Table 5.6-1 Transmission bandwidth configuration N_{RB} in E-UTRA channel bandwidths

Channel bandwidth $BW_{Channel}$ [MHz]	1.4	3	5	10	15	20
Transmission bandwidth configuration N_{RB}	6	15	25	50	75	100

Table 6.12-1: OFDM parameters.

Configuration		Cyclic prefix length $N_{CP,l}$
Normal cyclic prefix	$\Delta f = 15\,\text{kHz}$	160 for $l = 0$ 144 for $l = 1,2,\ldots,6$
Extended cyclic prefix	$\Delta f = 15\,\text{kHz}$	512 for $l = 0,1,\ldots,5$
	$\Delta f = 7.5\,\text{kHz}$	1024 for $l = 0,1,2$

Δf = 15 kHz : IFFT Length = 2048
Δf = 7.5 kHz : IFFT Length = 4096

Sampling Rate (Complex) = 30.72 MHz

Table 6.2.3-1: Physical resource blocks parameters. DL

Configuration		N_{sc}^{RB}	N_{symb}^{DL}
Normal cyclic prefix	$\Delta f = 15\,\text{kHz}$	12	7
Extended cyclic prefix	$\Delta f = 15\,\text{kHz}$		6
	$\Delta f = 7.5\,\text{kHz}$	24	3

```
LTE ----- Release 8 ----- FDD ----- DL ----- Full Duplex ----- MBSFN Transmission Subframe
                  |         |         |                     |
                  |         |         |                     |-- non-MBSFN Transmission Subframe
                  |         |         |
                  |         |         |
                  |         |         |-- Half Duplex ----- MBSFN Transmission Subframe
                  |         |                               |
                  |         |                               |-- non-MBSFN Transmission Subframe
                  |         |
                  |         |-- UL
                  |
                  |
                  |-- TDD ----- DL ----- MBSFN Transmission Subframe
                            |         |
                            |         |-- non-MBSFN Transmission Subframe
                            |
                            |-- UL
```

The PHICH duration is configurable by higher layers according to Table 6.9.3-1. The duration configured puts a lower limit on the size of the control region signalled by the PCFICH.

In TDD, the PSS shall be mapped to the third OFDM symbol in subframes 1 and 6.

Table 6.9.3-1: PHICH duration in MBSFN and non-MBSFN subframes.

PHICH duration	Non-MBSFN subframes: Subframes 1 and 6 in case of frame structure type 2 TDD	Non-MBSFN subframes: All other cases	MBSFN subframes: On a carrier supporting both PDSCH and PMCH
Normal	1	1	1
Extended	2	3	2

Normal CP => 8 orthogonal sequence indexes (i.e. 8 HI's)
Extended CP => 4 orthogonal sequence indexes (i.e. 4 HI's)

For frame structure type 1, the number of PHICH groups N_{PHICH}^{group} is constant in all subframes and given by FDD

$$N_{PHICH}^{group} = \begin{cases} \left\lceil N_g \left(N_{RB}^{DL}/8 \right) \right\rceil & \text{for normal cyclic prefix} \\ 2 \cdot \left\lceil N_g \left(N_{RB}^{DL}/8 \right) \right\rceil & \text{for extended cyclic prefix} \end{cases}$$

where $N_g \in \{1/6, 1/2, 1, 2\}$ is provided by higher layers. The index n_{PHICH}^{group} ranges from 0 to $N_{PHICH}^{group} - 1$.

TDD

For frame structure type 2, the number of PHICH groups may vary between downlink subframes and is given by $m_i \cdot N_{PHICH}^{group}$ where m_i is given by Table 6.9-1 and N_{PHICH}^{group} by the expression above. The index n_{PHICH}^{group} in a downlink subframe with non-zero PHICH resources ranges from 0 to $m_i \cdot N_{PHICH}^{group} - 1$.

Table 6.9-1: The factor m_i for frame structure type 2. TDDConfig TDD

Uplink-downlink configuration	Subframe number i: 0	1	2	3	4	5	6	7	8	9
0	2	1	-	-	-	2	1	-	-	-
1	0	1	-	-	1	0	1	-	-	1
2	0	0	-	1	0	0	0	-	1	0
3	1	0	-	-	-	0	0	0	1	1
4	0	0	-	-	0	0	0	0	1	1
5	0	0	-	0	0	0	0	0	1	0
6	1	1	-	-	-	1	1	-	-	1

This is the perfect picture for base-station. But for UE, we need to shift every UL subframe to the left. This is why we have a special subframe when switching from DL to UL. But we don't have a special subframe when switching from UL to DL.

Table 6.7-1: Number of OFDM symbols used for PDCCH. CFI

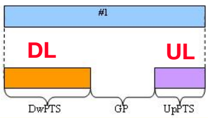
Subframe	Number of OFDM symbols for PDCCH when $N_{RB}^{DL} > 10$	Number of OFDM symbols for PDCCH when $N_{RB}^{DL} \leq 10$
Subframe 1 and 6 for frame structure type 2 TDD	1, 2	2
MBSFN subframes on a carrier supporting both PMCH and PDSCH for 1 or 2 cell specificc antenna ports	1, 2	2
MBSFN subframes on a carrier supporting both PMCH and PDSCH for 4 cell specific antenna ports	2	2
MBSFN subframes on a carrier not supporting PDSCH	0	0
All other cases	1, 2, 3	2, 3, 4

Table 6.8.1-1: Supported PDCCH formats

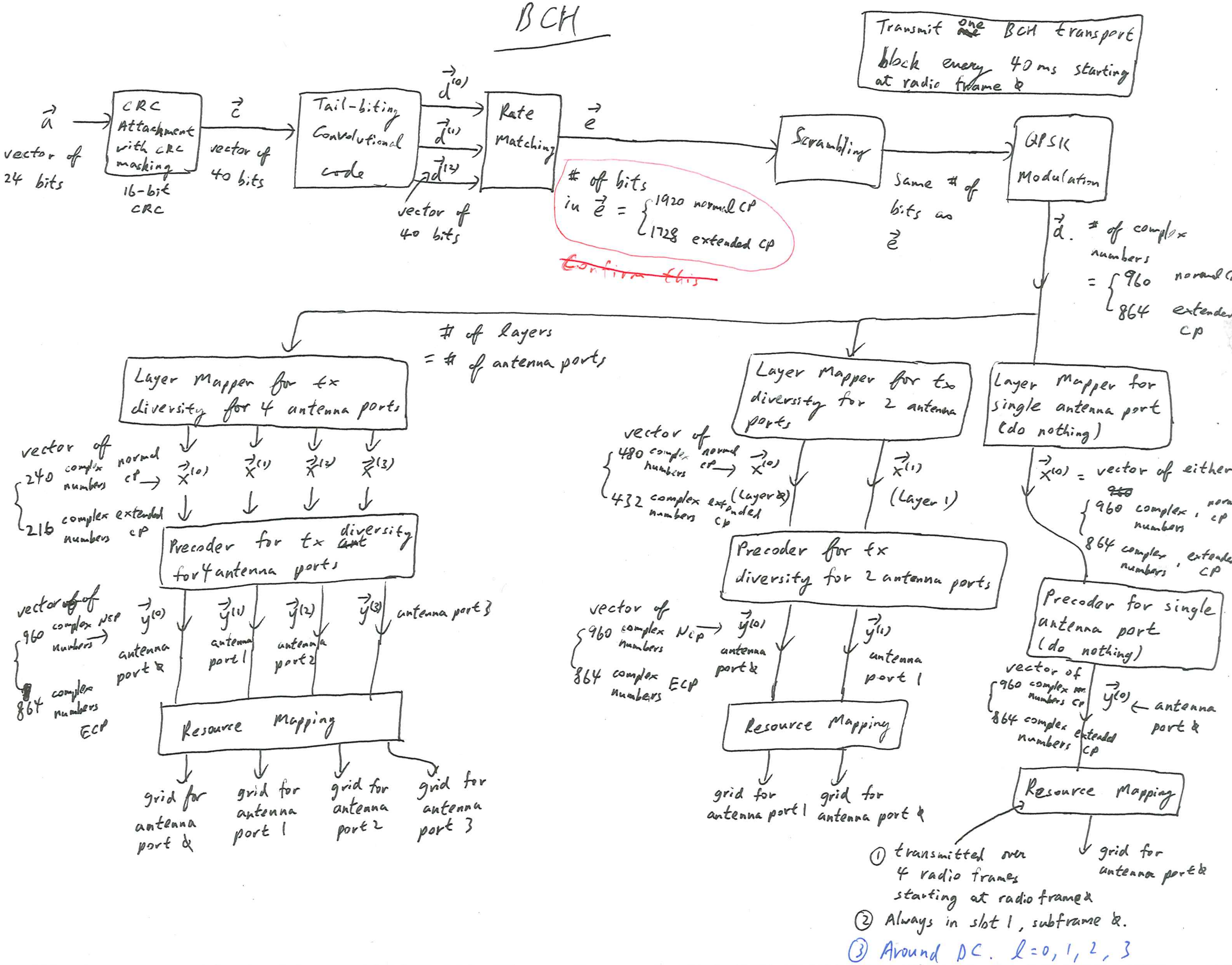
PDCCH format	Number of CCEs	Number of resource-element groups	Number of PDCCH bits
0	1	9	72
1	2	18	144
2	4	36	288
3	8	72	576

