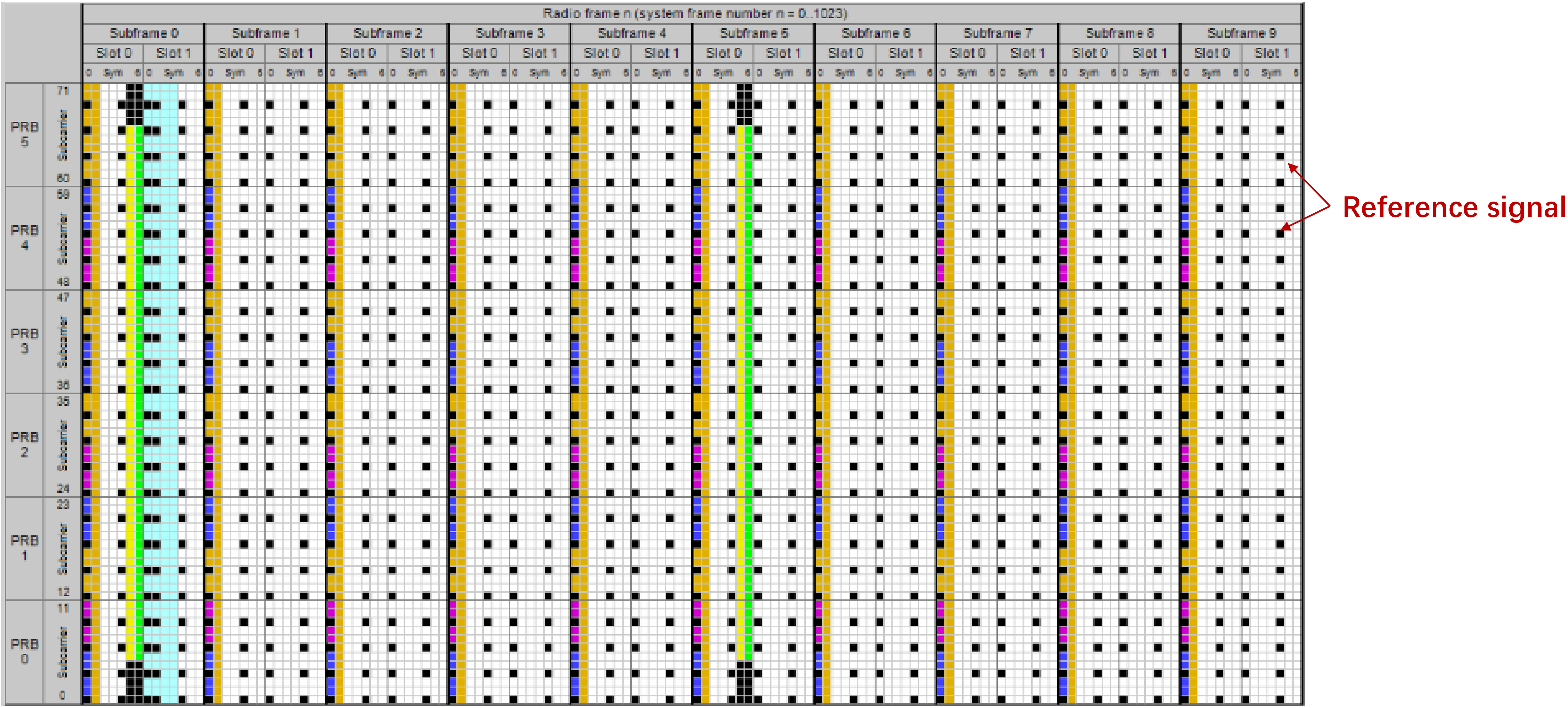
# Synchronization of Cellular Systems

**Lecturer: Dr. Rui Wang**




- PSCH (Primary Synchronization Channel)
- SSCH (Secondary Synchronization Channel)
- PBCH (Physical Broadcast Channel)
- RS (cell-specific Reference Signal) for selected Tx antenna port
- PCFICH (Physical Control Format Indicator Channel)
- PHICH (Physical Hybrid ARQ (Automatic Repeat reQuest) Indicator Channel)
- PDCCH (Physical Downlink Control Channel)
- Available for PDSCH (Physical Downlink Shared Channel)

# Downlink PHY in LTE

- **Physical channels:** a set of Resource Elements carrying information originating from higher layers
  - Physical Downlink Shared Channel, PDSCH
  - Physical Broadcast Channel, PBCH
  - Physical Multicast Channel, PMCH
  - Physical Control Format Indicator Channel, PCFICH
  - Physical Downlink Control Channel, PDCCH
  - Physical Hybrid ARQ Indicator Channel, PHICH

- **Physical signals:** a set of Resource Elements NOT carrying information originating from higher layers
  - Reference signal: channel estimation

# Initial Access

- When one mobile device is turned on, it knows the potential frequencies where there might be cellular service.
- But it does not know the bandwidth of the service, sampling frequency, the timing of frames …

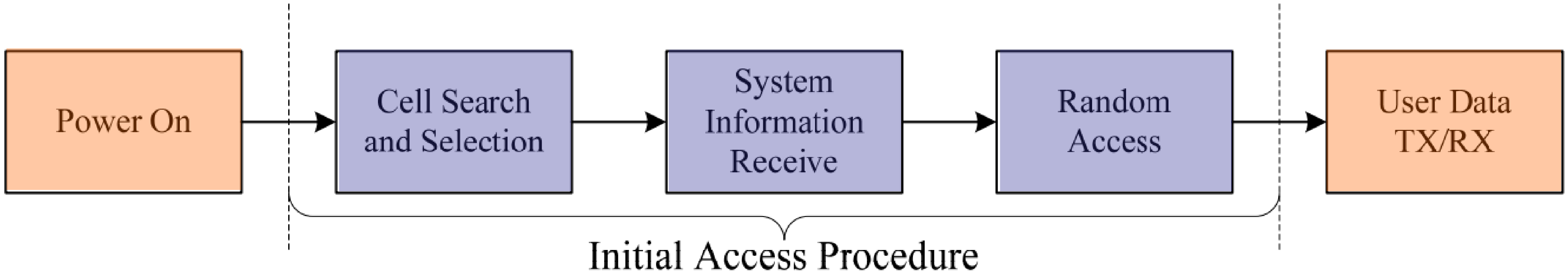
| Channel bandwidth [MHz] | 1.4 | 3 | 5 | 10 | 15 | 20 |
|---|---|---|---|---|---|---|
| Number of resource blocks ($N_{RB}$) | 6 | 15 | 25 | 50 | 75 | 100 |
| Number of occupied subcarriers | 72 | 180 | 300 | 600 | 900 | 1200 |
| IDFT(Tx)/DFT(Rx) size | 128 | 256 | 512 | 1024 | 1536 | 2048 |
| Sample rate [MHz] | 1.92 | 3.84 | 7.68 | 15.36 | 23.04 | 30.72 |
| Samples per slot | 960 | 1920 | 3840 | 7680 | 11520 | 15360 |

# Initial Access

- When one mobile device is turned on, it knows the potential frequencies where there might be cellular service.
- But it does not know the bandwidth of the service, sampling frequency, the timing of frames …
- In WiFi, bandwidth, sampling frequency and FFT size are all fixed; so we just need to detection the arrival timing of PPDU, everything follows.

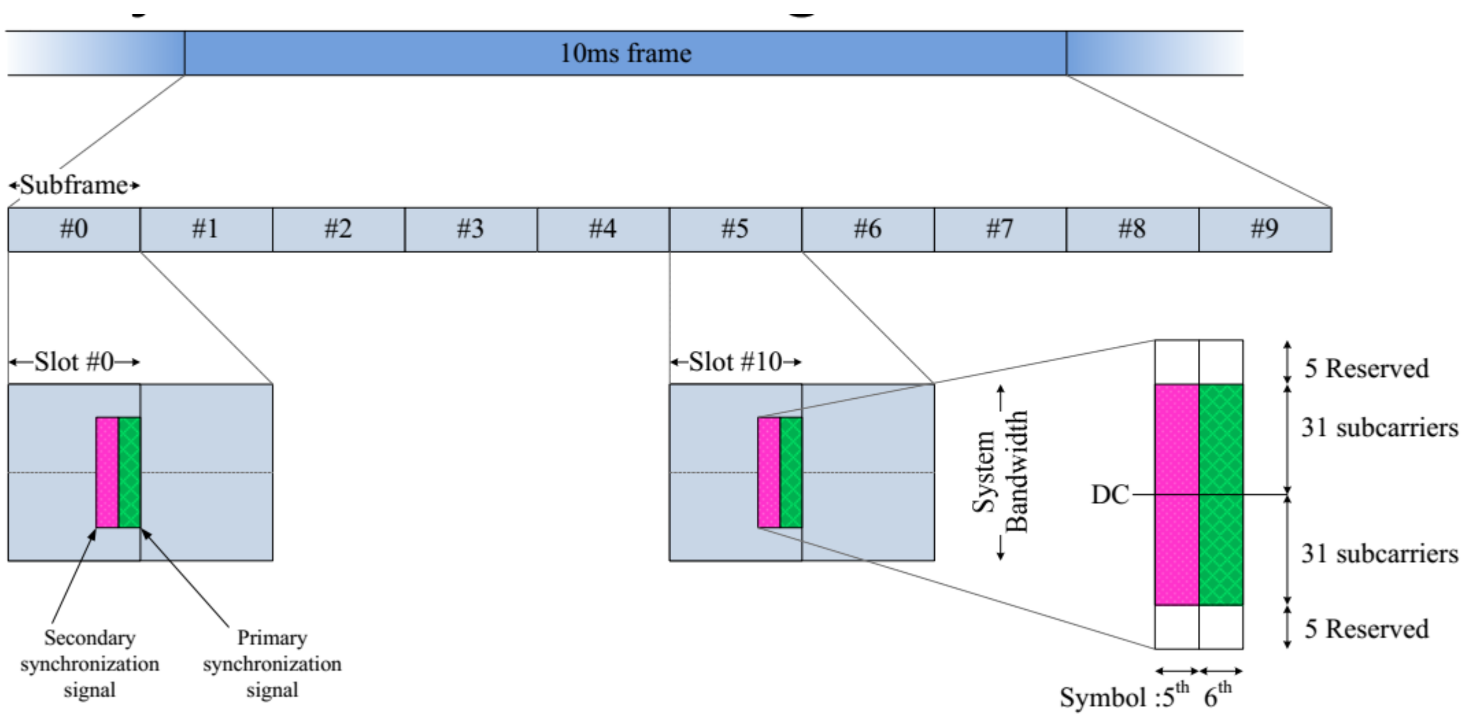
# Initial Access

- Initial access procedure for LTE
  - Synchronization: find the frames via PSS (Primary synchronization signal)
  - Cell search: tell the BSs via PSS+SSS (Secondary synchronization signal)
  - System information (e.g., sampling frequency and FFT size) receiving via PBCH and etc.
  - Random access



# PSS & SSS Location

FDD




- PSS
  - Using non-coherent detection, estimate 5msec timing and physical-layer identity
  - Channel estimation information for SSS
- SSS
  - Physical-layer identity (Cell ID) is obtained
  - Mapped to one of 168 cell ID groups (168 ID groups for 504 Cell IDs)

# Cell Identity (TS36.211 6.11)

"There are 504 unique physical-layer cell identities. The physical-layer cell identities are grouped into 168 unique physical-layer cell-identity groups, each group containing three unique identities."

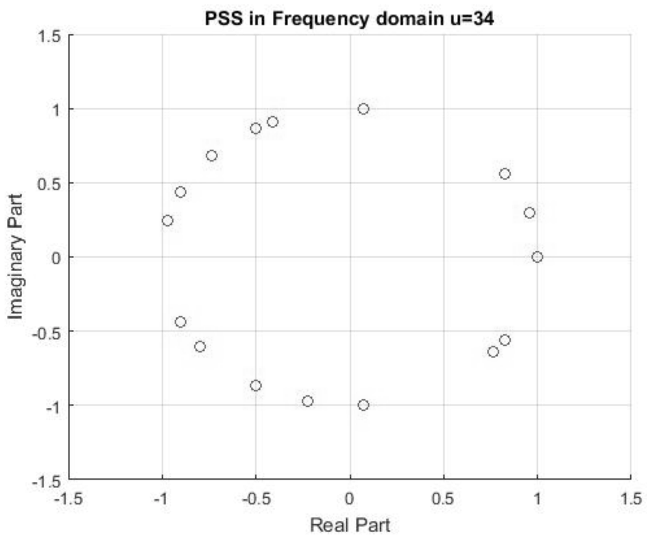
"A physical-layer cell identity $N_{\mathrm{ID}}^{\mathrm{cell}} = 3N_{\mathrm{ID}}^{(1)} + N_{\mathrm{ID}}^{(2)}$ is thus uniquely defined by a number $N_{\mathrm{ID}}^{(1)}$ in the range of 0 to 167, representing the physical-layer cell-identity group, and a number $N_{\mathrm{ID}}^{(2)}$ in the range of 0 to 2, representing the physical-layer identity within the physical-layer cell-identity group."

