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Foreword

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1 Scope

The present document describes the physical channels and signals for 5G-NR.

2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- [1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".
- [2] 3GPP TS 38.201: "NR; Physical Layer – General Description"
- [3] 3GPP TS 38.202: "NR; Services provided by the physical layer"
- [4] 3GPP TS 38.212: "NR; Multiplexing and channel coding"
- [5] 3GPP TS 38.213: "NR; Physical layer procedures for control "
- [6] 3GPP TS 38.214: "NR; Physical layer procedures for data "
- [7] 3GPP TS 38.215: "NR; Physical layer measurements"
- [8] 3GPP TS 38.104: "NR; Base Station (BS) radio transmission and reception"
- [9] void
- [10] 3GPP TS 38.306: "NR; User Equipment (UE) radio access capabilities"

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following definitions apply:

3.2 Symbols

For the purposes of the present document, the following symbols apply:

| | |
|------------------------|---|
| $(k,l)_{p,\mu}$ | Resource element with frequency-domain index k and time-domain index l for antenna port p and subcarrier spacing configuration μ ; see clause 4.4.3 |
| $a_{k,l}^{(p,\mu)}$ | Value of resource element (k,l) for antenna port p and subcarrier spacing configuration μ ; see clause 4.4.3 |
| β | Amplitude scaling for a physical channel/signal |
| $c(n)$ | PN sequence; see clause 5.2.1 |
| Δf | Subcarrier spacing |
| Δf_{RA} | Subcarrier spacing for random-access preambles |
| κ | The ratio between T_s and T_c ; see clause 4.1 |
| k | Subcarrier index relative to a reference |
| l | OFDM symbol index relative to a reference |
| μ | Subcarrier spacing configuration, $\Delta f = 2^\mu \cdot 15$ [kHz] |
| $M_{\text{bit}}^{(q)}$ | Number of coded bits to transmit on a physical channel [for codeword q] |

