9 Sidelink

9.1 Overview

A sidelink is used for ProSe direct communication and ProSe direct discovery between UEs.

9.1.1 Physical channels

A sidelink physical channel corresponds to a set of resource elements carrying information originating from higher layers and is the interface defined between 3GPP TS 36.212 [3] and the present document 3GPP TS 36.211. The following sidelink physical channels are defined:

- Physical Sidelink Shared Channel, PSSCH
- Physical Sidelink Control Channel, PSCCH
- Physical Sidelink Discovery Channel, PSDCH
- Physical Sidelink Broadcast Channel, PSBCH

Generation of the baseband signal representing the different physical sidelink channels is illustrated in Figrue 5.3-1.

9.1.2 Physical signals

A sidelink physical signal is used by the physical layer but does not carry information originating from higher layers. The following sidelink physical signals are defined:

- Demodulation reference signal
- Synchronization signal

9.1.3 Handling of simultaneous sidelink and uplink/downlink transmissions

For a given frequency, on an uplink subframe included in *discTxGapConfig* [9], a UE shall not transmit an uplink transmission that is not a PRACH transmission and that is partly or completely overlapping in time with a PSDCH transmission or a SLSS transmission for PSDCH by the same UE. Else, for a given carrier frequency and sidelink transmission mode 1 or 2 or sidelink discovery, a UE shall not transmit a sidelink signal or channel overlapping partly or completely in time with an uplink transmission from the same UE.

For a given carrier frequency, no PSDCH, PSCCH, or PSSCH transmission shall occur from a UE in a sidelink subframe configured for synchronization purposes by the higher-layer parameters

- *syncOffsetIndicator1* or *syncOffsetIndicator2* in [9] if the UE has no serving cell fulfilling the S criterion according to [10, clause 5.2.3.2], or
- *syncOffsetIndicator* in *commSyncConfig* or *discSyncConfig* which includes *txParameters* in [9] if the UE has a serving cell fulfilling the S criterion according to [10, clause 5.2.3.2]. The UE may assume the same configuration in *commSyncConfig* and *discSyncConfig*.

For a given carrier frequency, with the exception of PSSCH transmissions with transmission mode 1 and same sidelink cyclic prefix as PUSCH, no sidelink transmissions shall occur in sidelink subframe n from a UE if uplink SRS is transmitted from the same UE in uplink subframe n.

A UE with limited transmission capabilities, on an uplink subframe included in *discTxGapConfig* [9], shall first prioritize a PSDCH transmission or a SLSS transmission for PSDCH over an uplink transmission that is not a PRACH transmission. Else, a UE with limited transmission capabilities shall at a given time first prioritize uplink transmissions, followed by sidelink transmission mode 1 or 2 or sidelink discovery.

A UE with limited transmission capabilities shall at a given time prioritize sidelink communication transmissions (PSSS, SSSS, PSBCH, PSSCH, PSCCH) over sidelink discovery transmissions (PSDCH).

A UE with limited reception capabilities, on a downlink subframe included in *discRxGapConfig* [9], shall first prioritize reception of PSDCH or reception of SLSS for PSDCH over downlink reception. Else, a UE with limited reception capabilities shall at a given time first prioritize downlink reception over sidelink reception.

A UE with limited reception capabilities shall at a given time first prioritize sidelink communication reception, sidelink discovery reception on carriers configured by the eNodeB, and last sidelink discovery reception on carriers not configured by the eNodeB.

9.2 Slot structure and physical resources

Sidelink transmissions are organized into radio frames with a duration of T_{f}, each consisting of 20 slots of duration T_{slot}. A sidelink subframe consists of two consecutive slots, starting with an even-numbered slot.

9.2.1 Resource grid

A transmitted physical channel or signal in a slot is described by a resource grid of $N_{\mathrm{RB}}^{\mathrm{SL}} N_{\mathrm{sc}}^{\mathrm{RB}}$ subcarriers and $N_{\mathrm{symb}}^{\mathrm{SL}}$ SC-FDMA symbols. The sidelink bandwidth $N_{\mathrm{RB}}^{\mathrm{SL}} = N_{\mathrm{RB}}^{\mathrm{UL}}$ if the S criterion according to [10, clause 5.2.3.2] is fulfilled for a serving cell having the same uplink carrier frequency as the sidelink, otherwise a preconfigured value is used [9].

The sidelink cyclic prefix is configured independently for type 1 discovery, type 2B discovery, sidelink transmission mode 1, sidelink transmission mode 2, control signalling, and PSBCH and synchronization signals. Configuration is per resource pool for discovery, sidelink transmission mode 2, and control signalling. The PSBCH and synchronization signals always use the same cyclic prefix.

Only normal cyclic prefix is supported for PSSCH, PSCCH, PSBCH, and synchronization signals for a sidelink configured with transmission mode 3 or 4.

The resource grid is illustrated in Figure 5.2.1-1.

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. There is one resource grid per antenna port. The antenna ports used for transmission of a physical channel or signal are shown in Table 9.2.1-1.

Table 9.2.1-1: Antenna ports used for different physical channels and signals

Physical channel or signal	Antenna port number
PSSCH	1000
PSCCH	1000
PSDCH	1000
PSBCH	1010
Synchronization signals	1020

9.2.2 Resource elements

Each element in the resource grid is called a resource element and is uniquely defined by the index pair (k,l) in a slot where $k = 0,...,N_{\mathrm{RB}}^{\mathrm{SL}} N_{\mathrm{sc}}^{\mathrm{RB}} - 1$ and $l = 0,...,N_{\mathrm{symb}}^{\mathrm{SL}} - 1$ are the indices in the frequency and time domains, respectively. Resource element (k,l) on antenna port p corresponds to the complex value $a_{k,l}^{(p)}$. When there is no risk for confusion, or no particular antenna port is specified, the index p may be dropped.

Quantities $a_{k,l}^{(p)}$ corresponding to resource elements not used for transmission of a physical channel or a physical signal in a slot shall be set to zero.

9.2.3 Resource blocks

A physical resource block is defined as $N_{\text{symb}}^{\text{SL}}$ consecutive SC-FDMA symbols in the time domain and $N_{\text{sc}}^{\text{RB}}$ consecutive subcarriers in the frequency domain, where $N_{\text{symb}}^{\text{SL}}$ and $N_{\text{sc}}^{\text{RB}}$ are given by Table 9.2.3-1. A physical resource block in the sidelink thus consists of $N_{\text{symb}}^{\text{SL}} \times N_{\text{sc}}^{\text{RB}}$ resource elements, corresponding to one slot in the time domain and 180 kHz in the frequency domain.

Table 9.2.3-1: Resource block parameters

Configuration	$N_{\text{sc}}^{\text{RB}}$	$N_{\text{symb}}^{\text{SL}}$
Normal cyclic prefix	12	7
Extended cyclic prefix	12	6

The relation between the physical resource block number n_{PRB} in the frequency domain and resource elements (k,l) in a slot is given by

$$n_{\text{PRB}} = \left\lfloor \frac{k}{N_{\text{sc}}^{\text{RB}}} \right\rfloor$$

9.2.4 Resource pool

The subframe pools and resource block pools are defined in [4].

For PSSCH, the number of the current slot in the subframe pool $n_{\text{ss}}^{\text{PSSCH}} = 2n_{\text{ssf}}^{\text{PSSCH}} + i$, where $i \in \{0,1\}$ is the number of the current slot within the current sidelink subframe $n_{\text{ssf}}^{\text{PSSCH}} = j \bmod 10$ with j equal to the subscript of l_j^{PSSCH}, defined in clauses 14.1.4 and 14.2.3 of [4] for sidelink transmission modes 1 and 2, respectively; and where $i \in \{0,1\}$ is the number of the current slot within the current sidelink subframe $n_{\text{ssf}}^{\text{PSSCH}} = k \bmod 10$ with k equal to the subscript of t_k^{SL}, defined in clauses 14.1.1.5 of [4] for sidelink transmission modes 3 and 4.

9.2.5 Guard period

The last SC-FDMA symbol in a sidelink subframe serves as a guard period and shall not be used for sidelink transmission.

9.3 Physical Sidelink Shared Channel

9.3.1 Scrambling

The block of bits $b(0),...,b(M_{\text{bit}}-1)$, where M_{bit} is the number of bits transmitted on the physical sidelink shared channel in one subframe shall be scrambled according to clause 5.3.1.

The scrambling sequence generator shall be initialised with $c_{\text{init}} = n_{\text{ID}}^{\text{X}} \cdot 2^{14} + n_{\text{ssf}}^{\text{PSSCH}} \cdot 2^{9} + 510$ at the start of every PSSCH subframe where

- for sidelink transmission modes 1 and 2, $n_{\text{ID}}^{\text{X}} = n_{\text{ID}}^{\text{SA}}$ is destination identity obtained from the sidelink control channel, and
- for sidelink transmission modes 3 and 4, $n_{\text{ID}}^{\text{X}} = \sum_{i=0}^{L-1} p_i \cdot 2^{L-1-i}$ with p and L given by clause 5.1.1 in [3] equals the decimal representation of CRC on the PSCCH transmitted in the same subframe as the PSSCH.

9.3.2 Modulation

Modulation shall be done according to clause 5.3.2. Table 9.3.2-1 specifies the modulation mappings applicable for the physical sidelink shared channel.

Table 9.3.2-1: PSSCH modulation schemes

Physical channel	Modulation schemes
PSSCH	QPSK, 16QAM, 64QAM

9.3.3 Layer mapping

Layer mapping shall be done according to clause 5.3.2A assuming a single antenna port, $\upsilon = 1$.

9.3.4 Transform precoding

Transform precoding shall be done according to clause 5.3.3 with $M_{\mathrm{RB}}^{\mathrm{PUSCH}}$ and $M_{\mathrm{sc}}^{\mathrm{PUSCH}}$ replaced by $M_{\mathrm{RB}}^{\mathrm{PSSCH}}$ and $M_{\mathrm{sc}}^{\mathrm{PSSCH}}$, respectively.

9.3.5 Precoding

Precoding shall be done according to clause 5.3.3A assuming a single antenna port, $\upsilon = 1$.

9.3.6 Mapping to physical resources

The block of complex-valued symbols $z(0),...,z(M_{\mathrm{symb}}^{\mathrm{ap}} - 1)$ shall be multiplied with the amplitude scaling factor β_{PSSCH} in order to conform to the transmit power P_{PSSCH} specified in [4], and mapped in sequence starting with $z(0)$ to physical resource blocks on antenna port p and assigned for transmission of PSSCH. The mapping to resource elements (k,l) corresponding to the physical resource blocks assigned for transmission and not used for transmission of reference signals shall be in increasing order of first the index k, then the index l, starting with the first slot in the subframe. If Transmission Format of SCI format 1 is set to 1, the resource elements in the last SC-FDMA symbol within a subframe shall not considered in the mapping process. Otherwise, the resource elements in the last SC-FDMA symbol within a subframe shall be counted in the mapping process but not transmitted.

If sidelink frequency hopping is disabled the set of physical resource blocks to be used for transmission is given by $n_{\mathrm{PRB}} = n'_{\mathrm{VRB}}$ where n'_{VRB} is obtained from [4, clause 14.1.1.2.1].

If sidelink frequency hopping with type 1 hopping is enabled, the set of physical resource blocks to be used for transmission is given by [4].

If sidelink frequency hopping with predefined hopping pattern is enabled, the set of physical resource blocks to be used for transmission is given by the sidelink control information together with a predefined pattern in clause 5.3.4 with the following exceptions:

- only inter-subframe hopping shall be used
- the number of subbands $N_{\mathrm{sb}} \in \{1,2,4\}$ is given by higher layers as described in [4, clause 14.1.1.2]
- the quantity $N_{\mathrm{RB}}^{\mathrm{HO}} \in \{0,...,110\}$ is given by higher layers as described in [4, clause 14.1.1.2]
- the quantity $n_{\mathrm{s}} = n_{\mathrm{ss}}^{\mathrm{PSSCH}}$ where $n_{\mathrm{ss}}^{\mathrm{PSSCH}}$ is given by clause 9.2.4
- the quantity $\mathrm{CURRENT\_TX\_NB} = n_{\mathrm{ssf}}^{\mathrm{PSSCH}}$

- the pseudo-random sequence generator is initialized at the start of each slot fulfilling $n_{\mathrm{ss}}^{\mathrm{PSSCH}} = 0$ with the initialization value $c_{\mathrm{init}} \in \{0,1,...,503,510\}$ given by *hoppingParameter-r12* in [9]
- the quantity n_{VRB} shall be replaced by n'_{VRB}, given by [4, clause 14.1.1.2.1]
- for sidelink transmission mode 1
  - $N_{\mathrm{RB}}^{\mathrm{UL}} = N_{\mathrm{RB}}^{\mathrm{SL}}$
- for sidelink transmission mode 2
  - $N_{\mathrm{RB}}^{\mathrm{UL}} = M_{\mathrm{RB}}^{\mathrm{PSSCH\_RP}}$ where $M_{\mathrm{RB}}^{\mathrm{PSSCH\_RP}}$ is given by [4, clause 14.1.3]
  - the quantity n_{PRB} shall be replaced by n'_{PRB}, given by [4, clause 14.1.1.4]
  - the physical resource block to use for transmission $n_{\mathrm{PRB}} = m_{n'_{\mathrm{PRB}}}^{\mathrm{PSSCH}}$ with m_j^{PSSCH} given by [4, clause 14.1.3]

9.4 Physical Sidelink Control Channel

9.4.1 Scrambling

The block of bits $b(0),...,b(M_{\mathrm{bit}} - 1)$, where M_{bit} is the number of bits transmitted on the physical sidelink control channel in one subframe shall be scrambled according to clause 5.3.1.

The scrambling sequence generator shall be initialised with $c_{\mathrm{init}} = 510$ at the start of every PSCCH subframe.

9.4.2 Modulation

Modulation shall be done according to clause 5.3.2. Table 9.4.2-1 specifies the modulation mappings applicable for the physical sidelink control channel.

Table 9.4.2-1: PSCCH modulation schemes

Physical channel	Modulation schemes
PSCCH	QPSK

9.4.3 Layer mapping

Layer mapping shall be done according to clause 5.3.2A assuming a single antenna port, $\upsilon = 1$.

9.4.4 Transform precoding

Transform precoding shall be done according to clause 5.3.3 with $M_{\mathrm{RB}}^{\mathrm{PUSCH}}$ and $M_{\mathrm{sc}}^{\mathrm{PUSCH}}$ replaced by $M_{\mathrm{RB}}^{\mathrm{PSCCH}}$ and $M_{\mathrm{sc}}^{\mathrm{PSCCH}}$, respectively.

9.4.5 Precoding

Precoding shall be done according to clause 5.3.3A assuming a single antenna port, $\upsilon = 1$.

9.4.6 Mapping to physical resources

The block of complex-valued symbols $z(0),...,z(M_{\text{symb}}^{\text{ap}}-1)$ shall be multiplied with the amplitude scaling factor β_{PSCCH} in order to conform to the transmit power P_{PSCCH} specified in [4], and mapped in sequence starting with $z(0)$ to physical resource blocks on antenna port p and assigned for transmission of PSCCH. The mapping to resource elements (k,l) corresponding to the physical resource blocks assigned for transmission and not used for transmission of reference signals shall be in increasing order of first the index k, then the index l, starting with the first slot in the subframe. Resource elements in the last SC-FDMA symbol within a subframe shall be counted in the mapping process but not transmitted.

9.5 Physical Sidelink Discovery Channel

9.5.1 Scrambling

The block of bits $b(0),...,b(M_{\text{bit}}-1)$, where M_{bit} is the number of bits transmitted on the physical sidelink discovery channel in one subframe shall be scrambled according to clause 5.3.1.

The scrambling sequence generator shall be initialised with $c_{\text{init}}=510$ at the start of each PSDCH subframe.

9.5.2 Modulation

Modulation shall be done according to clause 5.3.2. Table 9.5.2-1 specifies the modulation mappings applicable for the physical sidelink discovery channel.

Table 9.5.2-1: Sidelink modulation schemes

Physical channel	Modulation schemes
PSDCH	QPSK

9.5.3 Layer mapping

Layer mapping shall be done according to clause 5.3.2A assuming a single antenna port, $\upsilon=1$.

9.5.4 Transform precoding

Transform precoding shall be done according to clause 5.3.3 with $M_{\text{RB}}^{\text{PUSCH}}$ and $M_{\text{sc}}^{\text{PUSCH}}$ replaced by $M_{\text{RB}}^{\text{PSDCH}}$ and $M_{\text{sc}}^{\text{PSDCH}}$, respectively.

9.5.5 Precoding

Precoding shall be done according to clause 5.3.3A assuming a single antenna port, $\upsilon=1$.

9.5.6 Mapping to physical resources

The block of complex-valued symbols $z(0),...,z(M_{\text{symb}}^{\text{ap}}-1)$ shall be multiplied with the amplitude scaling factor β_{PSDCH} in order to conform to the transmit power P_{PSDCH} specified in [4], and mapped in sequence starting with $z(0)$ to physical resource blocks on antenna port p and assigned for transmission of PSDCH. The mapping to resource elements (k,l) corresponding to the physical resource blocks assigned for transmission and not used for transmission of reference signals shall be in increasing order of first the index k, then the index l, starting with the first slot in the subframe. Resource elements in the last SC-FDMA symbol within a subframe shall be counted in the mapping process but not transmitted.

The set of physical resource blocks that shall be used are given by [4, clause 14.3.1].

9.6 Physical Sidelink Broadcast Channel

9.6.1 Scrambling

The block of bits $b(0),...,b(M_{\mathrm{bit}}-1)$, where M_{bit} is the number of bits transmitted on the physical sidelink broadcast channel in one subframe, shall be scrambled according to clause 5.3.1. The scrambling sequence generator shall be initialised at the start of every PSBCH subframe with $c_{\mathrm{init}} = N_{\mathrm{ID}}^{\mathrm{SL}}$.

9.6.2 Modulation

Modulation shall be done according to clause 5.3.2. Table 9.6.2-1 specifies the modulation mappings applicable for the physical sidelink broadcast channel.

Table 9.6.2-1: PSBCH modulation schemes

Physical channel	Modulation schemes
PSBCH	QPSK

9.6.3 Layer mapping

Layer mapping shal be done according to clause 5.3.2A assuming a single antenna port, $\upsilon = 1$.

9.6.4 Transform precoding

Transform precoding shall be done according to clause 5.3.3 with $M_{\mathrm{RB}}^{\mathrm{PUSCH}}$ and $M_{\mathrm{sc}}^{\mathrm{PUSCH}}$ replaced by $M_{\mathrm{RB}}^{\mathrm{PSBCH}}$ and $M_{\mathrm{sc}}^{\mathrm{PSBCH}}$, respectively.

9.6.5 Precoding

Precoding shall be done according to clause 5.3.3A assuming a single antenna port, $\upsilon = 1$.

9.6.6 Mapping to physical resources

The block of complex-valued symbols $z(0),...,z(M_{\mathrm{symb}}^{\mathrm{ap}}-1)$ shall be multiplied with the amplitude scaling factor β_{PSBCH} in order to conform to the transmit power P_{PSBCH} specified in [4], and mapped in sequence starting with $z(0)$ to physical resource blocks on antenna port p. The PSBCH shall use the same set of resource blocks as the synchronization signal. The mapping to resource elements (k,l) corresponding to the physical resource blocks used for the PSBCH and not used for transmission of reference signals or synchronization signals shall be in increasing order of first the index k, then the index l, starting with the first slot in the subframe. The resource-element index k given by

$$k = k' - 36 + \frac{N_{\mathrm{RB}}^{\mathrm{SL}} N_{\mathrm{sc}}^{\mathrm{RB}}}{2}, \quad k' = 0,1,...,71$$

Resource elements in the last SC-FDMA symbol within a subframe should be counted in the mapping process but not transmitted.

9.7 Sidelink Synchronization Signals

A physical-layer sidelink synchronization identity is represented by $N_{\text{ID}}^{\text{SL}} \in \{0,1,...,335\}$, divided into two sets id_net and id_oon consisting of identities $\{0,1,...,167\}$ and $\{168,169,...,335\}$, respectively.

9.7.1 Primary sidelink synchronization signal

The primary sidelink synchronization signal is transmitted in two adjacent SC-FDMA symbols in the same subframe.

9.7.1.1 Sequence generation

Each of the two sequences $d_i(0),...,d_i(61), i = 1,2$ used for the primary sidelink synchronization signal in the two SC-FDMA symbols is given by clause 6.11.1.1 with root index $u = 26$ if $N_{\text{ID}}^{\text{SL}} \le 167$ and $u = 37$ otherwise.

