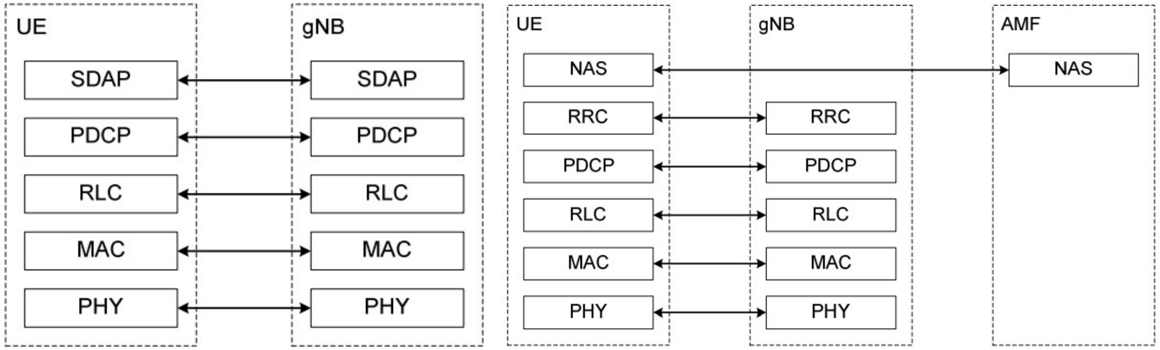
O-RAN.WG4.CUS.0-v05.00

Functional Split

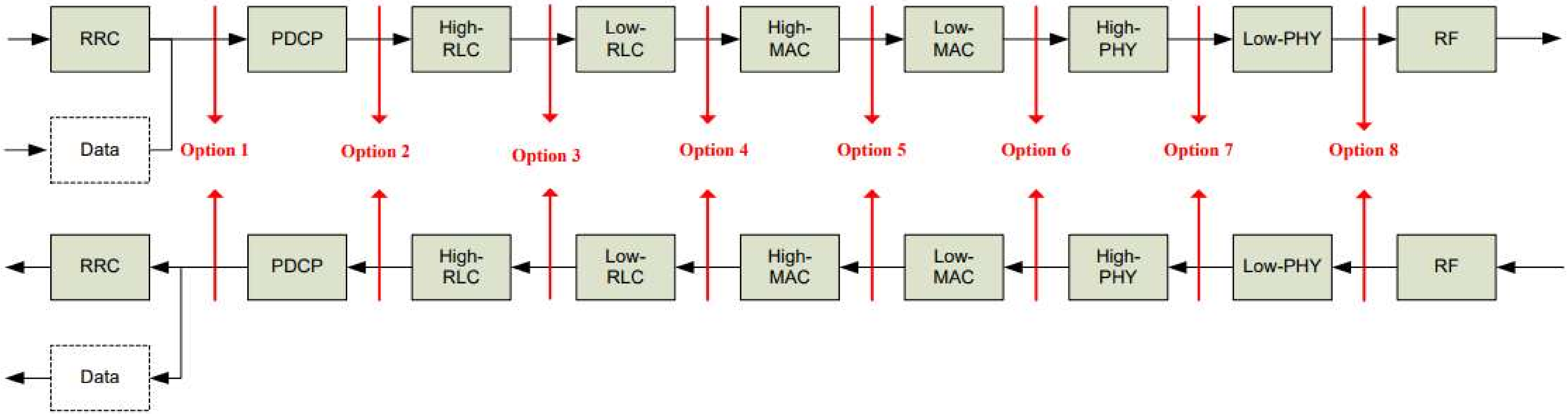
Split Options

- Radio Protocol Architecture
  - RRC/PDCP/RLC/MAC/PHY
- 3GPP TR 38.801
  - 8 options



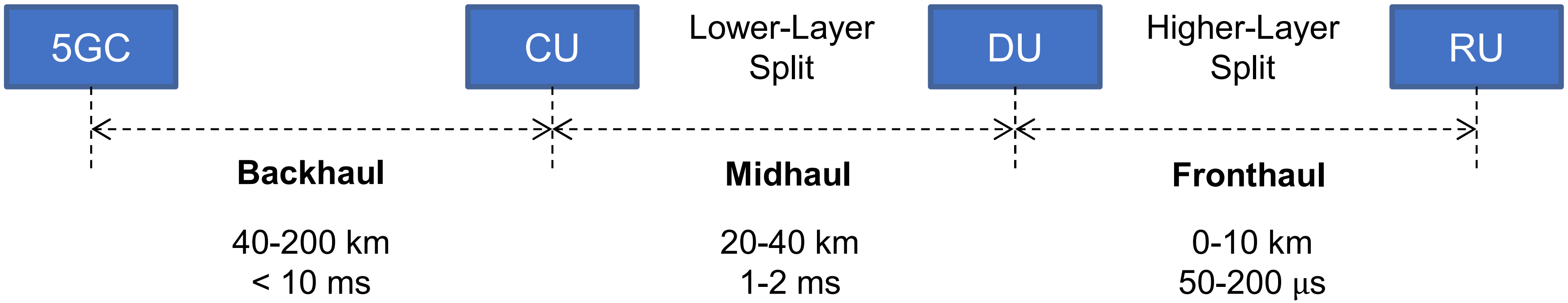
User Plane Protocol Stack

Control Plane Protocol Stack

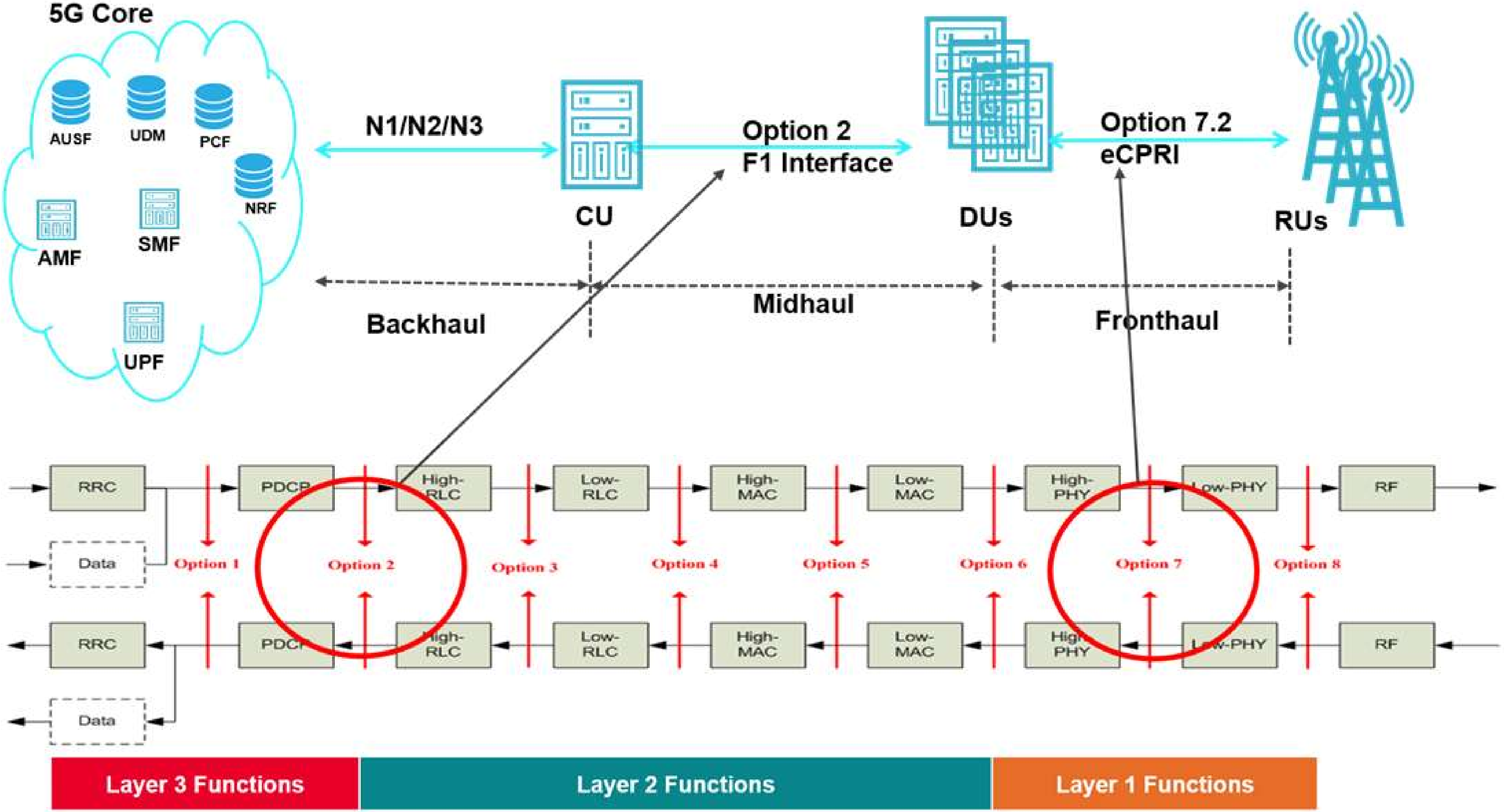


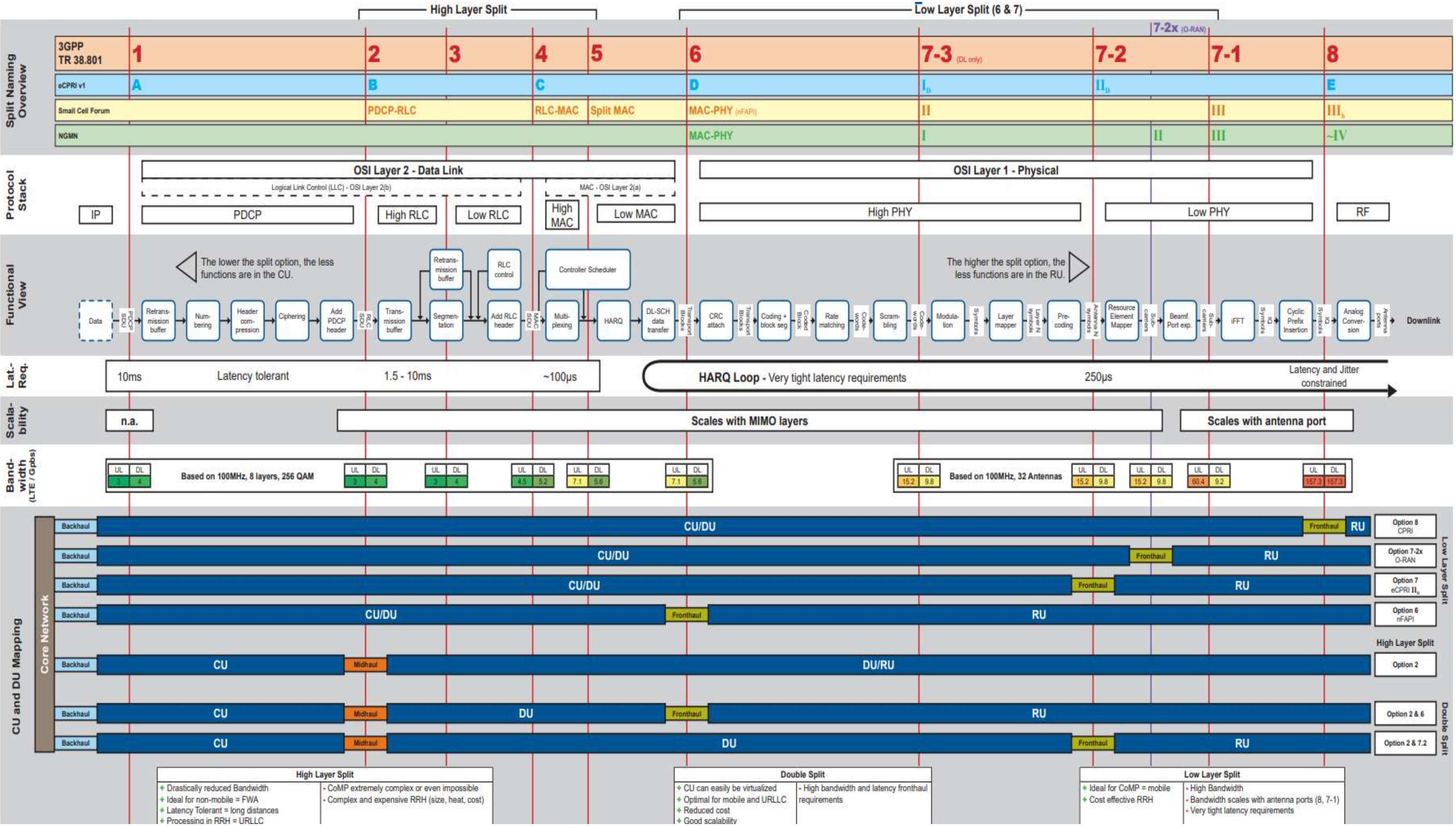
Split Options

- Higher-layer split (HLS)
  - 定義 DU-CU 的功能分層 (option 1~5)
- Lower-layer split (LLS)
  - 定義 RU-DU 的功能分層 (option 6~8)



5G RAN Functional Split

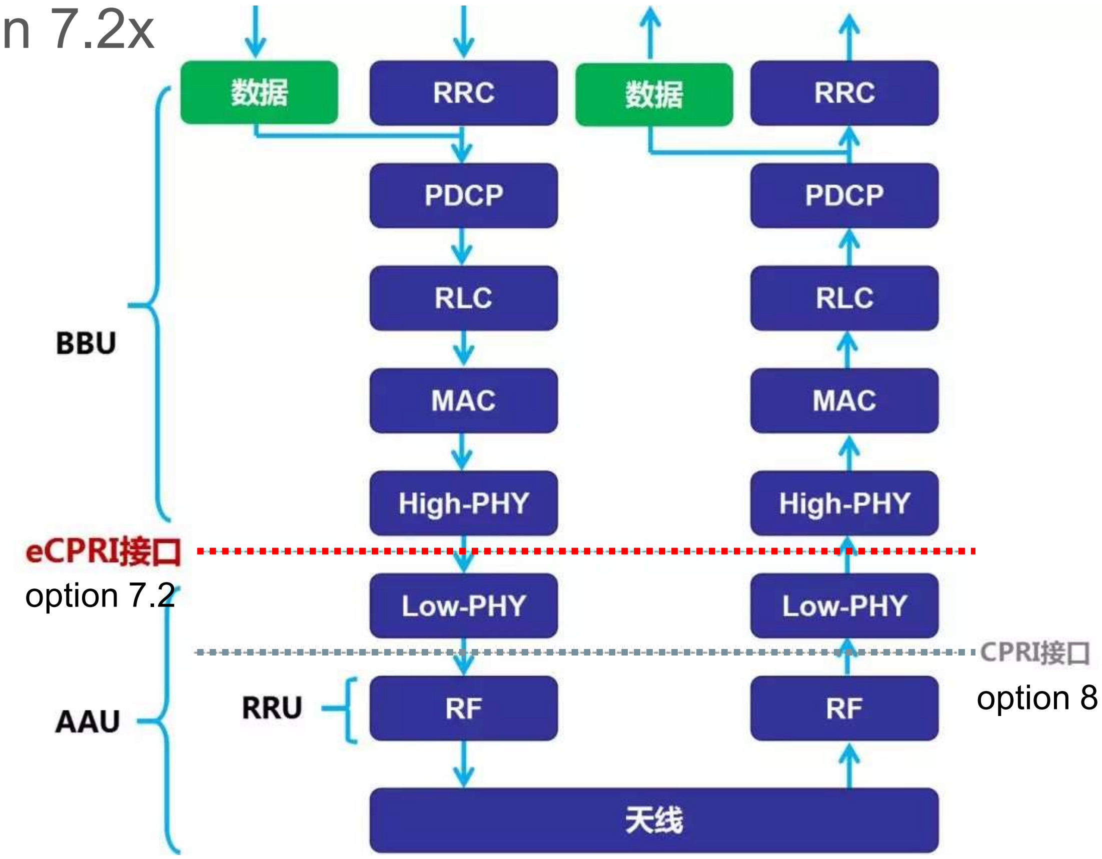




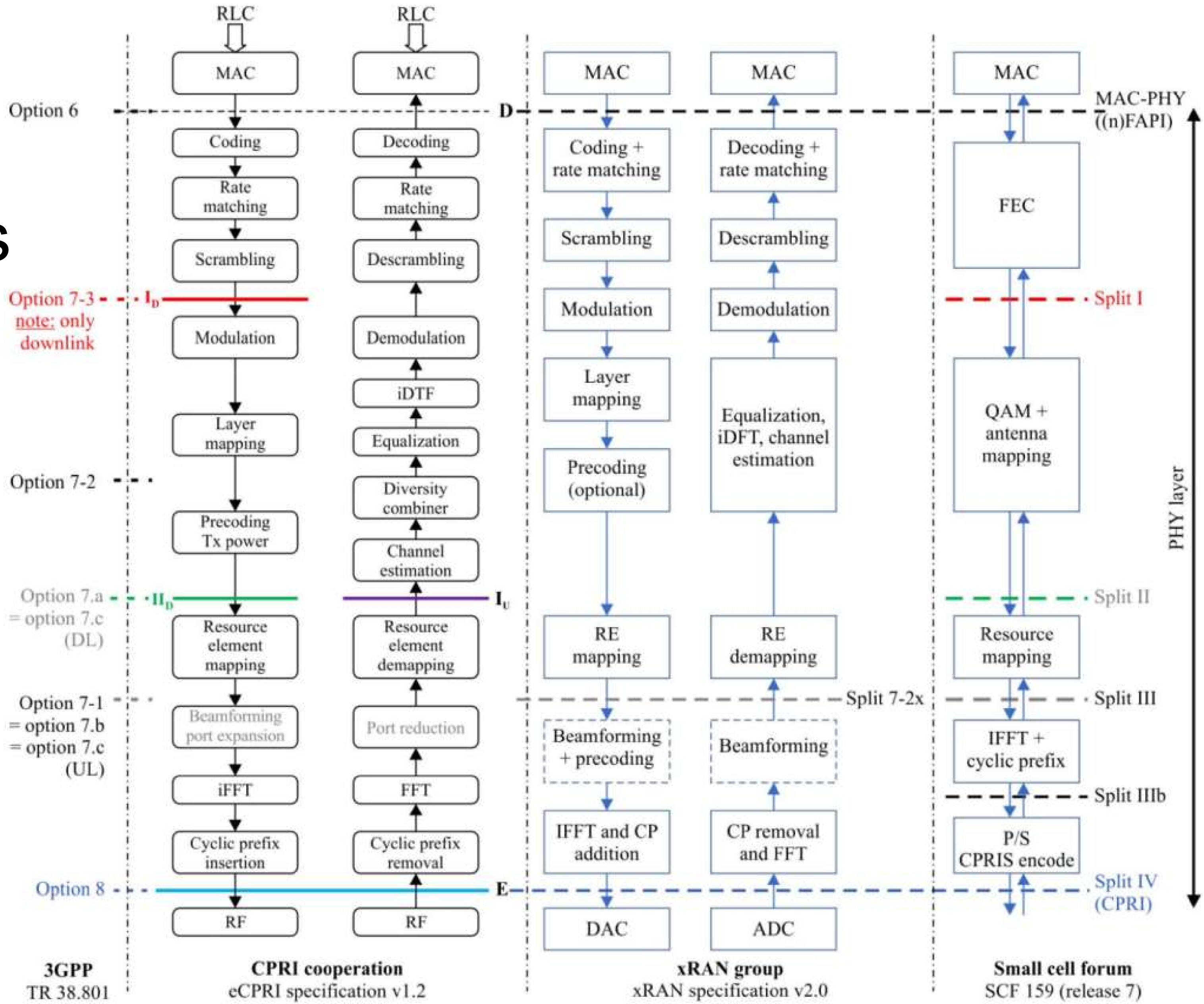
High Layer Split
Low Layer Split (6 & 7)
7-2x (O-RAN)
Split Naming Overview
3GPP TR 38.801
1
2
3
4
5
6
7-3 (DL only)
7-2
7-1
8
eCPRI v1
A
B
C
D
E
Small Cell Forum
PDCP-RLC
RLC-MAC
Split MAC
MAC-PHY (nFAPI)
NGMN
MAC-PHY
Protocol Stack
OSI Layer 2 - Data Link
Logical Link Control (LLC) - OSI Layer 2(b)
MAC - OSI Layer 2(a)
OSI Layer 1 - Physical
IP
PDCP
High RLC
Low RLC
High MAC
Low MAC
High PHY
Low PHY
RF
Functional View
The lower the split option, the less functions are in the CU.
The higher the split option, the less functions are in the RU.
Data
Retrans-mission buffer
Num-bering
Header com-pression
Ciphering
Add PDCP header
Trans-mission buffer
Segmen-tation
Add RLC header
RLC control
Controller Scheduler
Multi-plexing
HARQ
DL-SCH data transfer
CRC attach
Coding + block seg
Rate matching
Scram-bling
Modula-tion
Layer mapper
Pre-coding
Resource Element Mapper
Beamf. Port exp.
iFFT
Cyclic Prefix Insertion
Analog Conver-sion
Downlink
Lat.-Req.
10ms
Latency tolerant
1.5 - 10ms
~100µs
HARQ Loop - Very tight latency requirements
250µs
Latency and Jitter constrained
Scala-bility
n.a.
Scales with MIMO layers
Scales with antenna port
Band-width (LTE / Gpbs)
Based on 100MHz, 8 layers, 256 QAM
Based on 100MHz, 32 Antennas
UL DL
3 4
3 4
3 4
4.5 5.2
7.1 5.6
7.1 5.6
15.2 9.8
15.2 9.8
15.2 9.8
60.4 9.2
157.3 157.3
CU and DU Mapping
Core Network
Backhaul
CU/DU
Fronthaul
RU
Option 8 CPRI
Option 7-2x O-RAN
Option 7 eCPRI II
Option 6 nFAPI
Low Layer Split
High Layer Split
CU
Midhaul
DU/RU
Option 2
DU
Option 2 & 6
Option 2 & 7.2
Double Split
High Layer Split
+ Drastically reduced Bandwidth
+ Ideal for non-mobile = FWA
+ Latency Tolerant = long distances
+ Processing in RRH = URLLC
- CoMP extremely complex or even impossible
- Complex and expensive RRH (size, heat, cost)
Double Split
+ CU can easily be virtualized
+ Optimal for mobile and URLLC
+ Reduced cost
+ Good scalability
- High bandwidth and latency fronthaul requirements
Low Layer Split
+ Ideal for CoMP = mobile
+ Cost effective RRH
- High Bandwidth
- Bandwidth scales with antenna ports (8, 7-1)
- Very tight latency requirements