| | |
|---|---|
| $M_{\text{symb}}^{(q)}$ | Number of modulation symbols to transmit on a physical channel [for codeword q] |
| $M_{\text{symb}}^{\text{layer}}$ | Number of modulation symbols to transmit per layer for a physical channel |
| $M_{\text{sc}}^{\text{PUSCH}}$ | Scheduled bandwidth for uplink transmission, expressed as a number of subcarriers |
| $M_{\text{RB}}^{\text{PUSCH}}$ | Scheduled bandwidth for uplink transmission, expressed as a number of resource blocks |
| $M_{\text{symb}}^{\text{ap}}$ | Number of modulation symbols to transmit per antenna port for a physical channel |
| ν | Number of transmission layers |
| $N_{\text{BWP},i}^{\text{size}}$ | Size of bandwidth part i ; see clause 4.4.4.4 |
| $N_{\text{BWP},i}^{\text{start}}$ | Start of bandwidth part i ; see clause 4.4.4.4 |
| $N_{\text{CP},i}^{\mu}$ | Cyclic prefix length; see clause 5.3.1 |
| $N_{\text{grid},x}^{\text{size},\mu}$ | The size of the resource grid; see clauses 4.4.2 and 5.3 |
| $N_{\text{grid},x}^{\text{start},\mu}$ | The start of the resource grid; see clause 4.4.2 |
| $N_{\text{group}}^{\text{PT-RS}}$ | The number of PT-RS groups; see clause 6.3.1.4 |
| $N_{\text{ID}}^{\text{cell}}$ | Physical layer cell identity; see clause 7.4.2.1 |
| $N_{\text{RB}}^{\text{CORESET}}$ | Frequency-domain size of a control resource set; see clause 7.3.2.2 |
| $N_{\text{REG}}^{\text{CORESET}}$ | Number of resource-element groups in a CORESET; see clause 7.3.2.2 |
| $N_{\text{samp}}^{\text{group}}$ | Number of samples per PT-RS group; see clause 6.3.1.4 |
| $N_{\text{sc}}^{\text{RB}}$ | Number of subcarriers per resource block, see clause 4.4.4.1 |
| $N_{\text{slot}}^{\text{subframe},\mu}$ | Number of slots per subframe for subcarrier spacing configuration μ , see clause 4.3.2 |
| $N_{\text{slot}}^{\text{frame},\mu}$ | Number of slots per frame for subcarrier spacing configuration μ , see clause 4.3.2 |
| $N_{\text{symb}}^{\text{CORESET}}$ | Time duration of a control resource set; see clause 7.3.2.2 |
| $N_{\text{symb}}^{\text{PUCCH}}$ | Length of the PUCCH transmission in OFDM symbols; see clause 6.3.2.1 |
| $N_{\text{symb}}^{\text{subframe},\mu}$ | Number of OFDM symbols per subframe for subcarrier spacing configuration μ ; see clause 4.3.1 |
| $N_{\text{slot}}^{\text{symb}}$ | Number of symbols per slot |
| N_{TA} | Timing advance between downlink and uplink; see clause 4.3.1 |
| $N_{\text{TA,offset}}$ | A fixed offset used to calculate the timing advance; see clause 4.3.1 |
| $N_{\text{Rx-Tx}}$ | Minimum time from reception to transmission for a half-duplex UE; see clause 4.3.2 |
| n_{f} | System frame number (SFN) |
| n_{CRB}^{μ} | Common resource block number for subcarrier spacing configuration μ , see clause 4.4.4.3 |
| n_{PRB} | Physical resource block number; see clause 4.4.4.4 |
| n_{RNTI} | Radio network temporary identifier |
| n_{s}^{μ} | Slot number within a subframe for subcarrier spacing configuration μ ; see clause 4.3.2 |
| $n_{\text{s},f}^{\mu}$ | Slot number within a frame for subcarrier spacing configuration μ ; see clause 4.3.2 |
| p | Antenna port number |
| Q_{m} | Modulation order |
| ρ | Number of antenna ports |
| $\bar{r}_{u,v}(n)$ | Low-PAPR base sequence; see clause 5.2.2 |
| $r_{u,v}^{(\alpha,\delta)}(n)$ | Low-PAPR sequence; see clause 5.2.2 |
| $s_l^{(p,\mu)}(t)$ | The time-continuous signal on antenna port p and subcarrier spacing configuration μ for OFDM symbol l in a subframe; see clause 5.3.1 |
| T_{c} | Basic time unit for NR; see clause 4.1 |
| T_{f} | Radio frame duration; see clause 4.3.1 |
| T_{s} | Basic time unit for LTE |
| T_{sf} | Subframe duration; see clause 4.3.1 |
| T_{slot} | Slot duration; see clause 4.3.2 |
| T_{TA} | Timing advance between downlink and uplink; see clause 4.3.1 |
| W | Precoding matrix for spatial multiplexing |

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

| | |
|---------|--|
| BWP | Bandwidth part |
| CCE | Control channel element |
| CORESET | Control resource set |
| CRB | Common resource block |
| CSI | Channel-state information |
| CSI-RS | CSI reference signal |
| DCI | Downlink Control Information |
| DM-RS | Demodulation reference signal |
| FR1 | Frequency range 1 as defined in [8, TS 38.104] |
| FR2 | Frequency range 2 as defined in [8, TS 38.104] |
| IE | Information element |
| PBCH | Physical broadcast channel |
| PDCCH | Physical downlink control channel |
| PDSCH | Physical downlink shared channel |
| PRACH | Physical random-access channel |
| PRB | Physical resource block |
| PSS | Primary synchronization signal |
| PT-RS | Phase-tracking reference signal |
| PUCCH | Physical uplink control channel |
| PUSCH | Physical uplink shared channel |
| REG | Resource-element group |
| SRS | Sounding reference signal |
| SSS | Secondary synchronization signal |
| VRB | Virtual resource block |

4 Frame structure and physical resources

4.1 General

Throughout this specification, unless otherwise noted, the size of various fields in the time domain is expressed in time units $T_c = 1/(\Delta f_{\max} \cdot N_f)$ where $\Delta f_{\max} = 480 \cdot 10^3$ Hz and $N_f = 4096$. The constant $\kappa = T_s/T_c = 64$ where $T_s = 1/(\Delta f_{\text{ref}} \cdot N_{f,\text{ref}})$, $\Delta f_{\text{ref}} = 15 \cdot 10^3$ Hz and $N_{f,\text{ref}} = 2048$.

