5G physical layer specifications

EventHelix Follow
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The 5G specifications have been published as the 3GPP 38 series. Here we look at the physical layer specifications.

38.211: Physical channels and modulation

The scope is to establish the characteristics of the Layer-1 physical channels, generation of physical layer signals and modulation, and to specify:

- Definition of the uplink and doecewnlink physical channels
- Frame structure and physical resources
- Modulation mapping (BPSK, QPSK, etc.)
- OFDM signal generation
- Scrambling, modulation and up-conversion

- Physical shared channel in uplink and downlink
- Reference signal in uplink and downlink
- Physical random-access channel
- Primary and secondary synchronization signals

5G transmission numerologies

5G supports OFDM numerologies (μ) that can scale across the sub 6GHz to the mm-waves. The subcarrier scales from 15 KHz to 240 KHz (Δf).

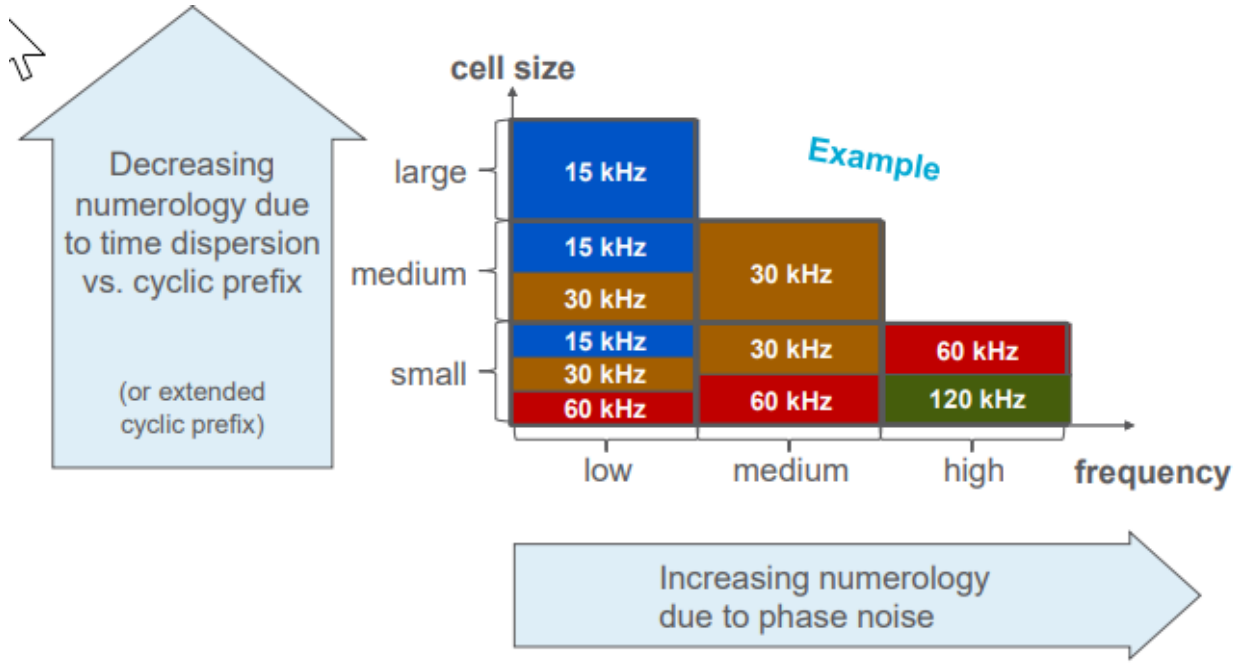
μ	$\Delta f = 2^{\mu} \cdot 15$ [kHz]	Cyclic prefix
0	15	Normal
1	30	Normal
2	60	Normal, Extended
3	120	Normal
4	240	Normal

Supported transmission numerologies in 5G (Credit: 3GPP TS 38.211 V15.1.0 Table 4.2–1)

The OFDM symbol duration and the cyclic prefix duration scale based on the numerology.

Subcarrier spacing	15kHz	30kHz (2 x 15kHz)	60kHz (4 x 15kHz)	15 x 2^nkHz, (n = 3, 4, ...)
OFDM symbol duration	66.67 µs	33.33 µs	16.67 µs	66.67/2^n µs
Cyclic prefix duration	4.69 µs	2.34 µs	1.17 µs	4.69/2^n µs
OFDM symbol including CP	71.35 µs	35.68 µs	17.84 µs	71.35/2^n µs
Number of OFDM symbols per slot	7 or 14	7 or 14	7 or 14	14
Slot duration	500 µs or 1,000 µs	250 µs or 500 µs	125 µs or 250 µs	1,000/2^n µs

The selection of numerology will depend upon the size of the cell and the frequency band. Large cells have a large time dispersion at the receiver. A large cyclic prefix needed to counter the larger time dispersion. Higher numerologies are preferable for higher frequencies as the wider subcarrier is less susceptible to phase noise.