# PSS (TS36.211 6.11.1)

- PSS is selected according to $N_{\mathrm{ID}}^{(2)}$
- PSS with length 62 is a Zadoff Chu sequence, which is generated as follows

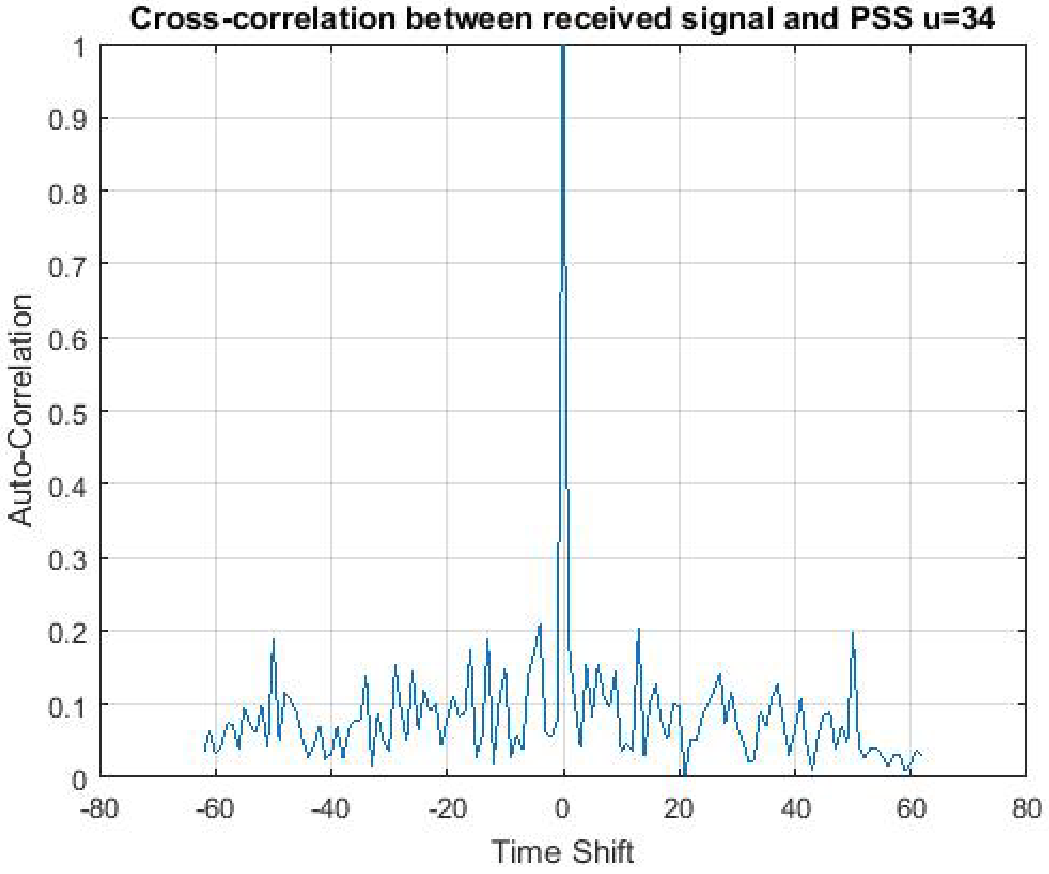
$$d_u(n) = \begin{cases} e^{-j\frac{\pi u n(n+1)}{63}} & n = 0,1,\ldots,30 \\ e^{-j\frac{\pi u(n+1)(n+2)}{63}} & n = 31,32,\ldots,61 \end{cases}$$

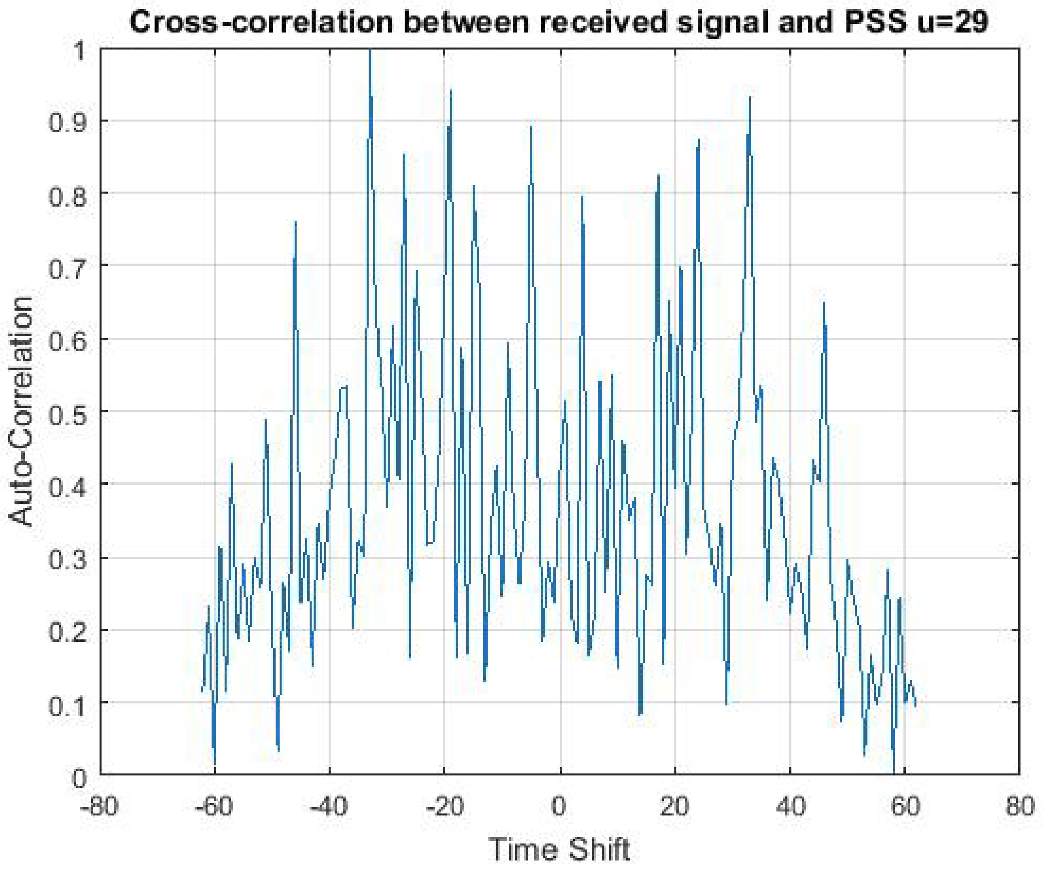
| $N_{\mathrm{ID}}^{(2)}$ | Root index $u$ |
|---|---|
| 0 | 25 |
| 1 | 29 |
| 2 | 34 |




- PSS sequences are orthogonal with respect to different u.
- PSS has small cross correlation with shifting

## Assume PSS with u=34 is transmitted



# Detection of PSS

- When power on, search PSS on all possible carrier frequency with sampling frequency 1.92MHz.
- Structure of CP can be used to find the timing of frames

| Channel bandwidth [MHz] | 1.4 | 3 | 5 | 10 | 15 | 20 |
|---|---|---|---|---|---|---|
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# Detection of PSS

Eliminate by LPF

- With sample frequency = 1.92MHz

$$x_n^{128} = \sum_{k=-63}^{64} a_k e^{\frac{j2\pi kn}{128}} = \underbrace{\sum_{k\neq 0, k=-31}^{31} a_k e^{\frac{j2\pi kn}{128}}}_{\text{Subcarriers for PSS}} + \boxed{\sum_{other\ k} a_k e^{\frac{j2\pi kn}{128}}}$$

- With sample frequency = 3.84MHz

$$x_n^{256} = \sum_{k=-127}^{128} a_k e^{\frac{j2\pi kn}{256}} = \sum_{k\neq 0, k=-31}^{31} a_k e^{\frac{j2\pi kn}{256}} + \boxed{\sum_{other\ k} a_k e^{\frac{j2\pi kn}{256}}}$$

# Detection of PSS

- 1.92MHz

$$x_n^{128} = \sum_{k=-63}^{64} a_k e^{\frac{j2\pi kn}{128}} = \sum_{k\neq 0, k=-31}^{31} a_k e^{\frac{j2\pi kn}{128}}$$

| | | | |
|---|---|---|---|
| $x_0^{128}$ | $x_1^{128}$ | … | $x_{127}^{128}$ |

- 3.84MHz

| | | | | | | |
|---|---|---|---|---|---|---|
| $x_0^{256}$ | $x_1^{256}$ | $x_2^{256}$ | $x_3^{256}$ | … | $x_{254}^{256}$ | $x_{255}^{256}$ |

$$x_n^{256} = \sum_{k=-127}^{128} a_k e^{\frac{j2\pi kn}{256}} = \sum_{k\neq 0, k=-31}^{31} a_k e^{\frac{j2\pi kn}{256}}$$

# Detection of PSS

- 1.92MHz

$$x_n^{128} = \sum_{k=-63}^{64} a_k e^{\frac{j2\pi kn}{128}} = \sum_{k\neq 0, k=-31}^{31} a_k e^{\frac{j2\pi kn}{128}}$$

| | | | |
|---|---|---|---|
| $x_0^{128}$ | $x_1^{128}$ | … | $x_{127}^{128}$ |

| | | | | | | |
|---|---|---|---|---|---|---|
| $x_0^{256}$ | $x_1^{256}$ | $x_2^{256}$ | $x_3^{256}$ | … | $x_{254}^{256}$ | $x_{255}^{256}$ |

- 3.84MHz

$$x_n^{256} = \sum_{k=-127}^{128} a_k e^{\frac{j2\pi kn}{256}} = \sum_{k\neq 0, k=-31}^{31} a_k e^{\frac{j2\pi kn}{256}}$$

# Detection of PSS

- 1.92MHz

$$x_n^{128} = \sum_{k=-63}^{64} a_k e^{\frac{j2\pi kn}{128}} = \sum_{k\neq 0,k=-31}^{31} a_k e^{\frac{j2\pi kn}{128}}$$

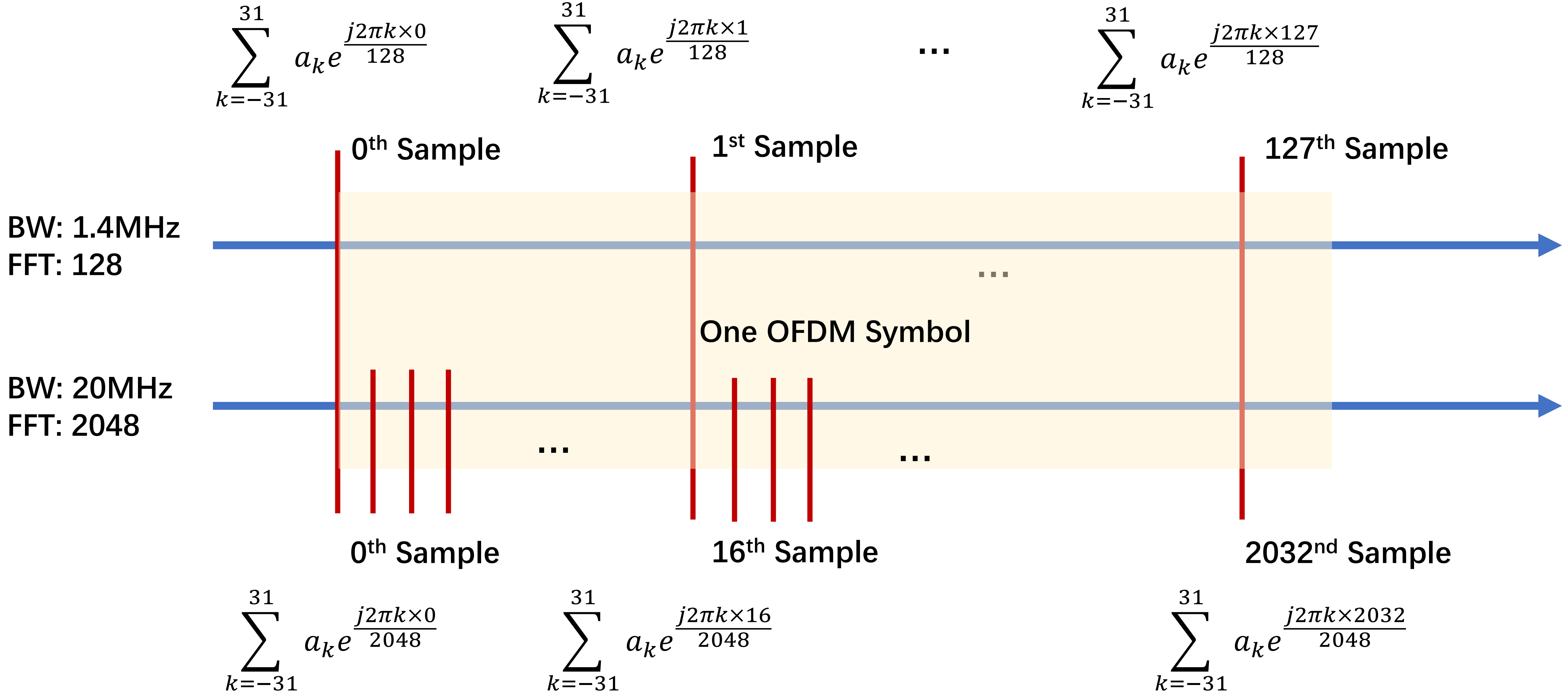
| | | | |
|---|---|---|---|
| $x_0^{128}$ | $x_1^{128}$ | … | $x_{127}^{128}$ |

- 3.84MHz

| | | | | | | |
|---|---|---|---|---|---|---|
| $x_0^{256}$ | $x_1^{256}$ | $x_2^{256}$ | $x_3^{256}$ | … | $x_{254}^{256}$ | $x_{255}^{256}$ |

$$x_n^{256} = \sum_{k=-127}^{128} a_k e^{\frac{j2\pi kn}{256}} = \sum_{k\neq 0,k=-31}^{31} a_k e^{\frac{j2\pi kn}{256}}$$

If we sample both with 1.92MHz, we have the same resulting sequences, which is the 128FFT of PSS