9.7.1.2 Mapping to resource elements

The sequence $d_i(n)$ shall be multiplied with the amplitude scaling factor $\sqrt{72/62} \cdot \beta_{\text{PSBCH}}$ and mapped to resource elements on antenna port 1020 in the first slot in the subframe according to

$$
\begin{aligned}
a_{k,l} &= d_i(n), \qquad n = 0,...,61 \\
k &= n - 31 + \frac{N_{\text{RB}}^{\text{SL}} N_{\text{sc}}^{\text{RB}}}{2} \\
l &= \begin{cases} 1,2 & \text{normal cyclic prefix} \\ 0,1 & \text{extended cyclic prefix} \end{cases}
\end{aligned}
$$

9.7.2 Secondary sidelink synchronization signal

The secondary sidelink synchronization signal is transmitted in two adjacent SC-FDMA symbols in the same subframe.

9.7.2.1 Sequence generation

Each of the two sequences $d_i(0),...,d_i(61), i = 1,2$ used for the secondary sidelink synchronization signal is given by clause 6.11.2.1 assuming

- subframe 0 with $N_{\text{ID}}^{(1)} = N_{\text{ID}}^{\text{SL}} \bmod 168$ and $N_{\text{ID}}^{(2)} = \lfloor N_{\text{ID}}^{\text{SL}} / 168 \rfloor$ for transmission modes 1 and 2, and
- subframe 5 for transmission modes 3 and 4.

9.7.2.2 Mapping to resource elements

The sequence $d_i(n)$ shall be multiplied with the amplitude scaling factor β_{SSSS} in order to conform to the transmit power specified in clause 14.4 in 3GPP TS 36.213 [4] and mapped to resource elements on antenna port 1020 in the second slot in the subframe according to

$$
\begin{aligned}
a_{k,l} &= d_i(n), \qquad n = 0,...,61 \\
k &= n - 31 + \frac{N_{\text{RB}}^{\text{SL}} N_{\text{sc}}^{\text{RB}}}{2} \\
l &= \begin{cases} 4,5 & \text{normal cyclic prefix} \\ 3,4 & \text{extended cyclic prefix} \end{cases}
\end{aligned}
$$

9.8 Demodulation reference signals

Demodulation reference signals associated with PSSCH, PSCCH, PSDCH, and PSBCH transmission shall be transmitted according to PUSCH in clause 5.5.2.1 with the following exceptions:

- The parameters in Tables 9.8-1, 9.8-2, and 9.8-3 shall be used.
- The term PUSCH shall be replaced by PSSCH, PSCCH, PSDCH or PSBCH, depending on the physical channel to which the reference signal is associated.
- Antenna ports are given by Table 9.2-1.
- The set of physical resource blocks used in the mapping process shall be identical to the corresponding PSSCH/PSCCH/PSDCH/PSBCH transmission.
- The index k in the mapping process in clause 5.5.2.1.2 corresponding to the case where higher-layer parameter *ul-DMRS-IFDMA* is not set shall be identical to that for the corresponding PSSCH/PSCCH/PSDCH/PSBCH transmission.
  - For sidelink transmission modes 3 and 4 on the PSSCH and PSCCH, the mapping shall use $l=2$ and $l=5$ for the first slot in the subframe and $l=1$ and $l=4$ for the second slot in the subframe.
  - For sidelink transmission modes 3 and 4 on the PSBCH, the mapping shall use $l=4$ and $l=6$ for the first slot in the subframe and $l=2$ for the second slot in the subframe.
- For sidelink transmission modes 1 and 2, the pseudo-random sequence generator in clause 5.5.1.3 shall be initialized at the start of each slot fulfilling $n_{\text{ss}}^{\text{PSSCH}}=0$. For sidelink transmission modes 3 and 4 the pseudo-random sequence generator in clause 5.5.1.3 shall be initialized at the start of each slot fulfilling $n_{\text{ss}}^{\text{PSSCH}} \bmod 2 = 0$.
- For sidelink transmission modes 3 and 4 on the PSCCH, the cyclic shift $n_{\text{cs},\lambda}$ to be applied for all DM-RS in a subframe shall be chosen according to clause 14.2.1 of [4].
- For sidelink transmission modes 1and 2 and sidelink discovery, the quantity m in clause 5.5.2.1.1 takes the values $m=0,1$ and for sidelink transmission modes 3and 4, the quantity m in clause 5.5.2.1.1 takes the values $m=0,1,2,3$ for PSSCH and $m=0,1,2$ for PSBCH.
- For sidelink transmission modes 3 and 4, the quantity n_{ID}^{X} equals the decimal representation of CRC on the PSCCH transmitted in the same subframe as the PSSCH according to $n_{\text{ID}}^{\text{X}}=\sum_{i=0}^{L-1} p_i \cdot 2^{L-1-i}$ with p and L given by clause 5.1.1 in [3].

Table 9.8-1: Reference signal parameters for PSSCH.

Parameter in clause 5.5.2.1		PSSCH Sidelink transmission modes 1 and 2	PSSCH Sidelink transmission modes 3 and 4
Group hopping		enabled	enabled
	$n_{\mathrm{ID}}^{\mathrm{RS}}$	$n_{\mathrm{ID}}^{\mathrm{SA}}$	$n_{\mathrm{ID}}^{\mathrm{X}}$
	n_{s}	$n_{\mathrm{ss}}^{\mathrm{PSSCH}}$	$2n_{\mathrm{ss}}^{\mathrm{PSSCH}}$ first DM-RS symbol in a slot $2n_{\mathrm{ss}}^{\mathrm{PSSCH}}+1$ second DM-RS symbol in a slot
	f_{ss}	$n_{\mathrm{ID}}^{\mathrm{SA}} \bmod 30$	$\lfloor n_{\mathrm{ID}}^{\mathrm{X}}/16 \rfloor \bmod 30$
Sequence hopping		disabled	disabled
Cyclic shift	$n_{\mathrm{cs},\lambda}$	$\lfloor n_{\mathrm{ID}}^{\mathrm{SA}}/2 \rfloor \bmod 8$	$\lfloor n_{\mathrm{ID}}^{\mathrm{X}}/2 \rfloor \bmod 8$
Orthogonal sequence	$\left[w^{\lambda}(\cdot)\right]$	$\begin{bmatrix}+1 & +1\end{bmatrix}$ if $n_{\mathrm{ID}}^{\mathrm{SA}} \bmod 2 = 0$ $\begin{bmatrix}+1 & -1\end{bmatrix}$ if $n_{\mathrm{ID}}^{\mathrm{SA}} \bmod 2 = 1$	$\begin{bmatrix}+1 & +1 & +1 & +1\end{bmatrix}$ if $n_{\mathrm{ID}}^{\mathrm{X}} \bmod 2 = 0$ $\begin{bmatrix}+1 & -1 & +1 & -1\end{bmatrix}$ if $n_{\mathrm{ID}}^{\mathrm{X}} \bmod 2 = 1$
Reference signal length	$M_{\mathrm{sc}}^{\mathrm{RS}}$	$M_{\mathrm{sc}}^{\mathrm{PSSCH}}$	$M_{\mathrm{sc}}^{\mathrm{PSSCH}}$
Number of layers	υ	1	1
Number of antenna ports	P	1	1

Table 9.8-2: Reference signal parameters for PSCCH.

Parameter in clause 5.5.2.1		PSCCH Sidelink transmission modes 1 and 2	PSCCH Sidelink transmission modes 3 and 4
Group hopping		disabled	disabled
	$n_{\mathrm{ID}}^{\mathrm{RS}}$	-	-
	n_{s}	-	-
	f_{ss}	0	8
Sequence hopping		disabled	disabled
Cyclic shift	$n_{\mathrm{cs},\lambda}$	0	{0, 3, 6, 9}
Orthogonal sequence	$\left[w^{\lambda}(\cdot)\right]$	$\begin{bmatrix}+1 & +1\end{bmatrix}$	$\begin{bmatrix}+1 & +1 & +1 & +1\end{bmatrix}$
Reference signal length	$M_{\mathrm{sc}}^{\mathrm{RS}}$	$M_{\mathrm{sc}}^{\mathrm{PSCCH}}$	$M_{\mathrm{sc}}^{\mathrm{PSCCH}}$
Number of layers	υ	1	1
Number of antenna ports	P	1	1

Table 9.8-3: Reference signal parameters for PSDCH and PSBCH.

Parameter in clause 5.5.2.1		PSDCH	PSBCH: Sidelink transmission modes 1 and 2	PSBCH: Sidelink transmission modes 3 and 4
Group hopping		disabled	disabled	disabled
	f_{ss}	0	$\lfloor N_{\mathrm{ID}}^{\mathrm{SL}}/16 \rfloor \bmod 30$	$\lfloor N_{\mathrm{ID}}^{\mathrm{SL}}/16 \rfloor \bmod 30$
Sequence hopping		disabled	disabled	disabled
Cyclic shift	$n_{\mathrm{cs},\lambda}$	0	$\lfloor N_{\mathrm{ID}}^{\mathrm{SL}}/2 \rfloor \bmod 8$	$\lfloor N_{\mathrm{ID}}^{\mathrm{SL}}/2 \rfloor \bmod 8$
(Orthogonal) sequence	$\begin{bmatrix} \cdots & w^{\lambda}(m) & \cdots \end{bmatrix}$	$\begin{bmatrix} +1 & +1 \end{bmatrix}$	$\begin{bmatrix} +1 & +1 \end{bmatrix}$ if $N_{\mathrm{ID}}^{\mathrm{SL}} \bmod 2 = 0$ $\begin{bmatrix} +1 & -1 \end{bmatrix}$ if $N_{\mathrm{ID}}^{\mathrm{SL}} \bmod 2 = 1$	$\begin{bmatrix} +1 & +1 & +1 \end{bmatrix}$ if $N_{\mathrm{ID}}^{\mathrm{SL}} \bmod 2 = 0$ $\begin{bmatrix} +1 & -1 & +1 \end{bmatrix}$ if $N_{\mathrm{ID}}^{\mathrm{SL}} \bmod 2 = 1$
Reference signal length	$M_{\mathrm{sc}}^{\mathrm{RS}}$	$M_{\mathrm{sc}}^{\mathrm{PSDCH}}$	$M_{\mathrm{sc}}^{\mathrm{PSBCH}}$	$M_{\mathrm{sc}}^{\mathrm{PSBCH}}$
Number of layers	υ	1	1	1
Number of antenna ports	P	1	1	1

9.9 SC-FDMA baseband signal generation

The time-continuous signal $s_l^{(p)}(t)$ for antenna port p in SC-FDMA symbol l in a sidelink slot is defined by clause 5.6 with $N_{\mathrm{RB}}^{\mathrm{UL}}$ replaced by $N_{\mathrm{RB}}^{\mathrm{SL}}$.

The cyclic prefix length for each sidelink channel or signal may differ from that configured for uplink transmissions.

9.10 Timing

Transmission of a sidelink radio frame number i from the UE shall start $(N_{\mathrm{TA,SL}} + N_{\mathrm{TA\ offset}}) \cdot T_{\mathrm{s}}$ seconds before the start of the corresponding timing reference frame at the UE. The UE is not required to receive sidelink or downlink transmissions earlier than $624T_{\mathrm{s}}$ after the end of a sidelink transmission.

For PSDCH transmission and sidelink synchronization signal transmission for PSDCH:

if the UE has a serving cell fulfilling the S criterion according to [10, clause 5.2.3.2]

- the timing of reference radio frame i equals that of downlink radio frame i of the cell c as given in Subclause 14.3.1 of [4] and
- $N_{\mathrm{TA\ offset}}$ is given by clause 8.1,

otherwise

- the timing of reference radio frame i is implicitly obtained from [4] and
- $N_{\mathrm{TA\ offset}} = 0$.

For all other sidelink transmissions:

if the UE has a serving cell fulfilling the S criterion according to [10, clause 5.2.3.2]

- the timing of reference radio frame i equals that of downlink radio frame i in the cell with the same uplink carrier frequency as the sidelink and
- $N_{\mathrm{TA\ offset}}$ is given by clause 8.1,

otherwise

- the timing of reference radio frame i is implicitly obtained from [4] and

- $N_{\text{TA offset}} = 0$.

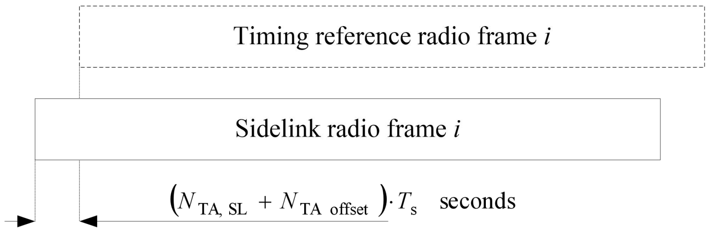

Figure 9.9-1: Sidelink timing relation.

The quantity $N_{\text{TA,SL}}$ differs between channels and signals according to

$$N_{\text{TA, SL}} = \begin{cases} N_{\text{TA}} & \text{for PSSCH in sidelink transmission mode 1} \\ 0 & \text{for all other cases} \end{cases}$$

10 Narrowband IoT

10.0 General

10.0.1 Frame structure

10.0.1.1 Frame structure type 1

Frame structure type 1 is applicable to FDD operation only.

10.0.1.2 Frame structure type 2

Frame structure type 2 is applicable to TDD operation only.

The following restrictions apply:

- Uplink-downlink configuration 0 and 6 are not supported.
- UpPTS is not used for NPUSCH or NPRACH.
- DwPTS and UpPTS in special subframe configuration 10 is not used for transmissions.
- On an NB-IoT carrier for which higher-layer parameter *operationModeInfo* indicates *inband-SamePCI* or *inband-DifferentPCI*, or higher-layer parameter *inbandCarrierInfo* is present, or on an NB-IoT carrier for *SystemInformationBlockType1-NB* for which *sib1-carrierInfo* indicates *non-anchor* and the value of the higher layer parameter *sib-GuardbandInfo* is set to *sib-GuardbandInbandSamePCI* or *sib-GuardbandinbandDiffPCI*, DwPTS in special subframe configuration 0 and 5 for normal cyclic prefix is not used for NPDCCH and NPDSCH transmission.

10.1 Uplink

10.1.1 Overview

10.1.1.1 Physical channels

The following narrowband physical channels are defined:

- Narrowband Physical Uplink Shared Channel, NPUSCH
- Narrowband Physical Random-Access Channel, NPRACH

10.1.1.2 Physical signals

The following uplink narrowband physical signals are defined:

- Narrowband demodulation reference signal

10.1.2 Slot structure and physical resources

10.1.2.1 Resource grid

A transmitted physical channel or signal in a slot is described by one or several resource grids of $N_{\mathrm{sc}}^{\mathrm{UL}}$ subcarriers and $N_{\mathrm{symb}}^{\mathrm{UL}}$ SC-FDMA symbols. The resource grid is illustrated in Figure 10.1.2.1-1. The slot number within a radio frame is denoted n_{s} where $n_{\mathrm{s}} \in \{0,1,...,19\}$ for $\Delta f = 15\,\mathrm{kHz}$ and $n_{\mathrm{s}} \in \{0,1,...,4\}$ for $\Delta f = 3.75\,\mathrm{kHz}$.

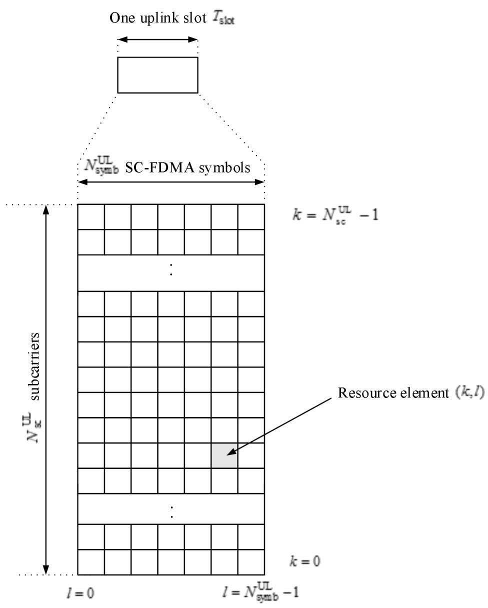

Figure 10.1.2.1-1: Uplink resource grid for NB-IoT

The uplink bandwidth in terms of subcarriers $N_{\mathrm{sc}}^{\mathrm{UL}}$, and the slot duration T_{slot} are given in Table 10.1.2.1-1.

Table 10.1.2.1-1: NB-IoT parameters.

Subcarrier spacing	$N_{\text{sc}}^{\text{UL}}$	T_{slot}
$\Delta f = 3.75\,\text{kHz}$	48	$61440 \cdot T_{\text{s}}$
$\Delta f = 15\,\text{kHz}$	12	$15360 \cdot T_{\text{s}}$

A single antenna port $p = 0$ is used for all uplink transmissions.

10.1.2.2 Resource elements

Each element in the resource grid is called a resource element and is uniquely defined by the index pair (k,l) in a slot where $k = 0,..., N_{\text{sc}}^{\text{UL}} - 1$ and $l = 0,..., N_{\text{symb}}^{\text{UL}} - 1$ are the indices in the frequency and time domains, respectively. Resource element (k,l) corresponds to the complex value $a_{k,l}$. Quantities $a_{k,l}$ corresponding to resource elements not used for transmission of a physical channel or a physical signal in a slot shall be set to zero.

10.1.2.3 Resource unit

Resource units are used to describe the mapping of the NPUSCH to resource elements. A resource unit is defined as $N_{\text{symb}}^{\text{UL}} N_{\text{slots}}^{\text{UL}}$ SC-FDMA symbols in the time domain and $N_{\text{sc}}^{\text{RU}}$ consecutive subcarriers in the frequency domain, where $N_{\text{sc}}^{\text{RU}}$ and $N_{\text{symb}}^{\text{UL}}$ are given by Tables 10.1.2.3-1 and 10.1.2.3-2 for frame structure types 1 and 2, respectively.

Table 10.1.2.3-1: Supported combinations of $N_{\text{sc}}^{\text{RU}}$, $N_{\text{slots}}^{\text{UL}}$, and $N_{\text{symb}}^{\text{UL}}$ for frame structure type 1.

NPUSCH format	Δf	$N_{\text{sc}}^{\text{RU}}$	$N_{\text{slots}}^{\text{UL}}$	$N_{\text{symb}}^{\text{UL}}$
1	3.75 kHz	1	16	7
	15 kHz	1	16	
		3	8	
		6	4	
		12	2	
2	3.75 kHz	1	4	
	15 kHz	1	4	

Table 10.1.2.3-2: Supported combinations of $N_{\text{sc}}^{\text{RU}}$, $N_{\text{slots}}^{\text{UL}}$, and $N_{\text{symb}}^{\text{UL}}$ for frame structure type 2.

NPUSCH format	Δf	Supported uplink-downlink configurations	$N_{\text{sc}}^{\text{RU}}$	$N_{\text{slots}}^{\text{UL}}$	$N_{\text{symb}}^{\text{UL}}$
1	3.75 kHz	1, 4	1	16	7
	15 kHz	1, 2, 3, 4, 5	1	16	
			3	8	
			6	4	
			12	2	
2	3.75 kHz	1, 4	1	4	
	15 kHz	1, 2, 3, 4, 5	1	4	

10.1.3 Narrowband physical uplink shared channel

The narrowband physical uplink shared channel supports two formats:

- NPUSCH format 1, used to carry the UL-SCH
- NPUSCH format 2, used to carry uplink control information

10.1.3.1 Scrambling

Scrambling shall be done according to clause 5.3.1. The scrambling sequence generator shall be initialised with $c_{\text{init}} = n_{\text{RNTI}} \cdot 2^{14} + n_f \bmod 2 \cdot 2^{13} + \lfloor n_s/2 \rfloor \cdot 2^9 + N_{\text{ID}}^{\text{Ncell}}$ where n_s is the first slot of the transmission of the codeword. In case of NPUSCH repetitions, the scrambling sequence shall be reinitialised according to the above formula after every $M_{\text{identical}}^{\text{NPUSCH}}$ transmissions of the codeword with n_s and n_f set to the first slot and the frame, respectively, used for the transmission of the repetition. The quantity $M_{\text{identical}}^{\text{NPUSCH}}$ is given by clause 10.1.3.6.

10.1.3.2 Modulation

Modulation shall be done according to clause 5.3.2 resulting in a block of modulated symbols $d^{(q)}(0),\ldots,d^{(q)}(M_{\text{symb}}^{(q)}-1)$. Table 10.1.3.2-1 specifies the modulation mappings applicable for the narrowband physical uplink shared channel.