Selecting the numerology based on cell size and frequency (cred: Ericsson)

Frames and subframes

Downlink and uplink transmissions are organized into frames into a 10ms frame as shown below:

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

Where:

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

$$\Delta f_{max} = 480 \cdot 10^3 \text{ Hz}$$

$$N_f = 4096$$

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

Slots

Just like LTE, a slot is always 14 symbols. The number of slots in a subframe depends on the numerology μ.

μ	N^{slot}_{symb}	$N^{frame,\mu}_{slot}$	$N^{subframe,\mu}_{slot}$
0	14	10	1
1	14	20	2
2	14	40	4
3	14	80	8
4	14	160	16

Number of OFDM symbols per slot, slots per frame, and slots per subframe for normal cyclic prefix. (Credit: 3GPP TS 38.211 V15.1.0 Table 4.3.2–1)

Symbol level TDD

5G slots support symbol level TDD formats. Each symbol can be designated as:

- D: Downlink
- U: Uplink
- X: Flexible

UE assumes that downlink reception can take place only in symbols marked D or X in the following table.

Similarly, the UT can transmit in the uplink only in slots marked U or X.

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	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	D	D	D	D	D	D	D	D	D	D	D	D	D	X
4	D	D	D	D	D	D	D	D	D	D	D	D	X	X
5	D	D	D	D	D	D	D	D	D	D	D	X	X	X
6	D	D	D	D	D	D	D	D	D	D	X	X	X	X
7	D	D	D	D	D	D	D	D	D	X	X	X	X	X
8	X	X	X	X	X	X	X	X	X	X	X	X	X	U
9	X	X	X	X	X	X	X	X	X	X	X	X	U	U
10	X	U	U	U	U	U	U	U	U	U	U	U	U	U
11	X	X	U	U	U	U	U	U	U	U	U	U	U	U
12	X	X	X	U	U	U	U	U	U	U	U	U	U	U
13	X	X	X	X	U	U	U	U	U	U	U	U	U	U
14	X	X	X	X	X	U	U	U	U	U	U	U	U	U
15	X	X	X	X	X	X	U	U	U	U	U	U	U	U
16	D	X	X	X	X	X	X	X	X	X	X	X	X	X
17	D	D	X	X	X	X	X	X	X	X	X	X	X	X
18	D	D	D	X	X	X	X	X	X	X	X	X	X	X
19	D	X	X	X	X	X	X	X	X	X	X	X	X	U
20	D	D	X	X	X	X	X	X	X	X	X	X	X	U
21	D	D	D	X	X	X	X	X	X	X	X	X	X	U
22	D	X	X	X	X	X	X	X	X	X	X	X	U	U
23	D	D	X	X	X	X	X	X	X	X	X	X	U	U
24	D	D	D	X	X	X	X	X	X	X	X	X	U	U
25	D	X	X	X	X	X	X	X	X	X	X	U	U	U
26	D	D	X	X	X	X	X	X	X	X	X	U	U	U
27	D	D	D	X	X	X	X	X	X	X	X	U	U	U
28	D	D	D	D	D	D	D	D	D	D	D	D	X	U
29	D	D	D	D	D	D	D	D	D	D	D	X	X	U
30	D	D	D	D	D	D	D	D	D	D	X	X	X	U
31	D	D	D	D	D	D	D	D	D	D	D	X	U	U
32	D	D	D	D	D	D	D	D	D	D	X	X	U	U
33	D	D	D	D	D	D	D	D	D	X	X	X	U	U
34	D	X	U	U	U	U	U	U	U	U	U	U	U	U
35	D	D	X	U	U	U	U	U	U	U	U	U	U	U
36	D	D	D	X	U	U	U	U	U	U	U	U	U	U
37	D	X	X	U	U	U	U	U	U	U	U	U	U	U
38	D	D	X	X	U	U	U	U	U	U	U	U	U	U
39	D	D	D	X	X	U	U	U	U	U	U	U	U	U
40	D	X	X	X	U	U	U	U	U	U	U	U	U	U
41	D	D	X	X	X	U	U	U	U	U	U	U	U	U
42	D	D	D	X	X	X	U	U	U	U	U	U	U	U
43	D	D	D	D	D	D	D	D	D	X	X	X	X	U
44	D	D	D	D	D	D	X	X	X	X	X	X	U	U
45	D	D	D	D	D	D	X	X	U	U	U	U	U	U
46	D	D	D	D	D	D	X	D	D	D	D	D	D	X
47	D	D	D	D	D	X	X	D	D	D	D	D	X	X
48	D	D	X	X	X	X	X	D	D	X	X	X	X	X
49	D	X	X	X	X	X	X	D	X	X	X	X	X	X
50	X	U	U	U	U	U	U	X	U	U	U	U	U	U
51	X	X	U	U	U	U	U	X	X	U	U	U	U	U
52	X	X	X	U	U	U	U	X	X	X	U	U	U	U
53	X	X	X	X	U	U	U	X	X	X	X	U	U	U
54	D	D	D	D	D	X	U	D	D	D	D	D	X	U
55	D	D	X	U	U	U	U	D	D	X	U	U	U	U
56	D	X	U	U	U	U	U	D	X	U	U	U	U	U
57	D	D	D	D	X	X	U	D	D	D	D	X	X	U
58	D	D	X	X	U	U	U	D	D	X	X	U	U	U
59	D	X	X	U	U	U	U	D	X	X	U	U	U	U
60	D	X	X	X	X	X	U	D	X	X	X	X	X	U