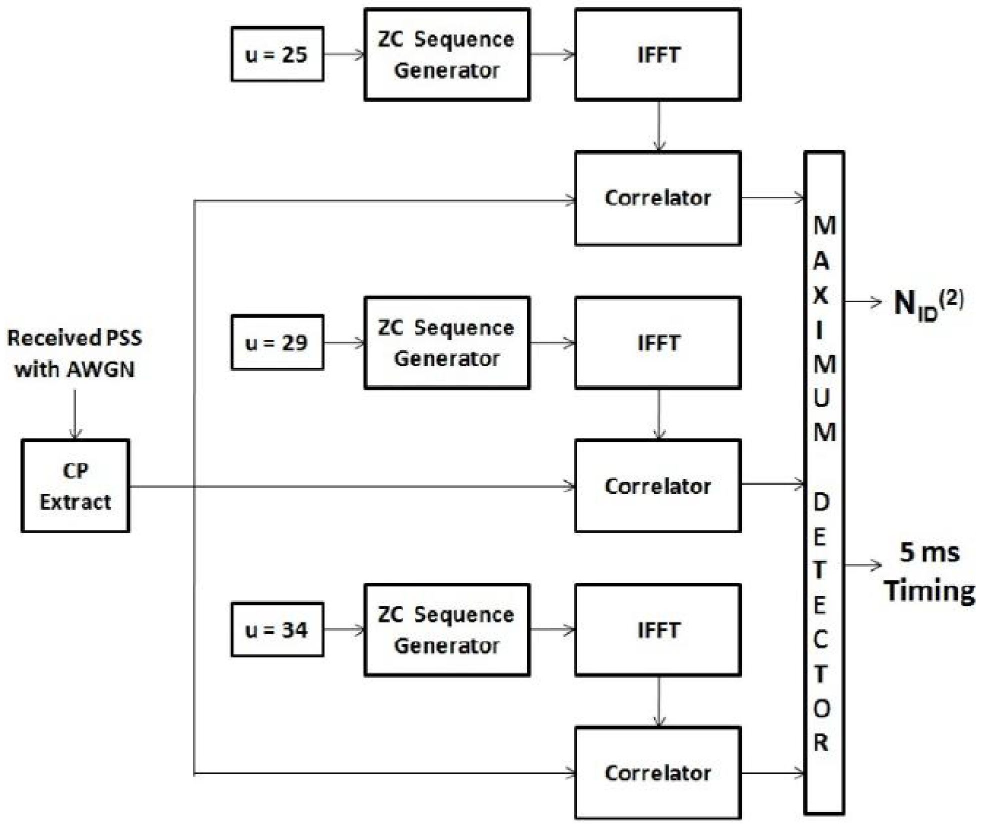
$\sum_{k=-31}^{31} a_k e^{\frac{j2\pi k\times 0}{128}}$
$\sum_{k=-31}^{31} a_k e^{\frac{j2\pi k\times 1}{128}}$
…
$\sum_{k=-31}^{31} a_k e^{\frac{j2\pi k\times 127}{128}}$
$0^{th}$ Sample
$1^{st}$ Sample
$127^{th}$ Sample
BW: 1.4MHz
FFT: 128
…
One OFDM Symbol
BW: 20MHz
FFT: 2048
…
…
$0^{th}$ Sample
$16^{th}$ Sample
$2032^{nd}$ Sample
$\sum_{k=-31}^{31} a_k e^{\frac{j2\pi k\times 0}{2048}}$
$\sum_{k=-31}^{31} a_k e^{\frac{j2\pi k\times 16}{2048}}$
$\sum_{k=-31}^{31} a_k e^{\frac{j2\pi k\times 2032}{2048}}$

# Detection of PSS

- No matter what sampling frequency is used
- If we get the OFDM symbol with PSS
- After LPF, if we sample with 1.92MHz, we always get the 128FFT of PSS

# Detection of PSS

- When power on, search PSS on all possible carrier frequency.
- Three possible PSSs should be searched simultaneously using cross-correlation.
- For FDD, PSS locates in the last OFDM symbols of slot #0, 10.
- When a PSS is found, the user knows $N_{ID}^{(2)}$ and timing of slot #0 or 10.



# Reading & Homework (14 April)

**3GPP TS 36.211**

- Related part in Section 4, 5.1, 5.2, 6.1, 6.2, 6.6, 6.11

**3GPP TS 38.211**

- Section 4

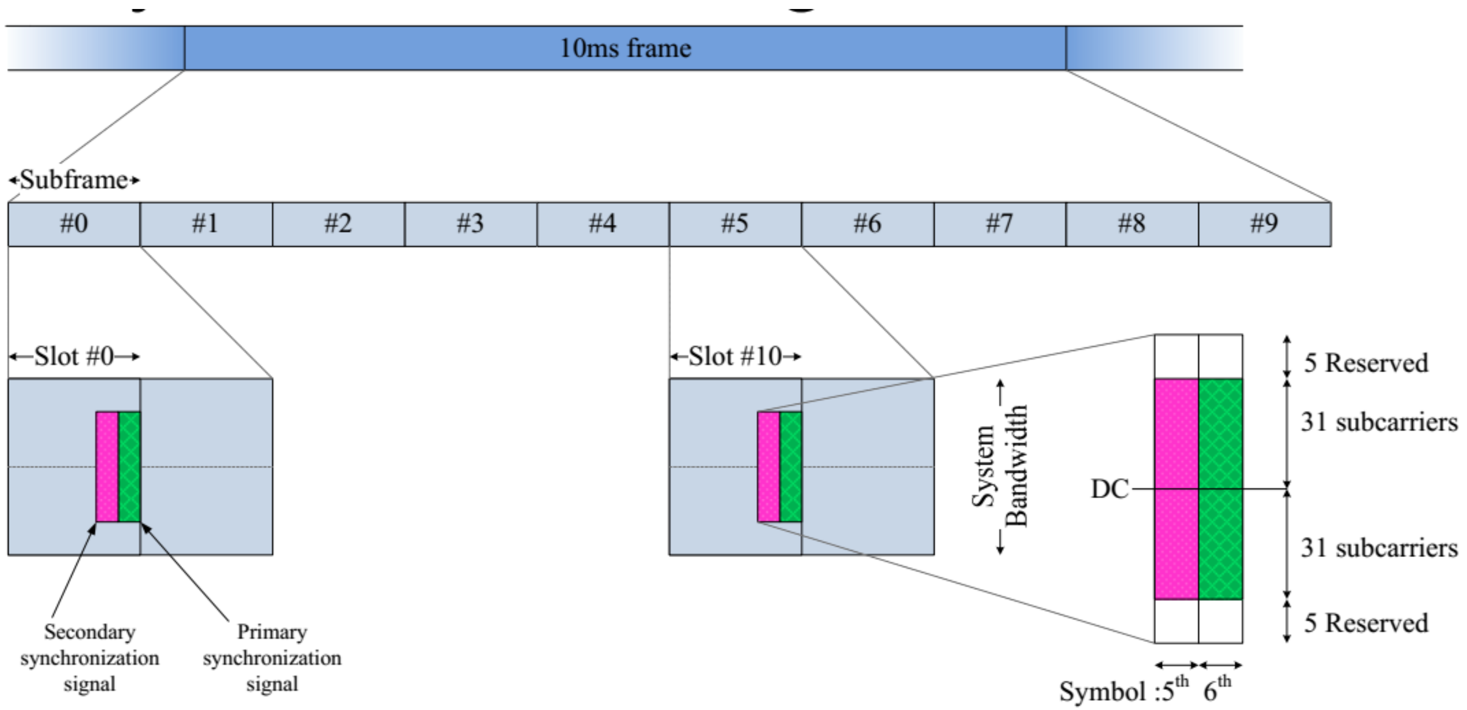
**Homework:** Please show the PSS detection error probability versus SNR via Mento Carlo simulations

# Recap: What we can do with PSS?

- OFDM-Symbol-level synchronization
- User detects the timing of the 0$^{th}$ or 5$^{th}$ subframe
- $N_{\mathrm{ID}}^{(2)}$ can be detected
- Remark:
  - Although the user does not know the actual bandwidth, it can detect the symbols of the lowest 128 subcarriers with 1.92MHz sampling frequency

# Recap: PSS & SSS Location

FDD




- PSS
  - Using non-coherent detection, estimate 5msec timing and physical-layer identity
  - Channel estimation information for SSS
- SSS
  - Physical-layer identity (Cell ID) is obtained
  - Mapped to one of 168 cell ID groups (168 ID groups for 504 Cell IDs)

# PSS Helps SSS Detection

- Use PSS, we can estimate the CSI of subcarriers from -31 to 31
- Since SSS symbol is next to PSS symbol, SSS can be estimated

# SSS (TS36.211 6.11.2)

- SSS is generated according to subframe index and cell ID.
- Thus, by the detection of SSS, the above information can be obtained.

$$x(\bar{i}+5) = \left(x(\bar{i}+2) + x(\bar{i})\right) \bmod 2, \qquad 0 \le \bar{i} \le 25$$

$$x(0)=0,\quad x(1)=0,\quad x(2)=0,\quad x(3)=0,\quad x(4)=1$$

$$\tilde{s}(i) = 1 - 2x(i), \qquad 0 \le i \le 30$$

$$m' = N_{\mathrm{ID}}^{(1)} + q(q+1)/2, \quad q = \left\lfloor \frac{N_{\mathrm{ID}}^{(1)} + q'(q'+1)/2}{30} \right\rfloor, \quad q' = \left\lfloor N_{\mathrm{ID}}^{(1)}/30 \right\rfloor$$

$$s_0^{(m_0)}(n) = \tilde{s}\left((n+m_0) \bmod 31\right)$$
$$s_1^{(m_1)}(n) = \tilde{s}\left((n+m_1) \bmod 31\right)$$

$$m_0 = m' \bmod 31$$
$$m_1 = \left(m_0 + \lfloor m'/31 \rfloor + 1\right) \bmod 31$$

$$d(2n) = \begin{cases} s_0^{(m_0)}(n)\, c_0(n) & \text{in subframe 0} \\ s_1^{(m_1)}(n)\, c_0(n) & \text{in subframe 5} \end{cases}$$
$$d(2n+1) = \begin{cases} s_1^{(m_1)}(n)\, c_1(n)\, z_1^{(m_0)}(n) & \text{in subframe 0} \\ s_0^{(m_0)}(n)\, c_1(n)\, z_1^{(m_1)}(n) & \text{in subframe 5} \end{cases} \qquad (0 \le n \le 30)$$

$$c_0(n) = \tilde{c}\left((n + N_{\mathrm{ID}}^{(2)}) \bmod 31\right)$$
$$c_1(n) = \tilde{c}\left((n + N_{\mathrm{ID}}^{(2)} + 3) \bmod 31\right)$$

$$z_1^{(m_0)}(n) = \tilde{z}\left((n + (m_0 \bmod 8)) \bmod 31\right)$$
$$z_1^{(m_1)}(n) = \tilde{z}\left((n + (m_1 \bmod 8)) \bmod 31\right)$$

$$\tilde{c}(i) = 1 - 2x(i), \qquad 0 \le i \le 30$$

$$\tilde{z}(i) = 1 - 2x(i), \qquad 0 \le i \le 30$$

$$x(\bar{i}+5) = \left(x(\bar{i}+3) + x(\bar{i})\right) \bmod 2, \qquad 0 \le \bar{i} \le 25$$
$$x(0)=0,\quad x(1)=0,\quad x(2)=0,\quad x(3)=0,\quad x(4)=1$$

$$x(\bar{i}+5) = \left(x(\bar{i}+4) + x(\bar{i}+2) + x(\bar{i}+1) + x(\bar{i})\right) \bmod 2, \qquad 0 \le \bar{i} \le 25$$
$$x(0)=0,\quad x(1)=0,\quad x(2)=0,\quad x(3)=0,\quad x(4)=1$$

# Detection of SSS

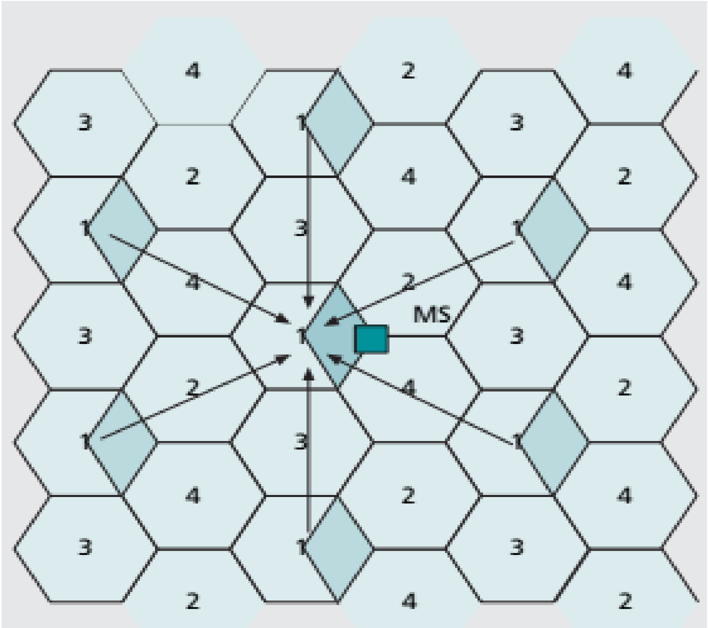
- When a PSS is found, the user continues to detect the SSS in one OFDM symbol before.
- Given $N_{ID}^{(2)}$ , there are 168 $\times$2 different possibilities of SSS in slot #0 and #10.
- The user could find which one is used, then $N_{ID}^{(1)}$ and frame timing
- Physical Cell Identities (PCI) = $3 \times N_{ID}^{(1)} + N_{ID}^{(2)}$
- Conclusion: After PSS and SSS detection, user knows the Cell ID and timing of frame

