NB-IOT protocol collection

1. NB-IOT 基本概念

- **Improved indoor coverage, support for massive number of low throughput devices, low delay sensitivity, ultra low device cast, low device power consumption**
- **NB-IOT should support 3 different modes of operation：**
  - ✓ 'Stand-alone operation' utilizing for example the spectrum currently being used by GERAN systems as a replacement of one or more GSM carriers, as well as scattered spectrum for potential IoT deployment.
  - ✓ 'Guard band operation' utilizing the unused resource blocks within a LTE carrier's guard-band
  - ✓ 'In-band operation' utilizing resource blocks within a normal LTE carrier

Figure 6 Three deployment scenarios of NB-IoT

- **180kHz UE RF bandwidth for both downlink and uplink**
- **上行支持 15kHz 和 3.75kHz 两种 subcarrier spacing；下行仅支持 15kHz 的 sub-carrier spacing**
  - ✓ 3.75kHz 只支持 single-Tone；可以提供更大的覆盖，CP 较长，对 timing 要求放松了；
  - ✓ 更小的功耗
- **仅支持 type-B half-duplex FDD operation**(type-B 定义参考 3GPP 36.211 R13 chapter6.2.5)

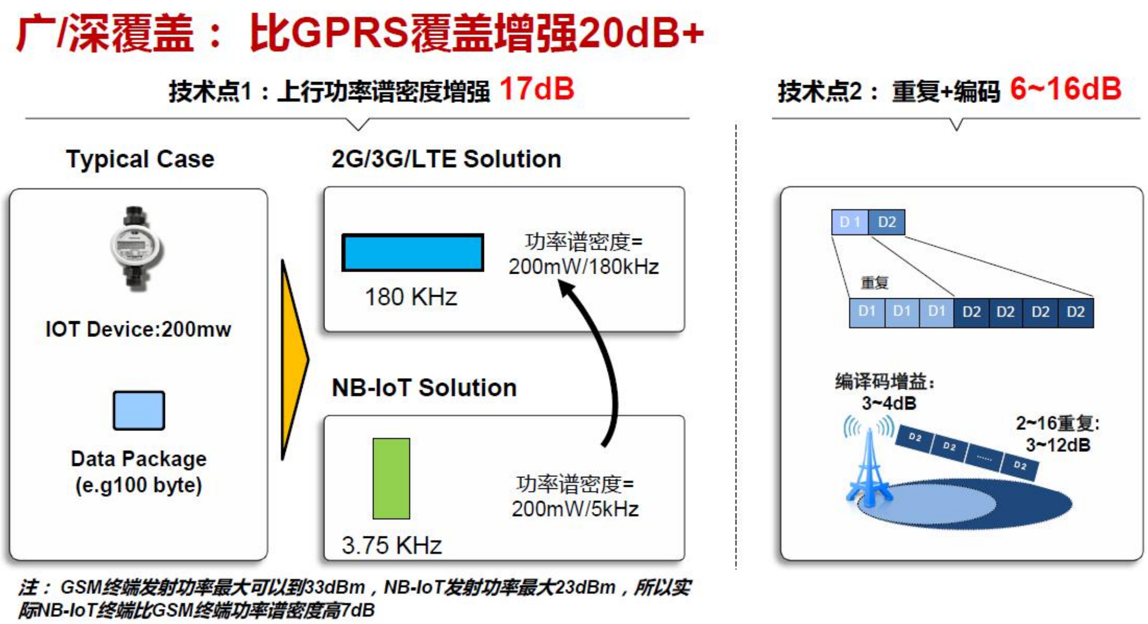
- **NB-IOT vs eMTC vs legacy LTE**

	LTE R9	NB-IoT
系统带宽	1.4M/3M/5M/10M/15M/20M	200kHz
工作模式	full duplex FDD/TDD	half-duplex FDD
最大传输速率	DL: 150Mbps; UL 50Mbps	DL/UL: ＜200kbps
频带部署方式	LTE 授权频段	带内，带外，保护带三种部署方式
覆盖范围(MCL)	~145dB	164dB
子载波间隔	DL/UL: 15kHz	DL: 15kHz, UL: 15kHz or 3.75kHz

传输模式	TM1-TM9	TM1/TM2 (单天线或双天线发送分集)
同步信号	PSS/SSS	NPSS/NSSS，构造以及相对间隔都与 R9 PSS/SSS 不同
随机接入	Preamble/RAR/MSG3/MSG4	NPRACH/NPDSCH
解调信号	DL: CRS UL: DMRS	DL: NRS UL: NDMRS
上下行信道探测	下行 CSI，上行 SRS	没有 CSI，没有 SRS
下行数据信道	PDSCH	NPDSCH
	QPSK, 16QAM, 64QAMP	QPSK
	1/3 turbo coding	1/3 Tail biting convolutional coding
	单子帧传输一个传输块	单个或多个子帧传输一个传输块
下行控制信道	PDCCH	NPDCCH
	和 PDSCH 在同一个子帧， 占用前几个 OS	占用单独的下行子帧，类似于 EPDCCH
	DCI Format 0/1/1A/2/2A/3/3A...	DCI Format N0/N1/N2
上行数据信道	PUSCH	NPUSCH
	15kHz sub-carrier spacing	15kHz or 3.75kHz sub-carrier spacing
	1/3 turbo coding	1/3 turbo coding
	单子帧传输一个传输块	以 Resource Unit(可以跨多个子帧)作为传输块的传输单位
	UL-SCH 和 UCI 在同一个子帧发送	UL-SCH 和 UCI 在不同子帧发送
省电技术	DRX	PSM, eDRX

	Peak data rate UL/DL (bps)	Band	UE Bandwidth	System Bandwidth	Coverage (dB, MCL)	Module cost ($)	Battery life (Years)	Capacity (Devices)
eMTC (R13)	1M	LTE band	1.4MHz	1.4/5/10/20MHz	157.7	8~10?	?	?
NB-IoT (R13) (Standalone)	~100k	G/U/L MSR /dedicated	200kHz	200kHz	164	~5	10+	~200k/cell/200kHz
NB-IoT (R13) (in-band)	~100k	LTE band	180kHz	180kHz	164	~5	10+	~200k/cell/200kHz
NB-IoT (R13) (Guardband)	~100k	LTE band	180kHz	180kHz	164	~5	10+	~200k/cell/200kHz

- ✓ eMTC can only be deployed within LTE system, while NB-IoT has more flexibility as it can be deployed in-band, guard band and standalone.
- ✓ NB-IoT can support up to 200k devices per cell per 200kHz
- ✓ The NB-IoT uplink transmission (3.75kHz, 15kHz) is much more efficient than eMTC wideband uplink transmission
- ✓ NB-IoT has about 6.3dB better coverage than eMTC



In-Band 操作的一些特殊处理？？？

- **Symbols and abbreviations**

$N_{\text{slots}}^{\text{UL}}$ Number of consecutive slots in an UL resource unit for NB-IoT

2. 36.211-d20

2.1 Uplink(10.1)

2.1.1 Uplink Physical channelsand signals(10.1.1.1)

The following narrowband physical channels are defined:

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

The following uplink narrowband physical signals are defined:

- Narrowband demodulation reference signal

Comment: 新增上行信道 NPUSCH 和 NPRACH，新增上行信号 NDMRS；

2.1.2 Uplink slot structure and physical resources(10.1.2.1)

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

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

Comment: 上行有两种时隙结构，一种是针对子载波间隔 15kHz 的，和 legacy LTE 的时隙结构相同；一种是针对子载波间隔 3.75kHz 的，一个 RB 内包含的子载波数是 48，是 legacy LTE 的 4 倍。同时时隙长度是 2ms，是 legacy LTE 的 4 倍。一个无线帧只包含 5 个 Slots。所以一个无线帧仍然是 10ms。

NB-IOT 上行总是使用 p=0 的单天线发送。

2.1.2.1 Uplink resource unit(10.1.2.3)

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

Table 10.1.2.3-1: Supported combinations of $N_{\mathrm{sc}}^{\mathrm{RU}}$, $N_{\mathrm{slots}}^{\mathrm{UL}}$, and $N_{\mathrm{symb}}^{\mathrm{UL}}$.

NPUSCH format	Δf	$N_{\mathrm{sc}}^{\mathrm{RU}}$	$N_{\mathrm{slots}}^{\mathrm{UL}}$	$N_{\mathrm{symb}}^{\mathrm{UL}}$
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	

Comment:NPUSCH 资源分配的基本单位称之为 Resource Unit。一个 Resource Unit 定义为 $N_{\mathrm{symb}}^{\mathrm{UL}} N_{\mathrm{slots}}^{\mathrm{UL}}$ 个连续的 SC-FDMA symbols 以及 $N_{\mathrm{sc}}^{\mathrm{RU}}$ 个连续子载波。

2.1.3 Narrowband physical uplink shared channel(10.1.3)

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

Comment: NPUSCH 包含两种 format，Format 1 用于传输 UL-SCH，Format 2 用于传输 UCI。不存在同时传输 UL-SCH 和 UCI 的 NPUSCH。

2.1.3.1 NPUSCH scrambling(10.1.3.1)

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 reinitialised according to the above formula after every $M_{\text{identical}}^{\text{NPUSCH}}$ transmissions of the codeword with 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.

Comment: NPUSCH 和 legacy PUSCH 一样，在调制之前需要做加扰。由于 NPUSCH 资源映射的单元包含最多 16 个 Slots，因此加扰使用的初始参数需要使用第一个 Slot index。如果 NPUSCH 有重传，那么在重传范围内，每 $M_{\text{identical}}^{\text{NPUSCH}}$ 次传输重新初始化一次扰码，使用该次重传中首个无线帧号和时隙号做初始化。因此在 $M_{\text{identical}}^{\text{NPUSCH}}$ 次重传范围内可以做解调前的数据合并，增加解调信噪比。具体可以参考 4.4

2.1.3.2 NPUSCH modulation(10.1.3.2)

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

2.1.3.3 NPUSCH layer mapping and precoding

Comment: NPUSCH 仅支持单天线发送。

2.1.3.4NPUSCH mapping to physical resources(10.1.3.6)

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.

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

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

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

The mapping of $z(0),\ldots,z(M_{\text{symb}}^{\text{ap}}-1)$ is then repeated until $M_{\text{rep}}^{\text{NPUSCH}} N_{\text{RU}} N_{\text{slots}}^{\text{UL}}$ slots have been transmitted. After transmissions of $256 \cdot 30720 T_s$ time units, a gap of $40 \cdot 30720 T_s$ time unitsshall be inserted where the NPUSCH transmission is postponed.

Comment: NPUSCH 可以映射在 N_{RU} 个资源单位上。一个 Resource unit 表示的是一段时间和载波组成的资源块。其中包含的时间是 $N_{\text{slots}}^{\text{UL}}$ 个 UL Slots， $N_{\text{slots}}^{\text{UL}}$ 根据 NPUSCH format 以及分配的 $N_{\text{sc}}^{\text{RU}}$ 查表，取值范围可以是 2/4/8/16。 N_{RU} 由 DCI format N0 里面的参数查表得到，取值范围是 1~10。 $M_{\text{rep}}^{\text{NPUSCH}}$ 就是 N_{Rep} (16.5 of 3GPP36.213)，取值范围是 1/2/4/8/16/32/64/128。

2.1.4 Demodulation reference signal(10.1.4)

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

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

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

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

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

$$r_u(n) = e^{j\alpha n} e^{j\varphi(n)\pi/4}, \quad 0 \le n < N_{\text{sc}}^{\text{RU}} - 1,$$

Comment: 解调参考信号是与小区 ID : $N_{\text{ID}}^{\text{Ncell}}$ 相关的序列。对于 $N_{\text{sc}}^{\text{RU}}=1$，DMRS 原始序列长度 $N_{\text{rep}}^{\text{NPUSCH}} N_{\text{slots}}^{\text{UL}} N_{\text{RU}}$ 定义为整个 NPUSCH 重传范围内，每个 slot 各一个子载波符号组合在一起的序列。对于 $N_{\text{sc}}^{\text{RU}} > 1$，DMRS 序列是针对一个时隙里面的序列，序列长度就是 $N_{\text{sc}}^{\text{RU}}$ 。

