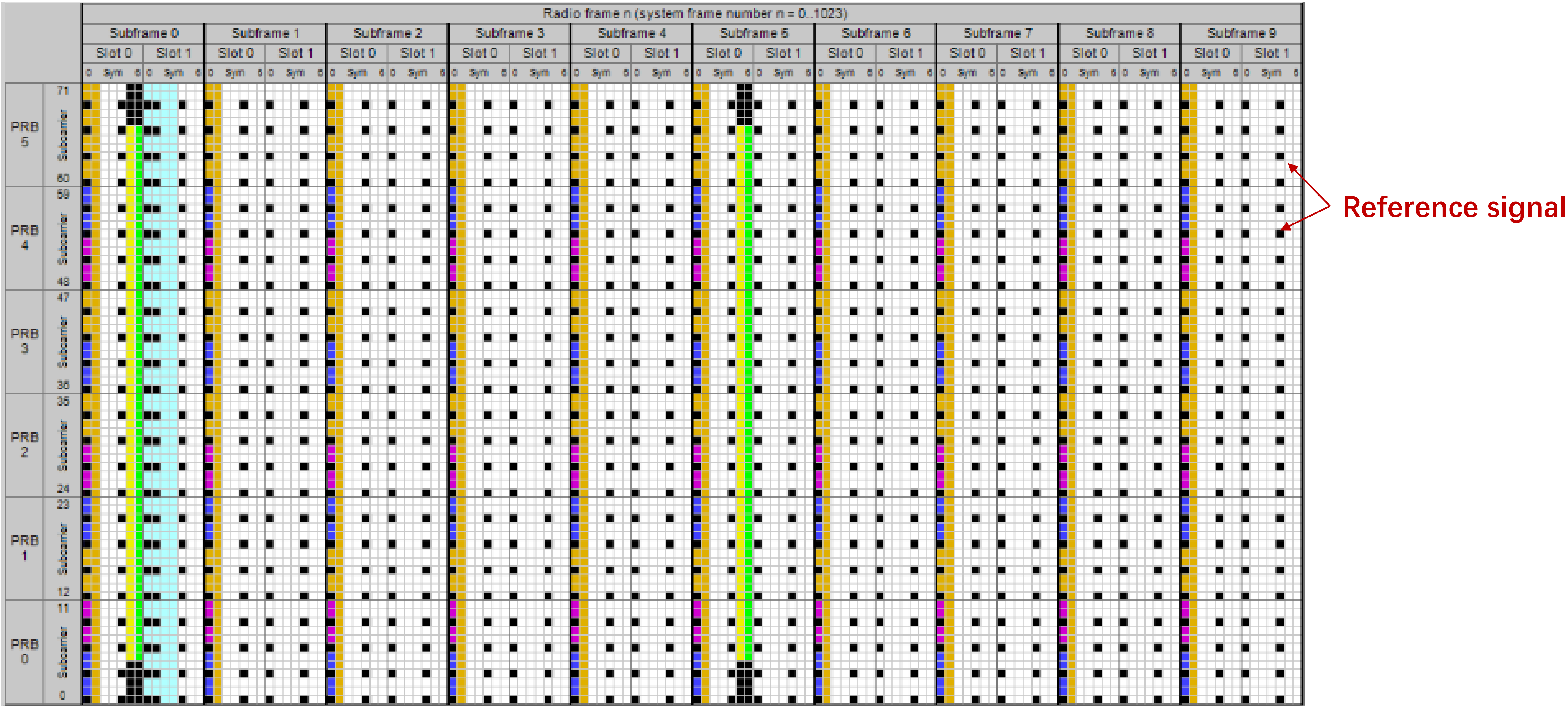
Synchronization of Cellular Systems

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 …

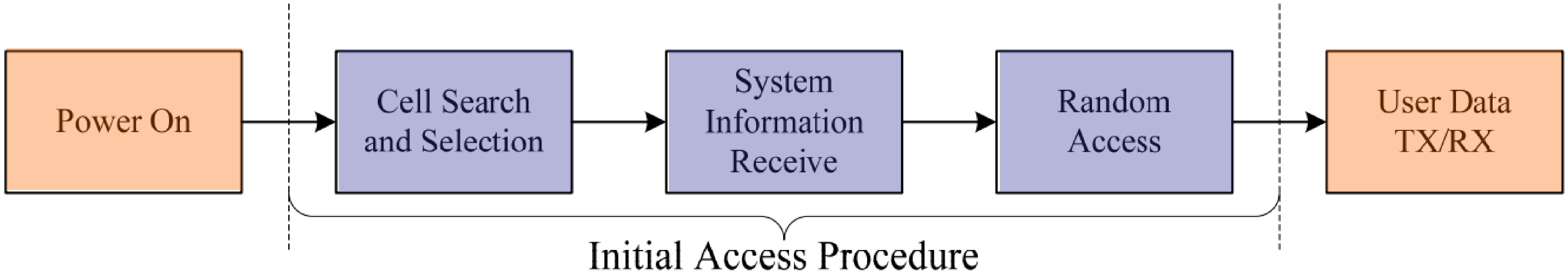
Channel bandwidth [MHz]	1.4	3	5	10	15	20
Number of resource blocks (N_{RB})	6	15	25	50	75	100
Number of occupied subcarriers	72	180	300	600	900	1200