# Discussion

- **What does the user obtain after PSS and SSS?**

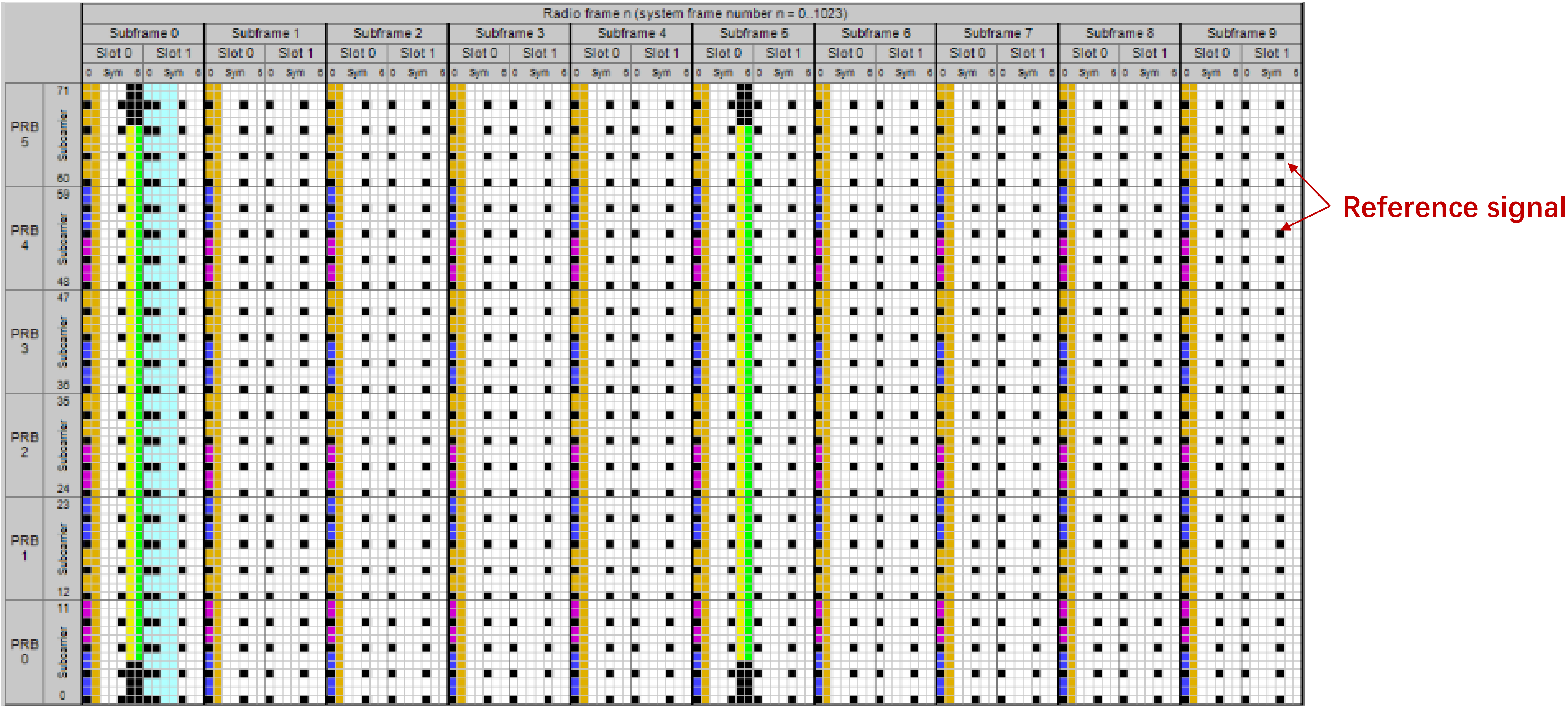
- How many BSs around, what their Cell IDs are, what their signal strengths are
- Synchronize with the strongest cell

- **What's the next step of receiving?**



# Physical Broadcast Channel (PBCH)

- Master information block (MIB) from upper layer is transmitted in PBCH
- PBCH is transmitted on every 10ms, the $0^{th}$ subframe of each frame, information in PBCH is updated every 40ms (4 frames)
- 4 OFDM symbols after PSS, 72 subcarriers (we are always able to detect the symbols on the lowest 128 subcarriers without actual bandwidth)
- 14bits MIB information, code rate = 1/3, scrambled with Cell ID, QPSK,

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- PDCCH (Physical Downlink Control Channel)
- Available for PDSCH (Physical Downlink Shared Channel)

# MIB

- Master information block (MIB) of system information is transmitted on PBCH

```
MasterInformationBlock ::=          SEQUENCE {
    dl-Bandwidth                        ENUMERATED {
                                            n6, n15, n25, n50, n75, n100},
    phich-Config                        PHICH-Config,
    systemFrameNumber                   BIT STRING (SIZE (8)),
    schedulingInfoSIB1-BR-r13           INTEGER (0..31),
    spare                               BIT STRING (SIZE (5))
}
```

# Up to now

- **PSS & SSS:** Synchronize with the desired cell
- **PBCH:** Know the bandwidth and FFT size
- What's the next? Detect the frame head --- **PDCCH**
- The issue of PDCCH detection: # of OFDM symbols is variable

"The **physical control format indicator channel** carries information about the number of OFDM symbols used for transmission of PDCCHs in a subframe."

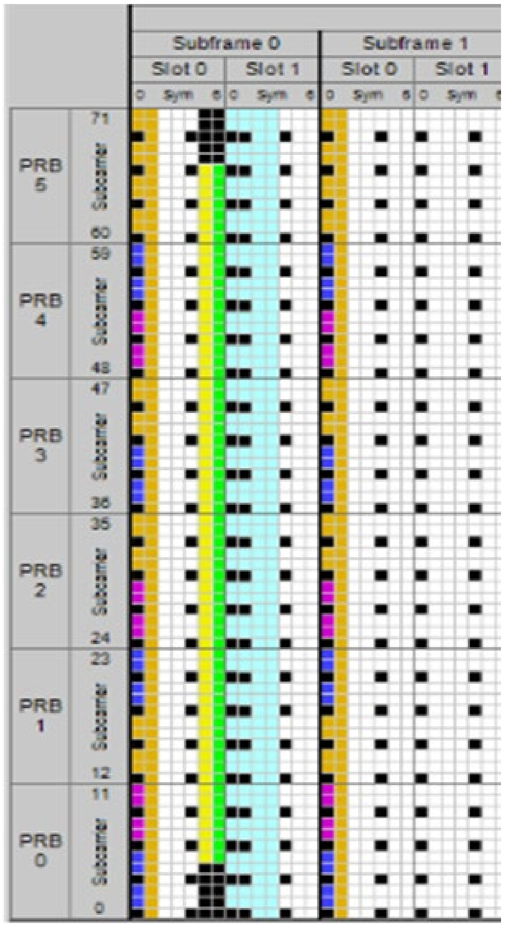
**--- TS36.211 v13 6.7**

# Control Format Indicator (CFI)

- CFI is an indicator telling how many OFDM symbols are used for carrying control channel (e.g, PDCCH and PHICH) at each subframe. (TS36.212 v13 5.3.4)
- This CFI is carried by a specific physical channel called **PCFICH**. (TS36.211 v13 6.7)
- PCFICH consists of 16REs at fixed locations of the first symbol in each subframe, carrying only CFI without any other information. (TS36.211 v13 6.7.4)
- QPSK

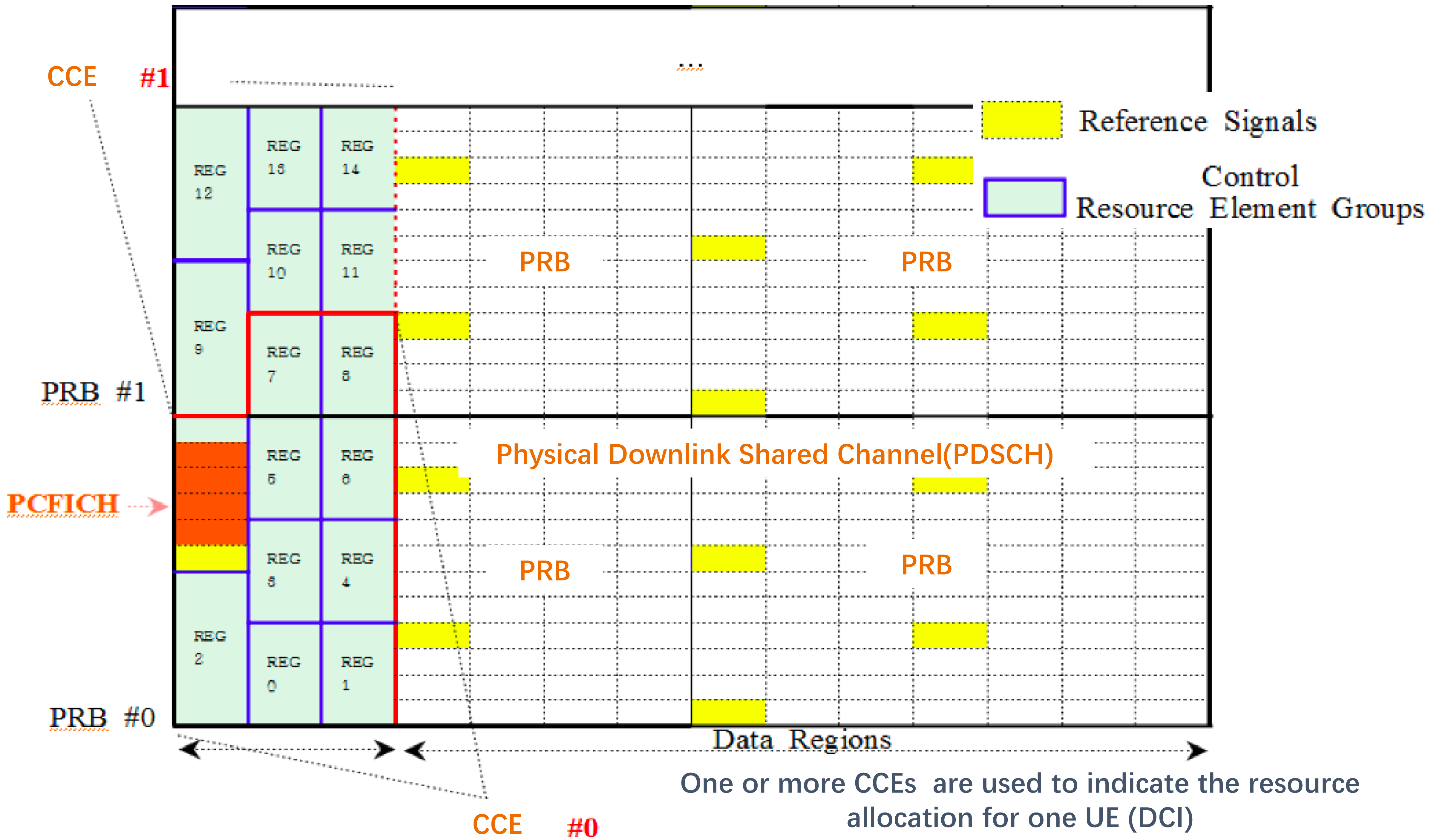
Table 5.3.4-1: CFI codewords

| CFI | CFI codeword $\langle b_0, b_1, \ldots, b_{31} \rangle$ |
|---|---|
| 1 | <0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1> |
| 2 | <1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0> |
| 3 | <1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1,0,1,1> |
| 4 (Reserved) | <0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0> |

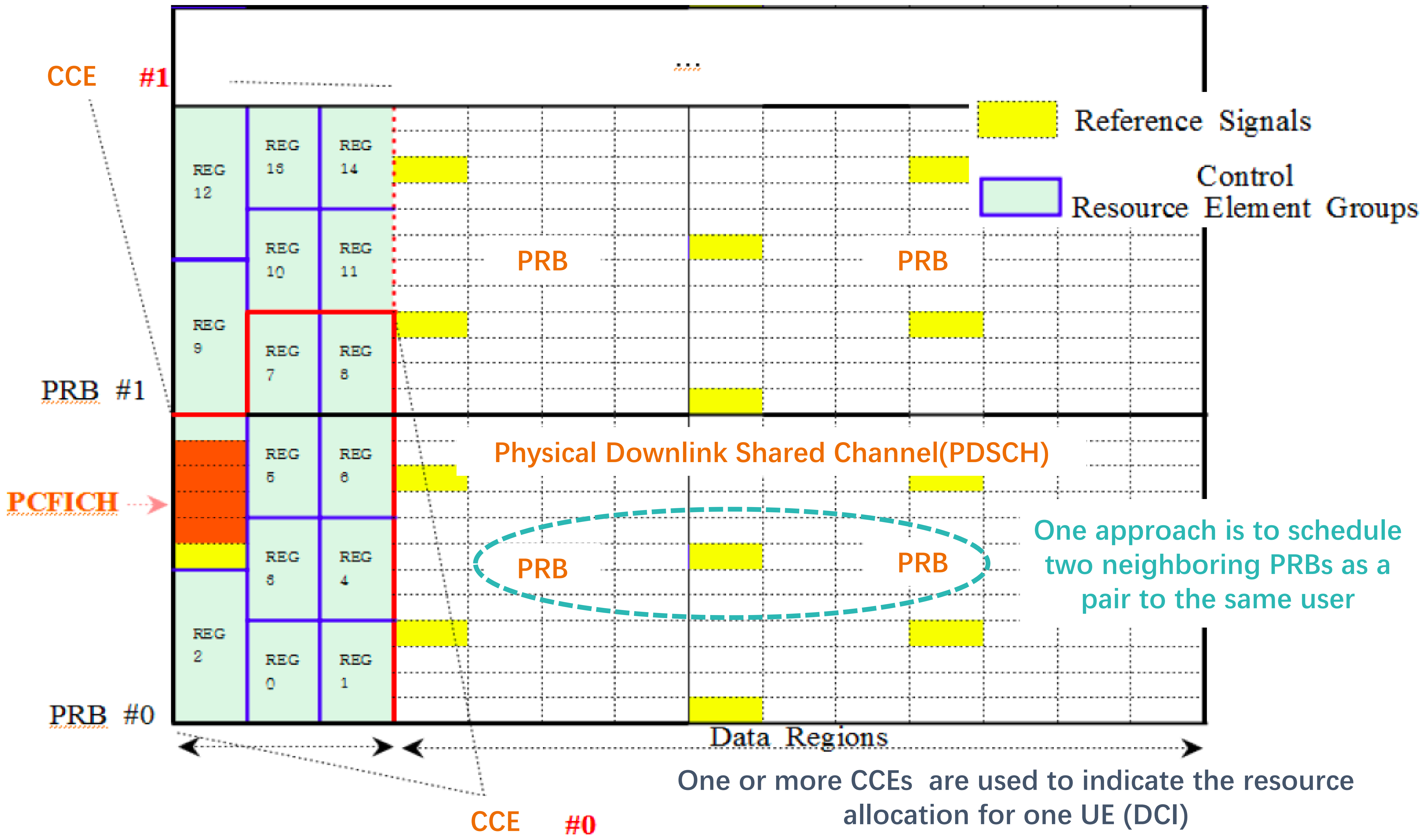


# Control Channel Element (CCE)

- "The **physical downlink control channel** carries scheduling assignments and other control information. A physical control channel is transmitted on an **aggregation of one or several consecutive control channel elements (CCEs)**, where **a control channel element corresponds to 9 resource element groups**." TS36.211 v13 6.8.1
- The RE in the control head is organized by control channel elements.
  - 1 CCE = 9 continuous REG ( Resource element Group )
  - 1 REG = 4 RE for PDCCH ( Resource Element )
- Since QPSK is used for CCE, one CCE can carry 72 bits
- Larger bandwidth and larger CFI lead to more CCE




