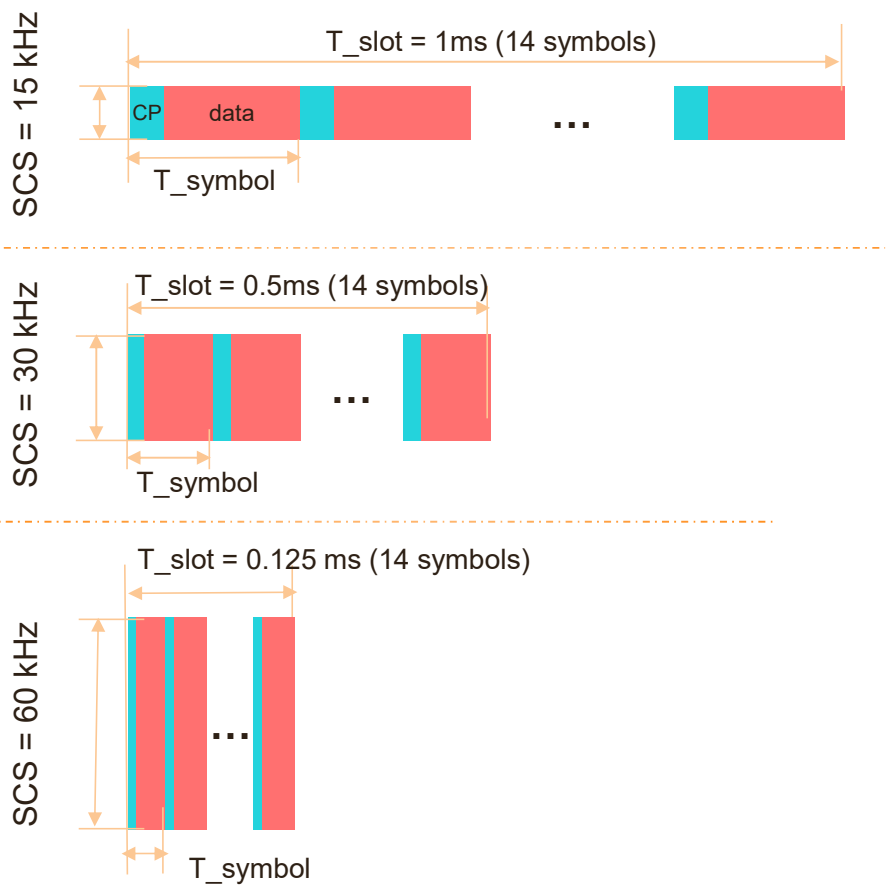
$$T_{sf} = \left(\Delta f_{max} \cdot N_f / 1000\right) T_c = 1 ms$$