IDFT(Tx)/DFT(Rx) size	128	256	512	1024	1536	2048
Sample rate [MHz]	1.92	3.84	7.68	15.36	23.04	30.72
Samples per slot	960	1920	3840	7680	11520	15360

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.

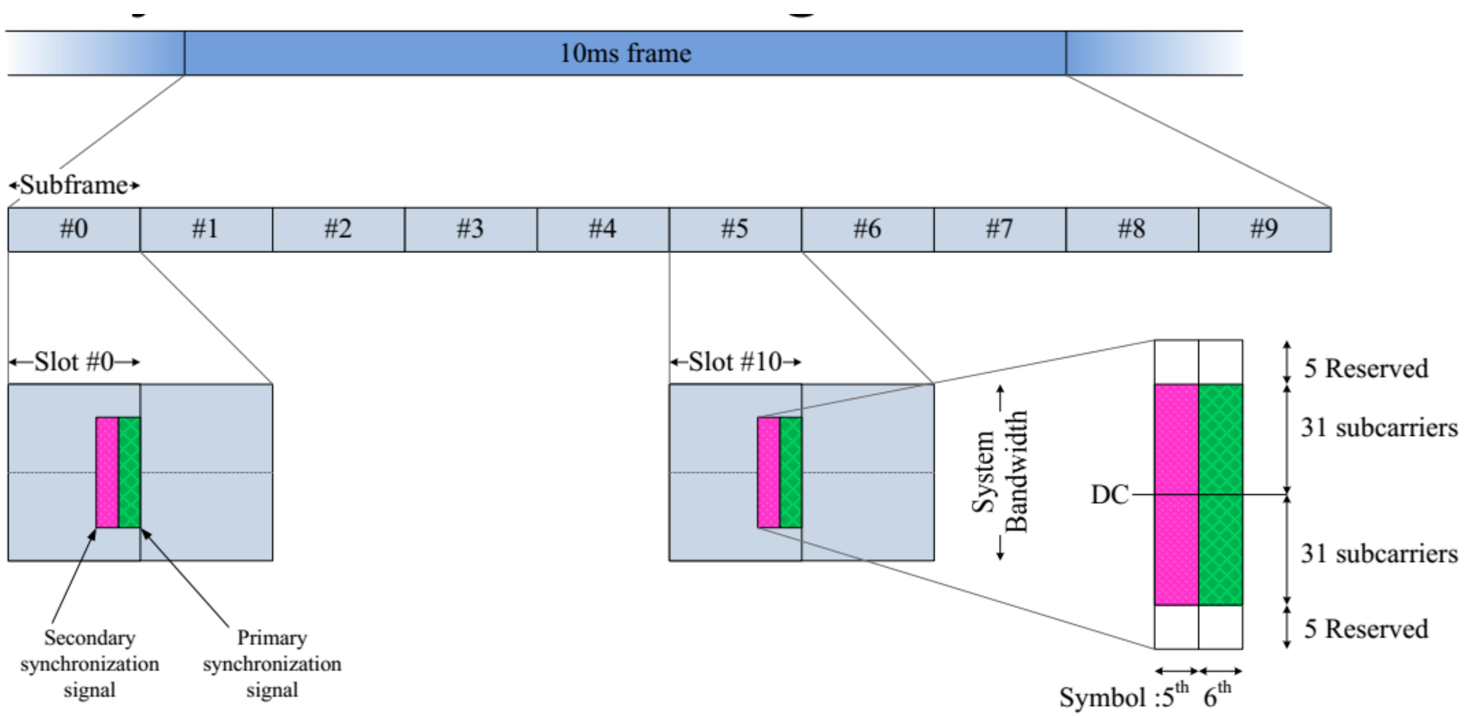
Initial Access

- 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."