Option 7.2x

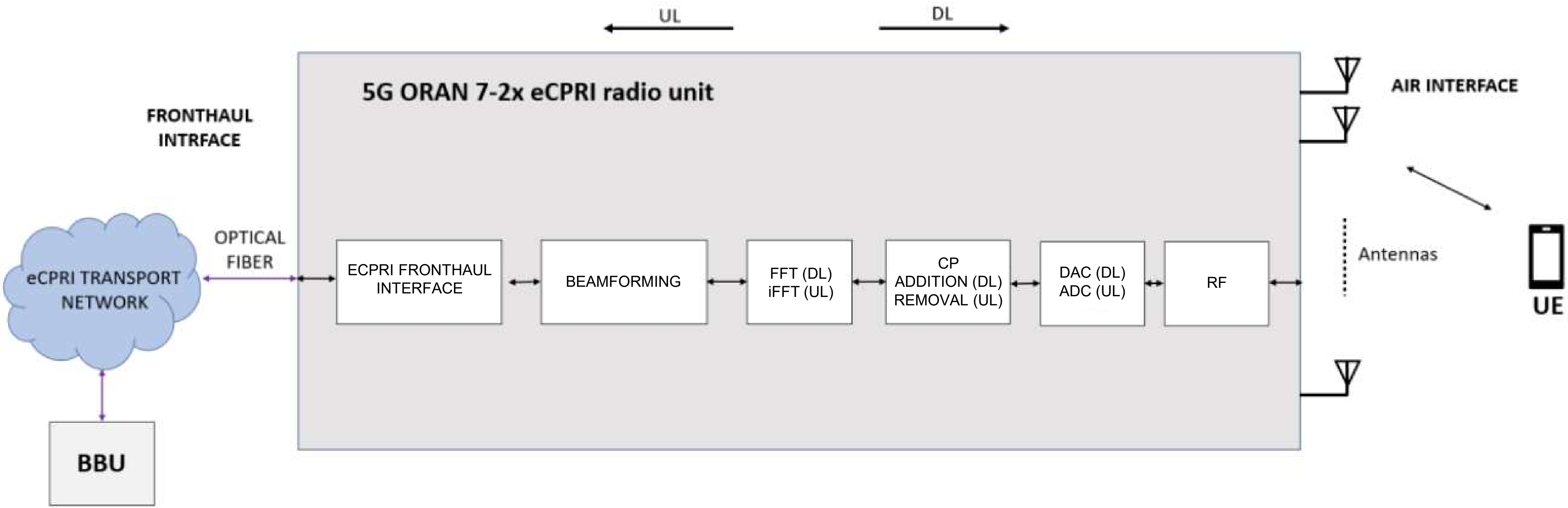
- 通訊協議每一層傳輸的數據封包會層層加碼，越到 PHY 數據封包越大
- 從 (4G)option 8 切割，改成 (5G)option 7.2x
  - 傳輸的介面不同，CPRI ➔ eCPRI
  - Fronthaul 傳輸的數據量變小
  - Throughput 變大
  - RU 變複雜
- 不同應用會使用不同的切割
  - Option 7.2 主要用在專網應用
  - Option 7.3 為公網應用為主



Lower Layer Functional Splits



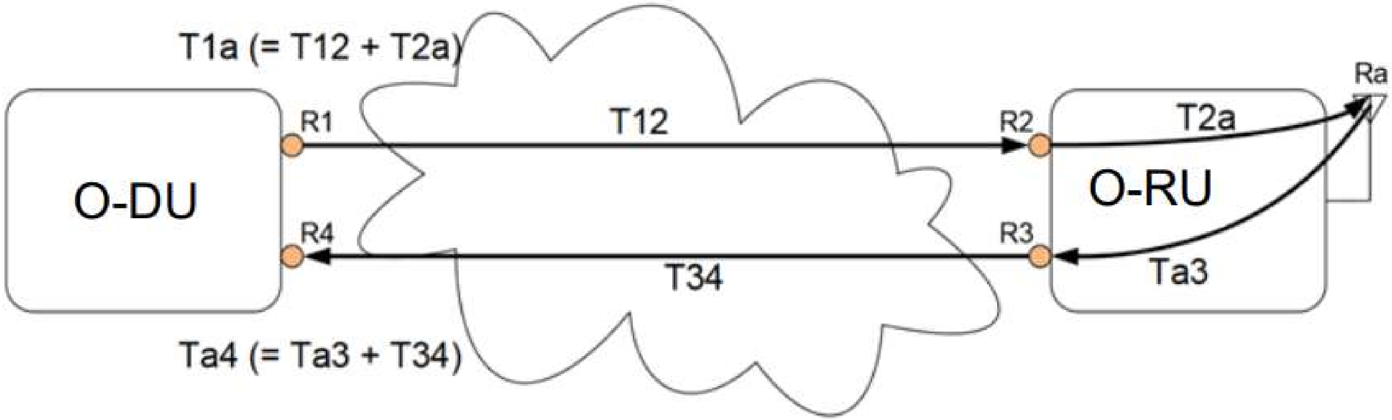
Radio Unit Architecture



DU-RU
Latency Requirements

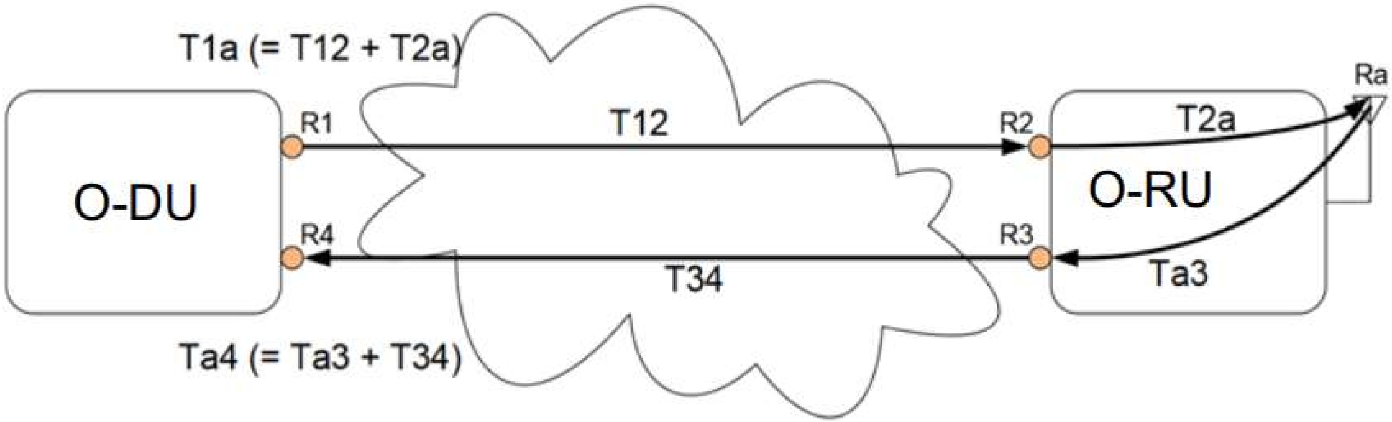
The Reference Points Defined for eCPRI

- O-DU: R1/ R4 – Transmit/ Receive interface at O-DU
- O-RU: R2/ R3 – Receive/ Transmit interface at O-RU
- Ra: Antenna interface at O-RU

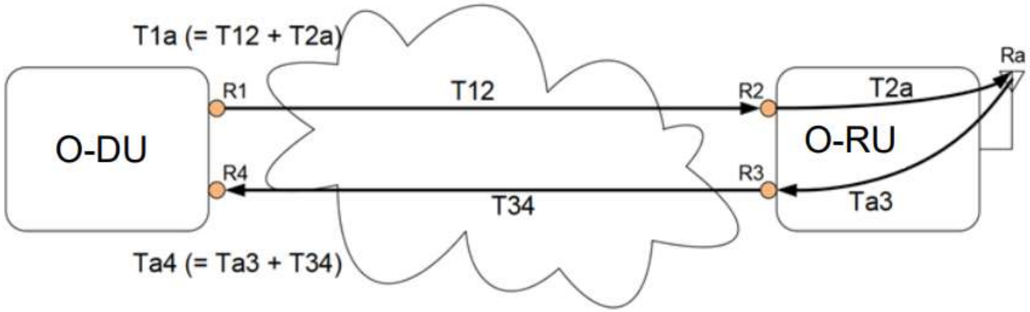


Delay Management

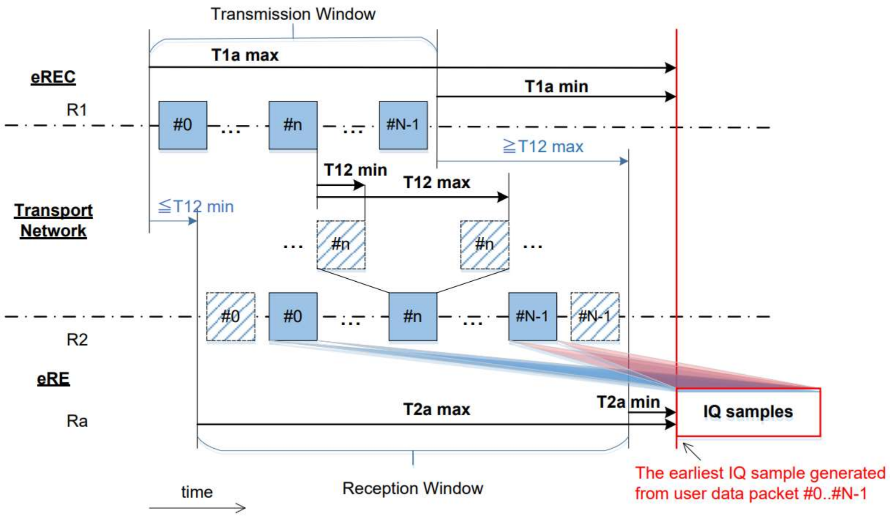
- 傳輸路徑
  - Downlink
    - T1a: from output at O-DU (R1) to transmission over the air
    - T2a: from reception at O-RU (R2) to transmission over the air
    - T12: from output at O-DU (R1) to reception at O-RU (R2)
  - Uplink
    - Ta3: from reception at O-RU antenna to output at O-RU port (R3)
    - Ta4: from reception at O-RU antenna to reception at O-DU port (R4)
    - T34: from output at O-RU port (R3) to reception at O-DU port (R4)

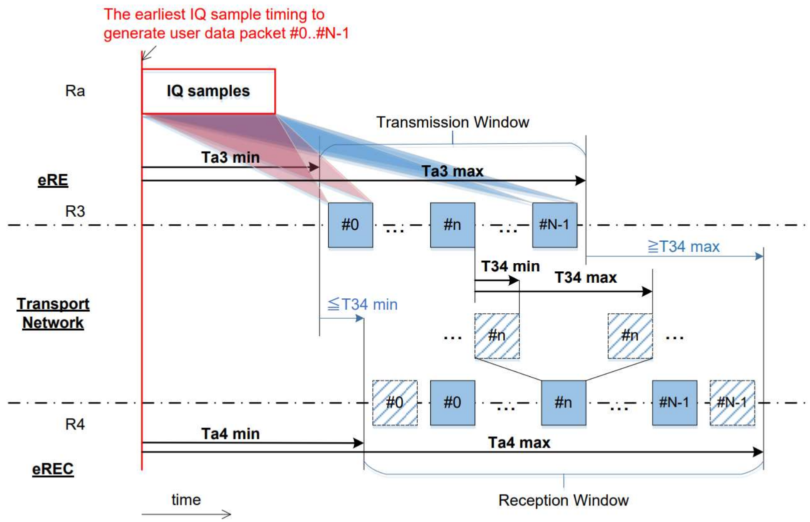


Delay Management



- 傳輸時間
  - Downlink
    - T1a max: 從 R1 可以傳送出資料的最早時間
    - T1a min: 從 R1 可以傳送出資料的最晚時間
    - T2a max: 在 R2 可以接收到資料的最早時間
    - T2a min: 在 R2 可以接收到資料的最晚時間
    - T12 max: 資料從 R1 到 R2 傳輸所需的最長時間
    - T12 min: 資料從 R1 到 R2 傳輸所需的最短時間
  - Uplink
    - Ta3 min: 從 R3 可以傳送出資料的最早時間
    - Ta3 max: 從 R3 可以傳送出資料的最晚時間
    - Ta4 min: 在 R4 可以接收到資料的最早時間
    - Ta4 max: 在 R4 可以接收到資料的最晚時間
    - T34 min: 資料從 R3 到 R4 傳輸所需的最短時間
    - T34 max:資料從 R3 到 R4 傳輸所需的最長時間



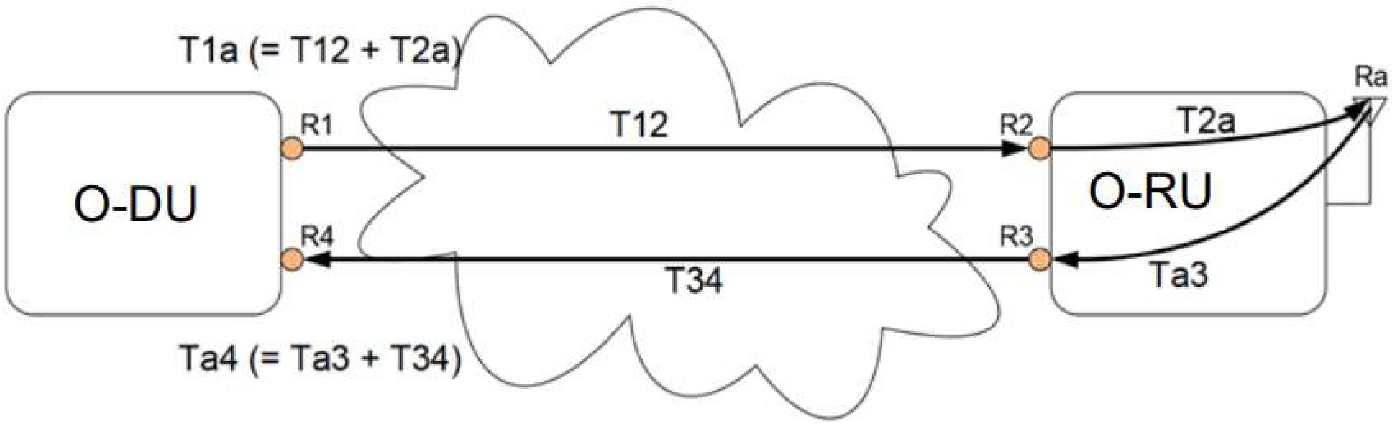


Delay Time Window

	Transmission(TX) Window	Reception(RX) Window	Transport Variation
Downlink	T1a max – T1a min	T2a max – T2a min	T12 max – T12 min
Uplink	Ta3 max – Ta3 min	Ta4 max – Ta4 min	T34 max – T34 min

T12, T34: Transport Delay

- TX Window: 定義資料必須傳送出的 最早時間 跟 最晚時間
- RX Window: 定義資料可以接收到的 最早時間 跟 最晚時間
- Reception Window ≥ Transmission Window + Transport Variation



Delay Relationships

- Downlink
  - $t = 0$: time of transmission (at air interface) of the first sample for symbol #0
    - 資料在 Ra 接收到的時間，訂為 0
  - start of transmission window = 0 - T1a_max = -T1a_max
  - end of transmission window = 0 - T1a_min = -T1a_min
  - start of reception window = 0 - T2a_max = -T2a_max
  - end of reception window = 0 - T2a_min = -T2a_min
  - start of processing in RU = 0 - T2a_min = -T2a_min
- 以 reception window 的角度來看
  - Start of rx window can accept a packet sent at start of tx window AND experienced min FH transport delay
    - $-T2a\_max \leq -T1a\_max + T12\_min$
  - End of rx window can accept a packet sent at end of tx window AND experienced max FH transport delay
    - $-T2a\_min \geq -T1a\_min + T12\_max$
  - ➔ $(T2a\_max - T2a\_min) \geq (T1a\_max - T1a\_min) + (T12\_max - T12\_min)$
    - Reception Window ≥ Transmission Window + Transport Variation

Delay Relationships

- Uplink
  - t = 0 : time of reception (at air interface) of the first sample for symbol #0
    - 資料從 Ra 傳出去的時間，訂為 0
  - end of processing in RU = 0 + Ta3_min = Ta3_min
  - start of transmission window = 0 + Ta3_min = Ta3_min
  - end of transmission window = 0 + Ta3_max = Ta3_max
  - start of reception window = 0 + Ta4_min = Ta4_min
  - end of reception window = 0 + Ta4_max = Ta4_max
- 以 reception window 的角度來看
  - Start of rx window can accept a packet sent at start of tx window AND experienced min FH transport delay
    - Ta4_min ≤ Ta3_min + T34_min
  - End of rx window can accept a packet sent at end of tx window AND experienced max FH transport delay
    - Ta4_max ≥ Ta3_max + T34_max
  - ➔ (Ta4_max - Ta4_min) ≥ (Ta3_max - Ta3_min) + (T34_max - T34_min)
    - Reception Window ≥ Transmission Window + Transport Variation

DU Transmission Window Sample

The following downlink example illustrates the concept:

- O-RU parameters: T2amin = 100 usec, T2amax = 260 usec
- Transport Parameters (direct fiber of known length): T12min = 50 usec, T12max = 51 usec

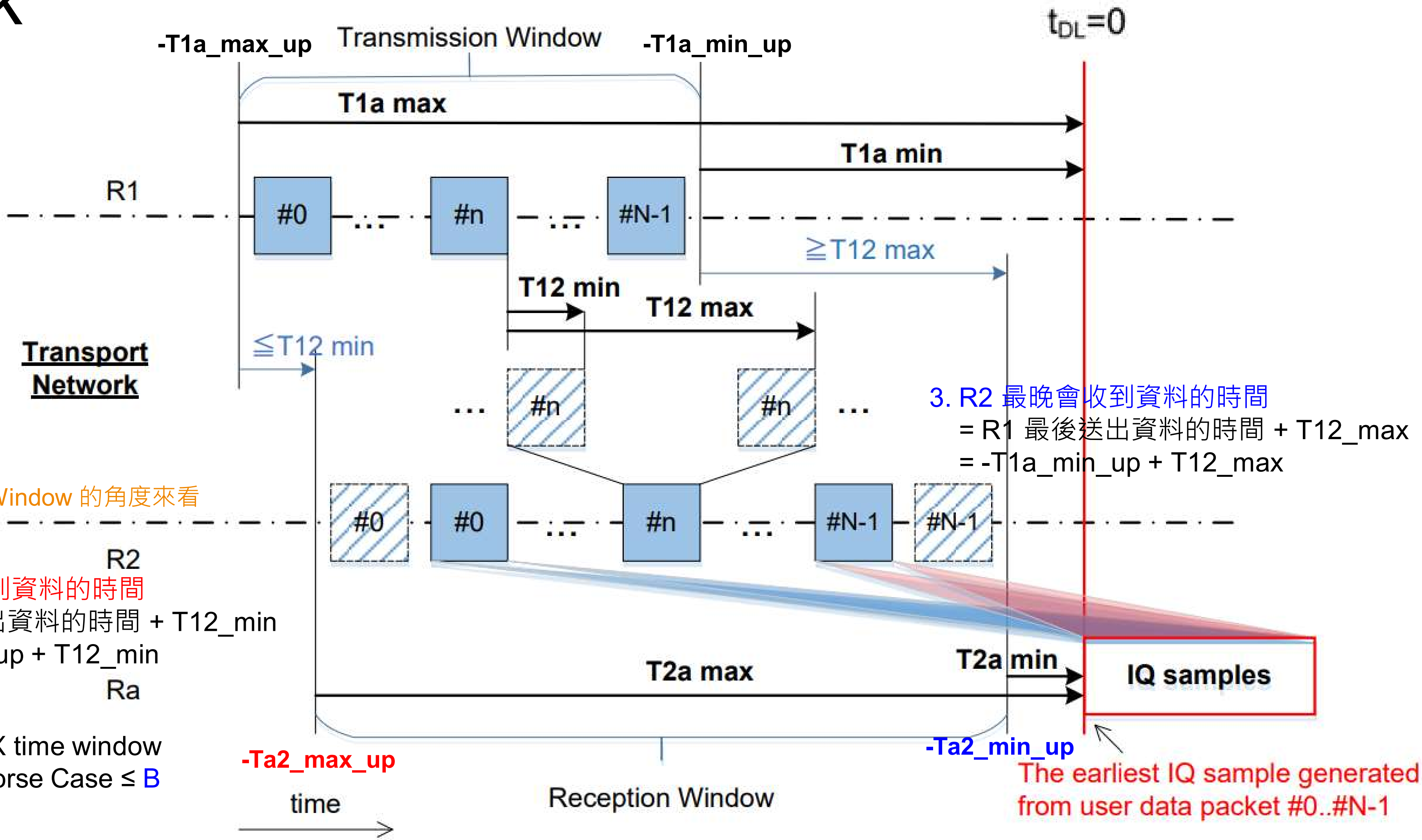
The result indicates an O-DU transmission window as follows:

- T1amax ≤ 260 + 50 (T1a_max ≤ T2a_max + T12_min)
- T1amin ≥ 100 + 51 (T1a_min ≥ T2a_min + T12_max)

- 100 ≤ T2a ≤ 260
- 50 ≤ T12 ≤ 51
- 100+51 ≤ T1a ≤ 260+50

Downlink

T1a_max_up ≤ T2a_max_up + T12_min ➔ -T2a_max_up ≤ -T1a_max_up + T12_min
T1a_min_up ≥ T2a_min_up + T12_max ➔ -T2a_min_up ≥ -T1a_min_up + T12_max