The block of modulated symbols shall be multiplied with a code c_{SR} resulting in a block of modulation symbols $\bar{d}^{(q)}(0),\ldots,\bar{d}^{(q)}\left(M_{\text{symb}}^{(q)}-1\right)$ according to

$$\bar{d}^{(q)}(i) = c_{\text{SR}}(i) d^{(q)}(i)$$

where

- $c_{\text{SR}}(i) = (-1)^i, i = 0,1,\ldots,15$ in case a positive scheduling request according to [4] is to be transmitted using NPUSCH format 2
- $c_{\text{SR}}(i) = 1$ otherwise

Table 10.1.3.2-1: NPUSCH modulation schemes

NPUSCH format	$N_{\text{sc}}^{\text{RU}}$	Modulation scheme
1	1	BPSK, QPSK
	>1	QPSK
2	1	BPSK

10.1.3.3 Layer mapping

Layer mapping shall be done according to clause 5.3.2A with $\upsilon = 1$ using $\bar{d}^{(q)}(0),\ldots,\bar{d}^{(q)}\left(M_{\text{symb}}^{(q)}-1\right)$ instead of $d^{(q)}(0),\ldots,d^{(q)}(M_{\text{symb}}^{(q)}-1)$.

10.1.3.4 Transform precoding

Transform precoding shall be done according to clause 5.3.3 with $M_{\text{RB}}^{\text{PUSCH}} = 1$ and $M_{\text{sc}}^{\text{PUSCH}}$ replaced by $M_{\text{sc}}^{\text{NPUSCH}}$.

10.1.3.5 Precoding

Precoding shall be done according to clause 5.3.3A assuming a single antenna port.

10.1.3.6 Mapping to physical resources

NPUSCH can be mapped to one or more than one resource units, N_{RU}, as given by clause 16.5.1.2 of 3GPP TS 36.213 [4], each of which shall be transmitted $M_{\text{rep}}^{\text{NPUSCH}}$ times.

The block of complex-valued symbols $z(0),...,z(M_{\text{symb}}^{\text{ap}}-1)$ shall be multiplied with the amplitude scaling factor β_{NPUSCH} in order to conform to the transmit power P_{NPUSCH} specified in [4], and mapped in sequence starting with $z(0)$ to subcarriers assigned for transmission of NPUSCH. The mapping to resource elements (k,l) corresponding to the subcarriers assigned for transmission and not used for transmission of reference signals, shall be in increasing order of first the index k, then the index l, starting with the first slot in the assigned resource unit.

After mapping to N_{slots} slots, the N_{slots} slots shall be repeated $M_{\text{identical}}^{\text{NPUSCH}}-1$ additional times, before continuing the mapping of $z(\cdot)$ to the following slot, where

$$M_{\text{identical}}^{\text{NPUSCH}} = \begin{cases} \min\left(\left\lceil M_{\text{rep}}^{\text{NPUSCH}}/2\right\rceil, 4\right) & N_{\text{sc}}^{\text{RU}} > 1 \\ 1 & N_{\text{sc}}^{\text{RU}} = 1 \end{cases}$$

$$N_{\text{slots}} = \begin{cases} 1 & \Delta f = 3.75\,\text{kHz} \\ 2 & \Delta f = 15\,\text{kHz} \end{cases}$$

For NPUSCH Format 1 and 2 on frame structure type 2 with $\Delta f = 3.75$ kHz ,

the NPUSCH transmission is carried out in the first set of N_{slots} slots spanning over two contiguous uplink subframes not overlapping with any uplink subframe configured as invalid;

for TDD configuration 1 and 4, if the starting position for the NPUSCH is indicated as the second of the two contiguous uplink subframes, the NPUSCH transmission is postponed until the start of two consecutive uplink subframes.

If a mapping to N_{slots} slots or a repetition of the mapping contains a resource element which overlaps with any configured NPRACH resource according to *NPRACH-ConfigSIB-NB*, or if it overlaps with any configured NPRACH resource according to *nprach-ParametersList* and the UE indicates *multiCarrier-NPRACH* as supported

- for $\Delta f = 3.75\,\text{kHz}$ the NPUSCH transmission in overlapped N_{slots} slots is postponed until the next N_{slots} slots not overlapping with any configured NPRACH resource.
- for $\Delta f = 15\,\text{kHz}$ the NPUSCH transmission in overlapped N_{slots} slots is postponed until the next N_{slots} slots starting with the first slot satisfying $n_s \bmod 2 = 0$ and not overlapping with any configured NPRACH resource.

NPRACH gaps as defined in section 10.1.6.1 are not part of the NPRACH resource. For frame structure type 2, the valid uplink subframes which are not used for NPRACH transmission when it is not possible to map G symbol groups back-to-back are not part of the NPRACH resource. The mapping of $z(0),...,z(M_{\text{symb}}^{\text{ap}}-1)$ is then repeated until $M_{\text{rep}}^{\text{NPUSCH}} N_{\text{RU}} N_{\text{slots}}^{\text{UL}}$ slots have been transmitted. After transmissions and/or postponements due to NPRACH of $256 \cdot 30720 T_{\text{s}}$ time units, for frame structure type 1, a gap of $40 \cdot 30720 T_{\text{s}}$ time units shall be inserted where the NPUSCH transmission is postponed. The portion of a postponement due to NPRACH which coincides with a gap is counted as part of the gap.

When higher layer parameter *npusch-AllSymbols* is set to false, resource elements in SC-FDMA symbols overlapping with a symbol configured with SRS according to *srs-SubframeConfig* shall be counted in the NPUSCH mapping but not used for transmission of the NPUSCH. When higher layer parameter *npusch-AllSymbols* is set to true, all symbols are transmitted.

10.1.4 Demodulation reference signal

10.1.4.1 Reference signal sequence

10.1.4.1.1 Reference signal sequence for $N_{\text{sc}}^{\text{RU}} = 1$

The reference signal sequence $\bar{r}_u(n)$ for $N_{\text{sc}}^{\text{RU}} = 1$ is defined by

$$\bar{r}_u(n) = \frac{1}{\sqrt{2}}(1+j)\big(1-2c(n)\big)w(n \bmod 16), \quad 0 \le n < M_{\text{rep}}^{\text{NPUSCH}} N_{\text{slots}}^{\text{UL}} N_{\text{RU}}$$

where the binary sequence $c(n)$ is defined by clause 7.2 and shall be initialised with $c_{\text{init}} = 35$ at the start of the NPUSCH transmission. The quantity $w(n)$ is given by Table 10.1.4.1.1-1 where $u = N_{\text{ID}}^{\text{Ncell}} \bmod 16$ for NPUSCH format 2, and for NPUSCH format 1if group hopping is not enabled, and by clause 10.1.4.1.3 if group hopping is enabled for NPUSCH format 1.

Table 10.1.4.1.1-1: Definition of $w(n)$

u	$w(0),\ldots,w(15)$															
0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1
2	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1
3	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1
4	1	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1
5	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1
6	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1
7	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1	1	-1
8	1	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1
9	1	-1	1	-1	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1
10	1	1	-1	-1	1	1	-1	-1	-1	-1	1	1	-1	-1	1	1
11	1	-1	-1	1	1	-1	-1	1	-1	1	1	-1	-1	1	1	-1
12	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1
13	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1	1	-1	1	-1
14	1	1	-1	-1	-1	-1	1	1	-1	-1	1	1	1	1	-1	-1
15	1	-1	-1	1	-1	1	1	-1	-1	1	1	-1	1	-1	-1	1

The reference signal sequence for NPUSCH format 1 is given by:

$$r_u(n) = \bar{r}_u(n)$$

The reference signal sequence for NPUSCH format 2 is given by

$$r_u(3n+m) = \overline{w}(m)\bar{r}_u(n), \quad m = 0,1,2$$

where $\overline{w}(m)$ is defined in Table 5.5.2.2.1-2 with the sequence index chosen according to $\left(\sum_{i=0}^{7} c(8n_s + i)2^i\right) \bmod 3$ with $c_{\text{init}} = N_{\text{ID}}^{\text{Ncell}}$.

10.1.4.1.2 Reference signal sequence for $N_{\text{sc}}^{\text{RU}} > 1$

The reference signal sequences $r_u(n)$ for $N_{\text{sc}}^{\text{RU}} > 1$ is defined by a cyclic shift α of a base sequence according to

$$r_u(n) = e^{j\alpha n} e^{j\phi(n)\pi/4}, \quad 0 \le n < N_{\text{sc}}^{\text{RU}},$$

where $\phi(n)$ is given by Table 10.1.4.1.2-1 for $N_{\text{sc}}^{\text{RU}} = 3$, Table 10.1.4.1.2-2 for $N_{\text{sc}}^{\text{RU}} = 6$ and Table 5.5.1.2-1 for $N_{\text{sc}}^{\text{RU}} = 12$.

If group hopping is not enabled, the base sequence index u is given by higher layer parameters *threeTone-BaseSequence*, *sixTone-BaseSequence*, and *twelveTone-BaseSequence* for $N_{\text{sc}}^{\text{RU}} = 3$, $N_{\text{sc}}^{\text{RU}} = 6$, and $N_{\text{sc}}^{\text{RU}} = 12$, respectively. If not signalled by higher layers, the base sequence is given by

$$u = \begin{cases} N_{\mathrm{ID}}^{\mathrm{Ncell}} \bmod 12 & \text{for } N_{\mathrm{sc}}^{\mathrm{RU}} = 3 \\ N_{\mathrm{ID}}^{\mathrm{Ncell}} \bmod 14 & \text{for } N_{\mathrm{sc}}^{\mathrm{RU}} = 6 \\ N_{\mathrm{ID}}^{\mathrm{Ncell}} \bmod 30 & \text{for } N_{\mathrm{sc}}^{\mathrm{RU}} = 12 \end{cases}$$

If group hopping is enabled, the base sequence index u is given by clause 10.1.4.1.3.

The cyclic shift α for $N_{\mathrm{sc}}^{\mathrm{RU}} = 3$ and $N_{\mathrm{sc}}^{\mathrm{RU}} = 6$ is derived from higher layer parameters *threeTone-CyclicShift* and *sixTone-CyclicShift*, respectively, as defined in Table 10.1.4.1.2-3. For $N_{\mathrm{sc}}^{\mathrm{RU}} = 12$, $\alpha = 0$.

Table 10.1.4.1.2-1: Definition of $\phi(n)$ for $N_{\mathrm{sc}}^{\mathrm{RU}} = 3$

u	$\phi(0), \phi(1), \phi(2)$		
0	1	-3	-3
1	1	-3	-1
2	1	-3	3
3	1	-1	-1
4	1	-1	1
5	1	-1	3
6	1	1	-3
7	1	1	-1
8	1	1	3
9	1	3	-1
10	1	3	1
11	1	3	3

Table 10.1.4.1.2-2: Definition of $\phi(n)$ for $N_{\mathrm{sc}}^{\mathrm{RU}} = 6$

u	$\phi(0), \ldots, \phi(5)$					
0	1	1	1	1	3	-3
1	1	1	3	1	-3	3
2	1	-1	-1	-1	1	-3
3	1	-1	3	-3	-1	-1
4	1	3	1	-1	-1	3
5	1	-3	-3	1	3	1
6	-1	-1	1	-3	-3	-1
7	-1	-1	-1	3	-3	-1
8	3	-1	1	-3	-3	3
9	3	-1	3	-3	-1	1
10	3	-3	3	-1	3	3
11	-3	1	3	1	-3	-1
12	-3	1	-3	3	-3	-1
13	-3	3	-3	1	1	-3

Table 10.1.4.1.2-3: Definition of α

$N_{\mathrm{sc}}^{\mathrm{RU}} = 3$		$N_{\mathrm{sc}}^{\mathrm{RU}} = 6$	
threeTone-CyclicShift	α	*sixTone-CyclicShift*	α
0	0	0	0
1	$2\pi/3$	1	$2\pi/6$
2	$4\pi/3$	2	$4\pi/6$
		3	$8\pi/6$

10.1.4.1.3 Group hopping

For the reference signal for NPUSCH format 1, sequence-group hopping can be enabled where the sequence-group number u in slot n_s is defined by a group hopping pattern $f_\mathrm{gh}(n_\mathrm{s})$ and a sequence-shift pattern f_ss according to

$$u = \left(f_\mathrm{gh}(n_\mathrm{s}) + f_\mathrm{ss}\right) \bmod N_\mathrm{seq}^\mathrm{RU}$$

where the number of reference signal sequences available for each resource unit size, $N_\mathrm{seq}^\mathrm{RU}$ is given by Table 10.1.4.1.3-1.

Table 10.1.4.1.3-1: Definition of $N_\mathrm{seq}^\mathrm{RU}$

$N_\mathrm{sc}^\mathrm{RU}$	$N_\mathrm{seq}^\mathrm{RU}$
1	16
3	12
6	14
12	30

Sequence-group hopping can be enabled or disabled by means of the cell-specific parameter *groupHoppingEnabled* provided by higher layers. Sequence-group hopping for NPUSCH can be disabled for a certain UE through the higher-layer parameter *groupHoppingDisabled* despite being enabled on a cell basis unless the NPUSCH transmission corresponds to a Random Access Response Grant or a retransmission of the same transport block as part of the contention based random access procedure.

The group-hopping pattern $f_\mathrm{gh}(n_\mathrm{s})$ is given by

$$f_\mathrm{gh}(n_\mathrm{s}) = \left(\sum_{i=0}^{7} c(8n'_\mathrm{s} + i)\cdot 2^i\right) \bmod N_\mathrm{seq}^\mathrm{RU}$$

where $n'_\mathrm{s} = n_\mathrm{s}$ for $N_\mathrm{sc}^\mathrm{RU} > 1$ and n'_s is the slot number of the first slot of the resource unit for $N_\mathrm{sc}^\mathrm{RU} = 1$. The pseudo-random sequence $c(i)$ is defined by clause 7.2. The pseudo-random sequence generator shall be initialized with $c_\mathrm{init} = \left\lfloor \frac{N_\mathrm{ID}^\mathrm{Ncell}}{N_\mathrm{seq}^\mathrm{RU}} \right\rfloor$ at the beginning of the resource unit for $N_\mathrm{sc}^\mathrm{RU} = 1$ and in every even slot for $N_\mathrm{sc}^\mathrm{RU} > 1$.

The sequence-shift pattern f_ss is given by

$$f_\mathrm{ss} = \left(N_\mathrm{ID}^\mathrm{Ncell} + \Delta_\mathrm{ss}\right) \bmod N_\mathrm{seq}^\mathrm{RU}$$

where $\Delta_\mathrm{ss} \in \{0,1,...,29\}$ is given by higher-layer parameter *groupAssignmentNPUSCH*. If no value is signalled , $\Delta_\mathrm{ss} = 0$.

10.1.4.2 Mapping to physical resources

The sequence $r(\cdot)$ shall be multiplied with the amplitude scaling factor β_NPUSCH and mapped in sequence starting with $r(0)$ to the sub-carriers.

The set of sub-carriers used in the mapping process shall be identical to the corresponding NPUSCH transmission as defined in clause 10.1.3.6.

The mapping to resource elements (k,l) shall be in increasing order of first k , then l , and finally the slot number. The values of the symbol index l in a slot are given in Table 10.1.4.2-1.

Table 10.1.4.2-1: Demodulation reference signal location for NPUSCH.

NPUSCH format	Values for l	
	$\Delta f = 3.75\,\text{kHz}$	$\Delta f = 15\,\text{kHz}$
1	4	3
2	0,1,2	2,3,4

10.1.5 SC-FDMA baseband signal generation

For $N_{\text{sc}}^{\text{RU}} > 1$, the time-continuous signal $s_l(t)$ in SC-FDMA symbol l in a slot is defined by clause 5.6 with the quantity $N_{\text{RB}}^{\text{UL}} N_{\text{sc}}^{\text{RB}}$ replaced by $N_{\text{sc}}^{\text{UL}}$.

For $N_{\text{sc}}^{\text{RU}} = 1$, the time-continuous signal $s_{k,l}(t)$ for sub-carrier index k in SC-FDMA symbol l in an uplink slot is defined by

$$s_{k,l}(t) = a_{k^{(-)},l} \cdot e^{j\phi_{k,l}} \cdot e^{j2\pi(k+1/2)\Delta f(t - N_{\text{CP},l}T_{\text{s}})}$$
$$k^{(-)} = k + \lfloor N_{\text{sc}}^{\text{UL}}/2 \rfloor$$

for $0 \le t < (N_{\text{CP},l} + N)T_{\text{s}}$ where parameters for $\Delta f = 15\,\text{kHz}$ and $\Delta f = 3.75\,\text{kHz}$ are given in Table 10.1.5-1, $a_{k^{(-)},l}$ is the modulation value of symbol l, and the phase rotation $\phi_{k,l}$ is defined by

$$\phi_{k,l} = \rho(\tilde{l} \bmod 2) + \varphi_k(\tilde{l})$$
$$\rho = \begin{cases} \dfrac{\pi}{2} & \text{for BPSK} \\ \dfrac{\pi}{4} & \text{for QPSK} \end{cases}$$
$$\varphi_k(\tilde{l}) = \begin{cases} 0 & \tilde{l} = 0 \\ \varphi_k(\tilde{l} - 1) + 2\pi\Delta f(k + 1/2)(N + N_{CP,l})T_{\text{s}} & \tilde{l} > 0 \end{cases}$$
$$\tilde{l} = 0,1,\ldots, M_{\text{rep}}^{\text{NPUSCH}} N_{\text{RU}} N_{\text{slots}}^{\text{UL}} N_{\text{symb}}^{\text{UL}} - 1$$
$$l = \tilde{l} \bmod N_{\text{symb}}^{\text{UL}}$$

where $\tilde{l}$ is a symbol counter that is reset at the start of a transmission and incremented for each symbol during the transmission.

Table 10.1.5-1: SC-FDMA parameters for $N_{\text{sc}}^{\text{RU}} = 1$

Parameter	$\Delta f = 3.75\,\text{kHz}$	$\Delta f = 15\,\text{kHz}$
N	8192	2048
Cyclic prefix length $N_{\text{CP},l}$	256	160 for $l = 0$ 144 for $l = 1,2,...,6$
Set of values for k	-24,-23,…,23	-6,-5,…,5

The SC-FDMA symbols in a slot shall be transmitted in increasing order of l, starting with $l = 0$, where SC-FDMA symbol $l > 0$ starts at time $\sum_{l'=0}^{l-1}(N_{\text{CP},l'} + N)T_{\text{s}}$ within the slot. For $\Delta f = 3.75\,\text{kHz}$, the remaining $2304T_{\text{s}}$ in T_{slot} are not transmitted and used for guard period.

Only normal CP is supported for Narrowband IoT uplink in this release of the specification.

10.1.6 Narrowband physical random-access channel

10.1.6.1 Time and frequency structure

The physical layer random access preamble is based on single-subcarrier frequency-hopping symbol groups. A symbol group is illustrated in Figure 10.1.6.1-1, consisting of a cyclic prefix of length T_{CP} and a sequence of N identical symbols with total length T_{SEQ}. The total number of symbol groups in a preamble repetition unit is denoted by P. The number of time-contiguous symbol groups is given by G.

The parameter values for frame structures 1 and 2 are listed in Tables 10.1.6.1-1 and 10.1.6.1-2, respectively.

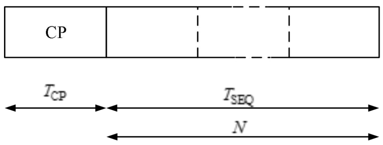

Figure 10.1.6.1-1: Random access symbol group

Table 10.1.6.1-1: Random access preamble parameters for frame structure type 1

Preamble format	G	P	N	T_{CP}	T_{SEQ}
0	4	4	5	$2048T_s$	$5 \cdot 8192\,T_s$
1	4	4	5	$8192T_s$	$5 \cdot 8192\,T_s$
2	6	6	3	$24576T_s$	$3 \cdot 24576T_s$

Table 10.1.6.1-2: Random access preamble parameters for frame structure type 2

Preamble format	Supported uplink-downlink configurations	G	P	N	T_{CP}	T_{SEQ}
0	1, 2, 3, 4, 5	2	4	1	$4778T_s$	$1 \cdot 8192T_s$
1	1, 4	2	4	2	$8192T_s$	$2 \cdot 8192T_s$
2	3	2	4	4	$8192T_s$	$4 \cdot 8192T_s$
0-a	1, 2, 3, 4, 5	3	6	1	$1536T_s$	$1 \cdot 8192T_s$
1-a	1, 4	3	6	2	$3072T_s$	$2 \cdot 8192T_s$

The preamble consisting of P symbol groups shall be transmitted $N_{\text{rep}}^{\text{NPRACH}}$ times. For frame structure type 2, when an invalid uplink subframe overlaps the transmission of G symbol groups without a gap, the G symbol groups are dropped. For frame structure type 2, the transmission of G symbol groups are aligned with the subframe boundary.

The transmission of a random-access preamble, if triggered by the MAC layer, is restricted to certain time and frequency resources.