One or more CCEs are used to indicate the resource allocation for one UE (DCI)


CCE #1
...
Reference Signals
Control Resource Element Groups
REG 12
REG 13
REG 14
REG 10
REG 11
REG 9
REG 7
REG 8
PRB
PRB
PRB #1
Physical Downlink Shared Channel(PDSCH)
REG 5
REG 6
PCFICH
REG 3
REG 4
PRB
PRB
One approach is to schedule two neighboring PRBs as a pair to the same user
REG 2
REG 0
REG 1
PRB #0
Data Regions
One or more CCEs are used to indicate the resource allocation for one UE (DCI)
CCE #0

# Downlink Control Indicator (TS36.212 v13 5.3.3)

- The information carried by each PDCCH is call Downlink Control Indicator (DCI)
- DCI maintains at least the following information
  - which resource blocks carry your data
  - what kind of modulation and coding scheme is used for the data transmission
- One DCI is carried by one or multiple CCE

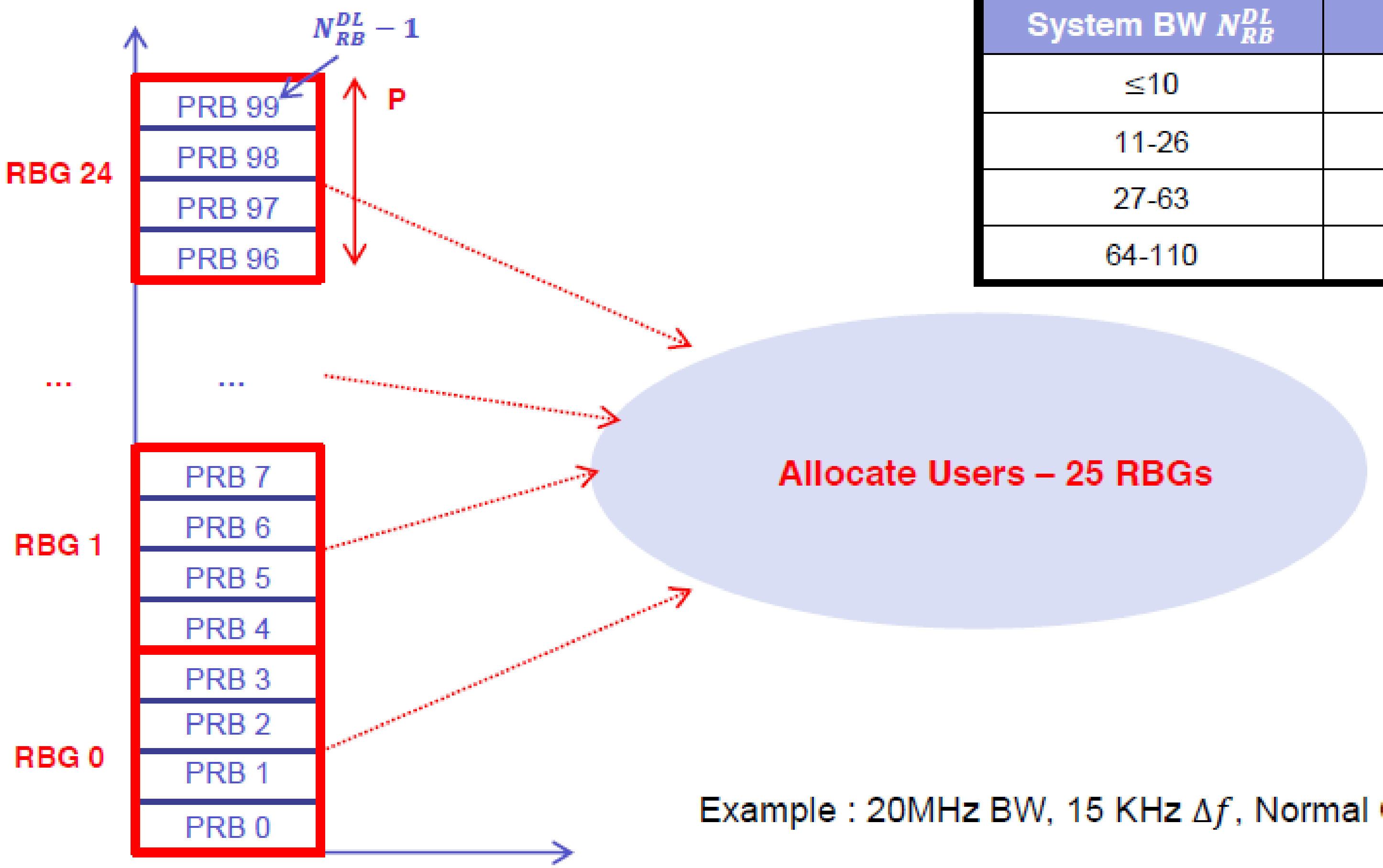
| DCI Format | Usage | Major Contents |
|---|---|---|
| Format 0 | UL Grant. Resource Allocation for UL Data | RB Assignment,TPC,PUSCH Hopping Flag |
| Format 1 | DL Assignment for SISO | RB Assignment,TPC, HARQ |
| Format 1A | DL Assignment for SISO (compact) | RB Assignment,TPC, HARQ |
| Format 1B | DL Assignment for MIMO with Rank 1 | RB Assignment,TPC, HARQ,TPMI, PMI |
| Format 1C | DL Assignment for SISO (minimum size) | RB Assignment |
| Format 1D | DL Assignment for Multi User MIMO | RB Assignment,TPC, HARQ,TPMI,DL Power Offset |
| Format 2 | DL Assignment for Closed Loop MIMO | RB Assignment,TPC, HARQ, Precoding Information |
| Format 2A | DL Assignment for Open Loop MIMO | RB Assignment,TPC, HARQ, Precoding Information |
| Format 2B | DL Assignment for TM8 (Dual Layer Beamforming) | RB Assignment,TPC, HARQ, Precoding Information |
| Format 2C | DL Assignment for TM9 | RB Assignment,TPC, HARQ, Precoding Information |
| Format 3 | TPC Commands for PUCCH and PUSCH with 2 bit power adjustment | Power Control Only |
| Format 3A | TPC Commands for PUCCH and PUSCH with 1 bit power adjustment | Power Control Only |
| Format 4 | UL Assignment for UL MIMO (up to 4 layers) | RB Assignment,TPC, HARQ, Precoding Information |

# PDSCH Resource Allocation

| Resource Allocation | | Purpose | DCI Format |
|---|---|---|---|
| DL Scheduling | Type 0 | Resource Block Group (RBG) based | 1 |
| | | RBG based (MIMO : Closed Loop) | 2 |
| | | RBG based (MIMO : Open Loop) | 2A |
| | Type 1 | Selected RBG Subset based | 1 |
| | | Selected RBG Subset based (MIMO : Closed Loop) | 2 |
| | | Selected RBG Subset based (MIMO Open Loop) | 2A |
| | Type 2 | VRB based Compact Scheduling + Random Access | 1A |
| | | VRB based Compact Scheduling with MIMO | 1B |
| | | VRB based Very Compact Scheduling | 1C |
| | | VRB based Compact Scheduling with MIMO & Power Offset | 1D |
| UL Scheduling | | VRB based UL Scheduling | 0 |

(Reference : pp. 22-25 3GPP TS 36.213 V8.8.0 (2009-09))

# DL Resource Allocation : Type 0




| System BW $N_{RB}^{DL}$ | RGB Size (P) |
|---|---|
| ≤10 | 1 |
| 11-26 | 2 |
| 27-63 | 3 |
| 64-110 | 4 |

Example : 20MHz BW, 15 KHz $\Delta f$, Normal CP

# ▪ DCI Format 1

| Bits | Field |
|---|---|
| 1 | Resource Allocation Header: ***Resource Allocation Type 0*** or 1 |
| $\left\lceil \frac{N_{RB}^{DL}}{P} \right\rceil$ | ***Resource Assignment*** |
| 5 | ***MCS*** |
| 3 or 4 | HARQ Process : 3 for FDD, 4 for TDD |
| 1 | New Data Indicator |
| 2 | Redundancy Version |
| 2 | UL Power Control (PUCCH) |
| 2 | Downlink Assignment Index : TDD |

| | | |
|---|---|---|
| DCI-FORMAT-1-10MHz | | SEQUENCE |
| ResoureAllocation | RAType0 | CHOICE |
| RAType0 | | SEQUENCE |
| RB-Assign | 00110100000000000 | BIT STRING |
| MCS | 0 | INTEGER |
| HARQ-Process | 0 | INTEGER |
| NDI | 0 | BIT STRING |
| RV | 0 | INTEGER |
| TPC | 00 | BIT STRING |
| DAI | 00 | BIT STRING |

Bit 2 Bit 3 Bit 5

10 Mhz = 50 RBs

<table>
<tr><td>PRB</td><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td></tr>
<tr><td>RBG</td><td colspan="3">RBG 0</td><td colspan="3">RBG 1</td><td colspan="3">RBG 2</td><td colspan="3">RBG 3</td><td colspan="3">RBG 4</td><td colspan="3">RBG 5</td><td colspan="3">RBG 6</td><td colspan="3">RBG 7</td><td colspan="3">RBG 8</td></tr>
<tr><td>Bitmap</td><td colspan="3">0</td><td colspan="3">0</td><td colspan="3">1</td><td colspan="3">1</td><td colspan="3">0</td><td colspan="3">1</td><td colspan="3">0</td><td colspan="3">0</td><td colspan="3">0</td></tr>
</table>

<table>
<tr><td>PRB</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td><td>32</td><td>33</td><td>34</td><td>35</td><td>36</td><td>37</td><td>38</td><td>39</td><td>40</td><td>41</td><td>42</td><td>43</td><td>44</td><td>45</td><td>46</td><td>47</td><td>48</td><td>49</td></tr>
<tr><td>RBG</td><td colspan="3">RBG 9</td><td colspan="3">RBG 10</td><td colspan="3">RBG 11</td><td colspan="3">RBG 12</td><td colspan="3">RBG 13</td><td colspan="3">RBG 14</td><td colspan="3">RBG 15</td><td colspan="2">RBG16</td></tr>
<tr><td>Bitmap</td><td colspan="3">0</td><td colspan="3">0</td><td colspan="3">0</td><td colspan="3">0</td><td colspan="3">0</td><td colspan="3">0</td><td colspan="3">0</td><td colspan="2">0</td></tr>
</table>

RBG

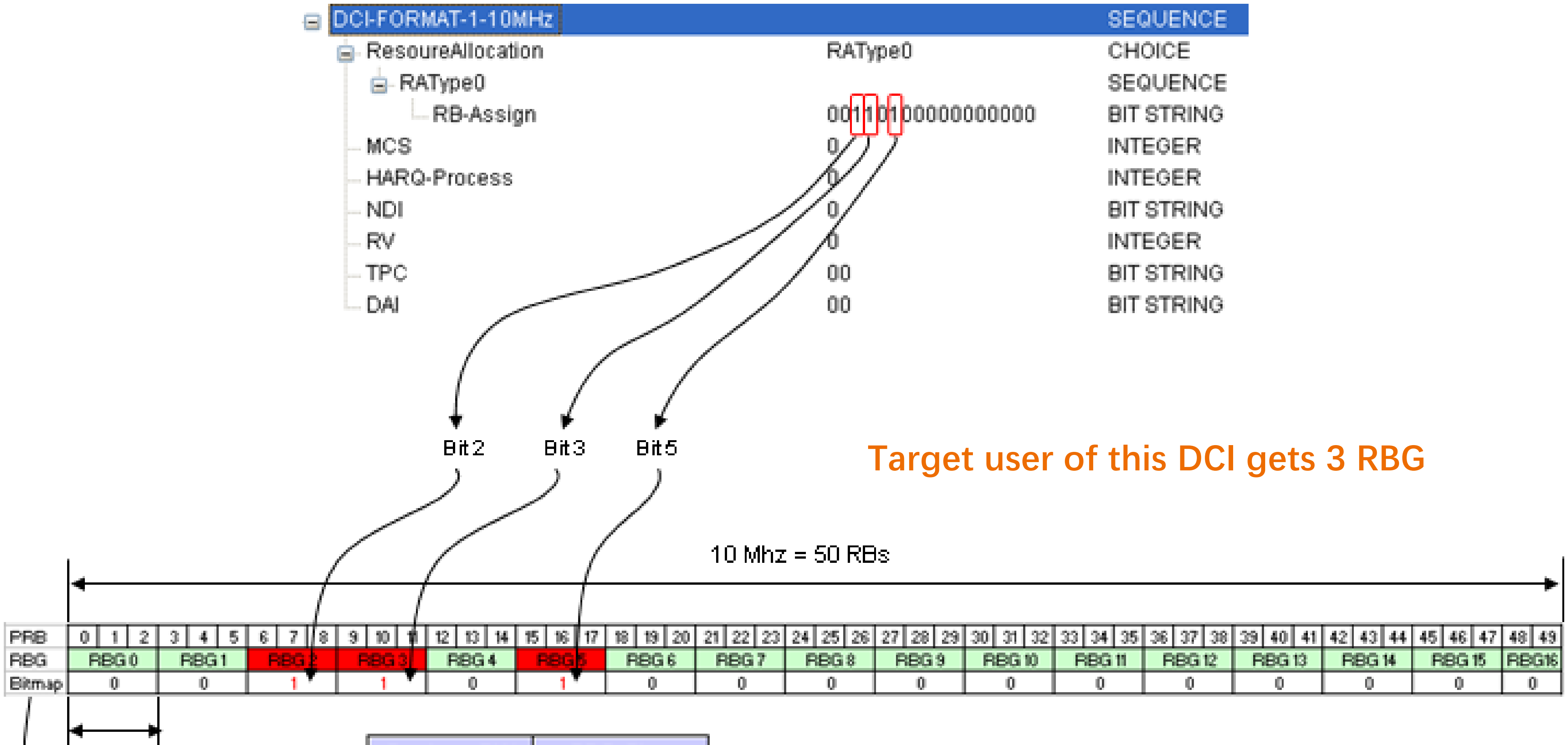
3 RBs in 1 RBG

| System BW | RBG Size |
|---|---|
| 1.4 | 1 |
| 3 | 2 |
| 5 | 2 |
| 10 | 3 |
| 15 | 4 |
| 20 | 4 |