1. 以 Rx Window 的角度來看

2. R2 最早能收到資料的時間
= R1 開始送出資料的時間 + T12_min
= -T1a_max_up + T12_min

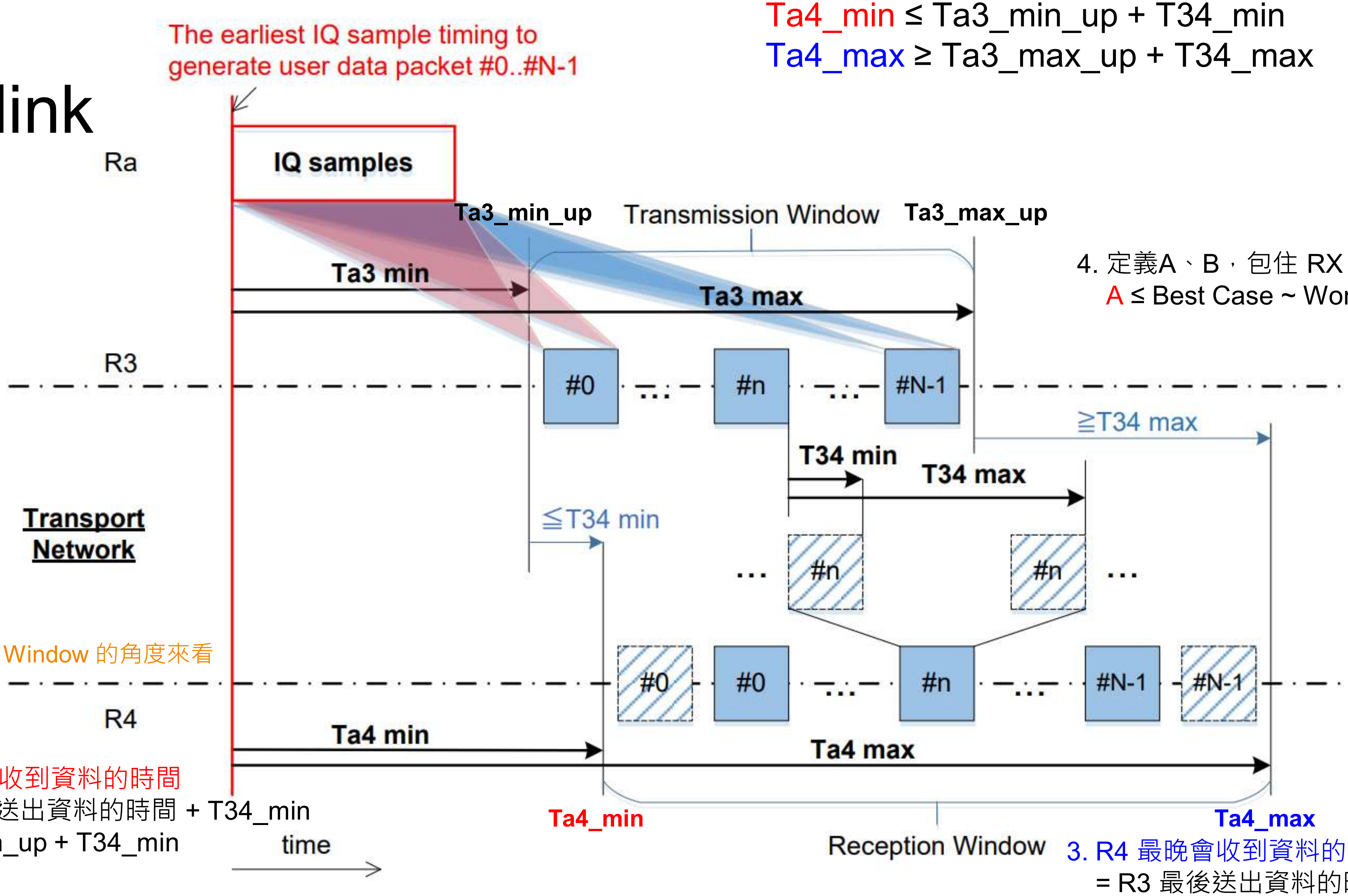
3. R2 最晚會收到資料的時間
= R1 最後送出資料的時間 + T12_max
= -T1a_min_up + T12_max

4. 定義A、B，包住 RX time window
A ≤ Best Case ~ Worse Case ≤ B

Uplink

$Ta4\_min \le Ta3\_min\_up + T34\_min$

$Ta4\_max \ge Ta3\_max\_up + T34\_max$

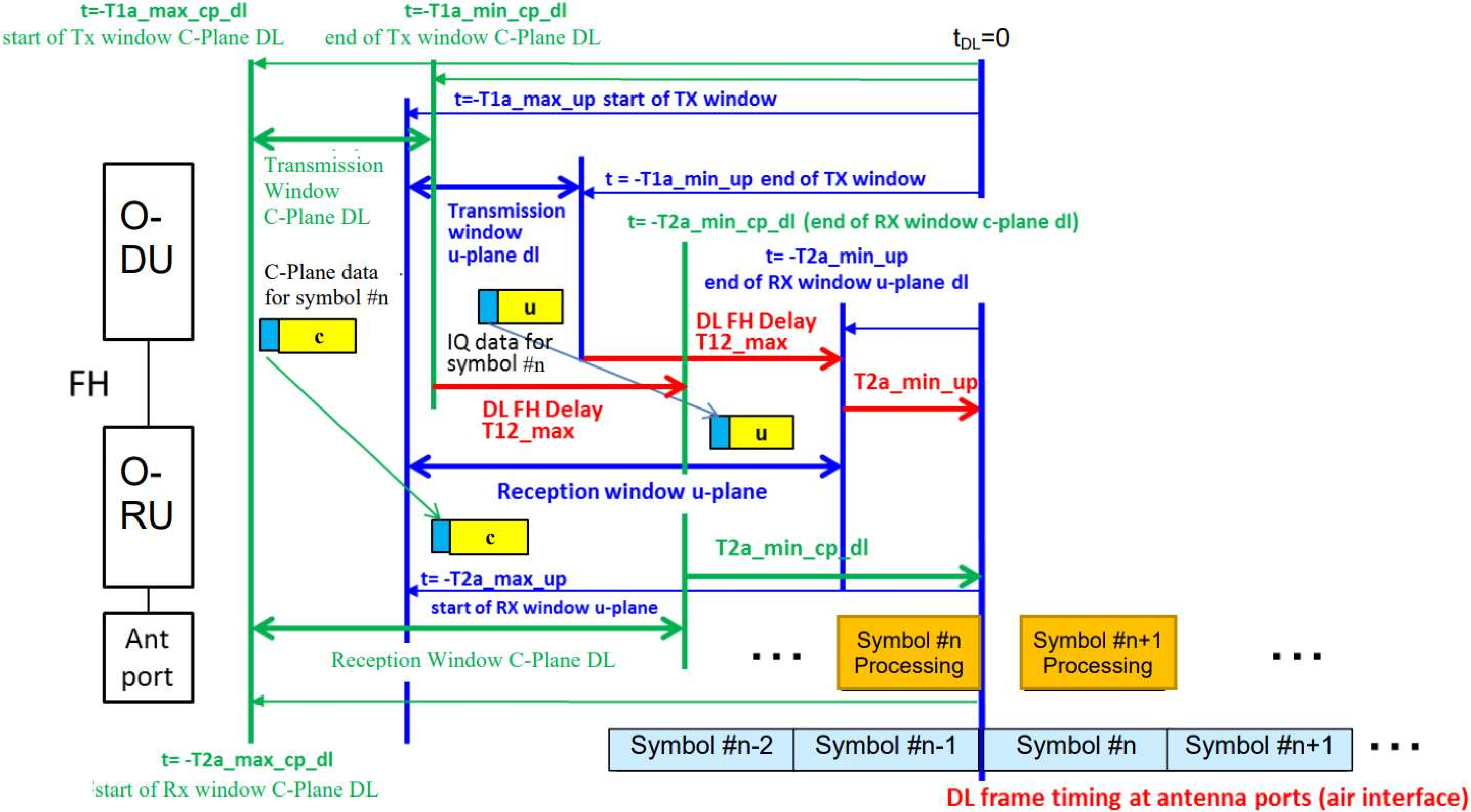


1. 以 Rx Window 的角度來看

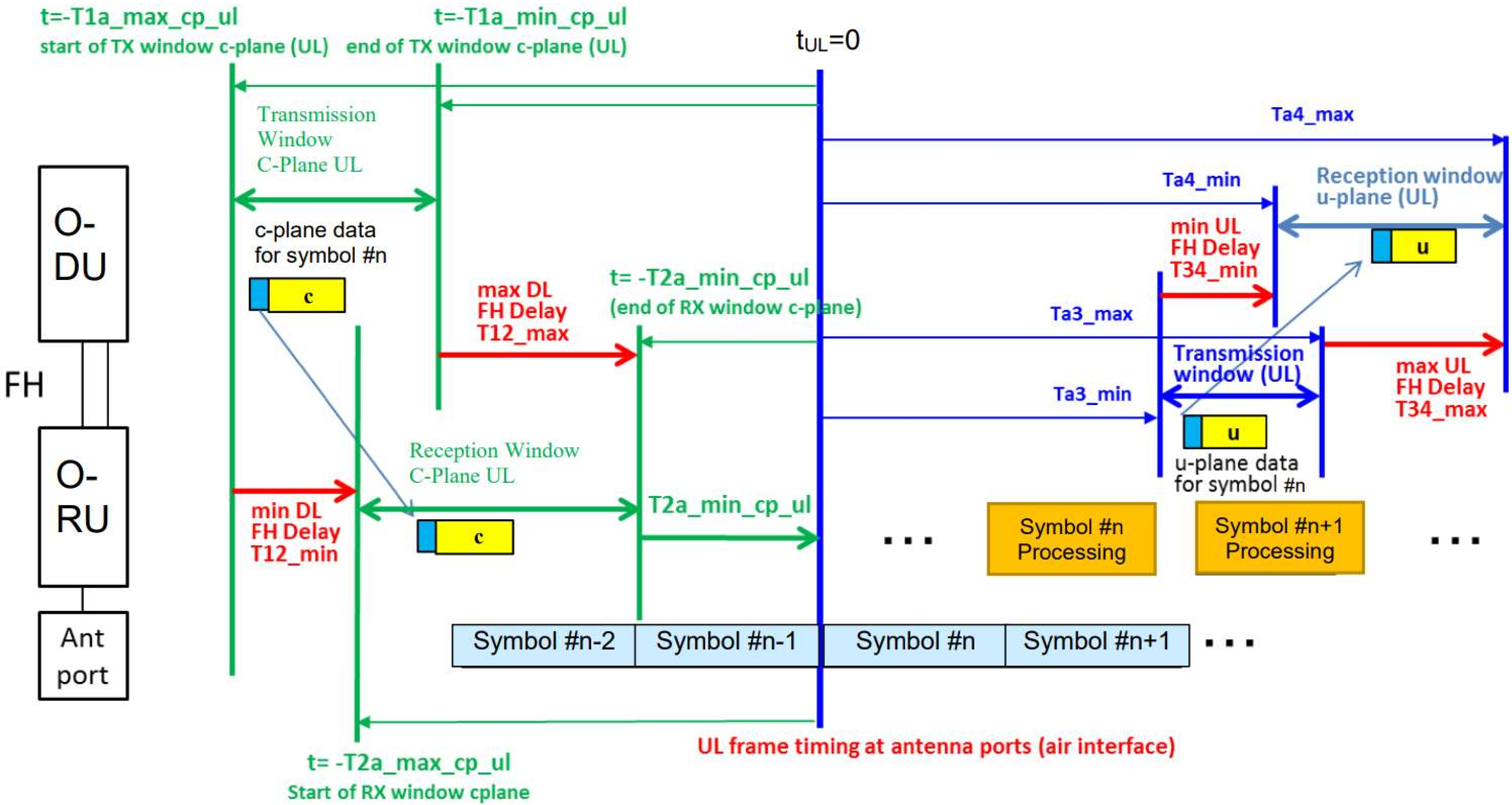
2. R4 最早能收到資料的時間
= R3 開始送出資料的時間 + T34_min
= Ta3_min_up + T34_min

3. R4 最晚會收到資料的時間
= R3 最後送出資料的時間 + T34_max
= Ta3_max_up + T34_max

4. 定義A、B，包住 RX time window
A ≤ Best Case ~ Worse Case ≤ B



t=-T1a_max_cp_dl
start of Tx window C-Plane DL
t=-T1a_min_cp_dl
end of Tx window C-Plane DL
tDL=0
t=-T1a_max_up start of TX window
t = -T1a_min_up end of TX window
O-DU
FH
O-RU
Ant port
Transmission Window C-Plane DL
C-Plane data for symbol #n
c
Transmission window u-plane dl
u
IQ data for symbol #n
t= -T2a_min_cp_dl (end of RX window c-plane dl)
t= -T2a_min_up
end of RX window u-plane dl
DL FH Delay T12_max
T2a_min_up
DL FH Delay T12_max
u
Reception window u-plane
c
T2a_min_cp_dl
t= -T2a_max_up
start of RX window u-plane
Reception Window C-Plane DL
...
Symbol #n Processing
Symbol #n+1 Processing
...
Symbol #n-2
Symbol #n-1
Symbol #n
Symbol #n+1
...
t= -T2a_max_cp_dl
start of Rx window C-Plane DL
DL frame timing at antenna ports (air interface)


t=-T1a_max_cp_ul
start of TX window c-plane (UL)
t=-T1a_min_cp_ul
end of TX window c-plane (UL)
tUL=0
Transmission Window C-Plane UL
O-DU
FH
O-RU
Ant port
c-plane data for symbol #n
c
max DL FH Delay T12_max
t= -T2a_min_cp_ul
(end of RX window c-plane)
Ta4_max
Ta4_min
Reception window u-plane (UL)
u
min UL FH Delay T34_min
Ta3_max
Transmission window (UL)
Ta3_min
max UL FH Delay T34_max
u
u-plane data for symbol #n
Reception Window C-Plane UL
min DL FH Delay T12_min
c
T2a_min_cp_ul
Symbol #n Processing
Symbol #n+1 Processing
Symbol #n-2
Symbol #n-1
Symbol #n
Symbol #n+1
t= -T2a_max_cp_ul
Start of RX window cplane
UL frame timing at antenna ports (air interface)

Delay Boundaries Relationships

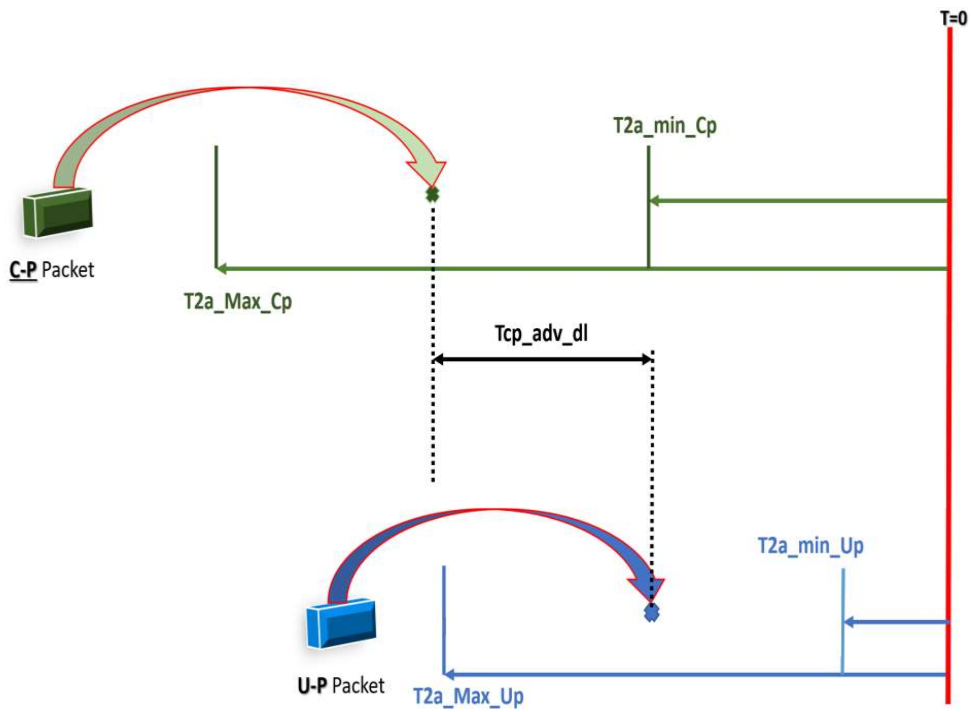
- U-Plane DL
  - T1a_max_up ≤ T2a_max_up + T12_min
  - T1a_min_up ≥ T2a_min_up + T12_max
  - T2a_max_up ≥ T2a_min_up + (T12_max - T12_min) + O-DU Transmission Window
  - T2a_min_up: Specidied per Use Case
- C-Plane DL
  - T1a_max_cp_dl ≤ T2a_max_cp_dl + T12_min
  - T1a_min_cp_dl ≥ T2a_min_cp_dl + T12_max
  - T1a_max_cp_dl ≥ T1a_max_up + Tcp_adv_dl
  - T1a_min_cp_dl = T1a_min_up + Tcp_adv_dl
  - T2a_max_cp_dl ≥ T2a_max_up + Tcp_adv_dl
  - T2a_min_cp_dl = T2a_min_up + Tcp_adv_dl

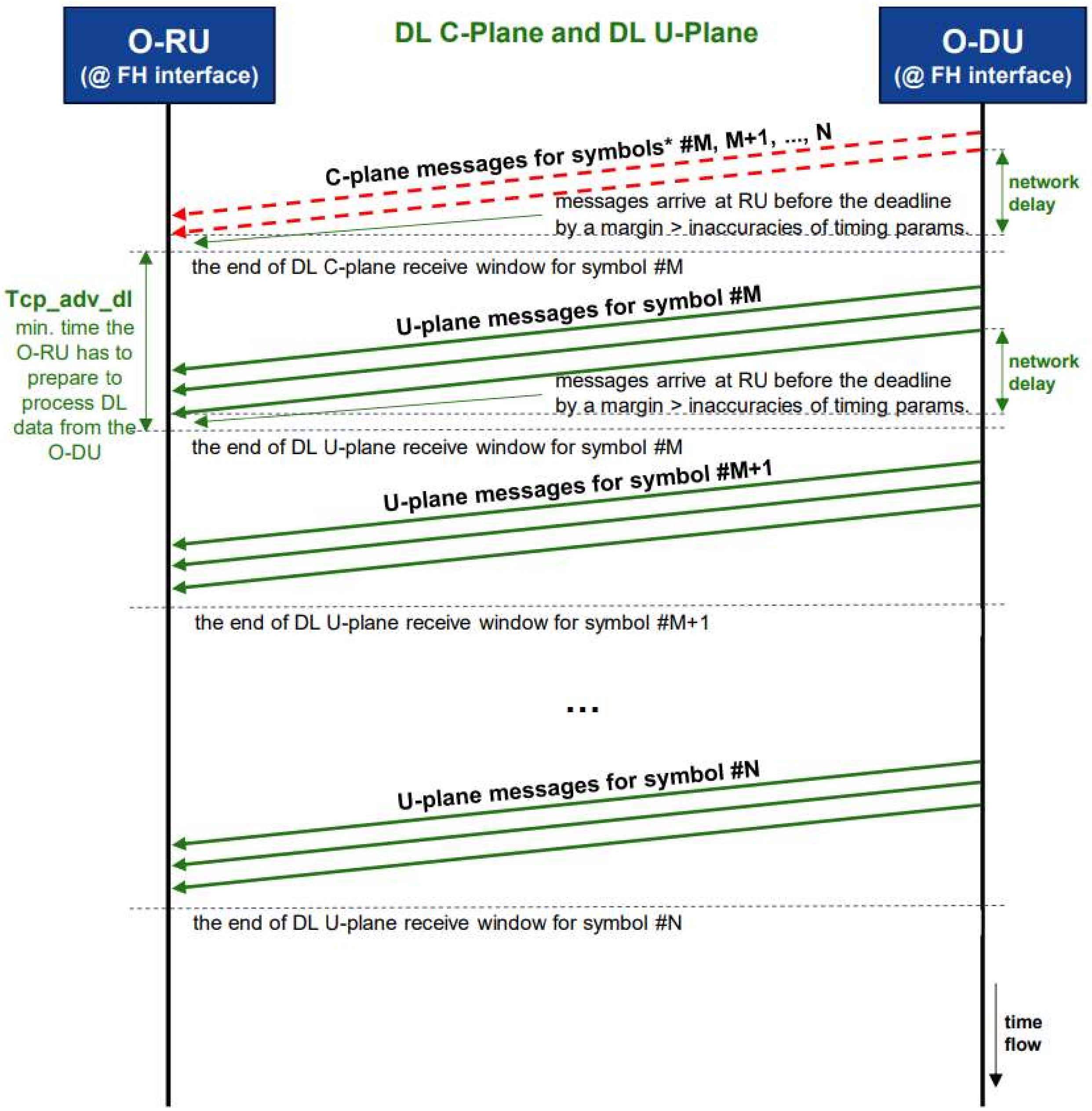
Delay Boundaries Relationships

- U-Plane UL
  - Ta3_max ≤ Ta3_min + O-RU Transmission Window
  - Ta3_min: Specidied per Use Case
  - Ta4_max ≥ Ta3_max + T34_max
  - Ta4_min ≤ Ta3_min + T34_min
- C-Plane UL
  - T1a_max_cp_ul ≤ T2a_max_cp_ul + T12_min
  - T1a_min_cp_ul ≥ T2a_min_cp_ul + T12_max
  - T2a_max_cp_ul ≥ T2a_min_cp_ul + (T12_max - T12_min) + O-DU uplink C-Plane Transmission Window
  - T2a_min_cp_ul