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

Comment: DMRS 根据不同的 NPUSCH format 映射在不同的 symbol 上。在该 symbol 上会映射所有的 subcarriers。

2.1.4 SC-FDMA baseband signal generation

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

Comment: $N_{\mathrm{sc}}^{\mathrm{RU}} > 1$时，IFFT 过程和 PUSCH 的 IFFT 过程相同。

For $N_{\mathrm{sc}}^{\mathrm{RU}} = 1$, 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

$$s_{k,l}(t) = a_{k^{(-)},l} \cdot e^{j\varphi_{k,l}} \cdot e^{j2\pi(k+1/2)\Delta f\left(t - N_{\mathrm{CP},l} T_s\right)}$$
$$k^{(-)} = k + \left\lfloor N_{\mathrm{sc}}^{\mathrm{RB}}/2 \right\rfloor$$

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

$$\varphi_{k,l} = \rho\left(\tilde{l} \bmod 2\right) + \hat{\varphi}_k\left(\tilde{l}\right)$$
$$\rho = \begin{cases} \dfrac{\pi}{2} & \text{for BPSK} \\ \dfrac{\pi}{4} & \text{for QPSK} \end{cases}$$
$$\hat{\varphi}_k\left(\tilde{l}\right) = \begin{cases} 0 & \tilde{l} = 0 \\ \hat{\varphi}_k\left(\tilde{l} - 1\right) + 2\pi\Delta f\left(k + 1/2\right)\left(N + N_{CP,l}\right)T_s & \tilde{l} > 0 \end{cases}$$
$$\tilde{l} = 0,1,\ldots, M_{\mathrm{rep}}^{\mathrm{NPUSCH}} N_{\mathrm{RU}} N_{\mathrm{slots}}^{\mathrm{UL}} N_{\mathrm{symb}}^{\mathrm{UL}} - 1$$
$$l = \tilde{l} \bmod N_{\mathrm{symb}}^{\mathrm{UL}}$$

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

Comment: 对 $N_{\mathrm{sc}}^{\mathrm{RU}} = 1$，每个 symbol 只有一个调制符号，按照上述公式对每一个调制符号做处理之后生成最终的发送符号。每一个 symbol 生成的时域信号仍然会按照 legacy PUSCH 的做法增加 $N_{\mathrm{CP},l}$ 的循环前缀。这个从公式中包含的 $e^{j2\pi(k+1/2)\Delta f\left(t-N_{\mathrm{CP},l}T_s\right)}$ 该项，以及 $0 \le t < \left(N_{\mathrm{CP},l} + N\right)T_s$ 可以推算出来。**注意上述公式中 k 的取值是根据实际分配的子载波位置取一个值就可以了，**因为实际也只分配了一个子载波。而不用按照传统的 IFFT 中不同的 k 旋转累加得到不同时刻的采样信号。

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

Parameter	$\Delta f = 3.75\,\mathrm{kHz}$	$\Delta f = 15\,\mathrm{kHz}$
N	8192	2048
Cyclic prefix length $N_{\mathrm{CP},l}$	256	160 for $l = 0$ 144 for $l = 1,2,\ldots,6$
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 $\sum_{l'=0}^{l-1}(N_{\mathrm{CP},l'} + N)T_{\mathrm{s}}$ within the slot. For $\Delta f = 3.75\ \mathrm{kHz}$, the remaining $2304T_{\mathrm{s}}$ 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.

Comment: 对于 $\Delta f = 15\ \mathrm{kHz}$，每个 symbol 内包含的采样时刻是：$0 \le t < (N_{\mathrm{CP},l} + N)T_{\mathrm{s}}$，一个 slot 包含 7 个 symbol，则累计一个 Slot 包含了 15360 个采样点，合计刚好是 0.5ms。而对于 $\Delta f = 3.75\ \mathrm{kHz}$，采样间隔 Ts 是相同的，每个 symobl 内包含的采样时刻是 $0 \le t < (N_{\mathrm{CP},l} + N)T_{\mathrm{s}}$。根据上表计算得到一个 slot 共 7 个 symbol 的采样点数是(8192+256)*7=59136。而实际定义的 $\Delta f = 3.75\ \mathrm{kHz}$ 格式的 NPUSCH Slot 长度是 2ms，包含 15360*4=61440 个采样点，因此还有 2304 个采样点是空闲的，用作保护间隔。

2.1.6 Narrowband physical random access channel

2.1.6.1 Time and frequency structure(10.1.6.1)

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 5 identical symbols with total length T_{SEQ}. The parameter values are listed in Table 10.1.6.1-1.

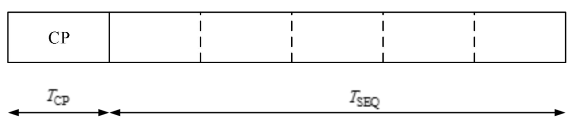


Figure 10.1.6.1-1: Random access symbol group

Table 10.6.1.1-1: Random access preamble parameters

Preamble format	T_{CP}	T_{SEQ}
0	$2048T_{\mathrm{s}}$	$5 \cdot 8192T_{\mathrm{s}}$
1	$8192T_{\mathrm{s}}$	$5 \cdot 8192T_{\mathrm{s}}$

The preamble consisting of 4 symbol groups transmitted without gaps shall be transmitted $N_{\mathrm{rep}}^{\mathrm{NPRACH}}$ times.

Comment: Preamble 信号是一个单子载波，跳频的 symbol groups。每个 symbol group 由 CP 和 5 个完全相同的符号组成。包含两种 preamble format，主要是定义的 CP 长度不同。两种 preamble symbol group 总长度都是 1.x 个子帧长度。Preamble 信号包含连续的 4 个 symbol group，中间没有任何 gap。并且最后的 symbol groups 还会重传 $N_{\mathrm{rep}}^{\mathrm{NPRACH}}$ 次。

注意：**1. Symbol group 之间没有 GAP，并且 symbol group 不是 TTI 的整数倍；2. Symbol groups 之间没有 GAP，并且 symbol group 不是 TTI 的整数倍。**

Suppose:							
Preamble format 1; numRepetitionsPerPreambleAttempt-r13 = n2							
CP	CP	CP	CP	CP	CP	CP	CP
symbol group	symbol group	symbol group	symbol group	symbol group	symbol group	symbol group	symbol group
symbol groups				symbol groups - repetition			
One preamble transmission attemp							

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 sub-carrier allocated to NPRACH $N_{\text{scoffset}}^{\text{NPRACH}}$ (*nprach-SubcarrierOffset*),
- number of sub-carriers allocated to NPRACH $N_{\text{sc}}^{\text{NPRACH}}$ (*nprach-NumSubcarriers*),
- number of NPRACH repetitions per attempt $N_{\text{rep}}^{\text{NPRACH}}$ (*nprach-NumRepetitions*),
- 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-SubcarrierRangeStart*).

Comment: 上述参数都在 NPRACH-ConfigSIB-NB (RadioResourceConfigCommonSIB-NB<-SystemInformationBlockType2-NB)消息里面。

NPRACH transmission can start only $N_{\text{start}}^{\text{NPRACH}} \cdot 30720 T_s$ time units after the start of a radio frame fulfilling $n_f \bmod \left(N_{\text{period}}^{\text{NPRACH}}/10\right) = 0$. After transmissions of $4 \cdot 64 \left(T_{\text{CP}} + T_{\text{SEQ}}\right)$ time units, a gap of $40 \cdot 30720 T_s$ time unitsshall be inserted.

Comment: NPRACH 发送的起始时刻需要满足上述条件，参考下面的示意图。Preamble 连续发送 $4 \cdot 64 \left(T_{\text{CP}} + T_{\text{SEQ}}\right)$时间之后，需要增加 40ms 的 GAP。从该描述可以进一步确认：preamble 的 symbol group 之间，以及 symbol groups(含 4 个 group)之间都不存在 GAP。在发送 preamble 期间，除了起始时刻是根据帧边界对齐的，preamble 发送重传期间已经不考虑帧号和帧边界了。

Valid NPRACH transmission start time

Suppose:

nprach-Periodicity-r13 = ms240; nprach-StartTime-r13 = ms8

SFN	0	1	2	3
TTI	0 5	0 5	0 5	0 5
Preamble	Start of NPrach	repetition of NPRACH........		
SFN	4, 5, 6, ... , 21, 22, 23			
SFN	24	25	26	27
TTI	0 5	0 5	0 5	0 5
Preamble	Start of NPrach	repetition of NPRACH........		
SFN	28, 29, 30, ... , 45, 46, 47			
SFN	48	49	50	51
TTI	0 5	0 5	0 5	0 5
Preamble	Start of NPrach	repetition of NPRACH........		

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

The NPRACH subcarriers are split in two sets of subcarriers, $\{0,1,\ldots,N_{\text{sc}}^{\text{NPRACH}} N_{\text{MSG3}}^{\text{NPRACH}} - 1\}$ and $\{N_{\text{sc}}^{\text{NPRACH}} N_{\text{MSG3}}^{\text{NPRACH}},\ldots,N_{\text{sc}}^{\text{NPRACH}} - 1\}$, 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. Frequency hopping shall be used within the 12 subcarriers, 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 $n_{\text{start}} = N_{\text{scoffset}}^{\text{NPRACH}} + \lfloor n_{\text{init}} / N_{\text{sc}}^{\text{RA}} \rfloor \cdot N_{sc}^{RA}$ and

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

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

$$f(-1) = 0$$

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 $\{0,1,\ldots,N_{\text{sc}}^{\text{NPRACH}} - 1\}$, and the pseudo random sequence $c(n)$ is given by clause 7.2. The pseudo random sequence generator shall be initialised with $c_{\text{init}} = N_{\text{ID}}^{\text{Ncell}}$.

Comment: 一个 preamble 由 4 个 symbol group 组成，然后该 preamble 还会重传 $N_{\text{rep}}^{\text{NPRACH}}$ 次。从上面的公式看，每一个 symbol group 发送的 subcarrier 会跳频(preamble 是单 subcarrier 发送的)，

并且公式中计算某一个 symbol group 跳频后的 subcarrier 所使用的 symbol group index i 可以取值大于等于 4，因此这里应该是把 $N_{\text{rep}}^{\text{NPRACH}}$ 次重传的 symbol group 统一考虑跳频了。

Preamble subcarrier frequency hopping between symbol group								
Suppose:								
N_sc_UL = 48; preamble format 1; nprach-Periodicity = ms240; nprach-StartTime-r13 = ms8;								
nprach-NumSubcarriers = n24; nprach-SubcarrierOffset = n12; nprach-NumRepetitions = n2;								
nprach-SubcarrierRangeStart = 1/3; N_sc_RA = 12; n_init = 16; n_start = 24;								
Suppose : f(0) = 5; f(1) = 3; f(2) = 6; f(3) = 4; f(4) = 1;								
SFN+TTI	Start : SFN = 0, TTI = 8							
preamble	CP	CP	CP	CP	CP	CP	CP	CP
sym group	symbol group	symbol group	symbol group	symbol group	symbol group	symbol group	symbol group	symbol group
subcarrier	28	29	35	34	31	30	24	25
repetition	symbol groups				symbol groups - repetition			

2.1.6.2 Baseband signal generation(10.1.6.2)

The time-continuous random access signal $s(t)$ is defined by

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

where 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], $k_0=-N_{\text{sc}}^{\text{UL}}/2$, $K=\Delta f/\Delta f_{\text{RA}}$, $\Delta f=15\text{ kHz}$ 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 $n_{\text{SC}}^{\text{RA}}$ 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}
0, 1	3.75 kHz

Comment: preamble 是单 subcarrier，子载波间隔是 Δf_{RA} = 3.75kHz 的信号。

2.2 Downlink(10.2)

2.2.1 Physical channels and signals(10.2.1.1 & 10.2.1.2)

The following downlink physical channels are defined:

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

The following downlink physical signals are defined:

- Narrowband reference signal, NRS
- Narrowband synchronization signal

Comment: NB-IoT 定义的下行信道包含 NPDSCH, NPBCH, NPDCCH，下行信号包含 NRS，NSS。

2.2.2 Slot structure and physical resource elements(10.2.2)

NB-IOT 下行时隙格式和资源分配单元定义与 legacy LTE 相同。

2.2.3 Narrowband physical downlink shared channel(10.2.3)

2.2.3.1 NPDSCH scrambling(10.2.3.1)

Scrambling shall be done according to clause 6.3.1. The scrambling sequence generator shall be initialised with $c_{\mathrm{init}} = n_{\mathrm{RNTI}} \cdot 2^{14} + n_f \bmod 2 \cdot 2^{13} + \lfloor n_s/2 \rfloor \cdot 2^9 + N_{\mathrm{ID}}^{\mathrm{Ncell}}$ 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 $\min\left(M_{\mathrm{rep}}^{\mathrm{NPDSCH}}, 4\right)$ 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.