4.2 Numerologies

Multiple OFDM numerologies are supported as given by Table 4.2-1 where μ and the cyclic prefix for a bandwidth part are obtained from the higher-layer parameter *subcarrierSpacing* and *cyclicPrefix*, respectively.

Table 4.2-1: Supported transmission numerologies.

| 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 |

4.3 Frame structure

4.3.1 Frames and subframes

Downlink and uplink transmissions are organized into frames with $T_f = (\Delta f_{\max} N_f / 100) \cdot T_c = 10$ ms duration, each consisting of ten subframes of $T_{sf} = (\Delta f_{\max} N_f / 1000) \cdot T_c = 1$ ms duration. The number of consecutive OFDM symbols per subframe is $N_{\text{ymb}}^{\text{subframe}, \mu} = N_{\text{ymb}}^{\text{slot}} N_{\text{slot}}^{\text{subframe}, \mu}$. Each frame is divided into two equally-sized half-frames of five subframes each with half-frame 0 consisting of subframes 0 – 4 and half-frame 1 consisting of subframes 5 – 9.

There is one set of frames in the uplink and one set of frames in the downlink on a carrier.

Uplink frame number i for transmission from the UE shall start $T_{TA} = (N_{TA} + N_{TA, \text{offset}}) T_c$ before the start of the corresponding downlink frame at the UE where $N_{TA, \text{offset}}$ is given by [5, TS 38.213].

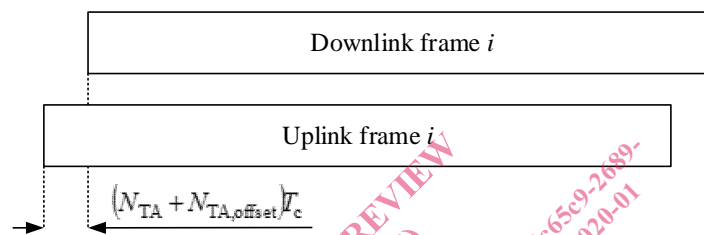


Figure 4.3.1-1: Uplink-downlink timing relation.

4.3.2 Slots

For subcarrier spacing configuration μ , slots are numbered $n_s^\mu \in \{0, \dots, N_{\text{slot}}^{\text{subframe}, \mu} - 1\}$ in increasing order within a subframe and $n_{s,f}^\mu \in \{0, \dots, N_{\text{slot}}^{\text{frame}, \mu} - 1\}$ in increasing order within a frame. There are $N_{\text{ymb}}^{\text{slot}}$ consecutive OFDM symbols in a slot where $N_{\text{ymb}}^{\text{slot}}$ depends on the cyclic prefix as given by Tables 4.3.2-1 and 4.3.2-2. The start of slot n_s^μ in a subframe is aligned in time with the start of OFDM symbol $n_s^\mu N_{\text{ymb}}^{\text{slot}}$ in the same subframe.

OFDM symbols in a slot can be classified as 'downlink', 'flexible', or 'uplink'. Signaling of slot formats is described in subclause 11.1 of [5, TS 38.213].

In a slot in a downlink frame, the UE shall assume that downlink transmissions only occur in 'downlink' or 'flexible' symbols.

In a slot in an uplink frame, the UE shall only transmit in 'uplink' or 'flexible' symbols.

A UE not capable of full-duplex communication and not supporting simultaneous transmission and reception as defined by parameter *simultaneousRxTxInterBandENDC*, *simultaneousRxTxInterBandCA* or *simultaneousRxTxSUL* [10, TS 38.306] among all cells within a group of cells is not expected to transmit in the uplink in one cell within the group of cells earlier than $N_{\text{Rx-Tx}} T_c$ after the end of the last received downlink symbol in the same or different cell within the group of cells where $N_{\text{Rx-Tx}}$ is given by Table 4.3.2-3.