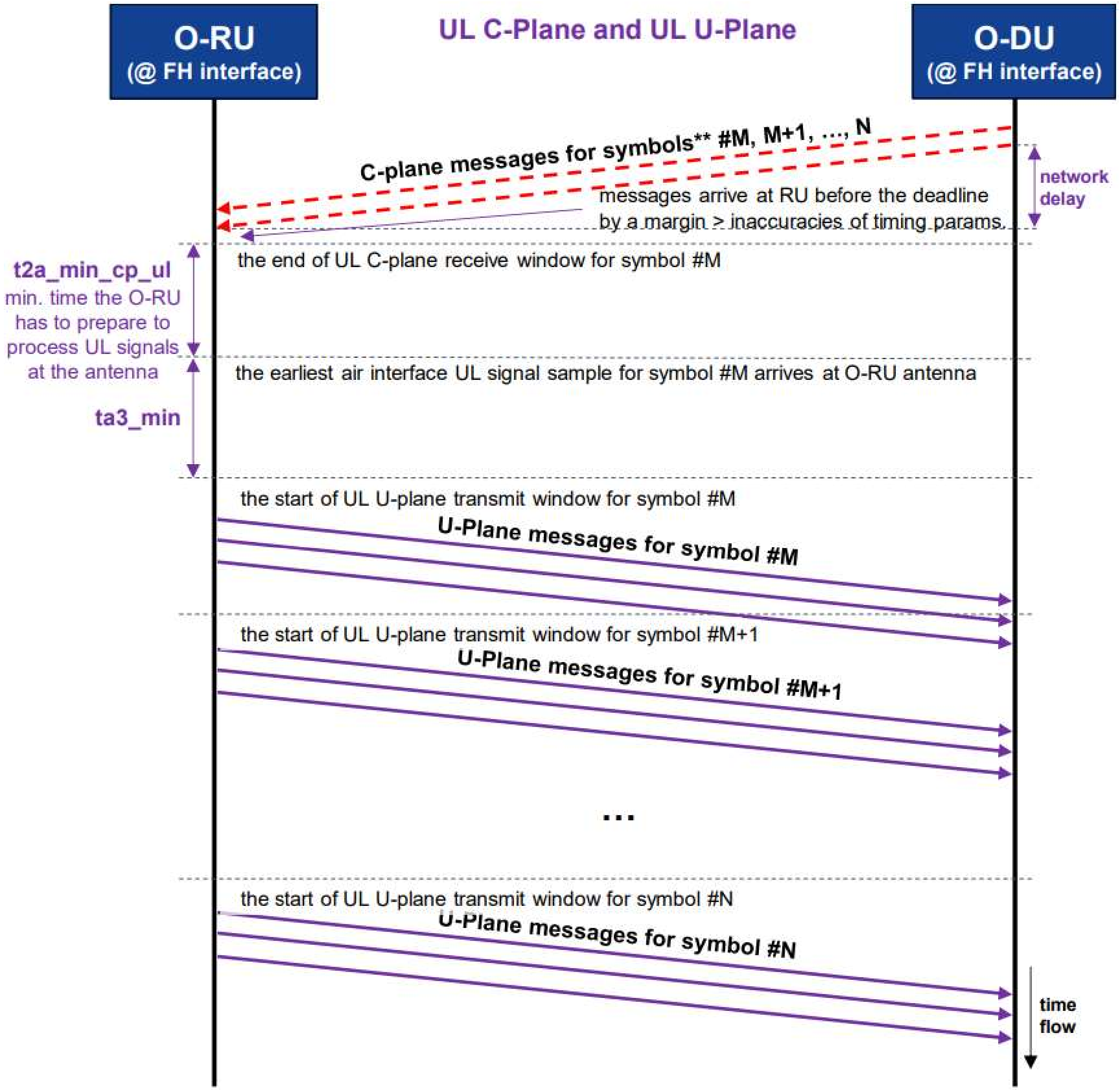
Delay Boundaries Relationships

- Tcp_adv_dl
  - Smallest time advance to receive Downlink Data C-Plane message before the first IQ data can be processed
  - 在可以處理第一筆 IQ data 前，收到 DL C-Plane 的最短時間
- T1a_max_cp_dl ≥ T1a_max_up + Tcp_adv_dl
  - -T1a_max_up ≥ -T1a_max_cp_dl + Tcp_adv_dl
- T1a_min_cp_dl = T1a_min_up + Tcp_adv_dl
  - -T1a_min_up = -T1a_min_cp_dl + Tcp_adv_dl
- T2a_max_cp_dl ≥ T2a_max_up + Tcp_adv_dl
  - -T2a_max_up ≥ -T2a_max_cp_dl + Tcp_adv_dl
- T2a_min_cp_dl = T2a_min_up + Tcp_adv_dl
  - -T2a_min_up = -T2a_min_cp_dl + Tcp_adv_dl





O-RU
(@ FH interface)
DL C-Plane and DL U-Plane
O-DU
(@ FH interface)
C-plane messages for symbols* #M, M+1, ..., N
network delay
messages arrive at RU before the deadline by a margin > inaccuracies of timing params.
the end of DL C-plane receive window for symbol #M
Tcp_adv_dl
min. time the O-RU has to prepare to process DL data from the O-DU
U-plane messages for symbol #M
network delay
messages arrive at RU before the deadline by a margin > inaccuracies of timing params.
the end of DL U-plane receive window for symbol #M
U-plane messages for symbol #M+1
the end of DL U-plane receive window for symbol #M+1
...
U-plane messages for symbol #N
the end of DL U-plane receive window for symbol #N
time flow


O-RU
(@ FH interface)
UL C-Plane and UL U-Plane
O-DU
(@ FH interface)
C-plane messages for symbols** #M, M+1, ..., N
network delay
messages arrive at RU before the deadline by a margin > inaccuracies of timing params.
t2a_min_cp_ul
min. time the O-RU has to prepare to process UL signals at the antenna
the end of UL C-plane receive window for symbol #M
the earliest air interface UL signal sample for symbol #M arrives at O-RU antenna
ta3_min
the start of UL U-plane transmit window for symbol #M
U-Plane messages for symbol #M
the start of UL U-plane transmit window for symbol #M+1
U-Plane messages for symbol #M+1
...
the start of UL U-plane transmit window for symbol #N
U-Plane messages for symbol #N
time flow

Delay Categories

- 分類是為了便於讓運行的 O-DU/O-RU 可以根據 Netwrok delay 進行適配
- O-RU
  - T2a_min_up
    - (Downlink)
      O-RU 最晚會接收到資料的時間
  - Ta3_max
    - (Uplink)
      O-RU 最晚會發送出資料的時間
- O-DU
  - T1a_max_up - Txmax
    - (Downlink)
      ≒T1a_min_up
      O-DU 最晚會發送出資料的時間
  - Ta4_max_up
    - O-DU 最晚會接收到資料的時間

O-RU Category

Category	• T2a_min_up OR • Ta3_max [μsec]
O	0 to 50
P	51 to 70
Q	71 to 90
R	91 to 110
S	111 to 130
T	131 to 150
U	151 to 170
V	171 to 190
W	191 to 210
X	211 to 230
Y	231 to 250
Z	251 to 270
ZZ	≥271

O-DU Category

Category	• $T1a\_max\_up_{O\text{-}DU}$ - $Txmax_{O\text{-}DU}$ • $Ta4\_max\_up_{O\text{-}DU}$ [μsec]
AAAA	≥30000
AAA	10000 to 29999
AA	3000 to 9999
A	400 to 2999
B	380 to 399
C	360 to 379
D	340 to 359
E	320 to 339
F	300 to 319
G	280 to 299
H	260 to 279
I	240 to 259
J	220 to 239
K	200 to 219
L	180 to 199
M	160 to 179
N	0 to 159

Delay Sub-Categories

- TXmax
  - O-DU TX window 的最大範圍值
- Ta3_max - Ta3_min
  - O-RU TX window
- T2a_max_up – T2a_min_up
  - O-RU RX window
- RXmax
  - O-DU RX window 的最大範圍值

Transmit Window Sub-Category	
Sub-Category	• $TXmax_{O\text{-}DU}$ • Ta3_max - Ta3_min [in usec]
.20	≥ 200
.19	190 to 199
.18	180 to 189
.17	170 to 179
.16	160 to 169
.15	150 to 159
.14	140 to 149
.13	130 to 139
.12	120 to 129
.11	110 to 119
.10	100 to 109
.09	90 to 99
.08	80 to 89
.07	70 to 79
.06	60 to 69
.05	50 to 59
.04	40 to 49
.03	30 to 39
.02	20 to 29
.01	10 to 19
.00	0 to 9

Receive Window Sub-Category	
Sub-Category	• T2a_max_up - T2a_min_up • $RXmax_{O\text{-}DU}$ [in usec]
.1000	≥ 10000
.300	3000 to 9999
.100	1000 to 2999
.40	400 to 999
.38	380 to 399
.36	360 to 379
.34	340 to 359
.32	320 to 339
.30	300 to 319
.28	280 to 299
.26	260 to 279
.24	240 to 259
.22	220 to 239
.20	200 to 219
.18	180 to 199
.16	160 to 179
.14	140 to 159
.12	120 to 139
.10	100 to 119
.08	80 to 99
.06	60 to 79
.04	40 to 59
.02	20 to 39
.01	10 to 19
.00	0 to 9

Table B-6 : Latency_min (Minimum supported T12_max/ T34_max in µsec)

	O-DU													
RU	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**
O	350	330	310	290	270	250	230	210	190	170	150	130	110	0
P	330	310	290	270	250	230	210	190	170	150	130	110	90	0
Q	310	290	270	250	230	210	190	170	150	130	110	90	70	0
R	290	270	250	230	210	190	170	150	130	110	90	70	50	0
S	270	250	230	210	190	170	150	130	110	90	70	50	30	0
T	250	230	210	190	170	150	130	110	90	70	50	30	10	0
U	230	210	190	170	150	130	110	90	70	50	30	10	0	0
V	210	190	170	150	130	110	90	70	50	30	10	0	0	0
W	190	170	150	130	110	90	70	50	30	10	0	0	0	0
X	170	150	130	110	90	70	50	30	10	0	0	0	0	0
Y	150	130	110	90	70	50	30	10	0	0	0	0	0	0
Z	130	110	90	70	50	30	10	0	0	0	0	0	0	0

Table B-7 : Latency max (Maximum supported T12 max/ T34 max in µsec)

	O-DU													
RU	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**
O	3000	399	379	359	339	319	299	279	259	239	219	199	179	159
P	2949	348	328	308	288	268	248	228	208	188	168	148	128	108
Q	2929	328	308	288	268	248	228	208	188	168	148	128	108	88
R	2909	308	288	268	248	228	208	188	168	148	128	108	88	68
S	2889	288	268	248	228	208	188	168	148	128	108	88	68	48
T	2869	268	248	228	208	188	168	148	128	108	88	68	48	28
U	2849	248	228	208	188	168	148	128	108	88	68	48	28	8
V	2829	228	208	188	168	148	128	108	88	68	48	28	8	0
W	2809	208	188	168	148	128	108	88	68	48	28	8	0	0
X	2789	188	168	148	128	108	88	68	48	28	8	0	0	0
Y	2769	168	148	128	108	88	68	48	28	8	0	0	0	0
Z	2749	148	128	108	88	68	48	28	8	0	0	0	0	0

Table B-10 : Dynamic Range (in Km) for sub-category pairs

	Receive Window																				
TxMax	.40	.38	.36	.34	.32	.30	.28	.26	.24	.22	.20	.18	.16	.14	.12	.10	.08	.06	.04	.02	.01
.20	40	36	32	28	24	20	16	12	8	4											
.19	42	38	34	30	26	22	18	14	10	6	2										
.18	44	40	36	32	28	24	20	16	12	8	4										
.17	46	42	38	34	30	26	22	18	14	10	6	2									
.16	48	44	40	36	32	28	24	20	16	12	8	4									
.15	50	46	42	38	34	30	26	22	18	14	10	6	2								
.14	52	48	44	40	36	32	28	24	20	16	12	8	4								
.13	54	50	46	42	38	34	30	26	22	18	14	10	6	2							
.12	56	52	48	44	40	36	32	28	24	20	16	12	8	4							
.11	58	54	50	46	42	38	34	30	26	22	18	14	10	6	2						
.10	60	56	52	48	44	40	36	32	28	24	20	16	12	8	4						
.09	62	58	54	50	46	42	38	34	30	26	22	18	14	10	6	2					
.08	64	60	56	52	48	44	40	36	32	28	24	20	16	12	8	4					
.07	66	62	58	54	50	46	42	38	34	30	26	22	18	14	10	6	2				
.06	68	64	60	56	52	48	44	40	36	32	28	24	20	16	12	8	4				
.05	70	66	62	58	54	50	46	42	38	34	30	26	22	18	14	10	6	2			
.04	72	68	64	60	56	52	48	44	40	36	32	28	24	20	16	12	8	4			
.03	74	70	66	62	58	54	50	46	42	38	34	30	26	22	18	14	10	6	2		
.02	76	72	68	64	60	56	52	48	44	40	36	32	28	24	20	16	12	8	4		
.01	78	74	70	66	62	58	54	50	46	42	38	34	30	26	22	18	14	10	6	2	
.00	80	76	72	68	64	60	56	52	48	44	40	36	32	28	24	20	16	12	8	4	2

O-RU

O-RU	Parameters	
Downlink	T2a_min_up	71
	T2a_max_up	428
	Category	Q.35
Uplink	Ta3_min	20
	Ta3_max	32
	Category	O.01

O-RU Category	
Category	• T2a_min_up OR • Ta3_max [usec]
O	0 to 50
P	51 to 70
Q	71 to 90
R	91 to 110
S	111 to 130
T	131 to 150
U	151 to 170
V	171 to 190
W	191 to 210
X	211 to 230
Y	231 to 250
Z	251 to 270
ZZ	≥ 271

Transmit Window Sub-Category	
Sub-Category	• $TXmax_{O\text{-}DU}$ • Ta3_max - Ta3_min [in usec]
.20	≥ 200
.19	190 to 199
.18	180 to 189
.17	170 to 179
.16	160 to 169
.15	150 to 159
.14	140 to 149
.13	130 to 139
.12	120 to 129
.11	110 to 119
.10	100 to 109
.09	90 to 99
.08	80 to 89
.07	70 to 79
.06	60 to 69
.05	50 to 59
.04	40 to 49
.03	30 to 39
.02	20 to 29
.01	10 to 19
.00	0 to 9

Receive Window Sub-Category	
Sub-Category	• T2a_max_up - T2a_min_up • $RXmax_{O\text{-}DU}$ [in usec]
.1000	≥ 10000
.300	3000 to 9999
.100	1000 to 2999
.40	400 to 999
.38	380 to 399
.36	360 to 379
.34	340 to 359
.32	320 to 339
.30	300 to 319
.28	280 to 299
.26	260 to 279
.24	240 to 259
.22	220 to 239
.20	200 to 219
.18	180 to 199
.16	160 to 179
.14	140 to 159
.12	120 to 139
.10	100 to 119
.08	80 to 99
.06	60 to 79
.04	40 to 59
.02	20 to 39
.01	10 to 19
.00	0 to 9

O-DU

O-DU	Parameters	
Downlink	T1a_max_up	196
	TXmax	100
	Category	N.10
Uplink	Ta4_max	75
	RXmax	75
	Category	N.07

O-DU Category	
Category	• T1a_max_up$_{O-DU}$ - Txmax$_{O-DU}$ • Ta4_max_up$_{O-DU}$ [µsec]
AAAA	≥30000
AAA	10000 to 29999
AA	3000 to 9999
A	400 to 2999
B	380 to 399
C	360 to 379
D	340 to 359
E	320 to 339
F	300 to 319
G	280 to 299
H	260 to 279
I	240 to 259
J	220 to 239
K	200 to 219
L	180 to 199
M	160 to 179
N	0 to 159

Transmit Window Sub-Category	
Sub-Category	• TXmax$_{O-DU}$ • Ta3_max - Ta3_min [in usec]
.20	≥200
.19	190 to 199
.18	180 to 189
.17	170 to 179
.16	160 to 169
.15	150 to 159
.14	140 to 149
.13	130 to 139
.12	120 to 129
.11	110 to 119
.10	100 to 109
.09	90 to 99
.08	80 to 89
.07	70 to 79
.06	60 to 69
.05	50 to 59
.04	40 to 49
.03	30 to 39
.02	20 to 29
.01	10 to 19
.00	0 to 9

Receive Window Sub-Category	
Sub-Category	• T2a_max_up - T2a_min_up • RXmax$_{O-DU}$ [in usec]
.1000	≥10000
.300	3000 to 9999
.100	1000 to 2999
.40	400 to 999
.38	380 to 399
.36	360 to 379
.34	340 to 359
.32	320 to 339
.30	300 to 319
.28	280 to 299
.26	260 to 279
.24	240 to 259
.22	220 to 239
.20	200 to 219
.18	180 to 199
.16	160 to 179
.14	140 to 159
.12	120 to 139
.10	100 to 119
.08	80 to 99
.06	60 to 79
.04	40 to 59
.02	20 to 39
.01	10 to 19
.00	0 to 9

Evaluating O-DU / O-RU Combinations

O-RU	Parameters	
Downlink	T2a_min_up	71
	T2a_max_up	428
	Category	Q.35
Uplink	Ta3_min	20
	Ta3_max	32
	Category	O.01

O-DU	Parameters	
Downlink	T1a_max_up	196
	TXmax	100
	Category	N.10
Uplink	Ta4_max	75
	RXmax	75
	Category	N.07

T2a_min_up	71
T2a_max_up	428
Ta3_min	20
Ta3_max	32
T1a_min_cp_dl	285
T1a_max_cp_dl	470
T1a_min_cp_ul	285
T1a_max_cp_ul	429
T1a_min_up	96
T1a_max_up	196
Ta4_min	0
Ta4_max	75

		T12_max/T34_max	KM
Downlink	NQ	0~88	50
Uplink	NO	0~159	12

1. Transport delay: The uplink value is higher, so downlink becomes the limiting factor for this combination.
2. Max range of ~ 12 KM

Measured Transport Delay

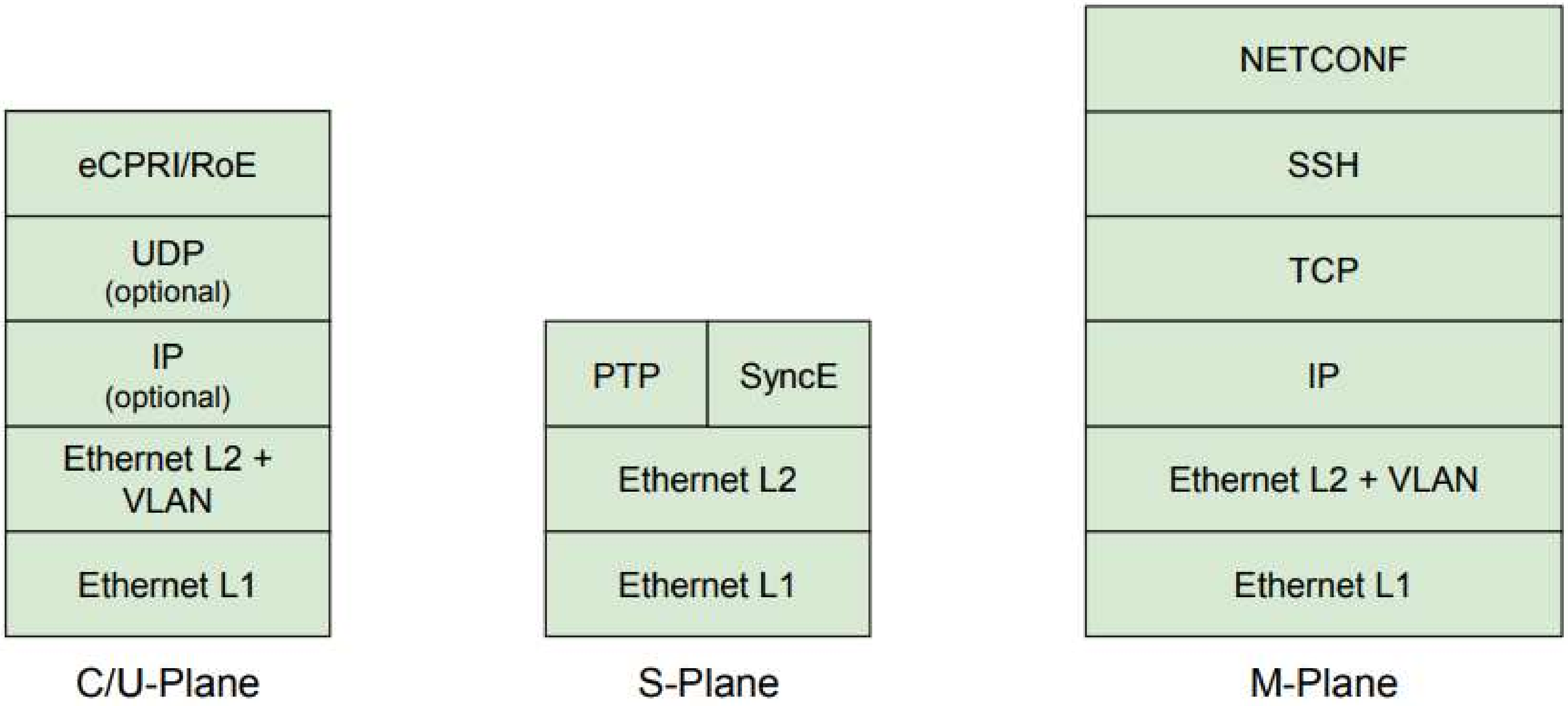
- A special eCPRI message to measure T12 and T34

Table 2-17 : eCPRI One-Way Delay Measurement Message

One-Way Delay Measurement (Type 5)									
0 (msb)	1	2	3	4	5	6	7 (lsb)	# of bytes	
ecpriVersion				ecpriReserved			ecpriConcatenation	1	Octet 1
ecpriMessage = 5								1	Octet 2
ecprPayload								2	Octet 3
Measurement ID								1	Octet 5
Action Type								1	Octet 6
TimeStamp (seconds)								6	Octet 7
TimeStamp (nanoseconds)								4	Octet 13
Compensation value (nanoseconds)								8	Octet 17

Fronthaul Interface

Protocol Architecture



Transport Architecture

- eCPRI Transport Header

Section Type : any									
0 (msb)	1	2	3	4	5	6	7 (lsb)	# of bytes	
ecpriVersion				ecpriReserved			ecpriConcatenation	1	Octet 1
ecpriMessage								1	Octet 2
ecpriPayload								2	Octet 3
ecpriRtcid / ecpriPcid								2	Octet 5
ecpriSeqid								2	Octet 7

eCPRI header

- ecpriVersion
  - 0001 ➔ eCPRI version 1.0, 1.1, 1.2 and 2.0
- ecpriReserved
  - 000
- ecpriConcatenation
  - 0 ➔ No concatenation
  - multiple eCPRI messages in a single Ethernet payload
- ecpriMessage
  - In the spec, only three message types are defined
    - 0000 0000 ➔ IQ data
    - 0000 0010 ➔ real-time control data
    - 0000 0101 ➔ transport network delay measurement
      - A special message of eCPRI One-Way Delay Measurement

eCPRI header

- eAxC ID (extended antenna-carrier identifier)
  - ecpriRtcid
    - C-Plane
  - ecpriPcid
    - U-Plane

0 (msb)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15 (lsb)
DU_Port_ID				BandSector_ID				CC_ID				RU_Port_ID			

- ecpriSeqid

Transport Architecture

- As an alternative to eCPRI as a transport header, IEEE 1914.3 may be used.
- RoE (Radio over Ethernet)

Section Type : any									
0 (msb)	1	2	3	4	5	6	7 (lsb)	# of bytes	
RoEsubType								1	Octet 1
RoEflowId								1	Octet 2
RoElength								2	Octet 3
RoEorderInfo								4	Octet 5

RoE

- RoEsubType
  - indicates the range 128 to 191
  - 根據查表得到
    - a unique Organization or Company ID
    - payload type

RoE subType	OUI/CID subType mapping table (.mapSubtype)	
	OUI/CID Mapping (3 bytes) bit39 <----------------------------------	Payload structure mapping (2 bytes) --> bit 0
128	xRAN=0xFAEB6E	0x0001, IQ (No concatenation)
129	xRAN=0xFAEB6E	0x0002, IQ (With concatenation)
130	xRAN=0xFAEB6E	0x0003, Ctrl (No concatenation)
131	xRAN=0xFAEB6E	0x0004, Ctrl (With concatenation)
132 to 191	xRAN=0xXXXXXX (don't care)	0xFFFF (IEEE1914.3 default), unused/unmapped by xRAN in this version of the O-RAN specification.