**Table 7.1.6.1-1:**

| System Bandwidth $N_{RB}^{DL}$ | RBG Size ($P$) |
|---|---|
| ≤10 | 1 |
| 11 – 26 | 2 |
| 27 – 63 | 3 |
| 64 – 110 | 4 |

Bitmap represents which RBG is allocated for data transmission. 1 indicate 'allocated', 0 indicated 'not-allocated'




**Target user of this DCI gets 3 RBG**

| System BW | RBG Size |
|---|---|
| 1.4 | 1 |
| 3 | 2 |
| 5 | 2 |
| 10 | 3 |
| 15 | 4 |
| 20 | 4 |

**Table 7.1.6.1-1:**

| System Bandwidth $N_{RB}^{DL}$ | RBG Size ($P$) |
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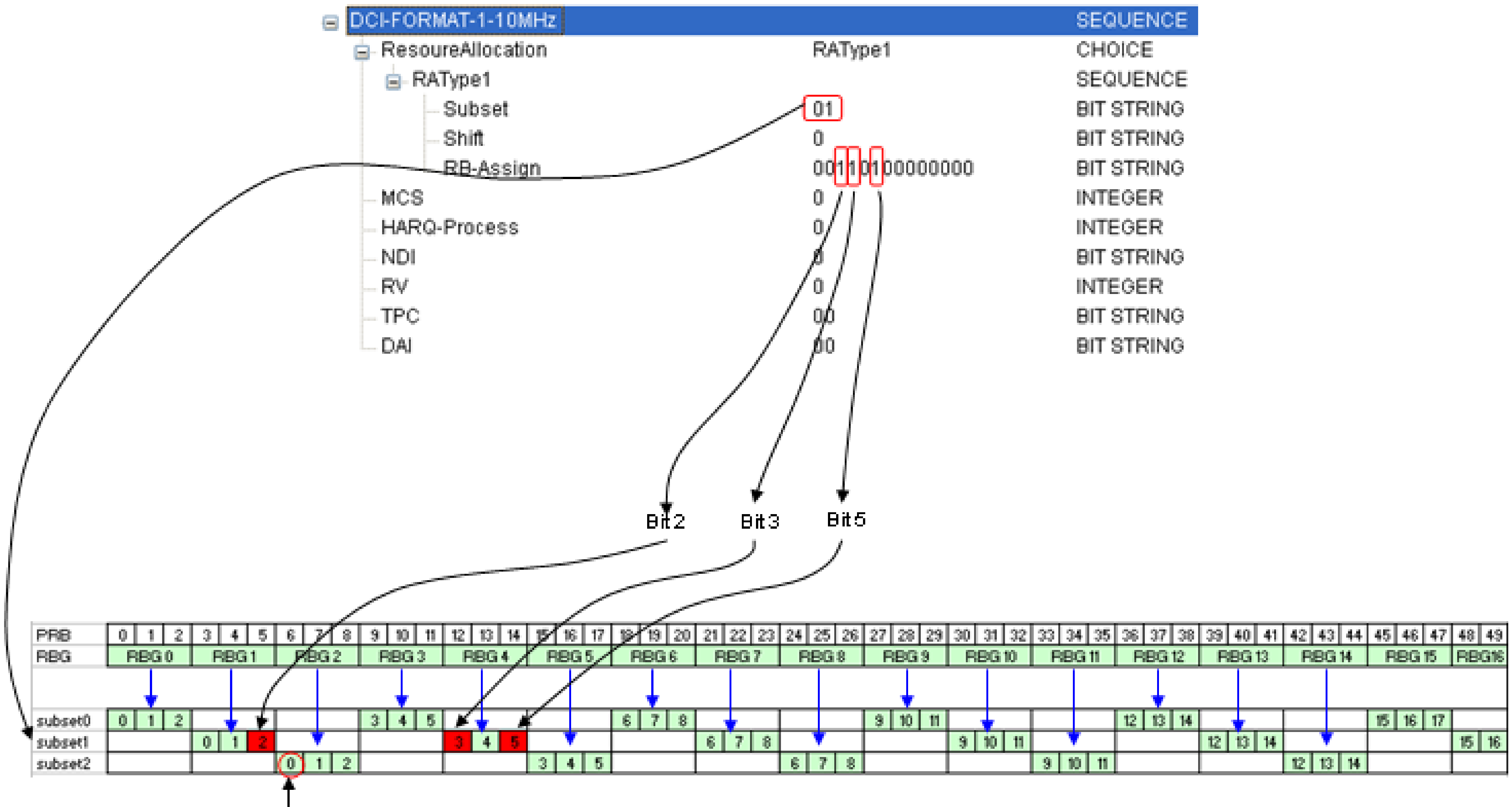
Bitmap represents which RBG is allocated for data transmission. 1 indicate 'allocated', 0 indicated 'not-allocated'

# DL Resource Allocation : Type 1




These number indicates the bit position of RBs allocated for each of the subset

# Homework (21 April)

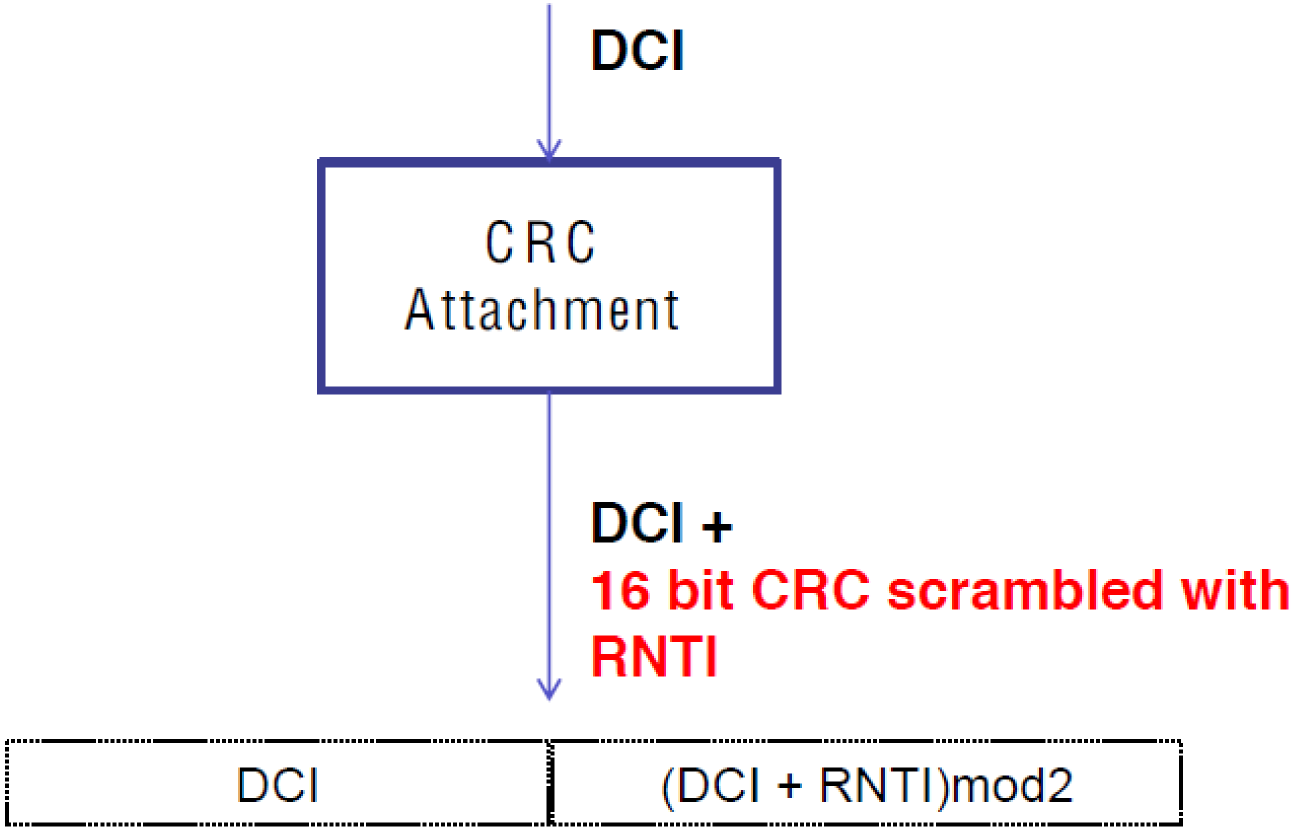
**Please explain DCI formats 2 and 4.**

# What’s the next issue?

- How to find the exact REs carrying one PDCCH?  --- Blind detection
- How to determine the receiver of one PDCCH? --- CRC checking bits

# Whose PDCCH?

✓ With RNTI (Radio Network Temporary Identifier) : User Identification



# DCI Encoding (TS36.212 v13 5.3.3)

- Denote the bits of the PDCCH payload by $a_0, a_1, a_2, a_3, \ldots, a_{A-1}$

and the parity bits by $p_0, p_1, p_2, p_3, \ldots, p_{L-1}$

resulting $b_0, b_1, b_2, b_3, \ldots, b_{B-1}$

- Denote the user's RNTI as $x_{rnti,0}, x_{rnti,1}, \ldots, x_{rnti,15}$

form the sequence of bits

$$c_k = b_k \quad \text{for } k = 0, 1, 2, \ldots, A\text{-}1$$

$$c_k = \left(b_k + x_{rnti,k-A}\right) \bmod 2 \quad \text{for } k = A, A+1, A+2, \ldots, A+15.$$

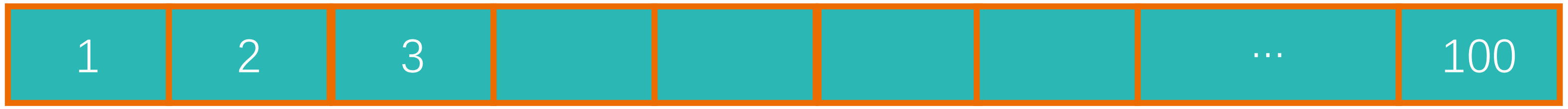
- Tail biting convolutional coding with rate 1/3

# CCE Aggregation

- DCI is transmitted by PDCCH (CCEs)
- If the DCI size is larger than 72bits, 2,4,8 CCEs can be aggregated
- For example, 50 bits after coding=>1CCE; 100 bits after coding => 2 CCEs
- CCE Aggregation levels: 1, 2, 4, 8

# Discussion

- How can one UE find the CCEs (DCI) for him?
- For example, if there are 100 CCEs in one subframe, UE has to try 100+99+97+93 possibilities, complexity is very high
- LTE system limits the search possibilities with certain CCE allocation pattern



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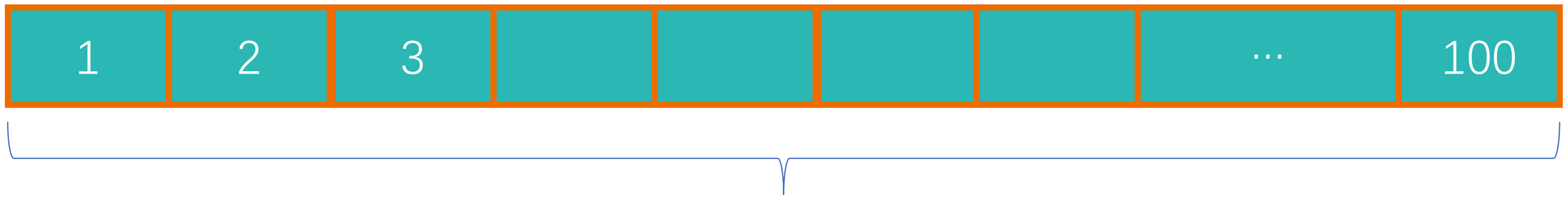


If one PDCCH occupies one CCE, there are 100 possibilities

# Discussion

- How can one UE find the CCEs (DCI) for him?
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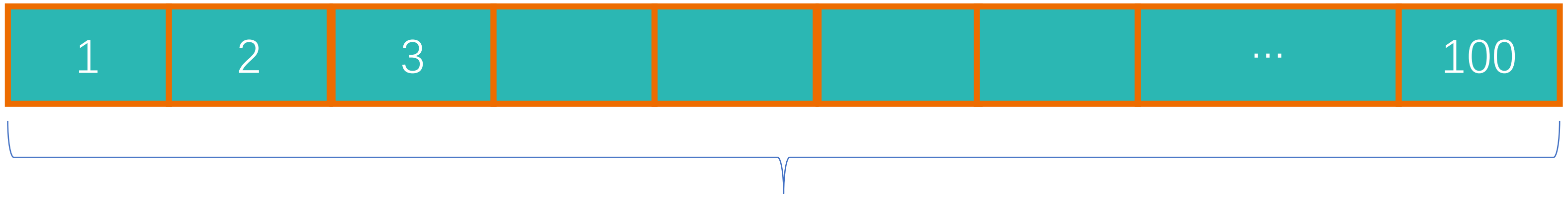


If one PDCCH occupies two CCEs, there are 99 possibilities:1+2, 2+3, 3+4, …, 99+100

# Discussion

- How can one UE find the CCEs (DCI) for him?
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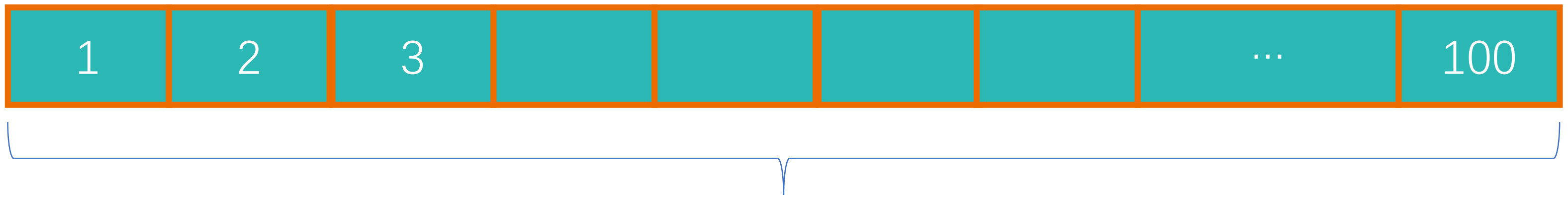
- LTE system limits the search possibilities with certain CCE allocation pattern