A NPRACH configuration provided by higher layers contains the following:

- NPRACH resource periodicity $N_{\text{period}}^{\text{NPRACH}}$ (*nprach-Periodicity*),

- frequency location of the first subcarrier allocated to NPRACH $N_{\text{scoffset}}^{\text{NPRACH}}$ (*nprach-SubcarrierOffset*),
- number of subcarriers allocated to NPRACH $N_{\text{sc}}^{\text{NPRACH}}$ (*nprach-NumSubcarriers*),
- number of starting sub-carriers allocated to UE initiated random access $N_{\text{sc\_cont}}^{\text{NPRACH}}$ (*nprach-NumCBRA-StartSubcarriers*),
- number of NPRACH repetitions per attempt $N_{\text{rep}}^{\text{NPRACH}}$ (*numRepetitionsPerPreambleAttempt*),
- NPRACH starting time $N_{\text{start}}^{\text{NPRACH}}$ (*nprach-StartTime*),
- Fraction for calculating starting subcarrier index for the range of NPRACH subcarriers reserved for indication of UE support for multi-tone msg3 transmission $N_{\text{MSG3}}^{\text{NPRACH}}$ (*nprach-SubcarrierMSG3-RangeStart*).

NPRACH transmission can start only $N_{\text{start}}^{\text{NPRACH}} \cdot 30720 T_{\text{s}}$ time units after the start of a radio frame fulfilling $n_{\text{f}} \bmod \left(N_{\text{period}}^{\text{NPRACH}} / 10 \right) = 0$. For frame structure type 1, after transmissions of $4 \cdot 64 \left(T_{\text{CP}} + T_{\text{SEQ}} \right)$ time units for preamble formats 0 and 1, or $16 \cdot 6 (T_{CP} + T_{SEQ})$ time units for preamble format 2, a gap of $40 \cdot 30720 T_{\text{s}}$ time units shall be inserted.

NPRACH configurations where $N_{\text{scoffset}}^{\text{NPRACH}} + N_{\text{sc}}^{\text{NPRACH}} > N_{\text{sc}}^{\text{UL}}$ are invalid.

The NPRACH starting subcarriers allocated to UE initiated random access are split in two sets of subcarriers, $\left\{0,1,...,\left\lfloor N_{\text{sc\_cont}}^{\text{NPRACH}} N_{\text{MSG3}}^{\text{NPRACH}} \right\rfloor - 1\right\}$ and $\left\{\left\lfloor N_{\text{sc\_cont}}^{\text{NPRACH}} N_{\text{MSG3}}^{\text{NPRACH}} \right\rfloor,..., N_{\text{sc\_cont}}^{\text{NPRACH}} - 1\right\}$, where the second set, if present, indicate UE support for multi-tone msg3 transmission.

The frequency location of the NPRACH transmission is constrained within $N_{\text{sc}}^{\text{RA}} = 12$ sub-carriers, and within $N_{sc}^{RA} = 36$ subcarriers when preamble format 2 as described in Table 10.1.6.1-1 is configured. Frequency hopping shall be used within the 12 subcarriers and 36 subcarriers when preamble format 2 as described in Table 10.1.6.1-1 is configured, where the frequency location of the i^{th} symbol group is given by $n_{\text{sc}}^{\text{RA}}(i) = n_{\text{start}} + \tilde{n}_{\text{SC}}^{\text{RA}}(i)$ where $n_{\text{start}} = N_{\text{scoffset}}^{\text{NPRACH}} + \left\lfloor n_{\text{init}} / N_{\text{sc}}^{\text{RA}} \right\rfloor \cdot N_{sc}^{RA}$. The quantity $\tilde{n}_{\text{sc}}^{\text{RA}}(i)$ depends on the frame structure.

For frame structure type 1:

- if $G = 4$, $P = 4$ for preamble formats 0 and 1 as described in Table 10.1.6.1-1:

$$\tilde{n}_{\text{sc}}^{\text{RA}}(i) = \begin{cases} \left(\tilde{n}_{\text{sc}}^{\text{RA}}(0) + f(i/4) \right) \bmod N_{\text{sc}}^{\text{RA}} & i \bmod 4 = 0 \text{ and } i > 0 \\ \tilde{n}_{\text{sc}}^{\text{RA}}(i-1) + 1 & i \bmod 4 = 1,3 \text{ and } \tilde{n}_{\text{sc}}^{\text{RA}}(i-1) \bmod 2 = 0 \\ \tilde{n}_{\text{sc}}^{\text{RA}}(i-1) - 1 & i \bmod 4 = 1,3 \text{ and } \tilde{n}_{\text{sc}}^{\text{RA}}(i-1) \bmod 2 = 1 \\ \tilde{n}_{\text{sc}}^{\text{RA}}(i-1) + 6 & i \bmod 4 = 2 \text{ and } \tilde{n}_{\text{sc}}^{\text{RA}}(i-1) < 6 \\ \tilde{n}_{\text{sc}}^{\text{RA}}(i-1) - 6 & i \bmod 4 = 2 \text{ and } \tilde{n}_{\text{sc}}^{\text{RA}}(i-1) \geq 6 \end{cases}$$

$$f(t) = \left(f(t-1) + \left(\sum_{n=10t+1}^{10t+9} c(n) 2^{n-(10t+1)} \right) \bmod \left(N_{\text{sc}}^{\text{RA}} - 1 \right) + 1 \right) \bmod N_{\text{sc}}^{\text{RA}}$$

$$f(-1) = 0$$

where $\tilde{n}_{\text{SC}}^{\text{RA}}(0) = n_{\text{init}} \bmod N_{sc}^{RA}$ with n_{init} being the subcarrier selected by the MAC layer from $\{0,1,..., N_{\text{sc}}^{\text{NPRACH}} - 1\}$, and the pseudo random sequence $c(n)$ is given by clause 7.2. The pseudo random sequence generator shall be initialised with $c_{\text{init}} = N_{\text{ID}}^{\text{Ncell}}$.

- if $G = 6$, $P = 6$ for preamble format 2 as described in Table 10.1.6.1-1:

$$\tilde{n}_{SC}^{RA}(i)=\begin{cases}\left(\tilde{n}_{SC}^{RA}(0)+f(i/6)\right)\bmod N_{sc}^{RA} & i \bmod 6=0 \text{ and } i>0\\ \tilde{n}_{SC}^{RA}(i-1)+1 & i \bmod 6=1,5 \text{ and } \tilde{n}_{SC}^{RA}(i-1) \bmod 2=0\\ \tilde{n}_{SC}^{RA}(i-1)-1 & i \bmod 6=1,5 \text{ and } \tilde{n}_{SC}^{RA}(i-1) \bmod 2=1\\ \tilde{n}_{SC}^{RA}(i-1)+3 & i \bmod 6=2,4 \text{ and } \left\lfloor \tilde{n}_{SC}^{RA}(i-1)/3\right\rfloor \bmod 2=0\\ \tilde{n}_{SC}^{RA}(i-1)-3 & i \bmod 6=2,4 \text{ and } \left\lfloor \tilde{n}_{SC}^{RA}(i-1)/3\right\rfloor \bmod 2=1\\ \tilde{n}_{SC}^{RA}(i-1)+18 & i \bmod 6=3 \text{ and } \tilde{n}_{SC}^{RA}(i-1)<18\\ \tilde{n}_{SC}^{RA}(i-1)-18 & i \bmod 6=3 \text{ and } \tilde{n}_{SC}^{RA}(i-1)\geq 18\end{cases}$$

$$f(t)=\left(f(t-1)+\left(\sum_{n=10t+1}^{10t+9} c(n)2^{n-(10t+1)}\right)\bmod(N_{sc}^{RA}-1)+1\right)\bmod N_{sc}^{RA}$$

$$f(-1)=0$$

where $\tilde{n}_{SC}^{RA}(0)=n_{\text{init}} \bmod N_{sc}^{RA}$ with n_{init} being the subcarrier selected by the MAC layer from $\{0,1,...,N_{\text{sc}}^{\text{NPRACH}}-1\}$, and the pseudo random sequence $c(n)$ is given by clause 7.2. The pseudo random sequence generator shall be initialised with $c_{\text{init}}=N_{\text{ID}}^{\text{Ncell}}$.

For frame structure type 2:

- if $G=2,\ P=4$ for preamble formats 0, 1, and 2 as described in Table 10.1.6.1-2:

$$\tilde{n}_{SC}^{RA}(i)=\begin{cases} Y & i \bmod 8=0,2 \text{ and } i>0\\ \tilde{n}_{SC}^{RA}(i-1)+1 & i \bmod 8=1 \text{ and } \tilde{n}_{SC}^{RA}(i-1)=0,2,4,6,8,10\\ \tilde{n}_{SC}^{RA}(i-1)-1 & i \bmod 8=1 \text{ and } \tilde{n}_{SC}^{RA}(i-1)=1,3,5,7,9,11\\ \tilde{n}_{SC}^{RA}(i-1)+6 & i \bmod 8=3 \text{ and } \tilde{n}_{SC}^{RA}(i-1)=0,1,2,3,4,5\\ \tilde{n}_{SC}^{RA}(i-1)-6 & i \bmod 8=3 \text{ and } \tilde{n}_{SC}^{RA}(i-1)=6,7,8,9,10,11\\ 2\left\lfloor\frac{Y}{2}\right\rfloor+1 & i \bmod 8=4 \text{ and } \tilde{n}_{SC}^{RA}(i-4)=0,2,4,6,8,10\\ 2\left\lfloor\frac{Y}{2}\right\rfloor & i \bmod 8=4 \text{ and } \tilde{n}_{SC}^{RA}(i-4)=1,3,5,7,9,11\\ \tilde{n}_{SC}^{RA}(i-1)-1 & i \bmod 8=5 \text{ and } \tilde{n}_{SC}^{RA}(i-1)=1,3,5,7,9,11\\ \tilde{n}_{SC}^{RA}(i-1)+1 & i \bmod 8=5 \text{ and } \tilde{n}_{SC}^{RA}(i-1)=0,2,4,6,8,10\\ Y \bmod 6+6 & i \bmod 8=6 \text{ and } \tilde{n}_{SC}^{RA}(i-4)=0,1,2,3,4,5\\ Y \bmod 6 & i \bmod 8=6 \text{ and } \tilde{n}_{SC}^{RA}(i-4)=6,7,8,9,10,11\\ \tilde{n}_{SC}^{RA}(i-1)-6 & i \bmod 8=7 \text{ and } \tilde{n}_{SC}^{RA}(i-1)=6,7,8,9,10,11\\ \tilde{n}_{SC}^{RA}(i-1)+6 & i \bmod 8=7 \text{ and } \tilde{n}_{SC}^{RA}(i-1)=0,1,2,3,4,5\end{cases}$$

$$Y=\left(\tilde{n}_{SC}^{RA}(0)+f(i/2)\right)\bmod N_{sc}^{RA}$$

$$f(t)=\left(f(t-1)+\left(\sum_{n=10t+1}^{10t+9} c(n)2^{n-(10t+1)}\right)\bmod(N_{sc}^{RA}-1)+1\right)\bmod N_{sc}^{RA}$$

$$f(-1)=0$$

where $\tilde{n}_{SC}^{RA}(0)=n_{\text{init}} \bmod N_{sc}^{RA}$ with n_{init} being the subcarrier selected by the MAC layer from $\{0,1,...,N_{\text{sc}}^{\text{NPRACH}}-1\}$, and the pseudo random sequence $c(n)$ is given by clause 7.2. The pseudo random sequence generator shall be initialised with $c_{\text{init}}=N_{\text{ID}}^{\text{Ncell}}$.

- if $G=3,\ P=6$ for preamble formats 0-a, 1-a, as described in Table 10.1.6.1-2:

$$\tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i)=\begin{cases}\left(\tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(0)+f(i/3)\right)\mathrm{mod}N_{sc}^{RA} & i \bmod 6=0,3 \text{ and } i>0\\ \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-1)+1 & i \bmod 6=1 \text{ and } \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-1)=0,2,4,6,8,10\\ \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-1)-1 & i \bmod 6=2 \text{ and } \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-2)=0,2,4,6,8,10\\ \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-1)-1 & i \bmod 6=1 \text{ and } \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-1)=1,3,5,7,9,11\\ \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-1)+1 & i \bmod 6=2 \text{ and } \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-2)=1,3,5,7,9,11\\ \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-1)+6 & i \bmod 6=4 \text{ and } \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-1)=0,1,2,3,4,5\\ \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-1)-6 & i \bmod 6=5 \text{ and } \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-2)=0,1,2,3,4,5\\ \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-1)-6 & i \bmod 6=4 \text{ and } \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-1)=6,7,8,9,10,11\\ \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-1)+6 & i \bmod 6=5 \text{ and } \tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(i-2)=6,7,8,9,10,11\end{cases}$$

$$f(t)=\left(f(t-1)+\left(\sum_{n=10t+1}^{10t+9}c(n)2^{n-(10t+1)}\right)\mathrm{mod}(N_{\mathrm{sc}}^{\mathrm{RA}}-1)+1\right)\mathrm{mod}\ N_{sc}^{\mathrm{RA}}$$

$$f(-1)=0$$

where $\tilde{n}_{\mathrm{SC}}^{\mathrm{RA}}(0)=n_{\mathrm{init}} \bmod N_{sc}^{RA}$ with n_{init} being the subcarrier selected by the MAC layer from $\{0,1,...,N_{\mathrm{sc}}^{\mathrm{NPRACH}}-1\}$, and the pseudo random sequence $c(n)$ is given by clause 7.2. The pseudo random sequence generator shall be initialised with $c_{\mathrm{init}}=N_{\mathrm{ID}}^{\mathrm{Ncell}}$.

10.1.6.2 Baseband signal generation

The time-continuous random-access signal $s_i(t)$ for symbol group i is defined by

$$s_i(t)=\beta_{\mathrm{NPRACH}}e^{j2\pi\left(n_{\mathrm{SC}}^{\mathrm{RA}}(i)+Kk_0+1/2+\varphi\right)\Delta f_{\mathrm{RA}}(t-T_{\mathrm{CP}})}$$

where $0\le t\le T_{\mathrm{SEQ}}+T_{\mathrm{CP}}$, β_{NPRACH} is an amplitude scaling factor in order to conform to the transmit power P_{NPRACH} specified in clause 16.3.1 in 3GPP TS 36.213 [4], $k_0=-N_{\mathrm{sc}}^{\mathrm{UL}}/2$, $K=\Delta f/\Delta f_{\mathrm{RA}}$ accounts for the difference in subcarrier spacing between the random access preamble and uplink data transmission, and the location in the frequency domain controlled by the parameter $n_{\mathrm{SC}}^{\mathrm{RA}}(i)$ is derived from clause 10.1.6.1. The variable Δf_{RA} is given by Table 10.1.6.2-1.

Table 10.1.6.2-1: Random access baseband parameters

Preamble format	Δf_{RA}	
	Frame Structure Type 1	Frame Structure Type 2
0, 1	3.75 kHz	
0-a, 1-a		3.75 kHz
2	1.25 kHz	3.75 kHz

10.1.7 Modulation and upconversion

Modulation and upconversion to the carrier frequency of the complex-valued baseband signal or the complex-valued NPRACH baseband signal is shown in Figure 5.8-1. The filtering required prior to transmission is defined by the requirements in 3GPP TS 36.101 [7].

10.2 Downlink

10.2.1 Overview

10.2.1.1 Physical channels

A downlink narrowband physical channel corresponds to a set of resource elements carrying information originating from higher layers and is the interface defined between 3GPP TS 36.212 [3] and the present document 3GPP TS 36.211.

The following downlink physical channels are defined:

- Narrowband Physical Downlink Shared Channel, NPDSCH
- Narrowband Physical Broadcast Channel, NPBCH
- Narrowband Physical Downlink Control Channel, NPDCCH

10.2.1.2 Physical signals

A downlink narrowband physical signal corresponds to a set of resource elements used by the physical layer but does not carry information originating from higher layers. The following downlink physical signals are defined:

- Narrowband reference signal, NRS
- Narrowband synchronization signal
- Narrowband positioning reference signal, NPRS
- Narrowband wake up signal, NWUS

10.2.2 Slot structure and physical resource elements

10.2.2.1 Resource grid

The transmitted signal on one antenna port in each slot is described by a resource grid of size one resource block as defined in clause 6.2.3.

Only $\Delta f = 15\,\text{kHz}$ is supported.

Narrowband positioning reference signals are transmitted on antenna port $p = 2006$. The channel over which a symbol on antenna port $p = 2006$ is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed only within M consecutive subframes where

- if the higher layer parameter *nprsBitmap* is configured , M equals the length of the *nprsBitmap*;
- if the higher layer parameter *nprsBitmap* is not configured, $M = N_{\text{NPRS}}$ where N_{NPRS} is configured by higher layers.

10.2.2.2 Resource elements

Resource elements are defined according to clause 6.2.2.

10.2.2.3 Guard period for half-duplex FDD operation

Only type-B half-duplex FDD operation is supported.

10.2.2.4 Guard period for TDD operation

For frame structure type 2, if a NB-IoT UE is configured with higher layer parameter *twoHARQ-ProcessesConfig*, a guard period is created by the UE by

- not receiving the first part of the first OFDM symbol of a downlink subframe immediately following an uplink subframe from the same UE for 15-kHz subcarrier spacing on an NB-IoT carrier for which higher-layer parameter *operationModeInfo* indicates *guardband* or *standalone*, or higher-layer parameter *inbandCarrierInfo* is not present.

10.2.3 Narrowband physical downlink shared channel

10.2.3.1 Scrambling

Scrambling shall be done according to clause 6.3.1. If the NPDSCH is carrying the BCCH, the scrambling sequence generator shall be initialised with $c_{\text{init}} = n_{\text{RNTI}} \cdot 2^{15} + (N_{\text{ID}}^{\text{Ncell}} + 1)((n_f \bmod 61) + 1)$. Otherwise, the scrambling sequence generator shall be initialised with $c_{\text{init}} = n_{\text{RNTI}} \cdot 2^{14} + n_{\text{f}} \bmod 2 \cdot 2^{13} + \lfloor n_{\text{s}}/2 \rfloor \cdot 2^9 + N_{\text{ID}}^{\text{Ncell}}$ where n_{s} is the first slot of the transmission of the codeword.

In case of NPDSCH repetitions and the NPDSCH carrying the BCCH, the scrambling sequence generator shall be reinitialized according to the expression above for each repetition.

In case of NPDSCH repetitions and the NPDSCH is not carrying the BCCH, the scrambling sequence generator shall be reinitialized according to the expression above after every $\min\left(M_{\text{rep}}^{\text{NPDSCH}}, 4\right)$ transmission of the codeword with n_{s} and n_{f} set to the first slot and the frame, respectively, used for the transmission of the repetition.

10.2.3.2 Modulation

Modulation shall be done according to clause 6.3.2 using one of the modulation schemes in Table 10.2.3-1

Table 10.2.3-1: Modulation schemes

Physical channel	Modulation schemes
NPDSCH	QPSK

10.2.3.3 Layer mapping and precoding

Layer mapping and precoding shall be done according to clause 6.6.3 using the same set of antenna ports as the NPBCH.

10.2.3.4 Mapping to resource elements

NPDSCH can be mapped to one or more than one subframes, N_{SF}, as given by clause 16.4.1.3 of 3GPP TS 36.213 [4], each of which shall be transmitted $M_{\text{rep}}^{\text{NPDSCH}}$ times.

For each of the antenna ports used for transmission of the physical channel, the block of complex-valued symbols $y^{(p)}(0),...,y^{(p)}(M_{\text{symb}}^{\text{ap}}-1)$ shall be mapped to resource elements (k,l) which meet all of the following criteria in the current subframe:

- the subframe is not used for transmission of NPBCH, NPSS, or NSSS, and
- except in a special subframe when $M_{\text{rep}}^{\text{NPDSCH}} > 1$, they are assumed by the UE not to be used for NRS, and
- they are not overlapping with resource elements used for CRS as defined in clause 6 (if any), and
- the index l in the first slot in a subframe fulfils $l \geq l_{\text{DataStart}}$ where $l_{\text{DataStart}}$ is given by clause 16.4.1.4 of 3GPP TS 36.213 [4], and
- in addition, for frame structure Type 2
  - in a special subframe, if $M_{\text{rep}}^{\text{NPDSCH}} = 1$, they are in DwPTS
  - in a special subframe, if $M_{\text{rep}}^{\text{NPDSCH}} > 1$, they are not NRS locations in subframes which are not special subframes.

The mapping of $y^{(p)}(0),...,y^{(p)}(M_{\text{symb}}^{\text{ap}}-1)$ in sequence starting with $y^{(p)}(0)$ to resource elements (k,l) on antenna port p meeting the criteria above shall be in increasing order of first the index k and then the index l, starting with the first slot and ending with the second slot in a subframe. For NPDSCH not carrying BCCH, after mapping to a subframe, the subframe shall be repeated for $\min\left(M_{\text{rep}}^{\text{NPDSCH}},4\right)-1$ additional subframes, before continuing the mapping of $y^{(p)}(\cdot)$ to the following subframe.