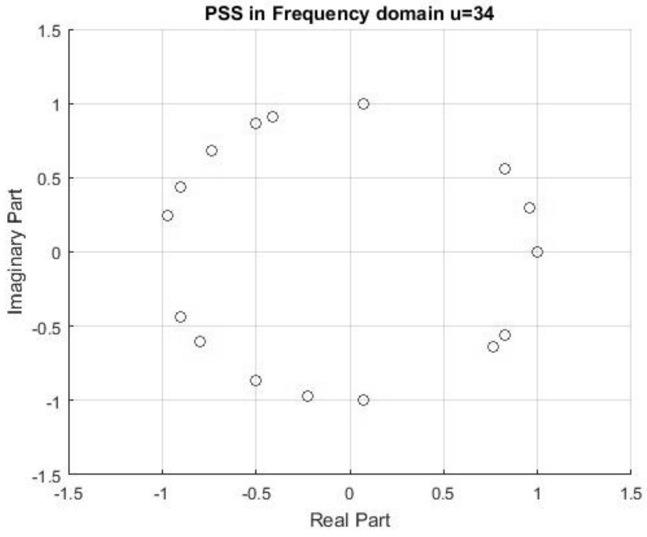
"A physical-layer cell identity $N_{\mathrm{ID}}^{\mathrm{cell}} = 3N_{\mathrm{ID}}^{(1)} + N_{\mathrm{ID}}^{(2)}$ is thus uniquely defined by a number $N_{\mathrm{ID}}^{(1)}$ in the range of 0 to 167, representing the physical-layer cell-identity group, and a number $N_{\mathrm{ID}}^{(2)}$ in the range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

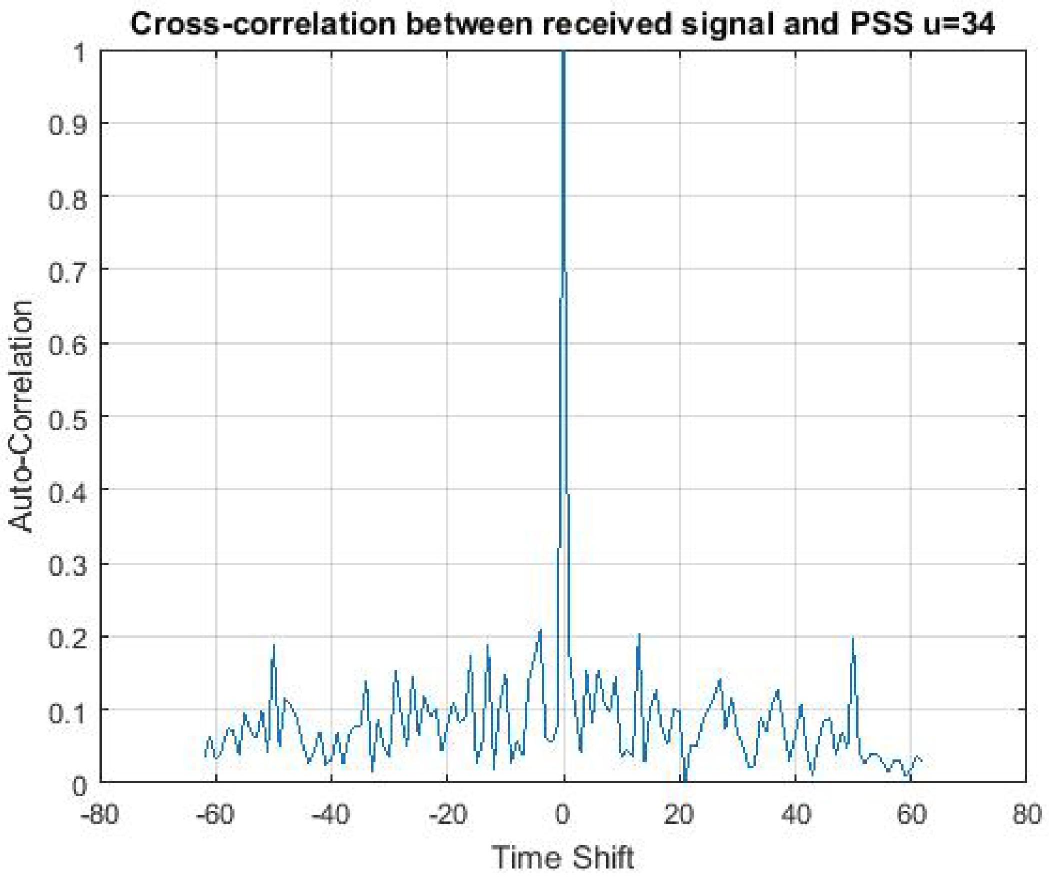
$$d_u(n) = \begin{cases} e^{-j\frac{\pi u n(n+1)}{63}} & n = 0,1,\ldots,30 \\ e^{-j\frac{\pi u (n+1)(n+2)}{63}} & n = 31,32,\ldots,61 \end{cases}$$