Special subframe configuration SSC	Normal cyclic prefix in downlink: DwPTS	Normal cyclic prefix in downlink: UpPTS, Normal cyclic prefix in uplink	Normal cyclic prefix in downlink: UpPTS, Extended cyclic prefix in uplink	Extended cyclic prefix in downlink: DwPTS	Extended cyclic prefix in downlink: UpPTS, Normal cyclic prefix in uplink	Extended cyclic prefix in downlink: UpPTS, Extended cyclic prefix in uplink
0	3	1	1	3	1	1
1	9			8		
2	10			9		
3	11			10		
4	12			3	2	2
5	3	2	2	8		
6	9			9		
7	10			-	-	-
8	11			-	-	-

Δf = 15 kHz



BCH



Transmit one BCH transport block every 40 ms starting at radio frame 0
$\vec{a}$
vector of 24 bits
CRC Attachment with CRC masking
16-bit CRC
$\vec{c}$
vector of 40 bits
Tail-biting Convolutional code
$\vec{d}^{(0)}$
$\vec{d}^{(1)}$
$\vec{d}^{(2)}$
vector of 40 bits
Rate Matching
$\vec{e}$
# of bits in $\vec{e} = \begin{cases} 1920 \text{ normal CP} \\ 1728 \text{ extended CP} \end{cases}$
~~Confirm this~~
Scrambling
Same # of bits as $\vec{e}$
QPSK Modulation
$\vec{d}$. # of complex numbers $= \begin{cases} 960 \text{ normal CP} \\ 864 \text{ extended CP} \end{cases}$
# of layers = # of antenna ports
Layer Mapper for tx diversity for 4 antenna ports
vector of 240 complex numbers normal CP → 216 complex numbers extended CP
$\vec{x}^{(0)}$ $\vec{x}^{(1)}$ $\vec{x}^{(2)}$ $\vec{x}^{(3)}$
Precoder for tx diversity for 4 antenna ports
vector of 960 complex numbers NCP → 864 complex numbers ECP
$\vec{y}^{(0)}$ antenna port 0
$\vec{y}^{(1)}$ antenna port 1
$\vec{y}^{(2)}$ antenna port 2
$\vec{y}^{(3)}$ antenna port 3
Resource Mapping
grid for antenna port 0
grid for antenna port 1
grid for antenna port 2
grid for antenna port 3
Layer Mapper for tx diversity for 2 antenna ports
vector of 480 complex numbers normal CP → 432 complex numbers extended CP
$\vec{x}^{(0)}$ (Layer 0)
$\vec{x}^{(1)}$ (Layer 1)
Precoder for tx diversity for 2 antenna ports
vector of 960 complex numbers NCP → 864 complex numbers ECP
$\vec{y}^{(0)}$ antenna port 0
$\vec{y}^{(1)}$ antenna port 1
Resource Mapping
grid for antenna port 1
grid for antenna port 0
Layer Mapper for single antenna port (do nothing)
$\vec{x}^{(0)}$ = vector of either ~~960~~ 960 complex numbers, normal CP; 864 complex numbers, extended CP
Precoder for single antenna port (do nothing)
vector of 960 complex numbers CP; 864 complex numbers extended CP
$\vec{y}^{(0)}$ ← antenna port 0
Resource Mapping
grid for antenna port 0
① transmitted over 4 radio frames starting at radio frame 0
② Always in slot 1, subframe 0.
③ Around DC. $l = 0, 1, 2, 3$

CFI

$\boxed{CFI = \{1, 2, 3\}}$

$N_{RB}^{DL} > 10$:

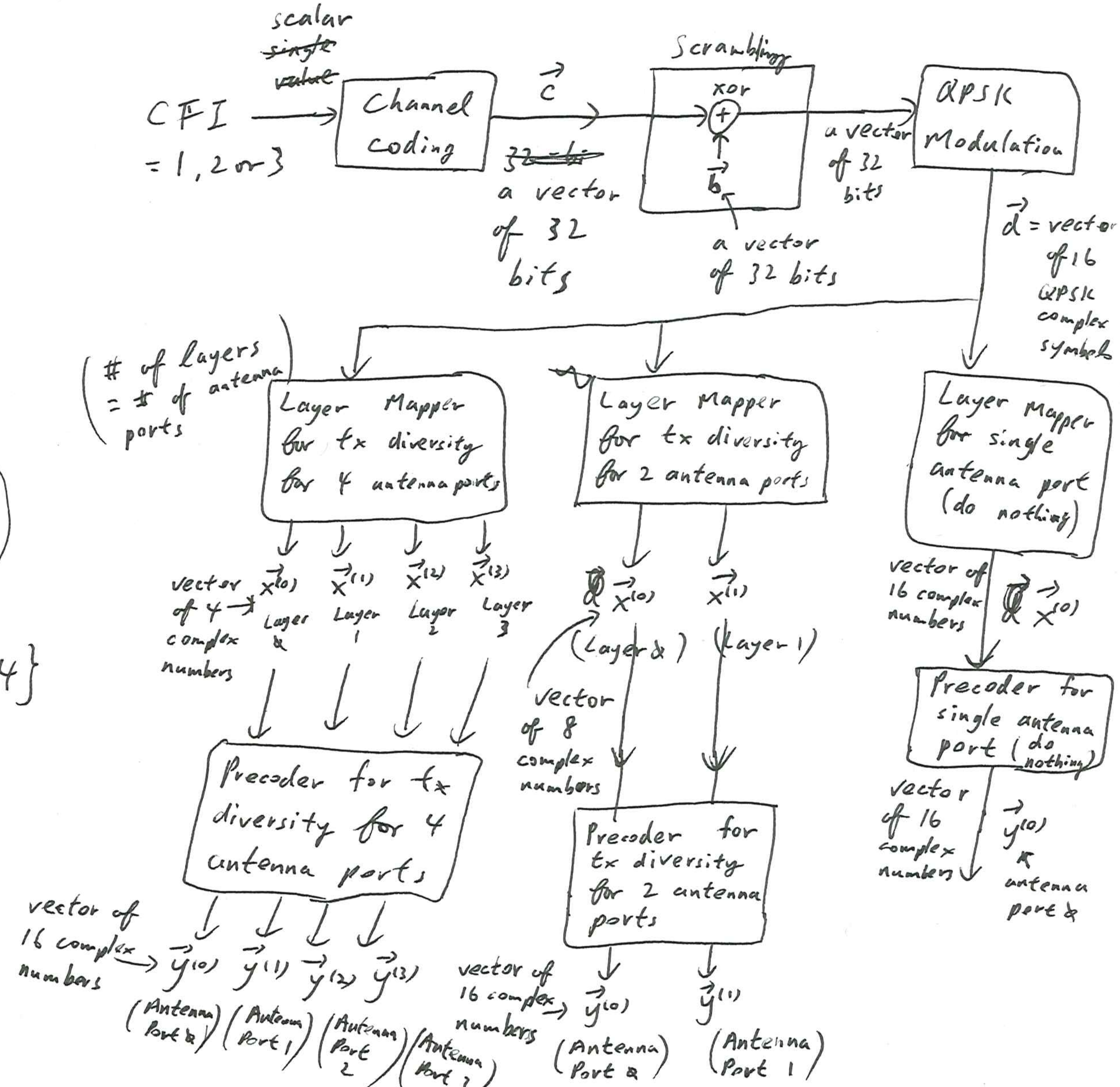
Timespan of DCI in ~~that~~ the same subframe in units of OFDM symbols = $CFI = \{1, 2, 3\}$

of ~~of the~~ OFDM symbols used for transmission of ~~P~~DCI (i.e. PDCCHs) in current subframe