The resource elements in a special subframe that are not part of DwPTS are counted but not used in the mapping if $M_{\text{rep}}^{\text{NPDSCH}}>1$. When $l=N_{\text{symb}}^{\text{DL}}-5, N_{\text{symb}}^{\text{DL}}-4$, the resource elements in a special subframe assumed by the UE for NRSs are counted but not used in the mapping if $M_{\text{rep}}^{\text{NPDSCH}}>1$.

For frame structure type 1, for NPDSCH associated with C-RNTI when *interferenceRandomisationConfig* is configured, or NPDSCH associated with RA-RNTI, TC-RNTI or P-RNTI and transmitted in an NB-IoT carrier configured by *SystemInformationBlockType22-NB*, or NPDSCH associated with G-RNTI or SC-RNTI, or for frame structure type 2, for NPDSCH not carrying the BCCH, define $y_{n_f,n_s}^{(p)}(0),...,y_{n_f,n_s}^{(p)}(S-1)$ as the block of complex-valued symbols mapped to subframe number $\lfloor n_s/2 \rfloor$ and radio frame number n_f. Each complex-valued symbol $y_{n_f,n_s}^{(p)}(i)$ shall be multiplied with $\theta_{n_f,n_s}(i)$ before its transmission, with

$$\theta_{n_f,n_s}(i)=\begin{cases} 1, \text{if } c_{n_f,n_s}(2i)=0 \text{ and } c_{n_f,n_s}(2i+1)=0 \\ -1, \text{if } c_{n_f,n_s}(2i)=0 \text{ and } c_{n_f,n_s}(2i+1)=1 \\ j, \text{if } c_{n_f,n_s}(2i)=1 \text{ and } c_{n_f,n_s}(2i+1)=0 \\ -j, \text{if } c_{n_f,n_s}(2i)=1 \text{ and } c_{n_f,n_s}(2i+1)=1 \end{cases}$$

where the scrambling sequence $c_{n_f,n_s}(j), j=0,...2S-1$ is given by clause 7.2, and shall be initialized at the start of each subframe with $c_{init}=(n_{RNTI}+1)\left(\left(10n_f+\lfloor n_s/2\rfloor\right)\bmod 61+1\right)2^9+N_{\text{ID}}^{\text{Ncell}}$.

The mapping of $y^{(p)}(0),...,y^{(p)}(M_{\text{symb}}^{\text{ap}}-1)$ is then repeated until $M_{\text{rep}}^{\text{NPDSCH}}N_{\text{SF}}$ subframes have been transmitted. For frame structure type 2 , the resource elements in a special subframe that are not part of DwPTS are counted but not used in the repetition. When $l=N_{\text{symb}}^{\text{DL}}-5, N_{\text{symb}}^{\text{DL}}-4$, the resource elements in a special subframe assumed by the UE for NRSs are counted but not used in the repetition.

For NPDSCH carrying BCCH, the $y^{(p)}\left((k-1)M_{\text{symb}}^{\text{ap}}\right),...,y^{(p)}\left(kM_{\text{symb}}^{\text{ap}}-1\right)$ is mapped to N_{SF} subframes in sequence and then repeated until $M_{\text{rep}}^{\text{NPDSCH}}N_{\text{SF}}$ subframes have been transmitted, where

- $k=2$ for mapping NPDSCH carrying SystemInformationBlockType1-NB to subframe #3 for frame structure type 2;
- $k=1$ otherwise.

The NPDSCH transmission can be configured by higher layers with transmission gaps where the NPSDCH transmission is postponed. There are no gaps in the NPDSCH transmission if $R_{\max}<N_{\text{gap,threshold}}$ where $N_{\text{gap,threshold}}$ is given by the higher layer parameter *dl-GapThreshold* and $R_{\max}$ is given by [4]. The gap starting frame and subframe is given by $\left(10n_{\text{f}}+\lfloor n_{\text{s}}/2\rfloor\right)\bmod N_{\text{gap,period}}=0$ where the gap periodicity, $N_{\text{gap,period}}$, is given by the higher layer parameter *dl-GapPeriodicity*. The gap duration in number of subframes is given by $N_{\text{gap,duration}}=N_{\text{gap, coeff}}N_{\text{gap,period}}$, where $N_{\text{gap, coeff}}$ is given by the higher layer parameter *dl-GapDurationCoeff*. For NPDSCH carrying the BCCH there are no gaps in the transmission.

The UE shall not expect NPDSCH in subframe i if it is not a NB-IoT downlink subframe, except for transmissions of NPDSCH carrying *SystemInformationBlockType1-NB* in

- subframes 3 and 4 for frame structure type 1; and
- subframes 0, 4, and 5 for frame structure type 2.

In case of NPDSCH transmissions, in subframes that are not NB-IoT downlink subframes, the NPDSCH transmission is postponed until the next NB-IoT downlink subframe.

10.2.4 Narrowband physical broadcast channel

10.2.4.1 Scrambling

Scrambling shall be done according to clause 6.6.1 with M_{bit} denoting the number of bits to be transmitted on the NPBCH. M_{bit} equals 1600 for normal cyclic prefix. The scrambling sequence shall be initialised with $c_{\text{init}} = N_{\text{ID}}^{\text{Ncell}}$ in radio frames fulfilling $n_{\text{f}} \bmod 64 = 0$.

10.2.4.2 Modulation

Modulation shall be done according to clause 6.6.2 using the modulation scheme in Table 10.2.4.2-1

Table 10.2.4.2-1: Modulation schemes for NPBCH

Physical channel	Modulation schemes
NPBCH	QPSK

10.2.4.3 Layer mapping and precoding

Layer mapping and precoding shall be done according to clause 6.6.3 with $P \in \{1,2\}$. The UE shall assume antenna ports 2000 and 2001 are used for the transmission of the narrowband physical broadcast channel.

10.2.4.4 Mapping to resource elements

The block of complex-valued symbols $y^{(p)}(0),...,y^{(p)}(M_{\text{symb}}-1)$ for each antenna port is transmitted in subframe 0 for frame structure type 1 or subframe 9 for frame structure type 2 during 64 consecutive radio frames starting in each radio frame fulfilling $n_{\text{f}} \bmod 64 = 0$. The quantity $M_{\text{symb}} = 800$ for normal cyclic prefix. Define $y_f^{(p)}(0),...,y_f^{(p)}(K-1)$ as the block of complex-valued symbols to be transmitted in subframe 0 of radio frame $f = n_{\text{f}} \bmod 64$, as $y_f^{(p)}(i) = \theta_f(i) y^{(p)}(K\lfloor f/8 \rfloor + i)$, $i = 0,...,99$ with $K = 100$ for normal cyclic prefix, and

$$\theta_f(i) = \begin{cases} 1, \text{if } c_f(2i) = 0 \text{ and } c_f(2i+1) = 0 \\ -1, \text{if } c_f(2i) = 0 \text{ and } c_f(2i+1) = 1 \\ j, \text{if } c_f(2i) = 1 \text{ and } c_f(2i+1) = 0 \\ -j, \text{if } c_f(2i) = 1 \text{ and } c_f(2i+1) = 1 \end{cases}$$

where the scrambling sequence $c_f(j)$, $j = 0,...,199$ is given by clause 7.2, and shall be initialized at the start of each radio frame with $c_{\text{init}} = (N_{\text{ID}}^{\text{Ncell}} + 1)(n_f \bmod 8 + 1)^3 \cdot 2^9 + N_{\text{ID}}^{\text{Ncell}}$. The block of complex-valued symbols $y_f^{(p)}(0),...,y_f^{(p)}(K-1)$ shall be mapped in sequence starting with $y_f^{(p)}(0)$ to resource elements (k,l). The mapping to resource elements (k,l) not reserved for transmission of reference signals shall be in increasing order of first the index k, then the index l. The first three OFDM symbols in a subframe shall not be used in the mapping process.

For the purpose of the mapping, the UE shall assume cell-specific reference signals for antenna ports 0-3 and narrowband reference signals for antenna ports 2000 and 2001 being present irrespective of the actual configuration. The frequency shift of the cell-specific reference signals shall be calculated by replacing $N_{\text{ID}}^{\text{cell}}$ with $N_{\text{ID}}^{\text{Ncell}}$ in the calculation of v_{shift} in clause 6.10.1.2.

10.2.5 Narrowband physical downlink control channel

10.2.5.1 NPDCCH formats

The narrowband physical downlink control channel carries control information. A narrowband physical control channel is transmitted on an aggregation of one or two consecutive narrowband control channel elements (NCCEs), where a narrowband control channel element corresponds to 6 consecutive subcarriers in a subframe where NCCE 0 occupies subcarriers 0 through 5 and NCCE 1 occupies subcarriers 6 through 11. The NPDCCH supports multiple formats as listed in Table 10.2.5.1-1. For NPDCCH format 1, both NCCEs belong to the same subframe.

One or two NPDCCHs can be transmitted in a subframe.

Table 10.2.5.1-1: Supported NPDCCH formats

NPDCCH format	Number of NCCEs
0	1
1	2

10.2.5.2 Scrambling

Scrambling shall be done according to clause 6.8.2. The scrambling sequence shall be initialised at the start of subframe k_0 according to [4] Subclause 16.6 and after every 4th NPDCCH subframe with $c_{\text{init}} = \lfloor n_s/2 \rfloor 2^9 + N_{\text{ID}}^{\text{Ncell}}$ where n_s is the first slot of the NPDCCH subframe in which scrambling is (re-)initialized.

10.2.5.3 Modulation

Modulation shall be done according to clause 6.8.3 using the modulation scheme in Table 10.2.5.3-1

Table 10.2.5.3-1: Modulation schemes

Physical channel	Modulation schemes
NPDCCH	QPSK

10.2.5.4 Layer mapping and precoding

Layer mapping and precoding shall be done according to clause 6.6.3 using the same set of antenna ports as the NPBCH.

10.2.5.5 Mapping to resource elements

The block of complex-valued symbols $y(0),...,y(M_{\text{symb}}-1)$ shall be mapped in sequence starting with $y(0)$ to resource elements (k,l) on the associated antenna port which meet all of the following criteria:

- they are part of the NCCE(s) assigned for the NPDCCH transmission, and
- they are not used for transmission of NPBCH, NPSS, or NSSS , and
- except in a special subframe when NPDCCH is transmitted in more than one subframe, they are assumed by the UE not to be used for NRS, and
- they are not overlapping with resource elements used for CRS as defined in clause 6 (if any), and
- the index l in the first slot in a subframe fulfils $l \geq l_{\text{NPDCCHStart}}$ where $l_{\text{NPDCCHStart}}$ is given by clause 16.6.1 of 3GPP TS 36.213 [4],
- in addition, for frame structure Type 2,
    - in a special subframe where the NPDCCH is transmitted in one subframe, they are in DwPTS

- in a special subframe where the NPDCCH is transmitted in more than one subframe, they are not NRS locations when the subframe is not a special subframe..

The mapping to resource elements (k,l) on antenna port p meeting the criteria above shall be in increasing order of first the index k and then the index l, starting with the first slot and ending with the second slot in a subframe. Denote $y_{n_f,n_s}(0),...,y_{n_f,n_s}(T-1)$ as the complex-valued symbols that are mapped to resource elements meeting the criteria above in subframe $\lfloor n_s/2 \rfloor$, with the insertion of <NIL> elements in the locations of resource elements which are not part of the NCCE(s) assigned for the NPDCCH transmission.

If the NPDCCH is transmitted in more than one subframe, the resource elements in a special subframe that are not part of DwPTS are counted but not used in the mapping. When $l = N_{\mathrm{symb}}^{\mathrm{DL}} - 5, N_{\mathrm{symb}}^{\mathrm{DL}} - 4$, the resource elements in a special subframe assumed by the UE for NRSs are counted but not used in the mapping if the NPDCCH is transmitted in more than one subframe.

For frame structure type 1, for NPDCCH associated with RA-RNTI, TC-RNTI or P-RNTI and transmitted in an NB-IoT carrier configured by *SystemInformationBlockType22-NB,* or NPDCCH associated with G-RNTI or SC-RNTI, or for NPDCCH associated with C-RNTI when *interferenceRandomisationConfig* is used according to [11], or for frame structure type 2, each complex-valued symbol $y_{n_f,n_s}(i), i = 0,...,T-1$ shall be multiplied with $\theta_{n_f,n_s}(i), i = 0,...,T-1$ where

$$\theta_{n_f,n_s}(i) = \begin{cases} 1, \text{if } c_{n_f,n_s}(2i) = 0 \text{ and } c_{n_f,n_s}(2i+1) = 0 \\ -1, \text{if } c_{n_f,n_s}(2i) = 0 \text{ and } c_{n_f,n_s}(2i+1) = 1 \\ j, \text{if } c_{n_f,n_s}(2i) = 1 \text{ and } c_{n_f,n_s}(2i+1) = 0 \\ -j, \text{if } c_{n_f,n_s}(2i) = 1 \text{ and } c_{n_f,n_s}(2i+1) = 1 \end{cases}$$

where the scrambling sequence $c_{n_f,n_s}(j), j = 0,...2T-1$ is given by clause 7.2, and shall be initialized at the start of each subframe with $c_{init} = \left(N_{\mathrm{ID}}^{\mathrm{Ncell}} + 1\right)\left(\left(10n_f + \lfloor n_s/2 \rfloor\right) \bmod 8192 + 1\right)2^9 + N_{\mathrm{ID}}^{\mathrm{Ncell}}$.

The NPDCCH transmission can be configured by higher layers with transmissions gaps where the NPDCCH transmission is postponed. The configuration is the same as described for NPDSCH in clause 10.2.3.4.

The UE shall not expect NPDCCH in subframe i if it is not a NB-IoT downlink subframe. In case of NPDCCH transmissions, in subframes that are not NB-IoT downlink subframes, the NPDCCH transmission is postponed until the next NB-IoT downlink subframe.

10.2.6 Narrowband reference signal (NRS)

Before a UE obtains *operationModeInfo*:

- If frame structure type 1 is used, the UE may assume narrowband reference signals (NRSs) are transmitted in subframes #0 and #4 and in subframes #9 not containing NSSS.

- If frame structure type 2 is used, the UE may assume narrowband reference signals (NRSs) are transmitted in subframes #9 and in subframes #0 not containing NSSS.

On an NB-IoT carrier for which a UE receives higher-layer parameter *operationModeInfo* indicating *guardband* or *standalone.*

- If frame structure type 1 is used, before the UE obtains *SystemInformationBlockType1-NB*, the UE may assume narrowband reference signals are transmitted in subframes #0, #1, #3, #4 and in subframes #9 not containing NSSS.

- If frame structure type 2 is used, before the UE obtains *SystemInformationBlockType1-NB*, the UE may assume narrowband reference signals are transmitted in subframes #9, and in subframes #0 not containing NSSS, and in subframes #4 if subframes #4 is configured for *SystemInformationBlockType1-NB* transmissions.

- If frame structure type 1 is used, after the UE obtains *SystemInformationBlockType1-NB*, the UE may assume narrowband reference signals are transmitted in subframes #0, #1, #3, #4, subframes #9 not containing NSSS, and in NB-IoT downlink subframes.

- If frame structure type 2 is used, after the UE obtains *SystemInformationBlockType1-NB*, the UE may assume narrowband reference signals are transmitted in subframes #9, subframes #0 not containing NSSS, in subframes #4 if subframes #4 is configured for *SystemInformationBlockType1-NB* transmissions, and in NB-IoT downlink subframes.

On an NB-IoT carrier for *SystemInformationBlockType1-NB* for which *sib1-carrierInfo-NB* indicates *non-anchor* for frame structure type 2, before the UE obtains *SystemInformationBlockType1-NB*, the UE may assume narrowband reference signals are transmitted in subframes #0 and #5. After the UE obtains *SystemInformationBlockType1-NB*, the UE may assume narrowband reference signals are transmitted in subframes #0, #5, and in NB-IoT downlink subframes indicated by *tdd-SI-SubframesBitmap*.

On an NB-IoT carrier for which *DL-CarrierConfigCommon-NB* is present and no *inbandCarrierInfo* is present.

- When an NB-IoT UE is configured by higher layers to decode NPDCCH with CRC scrambled by the P-RNTI, the UE may assume NRSs are transmitted in the NPDCCH candidate where the UE finds a DCI with CRC scrambled by the P-RNTI. The UE may also assume NRSs are transmitted 10 in NB-IoT DL subframes before and in 4 NB-IoT DL subframes after the NPDCCH candidate where the UE finds a DCI with CRC scrambled by the P-RNTI, where NB-IoT DL subframes without NRS are not counted. If the DCI with CRC scrambled by the P-RNTI schedules a NPDSCH, the UE may assume NRSs are transmitted in the NB-IoT DL subframes carrying the NPDSCH as well as in 4 NB-IoT DL subframes before and after the scheduled NPDSCH, where NB-IoT DL subframes without NRS are not counted.

- During the window controlled by higher layers where the UE shall attempt to decode the NPDCCH with DCI scrambled by RA-RNTI (see [8], subclause 5.1.4), the UE may assume NRSs are transmitted in the Type-2 CSS configured by higher layers, as well as in 10 NB-IoT DL subframes before and in 4 NB-IoT DL subframes after each Type-2 CSS, where NB-IoT DL subframes without NRS are not counted. If a DCI scrambled by the RA-RNTI is detected, the UE may assume NRSs are transmitted in the NPDSCH scheduled by the DCI scrambled by the RA-RNTI, as well as in 4 NB-IoT DL subframes before and after the scheduled NPDSCH, where NB-IoT DL subframes without NRS are not counted. In addition, when the UE attempts to decode a DCI with CRC scrambled by the RA-RNTI as well as receiving the NPDSCH scheduled by the DCI scrambled by the RA-RNTI, the UE may assume NRSs are transmitted in subframes #0, #1, #3, #4 and #9.

- During random access procedure, when an NB-IoT UE is configured by higher layers to decode NPDCCH with CRC scrambled by the temporary C-RNTI and/or the C-RNTI, before the the DCI scrambled by temporary C-RNTI and/or C-RNTI is detected, the UE may assume NRSs are transmitted in the Type-2 CSS configured by higher layers, as well as in 10 NB-IoT DL subframes before the start of each Type-2 CSS and in 4 NB-IoT DL subframes after the end of each Type-2 CSS until the mac-ContentionResolutionTimer expires, where NB-IoT DL subframes without NRS are not counted. If a DCI scrambled by the temporary C-RNTI or C-RNTI is detected, the UE may assume NRSs are transmitted in the NPDSCH scheduled by the DCI scrambled by the temporary C-RNTI or C-RNTI as well as in 4 NB-IoT DL subframes before and after the scheduled NPDSCH, where NB-IoT DL subframes without NRS are not counted.

- An NB-IoT UE may assume NRSs are transmitted in NB-IoT DL subframes that are used for Type1A-NPDCCH common search space, and Type2A-NPDCCH common search space, as well as in 10 NB-IoT DL subframes prior and in 4 NB-IoT DL subframes after each Type1A-NPDCCH common search space and Type2A-NPDCCH common search space. A UE may assume NRSs are transmitted in NB-IoT DL subframes carrying NPDSCH scheduled by DCI CRC scrambled by G-RNTI or SC-RNTI as well as 4 NB-IoT DL subframes prior and after the scheduled NPDSCH, where NB-IoT DL subframes without NRS are not counted.

- In other cases, if frame structure typ1 is used, the UE may assume NRSs are transmitted in subframes #0, #1, #3, #4, #9, and in NB-IoT downlink subframes and shall not expect NRSs in other downlink subframes.

On an NB-IoT carrier for which a UE receives higher-layer parameter *operationModeInfo* indicating *inband-SamePCI* or *inband-DifferentPCI.*

- If frame structure type 1 is used, before the UE obtains *SystemInformationBlockType1-NB*, the UE may assume narrowband reference signals are transmitted in subframes #0, #4 and in subframes #9 not containing NSSS, and in subframes #3 which contain *SystemInformationBlockType1-NB* when *additionalTransmissionSIB1* is configured as TRUE.

- If frame structure type 2 is used, before the UE obtains *SystemInformationBlockType1-NB*, the UE may assume narrowband reference signals are transmitted in subframes #9, and in subframes #0 not containing NSSS, and in subframes #4 if subframes #4 is configured for *SystemInformationBlockType1-NB* transmissions.

- If frame structure type 1 is used, after the UE obtains SystemInformationBlockType1-NB, the UE may assume narrowband reference signals are transmitted in subframes #0, #4, subframes #9 not containing NSSS, subframes #3 which contain SystemInformationBlockType1-NB when *additionalTransmissionSIB1* is configured as TRUE, and in NB-IoT downlink subframes.