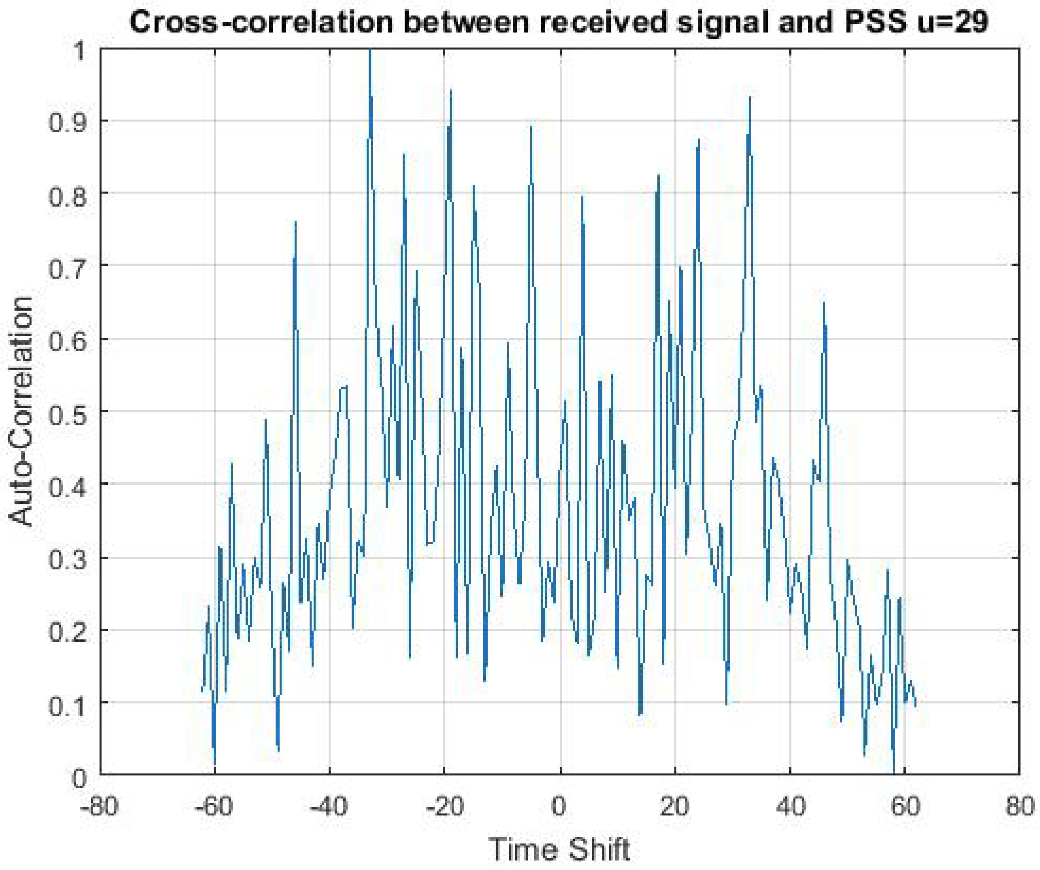
$N_{\mathrm{ID}}^{(2)}$	Root index u
0	25
1	29
2	34



- 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

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Detection of PSS

- With sample frequency = 1.92MHz

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

Eliminate by LPF

- 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}

- 3.84MHz

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

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Detection of PSS

- 1.92MHz

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x_0^{128}	x_1^{128}	…	x_{127}^{128}