A UE not capable of full-duplex communication and not supporting simultaneous transmission and reception as defined by parameter *simultaneousRxTxInterBandENDC*, *simultaneousRxTxInterBandCA* or *simultaneousRxTxSUL* [10, TS 38.306] among all cells within a group of cells is not expected to receive in the downlink in one cell within the group of cells earlier than $N_{\text{Tx-Rx}} T_c$ after the end of the last transmitted uplink symbol in the same or different cell within the group of cells where $N_{\text{Tx-Rx}}$ is given by Table 4.3.2-3.

A UE not capable of full-duplex communication is not expected to transmit in the uplink earlier than $N_{\text{Rx-Tx}} T_c$ after the end of the last received downlink symbol in the same cell where $N_{\text{Rx-Tx}}$ is given by Table 4.3.2-3.

A UE not capable of full-duplex communication is not expected to receive in the downlink earlier than $N_{\text{Tx-Rx}}T_c$ after the end of the last transmitted uplink symbol in the same cell where $N_{\text{Tx-Rx}}$ is given by Table 4.3.2-3.

Table 4.3.2-1: Number of OFDM symbols per slot, slots per frame, and slots per subframe for normal cyclic prefix.

| μ | $N_{\text{slot}}^{\text{slot,}\mu}$ | $N_{\text{slot}}^{\text{frame,}\mu}$ | $N_{\text{slot}}^{\text{subframe,}\mu}$ |
|-------|-------------------------------------|--------------------------------------|---|
| 0 | 14 | 10 | 1 |
| 1 | 14 | 20 | 2 |
| 2 | 14 | 40 | 4 |
| 3 | 14 | 80 | 8 |
| 4 | 14 | 160 | 16 |

Table 4.3.2-2: Number of OFDM symbols per slot, slots per frame, and slots per subframe for extended cyclic prefix.

| μ | $N_{\text{slot}}^{\text{slot,}\mu}$ | $N_{\text{slot}}^{\text{frame,}\mu}$ | $N_{\text{slot}}^{\text{subframe,}\mu}$ |
|-------|-------------------------------------|--------------------------------------|---|
| 2 | 12 | 40 | 4 |

Table 4.3.2-3: Transition time $N_{\text{Rx-Tx}}$ and $N_{\text{Tx-Rx}}$

| Transition time | FR1 | FR2 |
|--------------------|-------|-------|
| $N_{\text{Tx-Rx}}$ | 25600 | 13792 |
| $N_{\text{Rx-Tx}}$ | 25600 | 13792 |

4.4 Physical resources

4.4.1 Antenna ports

An antenna port is defined such that the channel over which a symbol on the antenna port is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed.

For DM-RS associated with a PDSCH, the channel over which a PDSCH symbol on one antenna port is conveyed can be inferred from the channel over which a DM-RS symbol on the same antenna port is conveyed only if the two symbols are within the same resource as the scheduled PDSCH, in the same slot, and in the same PRG as described in clause 5.1.2.3 of [6, TS 38.214].

For DM-RS associated with a PDCCH, the channel over which a PDCCH symbol on one antenna port is conveyed can be inferred from the channel over which a DM-RS symbol on the same antenna port is conveyed only if the two symbols are within resources for which the UE may assume the same precoding being used as described in clause 7.3.2.2.

For DM-RS associated with a PBCH, the channel over which a PBCH symbol on one antenna port is conveyed can be inferred from the channel over which a DM-RS symbol on the same antenna port is conveyed only if the two symbols are within a SS/PBCH block transmitted within the same slot, and with the same block index according to clause 7.4.3.1.

Two antenna ports are said to be quasi co-located if the large-scale properties of the channel over which a symbol on one antenna port is conveyed can be inferred from the channel over which a symbol on the other antenna port is conveyed. The large-scale properties include one or more of delay spread, Doppler spread, Doppler shift, average gain, average delay, and spatial Rx parameters.