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

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



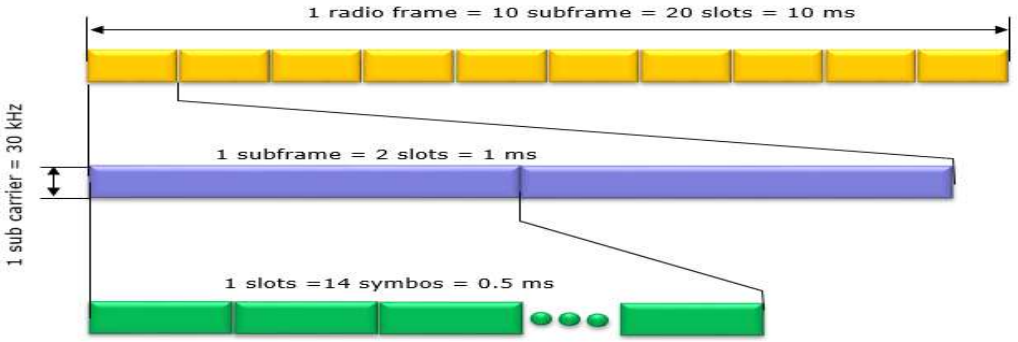
Frame Structure Architecture

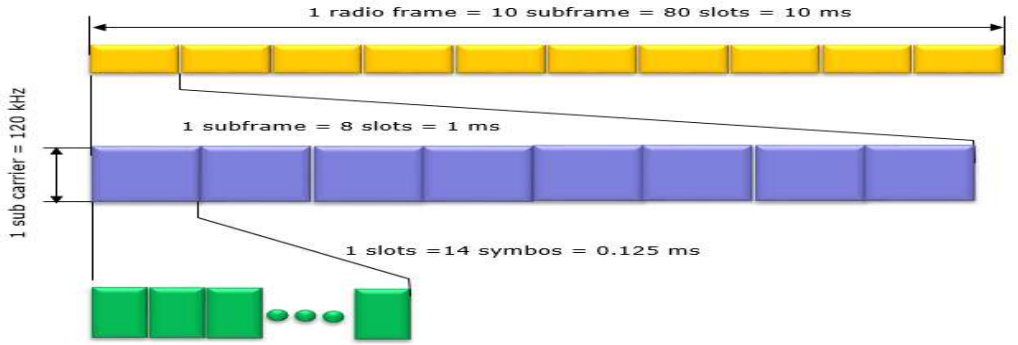
- **Frame length: 10ms**
  - SFN range: 0 to 1023
- **Subframe length: 1ms**
  - Subframe index per system frame: 0 to 9
- **Slot length: 14 symbols**

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

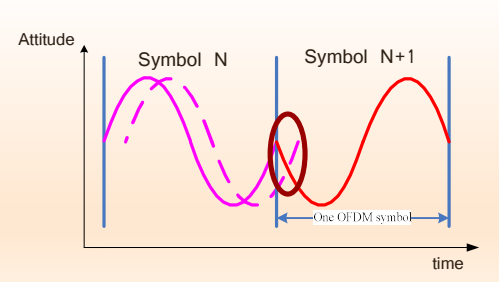
- **Frame structure architecture:**
  - Example: SCS = 30 kHz/120 kHz

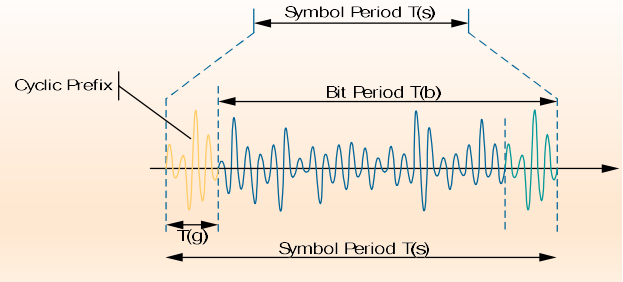




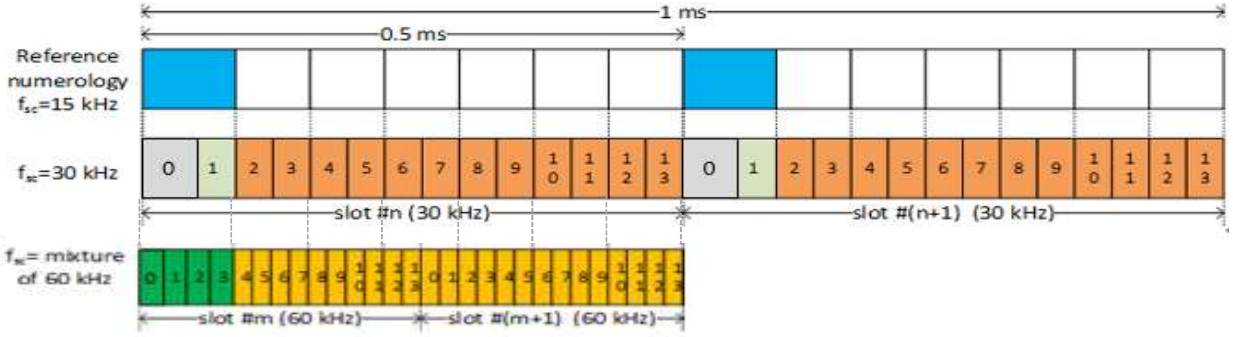
Cyclic Prefix (CP)

- **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