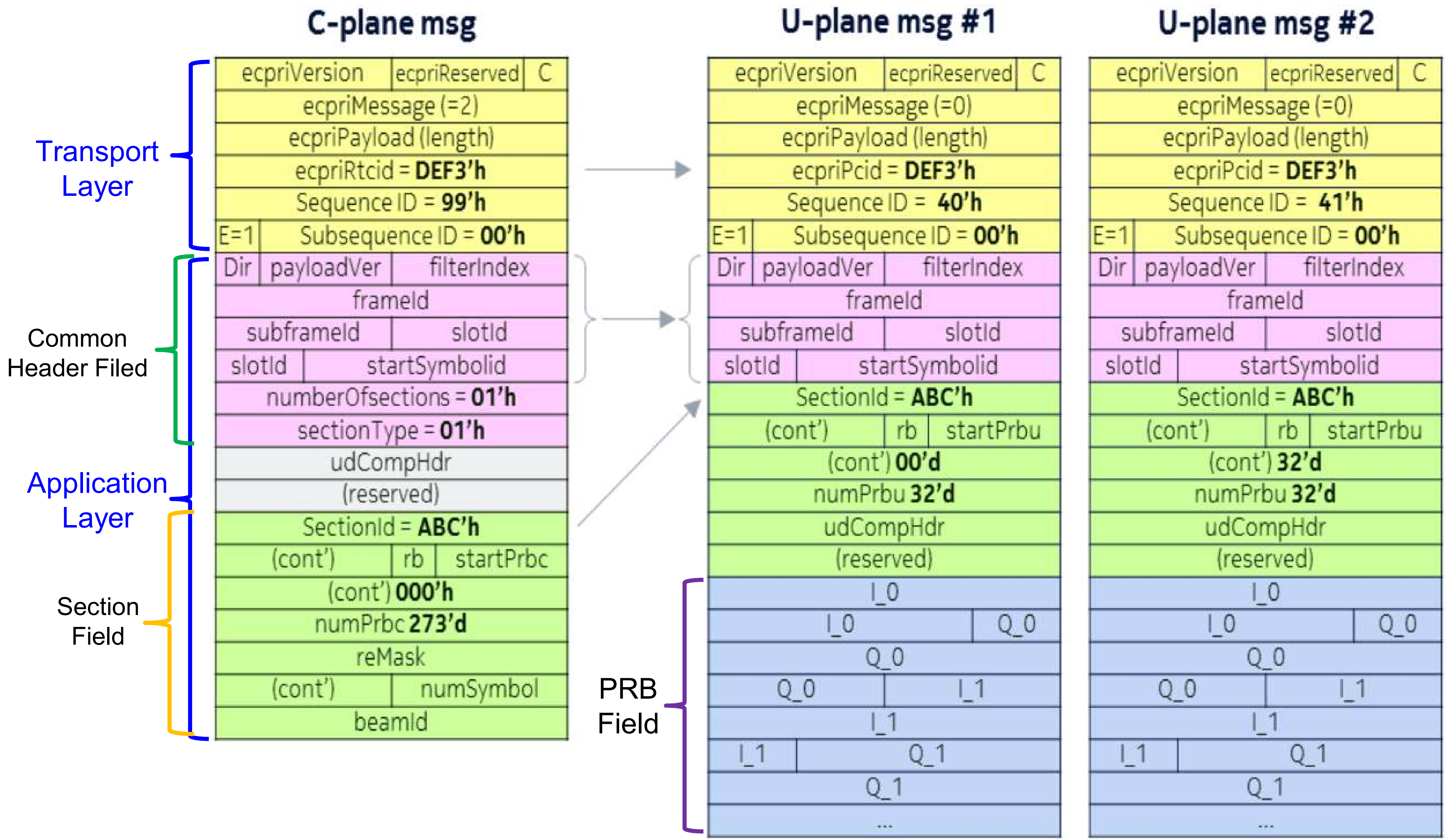
RoE

- RoEflowID
  - A mechanism which can identify specific flows between end-points
  - This field is currently unused
- RoElength
  - the size in bytes of the payload part of the message

RoE

- RoEorderInfo

Field	Length	Note
DU_Port_ID	16 bits	Used to differentiate processing units at O-DU (e.g., different baseband cards). It is expected the O-DU will assign these bits, and the O-RU will attach the same value to the UL U-Plane messages carrying the same sectionId data. See sub-clause 3.1.3.1.6 for further information.
BandSector_ID		Aggregated cell identifier (distinguishes bands and sectors supported by the O-RU). See sub-clause 3.1.3.1.6 for further information.
CC_ID		Distinguishes Carrier Components supported by the O-RU. See sub-clause 3.1.3.1.6 for further information.
RU_Port_ID		Used to differentiate spatial streams or beams on the O-RU. See sub-clause 3.1.3.1.6 for further information.
Sequence_ID	8 bits	Unique message ordering sequence. See sub-clause 3.1.3.1.7 for further information.
E_Bit	1 bit	Marks the last message pertaining to the section. See sub-clause 3.1.3.1.7 for further information.
Subsequence_ID	7 bits	Unique message ordering sub-sequence. See sub-clause 3.1.3.1.7 for further information.


C-plane msg
U-plane msg #1
U-plane msg #2
Transport Layer
Common Header Filed
Application Layer
Section Field
PRB Field
ecpriVersion
ecpriReserved
C
ecpriMessage (=2)
ecpriPayload (length)
ecpriRtcid = DEF3'h
Sequence ID = 99'h
E=1
Subsequence ID = 00'h
Dir
payloadVer
filterIndex
frameId
subframeId
slotId
slotId
startSymbolid
numberOfsections = 01'h
sectionType = 01'h
udCompHdr
(reserved)
SectionId = ABC'h
(cont')
rb
startPrbc
(cont') 000'h
numPrbc 273'd
reMask
(cont')
numSymbol
beamId
ecpriMessage (=0)
ecpriPcid = DEF3'h
Sequence ID = 40'h
Sequence ID = 41'h
SectionId = ABC'h
(cont')
rb
startPrbu
(cont') 00'd
(cont') 32'd
numPrbu 32'd
udCompHdr
(reserved)
I_0
Q_0
I_1
Q_1
...

C-plane

- 格式包含 eCPRI 的 Transport Header 和 Radio 的控制信息，其中 Radio 的控制信息依照不同 section type 來劃分，目前共訂定六種 section types

Section Type	Target Scenario	Remarks
0	Unused Resource Blocks or symbols in Downlink or Uplink	Indicates to O-RU that certain Resource Blocks or symbols will not be used (idle periods, guard periods). Likewise, there are no associated U-Plane messages containing IQ data for this Section Type. The purpose is to inform the O-RU that transmissions may be halted during the specified idle interval for e.g. power-savings or to provide an interval for calibration.
1	Most DL/UL radio channels*	Here “most” refers to channels not requiring time or frequency offsets such as are needed for mixed-numerology channels
3	PRACH and mixed-numerology channels*	Channels requiring time or frequency offsets or different-than-nominal SCS values
5	UE scheduling information (UE-ID assignment to section)	Provides scheduling information for UE-IDs
6	Channel information	Sends UE-specific channel information from the O-DU to the O-RU
7	LAA	Messages communicated between O-DU and the O-RU in both directions to configure LBT for PDSCH/DRS transmission and to report the LBT outcome.

U-plane

- 格式如同 C-plane，包括 eCPRI 的 Transport Header 及上行或下行的頻域 IQ data，並對應 C-plane 的六種 section types

S-plane

- O-RAN 基於 SyncE（Synchronous Ethernet）及 PTP（IEEE Precision Time Protocol）並以乙太網路做為時間與頻率的傳遞媒介，有四種 topology：C1、C2、C3、C4
  - C1 是 O-DU 與 O-RU 點對點連接，並以 O-DU 為 SyncE 與 PTP 的同步源，使 O-RU 與之同步
  - C2 以 O-DUs 為同步源，使 O-RUs 透過一個或多個與乙太網路交換器（Ethernet switch）與 O-DU 進行同步
  - C3 的架構與 C2 相同，差別在於 C3 的 O-DUs 與 O-RUs 皆扮演從屬時鐘（Slave Clock），同步信息從同步源發出，經過中間的乙太網路交換器，轉發至 O-DUs 與 O-RUs，使 O-DUs 與 O-RUs與之同步
  - C4 是 O-RU 自行連接 PRTC，而 fronthaul network 不需支援 PTP 及 SyncE

M-plane

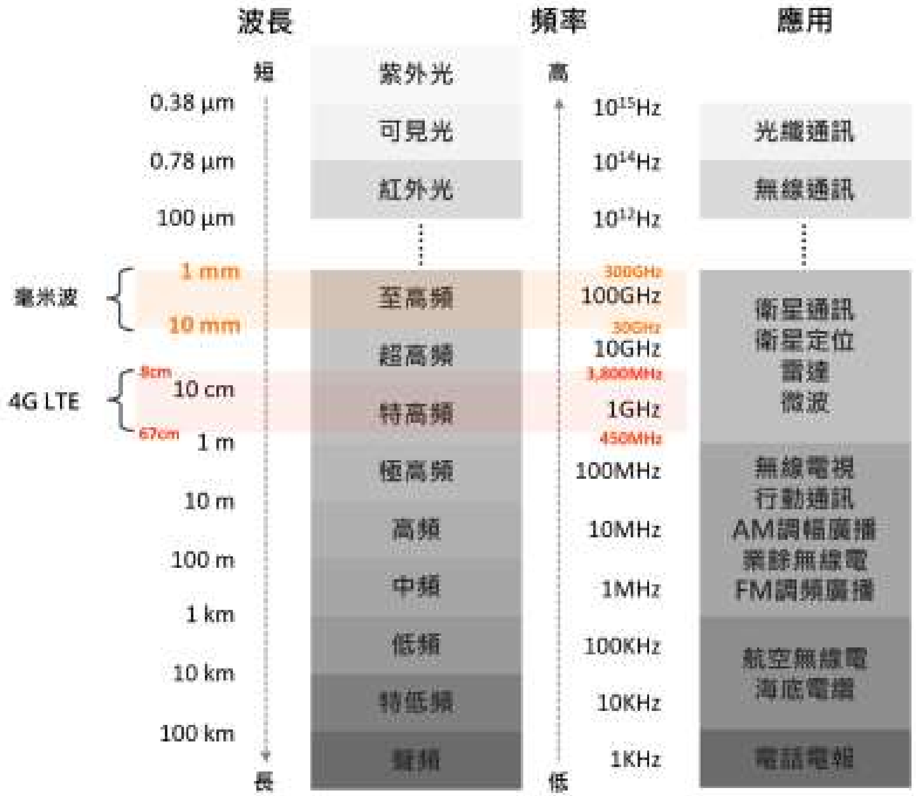
- 主要透過網管協定 NETCONF 與資料模型 YANG，管理參數及波束形成、天線陣列維度等相關資訊
- 除階層式（Hierarchical）架構外，亦提供混合式（Hybrid），讓 Network Management System 無需透過 DU 直接與 RU 進行連接

Communications

Wireless Communication

- 無線通訊 (Wireless Communication)，即是利用電磁波來進行各種資訊交換
- 電磁波特性

	高頻訊號	低頻訊號
波長	短	長
方向性	定向	無方向性
繞射能力	弱	強
穿透能力	強	弱
電波衰減	大	小
覆蓋能力	弱	強
基地台承載量	多	少
功率傳送增益比	小	大
終端天線	短	長



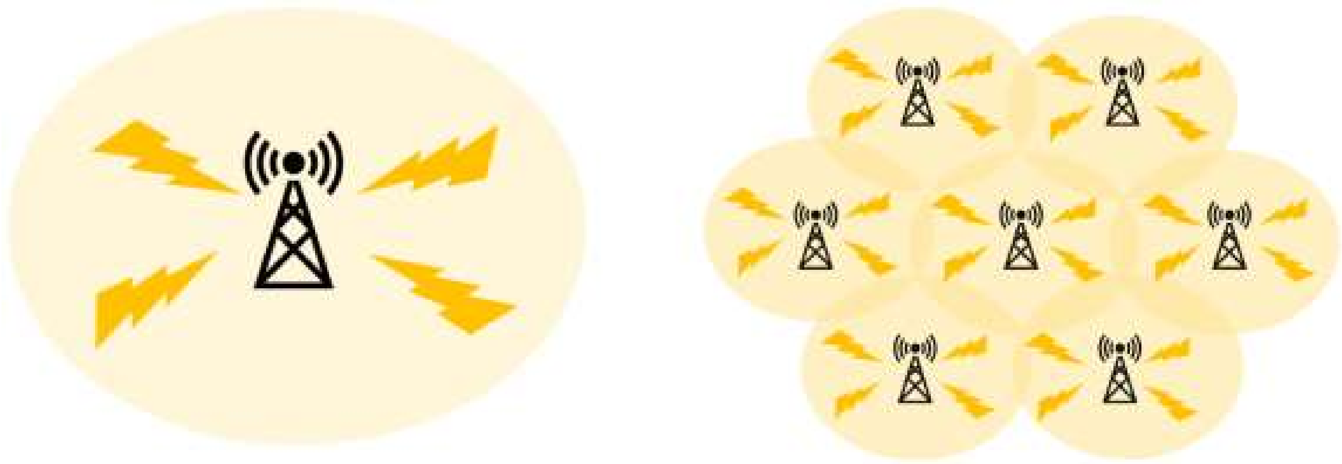
通訊電磁波頻譜

Features for 5th Generation Mobile Networks

- 微基站 Small Cell
- 多天線技術 Massive MIMO (Multiple-Input Multiple-Output)
- 波束成型 Beamforming

Small Cell

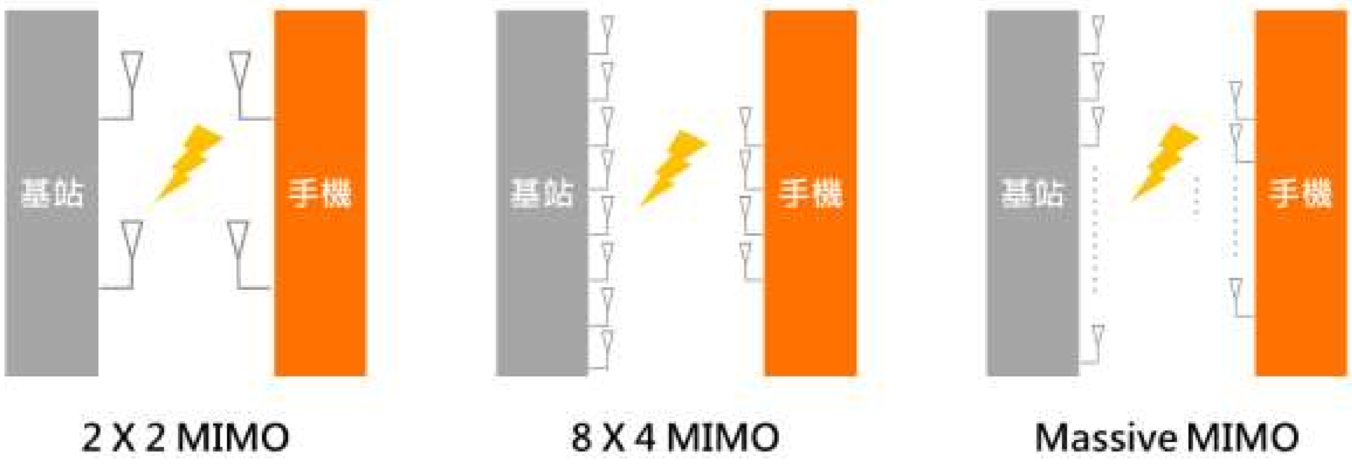
- 高頻段部署時，電磁波的繞射能力就變得更弱，傳輸距離及覆蓋範圍也會相對縮小
- 比之 4G，5G 必須採用多個微型基地台才能覆蓋到同樣的區域

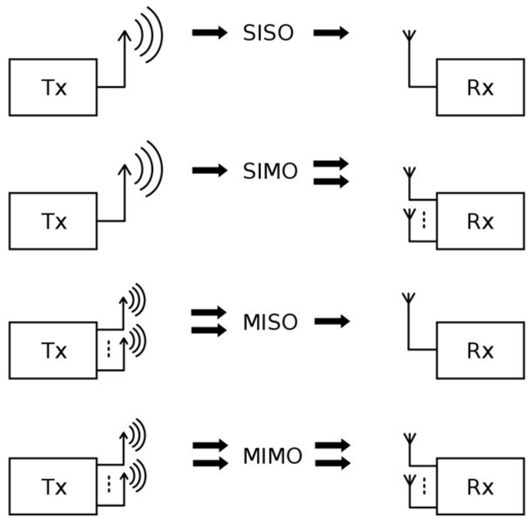


4G概念圖　　5G概念圖

Massive MIMO

- 根據電磁波原理，波長越短，天線就可做的愈小
- 透過多根天線發送，多根天線接收，讓資料傳輸量變大

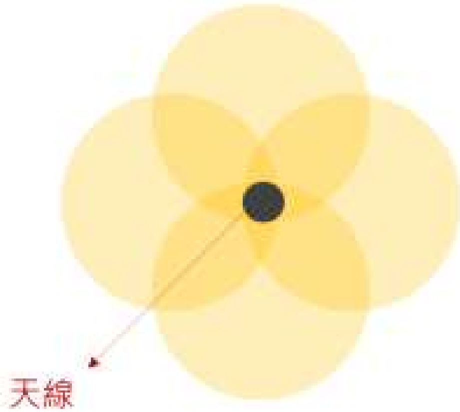




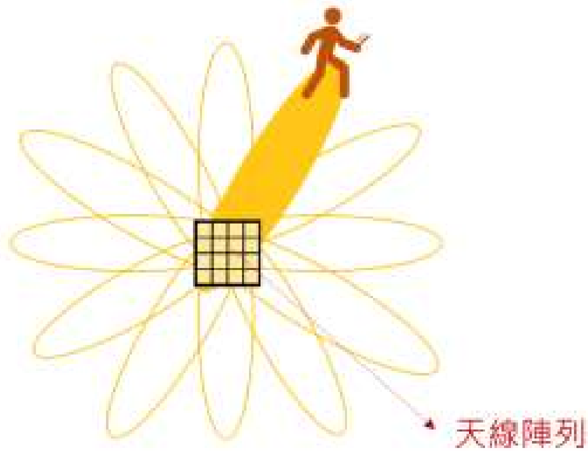
The input is the transmitter as it transmits into the link or signal path, and the output is the receiver.