4.4.2 Resource grid

For each numerology and carrier, a resource grid of $N_{\text{grid},x}^{\text{size,}\mu} N_{\text{sc}}^{\text{RB}}$ subcarriers and $N_{\text{symbol}}^{\text{subframe,}\mu}$ OFDM symbols is defined, starting at common resource block $N_{\text{grid}}^{\text{start,}\mu}$ indicated by higher-layer signalling. There is one set of resource grids per

transmission direction (uplink or downlink) with the subscript x set to DL and UL for downlink and uplink, respectively. When there is no risk for confusion, the subscript x may be dropped. There is one resource grid for a given antenna port p , subcarrier spacing configuration μ , and transmission direction (downlink or uplink).

The carrier bandwidth $N_{\text{grid}}^{\text{size},\mu}$ for subcarrier spacing configuration μ is given by the higher-layer parameter *carrierBandwidth* in the *SCS-SpecificCarrier* IE. The starting position $N_{\text{grid}}^{\text{start},\mu}$ for subcarrier spacing configuration μ is given by the higher-layer parameter *offsetToCarrier* in the *SCS-SpecificCarrier* IE.

The frequency location of a subcarrier refers to the center frequency of that subcarrier.

For the downlink, the higher-layer parameter *txDirectCurrentLocation* in the *SCS-SpecificCarrier* IE indicates the location of the transmitter DC subcarrier in the downlink for each of the numerologies configured in the downlink. Values in the range 0 – 3299 represent the number of the DC subcarrier and the value 3300 indicates that the DC subcarrier is located outside the resource grid.

For the uplink, the higher-layer parameter *txDirectCurrentLocation* in the *UplinkTxDirectCurrentBWP* IE indicates the location of the transmitter DC subcarrier in the uplink for each of the configured bandwidth parts, including whether the DC subcarrier location is offset by 7.5 kHz relative to the center of the indicated subcarrier or not. Values in the range 0 – 3299 represent the number of the DC subcarrier, the value 3300 indicates that the DC subcarrier is located outside the resource grid, and the value 3301 indicates that the position of the DC subcarrier in the uplink is undetermined.

4.4.3 Resource elements

Each element in the resource grid for antenna port p and subcarrier spacing configuration μ is called a resource element and is uniquely identified by $(k, l)_{p,\mu}$ where k is the index in the frequency domain and l refers to the symbol position in the time domain relative to some reference point. Resource element $(k, l)_{p,\mu}$ corresponds to a physical resource and the complex value $a_{k,l}^{(p,\mu)}$. When there is no risk for confusion, or no particular antenna port or subcarrier spacing is specified, the indices p and μ may be dropped, resulting in $a_{k,l}^{(p)}$ or $a_{k,l}$.

4.4.4 Resource blocks

4.4.4.1 General

A resource block is defined as $N_{\text{sc}}^{\text{RB}} = 12$ consecutive subcarriers in the frequency domain.

4.4.4.2 Point A

Point A serves as a common reference point for resource block grids and is obtained from:

- *offsetToPointA* for a PCell downlink where *offsetToPointA* represents the frequency offset between point A and the lowest subcarrier of the lowest resource block, which has the subcarrier spacing provided by the higher-layer parameter *subCarrierSpacingCommon* and overlaps with the SS/PBCH block used by the UE for initial cell selection, expressed in units of resource blocks assuming 15 kHz subcarrier spacing for FR1 and 60 kHz subcarrier spacing for FR2;
- *absoluteFrequencyPointA* for all other cases where *absoluteFrequencyPointA* represents the frequency-location of point A expressed as in ARFCN.

4.4.4.3 Common resource blocks

Common resource blocks are numbered from 0 and upwards in the frequency domain for subcarrier spacing configuration μ . The center of subcarrier 0 of common resource block 0 for subcarrier spacing configuration μ coincides with 'point A'.

The relation between the common resource block number n_{CRB}^{μ} in the frequency domain and resource elements (k, l) for subcarrier spacing configuration μ is given by