- If frame structure type 2 is used, after the UE obtains *SystemInformationBlockType1-NB*, the UE may assume narrowband reference signals are transmitted in subframes #9, subframes #0 not containing NSSS, in subframes #4 if subframes #4 is configured for *SystemInformationBlockType1-NB* transmissions, and in NB-IoT downlink subframes

On an NB-IoT carrier for which *DL-CarrierConfigCommon-NB* is present and *inbandCarrierInfo* is present:

- When an NB-IoT UE is configured by higher layers to decode NPDCCH with CRC scrambled by the P-RNTI, the UE may assume NRSs are transmitted in the NPDCCH candidate where the UE finds a DCI with CRC scrambled by the P-RNTI. The UE may also assume NRSs are transmitted in10 NB-IoT DL subframes before and in 4 NB-IoT DL subframes after the NPDCCH candidate, where NB-IoT DL subframes without NRS are not counted. If the DCI with CRC scrambled by the P-RNTI schedules a NPDSCH, the UE may assume NRSs are transmitted in the NB-IoT DL subframes carrying the NPDSCH as well as 4 NB-IoT DL subframes before and after the scheduled NPDSCH, where NB-IoT DL subframes without NRS are not counted.

- During random access procedure, during the window controlled by higher layers where the UE shall attempt to decode the NPDCCH with DCI scrambled by RA-RNTI (see [8], subclause 5.1.4), before the DCI scrambled by RA-RNTI is detected, the UE may assume NRSs are transmitted in the Type-2 CSS configured by higher layers, as well as in 10 NB-IoT DL subframes before and in 4 NB-IoT DL subframes after the start of each Type-2 CSS, where NB-IoT DL subframes without NRS are not counted. If a DCI scrambled by the RA-RNTI is detected, the UE may assume NRSs are transmitted in the NPDSCH scheduled by the DCI scrambled by the RA-RNTI, as well as in 4 NB-IoT DL subframes before and after the scheduled NPDSCH, where NB-IoT DL subframes without NRS are not counted. In addition, when the UE attempts to decode a DCI with CRC scrambled by the RA-RNTI as well as receiving the NPDSCH scheduled by the DCI scrambled by the RA-RNTI, the UE may assume NRSs are transmitted in subframes #0, #4 and #9.

- During random access procedure, when an NB-IoT UE is configured by higher layers to decode NPDCCH with CRC scrambled by the temporary C-RNTI and/or the C-RNTI, before the DCI scrambled by temporary C-RNTI and/or C-RNTI, is detected, the UE may assume NRSs are transmitted in the Type-2 CSS configured by higher layers, as well as in 10 NB-IoT DL subframes before the start of each Type-2 CSS and in 4 NB-IoT DL subframes after the end of each Type-2 CSS until the mac-ContentionResolutionTimer expires, where NB-IoT DL subframes without NRS are not counted. If a DCI scrambled by the temporary C-RNTI or C-RNTI is detected, the UE may assume NRSs are transmitted in the NPDSCH scheduled by the DCI scrambled by the temporary C-RNTI or C-RNTI as well as in 4 NB-IoT DL subframes before and after the scheduled NPDSCH, where NB-IoT DL subframes without NRS are not counted.

- An NB-IoT UE may assume NRSs are transmitted in NB-IoT DL subframes that are used for Type1A-NPDCCH common search space, and Type2A-NPDCCH common search space, as well as in 10 NB-IoT DL subframes prior and in 4 NB-IoT DL subframes after each Type1A-NPDCCH common search space and Type2A-NPDCCH common search space, where NB-IoT DL subframes without NRS are not counted. A UE may assume NRSs are transmitted in NB-IoT DL subframes carrying NPDSCH scheduled by DCI CRC scrambled by G-RNTI or SC-RNTI as well as in 4 NB-IoT DL subframes prior and after the scheduled NPDSCH, where NB-IoT DL subframes without NRS are not counted.

- In other cases, if frame structure type 1 is used, the UE may assume NRSs are transmitted in subframes #0, #4, #9, and in NB-IoT downlink subframes and shall not expect NRSs in other downlink subframes.

On an NB-IoT carrier for which *DL-CarrierConfigDedicated-NB* is present and no *inbandCarrierInfo* is present:

- If frame structure type 1 is used, the UE may assume NRSs are transmitted in subframes #0, #1, #3, #4, #9, and in NB-IoT downlink subframes and shall not expect NRSs in other downlink subframes.

On an NB-IoT carrier for which *DL-CarrierConfigDedicated-NB* is present and *inbandCarrierInfo* is present:

- If frame structure type 1 is used, the UE may assume NRSs are transmitted in subframes #0, #4, #9, and in NB-IoT downlink subframes and shall not expect NRSs in other downlink subframes.

An NB-IoT UE may assume NRSs are not transmitted in subframes that are configured by higher layer parameter *nprsBitmap* for narrowband positioning reference signal transmission.

10.2.6.1 Sequence generation

The narrowband reference sequence shall be initialised according to clause 6.10.1.1 where $N_{\mathrm{ID}}^{\mathrm{cell}}$ is replaced with $N_{\mathrm{ID}}^{\mathrm{Ncell}}$.

10.2.6.2 Mapping to resource elements

Narrowband reference signals are transmitted on one or two antenna ports $p \in \{2000, 2001\}$.

If the higher layer indicates UE may assume that $N_{\mathrm{ID}}^{\mathrm{cell}}$ is equal to $N_{\mathrm{ID}}^{\mathrm{Ncell}}$, UE may assume

- the number of antenna ports for the cell-specific reference signals as defined in clause 6.10.1 is the same as for the narrowband reference signals,
- the antenna ports for cell-specific reference signals {0, 1} are equivalent to antenna ports for narrowband reference signals {2000, 2001}, respectively, and
- the cell-specific reference signals are available in all subframes where the narrowband reference signals are available.

If the higher layer does not indicate UE may assume that $N_{\mathrm{ID}}^{\mathrm{cell}}$ is equal to $N_{\mathrm{ID}}^{\mathrm{Ncell}}$, UE may assume

- the number of antenna port for the cell-specific reference signals as defined in clause 6.10.1 is obtained from the higher layer parameter *eutra-NumCRS-Ports*,
- the cell-specific reference signals are available in all subframes where the narrowband reference signals are available, and

  the cell-specific frequency shift for cell-specific reference signals as defined in clause 6.10.1.2 is given by $v_{\mathrm{shift}} = N_{\mathrm{ID}}^{\mathrm{Ncell}} \bmod 6$.

The reference signal sequence $r_{l,n_\mathrm{s}}(m)$ shall be mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ used as reference symbols for antenna port p in slot n_s according to

$$a_{k,l}^{(p)} = r_{l,n_\mathrm{s}}(m')$$

where

$$\begin{aligned} k &= 6m + (v + v_{\mathrm{shift}}) \bmod 6 \\ l &= N_{\mathrm{symb}}^{\mathrm{DL}} - 2, N_{\mathrm{symb}}^{\mathrm{DL}} - 1 \\ m &= 0,1 \\ m' &= m + N_{\mathrm{RB}}^{\mathrm{max,DL}} - 1 \end{aligned}$$

When frame structure type 2 is used, the following values of l apply for the generation of NRSs in special subframes

- $l = N_{\mathrm{symb}}^{\mathrm{DL}} - 5, N_{\mathrm{symb}}^{\mathrm{DL}} - 4$ in each slot for special subframe configurations {3, 4, 8}
- $l = N_{\mathrm{symb}}^{\mathrm{DL}} - 5, N_{\mathrm{symb}}^{\mathrm{DL}} - 4$ in the first slot for special subframe configurations {9, 10}
- $l = N_{\mathrm{symb}}^{\mathrm{DL}} - 2, N_{\mathrm{symb}}^{\mathrm{DL}} - 1$ in the first slot for special subframe configurations {1, 2, 6, 7}.

The variables v and v_{shift} define the position in the frequency domain for the different reference signals where v is given by

$$v = \begin{cases} 0 & \text{if } p = 2000 \text{ and } l \in \left\{ N_{\text{symb}}^{\text{DL}} - 2, N_{\text{symb}}^{\text{DL}} - 5 \right\} \\ 3 & \text{if } p = 2000 \text{ and } l \in \left\{ N_{\text{symb}}^{\text{DL}} - 1, N_{\text{symb}}^{\text{DL}} - 4 \right\} \\ 3 & \text{if } p = 2001 \text{ and } l \in \left\{ N_{\text{symb}}^{\text{DL}} - 2, N_{\text{symb}}^{\text{DL}} - 5 \right\} \\ 0 & \text{if } p = 2001 \text{ and } l \in \left\{ N_{\text{symb}}^{\text{DL}} - 1, N_{\text{symb}}^{\text{DL}} - 4 \right\} \end{cases}$$

The cell-specific frequency shift is given by $v_{\text{shift}} = N_{\text{ID}}^{\text{Ncell}} \bmod 6$.

Resource elements (k, l) used for transmission of narrowband reference signals on any of the antenna ports in a slot shall not be used for any transmission on any other antenna port in the same slot and set to zero.

Narrowband reference signals shall not be transmitted in subframes containing NPSS or NSSS.

For frame structure type 2, narrowband reference signals shall not be transmitted in special subframe for configurations 0 and 5.

Figure 10.2.6.2-1 illustrates the resource elements used for reference signal transmission according to the above definition. The notation R_p is used to denote a resource element used for reference signal transmission on antenna port p.

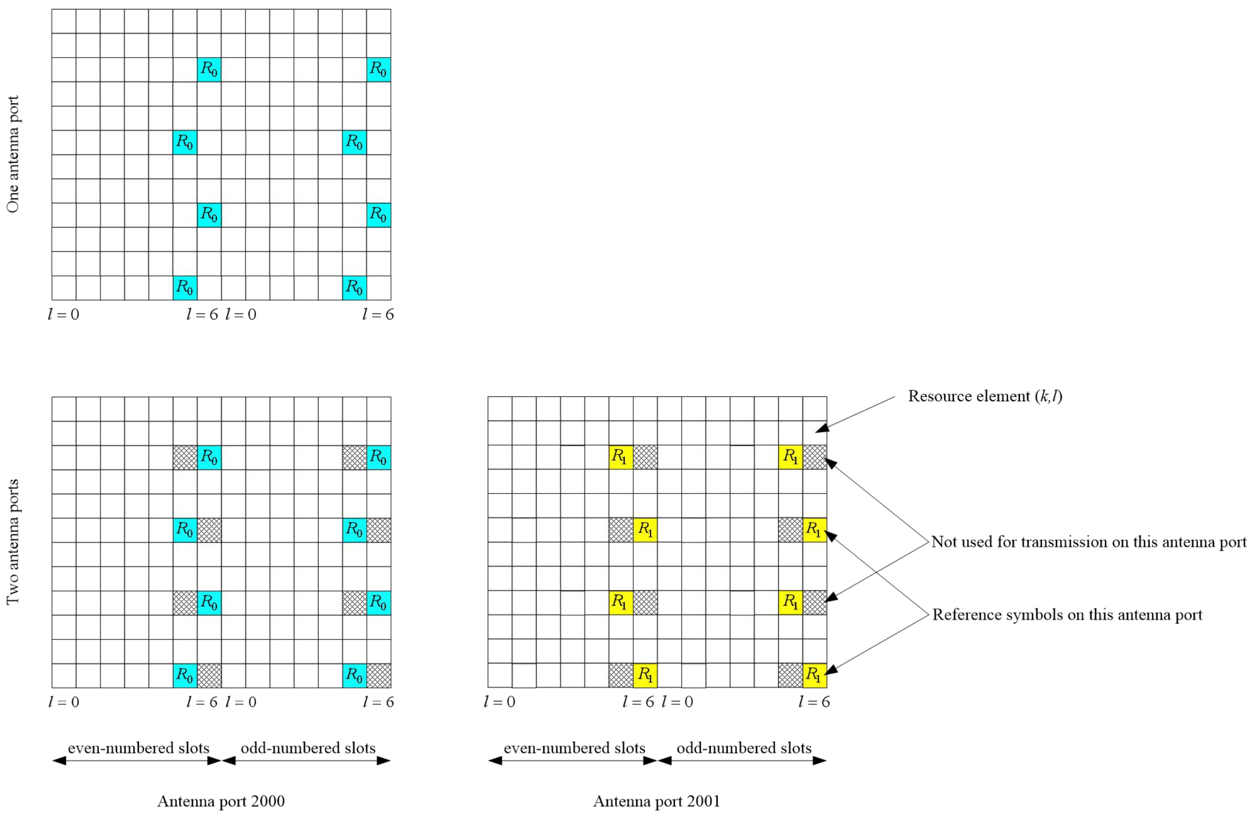

Figure 10.2.6.2-1. Mapping of downlink narrowband reference signals (normal cyclic prefix)

10.2.6A Narrowband positioning reference signal (NPRS)

Narrowband positioning reference signals (NPRSs) shall only be transmitted in resource blocks in NB-IoT carriers configured for NPRS transmission. In a subframe configured for NPRS transmission, the starting positions of the OFDM symbols configured for NPRS transmission shall be identical to those in a subframe in which all OFDM symbols have the same cyclic prefix length as the OFDM symbols configured for NPRS transmission. NPRS are defined for $\Delta f = 15$ kHz and normal CP only.

NPRSs are transmitted on antenna port 2006.

10.2.6A.1 Sequence generation

The NPRS sequence $r_{l,n_\mathrm{s}}(m)$ is defined by

$$r_{l,n_\mathrm{s}}(m) = \frac{1}{\sqrt{2}}\left(1 - 2\cdot c(2m)\right) + j\frac{1}{\sqrt{2}}\left(1 - 2\cdot c(2m+1)\right), \quad m = 0,1,...,2N_\mathrm{RB}^\mathrm{max,DL} - 1$$

where n_s is the slot number within a radio frame, l is the OFDM symbol number within the slot. The pseudo-random sequence $c(i)$ is defined in clause 7.2. The pseudo-random sequence generator shall be initialised with

$$c_\mathrm{init} = 2^{28}\cdot\left\lfloor N_\mathrm{ID}^\mathrm{NPRS}/512\right\rfloor + 2^{10}\cdot\left(7\cdot\left(n_\mathrm{s}+1\right)+l+1\right)\cdot\left(2\cdot\left(N_\mathrm{ID}^\mathrm{NPRS} \bmod 512\right)+1\right) + 2\cdot\left(N_\mathrm{ID}^\mathrm{NPRS} \bmod 512\right) + N_\mathrm{CP}$$

at the start of each OFDM symbol where $N_\mathrm{ID}^\mathrm{NPRS} \in \{0,1,...,4095\}$ equals $N_\mathrm{ID}^\mathrm{Ncell}$ unless configured by higher layers and where $N_\mathrm{CP} = 1$.

10.2.6A.2 Mapping to resource elements

For an NB-IoT carrier which is configured for NPRS transmission, the reference signal sequence $r_{l,n_\mathrm{s}}(m)$ shall be mapped to complex-valued modulation symbols $a_{k,l}^{(p)}$ used as reference signal for antenna port p in slot n_s according to, for Type 1 NPRS:

$$a_{k,l}^{(p)} = r_{l,n_\mathrm{s}}(m')$$

or for Type 2 NPRS:

$$a_{k,l}^{(p)} = r_{l,n_s}\left(\left(m' + 2(n_f \bmod 64)\right) \bmod 220\right)$$

according to higher layer configuration, where

- when the higher layer parameter *operationModeInfoNPRS* for the configured NB-IoT carrier is set to in-band

$$\begin{aligned} & k = 6m + \left(6 - l + v_\mathrm{shift}\right) \bmod 6 \\ & l = \begin{cases} 3,5,6 & \text{if } n_\mathrm{s} \bmod 2 = 0 \\ 1,2,3,5,6 & \text{if } n_\mathrm{s} \bmod 2 = 1 \text{ and } \left(1 \text{ or } 2 \text{ PBCH antenna ports}\right) \\ 2,3,5,6 & \text{if } n_\mathrm{s} \bmod 2 = 1 \text{ and } \left(4 \text{ PBCH antenna ports}\right) \end{cases} \\ & m = 0,1 \\ & m' = m + 2\,n'_\mathrm{PRB} + N_\mathrm{RB}^\mathrm{max,DL} - \tilde{n} \end{aligned}$$

  where n'_PRB is signalled by higher layers *nprs-SequenceInfo*, and $\tilde{n} = 1$ if the higher layer parameter *nprs-SequenceInfo* indicates $N_\mathrm{RB}^\mathrm{DL}$ is odd, and $\tilde{n} = 0$ if the higher layer parameter *nprs-SequenceInfo* indicates $N_\mathrm{RB}^\mathrm{DL}$ is even.

- when the higher layer parameter *operationModeInfoNPRS* for the configured NB-IoT carrier is set to standalone or guard-band

$$\begin{aligned} & k = 6m + \left(6 - l + v_\mathrm{shift}\right) \bmod 6 \\ & l = 0, 1, 2, 3, 4, 5, 6 \\ & m = 0,1 \\ & m' = m + N_\mathrm{RB}^\mathrm{max,DL} - 1 \end{aligned}$$

and where $v_{\text{shift}} = N_{\text{ID}}^{\text{NPRS}} \bmod 6$. If $N_{\text{ID}}^{\text{NPRS}}$ is not configured by higher layers, $N_{\text{ID}}^{\text{NPRS}} = N_{\text{ID}}^{\text{Ncell}}$. The number of PBCH antenna ports is signalled by higher layers.

If higher layer parameter *nprsBitmap* is not configured, resource elements in OFDM symbols 5 and 6 in each slot shall not be used for transmission of NPRS. If the configured periodicity of Type 1 NPRS is equal to that of Type 2 NPRS, the UE is not expected to be configured with overlapped resource elements between Type 1 NPRS and Type 2 NPRS. Otherwise, a resource element configured for Type 1 NPRS shall not be used for Type 2 NPRS.

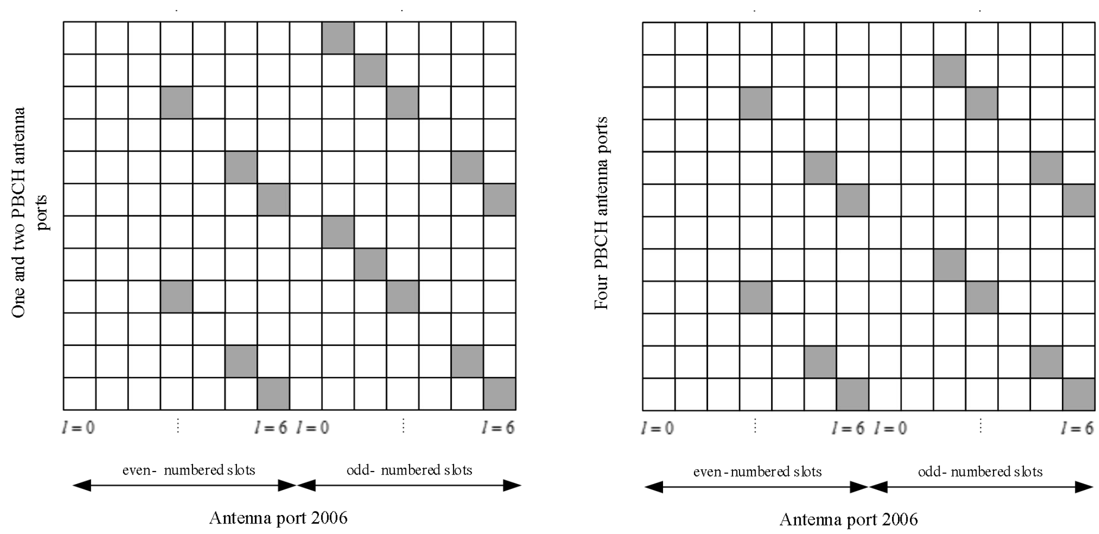

Figure 10.2.6A.2-1: Mapping of NPRS (*operationModeInfoNPRS* is set to in-band, *nprsBitmap* configured)

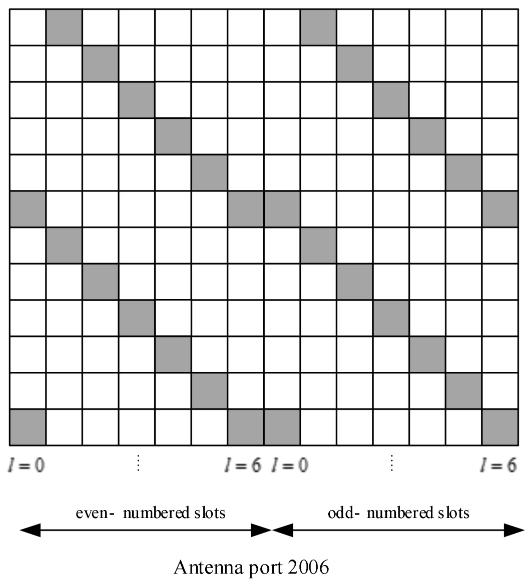

Figure 10.2.6A.2-2: Mapping of NPRS (*operationModeInfoNPRS* is set to standalone or guard-band, nprsBitmap configured)

10.2.6A.3 NPRS subframe configuration

On a NB-IoT DL carrier configured for NPRS transmission, an NB-IoT UE can assume NPRSs are transmitted in DL subframes configured by all higher layer parameters *nprsBitmap,* the NB-IoT carrier-specific subframe configuration period T_{NPRS}, the NB-IoT-carrier-specific starting subframe offset α_{NPRS}, and the number of consecutive downlink subframes N_{NPRS} where NPRS shall be transmitted. If frame structure type 2 is used, the UE shall not assume NPRSs are transmitted in special subframes.