Beamforming

- 一般電磁波的傳輸，就像是發光的燈泡，是向四周發射的方式來傳遞訊號
- 透過「天線陣列」定向發送和接收訊號的技術，將既有的全向覆蓋，轉換為精準的指向性傳輸，不僅延長了傳送距離，也大幅減少訊號的干擾



電磁波發射方向



波束成型發射方向

5G Applications

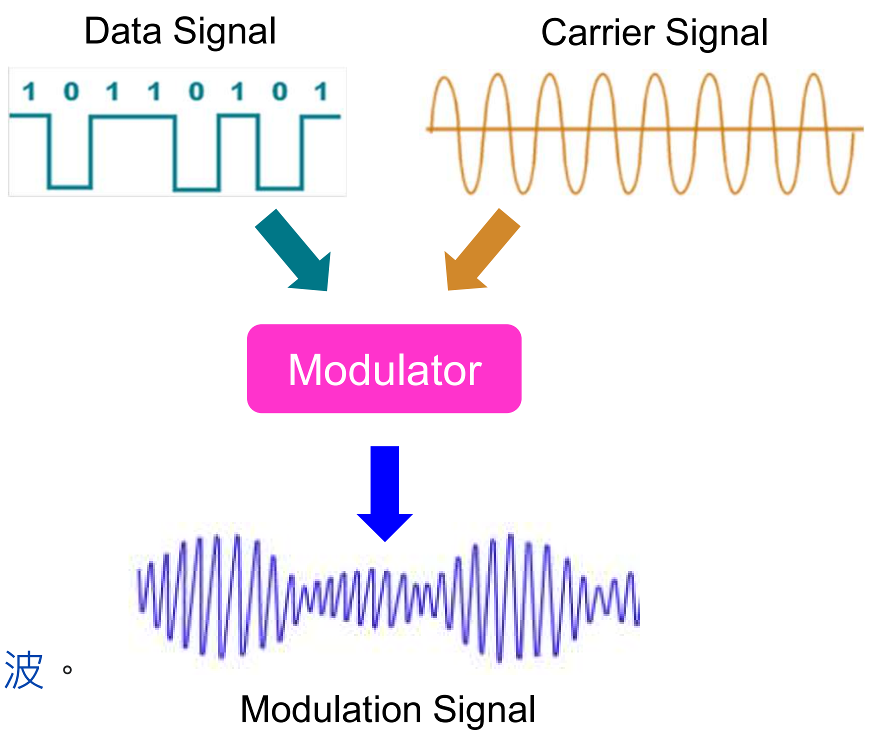
- Downlink 比之 Uplink
  - For example, DDDSU ➔ DL 頻寬是 UL 的 2.67 倍
- 5G 比之 4G
  - 平均會快 10 倍
    - 5G 的上傳會是 4G 下載的 3.75 倍
  - 5G加速智慧農業　推動農界科技革命 https://www.youtube.com/watch?v=z0izkLu83mo
    - 上傳速度的提升所產生的效益，比下載會更明顯
    - 可以從 end user 端，更快取得更多資料
  - AR/VR
    - 在上傳的需求比下載更大

Overview

- Modulation 調變
- Multiplexing 多工

Modulation

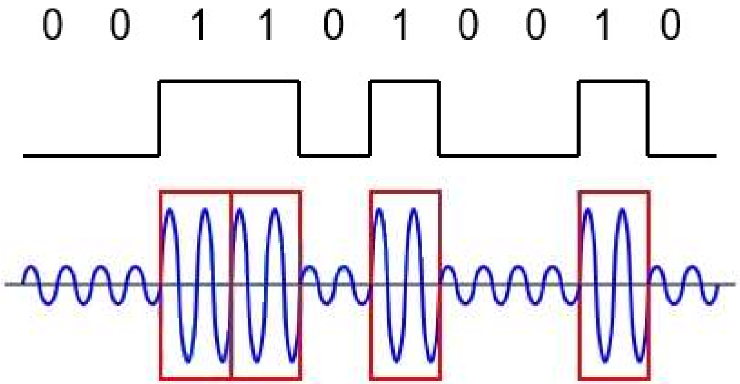
- Modulation 調變
  - 是一種將一個或多個週期性的載波混入想傳送之訊號的技術
  - 將電磁波調變成不同的波形，來代表 0 與 1 兩種不同的數位訊號
    - ASK (Amplitude Shift Keying)
    - FSK (Frequency Shift Keying)
    - PSK (Phase Shift Keying)
    - QAM (Quadrature Amplitude Modulation)
- Demodulation 解調
  - 調變的逆過程，用以解出原始的訊號



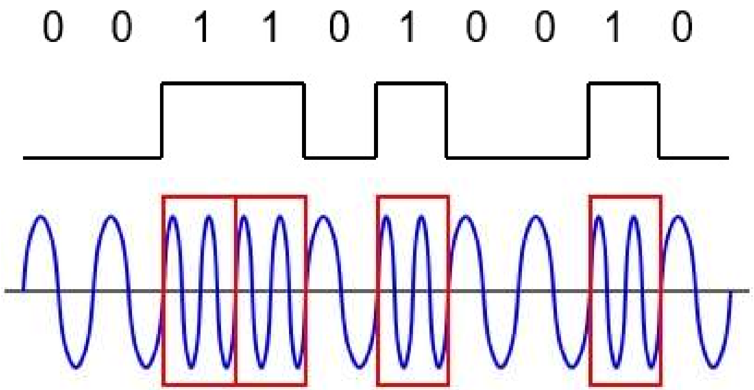
載波（ carrier wave ）是指被調變以傳輸訊號的波形，一般為正弦波。

Modulation

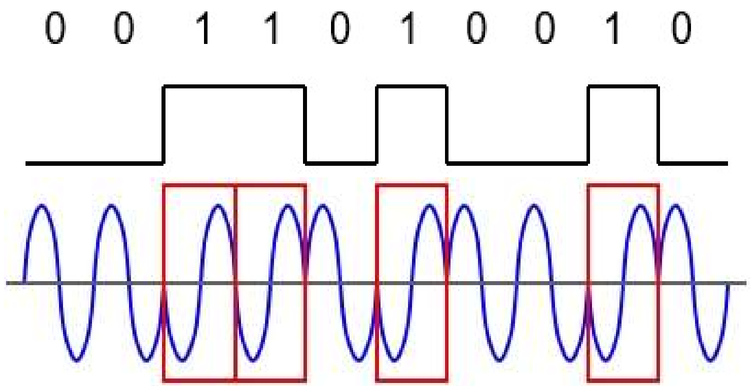
- ASK 振幅
- FSK 頻率
- PSK 相位
- QAM 振幅+相位



ASK



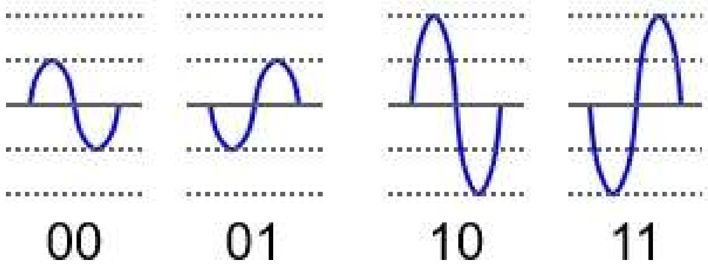
FSK



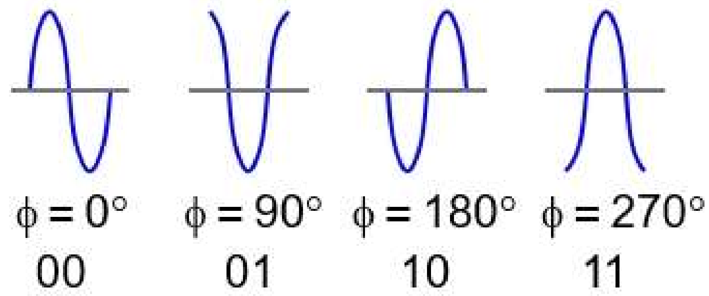
PSK

Modulation

- 4 QAM

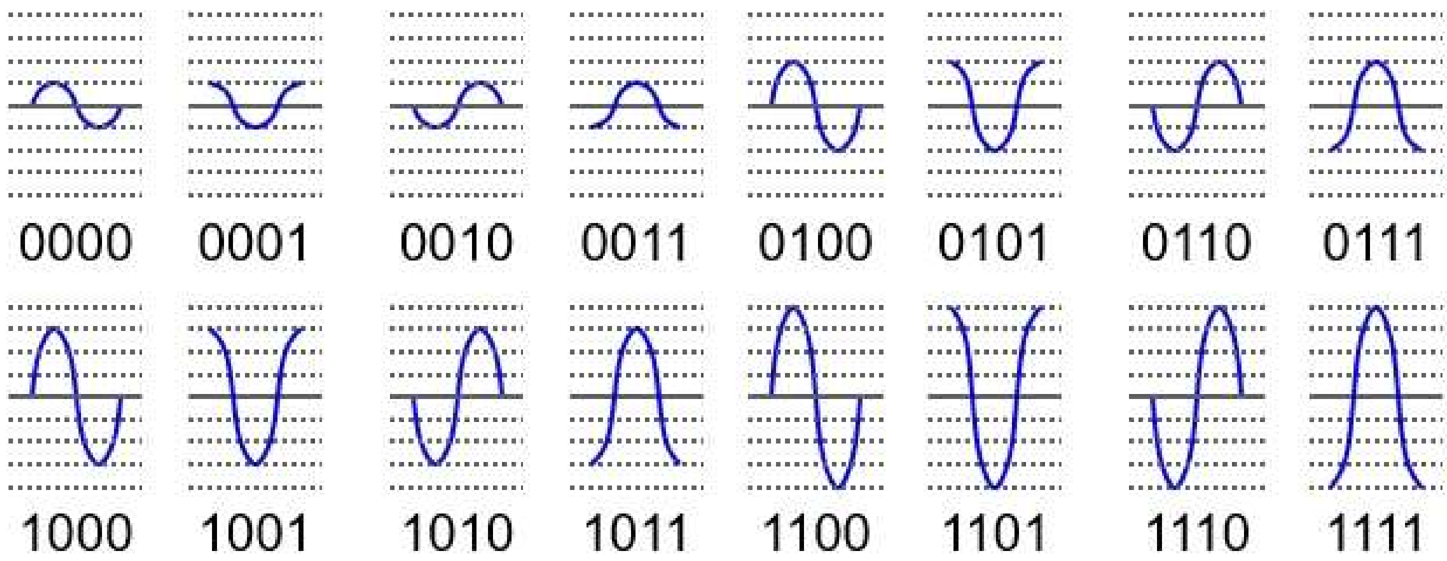


- QPSK



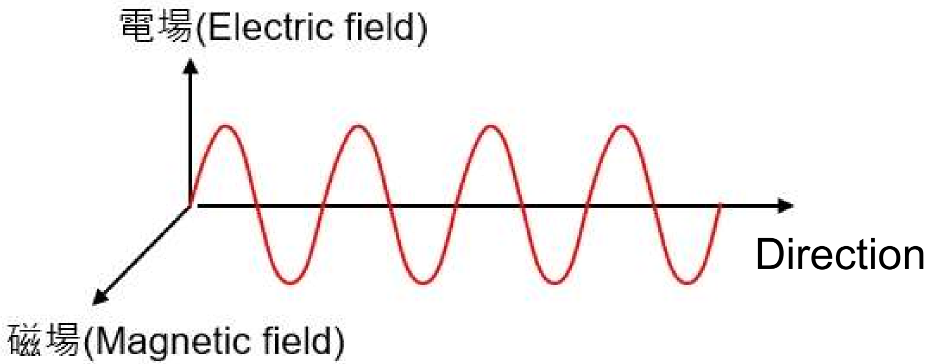
QPSK 比 4 QAM 簡單，所以實務上不會有 4 QAM

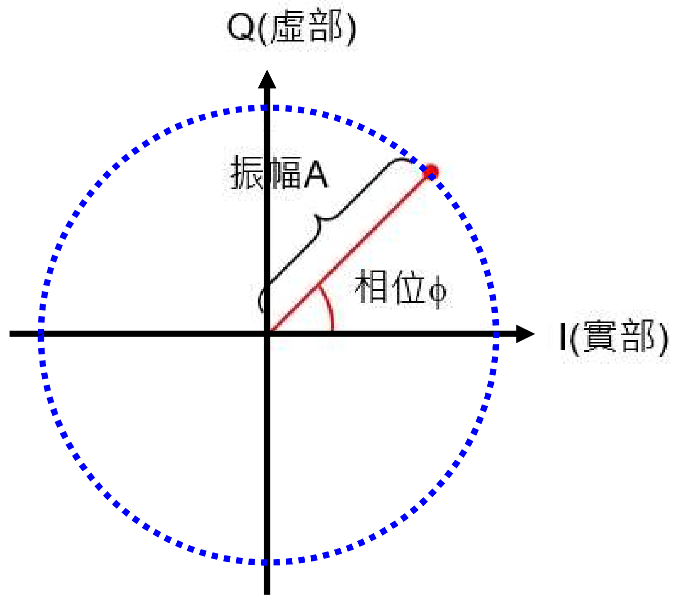
- 16 QAM



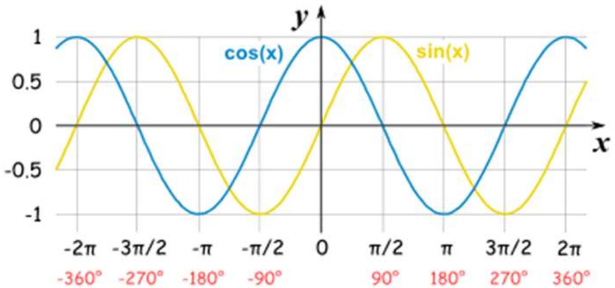
Modulation

- 電磁波
  - $S(t) = A\cos(2\pi f t + \varphi)$
    - A: 振幅
    - f: 頻率
    - φ: 相位
- 星座圖 Constellation Diagram
  - 在極座標上，顯示正弦波的強度跟相位
  - 每一個點就代表一種波形



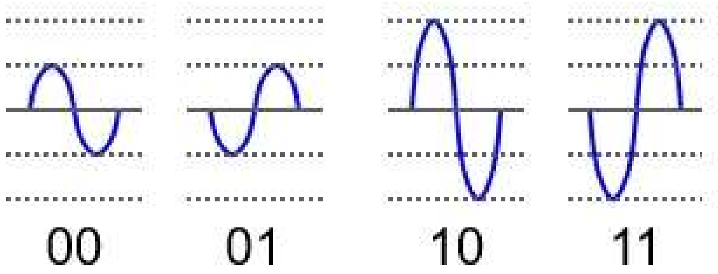


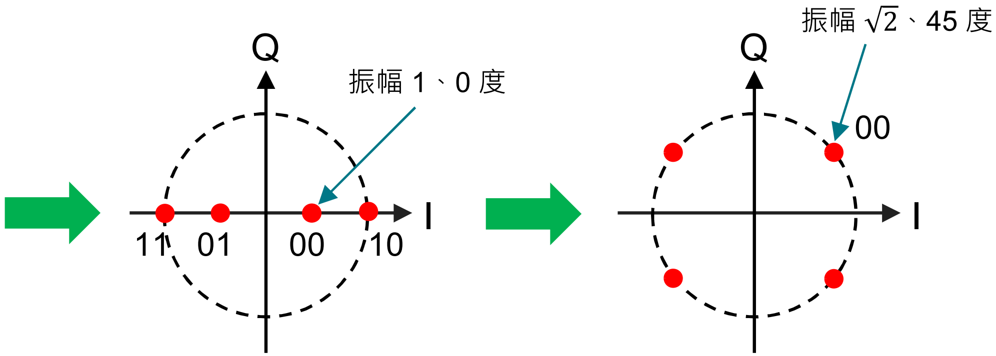
正弦、餘弦



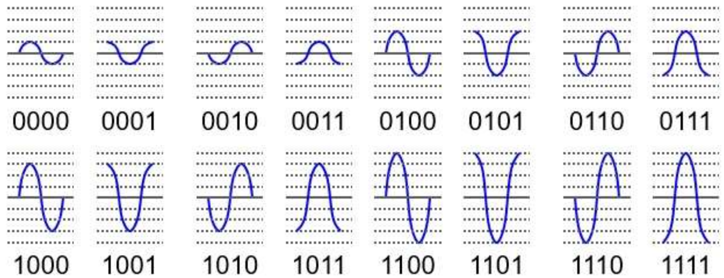
Modulation

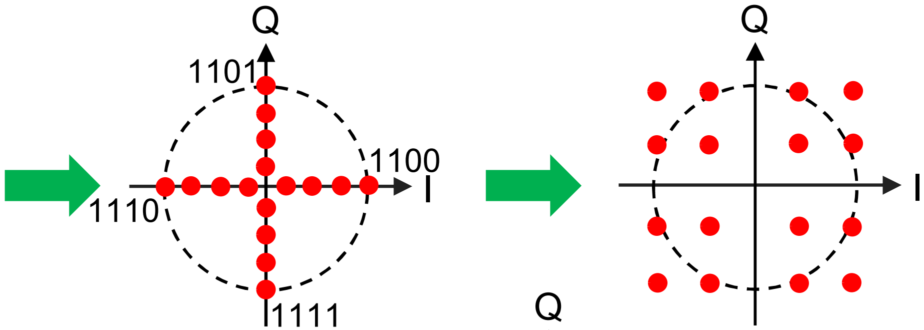
- 4 QAM



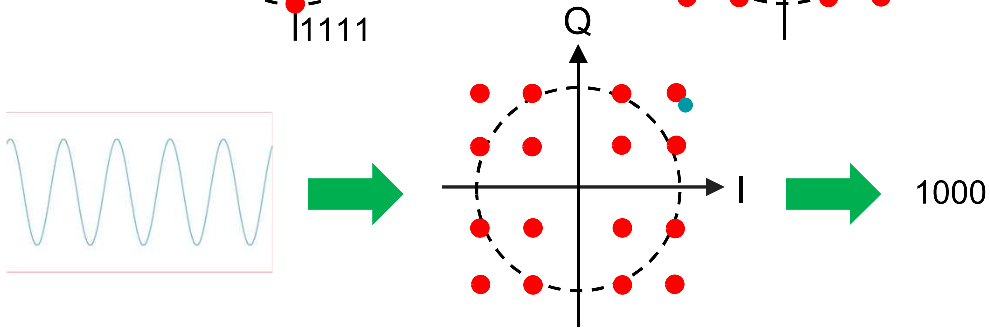


- 16 QAM

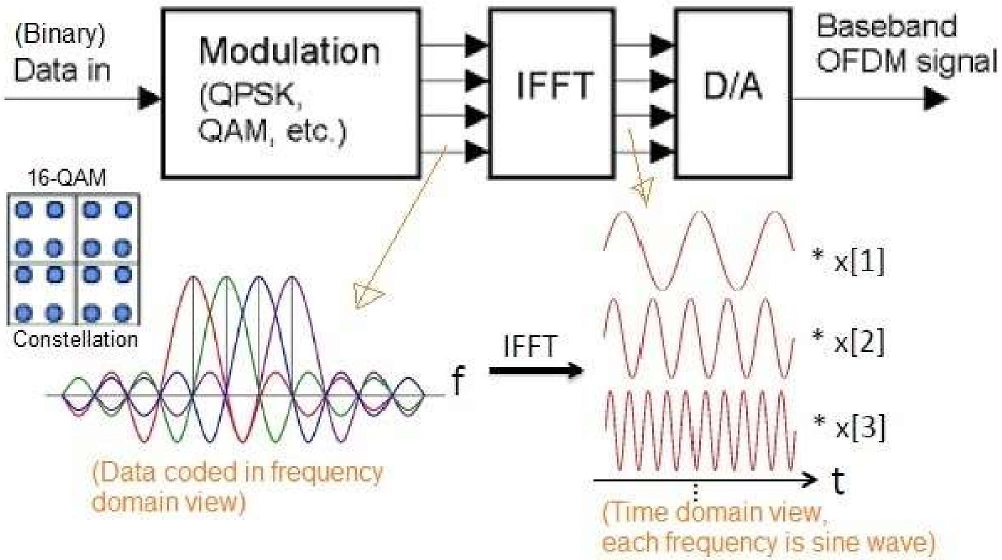




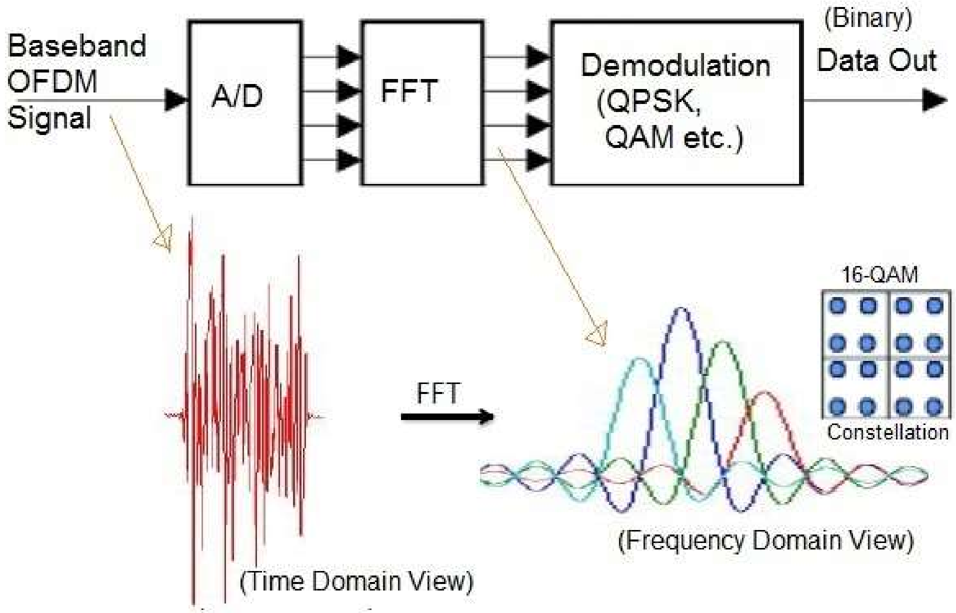
- 接收端收到電磁波，經過一連串處理之後，會得到振幅+相位的數據，對應到星座圖上的一個點，因為電磁波會有衰減跟干擾，所以這個點不會落在理想的位置上，藉由這個點的最短距離的Symbol，得到這個電磁波對應到的資料為何
- 一條電磁波 ➔ 使用 2^n QAM table ➔ 對應 n 個 bits 的資料



Modulation and Demodulation



Downlink



Uplink

Modulation

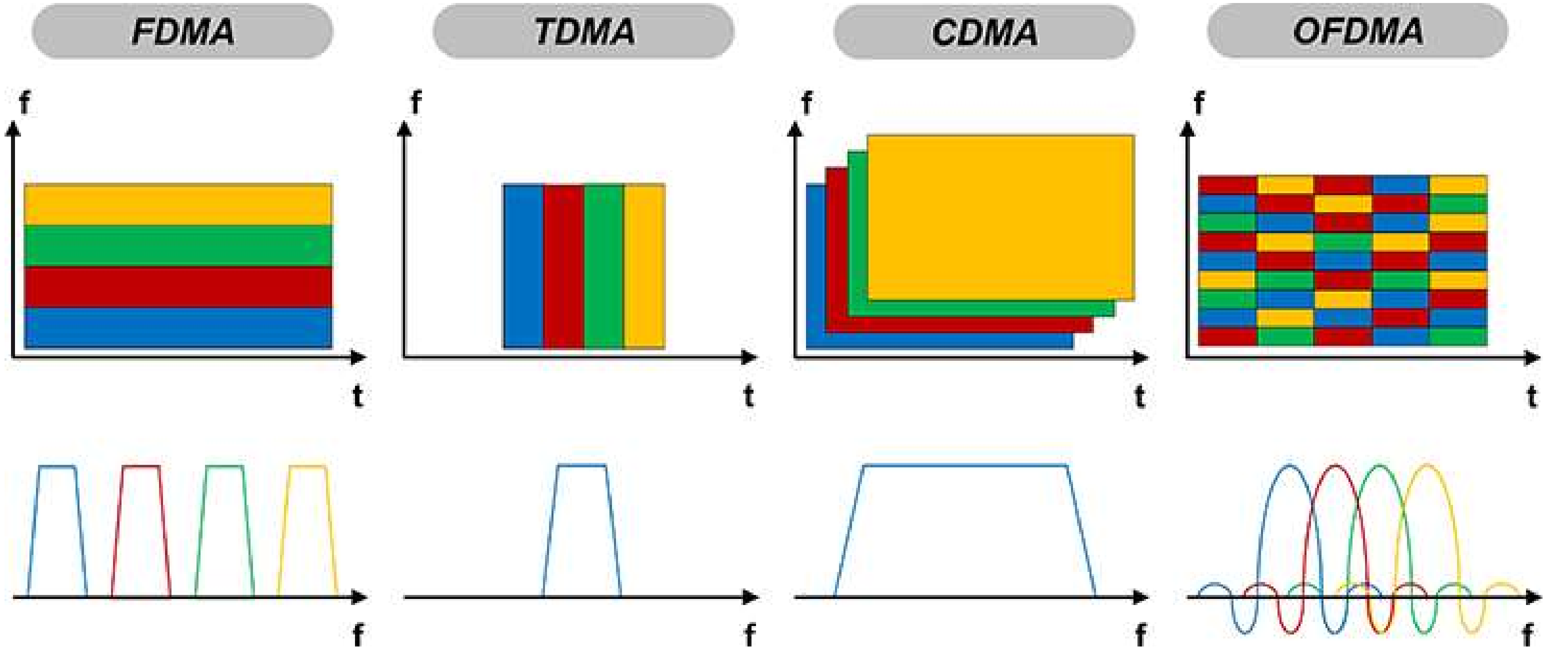
- 3G → QPSK, 16 QAM
- 4G → 64 QAM
- 5G → 256 QAM