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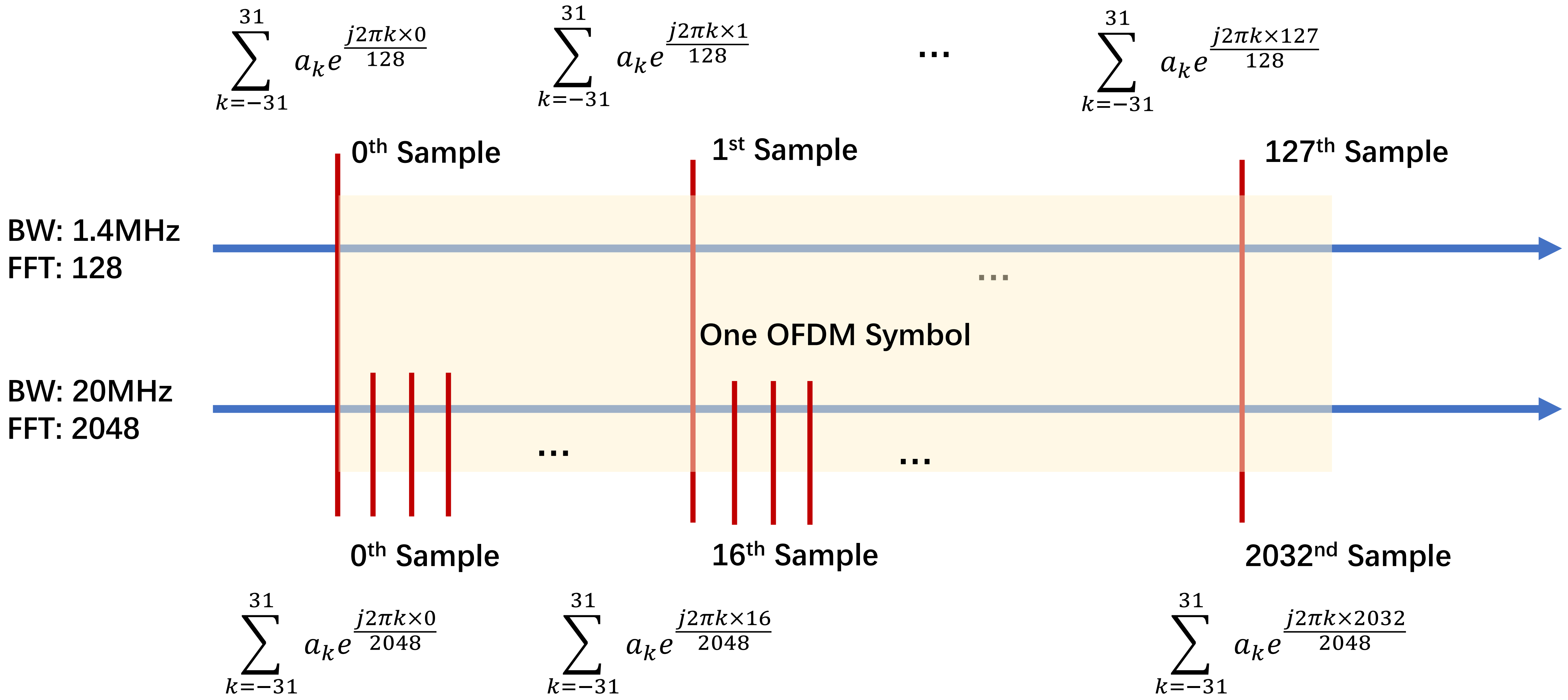
$$x_n^{256} = \sum_{k=-127}^{128} a_k e^{\frac{j2\pi kn}{256}} = \sum_{k\neq 0, k=-31}^{31} a_k e^{\frac{j2\pi kn}{256}}$$