$N_{RB}^{DL} \leq 10$:

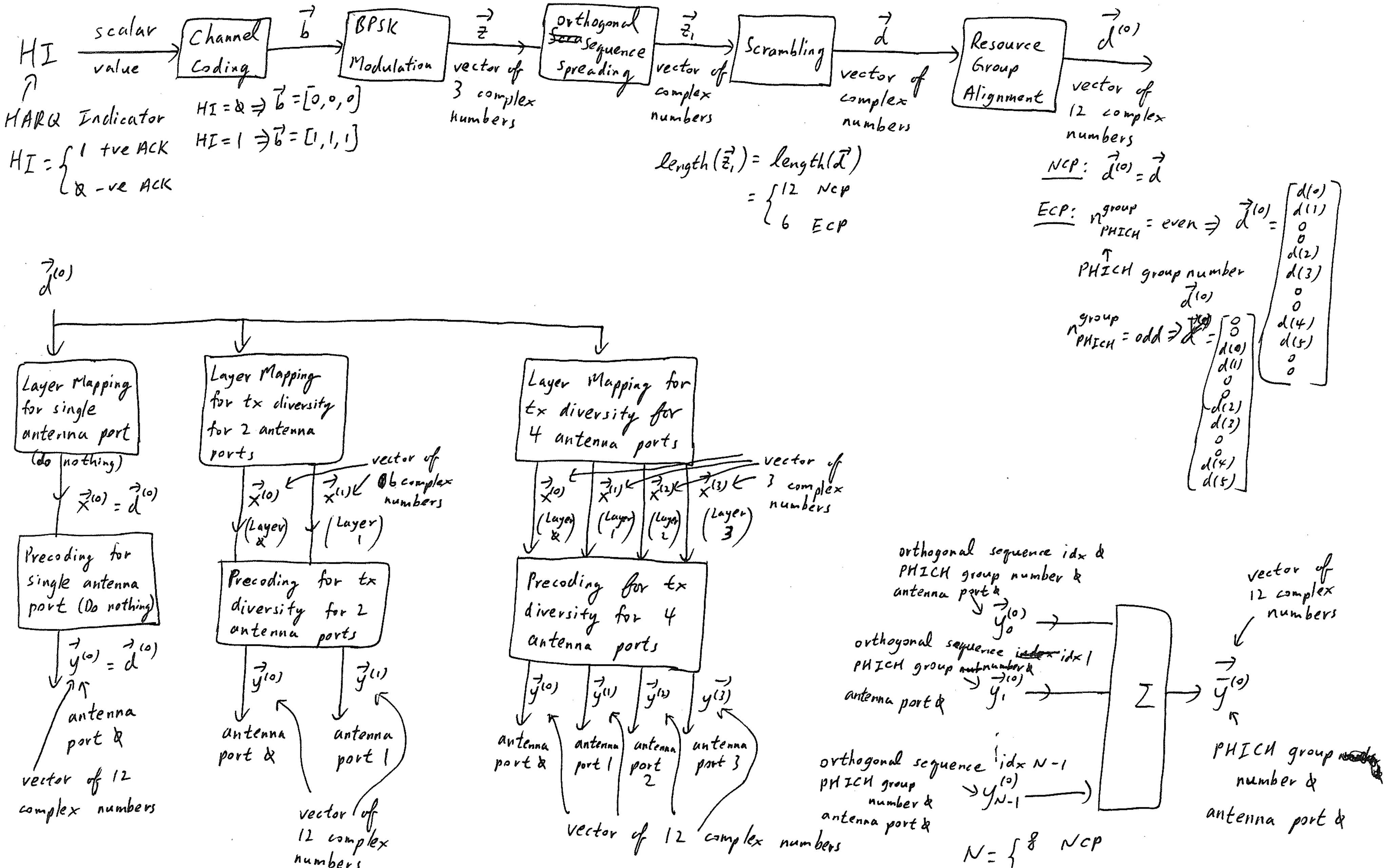
Time span of DCI in the same subframe in units of OFDM symbols = $CFI + 1 = \{2, 3, 4\}$

CFI is always transmitted in the first OFDM symbol in a subframe



PCFICH shall be transmitted on the same set of antenna ports as the PBCH

HI (1/2)

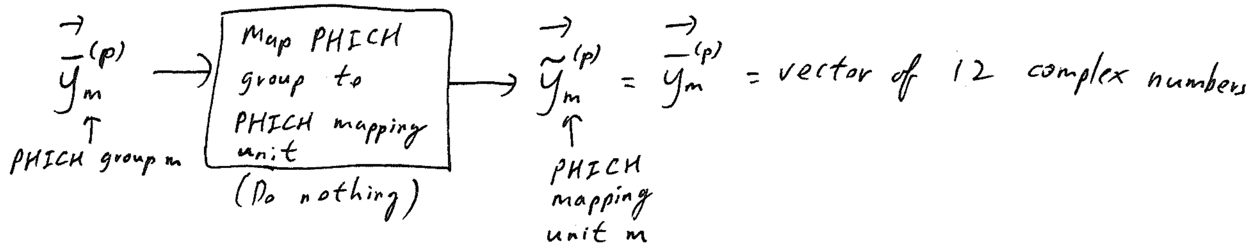


$\vec{y}^{(0)}$ corresponds to PHICH orthogonal sequence index i within PHICH group number j for antenna port 0

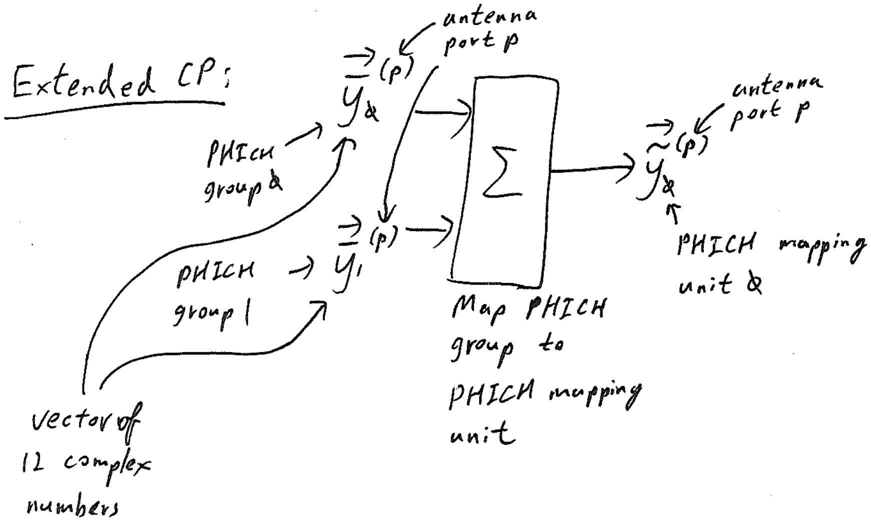
PHICH shall be transmitted on the same set of antenna ports as the PBCH.