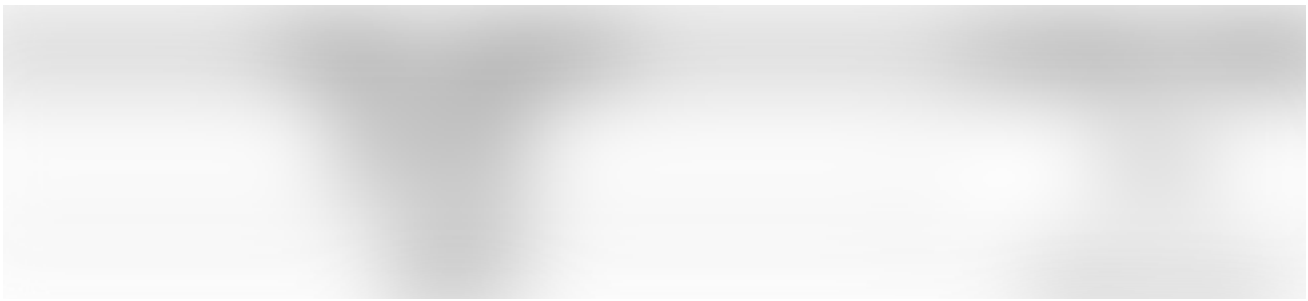
TS 38.212: Multiplexing and channel coding

The scope is to describe the transport channel and control channel data processing, including multiplexing, channel coding and interleaving, and to specify:

- Channel coding schemes
- Rate matching
- Uplink transport channels and control information
- Downlink transport channels and control information

Channel coding

5G NR traffic channels are encoded using the LDPC (Low Density Parity Check) coding. Control channels are encoded with the Polar codes.



Modulation schemes

5G-AN supports 1 to 8 bits per symbol (Q).

Downlink Control Channel (DCI) formats

A DCI transports downlink and uplink scheduling information, requests for aperiodic CQI reports, or uplink power control commands for one cell and one RNTI.

- **DCI format 0_0** is used for the scheduling of PUSCH in one cell.
- **DCI format 0_1** is used for the scheduling of PUSCH in one cell.
- **DCI format 1_0** is used for the scheduling of PDSCH in one DL cell.
- **DCI format 1_1** is used for the scheduling of PDSCH in one cell.
- **DCI format 2_0** is used for notifying the slot format.
- **DCI format 2_1** is used for notifying the PRB(s) and OFDM symbol(s) where UE may assume no transmission is intended for the UE.
- **DCI format 2_2** is used for the transmission of TPC commands for PUCCH and PUSCH.
- **DCI format 2_3** is used for the transmission of a group of TPC commands for SRS transmissions by one or more UEs. Along with a TPC command, a SRS request may also be transmitted.

TS 38.213: Physical layer procedures for control

The scope is to establish the characteristics of the physical layer procedures for control, and to specify:

- Synchronization procedures

- UE procedure for receiving control information

TS 38.214: Physical layer procedures for data

Cell search and timing adjustment

The scope is to establish the characteristics of the physical layer procedures for data, and to specify:

The cell search and timing adjustment procedures have been enhanced to work for 15 KHz t 240 KHz subcarrier spacing.

- Power control

Power control

- Physical downlink shared channel related procedures

The power control scheme has also been extended to work for all numerologies. The 2^μ te in the PUSCH power calculation factors in the different numerologies.

- Physical uplink shared channel related procedure

Downlink MCS index table

The downlink MCS index table specifies the modulation, coding and the overall spectral efficiency of the PDSCH.

MCS index table for PDSCH

Uplink MCS index table

The uplink MCS index table specifies the modulation, coding and the overall spectral efficiency of the PUSCH.

MCS index table for PUSCH

Downlink CQI reporting

The UE reports downlink CQI via a 4-bit field that is carried over the PUCCH or the PUSCH. Two different tables are defined.

- CQI reporting limited to 64-QAM

CQI reporting table (limited to 64-QAM)

- CQI reporting extended to 256-QAM

CQI reporting table (extended to 256-QAM)

TS 38.215: Physical layer measurements

The scope is to establish the characteristics of the physical layer measurements, and to specify:

- Control of UE/NG-RAN measurements

5G NR physical layer introduction

The following video provides a good overview of the 5G NR physical layer. The topics covered are:

Waveforms and frame structure

- Scalable numerology
- Numerology multiplexing
- Dynamic TDD

Millimeter waves

- Beam management
- Massive MIMO

Low latency

- CBG (code block group) retransmission
- Front loaded DMRS (demodulation reference signal)

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Understanding the 5G NR physical layer (slides)