If one PDCCH occupies four CCEs, there are 97 possibilities:1+2+3+4, …, 97+98+99+100

# Search Space

- The CCEs in control head of one subframe can be divided into: common and UE-specific search spaces

- Common search space
  - CCEs carry the DCIs that are common for all UEs, as well as single UEs.
  - Maximum number of CCEs present in common search space is 16.
  - Each UE should check the common search space

- UE-specific search space
  - CCEs for a particular UE only.
  - Different UEs have different search spaces

# Common Search Space

- The position of Common search space CCE's is always fixed starting from the first CCE index.
- Aggregation levels of 4 and 8 are used in common search space
- Aggregation level = 4
  - CCE index 0 - will contain consecutive CCE's from 0 to 3
  - CCE index 4 - will contain consecutive CCE's from 4 to 7
  - CCE index 8 - will contain consecutive CCE's from 8 - 11
  - CCE index 12 - will contain consecutive CCE's from 12 -15
- Aggregation level = 8
  - CCE index 0 - will contain consecutive CCE's from 0 to 7
  - CCE index 8 - will contain consecutive CCE's from 8 to 15

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CCE 0 | CCE1 | CCE2 | CCE3 | CCE4 | CCE5 | CCE6 | CCE7 | CCE8 | CCE9 | CCE10 | CCE11 | CCE12 | CCE13 | CCE14 | CCE15 | CCE16 | ... | ... | CCE99 |

# UE Specific Search Space

- The CCEs for one particular UE can be search at $L\left\{(Y_k+m')\bmod \lfloor N_{\mathrm{CCE},k}/L\rfloor\right\}$
  - L is the aggregation level
  - $N_{CCE,k}$ is the total number of CCEs in one subframe
  - $Y_k$ depends on UE and subframe index
  - m' = 0, …, M'-1, and M' is given by the following table

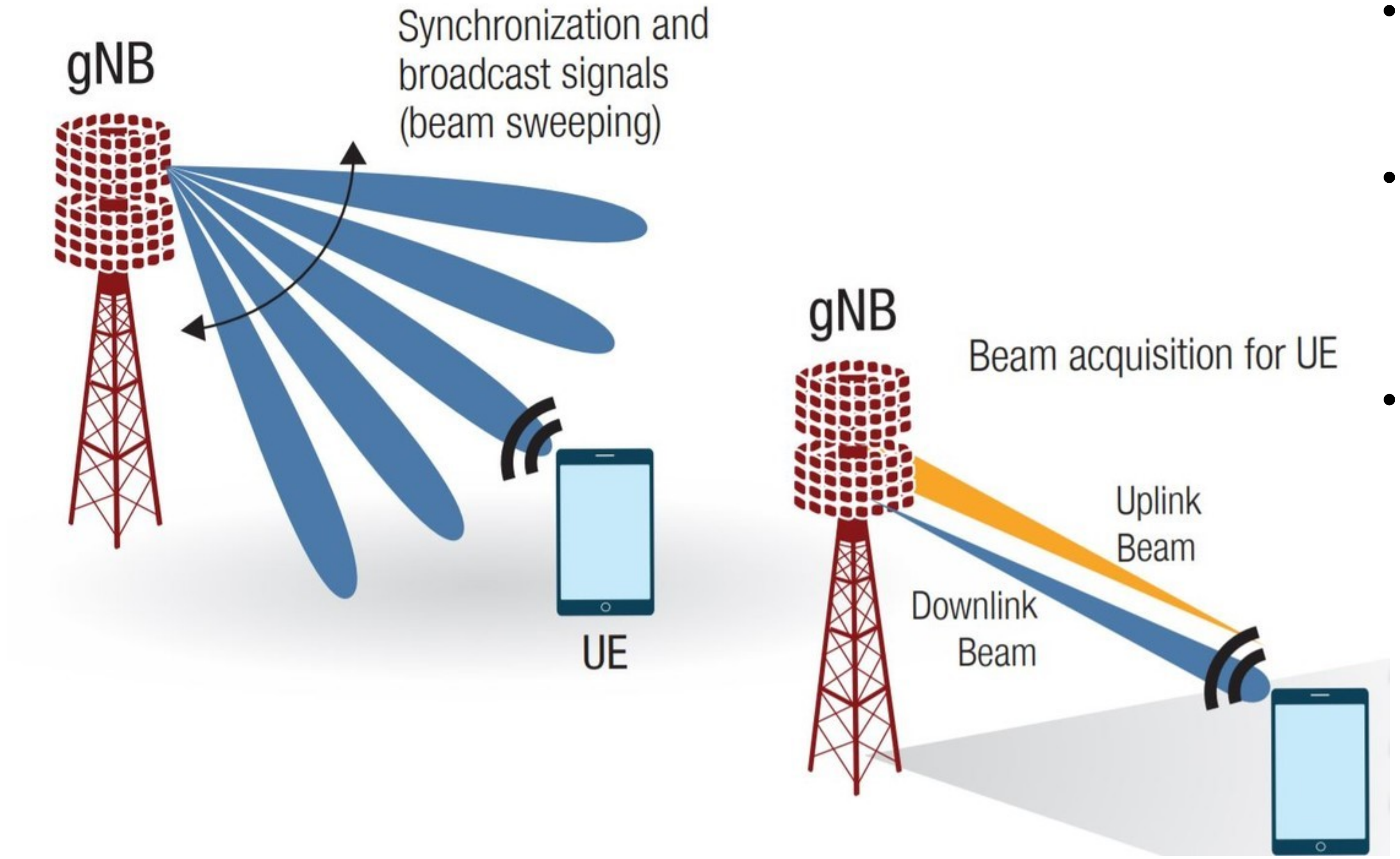
| Search space | | | Number of PDCCH candidates M' |
|---|---|---|---|
| Type | Aggregation level | Size [in CCEs] | |
| UE-specific | 1 | 6 | 6 |
| | 2 | 12 | 6 |
| | 4 | 8 | 2 |
| | 8 | 16 | 2 |
| Common | 4 | 16 | 4 |
| | 8 | 16 | 2 |

# Example

- 100 CCEs
- Yk = 53948
- L = 2
- m’ = 0, 1, 2, 3, 4, 5
- CCE candidates:
    - 2 {(53948 + 0) mod (100/2)} = 96 => Check CCEs #96 & #97
    - 2 {(53948 + 1) mod (100/2)} = 98 => Check CCEs #98 & #99
    - 2 {(53948 + 1) mod (100/2)} = 0 => Check CCEs #0 & #1
    - 2 {(53948 + 1) mod (100/2)} = 2 => Check CCEs #2 & #3
    - 2 {(53948 + 1) mod (100/2)} = 4 => Check CCEs #4 & #5

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CCE 0 | CCE1 | CCE2 | CCE3 | CCE4 | CCE5 | CCE6 | CCE7 | CCE8 | CCE9 | CCE10 | CCE11 | CCE12 | CCE13 | CCE14 | CCE15 | CCE16 | ... | ... | CCE99 |

# Issues of NR



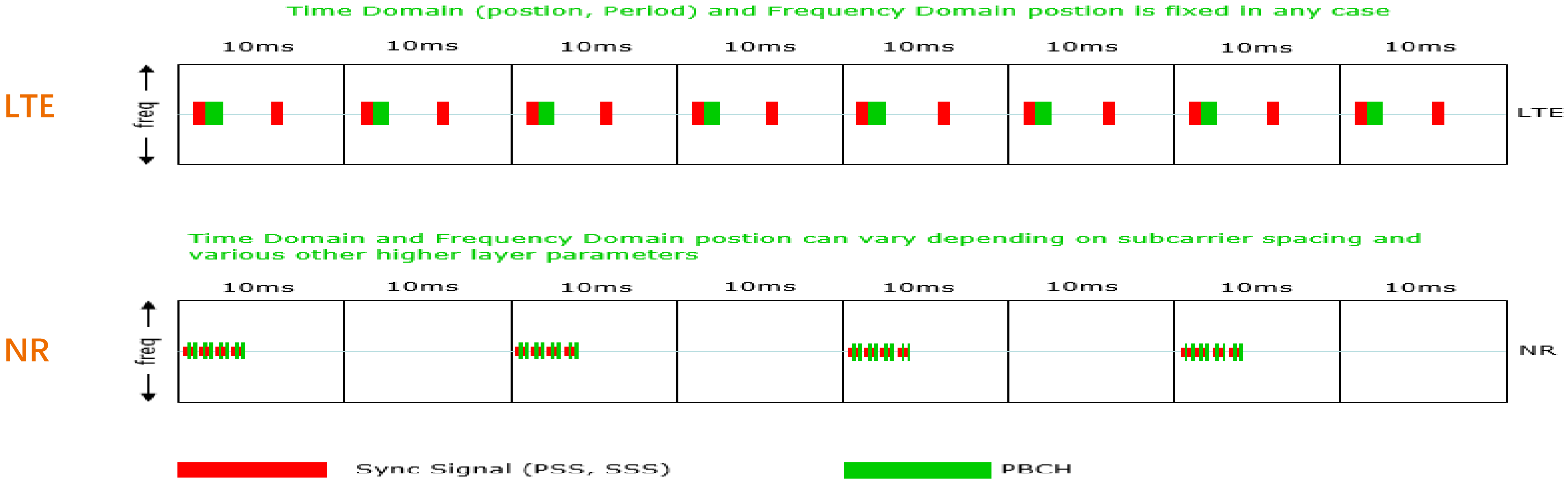

- One sector is further divided into a number of beams

- SS (Synchronization Signals) of one beam may not be received by on user in other beam

- User should determine the service beam in the synchronization procedure

# SS Block (TS38.211 v16 7.4.3)

- **In NR, SS Block (SSB)** stands for Synchronization Signal Block, it refers to the transmission opportunities for **PSS/SSS/PBCH**
- In LTE, we didn't use the term 'SS Block', although it already there



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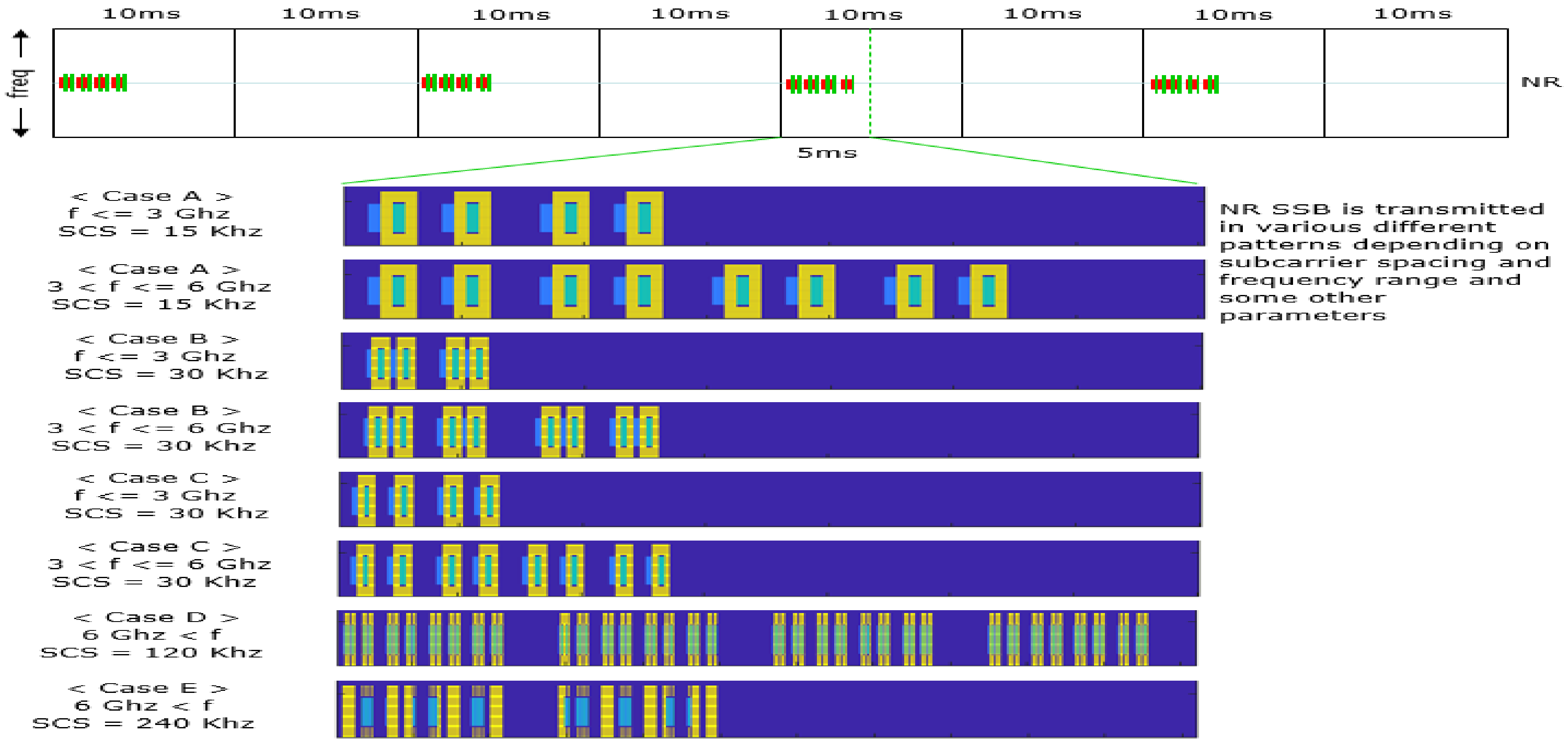