HI (2/2)

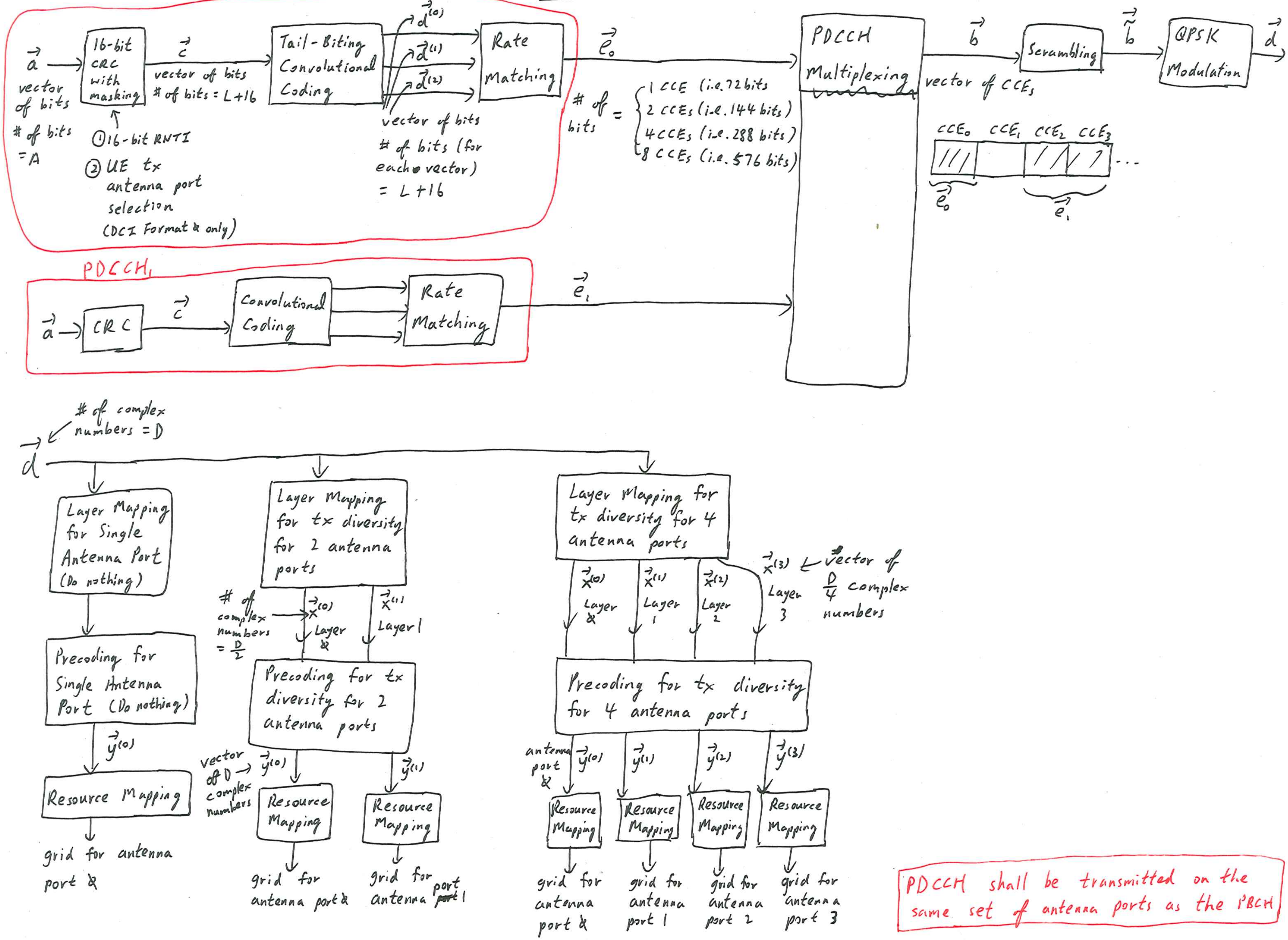
Normal CP:



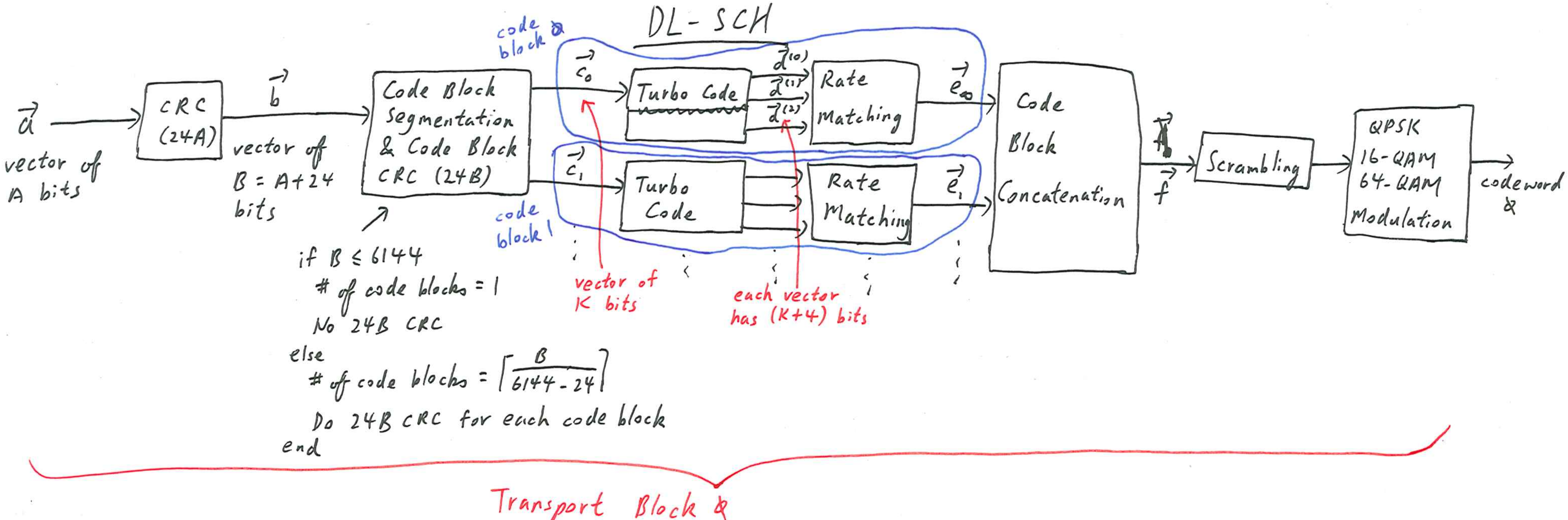
Extended CP:

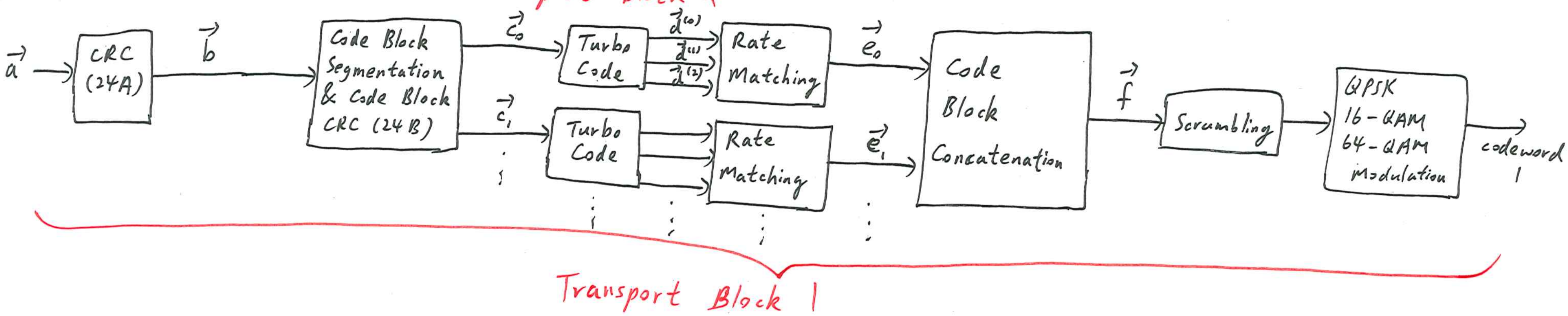


DCI

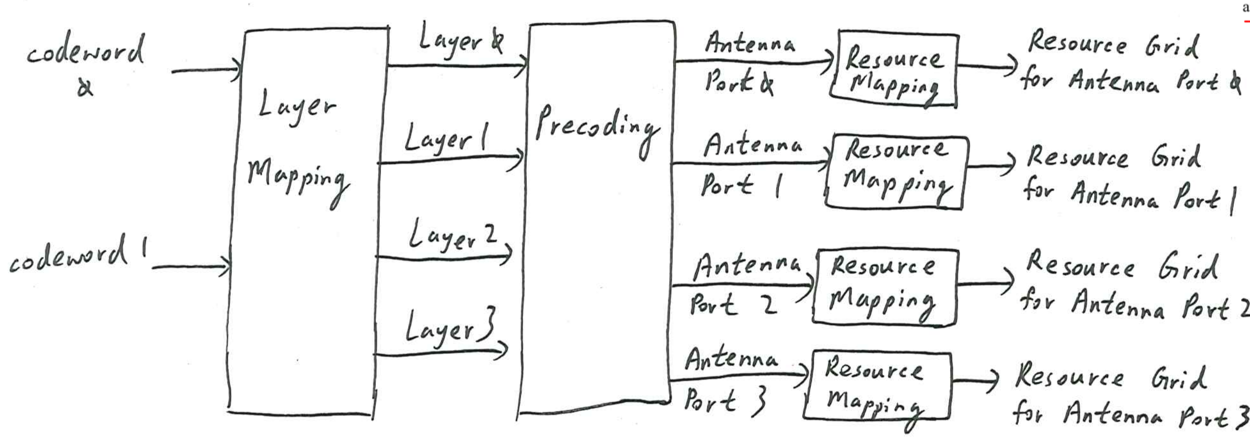


PDCCH shall be transmitted on the same set of antenna ports as the PBCH





- In resource blocks in which UE-specific reference signals are not transmitted, the PDSCH shall be transmitted on the same set of antenna ports as the PBCH, which is one of $\{0\}$, $\{0,1\}$, or $\{0,1,2,3\}$
- In resource blocks in which UE-specific reference signals are transmitted, the PDSCH shall be transmitted on antenna port $\{5\}$



SC-FDMA

Table 5.2.3-1: Resource block parameters.

Configuration	N_{sc}^{RB}	N_{symb}^{UL}
Normal cyclic prefix	12	7
Extended cyclic prefix	12	6

Table 5.6-1: SC-FDMA parameters.

Configuration	Cyclic prefix length $N_{CP,l}$
Normal cyclic prefix	160 for $l = 0$ 144 for $l = 1,2,...,6$
Extended cyclic prefix	512 for $l = 0,1,...,5$

Δf = 15 kHz : IFFT Length = 2048

Sampling Rate (Complex) = 30.72 MHz

8.1 Uplink-downlink frame timing

Transmission of the uplink radio frame number i from the UE shall start $(N_{TA} + N_{TA\ offset}) \times T_s$ seconds before the start of the corresponding downlink radio frame at the UE, where $0 \le N_{TA} \le 20512$, $N_{TA\ offset} = 0$ for frame structure type 1 and $N_{TA\ offset} = 624$ for frame structure type 2. Note that not all slots in a radio frame may be transmitted. One example hereof is TDD, where only a subset of the slots in a radio frame is transmitted.

1 subframe = 1 ms = 30720 Ts

In case of base-station perspective, downlink radio frame is perfectly aligned with uplink radio frame.

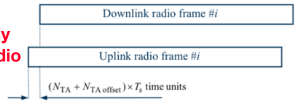


Figure 8.1-1: Uplink-downlink timing relation

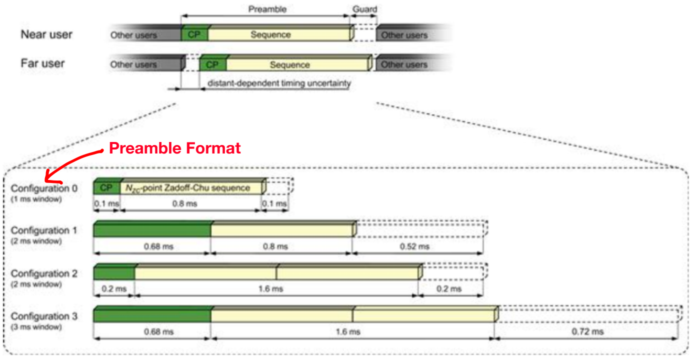
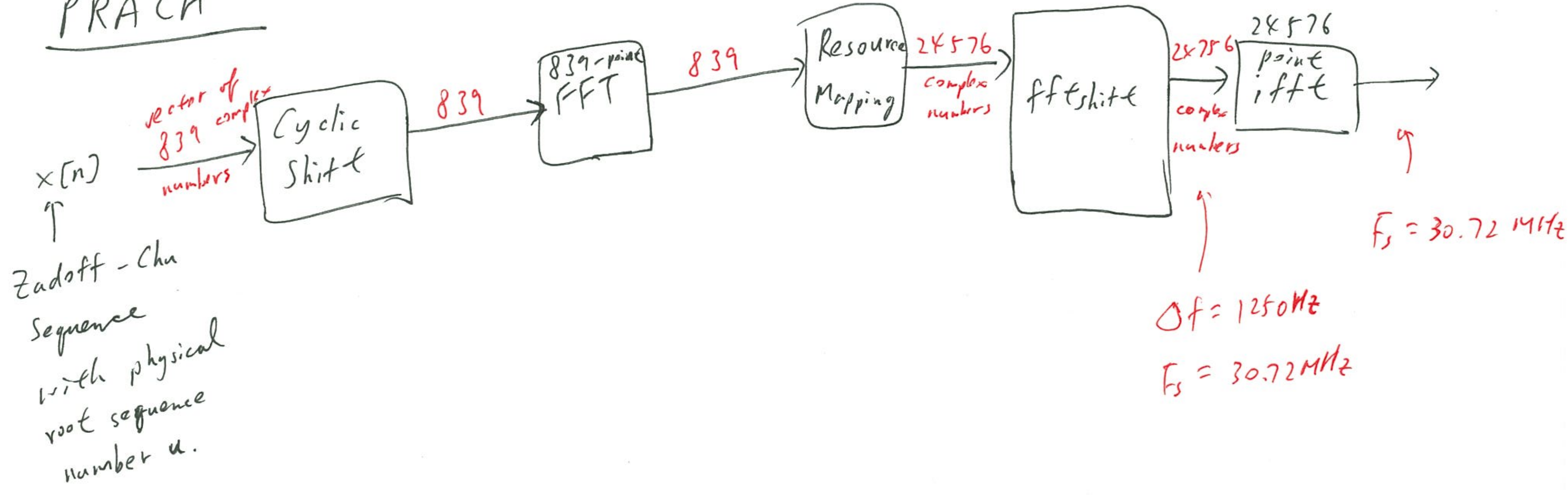