Multiplexing

- 在一個頻道上傳輸多路訊號的過程和技術
  - FDM (Frequency-Division Multiplexing)
    - 分頻多工
    - 用不同頻率來傳送不同資料
  - TDM (Time-Division Multiplexing)
    - 分時多工
    - 用不同時間區段來傳送不同資料
  - CDM (Code-Division Multiplexing)
    - 分碼多工
    - 用不同的代碼來區分傳送的不同資料 (對數據先進行編碼，然後全部疊加在一起)
  - OFDM (Orthogonal Frequency-Division Multiplexing)
    - 正交分頻多工
    - 用不同的正交子載波頻率來傳送不同資料

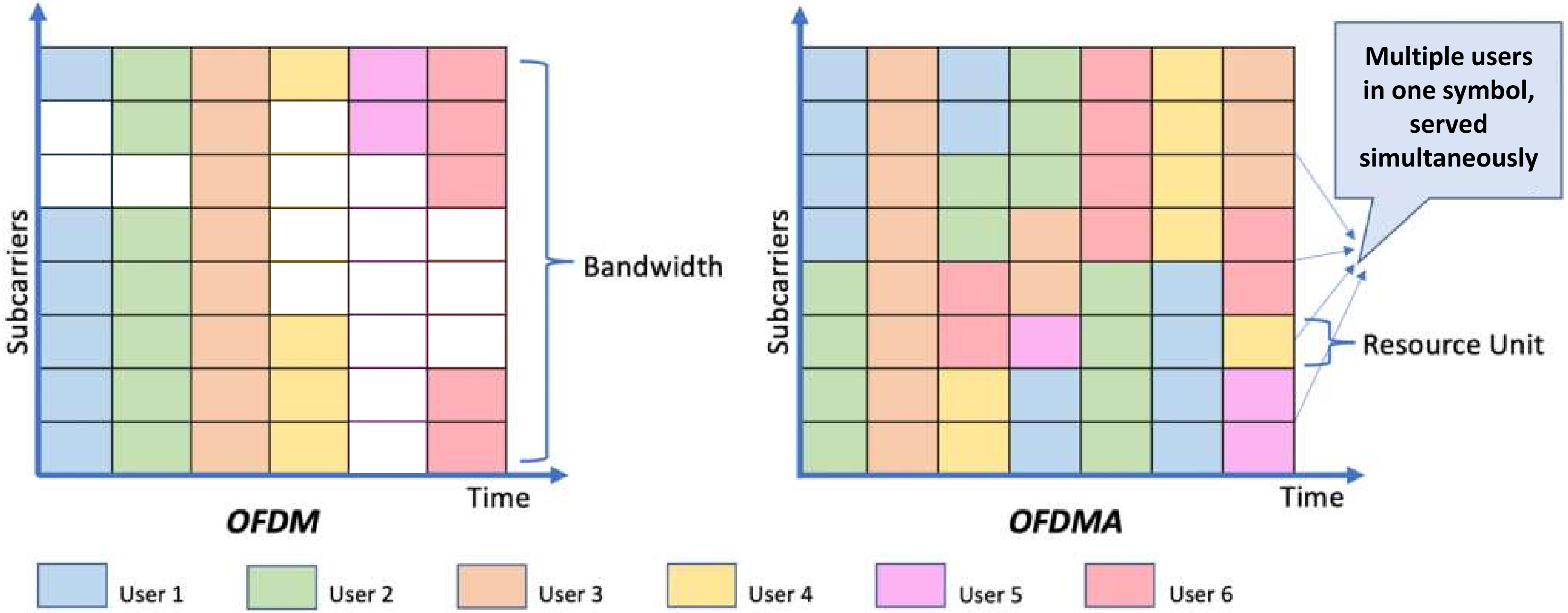
Multiplexing

- FDMA (Frequency-Division Multiple Access)
- TDMA (Time-Division Multiple Access)
- CDMA (Code-Division Multiple Access)
- OFDMA (Orthogonal Frequency-Division Multiple Access)



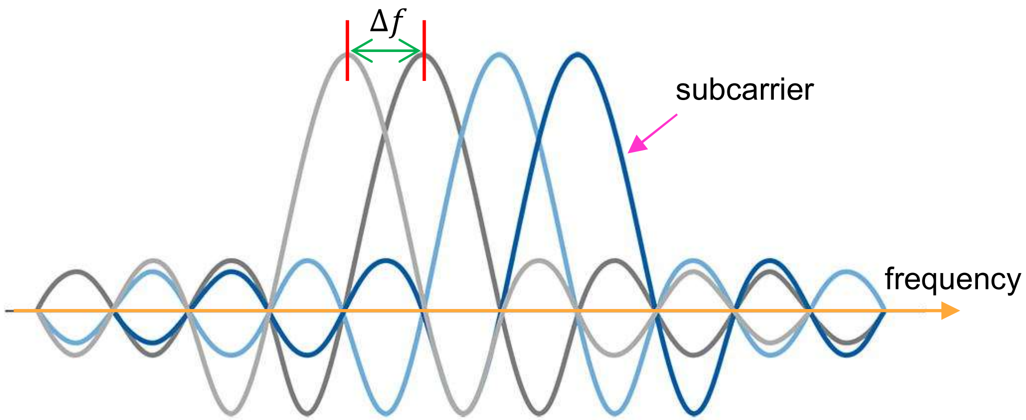
OFDM vs. OFDMA

- OFDM (Orthgonal Frequency-Division Multiplexing)
  - all subcarriers of the symbol are used for providing data to a specific user
- OFDMA (Orthgonal Frequency-Division Multiple Access)
  - the subcarrier of each symbol may be divided between multiple users
  - Better use of the radio resources



5G Waveforms

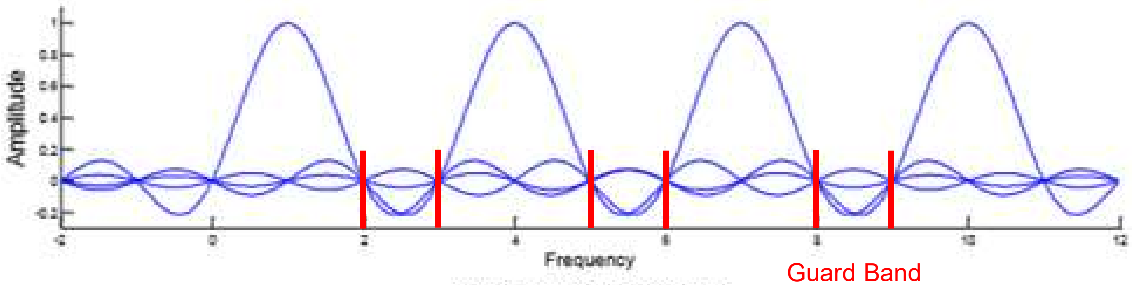
- 同 4G LTE 設計，採用 OFDM 波型
- OFDM Signal
  - Time domain
    - OFDM symbol
  - Frequency domain
    - subcarrier



OFDM Signal Frequency Spectra

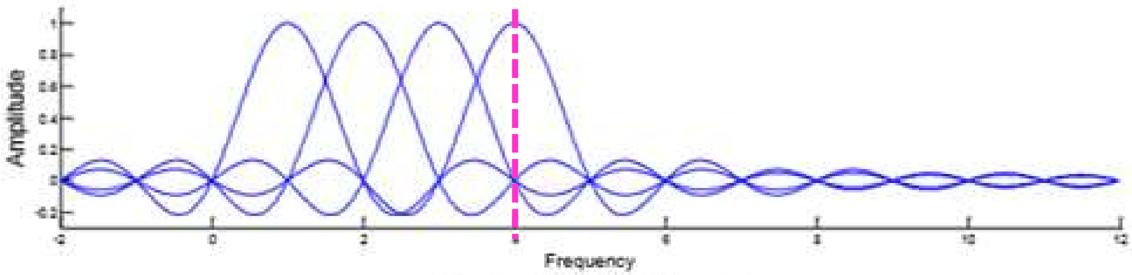
FDM vs. OFDM

- FDM
  - 利用不同的頻率來傳送資料，且其間要隔一段 Guard Band，避免互相干擾
    - Low spectral efficiency
- OFDM
  - 利用不同的正交頻率來傳送資料
    - 當兩個不同頻率的電磁波正交，代表電磁波完全無關，不互相干擾，也可以說它們的電磁波差異很大，即使混合在一起，也很容易再分離出來
  - No guard band between carriers
  - High spectral efficiency



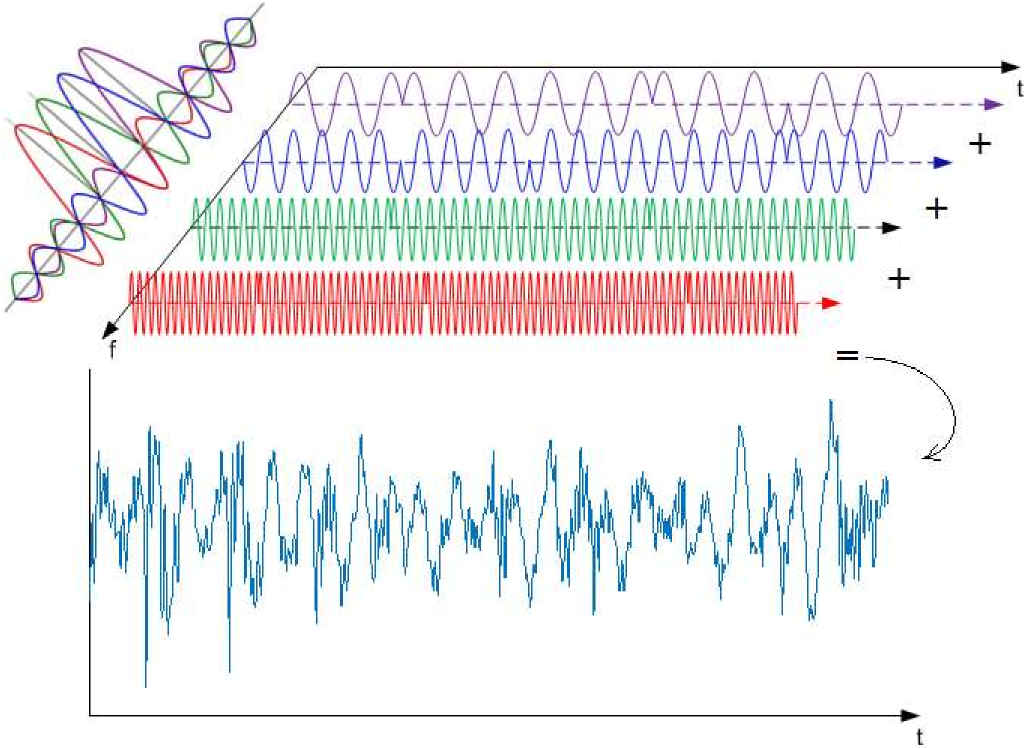
(a) Spectrum for FDM signal

carriers 間雖然都隔的很近，甚至重疊，但一個 carrier 的中心頻率，其他 carriers 是信號零點

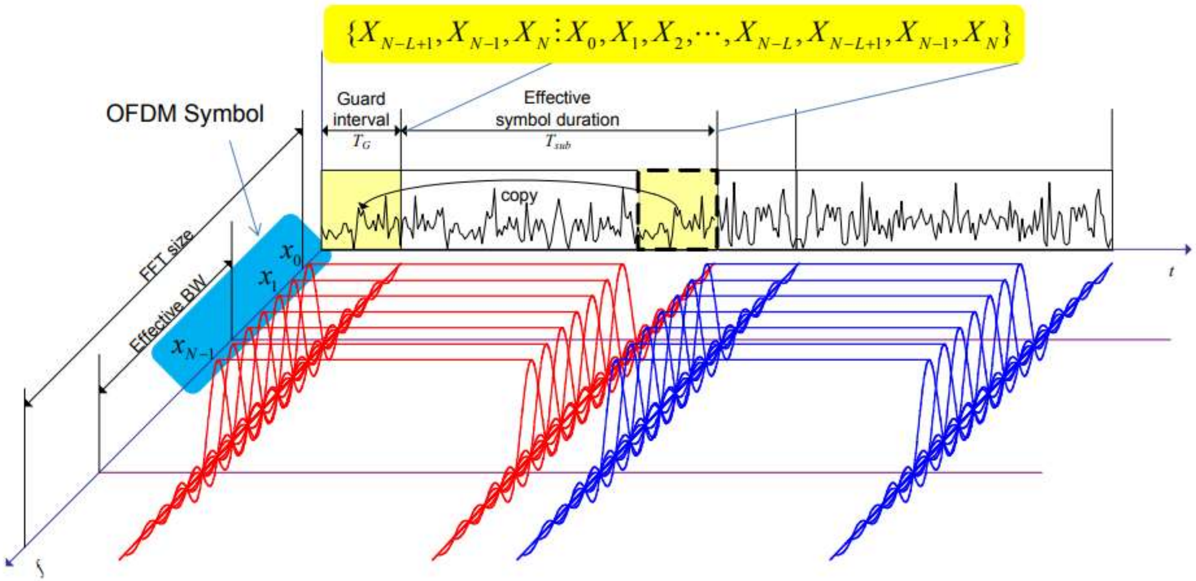


(b) Spectrum for OFDM signal

OFDM Frame

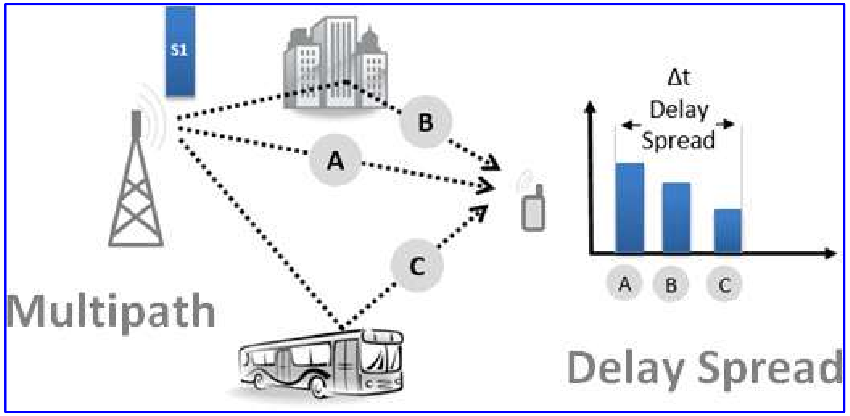


t
+
+
+
f
=
t

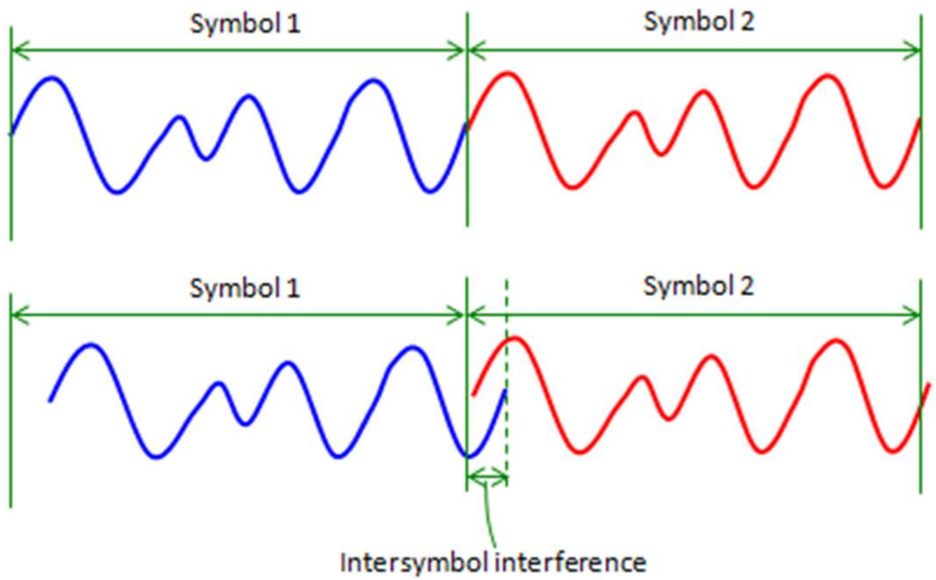


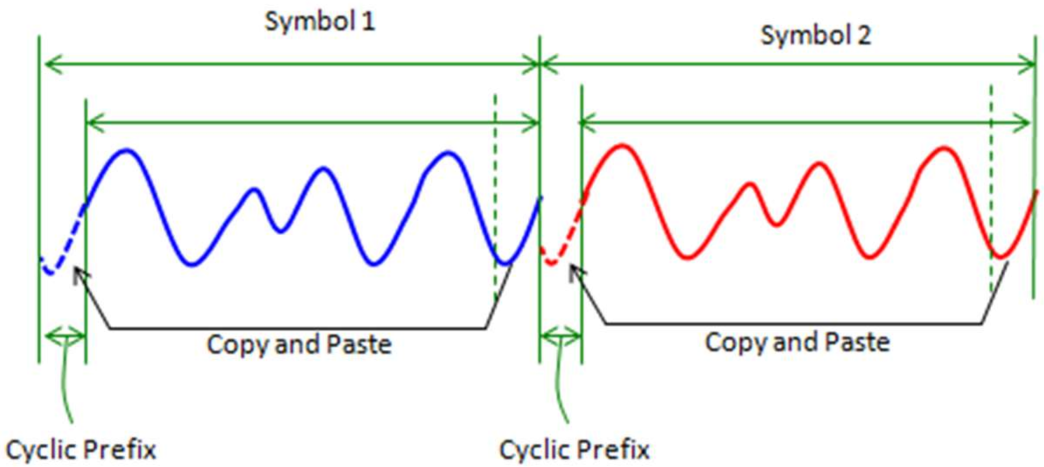
$\{X_{N-L+1}, X_{N-1}, X_N \vdots X_0, X_1, X_2, \cdots, X_{N-L}, X_{N-L+1}, X_{N-1}, X_N\}$
OFDM Symbol
Guard interval
T_G
Effective symbol duration
T_{sub}
copy
FFT size
Effective BW
x_0
x_1
x_{N-1}
t

OFDM and Cyclic Prefix



- 因多重路徑延遲擴散(Multi-path Delay Spread) 而產生符元間干擾 (Inter Symbol Interference, ISI)
  - 在每一個 OFDM Symbol 前加上一小段的防護區間(Guard Interval, GI)
    ➔ 當每一個 subcarrier 不再具有正交性的現象，會造成有載波間干擾(Inter Carrier Interference, ICI)
  - 為了保持 subcarrier 間的正交性，會採用一段連續的自身訊號，作為 GI 使用，此段訊號稱為循環字首(Cyclic Prefix, CP)





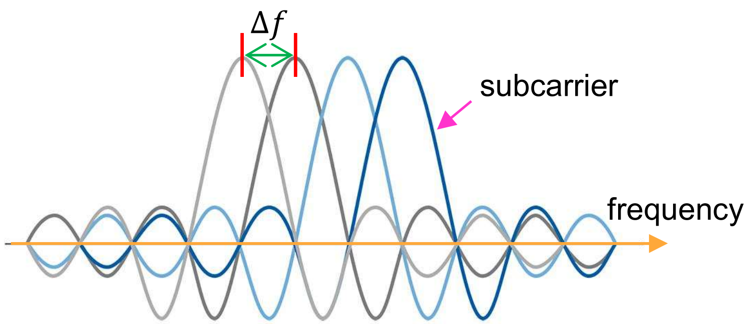
Cyclic Prefix

- 3GPP has specified two types of CP
  - Normal Cyclic Prefix
  - Extended Cyclic Prefix
    - 可以更好的抑制 Multi-path Delay 造成的干擾
    - 適用於在覆蓋範圍要求較大的場景下
    - supported only for 60 kHz subcarricr spacing

5G NR Numerology (μ) and Sub-Carrier Spacing (SCS)

- 4G LTE 只定義了 15 kHz
- 5G NR 中，定義了多種 subcarrier spacing
  - NR 設計上需支援從低頻段到超高頻的 mmWave
  - 子載波越密頻譜效率越高，但子載波間距小也較容易受到干擾且難抵抗衰減，因此須考量不同頻段特性來調整子載波間距
  - 6 GHz 以下的頻段來說，會使用15, 30, 60 kHz 較窄的子載波間距
  - 在毫米波頻段，為降低相位雜訊造成的干擾，則須使用60, 120 kHz 較寬的子載波間距

μ	$\Delta f = 15 \cdot 2^{\mu}\ kHz$ (Subcarrier Spacing)	Cyclic Prefix
0	15	Normal
1	30	Normal
2	60	Normal, Extended
3	120	Normal
4	240	Normal