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

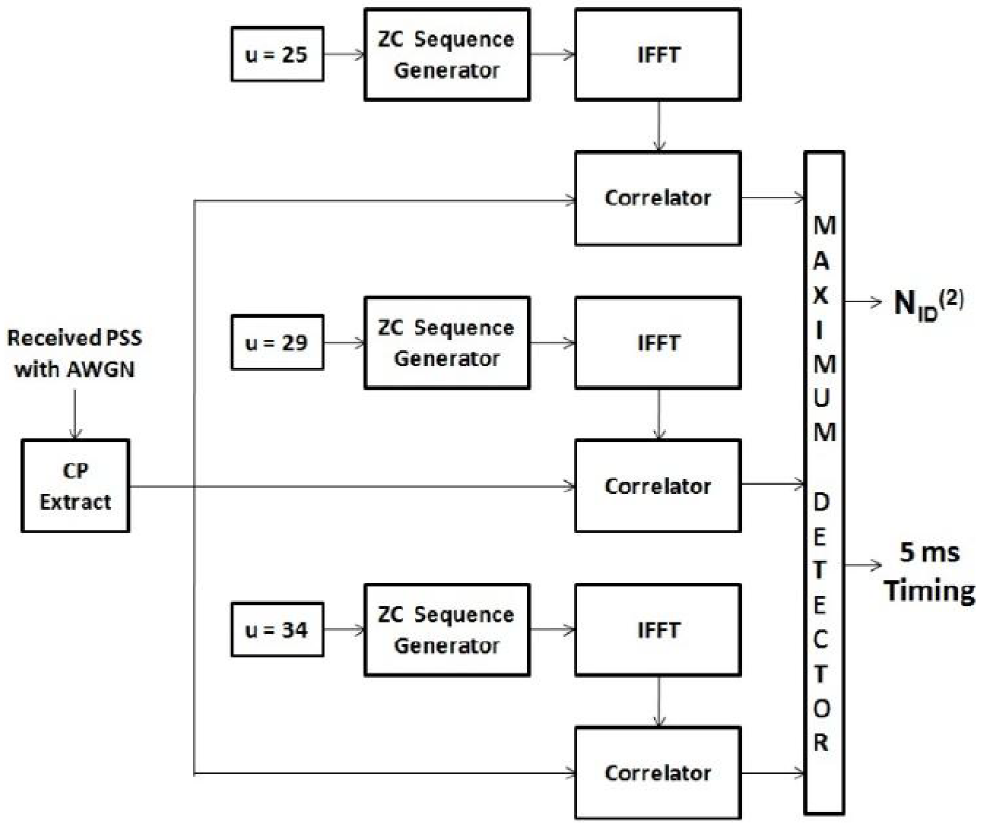

$\sum_{k=-31}^{31} a_k e^{\frac{j2\pi k\times 0}{128}}$
$\sum_{k=-31}^{31} a_k e^{\frac{j2\pi k\times 1}{128}}$
…
$\sum_{k=-31}^{31} a_k e^{\frac{j2\pi k\times 127}{128}}$
0th Sample
1st Sample
127th Sample
BW: 1.4MHz
FFT: 128
…
One OFDM Symbol
BW: 20MHz
FFT: 2048
…
…
0th Sample
16th Sample
2032nd Sample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