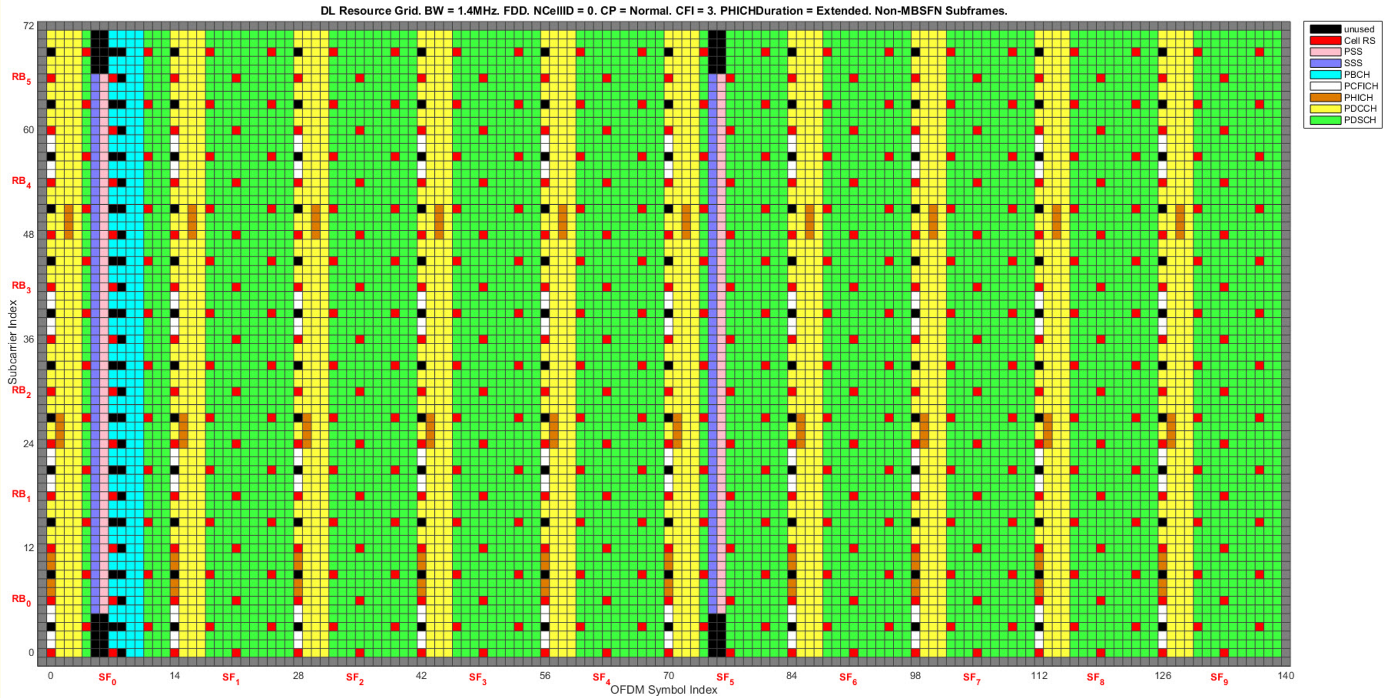
FIGURE 14.11 Different preamble formats

PRACH

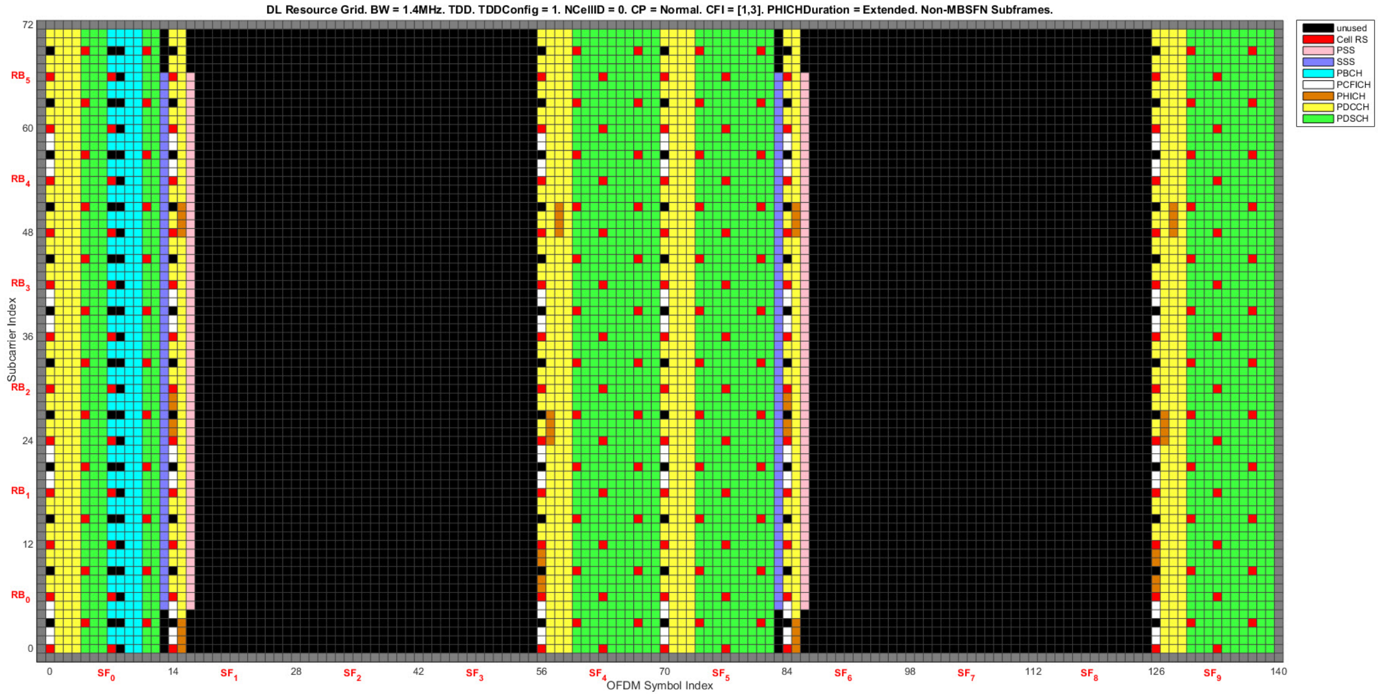


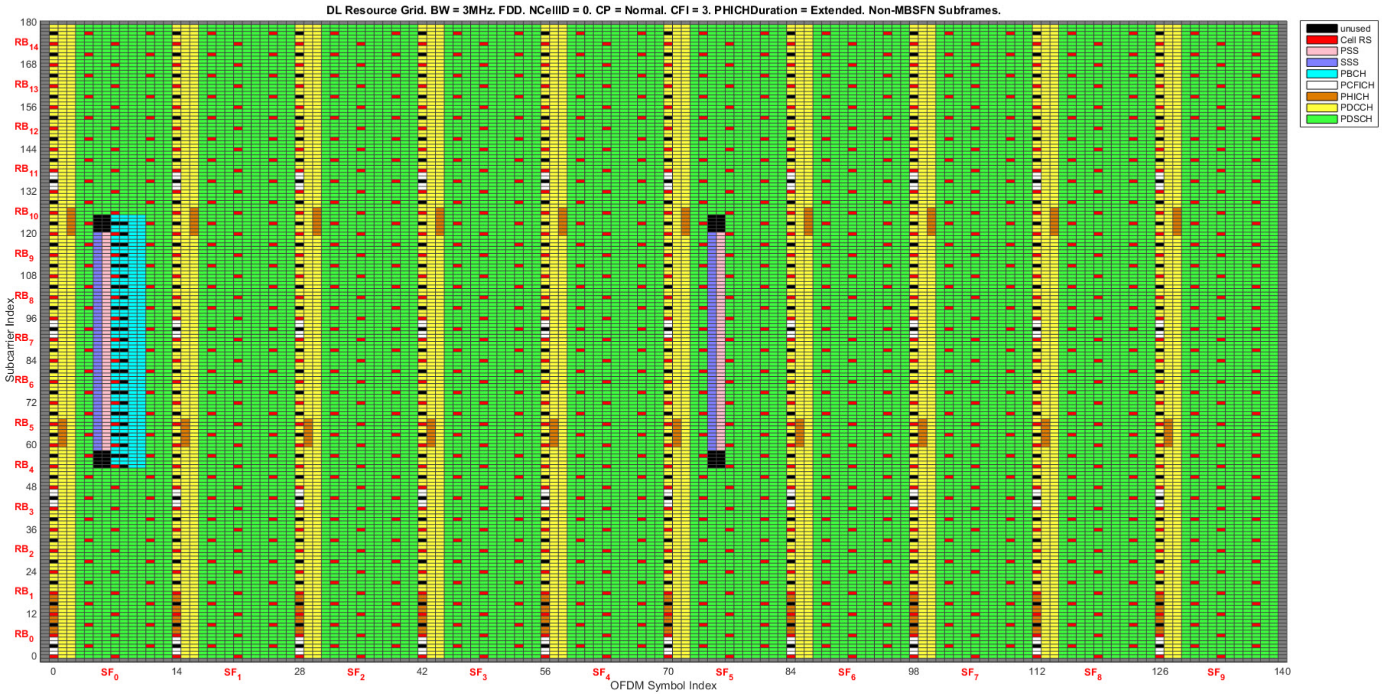
$\Delta f = \frac{F_s}{N}$

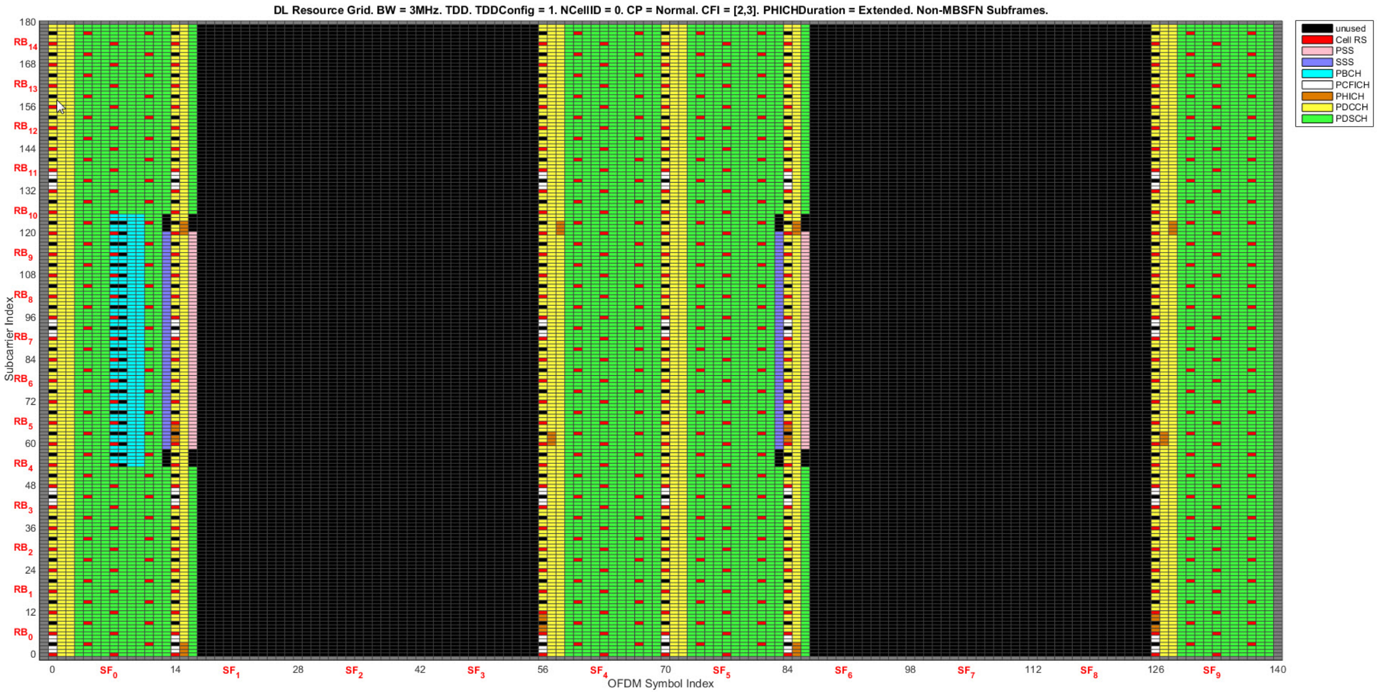
LTE\Iain\testPRACH.m



DL Resource Grid. BW = 1.4MHz. FDD. NCellID = 0. CP = Normal. CFI = 3. PHICHDuration = Extended. Non-MBSFN Subframes.
Subcarrier Index
OFDM Symbol Index
0
12
24
36
48
60
72
14
28
42
56
70
84
98
112
126
140
RB0
RB1
RB2
RB3
RB4
RB5
SF0
SF1
SF2
SF3
SF4
SF5
SF6
SF7
SF8
SF9
unused
Cell RS
PSS
SSS
PBCH
PCFICH
PHICH
PDCCH
PDSCH


DL Resource Grid. BW = 1.4MHz. TDD. TDDConfig = 1. NCellID = 0. CP = Normal. CFI = [1,3]. PHICHDuration = Extended. Non-MBSFN Subframes.
unused
Cell RS
PSS
SSS
PBCH
PCFICH
PHICH
PDCCH
PDSCH
Subcarrier Index
OFDM Symbol Index
0
12
24
36
48
60
72
RB_0
RB_1
RB_2
RB_3
RB_4
RB_5
0
14
28
42
56
70
84
98
112
126
140
SF_0
SF_1
SF_2
SF_3
SF_4
SF_5
SF_6
SF_7
SF_8
SF_9


DL Resource Grid. BW = 3MHz. FDD. NCellID = 0. CP = Normal. CFI = 3. PHICHDuration = Extended. Non-MBSFN Subframes.
Subcarrier Index
OFDM Symbol Index
unused
Cell RS
PSS
SSS
PBCH
PCFICH
PHICH
PDCCH
PDSCH
180
168
156
144
132
120
108
96
84
72
60
48
36
24
12
0
RB14
RB13
RB12
RB11
RB10
RB9
RB8
RB7
RB6
RB5
RB4
RB3
RB2
RB1
RB0
0
14
28
42
56
70
84
98
112
126
140
SF0
SF1
SF2
SF3
SF4
SF5
SF6
SF7
SF8
SF9


DL Resource Grid. BW = 3MHz. TDD. TDDConfig = 1. NCellID = 0. CP = Normal. CFI = [2,3]. PHICHDuration = Extended. Non-MBSFN Subframes.
unused
Cell RS
PSS
SSS
PBCH
PCFICH
PHICH
PDCCH
PDSCH
Subcarrier Index
0
12
24
36
48
60
72
84
96
108
120
132
144
156
168
180
RB_0
RB_1
RB_2
RB_3
RB_4
RB_5
RB_6
RB_7
RB_8
RB_9
RB_{10}
RB_{11}
RB_{12}
RB_{13}
RB_{14}
OFDM Symbol Index
0
14
28
42
56
70
84
98
112
126
140
SF_0
SF_1
SF_2
SF_3
SF_4
SF_5
SF_6
SF_7
SF_8
SF_9

Many sequences can be represented by a Fourier integral of the form