Comment: NPDSCH 的加扰与 legacy LTE 的 PDSCH 加扰类似，扰码序列也是根据 nRNTI, nf, ns, CellID 进行初始化。如果 NPDSCH 配置了重传，那么在重传范围内也存在多个 block，每个 block 最多 4 个子帧。在 block 内使用相同的扰码，这样可以达到解调段在解调前做数据合并。

2.2.3.2 NPDSCH modulation (10.2.3.2)

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

Comment: NPDSCH 仅支持 QPSK 调制。

2.2.3.3 Layer mapping and precoding(10.2.3.3)

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

Comment: NPDSCH 仅支持单天线发送或双天线的发送分集。

2.2.3.4 Mapping to physical resources(10.2.3.4)

NPDSCH can be mapped to one or more than one subframes, N_{SF}, as given by clause 16.4.1.5 of 3GPP TS 36.213 [4], each of which shall be transmitted $M_{\mathrm{rep}}^{\mathrm{NPDSCH}}$ times.

Comment: NPDSCH 资源可以映射在多个下行子帧上(N_{SF})， N_{SF} 取值范围是 1/2/3/4/5/6/8/10，在 DCI format N1/N2 里面指示。映射到 N_{SF} 个子帧的 NPDSCH 还需要在重传 $M_{\mathrm{rep}}^{\mathrm{NPDSCH}}$ 次，$M_{\mathrm{rep}}^{\mathrm{NPDSCH}}$ 的取值范围是 1/2/4/…/2048。如过 NPDSCH 携带的是 SIB1-NB，则重传次数是 4/8/16。

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
- 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].

Comment: NPDSCH 资源映射规则：跳过 NPBCH/NPSS/NSSS 所在子帧；跳过 NRS 资源位置；在 Inband mode 下跳过 CRS 资源位置以及头几个 OS 的 PDCCH 符号。

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 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 NPDSCH carrying BCCH, the $y^{(p)}(0),...,y^{(p)}(M_{\text{symb}}^{\text{ap}}-1)$ is mapped to N_{SF} subframes in sequence and then repeated until $M_{\text{rep}}^{\text{NPDSCH}} N_{\text{SF}}$ subframes have been transmitted.

Comment: NPDSCH 的重传，针对是否携带 BCCH 的处理是不同的。如果当前 NPDSCH 没有携带 BCCH，则在 NPDSCH 数据映射一个子帧之后(NPDSCH 数据量超过一个子帧)，立即对该子帧重传若干次；然后再将 NPDSCH 后续数据映射下一个子帧，直到数据映射和重传总子帧数达到 $M_{\text{rep}}^{\text{NPDSCH}} N_{\text{SF}}$。而对于携带 BCCH 的 NPDSCH，则先将 NPDSCH 数据完全映射到 N_{SF} 个子帧之后，再统一重传 $M_{\text{rep}}^{\text{NPDSCH}}$ 次，直到总的映射和重传子帧数达到 $M_{\text{rep}}^{\text{NPDSCH}} N_{\text{SF}}$。

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 dlGap-Threshold and $R_{\max}$ is given by [4]. The gap starting frame and subframe is given by $\left(10n_f + \lfloor n_s/2 \rfloor\right) \bmod N_{\text{gap,period}} = 0$ where the gap periodicity, $N_{\text{gap,period}}$, is given by the higher layer parameter dlGap-Periodicity. 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 dlGap-DurationCoeff. For NPDSCH carrying the BCCH there are no gaps in the transmission.

Comment:NPDSCH 传输可以配置 GAP，也就是传输一段时间之后暂停若干子帧。$R_{\max}$ 根据检测的 NPDCCH search space type，可以是 npdcch-NumRepetitions-r13(For NPDCCH UE-specific search space)/npdcch-NumRepetitionPaging-r13(For Type1-NPDCCH common search space)/npdcch-NumRepetitions-RA-r13(For type2-NPDCCH common search space)。$R_{\max}$ 取值范围是 1/2/4/8/16/32/64/128/256/512/1024/2048。dl-GapThreshold-r13 在 DL-GapConfig-NB 消息里配置，取值范围是 32/64/128/256。当 $R_{\max} < N_{\text{gap,threshold}}$ 时，NPDSCH 传输中间没有 GAP。GAP 的起始时刻以及 GAP 持续时间，都根据 DL-GapConfig-NB 里面的参数计算。

问题：NPDSCH 传输之间的 GAP 有什么作用？

The UE shall not expect NPDSCH in subframe i if it is not a NB-IoT downlinksubframe, except for transmissions of NPDSCH carrying SystemInformationBlockType1-NB in subframe 4. 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.

2.2.4 Narrowband physical broadcast channel(10.2.4)

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

Comment: Legacy LTE 的 PBCH 扰码在 $n_{\text{f}} \bmod 4 = 0$ 无线帧做初始化，NPBCH 的扰码则在满足 $n_{\text{f}} \bmod 64 = 0$ 的无线帧做初始化。

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

Comment: NPBCH 固定使用 QPSK 调制。

Layer mapping and precoding shall be done according to clause 6.6.3 with $P \in \{1,2\}$. The UE shall assume antenna ports R_{1000} and R_{1001} are used for the transmission of the narrowband physical broadcast channel.

Comment: NPBCH 固定使用单天线或双天线发送分集。

The block of complex-valued symbols $y^{(p)}(0),\ldots,y^{(p)}(M_{\text{symb}}-1)$ for each antenna port is transmitted in subframe 0 during 64 consecutive radio frames starting in each radio frame fulfilling $n_{\text{f}} \bmod 64 = 0$ and shall be mapped in sequence starting with $y(0)$ 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. After mapping to a subframe, the subframe shall be repeated in subframe 0 in the 7 following radio frames, before continuing the mapping of $y^{(p)}(\cdot)$ to subframe 0 in the following radio frame. 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 0 and 1 being present irrespective of the actual configuration. The frequency shift of the cell-specific reference signals shall be calculated by replacing $N_{\mathrm{ID}}^{\mathrm{cell}}$ with $N_{\mathrm{ID}}^{\mathrm{Ncell}}$ in the calculation of v_{shift} in clause 6.10.1.2.

Comment: 从满足 $n_{\mathrm{f}} \bmod 64 = 0$ 的无线帧的子帧 0 开始 NPBCH 资源映射，映射的时候跳过 NRS 资源。在映射第一个子帧之后在接下来的 7 个无线帧的子帧 0 上都重复该子帧 0 的内容。然后再第 8 个无线帧的子帧 0 映射 NPBCH 接下来的资源，直到映射满 64 个无线帧的子帧 0。

NPBCH resource mapping								
SFN	0	1	2	3	4	5	6	7
TTI	0	0	0	0	0	0	0	0
	1st part of NPBCH	repetition	repetition	repetition	repetition	repetition	repetition	repetition
SFN	8	9	10	11	12	13	14	15
TTI	0	0	0	0	0	0	0	0
	2nd part of NPBCH	repetition	repetition	repetition	repetition	repetition	repetition	repetition
SFN	16	17	18	19	20	21	22	23
TTI	0	0	0	0	0	0	0	0
	3rd part of NPBCH	repetition	repetition	repetition	repetition	repetition	repetition	repetition
SFN	24	25	26	27	28	29	30	31
TTI	0	0	0	0	0	0	0	0
	4th part of NPBCH	repetition	repetition	repetition	repetition	repetition	repetition	repetition
SFN	32	33	34	35	36	37	38	39
TTI	0	0	0	0	0	0	0	0
	5th part of NPBCH	repetition	repetition	repetition	repetition	repetition	repetition	repetition
SFN	40	41	42	43	44	45	46	47
TTI	0	0	0	0	0	0	0	0
	6th part of NPBCH	repetition	repetition	repetition	repetition	repetition	repetition	repetition
SFN	48	49	50	51	52	53	54	55
TTI	0	0	0	0	0	0	0	0
	7th part of NPBCH	repetition	repetition	repetition	repetition	repetition	repetition	repetition
SFN	56	57	58	59	60	61	62	63
TTI	0	0	0	0	0	0	0	0
	8th part of NPBCH	repetition	repetition	repetition	repetition	repetition	repetition	repetition

2.2.5 Narrowband physical downlink control channel(10.2.5)

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

Comment: NPDCCH 支持两种 format，对应 aggregation level1 or 2。在一个子帧里面可以包含两个 NCCE，NCCE 0 占用 subcarrier 0~5， NCCE 1 占用 subcarrier 6~11。在同一个子帧里可以支持 1 或 2 个 NPDCCH 同时传输。

Scrambling shall be done according to clause 6.6.1. The scrambling sequence shall be initialised at the start of the search space 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 for NPDCCH transmission after the initialisation.

Comment: 每 4 个 NPDCCH 子帧之后对扰码尽心初始化。

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

Comment: NPDCCH 固定使用 QPSK 调制方式。

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

Comment: NPDCCH 使用单天线发送或双天线发送分集。

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 assigned for the NPDCCH transmission, and
- they are not used for transmission of NPBCH, NPSS, or NSSS , and
- they are assumed by the UE not to be used for NRS, and
- they are not overlapping with resource elements used for PBCH, PSS, SSS, or 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].

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.

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 downlinksubframe. 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.

Comment: NPDCCH 资源映射规则：映射到相应的 NCCE 上；非 NPBCH/NPSS/NSSS 资源；非 NRS 资源；若工作在 Inband 模式，还需避开 PBCH/PSS/SSS/CRS 资源位置，避开前几个 OS 的 PDCCH 符号 $l \geq l_{\text{NPDCCHStart}}$。

可以配置在 NPDCCH 传输期间的 GAP，GAP 起始时刻以及持续长度的计算方法类似 NPDSCH 的 GAP。

2.2.6 Narrowband reference signal (NRS)(10.2.6)

The UE may assume narrowband reference signals are transmitted in all NB-IoT downlink subframes in a cell supporting NPDSCH transmission. The UE shall not expect narrowband reference signals in subframes that are not NB-IoT downlink subframes, except if these subframes contain NPBCH or NPDSCH carrying SystemInformationBlockType1-NB where narrowband reference signals shall be transmitted.

A UE without a NB-IoT downlink subframes configuration may assume narrowband reference signals are transmitted in subframes #0 and #4 and in subframes #9 not containing NSSS.

Comment: 在所有支持 NPDSCH 传输的下行子帧上都有 NRS 发送。在 NPBCH 或携带 SIB1-NB 的 PDSCH 子帧(可能是非 NB-IoT 下行子帧)上，也需要发送 NRS。如果高层没有 NB-IoT 下行子帧配置，那么在子帧 0/4 以及不是用于传输 NSSS 的子帧 9 上默认要传输 NRS。

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

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 .

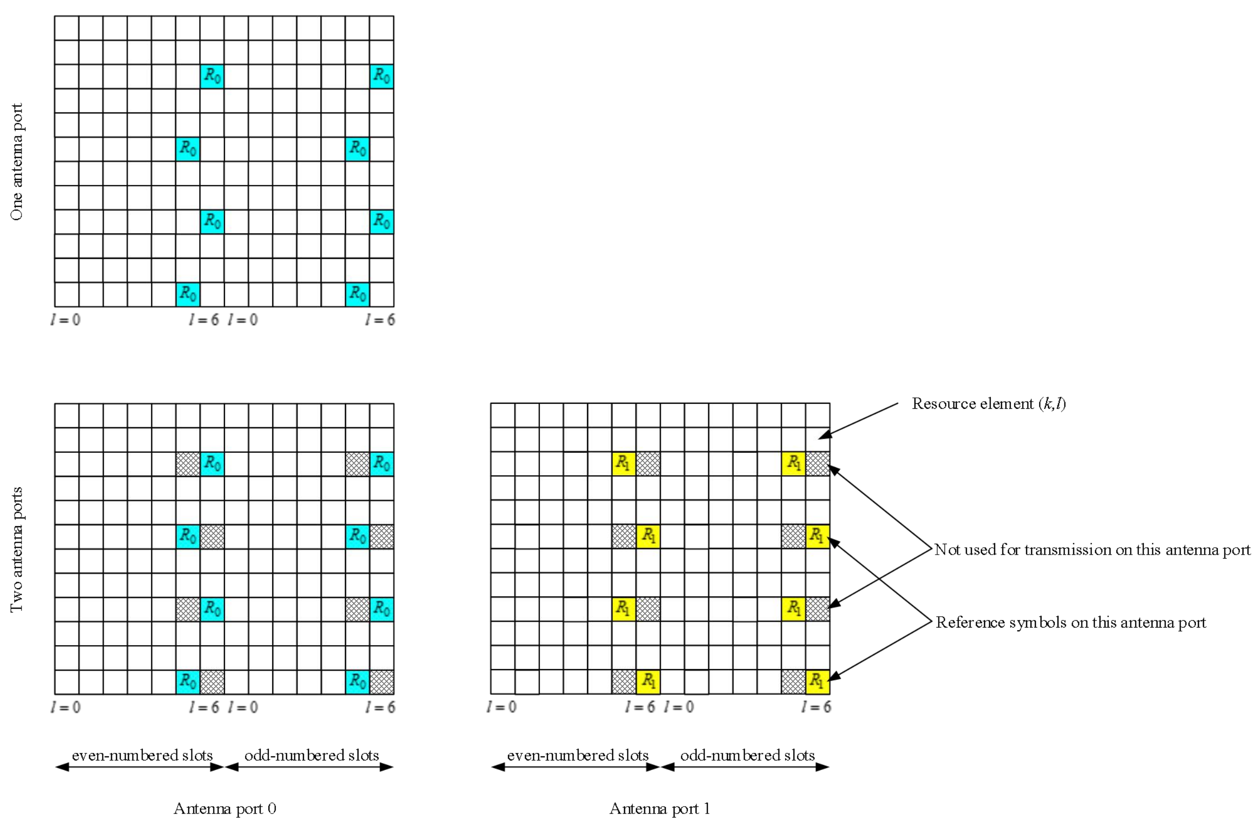


Figure 10.2.6.2-1. Mapping of downlink narrowband reference signals (normal cyclic prefix, *operationModeInfo* indicates ‘00’)