- If T_{NPRS}, α_{NPRS}, and N_{NPRS} are not configured for an NB-IoT downlink carrier configured for NPRS transmission, an NB-IoT UE shall assume NPRSs are transmitted in downlink subframes configured by higher layer parameter *nprsBitmap.*
- If *nprsBitmap* is not configured for an NB-IoT downlink carrier configured for NPRS transmission, an NB-IoT UE shall assume NPRSs are transmitted in downlink subframes configured by the higher layer parameters T_{NPRS}, α_{NPRS}, and N_{NPRS}.
- If the higher layer parameter *operationModeInfoNPRS* for the configured NB-IoT carrier is set to in-band, the higher layer parameters *nprsBitmap* shall be configured.
- If T_{NPRS}, α_{NPRS}, and N_{NPRS} are configured, the NPRS instances in the first subframe of the N_{NPRS} downlink subframes, shall satisfy $\left(10n_{\text{f}} + \lfloor n_{\text{s}}/2 \rfloor - \alpha_{\text{NPRS}} T_{\text{NPRS}}\right) \bmod T_{\text{NPRS}} = 0$.

The NPRSs shall not be mapped to resource elements (k,l) allocated to resource blocks of NPBCH, NPSS, NSSS, or *SystemInformationBlock-Type1-NB* regardless of their antenna port p.

10.2.6B Narrowband wake up signal (NWUS)

10.2.6B.1 Sequence generation

The NWUS sequence $w(m)$ in subframe $x = 0, 1, \dots, M-1$ is defined by

$$w(m) = \theta_{n_f, n_s}(m') \cdot e^{-\frac{j\pi u n(n+1)}{131}}$$

$$m = 0, 1, \dots, 131$$

$$m' = m + 132x$$

$$n = m \bmod 132$$

$$\theta_{n_f, n_s}(m') = \begin{cases} 1, \text{ if } c_{n_f, n_s}(2m') = 0 \text{ and } c_{n_f, n_s}(2m'+1) = 0 \\ -1, \text{ if } c_{n_f, n_s}(2m') = 0 \text{ and } c_{n_f, n_s}(2m'+1) = 1 \\ j, \text{ if } c_{n_f, n_s}(2m') = 1 \text{ and } c_{n_f, n_s}(2m'+1) = 0 \\ -j, \text{ if } c_{n_f, n_s}(2m') = 1 \text{ and } c_{n_f, n_s}(2m'+1) = 1 \end{cases}$$

$$u = \left(N_{\text{ID}}^{\text{Ncell}} \bmod 126\right) + 3$$

where M is the actual duration of NWUS as defined in [4].

The scrambling sequence $c_{n_f, n_s}(i), i = 0, 1, \dots, 2 \cdot 132M - 1$ is given by clause 7.2, and shall be initialized at the start of the NWUS with

$$c_{\text{init\_WUS}} = (N_{\text{ID}}^{\text{Ncell}} + 1)\left(\left(10 n_{\text{f\_start\_PO}} + \left\lfloor \frac{n_{\text{s\_start\_PO}}}{2} \right\rfloor\right) \bmod 2048 + 1\right) 2^9 + N_{\text{ID}}^{\text{Ncell}}$$

where $n_{\text{f\_start\_PO}}$ is the first frame of the first PO to which the NWUS is associated, and $n_{\text{s\_start\_PO}}$ is the first slot of the first PO to which the NWUS is associated.

10.2.6B.2 Mapping to resource elements

The same antenna port shall be used for all symbols of the NWUS within a subframe. The UE shall not assume that the NWUS is transmitted on the same antenna port as any of the downlink reference signals or synchronization signals. If only one NRS port is configured by the eNB, the UE may assume the transmission of all NWUS subframes is using the same antenna port; otherwise, the UE may assume the same antenna port is used for NWUS transmission in DL subframes $w0+2n$ and $w0+2n+1$, where w0 is the first DL subframe of the NWUS transmission as specified in [4], and n=0,1.

The NWUS sequence is mapped to the set of subframes in the actual NWUS duration as defined in [4], where in a subframe #4 in which *SystemInformationBlockType1-NB* is transmitted or a subframe in which an SI message is transmitted, the subframe is counted in the NWUS mapping but not used for transmission of NWUS.On an NB-IoT carrier for which a UE receives higher-layer parameter *operationModeInfo* indicating *inband-SamePCI*, *inband-DifferentPCI, guardband* or *standalone* or on an NB-IoT carrier for which *DL-CarrierConfigCommon-NB* is present, the NWUS sequence $w(m)$ shall be mapped to resource elements (k,l) in sequence, starting with $w(0)$ in increasing order of first the index $k = 0,1,\ldots,N_{sc}^{RB}-1,$ over the 12 assigned subcarriers and then the index $l = 3,4,\ldots,2N_{\text{symb}}^{\text{DL}}-1$ in each subframe in which NWUS is transmitted.

Additionally, on an NB-IoT carrier for which a UE receives higher-layer parameter *operationModeInfo* indicating *guardband* or *standalone,* or on an NB-IoT carrier for which *DL-CarrierConfigCommon-NB* is present and no *inbandCarrierInfo* is present*,* the resource mapping for the first three OFDM symbols in the subframe is performed as follows:

- The resource element (k,7) is mapped to resource element (k,0) of every index k over 12 assigned subcarriers
- The resource element (k,8) is mapped to resource element (k,1) of every index k over 12 assigned subcarriers
- The resource element (k,9) is mapped to resource element (k,2) of every index k over 12 assigned subcarriers

A resource element (k,l) overlapping with resource elements where cell-specific reference signals according to clause 6.10 are transmitted or NRSs according to clause 10.2.6 are transmitted shall not be used for NWUS transmission but is counted in the mapping process.

10.2.7 Synchronization signals

There are 504 unique physical-layer cell identities indicated by the narrowband secondary synchronization signal.

10.2.7.1 Narrowband primary synchronization signal (NPSS)

10.2.7.1.1 Sequence generation

The sequence $d_l(n)$ used for the narrowband primary synchronization signal is generated from a frequency-domain Zadoff-Chu sequence according to

$$d_l(n) = S(l)\cdot e^{-j\frac{\pi un(n+1)}{11}}, \quad n = 0,1,\ldots,10$$

where the Zadoff-Chu root sequence index $u = 5$ and $S(l)$ for different symbol indices l is given by Table 10.2.7.1.1-1.

Table 10.2.7.1.1-1: Definition of $S(l)$.

Cyclic prefix length	$S(3),\ldots,S(13)$										
Normal	1	1	1	1	-1	-1	1	1	1	-1	1

10.2.7.1.2 Mapping to resource elements

The same antenna port shall be used for all symbols of the narrowband primary synchronization signal within a subframe.

UE shall not assume that the narrowband primary synchronization signal is transmitted on the same antenna port as any of the downlink reference signals. The UE shall not assume that the transmissions of the narrowband primary synchronization signal in a given subframe use the same antenna port, or ports, as the narrowband primary synchronization signal in any other subframe.

The sequences $d_l(n)$ shall be mapped to resource elements (k,l) in increasing order of first the index $k = 0,1,...,N_{\mathrm{sc}}^{\mathrm{RB}} - 2$ and then the index $l = 3,4,...,2N_{\mathrm{symb}}^{\mathrm{DL}} - 1$ in subframe 5 in every radio frame. For resource elements (k,l) overlapping with resource elements where cell-specific reference signals according to clause 6.10 are transmitted, the corresponding sequence element $d(n)$ is not used for the NPSS but counted in the mapping process.

10.2.7.2 Narrowband secondary synchronization signal (NSSS)

10.2.7.2.1 Sequence generation

The sequence $d(n)$ used for the narrowband secondary synchronization signal is generated from a frequency-domain Zadoff-Chu sequence according to

$$d(n) = b_q(m) e^{-j2\pi\theta_f n} e^{-j\frac{\pi u n'(n'+1)}{131}}$$

where

$$\begin{aligned} n &= 0,1,...,131 \\ n' &= n \bmod 131 \\ m &= n \bmod 128 \\ u &= N_{\mathrm{ID}}^{\mathrm{Ncell}} \bmod 126 + 3 \\ q &= \left\lfloor \frac{N_{\mathrm{ID}}^{\mathrm{Ncell}}}{126} \right\rfloor \end{aligned}$$

The binary sequence $b_q(m)$ is given by Table 10.2.7.2.1-1. The cyclic shift θ_{f} in frame number n_{f} is given by

$$\theta_{\mathrm{f}} = \frac{33}{132}(n_{\mathrm{f}}/2) \bmod 4 .$$

Table 10.2.7.2.1-1: Definition of $b_q(m)$.

q	$b_q(0),...,b_q(127)$
0	[1 1]
1	[1 -1 -1 1 -1 1 1 -1 -1 1 1 -1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 -1 1 1 -1 -1 1 1 -1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 -1 1 1 -1 -1 1 1 - 1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 - 1 1 1 -1 -1 1 1 -1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 1 1 -1]
2	[1 -1 -1 1 -1 1 1 -1 -1 1 1 -1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 1 1 -1 -1 1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 -1 1 1 -1 -1 1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 1 1 -1 -1 1 1 - 1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 1 1 -1 -1 1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 -1 1 1 -1 -1 1 1 -1 1 - 1 -1 1]
3	[1 -1 -1 1 -1 1 1 -1 -1 1 1 -1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 1 1 -1 -1 1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 -1 1 1 -1 -1 1 1 -1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 -1 1 1 -1 -1 1 1 -1 1 -1 -1 1 1 -1 -1 1 - 1 1 1 -1 -1 1 1 -1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 1 -1 -1 1 -1 1 1 -1]

10.2.7.2.2 Mapping to resource elements

The same antenna port shall be used for all symbols of the narrowband secondary synchronization signal within a subframe.

The UE shall not assume that the narrowband secondary synchronization signal is transmitted on the same antenna port as any of the downlink reference signals. The UE shall not assume that the transmissions of the narrowband secondary synchronization signal in a given subframe use the same antenna port, or ports, as the narrowband secondary synchronization signal in any other subframe.

If indicated by higher layer, a UE may assume different precoders are applied for NSSS transmission in a number of consecutive NSSS occasions signalled by higher layer.

The sequence $d(n)$ shall be mapped to resource elements (k,l) in sequence starting with $d(0)$ in increasing order of first the index k over the 12 assigned subcarriers and then the index l over the assigned last $N_{\text{symb}}^{\text{NSSS}}$ symbols of subframe 9 for frame structure type 1 or subframe 0 for frame structure type 2 in radio frames fulfilling $n_{\text{f}} \bmod 2 = 0$, where $N_{\text{symb}}^{\text{NSSS}}$ is given by Table 10.2.7.2.2-1.

Table 10.2.7.2.2-1: NSSS number of symbols

Cyclic prefix length	$N_{\text{symb}}^{\text{NSSS}}$
Normal	11

For resource elements (k,l) overlapping with resource elements where cell-specific reference signals according to clause 6.10 are transmitted, the corresponding sequence element $d(n)$ is not used for the NSSS but counted in the mapping process.

10.2.8 OFDM baseband signal generation

For an NB-IoT carrier

- for which the higher layer parameter *operationModeInfo* indicates '*inband-DifferentPCI* ' and for all NB-IoT downlink physical channels and signals except NPRS,
- for which the higher layer parameter *operationModeInfo* indicates '*Guardband* ' or '*Standalone* ',
- for an NB-IoT carrier for which the higher layer parameter *CarrierConfigDedicated-NB* or *DL-CarrierConfigCommon-NB* is present and no *inbandCarrierInfo* is present, or
- for an NB-IoT carrier for which the higher layer parameters *CarrierConfigDedicated-NB* or *DL-CarrierConfigCommon-NB* is present and *inbandCarrierInfo* is present and the higher layers do not indicate $N_{\text{ID}}^{\text{Ncell}}$ is the same as $N_{\text{ID}}^{\text{cell}}$ and for all NB-IoT downlink physical channels and signals except NPRS,

the time-continuous signal $s_l^{(p)}(t)$ on antenna port p in OFDM symbol l in a downlink slot is defined by

$$s_l^{(p)}(t) = \sum_{k=-\lfloor N_{\text{sc}}^{\text{RB}}/2 \rfloor}^{\lceil N_{\text{sc}}^{\text{RB}}/2 \rceil - 1} a_{k^{(-)},l}^{(p)} \cdot e^{j2\pi(k+1/2)\Delta f\left(t - N_{\text{CP},l} T_{\text{s}}\right)}$$

for $0 \le t < \left(N_{\text{CP},l} + N\right) \times T_{\text{s}}$ where $k^{(-)} = k + \lfloor N_{sc}^{RB}/2 \rfloor$, $N = 2048$, $\Delta f = 15\,\text{kHz}$ and $a_{k,l}^{(p)}$ is the content of resource element (k,l) on antenna port p.

Otherwise, the time-continuous signal $s_{l'}^{(p)}(t)$ on antenna port p in OFDM symbol l', where $l' = l + N_{\text{symb}}^{\text{DL}}(n_s \bmod 4) \in \{0,...,27\}$ is the OFDM symbol index from the start of the last even-numbered subframe, is defined by

$$s_{l'}^{(p)}(t)=\sum_{k=-\left\lfloor N_{\mathrm{RB}}^{\mathrm{DL}} N_{\mathrm{sc}}^{\mathrm{RB}}/2\right\rfloor}^{-1} e^{\theta_{k^{(-)},l'}} a_{k^{(-)},l'}^{(p)} \cdot e^{j2\pi k\Delta f\left(t-N_{\mathrm{CP},l' \bmod N_{\mathrm{symb}}^{\mathrm{DL}}} T_{\mathrm{s}}\right)}+\sum_{k=1}^{\left\lceil N_{\mathrm{RB}}^{\mathrm{DL}} N_{\mathrm{sc}}^{\mathrm{RB}}/2\right\rceil} e^{\theta_{k^{(+)},l'}} a_{k^{(+)},l'}^{(p)} \cdot e^{j2\pi k\Delta f\left(t-N_{\mathrm{CP},l' \bmod N_{\mathrm{symb}}^{\mathrm{DL}}} T_{\mathrm{s}}\right)}$$

for $0 \leq t < \left(N_{\mathrm{CP},l}+N\right) \times T_{\mathrm{s}}$ where $k^{(-)}=k+\left\lfloor N_{\mathrm{RB}}^{\mathrm{DL}} N_{\mathrm{sc}}^{\mathrm{RB}}/2\right\rfloor$ and $k^{(+)}=k+\left\lfloor N_{\mathrm{RB}}^{\mathrm{DL}} N_{\mathrm{sc}}^{\mathrm{RB}}/2\right\rfloor-1$,

$\theta_{k,l'}=j2\pi f_{NB-IoT} T_s\left(l'N+\sum_{i=0}^{l'} N_{CP,i \bmod 7}\right)$ if resource element (k,l') is used for Narrowband IoT except for NPRS, and 0 otherwise including NPRS. The quantity $f_{\text{NB-IoT}}$ is the frequency location of the center of the Narrowband IoT PRB minus the frequency location of the center of the LTE signal.

Only normal CP is supported for Narrowband IoT downlink in this release of the specification.

10.2.9 Modulation and upconversion

Modulation and upconversion to the carrier frequency of the complex-valued OFDM baseband signal for each antenna port is shown in Figure 6.13-1. The filtering required prior to transmission is defined by the requirements in 3GPP TS 36.104 [6].

Annex A (informative): Change history

Change history							
Date	**TSG #**	**TSG Doc.**	**CR**	**Rev**	**Subject/Comment**	**Old**	**New**
2006-09-24	-	-	-		Draft version created	-	0.0.0
2006-10-09	-	-	-		Updated skeleton	0.0.0	0.0.1
2006-10-13	-	-	-		Endorsed by RAN1	0.0.1	0.1.0
2006-10-23	-	-	-		Inclusion of decision from RAN1#46bis	0.1.0	0.1.1
2006-11-06	-	-	-		Updated editor 's version	0.1.1	0.1.2
2006-11-09	-	-	-		Updated editor 's version	0.1.2	0.1.3
2006-11-10	-	-	-		Endorsed by RAN1#47	0.1.3	0.2.0
2006-11-27	-	-	-		Editor 's version, including decisions from RAN1#47	0.2.0	0.2.1
2006-12-14	-	-	-		Updated editor 's version	0.2.1	0.2.2
2007-01-15	-	-	-		Updated editor 's version	0.2.2	0.2.3
2007-01-19	-	-	-		Endorsed by RAN1#47bis	0.2.3	0.3.0
2007-02-01	-	-	-		Editor 's version, including decisions from RAN1#47bis	0.3.0	0.3.1
2007-02-12	-	-	-		Updated editor 's version	0.3.1	0.3.2
2007-02-16	-	-	-		Endorsed by RAN1#48	0.3.2	0.4.0
2007-02-16	-	-	-		Editor 's version, including decisions from RAN1#48	0.4.0	0.4.1
2007-02-21	-	-	-		Updated editor 's version	0.4.1	0.4.2
2007-03-03	RP_35	RP-070169			For information at RAN#35	0.4.2	1.0.0
2007-04-25	-	-	-		Editor 's version, including decisions from RAN1#48bis and RAN1 TDD Ad Hoc	1.0.0	1.0.1
2007-05-03	-	-	-	-	Updated editor 's version	1.0.1	1.0.2
2007-05-08	-	-	-	-	Updated editor 's version	1.0.2	1.0.3
2007-05-11	-	-	-	-	Updated editor 's version	1.0.3	1.0.4
2007-05-11	-	-	-	-	Endorsed by RAN1#49	1.0.4	1.1.0
2007-05-15	-	-	-	-	Editor 's version, including decisions from RAN1#49	1.1.0	1.1.1
2007-06-05	-	-	-	-	Updated editor 's version	1.1.1	1.1.2
2007-06-25	-	-	-	-	Endorsed by RAN1#49bis	1.1.2	1.2.0
2007-07-10	-	-	-	-	Editor 's version, including decisions from RAN1#49bis	1.2.0	1.2.1
2007-08-10	-	-	-	-	Updated editor 's version	1.2.1	1.2.2
2007-08-20	-	-	-	-	Updated editor 's version	1.2.2	1.2.3
2007-08-24	-	-	-	-	Endorsed by RAN1#50	1.2.3	1.3.0
2007-08-27	-	-	-	-	Editor 's version, including decisions from RAN1#50	1.3.0	1.3.1
2007-09-05	-	-	-	-	Updated editor 's version	1.3.1	1.3.2
2007-09-08	RP_37	RP-070729	-	-	For approval at RAN#37	1.3.2	2.0.0
12/09/07	RP_37	RP-070729			Approved version	2.0.0	8.0.0
28/11/07	RP_38	RP-070949	0001	-	Introduction of optimized FS2 for TDD	8.0.0	8.1.0
28/11/07	RP_38	RP-070949	0002	-	Introduction of scrambling sequences, uplink reference signal sequences, secondary synchronization sequences and control channel processing	8.0.0	8.1.0
05/03/08	RP_39	RP-080219	0003	1	Update of uplink reference-signal hopping, downlink reference signals, scrambling sequences, DwPTS/UpPTS lengths for TDD and control channel processing	8.1.0	8.2.0
28/05/08	RP_40	RP-080432	0004	-	Correction of the number of subcarriers in PUSCH transform precoding	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0005	-	Correction of PHICH mapping	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0006	-	Correction of PUCCH resource index for PUCCH format 2	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0007	3	Correction of the predefined hopping pattern for PUSCH	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0008	-	Non-binary hashing functions	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0009	1	PUCCH format 1	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0010	1	CR on Uplink DM RS hopping	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0012	1	Correction to limitation of constellation size of ACK transmission in PUSCH	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0015	1	PHICH mapping for one and two antenna ports in extended CP	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0016	1	Correction of PUCCH in absent of mixed format	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0017	-	Specification of CCE size and PHICH resource indication	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0018	3	Correction of the description of frame structure type 2	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0019	-	On Delta^pucch_shift correction	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0021	-	Corrections to Secondary Synchronization Signal Mapping	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0022	-	Downlink VRB mapping to PRB for distributed transmission	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0023	-	Clarification of modulation symbols to REs mapping for DVRB	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0024	1	Consideration on the scrambling of PDSCH	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0025	-	Corrections to Initialization of DL RS Scrambling	8.2.0	8.3.0