$$x[n] = \frac{1}{2\pi}\int_{-\pi}^{\pi} X(e^{j\omega})e^{j\omega n}\,d\omega, \qquad (2.130)$$

DTFT

where

$$X(e^{j\omega}) = \sum_{n=-\infty}^{\infty} x[n]e^{-j\omega n}. \qquad (2.131)$$

$$W_N = e^{-j(2\pi/N)}$$

Generally, the DFT analysis and synthesis equations are written as follows:

$$\text{Analysis equation:} \quad X[k] = \sum_{n=0}^{N-1} x[n]W_N^{kn}, \qquad 0 \le k \le N-1, \qquad (8.67)$$

$$\text{Synthesis equation:} \quad x[n] = \frac{1}{N}\sum_{k=0}^{N-1} X[k]W_N^{-kn}, \qquad 0 \le n \le N-1. \qquad (8.68)$$

$$x[n] = \frac{1}{N}\sum_{k=0}^{N-1} X[k]\, e^{j2\pi k \Delta f t}$$

That is, the fact that $X[k] = 0$ for k outside the interval $0 \le k \le N-1$ and that $x[n] = 0$ for n outside the interval $0 \le n \le N-1$ is implied, but not always stated explicitly. The relationship between $x[n]$ and $X[k]$ implied by Eqs. (8.67) and (8.68) will sometimes be denoted as

$$x[n] \overset{\mathcal{DFT}}{\longleftrightarrow} X[k]. \qquad (8.69)$$

In recasting Eqs. (8.11) and (8.12) in the form of Eqs. (8.67) and (8.68) for finite-duration sequences, we have not eliminated the inherent periodicity. As with the DFS, the DFT $X[k]$ is equal to samples of the periodic Fourier transform $X(e^{j\omega})$, and if Eq. (8.68) is evaluated for values of n outside the interval $0 \le n \le N-1$, the result will not be zero, but rather a periodic extension of $x[n]$. The inherent periodicity is always present. Sometimes, it causes us difficulty, and sometimes we can exploit it, but to totally ignore it is to invite trouble. In defining the DFT representation, we are simply recognizing that we are interested in values of $x[n]$ only in the interval $0 \le n \le N-1$, because $x[n]$ is really zero outside that interval, and we are interested in values of $X[k]$ only in the interval $0 \le k \le N-1$ because these are the only values needed in Eq. (8.68) to reconstruct $X[n]$.