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

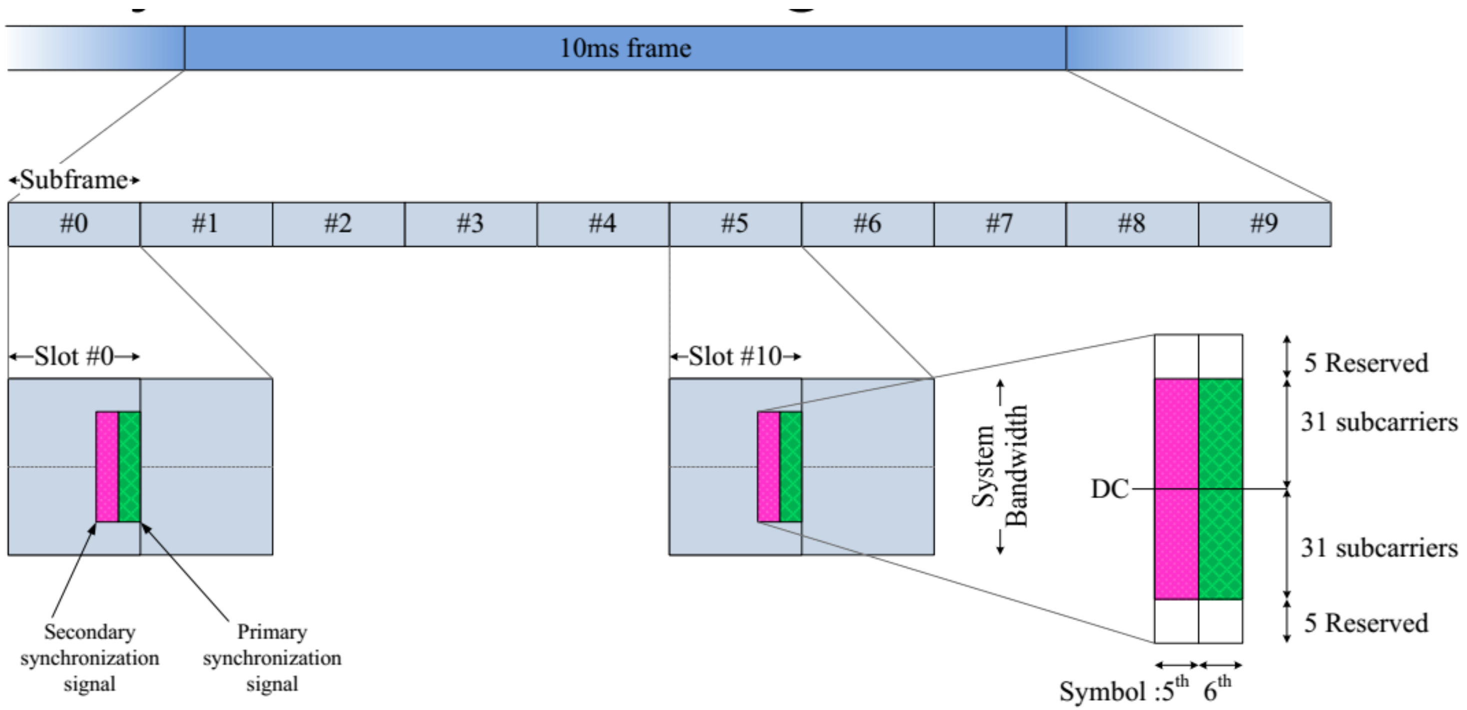
Detection of PSS

- 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.



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
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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.

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

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

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

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

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

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

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

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

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

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

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

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

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 ×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) = $3 \times N_{ID}^{(1)} + N_{ID}^{(2)}$

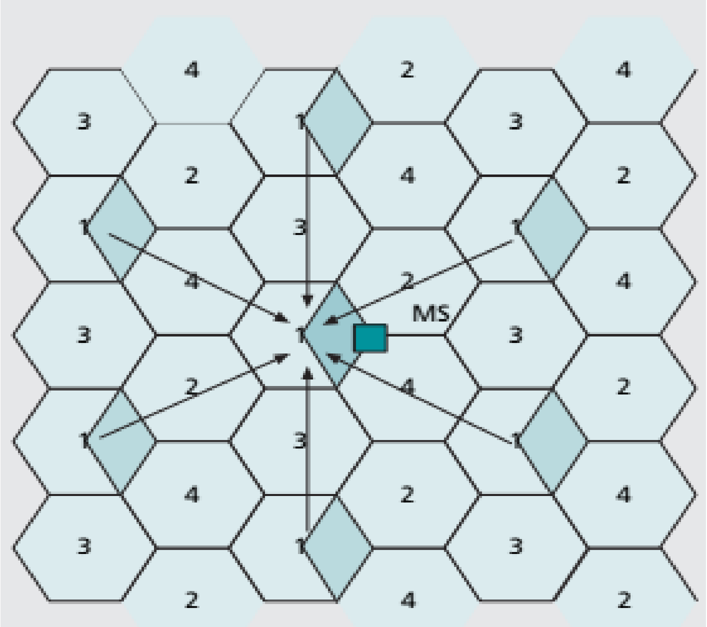
- Conclusion: After PSS and SSS detection, user knows the Cell ID and timing of frame