Change history							
Date	TSG #	TSG Doc.	CR	Rev	Subject/Comment	Old	New
28/05/08	RP_40	RP-080432	0026	1	CR on Downlink RS	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0027	-	CR on Uplink RS	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0028	1	Fixed timing advance offset for LTE TDD and half-duplex FDD	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0029	1	Timing of random access preamble format 4	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0030	1	Uplink sounding RS bandwidth configuration	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0031	-	Use of common RS when UE-specific RS are configured	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0032	1	Uplink RS Updates	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0033	-	Orthogonal cover sequence for shortened PUCCH format 1a and 1b	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0034	-	Clarification of PDCCH mapping	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0035	-	TDD PRACH time/frequency mapping	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0036	-	Cell Specific Uplink Sounding RS Subframe Configuration	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0038	-	PDCCH length for carriers with mixed MBSFN and Unicast Traffic	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0040	-	Correction to the scrambling sequence generation for PUCCH, PCFICH, PHICH, MBSFN RS and UE specific RS	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0041	-	PDCCH coverage in narrow bandwidths	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0042	-	Closed-Loop and Open-Loop Spatial Multiplexing	8.2.0	8.3.0
28/05/08	RP_40	RP-080432	0043	-	Removal of small-delay CDD	8.2.0	8.3.0
09/09/08	RP_41	RP-080668	48	1	Frequency Shifting of UE-specific RS	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	49	1	Correction of PHICH to RE mapping in extended CP subframe	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	50	-	Corrections to for handling remaining Res	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	51	-	PRACH configuration for frame structure type 1	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	52	2	Correction of PUCCH index generation formula	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	53	-	Orthogonal cover sequence for shortened PUCCH format 1a and 1b	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	54	-	Correction of mapping of ACK/NAK to binary bit values	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	56	2	Remaining issues on SRS hopping	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	57	1	Correction of n_cs(n_s) and OC/CS remapping for PUCCH formats 1/1a/1b and 2/2a/2b	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	59	-	Corrections to Rank information scrambling in Uplink Shared Channel	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	60	-	Definition on the slot number for frame structure type 2	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	61	-	Correction of the Npucch sequence upper limit for the formats 1/1a/1b	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	62	1	Clarifications for DMRS parameters	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	63	-	Correction of n_prs	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	64	1	Introducing missing L1 parameters to 36.211	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	65	3	Clarification on reception of synchronization signals	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	66	-	Correction to the downlink/uplink timing	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	67	-	ACK/NACK Scrambling scheme on PUCCH	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	68	-	DCI format1C	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	69	-	Refinement for REG Definition for n = 4	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	71	-	Correcting Ncs value for PRACH preamble format 0-3	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	73	-	Correction of the half duplex timing advance offset value	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	74	-	Correction to Precoding for Transmit Diversity	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	75	-	Clarification on number of OFDM symbols used for PDCCH	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	77	-	Number of antenna ports for PDSCH	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	78	-	Correction to Type 2 PUSCH predetermined hopping for Nsb=1 operation	8.3.0	8.4.0
09/09/08	RP_41	RP-080668	79	-	PRACH frequency location	8.3.0	8.4.0
03/12/08	RP_42	RP-081074	70	1	Correction for the definition of UE-specific reference signals	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	72	2	Corrections to precoding for large delay CDD	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	80	-	Correction to the definition of nbar_oc for extended CP	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	81	1	Specification of reserved REs not used for RS	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	82	2	Clarification of the random access preamble transmission timing	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	83	1	Indexing of PRACH resources within the radio frame	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	84	6	Alignment of RAN1/RAN2 specification	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	86	-	Clarification on scrambling of ACK/NAK bits for PUCCH format 2a/2b	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	87	-	Correction of introduction of shortened SR	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	88	-	Corrections to 36.211	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	89	-	Clarification on PUSCH DM RS Cyclic Shift Hopping	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	92	1	Correction to the uplink DM RS assignment	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	93	-	Clarify the RNTI used in scrambling sequence initialization	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	94	1	On linkage Among UL Power Control Parameters	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	95	-	Clarification on PUSCH pre-determined hopping pattern	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	96	-	Clarification of SRS sequence-group and base sequence number	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	97	1	SRS subframe configuration	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	98	-	Remaining SRS details for TDD	8.4.0	8.5.0

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Date	TSG #	TSG Doc.	CR	Rev	Subject/Comment	Old	New
03/12/08	RP_42	RP-081074	99	-	Clarifying UL VRB Allocation	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	100	-	Clarification on PUCCH resource hopping	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	101	-	Correction for definition of Qm and a pseudo code syntax error in Scrambling.	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	105	1	Remaining Issues on SRS of TDD	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	106	-	Correction of reference to RAN4 specification of supported uplink bandwidth	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	107	-	General corrections to SRS	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	109	2	Correction to PCFICH specification	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	110	1	Correction to Layer Mapping for Transmit Diversity with Four Antenna Ports	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	111	-	Correction of the mapping of cyclic shift filed in DCI format 0 to the dynamic cyclic shift offset	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	112	-	DRS collision handling	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	113	-	Clarification to enable reuse of non-active PUCCH CQI RBs for PUSCH	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	114	1	PUSCH Mirror Hopping operation	8.4.0	8.5.0
03/12/08	RP_42	RP-081074	108	1	Extended and normal cyclic prefix in DL and UL for LTE TDD	8.4.0	8.5.0
04/03/09	RP_43	RP-090234	115	1	Alignment of PRACH configuration index for FS type 1 and type 2	8.5.0	8.6.0
04/03/09	RP_43	RP-090234	118	1	Clarification for DRS Collision handling	8.5.0	8.6.0
04/03/09	RP_43	RP-090234	121	1	Removing inverse modulo operation	8.5.0	8.6.0
04/03/09	RP_43	RP-090234	123	1	Clarification on the use of preamble format 4	8.5.0	8.6.0
04/03/09	RP_43	RP-090234	124	-	Clarification of RNTI used in scrambling sequence	8.5.0	8.6.0
04/03/09	RP_43	RP-090234	125	1	Clarifying PDCCH RE mapping	8.5.0	8.6.0
04/03/09	RP_43	RP-090234	126	-	Correction of preamble format 4 timing	8.5.0	8.6.0
04/03/09	RP_43	RP-090234	127	2	Corrections to SRS	8.5.0	8.6.0
04/03/09	RP_43	RP-090234	128	2	Clarification of PDSCH Mapping to Resource Elements	8.5.0	8.6.0
04/03/09	RP_43	RP-090234	129	1	Alignment with correct ASN1 parameter names	8.5.0	8.6.0
04/03/09	RP_43	RP-090234	130	-	Correction to PUCCH format 1 mapping to physical resources	8.5.0	8.6.0
04/03/09	RP_43	RP-090234	132	-	Correction to type-2 PUSCH hopping	8.5.0	8.6.0
04/03/09	RP_43	RP-090234	134	-	Alignment of SRS configuration	8.5.0	8.6.0
27/05/09	RP_44	RP-090527	135	-	Correction on UE behavior for PRACH 20ms periodicity	8.6.0	8.7.0
15/09/09	RP_45	RP-090888	137	1	Clarification on DMRS sequence for PUSCH	8.7.0	8.8.0
15/09/09	RP_45	RP-090888	138	1	Correction to PHICH resource mapping for TDD and to PHICH scrambling	8.7.0	8.8.0
01/12/09	RP_46	RP-091168	142	-	Clarification of the transmit condition for UE specific reference signals	8.8.0	8.9.0
01/12/09	RP_46	RP-091172	139	2	Introduction of LTE positioning	8.9.0	9.0.0
01/12/09	RP_46	RP-091177	140	3	Editorial corrections to 36.211	8.9.0	9.0.0
01/12/09	RP_46	RP-091257	141	1	Introduction of enhanced dual layer transmission	8.9.0	9.0.0
16/03/10	RP_47	RP-100209	144	1	Removal of square brackets on positioning subframe periodicities	9.0.0	9.1.0
16/03/10	RP_47	RP-100209	145	-	Clarification of the CP length of empty OFDM symbols in PRS subframes	9.0.0	9.1.0
16/03/10	RP_47	RP-100210	146	-	Clarification of MBSFN subframe definition	9.0.0	9.1.0
07/12/10	RP_50	RP-101320	148	-	Introduction of Rel-10 LTE-Advanced features in 36.211	9.1.0	10.0.0
15/03/11	RP_51	RP-110254	149	1	Correction on UE behavior for PRACH preamble format 4	10.0.0	10.1.0
15/03/11	RP_51	RP-110256	150	-	Corrections to Rel-10 LTE-Advanced features in 36.211	10.0.0	10.1.0
01/06/11	RP_52	RP-110818	153	2	PUSCH interaction with periodic SRS	10.1.0	10.2.0
01/06/11	RP_52	RP-110819	154	1	Correction on describing PUCCH format 3	10.1.0	10.2.0
01/06/11	RP_52	RP-110821	155	3	Correction on codebooks for CSI-RS based feedback for up to 4 CSI-RS ports.	10.1.0	10.2.0
01/06/11	RP_52	RP-110821	156	-	Correction on overlapping non-zero-power and zero-power CSI-RS configurations	10.1.0	10.2.0
01/06/11	RP_52	RP-110821	157	-	Correction on CSI-RS configuration	10.1.0	10.2.0
01/06/11	RP_52	RP-110821	158	-	PDSCH transmission in MBSFN subframes	10.1.0	10.2.0
01/06/11	RP_52	RP-110823	159	-	Correction on implicit derivation of transmission comb per antenna port for SRS	10.1.0	10.2.0
01/06/11	RP_52	RP-110823	160	-	Uplink DMRS sequence in RACH procedure	10.1.0	10.2.0
15/09/11	RP_53	RP-111229	162	-	Corrections on DMRS for Extended CP	10.2.0	10.3.0
15/09/11	RP_53	RP-111228	163	-	Clarification of applicability of precoding power scaling factors for PDSCH	10.2.0	10.3.0
15/09/11	RP_53	RP-111228	164	-	Correction to modulation and upconversion on PRACH	10.2.0	10.3.0
15/09/11	RP_53	RP-111229	165	-	Clarification on cyclic prefix of PDSCH in MBSFN subframes	10.2.0	10.3.0
15/09/11	RP_53	RP-111229	166	3	Corrections on indication in scrambling identity field in DCI format 2B and 2C	10.2.0	10.3.0
05/12/11	RP_54	RP-111668	167	-	A correction to PDSCH precoding for CQI calculation	10.3.0	10.4.0
05/12/11	RP_54	RP-111668	168	-	Correction to figure of CSI-RS pattern in extended-CP subframe	10.3.0	10.4.0
13/06/12	RP_56	RP-120736	169	-	Correction to resource mapping for PDSCH	10.4.0	10.5.0
13/06/12	RP_56	RP-120739	171	-	Correction for DMRS group hopping and sequence hopping	10.4.0	10.5.0
13/06/12	RP_56	RP-120738	172	-	Correction to assumed CSI-RS transmissions in subframes used	10.4.0	10.5.0

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					for paging		
04/09/12	RP_57	RP-121274	170	4	Introduction of an additional special subframe configuration	10.5.0	11.0.0
04/09/12	RP_57	RP-121272	173	-	Inclusion of Rel-11 features	10.5.0	11.0.0
04/12/12	RP_58	RP-121839	175	-	Correction to assumed CSI-RS transmissions in secondary cells	11.0.0	11.1.0
04/12/12	RP_58	RP-121846	176	-	Correction to assumed CSI-RS transmissions in secondary cells	11.0.0	11.1.0
26/02/13	RP_59	RP-130254	178	-	Clarification of CSI RS mapping to resource elements	11.1.0	11.2.0
26/02/13	RP_59	RP-130254	180	-	Correction to CSI Reference Signals	11.1.0	11.2.0
26/02/13	RP_59	RP-130255	181	-	Additional clarifications/corrections for introducing Rel-11 features	11.1.0	11.2.0
11/06/13	RP_60	RP-130752	182	-	Correction to EPDCCH PRB pair indication	11.2.0	11.3.0
11/06/13	RP_60	RP-130752	183	-	CR on collision between EPDCCH and PSS/SSS/PBCH	11.2.0	11.3.0
03/09/13					MCC clean-up	11.3.0	11.4.0
03/09/13	RP_60	RP-131250	185	-	Correction to QCL behaviour on CRS	11.3.0	11.4.0
03/12/13	RP_62	RP-131894	186	-	Correction on the derivation of the non-MBSFN region by PCFICH	11.4.0	11.5.0
03/12/13	RP_62	RP-131896	184	3	Introduction of Rel 12 feature for Downlink MIMO Enhancement	11.5.0	12.0.0
03/03/14	RP_63	RP-140286	187	-	On PMCH starting symbol in an MBSFN subframe	12.0.0	12.1.0
10/06/14	RP_64	RP-140858	189	-	CR on antenna port definitions	12.1.0	12.2.0
10/06/14	RP_64	RP-140858	190	1	Clarification of downlink subframes	12.1.0	12.2.0
10/06/14	RP_64	RP-140862	191	-	Inclusion of eIMTA, TDD-FDD CA, and coverage enhancements	12.1.0	12.2.0
10/09/14	RP_65	RP-141485	192	-	Inclusion of low-cost MTC and 256QAM	12.2.0	12.3.0
10/09/14	RP_65	RP-141477	194	-	CR on port 5 UE-specific reference signal when PDSCH is overlapped with EPDCCH	12.2.0	12.3.0
08/12/14	RP_66	RP-142098	195	3	Clarification of PUSCH rate matching with SRS	12.3.0	12.4.0
08/12/14	RP_66	RP-142106	197	4	Inclusion of small-cell enhancements	12.3.0	12.4.0
09/03/15	RP_67	RP-150366	196	7	Inclusion of ProSe	12.4.0	12.5.0
09/03/15	RP_67	RP-150364	198	-	Correction on 256QAM applicability to PMCH	12.4.0	12.5.0
09/03/15	RP_67	RP-150364	199	-	Correction of discovery signal transmission	12.4.0	12.5.0
15/06/15	RP_68	RP-150935	201	-	Alignment of ProSe parameters	12.5.0	12.6.0
14/09/15	RP_69	RP-151465	203	-	Clarification on SRS BW configuration	12.6.0	12.7.0
07/12/15	RP_70	RP-152036	209	1	Modify max TA for dual connectivity	12.7.0	12.8.0
07/12/15	RP_70	RP-152025	206	2	Introduction of EB/FD-MIMO	12.8.0	13.0.0
07/12/15	RP_70	RP-152027	208	1	Introduction of Rel-13 eCA	12.8.0	13.0.0
07/12/15	RP_70	RP-152125	204	2	eD2D CR for 36.211	12.8.0	13.0.0
07/12/15	RP_70	RP-152258	205	4	Introduction of LAA	12.8.0	13.0.0

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Date	Meeting	TDoc	CR	Rev	Cat	Subject/Comment	New version
2016-03	RAN#71	RP-160359	210	-	F	Alignment eD2D CR for 36.211	13.1.0
2016-03	RAN#71	RP-160367	212	-	F	Clarification on PDSCH collision with PSS/SSS/PBCH	13.1.0
2016-03	RAN#71	RP-160357	213	-	F	Correction on support of CA with up to 32 CCs	13.1.0
2016-03	RAN#71	RP-160357	214	-	F	Correction on PUCCH format 4 and 5	13.1.0
2016-03	RAN#71	RP-160360	217	-	F	Correction on DRS subframe in 36.211	13.1.0
2016-03	RAN#71	RP-160360	218	-	F	Correction on EPDCCH start symbol in LAA	13.1.0
2016-03	RAN#71	RP-160360	219	-	F	Correction to MBSFN subframe configuration	13.1.0
2016-03	RAN#71	RP-160358	220	-	F	CR on CSI-RS configuration for more than eight antenna ports in 36.211	13.1.0
2016-03	RAN#71	RP-160358	221	-	F	CR on mismatch between 36.211 and 36.331	13.1.0
2016-03	RAN#71	RP-160358	222	-	F	Clarification on additional SC-FDMA symbols in UpPTS for SRS	13.1.0
2016-03	RAN#71	RP-160358	223	-	F	Correction on Precoding and definition of DMRS ports	13.1.0
2016-03	RAN#71	RP-160361	207	9	B	Introduction of LC/CE MTC	13.1.0
2016-06	RAN#72	RP-161063	216	2	F	CR on CSI-RS transmission in DwPTS	13.2.0
2016-06	RAN#72	RP-161067	224	8	B	Introduction of NB-IoT	13.2.0
2016-06	RAN#72	RP-161066	229	2	F	Collision between PSS/SSS/PBCH and MPDCCH/PDSCH for MTC	13.2.0
2016-06	RAN#72	RP-161066	230	-	F	DMRS initialization of CSS for MTC	13.2.0
2016-06	RAN#72	RP-161066	231	-	F	Missing words in PRACH starting subframe paragraph for MTC	13.2.0
2016-06	RAN#72	RP-161065	232	-	F	Correction to EPDCCH procedures for LAA FS 3	13.2.0
2016-06	RAN#72	RP-161063	233	-	F	Clarification on PDSCH mapping to resource elements	13.2.0
2016-06	RAN#72	RP-161063	234	-	F	CR on CSI-RS description in TS 36.211	13.2.0
2016-06	RAN#72	RP-161065	235	-	F	Corrections on the support of ending partial subframe in LAA	13.2.0
2016-06	RAN#72	RP-161063	236	-	F	Clarification of CSI-RS on extended CP	13.2.0
2016-06	RAN#72	RP-161063	237	-	F	Correction on description about UpPTS length for preamble format 4 for PRACH	13.2.0
2016-06	RAN#72	RP-161066	238	-	F	Correction to TS 36.211 for eMTC	13.2.0
2016-06	RAN#72	RP-161066	239	-	F	Narrow band hopping	13.2.0
2016-06	RAN#72	RP-161066	240	1	F	CR on MPDCCH format for Rmax=1 and 2/4 PRBs	13.2.0
2016-06	RAN#72	RP-161066	241	1	F	Correction on RE mapping in MBSFN subframe for BL/CE UEs in CEModeB	13.2.0
2016-06	RAN#72	RP-161063	242	-	F	Correction on the description about DMRS	13.2.0
2016-06	RAN#72	RP-161066	243	-	F	CR for TS36.211 related to 2+4 PRB set	13.2.0
2016-06	RAN#72	RP-161065	244	-	F	CR on UE assumptions on number of CRS ports in DRS	13.2.0
2016-06	RAN#72	RP-161066	245	-	F	Some corrections for eMTC	13.2.0
2016-06	RAN#72	RP-161066	247	-	F	Clarification of MPDCCH over empty CRS tones in PBCH repetition	13.2.0
2016-06	RAN#72	RP-161066	248	-	F	Scrambling sequence initialization	13.2.0
2016-06	RAN#72	RP-161066	249	-	F	On MPDCCH AL for 8 EREGs per ECCE in TS 36.211	13.2.0

2016-06	RAN#72	RP-161066	250	-	F	Overriding of valid-invalid subframes for R=1	13.2.0
2016-06	RAN#72	RP-161066	251	-	F	Scrambling Sequence for paging MPDCCH and PDSCH	13.2.0
2016-06	RAN#72	RP-161066	252	-	F	Scrambling sequence initialization for PDSCH	13.2.0
2016-09	RAN#73	RP-161563	253	-	F	Correction on DMRS for NB-IoT in TS 36.211	13.3.0
2016-09	RAN#73	RP-161563	254	1	F	Correction on NPRACH in TS 36.211	13.3.0
2016-09	RAN#73	RP-161563	255	-	F	Correction on SC-FDMA signal generation for NB-IoT in TS 36.211	13.3.0
2016-09	RAN#73	RP-161563	256	-	F	Corrections to RRC parameter names for NB-IoT in TS 36.211	13.3.0
2016-09	RAN#73	RP-161562	259	-	F	MPDCCH search-space with Temporary C-RNTI	13.3.0
2016-09	RAN#73	RP-161563	260	-	F	Correction on NPBCH in TS 36.211	13.3.0
2016-09	RAN#73	RP-161563	261	1	F	Correction on UL collisions in TS 36.211	13.3.0
2016-09	RAN#73	RP-161563	262	1	F	Correction on NPSS mapping in TS 36.211	13.3.0
2016-09	RAN#73	RP-161563	263	1	F	Corrections on the presence of NRS for standalone and guard band operation mode in TS 36.211	13.3.0
2016-09	RAN#73	RP-161561	264	-	F	Correction on the determination of EPDCCH starting position	13.3.0
2016-09	RAN#73	RP-161563	265	-	F	Corrections on NPDCCH scrambling in TS 36.211	13.3.0
2016-09	RAN#73	RP-161562	272	1	F	Frequency hopping for SI and paging messages for BL/CE UE	13.3.0
2016-09	RAN#73	RP-161562	275	-	F	Scrambling of DL DMRS for BL/CE UE	13.3.0
2016-09	RAN#73	RP-161562	276	-	F	Enable cross-subframe channel estimation for BL/CE UE	13.3.0
2016-09	RAN#73	RP-161562	278	-	F	Frequency hopping interval for MPDCCH during random access for BL/CE UE	13.3.0
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