TABLE 8.2 SUMMARY OF PROPERTIES OF THE DFT

Finite-Length Sequence (Length N)	N-point DFT (Length N)
1. $x[n]$	$X[k]$
2. $x_1[n]$, $x_2[n]$	$X_1[k]$, $X_2[k]$
3. $ax_1[n] + bx_2[n]$	$aX_1[k] + bX_2[k]$
4. $X[n]$	$Nx[((-k))_N]$
5. $x[((n-m))_N]$	$W_N^{km}X[k]$
6. $W_N^{-\ell n}x[n]$	$X[((k-\ell))_N]$
7. $\sum_{m=0}^{N-1} x_1[m]x_2[((n-m))_N]$	$X_1[k]X_2[k]$
8. $x_1[n]x_2[n]$	$\frac{1}{N}\sum_{\ell=0}^{N-1} X_1[\ell]X_2[((k-\ell))_N]$
9. $x^*[n]$	$X^*[((-k))_N]$
10. $x^*[((-n))_N]$	$X^*[k]$
11. $\mathcal{R}e\{x[n]\}$	$X_{ep}[k] = \frac{1}{2}\{X[((k))_N] + X^*[((-k))_N]\}$
12. $j\mathcal{I}m\{x[n]\}$	$X_{op}[k] = \frac{1}{2}\{X[((k))_N] - X^*[((-k))_N]\}$
13. $x_{ep}[n] = \frac{1}{2}\{x[n] + x^*[((-n))_N]\}$	$\mathcal{R}e\{X[k]\}$
14. $x_{op}[n] = \frac{1}{2}\{x[n] - x^*[((-n))_N]\}$	$j\mathcal{I}m\{X[k]\}$
Properties 15–17 apply only when $x[n]$ is real.	
15. Symmetry properties	$\begin{cases} X[k] = X^*[((-k))_N] \\ \mathcal{R}e\{X[k]\} = \mathcal{R}e\{X[((-k))_N]\} \\ \mathcal{I}m\{X[k]\} = -\mathcal{I}m\{X[((-k))_N]\} \\ \lvert X[k]\rvert = \lvert X[((-k))_N]\rvert \\ \angle\{X[k]\} = -\angle\{X[((-k))_N]\} \end{cases}$
16. $x_{ep}[n] = \frac{1}{2}\{x[n] + x[((-n))_N]\}$	$\mathcal{R}e\{X[k]\}$
17. $x_{op}[n] = \frac{1}{2}\{x[n] - x[((-n))_N]\}$	$j\mathcal{I}m\{X[k]\}$

Example 2.16 Frequency Response of the Moving-Average System

The impulse response of the moving-average system of Example 2.3 is

$$h[n] = \begin{cases} \dfrac{1}{M_1 + M_2 + 1}, & -M_1 \le n \le M_2, \\ 0, & \text{otherwise.} \end{cases}$$

Therefore, the frequency response is

$$H(e^{j\omega}) = \frac{1}{M_1 + M_2 + 1} \sum_{n=-M_1}^{M_2} e^{-j\omega n}. \tag{2.121}$$

For the causal moving average system, $M_1 = 0$ and Eq. (2.121) can be expressed as

$$H(e^{j\omega}) = \frac{1}{M_2 + 1} \sum_{n=0}^{M_2} e^{-j\omega n}. \tag{2.122}$$

Using Eq. (2.55), Eq. (2.122) becomes

$$\begin{aligned} H(e^{j\omega}) &= \frac{1}{M_2+1}\left(\frac{1 - e^{-j\omega(M_2+1)}}{1 - e^{-j\omega}}\right) \\ &= \frac{1}{M_2+1}\frac{(e^{j\omega(M_2+1)/2} - e^{-j\omega(M_2+1)/2})e^{-j\omega(M_2+1)/2}}{(e^{j\omega/2} - e^{-j\omega/2})e^{-j\omega/2}} \\ &= \frac{1}{M_2+1}\frac{\sin[\omega(M_2+1)/2]}{\sin \omega/2} e^{-j\omega M_2/2}. \end{aligned} \tag{2.123}$$

The magnitude and phase of $H(e^{j\omega})$ for this case, with $M_2 = 4$, are shown in Figure 2.19.

If the moving-average filter is symmetric, i.e., if $M_1 = M_2$, then Eq. (2.123) is replaced by

$$H(e^{j\omega}) = \frac{1}{2M_2+1}\frac{\sin[\omega(2M_2+1)/2]}{\sin(\omega/2)}. \tag{2.124}$$

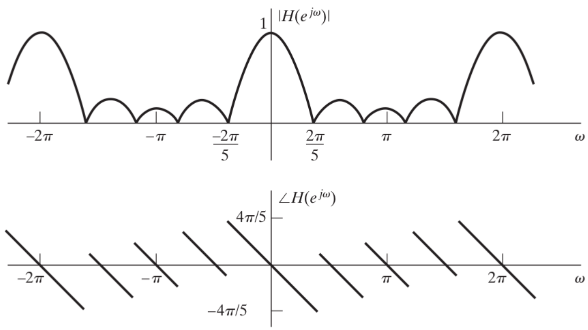
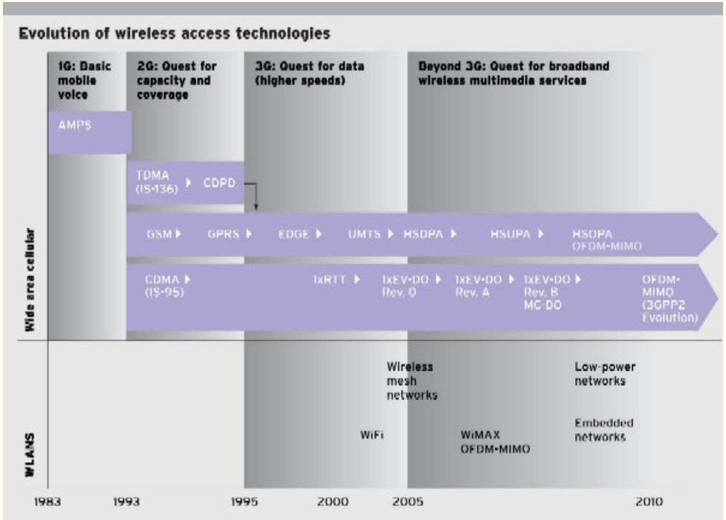
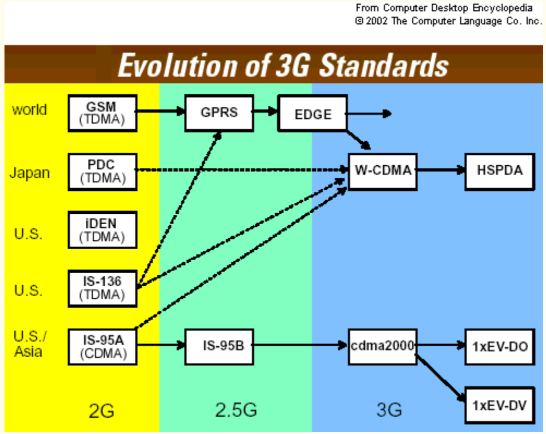


Figure 2.19 (a) Magnitude and (b) phase of the frequency response of the moving-average system for the case $M_1 = 0$ and $M_2 = 4$.


Evolution of wireless access technologies
1G: Basic mobile voice
2G: Quest for capacity and coverage
3G: Quest for data (higher speeds)
Beyond 3G: Quest for broadband wireless multimedia services
AMPS
TDMA (IS-136)
CDPD
GSM
GPRS
EDGE
UMTS
HSDPA
HSUPA
HSOPA OFDM-MIMO
CDMA (IS-95)
1xRTT
1xEV-DO Rev. 0
1xEV-DO Rev. A
1xEV-DO Rev. B MC-DO
OFDM-MIMO (3GPP2 Evolution)
Wireless mesh networks
Low-power networks
WiFi
WiMAX OFDM-MIMO
Embedded networks
Wide area cellular
WLANS
1983
1993
1995
2000
2005
2010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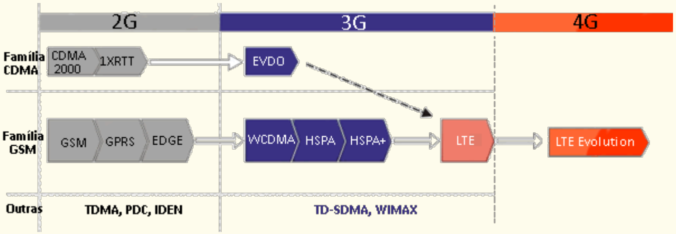
Evolution of 3G Standards
world
Japan
U.S.
U.S.
U.S./ Asia
GSM (TDMA)
PDC (TDMA)
iDEN (TDMA)
IS-136 (TDMA)
IS-95A (CDMA)
GPRS
EDGE
IS-95B
W-CDMA
HSPDA
cdma2000
1xEV-DO
1xEV-DV
2G
2.5G
3G


2G
3G
4G
Família CDMA
CDMA 2000
1XRTT
EVDO
Família GSM
GSM
GPRS
EDGE
WCDMA
HSPA
HSPA+
LTE
LTE Evolution
Outras
TDMA, PDC, IDEN
TD-SDMA, WIMAX

Ch4

Ch5

Ch6