# SS Block (TS38.211 v16 7.4.3)

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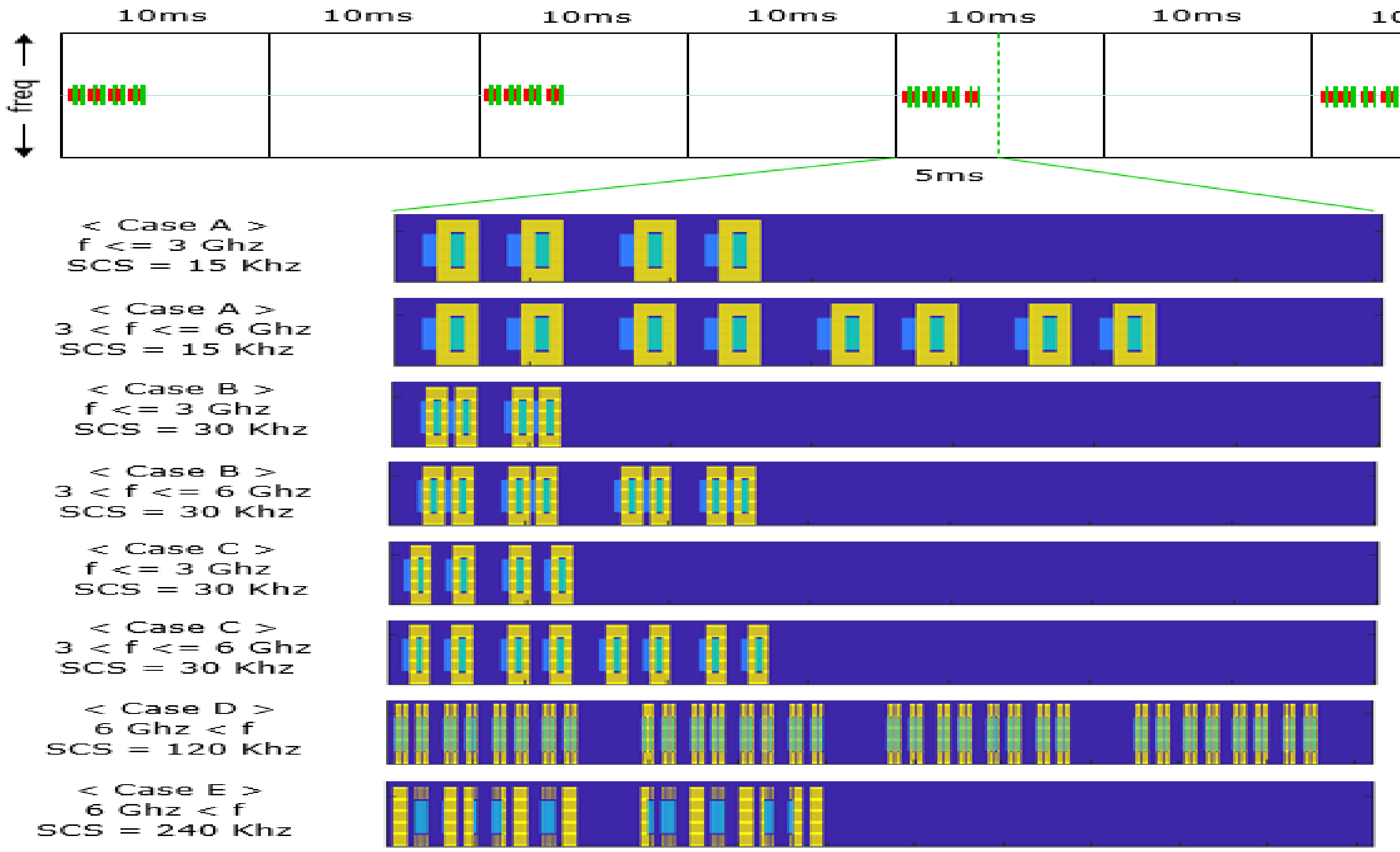
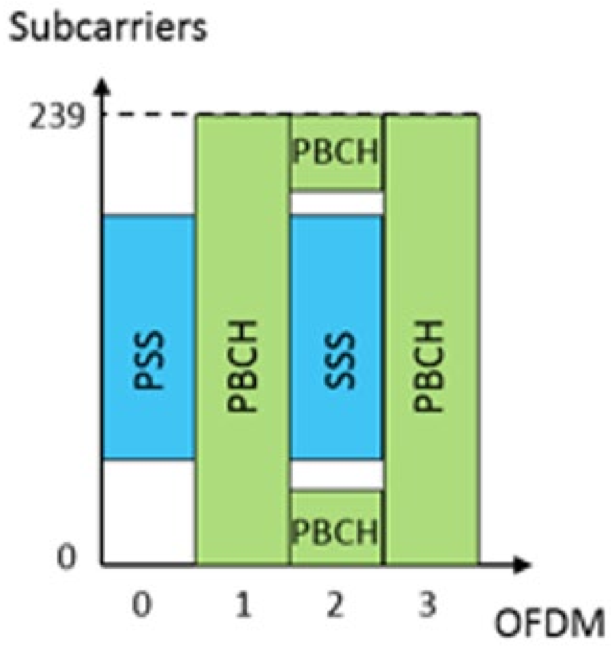


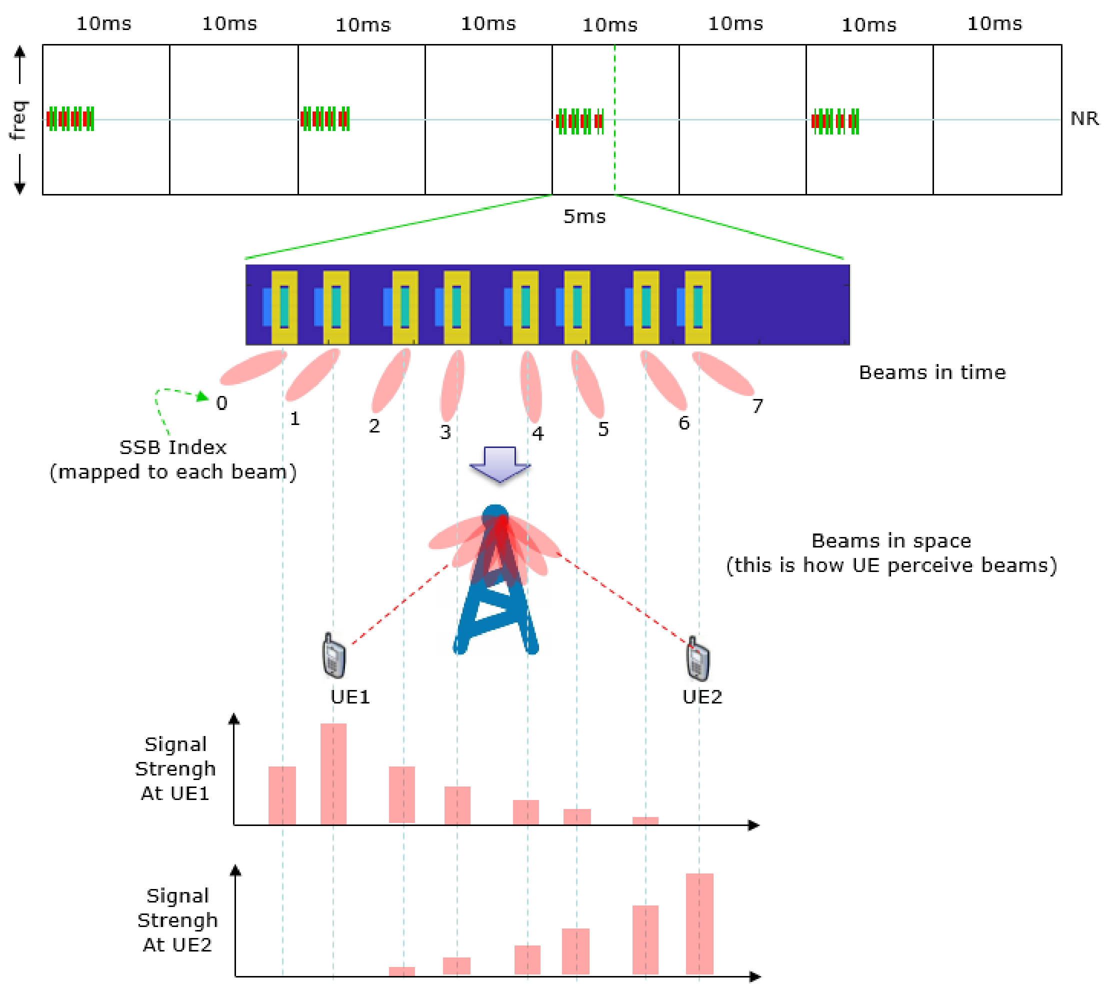



- “In the time domain, an SS/PBCH block consists of 4 OFDM symbols, numbered in increasing order from 0 to 3 within the SS/PBCH block”

**Table 7.4.3.1-1: Resources within an SS/PBCH block for PSS, SSS, PBCH, and DM-RS for PBCH.**

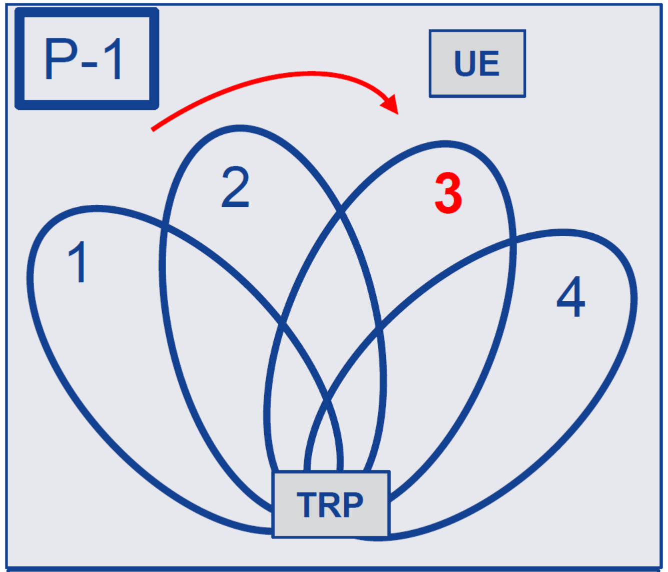
| Channel or signal | OFDM symbol number $l$ relative to the start of an SS/PBCH block | Subcarrier number $k$ relative to the start of an SS/PBCH block |
|---|---|---|
| PSS | 0 | 56, 57, …, 182 |
| SSS | 2 | 56, 57, …, 182 |
| Set to 0 | 0 | 0, 1, …, 55, 183, 184, …, 239 |
| | 2 | 48, 49, …, 55, 183, 184, …, 191 |
| PBCH | 1, 3 | 0, 1, …, 239 |
| | 2 | 0, 1, …, 47,<br>192, 193, …, 239 |
| DM-RS for PBCH | 1, 3 | $0+v, 4+v, 8+v, \ldots, 236+v$ |
| | 2 | $0+v, 4+v, 8+v, \ldots, 44+v$<br>$192+v, 196+v, \ldots, 236+v$ |

# Beam Sweeping via SSB

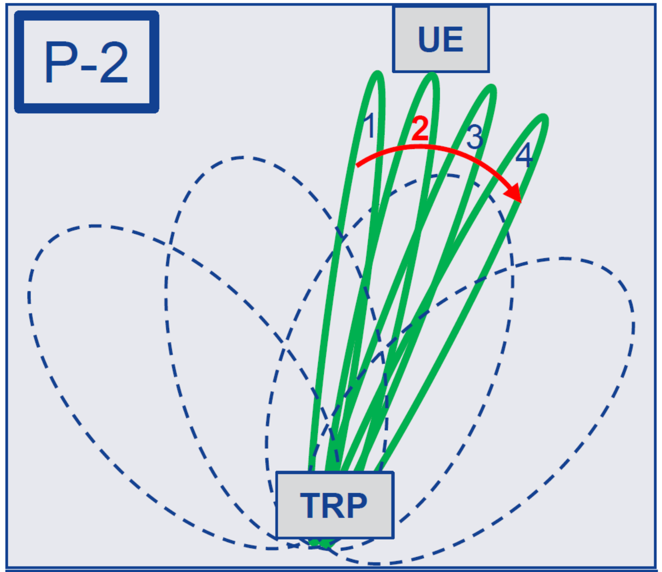



- Multiple SSBs are being transmitted with a certain interval.
- Each SSB can be identified by a unique number called SSB index
- Each SSB is transmitted via a specific beam radiated in a certain direction
- Multiple UEs are located at various places around a gNB.
- UE measures the signal strength of each SSB it detected for a certain period (a period of one SSB Set).
- From the measurement result, UE can identifies the SSB index with the strongest signal strength. This SSB with the strongest signal strength is the best beam for the UE.

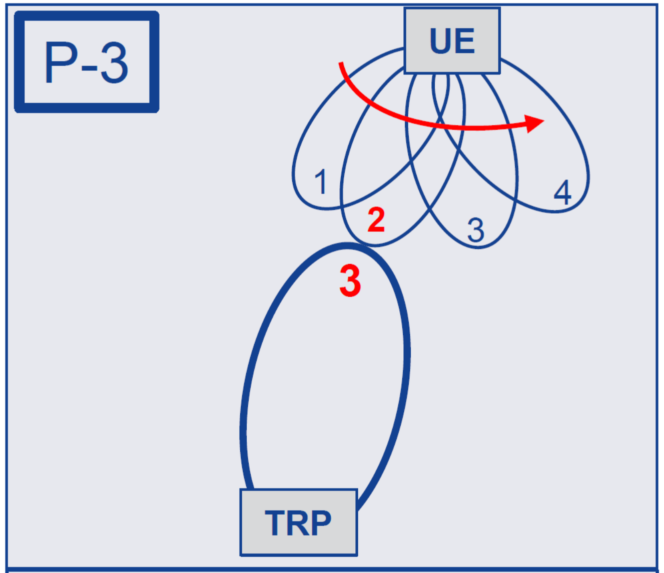
# Beam Management




- Initial gNB Beam Acquisition
- SSB or CSI-RS




- gNB Beam Refinement
- E.g., CSI-RS




- UE Beam Refinement

# Homework (28 April)

**Please dig more details on the beam sweeping mechanism of NR.**