Comment: NRS 发送资源分配图。

2.2.7 Synchronization signals(10.2.7)

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

Comment: NB-IoT 系统有 504 个不同的 Cell ID，CellID 完全在 NSSS 信号里面携带。

2.2.7.1 Narrowband primary synchronization signal (NPSS)

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

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

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

Comment: NPSS 序列是一个固定内容的 ZC 序列，其中不包含 Cell ID 信息。因此 NPSS 只能用于时间同步。

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 sequence $d_l(n)$ shall be mapped to resource elements (k,l) in increasing order of first the index $k = 0,1,\ldots,N_{\text{sc}}^{\text{RB}} - 2$ and then the index $l = 3,4,\ldots,N_{\text{symb}}^{\text{DL}} - 1$ 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.

Comment: 在一个子帧内不同符号的 NPSS 使用同一个天线端口；UE 不能假定 NPSS 使用和 NRS 相同的某一个天线端口（一定是使用其中的一个，但不能默认是某一个）；某一个子帧的 NPSS 和另一个子帧的 NPSS 使用的天线端口可以不同。

NPSS 映射在每个无线帧的子帧 5 上，每个子帧上映射从符号 3 到符号 13，每个符号映射 11 个子载波。

如果 NPSS 映射的 RE 与 CRS 冲突，则该 RE 不发送 NPSS，但 NPSS 资源不减少。

Note:采用 11 长度的短 ZC 序列是为了抗大频偏的问题。（如何理解？？？）

2.2.7.2 Narrowband secondary synchronization signal (NSSS)

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

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

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

$$\theta_f = \frac{33}{132}(n_f/2) \bmod 4 .$$

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

q	$b_q(0),\ldots,b_q(127)$
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]

Comment: NSSS 序列包含完整的 Cell ID 信息，序列长度是 132 个符号。

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

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.

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 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.

Comment: 在一个子帧内不同符号的 NSSS 使用同一个天线端口；UE 不能假定 NSSS 使用和 NRS 相同的某一个天线端口（一定是使用其中的一个，但不能默认是某一个）；某一个子帧的 NSSS 和另一个子帧的 NSSS 使用的天线端口可以不同。

NSSS 映射在每个偶数无线帧的子帧 9 的最后 11 个符号上，每个符号上映射 12 个子载波，因此总共的的序列长度是 132.

NSSS 映射资源和 CRS 冲突时，NSSS 不发送，但 NSSS 资源不较少。

NPSS/NSSS/NPBCH 映射位置描述如下图所示：

NPSS/NSSS/NPBCH 映射位置说明										
0	NPBCH					NPSS				NSSS
1	NPBCH					NPSS				
2	NPBCH					NPSS				NSSS
3	NPBCH					NPSS				
4	NPBCH					NPSS				NSSS
5	NPBCH					NPSS				
6	NPBCH					NPSS				NSSS
7	NPBCH					NPSS				
8	NPBCH					NPSS				NSSS
9	NPBCH					NPSS				
10	NPBCH					NPSS				NSSS
11	NPBCH					NPSS				
12	NPBCH					NPSS				NSSS
13	NPBCH					NPSS				
14	NPBCH					NPSS				NSSS
15	NPBCH					NPSS				
16	NPBCH					NPSS				NSSS
17	NPBCH					NPSS				
18	NPBCH					NPSS				NSSS
19	NPBCH					NPSS				
20	NPBCH					NPSS				NSSS
21	NPBCH					NPSS				
22	NPBCH					NPSS				NSSS
23	NPBCH					NPSS				
24	NPBCH					NPSS				NSSS
25	NPBCH					NPSS				
26	NPBCH					NPSS				NSSS
27	NPBCH					NPSS				
28	NPBCH					NPSS				NSSS
29	NPBCH					NPSS				
30	NPBCH					NPSS				NSSS
31	NPBCH					NPSS				
32	NPBCH					NPSS				NSSS
33	NPBCH					NPSS				
34	NPBCH					NPSS				NSSS
35	NPBCH					NPSS				
36	NPBCH					NPSS				NSSS
37	NPBCH					NPSS				
38	NPBCH					NPSS				NSSS
39	NPBCH					NPSS				
40	NPBCH					NPSS				NSSS
41	NPBCH					NPSS				
42	NPBCH					NPSS				NSSS
43	NPBCH					NPSS				
44	NPBCH					NPSS				NSSS
45	NPBCH					NPSS				
46	NPBCH					NPSS				NSSS
47	NPBCH					NPSS				
48	NPBCH					NPSS				NSSS
49	NPBCH					NPSS				
50	NPBCH					NPSS				NSSS
51	NPBCH					NPSS				
52	NPBCH					NPSS				NSSS
53	NPBCH					NPSS				
54	NPBCH					NPSS				NSSS
55	NPBCH					NPSS				
56	NPBCH					NPSS				NSSS
57	NPBCH					NPSS				
58	NPBCH					NPSS				NSSS
59	NPBCH					NPSS				
60	NPBCH					NPSS				NSSS
61	NPBCH					NPSS				
62	NPBCH					NPSS				NSSS
63	NPBCH					NPSS				

2.2.8 OFDM baseband signal generation(10.2.8)

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

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

for $0\le t<(N_{CP,l}+N)\times T_s$ 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.

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

Comment: NB-IoT 下行 OFDM 信号的生成与 legacy LTE 下行 OFDM 信号生成方式相同，只是没有跳过 DC 的处理。NB-IoT 仅支持 normal CP。

3. 36.212-d20

3.1 Mapping to physical channels(6.1)

For Narrowband IoT, transport channels are mapped onto narrowband physical channels, the channel coding, multiplexing, and interleaving of which are specified in sections 6.3 and 6.4 for the uplink and downlink, respectively. Table 6.1-1 specifies the mapping of the uplink transport channels to their corresponding physical channels. Table 6.1-2 specifies the mapping of the downlink transport channels to their corresponding physical channels.Table 6.1-3 specifies the mapping of control channel information to its corresponding physical channel.

Table 6.1-1

TrCH	Physical Channel
UL-SCH	NPUSCH (format 1)
RACH	NPRACH

Table 6.1-2

TrCH	Physical Channel
DL-SCH	NPDSCH
BCH	NPBCH
PCH	NPDSCH

Table 6.1-3

Control information	Physical Channel
UCI	NPUSCH (format 2)
DCI	NPDCCH

Comment: NB-IoT 相关的传输信道到物理信道的映射如上表所示。

3.2 Generic procedures(6.2)

The generic procedures for channel coding, multiplexing and interleaving are as in section 5.1 unless otherwise noted in section 6.

Usage of coding scheme and coding rate for the different types of TrCH is shown in table 6.2-1. Usage of coding scheme and coding rate for the different control information types is shown in table 6.2-2.

Table 6.2-1: Usage of channel coding scheme and coding rate for TrCHs.

TrCH	Coding scheme	Coding rate
UL-SCH	Turbo coding	1/3
BCH	Tail biting convolutional coding	1/3
DL-SCH		
PCH		

Table 6.2-2: Usage of channel coding scheme and coding rate for control information.

Control Information	Coding scheme	Coding rate
DCI	Tail biting convolutional coding	1/3
UCI	Block code	1/16

Comment: 不同传输信道以及控制信号的编码方式如上表所示。

3.3 Uplink transport channels and control information(6.3)

3.3.1 Uplink shared channel(6.3.2)

The CRC attachment, channel coding, and rate matching are performed according to sections 5.2.2.1, 5.2.2.3, and 5.2.2.4, respectively, with the following differences:

- In section 5.1.4.1.2 in the calculation of G' , Q_m is 1 for π/2-BPSK and 2 for π/4-QPSK, and rv_{idx} = 0 or 2.

In addition, after rate matching interleaving is applied per resource unit according to sections 5.2.2.7 and 5.2.2.8 without any control information in order to apply a time-first rather than frequency-first mapping, where the input sequence to 5.2.2.7 is the portion of e for a resource unit instead off,and where $C_{mux} = \left(N_{\text{symb}}^{\text{UL}} - 1\right) N_{\text{slots}}^{\text{UL}}$ is the number of SC-FDMA symbols for NPUSCH in a UL resource unit as given in section 10.1.2.3 of [2].

Comment:NPUSCH 的 CRC, channel coding, rate matching 的处理和 PUSCH 的处理相同，只是在 RM 的时候参数 Q_m 和 rv_{idx} 的设置有区别。在 rate matching 之后的 channel interleaver 过程中，按照先时域后频域的方式映射资源，而不是按照 PUSCH 的 inteleaver 过程中的先频域后时域映射。并且交织数据要映射的时域长度按照当前 NPUSCH 的 resource unit 格式，包含的 slots 数是不同的。

3.3.2Uplink control information on NPUSCH without UL-SCH data(6.3.3)

3.1 DCI FormatN0(6.4.3.1)

DCI format N0 is used for the scheduling of NPUSCH in one UL cell.

The following information is transmitted by means of the DCI format N0:

- Flag for format N0/format N1 differentiation – 1 bit, where value 0 indicates format N0 and value 1 indicates format N1

- Subcarrier indication – 6 bits as defined in section 16.5.1.1 of [3]

Table 16.5.1.1-1: Allocated subcarriers for NPUSCH with $\Delta f = 15\,\text{kHz}$.

Subcarrier indication field(I_{sc})	Set of Allocated subcarriers (n_{sc})
0 – 11	I_{sc}
12-15	$3(I_{sc}-12)+\{0,1,2\}$
16-17	$6(I_{sc}-16)+\{0,1,2,3,4,5\}$
18	$\{0,1,2,3,4,5,6,7,8,9,10,11\}$
19-63	Reserved

Comment: 根据查表得到指定的子载波；可以是指定的某 1 个子载波，3 个子载波，6 个子载波或 12 个子载波。

- Resource assignment – 3bits as defined in section 16.5.1.2 of [3]

Table 16.5.1.1-2: Number of resource units (N_{RU}) for NPUSCH.

I_{RU}	N_{RU}
0	1
1	2
2	3
3	4
4	5
5	6
6	8
7	10

Comment: 根据上表查得 N_{RU}，表示的是 NPUSCH 映射资源占用的 $N_{\text{slots}}^{\text{UL}}$ 个数。一个 NPUSCH 在资源映射(rate matching)时需要计算的资源个数是 N_{RU} * $N_{\text{slots}}^{\text{UL}}$ 个 UL slots，以及 n_{sc} 个子载波。

- Scheduling delay – 2 bits as defined in section 16.5.1 of [3]

Table 16.5.1-1: k_0 for DCI format N0.

I_{Delay}	k_0
0	8
1	16
2	32
3	64

Comment: 表示在收到 DCI N0 的最后一个子帧之后，k_0 个下行子帧之后开始 NPUSCH 发送。

- Modulation and coding scheme– 4bits as defined in section 16.5.1.2 of [3]

Table 16.5.1.2-1: Modulation and TBS index table for NPUSCH with $N_{sc}^{RU}=1$.