Discussion

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

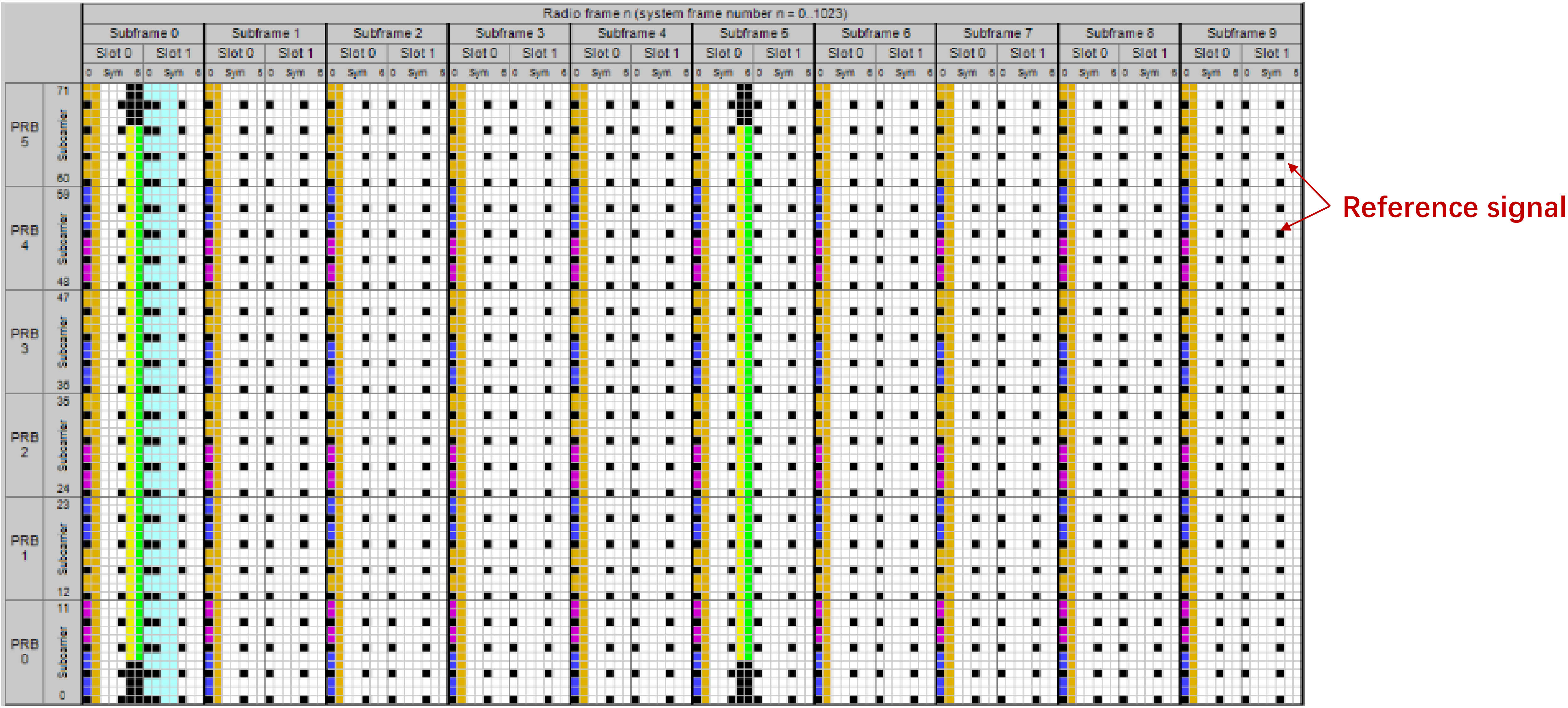
- How many BSs around, what their Cell IDs are, what their signal strengths are
- Synchronize with the strongest cell

- **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 0th 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 knowledge of actual bandwidth)
- 14bits MIB information, code rate = 1/3, scrambled with Cell ID, QPSK,



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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

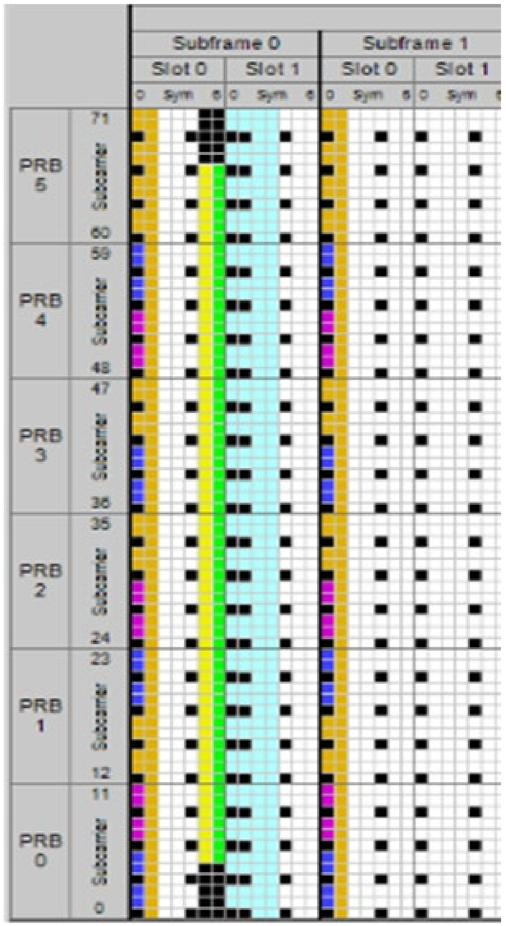

Table 5.3.4-1: CFI codewords

CFI	CFI codeword $< b_0, b_1, \ldots, b_{31} >$
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>

Reading & Homework (20 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

Assignment 5