MCS Index I_{MCS}	Modulation Order Q_m	TBS Index I_{TBS}
0	1	0
1	1	2
2	2	1
3	2	3
4	2	4
5	2	5
6	2	6
7	2	7
8	2	8
9	2	9
10	2	10

Comment: 若 $N_{sc}^{RU}>1$，则 UE 固定调制方式 QPSK。否则查询上表。

- Redundancy version – 1 bit as defined in section 16.5.1.2 of [3]
- Repetition number– 3bits as defined in section 16.5.1.2 of [3]
- New data indicator – 1 bit
- DCI subframe repetition number – 2 bits as defined in section 16.6 in [3]

4. 36.213-d20

4.1 Synchronization procedures(16.1)

Cell search is the procedure by which a UE acquires time and frequency synchronization with a cell and detects the narrowband physical layer Cell ID.

If the higher layer parameter *operationModeInfo* indicates '00' for a cell, the UE may assume that the narrowband physical layer cell ID is same as the physical layer cell ID for the cell.

The following signals are transmitted in the downlink to facilitate cell search for Narrowband IoT: the narrowband primary and narrowband secondary synchronization signals.

Comment: 如果 *operationModeInfo* 配置为'00'(*Inband-SamePCI* :indicates an in-band deployment and that the NB-IoT and LTE cell share the same physical cell id and have the same number of NRS and CRS ports)，则 NB Cell ID 和 legacy Cell ID 相同。

4.2 Random access procedure(16.3)

4.3 Narrowband physical downlink shared channel related procedures(16.4)

4.3.1 UE procedure for receiving the narrowband physical downlink shared channel(16.4.1)

A NB-IoT UE shall assume a subframe as a valid NB-IoT DL subframe if

- the UE determines that the subframe does not contain NPSS/NSSS/NPBCH/NB-SIB1 transmission, and
- the subframe is indicated as NB-IoT DL subframe by the higher layer parameter *downlinkBitmapNB*, if the UE is configured with the higher layer parameter *downlinkBitmapNB*.

Comment: NB-IoT 有效的下行子帧包含：非 NPSS/NSSS/NPBCH/NB-SIB1 子帧；SIB1-NB 中携带的参数 *downlinkBitmapNB* 中指定的下行子帧。

A UE shall upon detection on a given serving cell of a NPDCCH with DCI format N1, N2 ending in subframe n intended for the UE, decode, starting in $n+5$ DL subframe, the corresponding NPDSCH transmission in N consecutive NB-IoT DL subframe(s) k_i with $i = 0, 1, \ldots, N-1$ according to the NPDCCH information, where

- subframe n is the last subframe in which the NPDCCH is transmitted and is determined from the starting subframe of NPDCCH transmission and the DCI subframe repetition number field in the corresponding DCI;
- subframe(s) k_i with $i=0,1,\ldots,N-1$ are N consecutive NB-IoT DL subframe(s) excluding subframes used for SI messages where, $0<k_0<k_1<\ldots,k_{N-1}$,
- $N = N_{\text{Rep}} N_{\text{SF}}$, where the value of N_{Rep} is determined by the repetition number field in the corresponding DCI (see subclause 16.4.1.3), and the value of N_{SF} is determined by the resource assignment field in the corresponding DCI (see subclause 16.4.1.3), and
- the value of k_0 is determined by the scheduling delay field (I_{Delay}) for DCI format N1 according to Table 16.4.1-1, and $k_0 = 5$ for DCI format N2. The value of $R_{\max}$ is according to subclause 16.6 for the corresponding DCI format N1.

Table 16.4.1-1: k_0 for DCI format N1.

I_{Delay}	k_0	
	$R_{\max} < 128$	$R_{\max} \geq 128$
0	0	0
1	4	16
2	8	32
3	12	64
4	16	128
5	32	256
6	64	512
7	128	1024

A UE is not expected to receive transmissions in 3 DL subframes following the end of a NPUSCH transmission by the UE.

Comment: UE 在收到 NPDCCH DCI format N1/N2 之后的第 5 个下行子帧开始接收 NPDSCH。需要接收连续 N 个子帧的 NPDSCH， $N = N_{\text{Rep}} N_{\text{SF}}$ 。 N_{Rep} 和 N_{SF} 都在 DCI N1/N2 里面携带。 N_{Rep} 取值范围是 1/2/4/…/1536/2048。 N_{SF} 取值范围是 1/2/3/4/5/6/8/10。

4.3.1.1 NPDSCH starting position(16.4.1.4)

The starting OFDM symbol for NPDSCH is given by index $l_{\text{DataStart}}$ in the first slot in a subframe k and is determined as follows

- if subframe k is a subframe used for receiving SIB1-NB
  - $l_{\text{DataStart}} = 3$ if the value of the higher layer parameter *operationModeInfo* is set to '00' or '01'
  - $l_{\text{DataStart}} = 0$ otherwise
- else
  - $l_{\text{DataStart}}$ is given by the higher layer parameter *eutraControlRegionSize* if the value of the higher layer parameter *operationModeInfo* is set to '00' or '01'
  - $l_{\text{DataStart}} = 0$ otherwise

Comment: *operationModeInfo* = '00' or '01'表示的是 in-Band mode，此时每个子帧的前几个 OS 被用于 legacy LTE 的 PDCCH 传输，因此需要跳过。其他两种模式(guardband, standalone)下， $l_{\text{DataStart}} = 0$ 。

4.4 Narrowband physical uplink shared channel related procedures(16.5)

A UE shall upon detection on a given serving cell of a NPDCCH with DCI format N0 ending in NB-IoT DL subframe *n* intended for the UE, adjust, at the end of$n+k_0$ DL subframe, the corresponding NPUSCH transmission using NPUSCH format 1 in *N* consecutive NB-IoT UL slots n_i with $i = 0, 1, \ldots, N-1$ according to the NPDCCH information where

- subframe *n* is the last subframe in which the NPDCCH is transmitted and is determined from the starting subframe of NPDCCH transmission and the DCI subframe repetition number field in the corresponding DCI; and
- $N = N_{\text{Rep}} N_{\text{RU}} N_{\text{slots}}^{UL}$, where the value of N_{Rep} is determined by the repetition numberfield in the corresponding DCI (see subclause 16.5.1.1), the value of N_{RU} is determined by the resource assignmentfield in the corresponding DCI (see subclause 16.5.1.1), and the value of N_{slots}^{UL} is the number of NB-IoT UL slots of the resource unit (defined in clause 10.1.2.3 of [3]) corresponding to the allocated number of subcarriers (as determined in subclause 16.5.1.1) in the corresponding DCI,
- value of k_0 is determined by the scheduling delayfield (I_{Delay}) in the corresponding DCI according to Table 16.5.1-1.

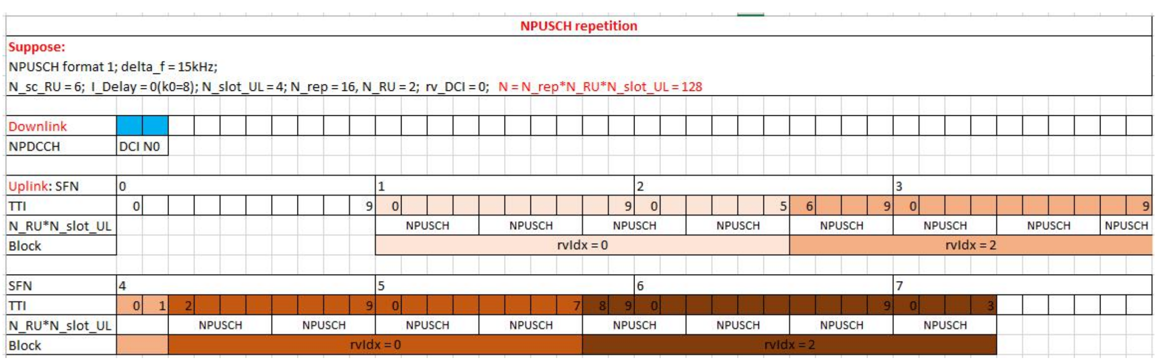
Table 16.5.1-1: k_0 for DCI format N0.

I_{Delay}	k_0
0	8
1	16
2	32
3	64

Comment: UE 在 NPDCCH 上检测到 DCI format N0 之后，在 k0 个下行子帧之后发送 NPUSCH，NPUSCH 发送连续 N 个 NB-IoT UL slots。$N = N_{\mathrm{Rep}} N_{\mathrm{RU}} N_{\mathrm{slots}}^{UL}$， N_{Rep} 和 N_{RU} 都在 DCI format N0 里面携带， N_{RU} 取值范围是 1~10， N_{Rep} 取值范围是 1/2/4/8/16/32/64/128。k_0 根据 DCI 里面的 I_{Delay} 查表得到。k_0 取值可以是 8/16/32/64。

NPUSCH is transmitted in N consecutive NB-IoT UL slots, n_i ,$i=0,1,\ldots,N-1$. The redundancy version $rv_{\mathrm{idx}}(j)$ of the NPUSCH transmission in j^{th} block of B consecutive NB-IoT UL slots n_i, $i = jB + b,\ b = 0,1,\ldots,B-1,\ j = 0,1,\ldots,\frac{N_{\mathrm{Rep}}}{L} - 1,\quad B = LN_{\mathrm{RU}} N_{\mathrm{slots}}^{UL}$ is determined by, $rv_{\mathrm{idx}}(j) = 2 \cdot \mathrm{mod}\left(rv_{\mathrm{DCI}} + j, 2\right)$, where $L = 1$ if $N_{\mathrm{sc}}^{\mathrm{RU}} = 1$, $L = \min\left(4, \left\lceil N_{\mathrm{Rep}} / 2 \right\rceil\right)$ otherwise. Portion of NPUSCH codeword with $rv_{\mathrm{idx}}(j)$ as defined in clause 6.3.2 in [4] mapped to slot $\left\lfloor \frac{b}{L} \right\rfloor$ of allocated N_{RU} resource unit(s) is transmitted in NB-IoT UL slots n_i $i = jB + L\left\lfloor \frac{b}{L} \right\rfloor + l,\ l = 0,1,\ldots,L-1$. for $\Delta f = 3.75kHz$ and $i = jB + 2L\left\lfloor \frac{b}{2L} \right\rfloor + 2l + \mathrm{mod}(\left\lfloor \frac{b}{L} \right\rfloor,\ \ 2), l = 0,1,\ldots L-1$ for $\Delta f = 15kHz$

Comment: NPUSCH 总共传输时间是 $N = N_{\mathrm{Rep}} N_{\mathrm{RU}} N_{\mathrm{slots}}^{UL}$； $N_{\mathrm{RU}} N_{\mathrm{slots}}^{UL}$ 是本次 NPUSCH 的资源映射单位，映射全部 NPUSCH 的符号。 N_{Rep} 是 NPUSCH 资源重复的次数。但是 N_{Rep} 会划分成多个长度为 L 的 block，每个 block 内会使用相同的 rvIdx 和扰码，用于数据解调前的合并。



4.5 Narrowband physical downlink control channel related procedures(16.6)

A UE shall monitor a set of NPDCCH candidates (described in subclause 10.2.2.1 of [3]) as configured by higher layer signalling for control information, where monitoring implies attempting to decode each of the NPDCCHs in the set according to all the monitored DCI formats.

The set of NPDCCH candidates to monitor are defined in terms of NPDCCH search spaces.

The UE shall monitor one or more of the following search spaces

- a Type1-NPDCCH common search space,
- a Type2-NPDCCH common search space, and
- a NPDCCH UE-specific search space.

A UE is not required to simultaneously monitor a NPDCCH UE-specific search space and a Type-1-NPDCCH common search space.

A UE is not required to simultaneously monitor a NPDCCH UE-specific search space and a Type2-NPDCCH common search space.

A UE is not required to simultaneously monitor a Type-1-NPDCCH common search space and a Type2-NPDCCH common search space.

Comment:

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5.1 NB-IoT Message definitions

5.1.1 MasterInformationBlock-NB

The *MasterInformationBlock-NB*includes the system information transmitted on BCH.

Signalling radio bearer: N/A

RLC-SAP: TM

Logical channel: BCCH

Direction: E-UTRAN to UE

MasterInformationBlock-NB

```
-- ASN1START

MasterInformationBlock-NB ::=   SEQUENCE {
    systemFrameNumber-MSB-r13       BIT STRING (SIZE (4)),
    hyperSFN-LSB-r13                BIT STRING (SIZE (2)),
    schedulingInfoSIB1-r13          INTEGER (0..15),
    systemInfoValueTag-r13          INTEGER (0..31),
    ab-Enabled-r13                  BOOLEAN,
    operationModeInfo-r13           CHOICE {
        inband-SamePCI-r13              Inband-SamePCI-NB-r13,
        inband-DifferentPCI-r13         Inband-DifferentPCI-NB-r13,
        guardband-r13                   Guardband-NB-r13,
        standalone-r13                  Standalone-NB-r13
    },
    spare                           BIT STRING (SIZE (11))
}
```

```
ChannelRasterOffset-NB-r13 ::= ENUMERATED {khz-7dot5, khz-2dot5, khz2dot5, khz7dot5}

Guardband-NB-r13 ::=            SEQUENCE {
    rasterOffset-r13                ChannelRasterOffset-NB-r13,
    spare                            BIT STRING (SIZE (3))
}

Inband-SamePCI-NB-r13 ::=       SEQUENCE {
    eutra-CRS-SequenceInfo-r13      INTEGER (0..31)
}

Inband-DifferentPCI-NB-r13 ::=  SEQUENCE {
    eutra-NumCRS-Ports-r13          ENUMERATED {same, four},
    rasterOffset-r13                ChannelRasterOffset-NB-r13,
    spare                           BIT STRING (SIZE (2))
}

Standalone-NB-r13 ::=           SEQUENCE {
    spare                           BIT STRING (SIZE (5))
}

-- ASN1STOP
```

***MasterInformationBlock-NB* field descriptions**
ab-Enabled Value TRUE indicates that access barring is enabled and that the UE shall acquire *SystemInformationBlockType14-NB* before initiating RRC connection establishment or resume.
eutra-CRS-SequenceInfo Information of the carrier containing NPSS/NSSS/NPBCH. Each value is associated with an E-UTRA PRB index as an offset from the middle of the LTE system sorted out by channel raster offset. See TS 36.211[21] and TS 36.213 [23].
eutra-NumCRS-Ports Number of E-UTRA CRS antenna ports, either the same number of ports as NRS or 4 antenna ports. See TS 36.211 [21], TS 36.212 [22], and TS 36.213 [23].
hyperSFN-LSB Indicates the 2 least significant bits of hyper SFN. The remaining bits are present in *SystemInformationBlockType1-NB.*
operationModeInfo Deployment scenario (in-band/guard-band/standalone) and related information. *Inband-SamePCI* indicates an in-band deployment and that the NB-IoT and LTE cell share the same physical cell id and have the same number of NRS and CRS ports. *Inband-DifferentPCI* indicates an in-band deployment and that the NB-IoT and LTE cell have different physical cell id. *guardband* indicatesa guard-band deployment. *standalone* indicates a standalone deployment.
rasterOffset NB-IoT offset from LTE channel raster. Unit in kHz in set { -7.5, -2.5, 2.5, 7.5} See TS 36.211[21] and TS 36.213 [23].
schedulingInfoSIB1 This field contains an index to a table specified in TS 36.213 [23, Table 16.4.1.3-3] that defines *SystemInformationBlockType1-NB* scheduling information.
systemFrameNumber-MSB Defines the 4 most significant bits of the SFN. As indicated in TS 36.211 [21],the 6 least significant bits of the SFN are acquired implicitly by decoding the NPBCH.
systemInfoValueTag Common for all SIBs other than MIB-NB, SIB14-NB and SIB16-NB.

5.2NB-IoT information elements(6.7.3)

5.2.1 DL-GapConfig-NB

The IE *DL-GapConfig-NB* is used to specify the downlink gap configuration for NPDCCH and NPDSCH. Downlink gaps only apply in RRC_CONNECTED mode.

DL-GapConfig-NB **information element**

```
-- ASN1START


DL-GapConfig-NB-r13 ::=     SEQUENCE {
    dl-GapThreshold-r13         ENUMERATED {n32, n64, n128, n256},
    dl-GapPeriodicity-r13       ENUMERATED {sf64, sf128, sf256, sf512},
    dl-GapDurationCoeff-r13     ENUMERATED {oneEighth, oneFourth, threeEighth, oneHalf}
}

-- ASN1STOP
```

DL-GapConfig-NB **field descriptions**
dl-GapDurationCoeff Coefficient to calculate the gap duration of a DL transmission: dl-GapDurationCoeff * dl-GapPeriodicity, Duration in number of subframes. See TS 36.211 [21] and TS 36.213 [23].
dl-GapPeriodicity Periodicity of a DL transmission gap in number of subframes. See TS 36.211 [21] and TS 36.213 [23].
dl-GapThreshold Threshold on the maximum number of repetitions configured for NPDCCH before application of DL transmission gap configuration, See TS 36.211 [21] and TS 36.213 [23].

5.2.1 NPUSCH-Config-NB

The IE *NPUSCH-ConfigCommon-NB* is used to specify the common NPUSCH configuration. The IE *NPUSCH-ConfigDedicated-NB* is used to specify the UE specific NPUSCH configuration.

NPUSCH-Config-NB**information element**

```
-- ASN1START

NPUSCH-ConfigCommon-NB-r13 ::=      SEQUENCE {
    ack-NACK-NumRepetitions-Msg4-r13    SEQUENCE (SIZE(1..maxNPRACH-Resources-NB-r13)) OF
                                                ACK-NACK-NumRepetitions-NB-r13,
    srs-SubframeConfig-r13              ENUMERATED {
                                            sc0, sc1, sc2, sc3, sc4, sc5, sc6, sc7,
                                            sc8, sc9, sc10, sc11, sc12, sc13, sc14, sc15
                                            }                           OPTIONAL,   --
Need OR
    dmrs-Config-r13                     SEQUENCE {
        threeTone-BaseSequence-r13          INTEGER (0..12)             OPTIONAL,   --
Need OP
        threeTone-CyclicShift-r13           INTEGER (0..2),
        sixTone-BaseSequence-r13            INTEGER (0..14)             OPTIONAL,   --
Need OP
        sixTone-CyclicShift-r13             INTEGER (0..3),
        twelveTone-BaseSequence-r13         INTEGER (0..30)             OPTIONAL    --
Need OP
    }       OPTIONAL,   -- Need OR
    ul-ReferenceSignalsNPUSCH-r13       UL-ReferenceSignalsNPUSCH-NB-r13
}

UL-ReferenceSignalsNPUSCH-NB-r13 ::=     SEQUENCE {
    groupHoppingEnabled-r13                 BOOLEAN,
    groupAssignmentNPUSCH-r13               INTEGER (0..29)
}
```

```
NPUSCH-ConfigDedicated-NB-r13 ::=   SEQUENCE {
    ack-NACK-NumRepetitions-r13         ACK-NACK-NumRepetitions-NB-r13  OPTIONAL,   --
Need ON
    npusch-AllSymbols-r13               BOOLEAN                         OPTIONAL,   --
Cond SRS
    groupHoppingDisabled-r13            ENUMERATED {true}               OPTIONAL    --
Need OR
}

ACK-NACK-NumRepetitions-NB-r13  ::= ENUMERATED {r1, r2, r4, r8, r16, r32, r64, r128}


-- ASN1STOP
```

***NPUSCH-Config-NB* field descriptions**
ack-NACK-NumRepetitions Number of repetitions for the ACK NACK resource unit carrying HARQ response to NPDSCH see TS 36.211 [21] and TS 36.213 [23].If absent, the value of *ack-NACK-NumRepetitions-Msg4* signalled in SIB2 is used.
ack-NACK-NumRepetitions-Msg4 Number of repetitions for ACK/NACK HARQ response to NPDSCH containing Msg4 per NPRACH resource, see TS 36.211 [21] and TS 36.213 [23].
groupAssignmentNPUSCH Parameter: ΔSS See TS 36.211 [21, 5.5.1.3].
groupHoppingDisabled Parameter: Disable-sequence-group-hopping, see TS 36.211 [21, 5.5.1.3].
groupHoppingEnabled Parameter: Group-hopping-enabled, see TS 36.211 [21, 5.5.1.3].
npusch-AllSymbols If set to TRUE, the UE shall use all NB-IoT symbols for NPUSCH transmission. If set to FALSE, the UE punctures the NPUSCH transmissions in the symbols that collides with SRS. If the field is not present, the UE uses all NB-IoT symbols for NPUSCH transmission.
sixTone-BaseSequence The base sequence of DMRS sequence in a cell for 6 tones transmission; see TS 36.211 [21]. If absent, it is given by NB-IoT CellID mod 14.
sixTone-CyclicShift Define 4 cyclic shifts for the 6-tone case, see TS 36.211 [21].
srs-SubframeConfig SRS SubframeConfiguration. See TS 36.211 [21, table 5.5.3.3-1]. Value sc0 corresponds to value 0, sc1 to value 1 and so on.
threeTone-BaseSequence The base sequence of DMRS sequence in a cell for 3 tones transmission; see TS 36.211 [21]. If absent, it is given by NB-IoT CellID mod 12.
threeTone-CyclicShift Define 3 cyclic shifts for the 3-tone case, see TS 36.211 [21].
twelveTone-BaseSequence The base sequence of DMRS sequence in a cell for 12 tonestransmission; see TS 36.211 [21]. If absent, it is given by NB-IoT CellID mod 30.
ul-ReferenceSignalsNPUSCH Used to specify parameters needed for the transmission on NPUSCH.

Conditional presence	**Explanation**
SRS	This field is optionally present, need OP,if srs-SubframeConfig is broadcasted. Otherwise, the IE is not present.

5.2.2 NPRACH-ConfigSIB-NB

The IE *NPRACH-ConfigSIB-NB* is used to specify the NPRACH configuration in the system information.

NPRACH-ConfigSIB-NB information elements

```
-- ASN1START

NPRACH-ConfigSIB-NB-r13 ::=         SEQUENCE {
    nprach-CP-Length-r13                ENUMERATED {us66dot7, us266dot7},
    rsrp-ThresholdsPrachInfoList-r13    RSRP-ThresholdsNPRACH-InfoList-NB-r13   OPTIONAL,   -- needOR
    nprach-ParametersList-r13           NPRACH-ParametersList-NB-r13
}

NPRACH-ParametersList-NB-r13 ::=    SEQUENCE (SIZE (1..maxNPRACH-Resources-NB-r13)) OF
NPRACH-Parameters-NB-r13

NPRACH-Parameters-NB-r13::=         SEQUENCE {
    nprach-Periodicity-r13                  ENUMERATED {ms40,ms80, ms160, ms240,
                                                        ms320, ms640, ms1280, ms2560},
    nprach-StartTime-r13                    ENUMERATED {ms8,ms16, ms32, ms64,
                                                        ms128, ms256, ms512, ms1024},
    nprach-SubcarrierOffset-r13             ENUMERATED {n0, n12, n24, n36, n2, n18, n34,
spare1},
    nprach-NumSubcarriers-r13               ENUMERATED {n12, n24, n36, n48},
    nprach-SubcarrierMSG3-RangeStart-r13    ENUMERATED {zero, oneThird, twoThird, one},
    maxNumPreambleAttemptCE-r13             ENUMERATED {n3, n4, n5, n6, n7, n8, n10,
spare1},
    numRepetitionsPerPreambleAttempt-r13    ENUMERATED {n1, n2, n4, n8, n16, n32, n64,
n128},
    npdcch-NumRepetitions-RA-r13            ENUMERATED {r1, r2, r4, r8, r16, r32, r64,
r128,
                                                        r256, r512, r1024, r2048,
                                                        spare4, spare3, spare2, spare1},
    npdcch-StartSF-CSS-RA-r13               ENUMERATED {v1dot5, v2, v4, v8, v16, v32, v48,
v64},
    npdcch-Offset-RA-r13                    ENUMERATED {zero, oneEighth, oneFourth,
threeEighth}
}

RSRP-ThresholdsNPRACH-InfoList-NB-r13 ::= SEQUENCE (SIZE(1..2)) OF RSRP-Range

-- ASN1STOP
```

***NPRACH-ConfigSIB-NB* field descriptions**
maxNumPreambleAttemptCE Maximum number of preamble transmission attempts per NPRACH resource. See TS 36.321 [6].
npdcch-NumRepetitions-RA Maximum number of repetitions for NPDCCH common search space (CSS) for RAR, Msg3 retransmission and Msg4, see TS 36.211 [21].
npdcch-Offset -RA Fractional period offset of starting subframe for NPDCCH common search space(CSS Type 2, see TS 36.211 [21] and TS 36.213 [23].
npdcch-StartSF-CSS-RA Starting subframe configuration for NPDCCH common search space (CSS), including RAR, Msg3 retransmission, and Msg4, see TS 36.211 [21] and TS 36.213 [23].
nprach-CP-Length Cyclic prefix length for NPRACH transmission, see TS 36.211 [21, 5.2.1]. Value us66dot7 corresponds to 66.7 microseconds and value us266dot7 corresponds to 266.7 microseconds.
nprach-NumSubcarriers Number of sub-carriers in a NPRACH resource. In number of subcarriers.
nprach-ParametersList Configures NPRACH parameters for each NPRACH resource. Up to three PRACH resources can be configured in a cell. Each NPRACH resource is associated with a different number of NPRACH repetitions.
nprach-Periodicity Periodicity of a NPRACH resource. Unit in millisecond.
nprach-StartTime Start time of the NPRACH resource in one period. Unit in millisecond.
nprach-SubcarrierOffset Frequency location of the NPRACH resource. In number of subcarriers, offset from sub-carrier 0.
nprach-SubcarrierMSG3-RangeStart Fraction for calculating the starting subcarrier index of the range reserved for indication of UE support for multi-tone Msg3 transmission, within the NPRACH resource.. Multi-tone Msg3 transmission is not supported for {32, 64, 128} repetitions of NPRACH. For at least one of the NPRACH resources with the number of NPRACH repetitions other than {32, 64, 128}, the value of *nprach-SubcarrierMSG3-RangeStart*should be less than 1.
numRepetitionPerPreambleAttempt Number of NPRACH repetitions per attempt for each NPRACH resource, See TS 36.211 [21].
rsrp-ThresholdsPrachInfoList The criterion for UEs to select a NPRACH resource. Up to 2 RSRP threshold values can be signalled. See TS 36.213 [23]. The first element corresponds to RSRP threshold 1, the second element corresponds to RSRP threshold 2. See TS 36.321 [6].If absent, there is only one NPRACH resource.

6. 新增信道介绍

- **NPUSCH(Narrowband Physical Uplink Shared Channel):**
  - ✓ 上行支持 15kHz 和 3.75kHz 两种 subcarrier spacing； 3.75kHz 对应的 Slot 长度是 15kHz 对应 Slot 长度的 4 倍

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

  - ✓ Resource unit

Resource units are used to describe the mapping of the NPUSCH to resource elements. A resource unit is defined as $N_{\text{symb}}^{\text{UL}} N_{\text{slots}}^{\text{UL}}$ consecutive 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 Table 10.1.2.3-1.

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

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	

- ✓ 两种 NPUSCH format:

  Format1 used to carry UL-SCH; format 2 used to carry uplink control information

- ✓ 编码方式:

  UL-SCH 使用 1/3 Turbo Coding； UCI 使用 1/16 Block code;

  NPUSCH 的 rate matching 结果是按照一个 Resource Unit 为单位输出的;

- ✓ NPUSCH 的 mapping:

  NPUSCH can be mapped to one or morethan one resource units, N_{RU} (1 to 10), each of which shall be transmitted $M_{\text{rep}}^{\text{NPUSCH}}$ (1 to 128)times.

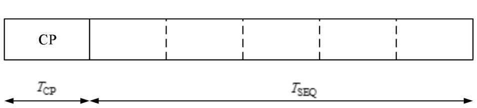
  NPUSCH 最终映射到 $N = N_{\text{Rep}} N_{\text{RU}} N_{\text{slots}}^{UL}$ 个 slot 上

  36.211 chapter 10.1.3.6 的描述比较晦涩？？？

- ✓ 如果 NPUSCH 发送时间超过 256ms，每 256ms 之后需要暂停 40ms 的发送;

➢ NPRACH(Narrowband Physical Random Access Channel):

- ✓ Time and frequency structure



Preamble format	T_{CP}	T_{SEQ}
0	$2048T_{\text{s}}$	$5 \cdot 8192T_{\text{s}}$
1	$8192T_{\text{s}}$	$5 \cdot 8192T_{\text{s}}$

- ✓ 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 sub-carrier allocated to NPRACH $N_{\text{scoffset}}^{\text{NPRACH}}$ (*nprach-SubcarrierOffset*),

- number of sub-carriers allocated to NPRACH $N_{\text{sc}}^{\text{NPRACH}}$ (*nprach-NumSubcarriers*),

- number of NPRACH repetitions per attempt $N_{\text{rep}}^{\text{NPRACH}}$ (*nprach-NumRepetitions*),

- 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-SubcarrierRangeStart*).

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 $n_{\text{f}} \bmod \left(N_{\text{period}}^{\text{NPRACH}} / 10 \right) = 0$. After transmissions of $4 \cdot 64 \left(T_{\text{CP}} + T_{\text{SEQ}} \right)$ time units, a gap of $40 \cdot 30720 T_{\text{s}}$ time unitsshall be inserted.

- **NPDSCH(Narrowband Physical Downlink Shared Channel)**
  - ✓ NPDSCH can be mapped to one or more than one subframes, N_{SF}, as given by clause 16.4.1.5 of 3GPP TS 36.213 [4], each of which shall be transmitted $M_{\text{rep}}^{\text{NPDSCH}}$ times
  - ✓ Resource allocation

Table 16.4.1.3-1: Number of subframes (N_{SF}) for NPDSCH.

I_{SF}	N_{SF}
0	1
1	2
2	3
3	4
4	5
5	6
6	8
7	10

Table 16.4.1.3-2: Number of repetitions (N_{Rep}) for NPDSCH.

I_{Rep}	N_{Rep}
0	1
1	2
2	4
3	8
4	16
5	32
6	64
7	128
8	192
9	256
10	384
11	512
12	768
13	1024
14	1536
15	2048

✓ NPDSCH start position

The starting OFDM symbol for NPDSCH is given by index $l_{\mathrm{DataStart}}$ in the first slot in a subframe k and is determined as follows

- if subframe k is a subframe used for receiving SIB1-NB
  - $l_{\mathrm{DataStart}} = 3$ if the value of the higher layer parameter *operationModeInfo* is set to '00' or '01'
  - $l_{\mathrm{DataStart}} = 0$ otherwise
- else
  - $l_{\mathrm{DataStart}}$ is given by the higher layer parameter *eutraControlRegionSize* if the value of the higher layer parameter *operationModeInfo* is set to '00' or '01'
  - $l_{\mathrm{DataStart}} = 0$ otherwise

✓ MCS 和 TBSize 的确定

NPDSCH 固定使用 QPSK 调制方式；1/3 Tail biting convolutional coding 编码方式

不需要 UE 发送 CQI/RI/PMI 信息？？？

NPDSCH 是否有不同 RV 版本的重传合并？(可能是没有的，因为每一次传输都已经是完整的编码后数据，RM 过程不存在打孔？？？)

- **NPDCCH(Narrowband Physical Downlink Control Channel)**
  - ✓ A UE shall monitor a set of NPDCCH candidates as configured by higher layer signalling for control information, where monitoring implies attempting to decode each of the NPDCCHs in the set according to all the monitored DCI formats.
  - ✓ 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.

Table 10.2.5.1-1: Supported NPDCCH formats

NPDCCH format	Number of NCCEs
0	1
1	2

  - ✓ NPDCCH 不能在 NPBCH, NPSS, NSSS 子帧上；
  - ✓ DCI Format N0 is used for the scheduling of NPUSCH in one UL cell. The following information is transmitted by means of the DCI format N0:

    - Flag for format N0/format N1 differentiation – 1 bit, where value 0 indicates format N0 and value 1 indicates format N1

    - Subcarrier indication; - Resource assignment; - Scheduling delay; - Modulation and coding scheme; - Redundancy version；- Repetition number；- New data indicator；- DCI subframe repetition number

  - ✓ DCI format N1 is used for the scheduling of one NPDSCH codeword in one celland random access procedure initiated by a NPDCCH order. The DCI corresponding to a NPDCCH order is carried by NPDCCH.The following information is transmitted by means of the DCI format N1:

    - Flag for format N0/format N1 differentiation – 1 bit, where value 0 indicates format N0 and value 1 indicates format N1

    - NPDCCH order indicator – 1 bit

    Format N1 is used for random access procedure initiated by a NPDCCH order only if NPDCCH order indicator is set to ‘1’, format N1 CRC is scrambled with C-RNTI, and all the remaining fields are set as follows:

    - Starting number of NPRACH repetitions；- Subcarrier indication of NPRACH；- All the remaining bits in format N1 are set to one;

    Otherwise,

- Scheduling delay; - Resource assignment; - Modulation and coding scheme ； - Repetition number ; - New data indicator； - HARQ-ACK resource； - DCI subframe repetition number；

When the format N1 CRC is scrambled with a RA-RNTI, then the following fields among the fields above are reserved:

- New data indicator； - HARQ-ACK resource

If the number of information bits in format N1 is less than that of format N0, zeros shall be appended to format N1 until the payload size equals that of format N0.

✓ DCI format N2 is used for for paging and direct indication.The following information is transmitted by means of the DCI format N2:

Flag for paging/direct indication differentiation – 1 bit, with value 0 for direct indication and value 1 for paging

If Flag=0:

- Direct Indication information – 8 bits provide direct indication of system information update and other fields, as defined in [6]

- Reserved information bits are added until the size is equal to that of format N2 with Flag=1

If Flag=1:

- Resource assignment ； - Modulation and coding scheme; - Repetition number ; - DCI subframe repetition number

使用 1/3 tail biting convolutional coding 编码方式

NPDCCH 的传输子帧长度如何确定的?

➢ **NPBCH**

✓ PBCH 的 TTI 长度为 8 个 frame，在 64 个 frame 内重复传输。每连续 8 个无线帧的子帧 0 传输的是相同内容，接下来 8 个子帧 0 传输另外的内容。

✓ 解码 PBCH 后，即可得到 64 frame 的边界(不同子帧的扰码不同)，即 SFN 的低 6bit。高 4bit 在 MIB 的 payload 里面。

✓ 做物理资源映射时，要避开 CRS(按照 4 ports)以及 NRS(按照 2 ports)。此处可以认为 CRS 与 NRS 具有相同的 RsShift。

➢ **SIB1-NB(在 NPDSCH 上传输)**

✓ The number of repetitions for the NPDSCH carrying SystemInformationBlockType1-NB is determined based on the parameter schedulingInfoSIB1-NB-r13 configured by higher-layers and according to Table 16.4.1.3-3.

Table 16.4.1.3-3: Number of repetitions for NPDSCH carrying *SystemInformationBlockType1-NB*.

Value of *schedulingInfoSIB1-NB-r13*	Number of NPDSCH repetitions
0	4
1	8
2	16
3	4
4	8
5	16
6	4
7	8
8	16
9	4
10	8
11	16
12-15	Reserved

✓ The starting radio frame for the first transmission of the NPDSCH carrying SystemInformationBlockType1-NB is determined according to Table 16.4.1.3-4.

Table 16.4.1.3-4: Starting radio frame for the first transmission of the NPDSCH carrying SystemInformationBlockType1-NB.

Number of NPDSCH repetitions	N_{ID}^{Ncell}	Starting radio frame number for NB-SIB1 repetitions (n_f *mod 256*)
4	N_{ID}^{Ncell} mod 4 = 0	0
	N_{ID}^{Ncell} mod 4 = 1	16
	N_{ID}^{Ncell} mod 4 = 2	32
	N_{ID}^{Ncell} mod 4 = 3	48
8	N_{ID}^{Ncell} mod 2 = 0	0
	N_{ID}^{Ncell} mod 2 = 1	16
16	N_{ID}^{Ncell} mod 2 = 0	0
	N_{ID}^{Ncell} mod 2 = 1	1

✓ SIB1-NB 每 256 个无线帧调度一次；每次调度的起始帧号，重复传输次数， MCS 均由 MIB-NB 中获取；NB-IoT 中没有 SI-RNTI。

➢ **SIBx-NB**

✓ SIBx 的接收也不需要 SI-RNTI，SIBx 的所有调度信息都在 SIB1-NB 中。

7. 新增信号介绍：

➢ **UL NDMRS(Narrowband demodulation reference signal):**

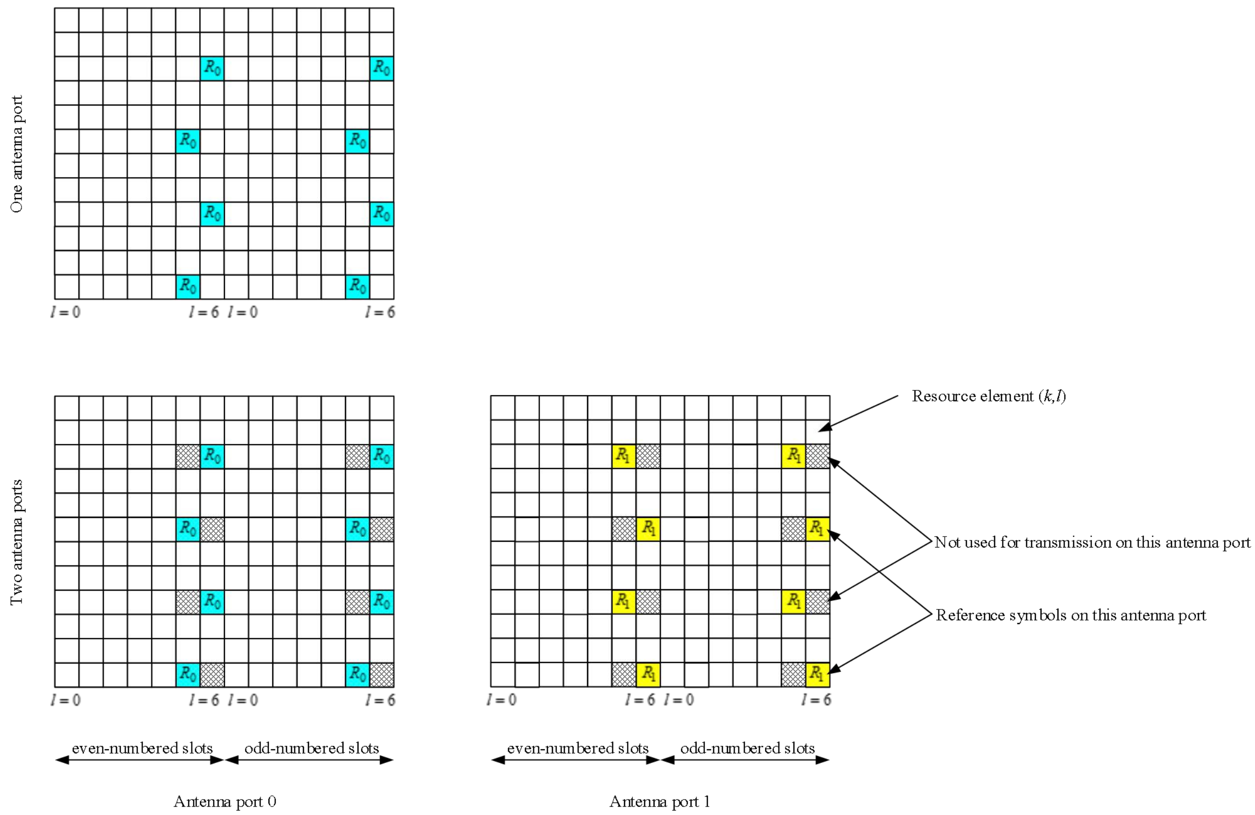
- ✓ The set of sub-carriers used in the mapping process shall be identical to the corresponding NPUSCH transmission as defined in clause 10.1.3.6.
- ✓ The mapping to resource elements (k,l) shall be in increasing order of first k, then l, and finally the slot number. The values of the symbol index l 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

➢ **NRS(Narrowband reference signal):**

- ✓ UE 可以假定 NRS 在所有支持 NPDSCH 发送的下行子帧发送；如果网络没有 NB-IoT 下行子帧配置参数，则 UE 可以假定子帧 0,4 以及没有包含 NSSS 的子帧 9 上是有 NRS 传输的；
- ✓ 传输 NPSS/NSSS 的子帧不会发送 NRS
- ✓ NRS 映射位置：



- **NPSS(Narrowband primary synchronization signal):**

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

Definition of S(l)

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

✓ The sequence $d_l(n)$ shall be mapped to resource elements (k,l) in increasing order of first the index $k=0,1,\ldots,N_{\mathrm{sc}}^{\mathrm{RB}}-2$ and then the index $l=3,4,\ldots,N_{\mathrm{symb}}^{\mathrm{DL}}-1$ 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(映射在每个无线帧的子帧 5 的 OS3 到 OS13，每个 OS 映射子载波 0 到 10)

Note:采用 11 长度的短 ZC 序列是为了抗大频偏的问题。

NPSS 序列内容不包含任何小区 ID 信息，因此完成 NPSS 相关只是获得了 10ms 同步

- **NSSS(Narrowband secondary synchronization signal):**

$$n = 0,1,\ldots,131$$
$$n' = n \bmod 131$$
$$m = n \bmod 128$$
$$u = N_{\mathrm{ID}}^{\mathrm{Ncell}} \bmod 126 + 3$$

- ✓ $d(n) = b_q(m) e^{-j2\pi\theta_f n} e^{-j\frac{\pi u n'(n'+1)}{131}}$; $q = \left\lfloor \frac{N_{\mathrm{ID}}^{\mathrm{Ncell}}}{126} \right\rfloor$

- ✓ 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 $N_{\mathrm{symb}}^{\mathrm{NSSS}}$ symbols of subframe 9 in radio frames fulfilling $n_{\mathrm{f}} \bmod 2 = 0$, where $N_{\mathrm{symb}}^{\mathrm{NSSS}}$ is given by Table 10.2.7.2.2-1. (映射在每个偶数无线帧的子帧 9 的最后 11 个 OS 上，总共 132 个 RE)

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

Note: NSSS 序列可以区分不同小区 ID，因此获得 NSSS 同步就获得了小区 ID

8. UL HARQ 流程

- NB-IoT 只有一个 UL Harq Process(36.321 5.4.2.1)
- NB-IoT 的上行 HARQ 是异步的(也就是说重传发生的时刻非固定；也就是说 NB-IoT 上行没有非自适应重传，重传都需要 UL Grant 指示)
- 如果子帧 n 是收到 NPDCCH DCI Format N0 的最后一个子帧，则 UE 需要从 $n+k_0$之后的 s 子帧开始连续发送 N 个 NPUSCH 子帧； $N = N_{\mathrm{Rep}} N_{\mathrm{RU}} N_{\mathrm{slots}}^{UL}$，这两个参数都在 DCI N0 中携带；

  - **Table 16.5.1-1: k_0 for DCI format N0.**

I_{Delay}	k_0
0	8
1	16
2	32
3	64

- 如果子帧 n-4 是 UE 发送 NPUSCH 的最后一个子帧，则 UE 需要从子帧 n 开始检测 ACK/NACK；(这里的 ACK/NACK 是在 NPDCCH 还是 NPDSCH 上接收？接收窗以及合并子帧如何确定?)

9. DL HARQ 流程

- NB-IoT 只有一个 DL Harq Process(36.321 5.3.2.1)
- 如果子帧 n 是收到 NPDCCH DCI Format N1/N2 的最后一个子帧，则 UE 需要从 n+5 之后的下行子帧开始接收连续 N 个 NPDSCH 子帧； $N = N_{\mathrm{Rep}} N_{\mathrm{SF}}$，这两个参数都在 DCI N1/N2 中携带；

- 如果子帧 n 是 UE 接收 NPDSCH 的最后一个子帧，UE 需要从子帧$n+k_0-1$开始选择 NPUSCH format2 发送 ACK/NACK，连续发送 N 个 NB-Iot UL Slots; $N = N_{\mathrm{Rep}}^{AN} N_{\mathrm{slots}}^{UL}$

Table 16.4.2-1: ACK/NACK subcarrier and k_0 for NPUSCH with subcarrier spacing $\Delta f = 3.75\,\mathrm{kHz}$.

ACK/NACK resource field	ACK/NACK subcarrier	k_0
0	38	13
1	39	13
2	40	13
3	41	13
4	42	13
5	43	13
6	44	13
7	45	13
8	38	21
9	39	21
10	40	21
11	41	21
12	42	21
13	43	21
14	44	21
15	45	21

Table 16.4.2-2: ACK/NACK subcarrier and k_0 for NPUSCH with subcarrier spacing $\Delta f = 15\,\mathrm{kHz}$.

ACK/NACK resource field	ACK/NACK subcarrier	k_0
0	0	13
1	1	13
2	2	13
3	3	13
4	0	15
5	1	15
6	2	15
7	3	15
8	0	17
9	1	17
10	2	17
11	3	17
12	0	18
13	1	18
14	2	18
15	3	18

10. 子帧类型的确定

确定上下行子帧和空闲子帧；
上行子帧需要确定 NPRACH, NPUSCH Format 1 format 2
下行子帧需要确定 NPSS，NSSS， NPBCH，NPDCCH, NPDSCH；
NPDSCH 需要再进一步确定其中携带的是 SIB1-NB, SIBx-NB, NPCH， DL-SCH 中的哪一个；

时序相关的协议描述：

- NPSS 在每个无线帧的子帧 5 发送，不受其他调度的影响；
- NSSS 在每个偶数无线帧的子帧 9 发送，不受其他调度影响；
- 如果基站没有配置 NB-IoT downlink subframe configuration，那么 UE 可以假定所有的子帧 0/4 以及奇数无线帧的子帧 9 为含 NRS 的下行子帧；(3GPP 36.211 --- 10.2.6)
- 子帧 n 是 NPDCCH format N1/N2 的最后一个子帧，则从子帧 n+5 个下行子帧开始的下行子帧是 NPDSCH；
- 子帧 n 是 NPDSCH 的最后一个子帧，UE 需要在子帧 n+k0-1 个下行子帧之后在 NPUSCH format 2 上发送 ACK/NACK。K0 是在 DCI format N1/N2 中携带，范围是{13,15,17,18} for 15kHz spacing， {13, 21} for 3.75kHz
- 子帧 n 是 NPDCCH format N0 的最后一个子帧，则从子帧 n+k0 个下行子帧之后开始发生那个 NPUSCH，k0 的取值由 DCI format N0 里面携带，范围是{8,16,32,64}
- 在子帧 n 发送了 NPUSCH 之后，UE 需要在子帧 n+4 开始检测 **ACK/NACK（在 NPDSCH 上？？？）；**
- 子帧 n 是 NPDCCH DCI Format N0 的最后一个子帧，那么在发送 NPUSCH 之前的所有子帧，UE 不需要检测别的 NPDCCH；
- 子帧 n 是 NPDCCH DCI Format N1/N2 的最后一个子帧，那么在接收 NPDSCH 之前的所有子帧，UE 不需要检测别的 NPDCCH；
- 在 NPDSCH 和相应的 NPUSCH(携带 ACK/NACK)之间的子帧，UE 不需要检测别的 NPDCCH；
- NPDCCH DCI Format N1 如果携带的是 NPDCCH order，则在发送 NPRACH 之前的子帧不需要检测 NPDCCH；
- 发送 NPUSCH 之后的 3 个子帧，UE 不需要检测 NPDCCH；

NPSS/NSSS/NPBCH 映射位置说明																																							
0										1										2										3									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				
4										5										6										7									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				
8										9										10										11									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				
12										13										14										15									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				
16										17										18										19									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				
20										21										22										23									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				
24										25										26										27									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				
28										29										30										31									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				
32										33										34										35									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				
36										37										38										39									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				
40										41										42										43									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				
44										45										46										47									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				
48										49										50										51									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				
52										53										54										55									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				
56										57										58										59									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				
60										61										62										63									
NPBCH					NPSS				NSSS	NPBCH					NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				

DL/UL Harq:

SFN = 0										1										2										3									
NPBCH	NPDCCH(DCI N1)				NPSS			NPDSCH	NSSS	NPBCH	NPDSCH	NPDSCH			NPSS					NPBCH					NPSS				NSSS	NPBCH	NPUSCH(AN)				NPSS	NPDCCH(DCI N0)			
4										5										6										7									
NPBCH					NPSS	NPUSCH			NSSS	NPBCH			NPDSCH(AN)		NPSS					NPBCH					NPSS				NSSS	NPBCH					NPSS				

11. 省电设计

➢ 芯片复杂度降低，工作电流小；

➢ PSM:

➢ eDRX:

➢ 长周期 TAR/RAU，减少终端发送位置更新的次数；

➢ 只支持小区选择和重选的移动性管理，减少测量开销；

12. 如何提高覆盖

➢ 上行功率谱密度大幅提高：同样是 23dBm 的最大上行发送功率，LTE R9 最小是分配在 1 个 RB（180kHz）的频带内，而 NB-IoT 如果选择上行 3.75kHz subcarrier spacing，则相比于 R9 中断的功率谱密度增强了 17dB (10*log(180/3.75) = 16.8)；GSM 最大发射功率是 33dBm，因此相比于 GSM 终端的发射功率谱密度也能提高 7dB；

- 重复+编码增益 6~16dB？？？

13. 低成本

- 180kHz 窄带系统，基带复杂度低
- 低采样率，缓存 Flash/RAM 要求小；
- 峰均比低，功放效率高，23dBm 发射功率可支持单片 SoC 内置功放 PA；？？？
- 协议栈简化，减少片内 FLASH/RAM
- 半双工