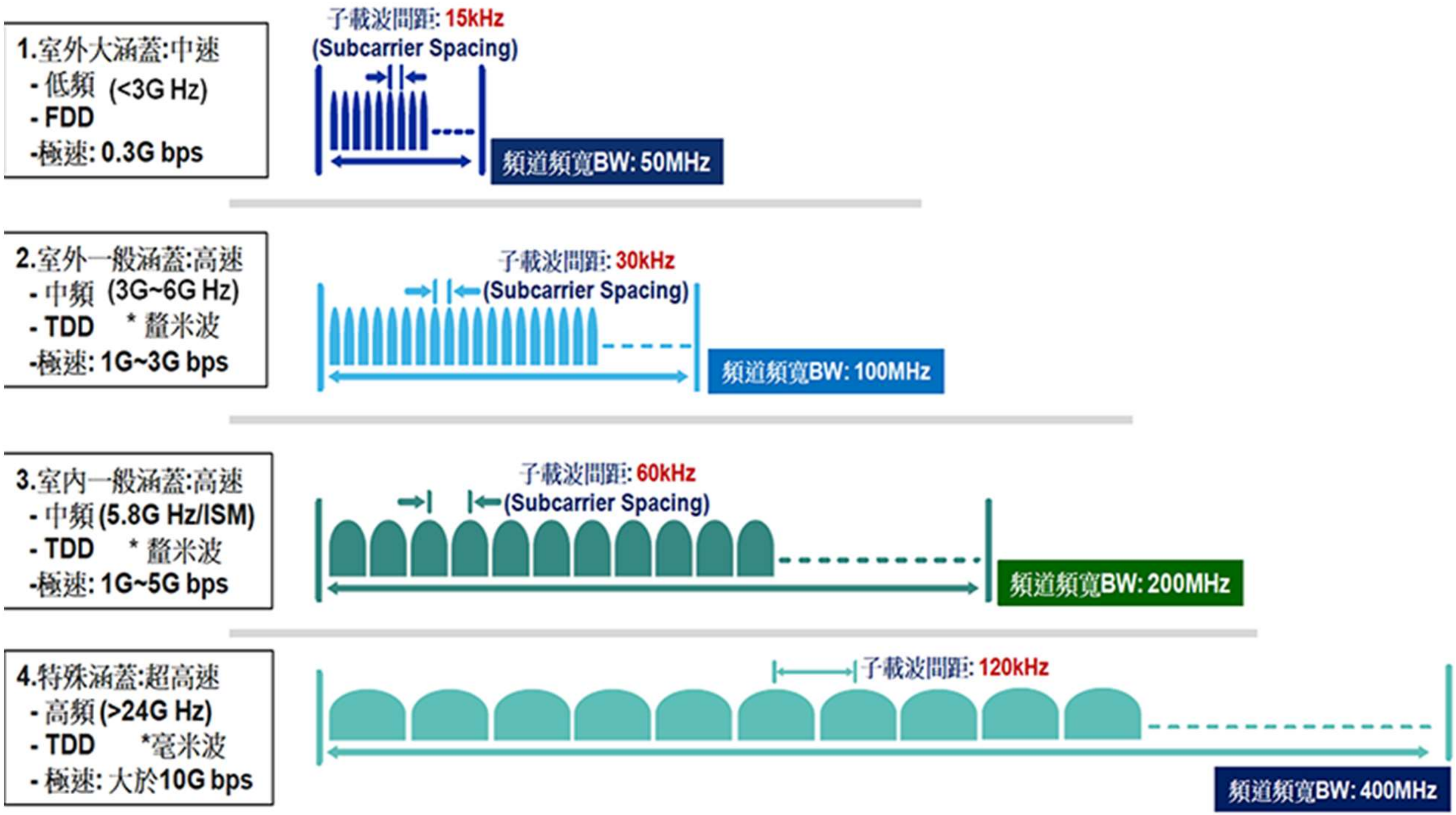


sample_app

```
[root@localhost usecase]# ls
cat_b  lte_a  lte_b  mu0_10mhz  mu0_20mhz  mu0_5mhz  mu1_100mhz  mu3_100mhz
```

- There are two types of O-RU
  - Category A – precoding function is implemented in O-DU
  - Category B – precoding function is implemented in O-RU
- mu0/mu1/mu3 ➔ SCS 15/30/120 kHz
- 5mhz/10mhz/20mhz/100mhz ➔ bandwidth

Multiple Numerology Scenario



5G NR

- 2 frequency ranges
  - FR1 (sub-6 GHz)
    - 3GPP TS 38.101-1
    - Bands numbered from 1 to 255 (eg. n78, n79….)
    - 410 MHz – 7.125 GHz
  - FR2 (mmWave)
    - 3GPP TS 38.101-2
    - Bands numbered from 257 to 511
    - 24.250 GHz – 52.600 GHz (Soon to be extended to 114.25 GHz)

5G NR

- Numerology and frequency range

μ	$\Delta f = 15 \cdot 2^{\mu}\ kHz$ (Subcarrier Spacing)	Supported frequency range	Maximum Bandwidth	$N_{RB}^{max,\mu}$
0	15	FR1	50	270
1	30	FR1	100	273
2	60	FR1, FR2	100 (FR1) 200 (FR2)	135 (FR1) 264 (FR2)
3	120	FR2	400	264
4	240	FR2	-	-

Channel Bandwidths

- 3GPP TS 38.101-1 Table 5.3.5-1 Channel bandwidths for each NR band

	NR band / SCS / UE Channel bandwidth												
NR Band	**SCS kHz**	**5 MHz**	**10[1,2] MHz**	**15[2] MHz**	**20[2] MHz**	**25[2] MHz**	**30 MHz**	**40 MHz**	**50 MHz**	**60 MHz**	**80 MHz**	**90 MHz**	**100 MHz**
n77	15		Yes	Yes	Yes			Yes	Yes				
	30		Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes	Yes
	60		Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes	Yes
n78	15		Yes	Yes	Yes			Yes	Yes				
	30		Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes	Yes
	60		Yes	Yes	Yes			Yes	Yes	Yes	Yes	Yes	Yes
n79	15							Yes	Yes				
	30							Yes	Yes	Yes	Yes		Yes
	60							Yes	Yes	Yes	Yes		Yes

$N_{RB}^{max,\mu}$

Table 5.3.2-1: Maximum transmission bandwidth configuration N_{RB}

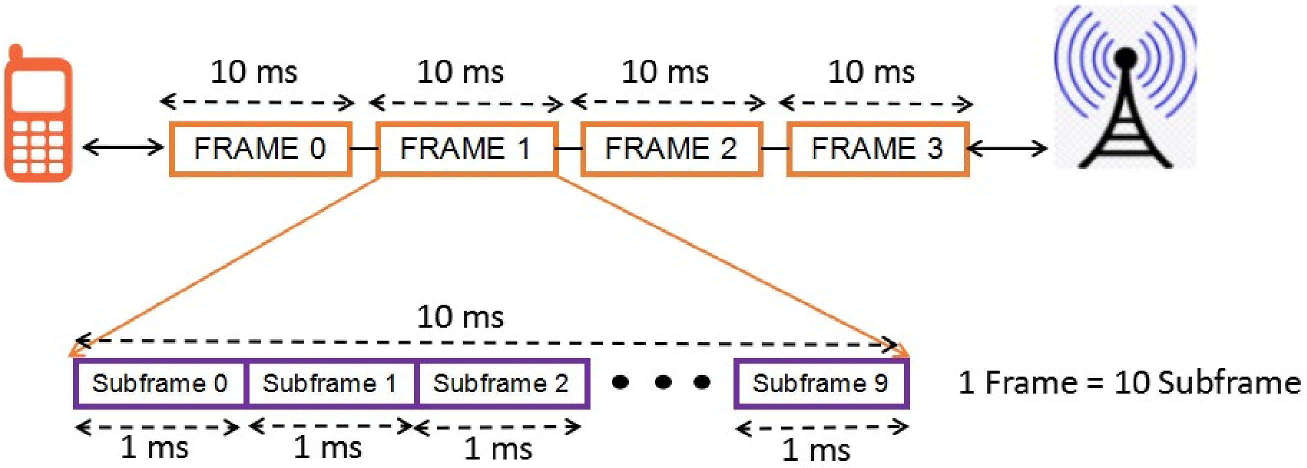
SCS (kHz)	5MHz	10MHz	15MHz	20 MHz	25 MHz	30 MHz	40 MHz	50MHz	60 MHz	80 MHz	90 MHz	100 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}
15	25	52	79	106	133	160	216	270	N/A	N/A	N/A	N/A
30	11	24	38	51	65	78	106	133	162	217	245	273
60	N/A	11	18	24	31	38	51	65	79	107	121	135

Table 5.3.2-1: Maximum transmission bandwidth configuration N_{RB}

SCS (kHz)	50MHz	100MHz	200MHz	400 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}
60	66	132	264	N.A
120	32	66	132	264

5G NR Radio Frame

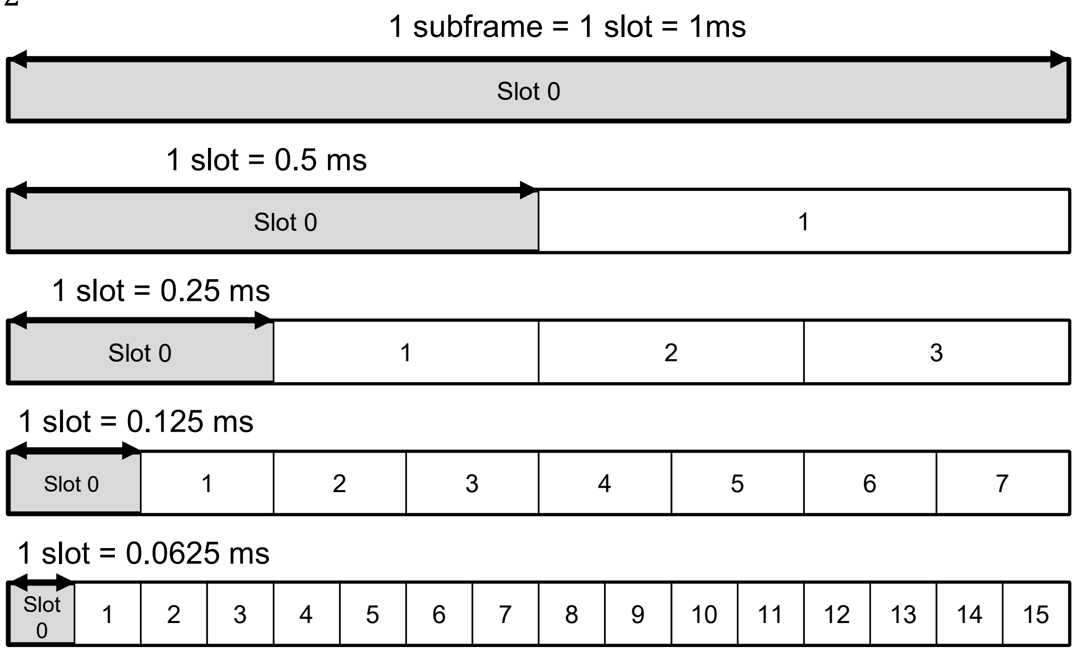
- Frame
  - Downlink and uplink transmissions are organized into frames
    - The 5G NR Radio Frame is in units of 10ms
    - 1 frame = 10 subframe
- Subframe
  - In time domain the basic unit is the *subframe*, being 1 ms long



5G NR Radio Frame

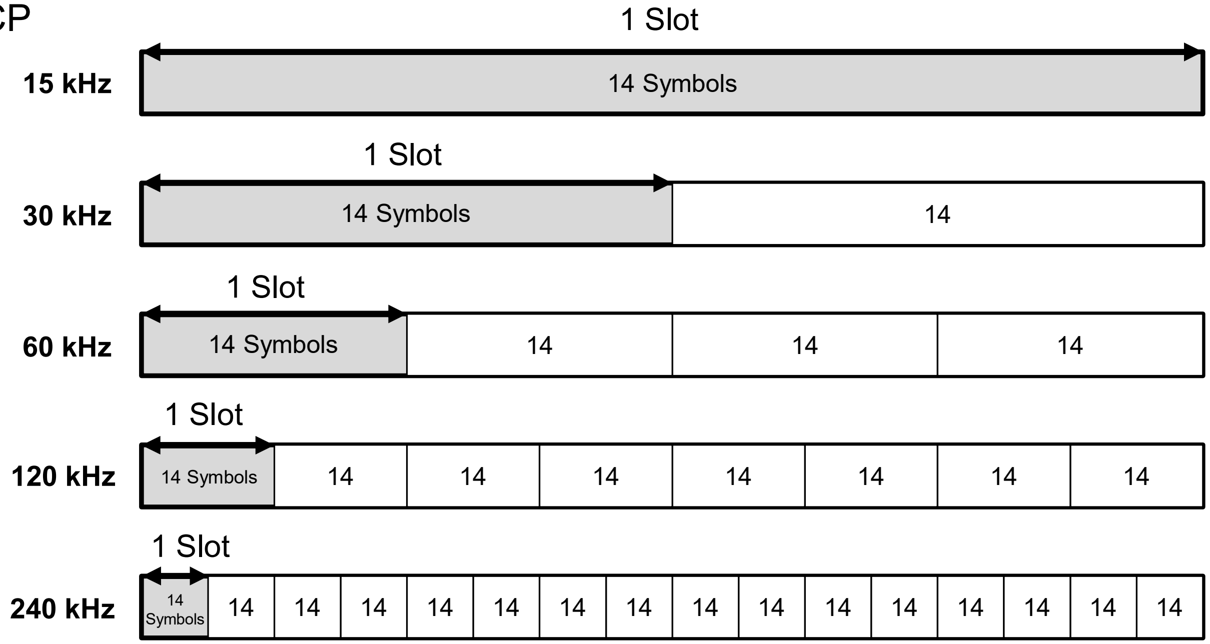
- Slot
  - Number of slots per subframe varies with carrier spacing

Numerology μ	Subcarrier Spacing	Slots per subframe $= 2^{\mu}$
0	**15 kHz**	**1**
1	**30 kHz**	**2**
2	**60 kHz**	**4**
3	**120 kHz**	**8**
4	**240 kHz**	**16**



5G NR Radio Frame

- Symbol
  - The number of OFDM symbols within a slot does not change with different subcarrier spacing
  - Symbol types: D/U/X
  - Slot (slot based scheduling)
    - 14 symbols in a slot of Normal CP
    - 12 symbols in a slot of Extended CP
  - Mini-slot (non-slot based scheduling)
    - 2, 4, or 7 symbols in a slot



5G NR Radio Frame

- 每個 Slot 中的內容可為
  - D (Downlink)
  - U (Uplink)
  - F (Flexible)/X/S
    - Detail in symbol is defined in 3GPP TS 38.213 Table 11.1.1-1 for 56 types

Format	Symbol number in a slot													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	D	D	D	D	D	D	D	D	D	D	D	D	D	D
1	U	U	U	U	U	U	U	U	U	U	U	U	U	U
2	F	F	F	F	F	F	F	F	F	F	F	F	F	F
3	D	D	D	D	D	D	D	D	D	D	D	D	D	F
4	D	D	D	D	D	D	D	D	D	D	D	D	F	F

- NR 支持 Symbol 的上下行變化，而 LTE 只支持到 Subframe

```
nFrameDuplexType=1 # 0 - FDD 1 - TDD
nTddPeriod=1 #[0-9] DDDSUUDDDD, for S it's 6:4:4
sSlotConfig0=0,0,0,0,0,0,0,0,0,0,0,0,0,0 # (0) - DL (1) - UL (2) - GUARD
sSlotConfig1=0,0,0,0,0,0,0,0,0,0,0,0,0,0 # (0) - DL (1) - UL (2) - GUARD
sSlotConfig2=0,0,0,0,0,0,0,0,0,0,0,0,0,0 # (0) - DL (1) - UL (2) - GUARD
sSlotConfig3=0,0,0,0,0,0,2,2,2,2,1,1,1,1 # (0) - DL (1) - UL (2) - GUARD
sSlotConfig4=1,1,1,1,1,1,1,1,1,1,1,1,1,1 # (0) - DL (1) - UL (2) - GUARD
sSlotConfig5=1,1,1,1,1,1,1,1,1,1,1,1,1,1 # (0) - DL (1) - UL (2) - GUARD
sSlotConfig6=0,0,0,0,0,0,0,0,0,0,0,0,0,0 # (0) - DL (1) - UL (2) - GUARD
sSlotConfig7=0,0,0,0,0,0,0,0,0,0,0,0,0,0 # (0) - DL (1) - UL (2) - GUARD
sSlotConfig8=0,0,0,0,0,0,0,0,0,0,0,0,0,0 # (0) - DL (1) - UL (2) - GUARD
sSlotConfig9=0,0,0,0,0,0,0,0,0,0,0,0,0,0 # (0) - DL (1) - UL (2) - GUARD
```

Slot

Symbol

Slot Format – DDDSU

numDlSlot=3 ➔ 3 個 D
numDlSymbol=12 ➔ S，其中有 12 個 D
numUlSlot=1 ➔ 1 個 U
numUlSymbol=0 ➔ S，其中有 0 個 U
p2Pres=0 ➔ 不使用第二組的設定
numDlSlotP2=3 ➔ 3 個 D
numDlSymbolP2=10 ➔ S，其中有 10 個 D
numUlSlotP2=1 ➔ 1 個 U
numUlSymbolP2=2 ➔ S，其中有 2 個 U

slot \ symbol	0	1	2	3	4	5	6	7	8	9	10	11	12	13
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
S	D	D	D	D	D	D	D	D	D	D	D	D	S	S
U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
S	D	D	D	D	D	D	D	D	D	D	S	S	U	U
U	U	U	U	U	U	U	U	U	U	U	U	U	U	U

Slot Format – DDDSUUDDDD

numDlSlot=3 ➔ 3 個 D
numDlSymbol=12 ➔ S，其中有 12 個 D
numUlSlot=2 ➔ 2 個 U
numUlSymbol=0 ➔ S，其中有 0 個 U
p2Pres=1 ➔ 接著使用第二組的設定
numDlSlotP2=4 ➔ 4 個 D
numDlSymbolP2=0 ➔ 沒有 S
numUlSlotP2=0 ➔ 0 個 U
numUlSymbolP2=0 ➔ 沒有 S

slot \ symbol	0	1	2	3	4	5	6	7	8	9	10	11	12	13
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
S	D	D	D	D	D	D	D	D	D	D	D	D	S	S
U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D

Slot Format – DDDSUUDSUU

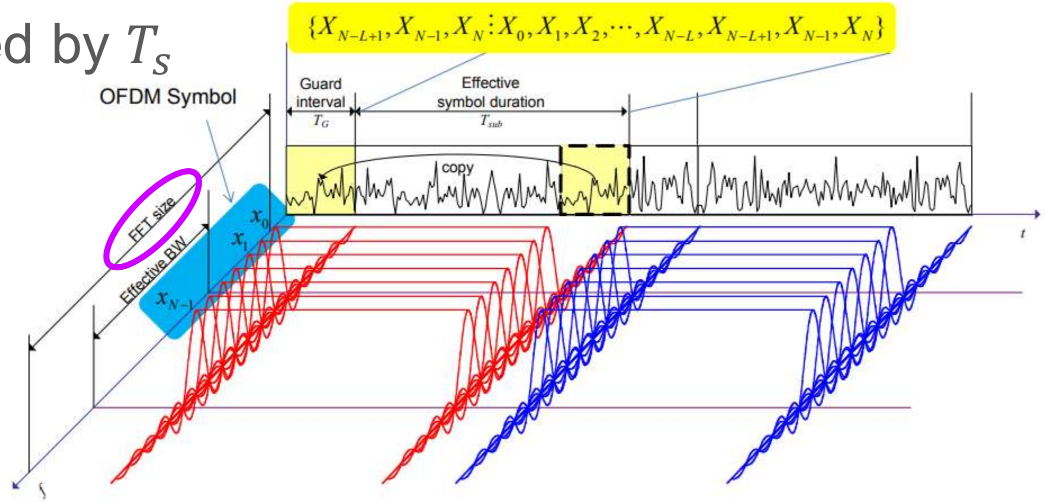
numDlSlot=3 ➔ 3 個 D
numDlSymbol=12 ➔ S，其中有 12 個 D
numUlSlot=2 ➔ 2 個 U
numUlSymbol=0 ➔ S，其中有 0 個 U
p2Pres=1 ➔ 接著使用第二組的設定
numDlSlotP2=1 ➔ 1 個 D
numDlSymbolP2=12 ➔ S，其中有 12 個 D
numUlSlotP2=2 ➔ 2 個 U
numUlSymbolP2=0 ➔ S，其中有 0 個 U

slot \ symbol	0	1	2	3	4	5	6	7	8	9	10	11	12	13
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
S	D	D	D	D	D	D	D	D	D	D	D	D	S	S
U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D
S	D	D	D	D	D	D	D	D	D	D	D	D	S	S
U	U	U	U	U	U	U	U	U	U	U	U	U	U	U
U	U	U	U	U	U	U	U	U	U	U	U	U	U	U

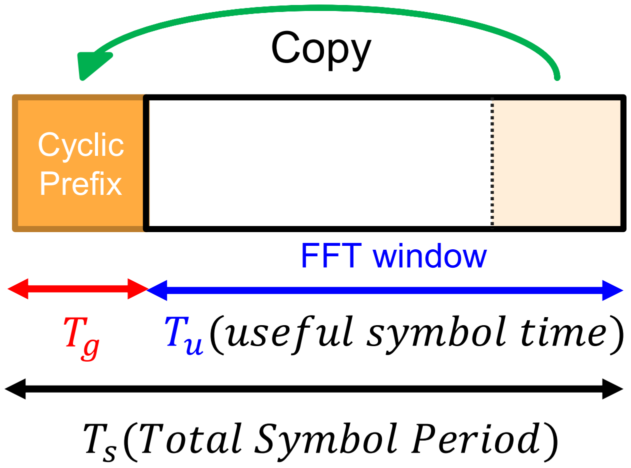
採樣: 在單位時間內取出數值，因為電磁波是連續的，所以透過採樣去取得

Basic Time Unit (Sampling Time)

- In NR, the basic time unit is represented by T_c
  - $T_c = 1/(\Delta f_{max} \times N_f) = 0.509\ ns$
    - $\Delta f_{max} = 480 \times 10^3$ ← subcarrier spacing (480 KHz)
    - $N_f = 4096$ ← FFT size
      - 最大支援 RBs 數目為 273
      - 273 RBs=3276 subcarriers
      - 取 $2^{12} = 4096$ 個採樣點
- In LTE, the basic time unit is represented by T_s
  - $\kappa = T_s/T_c = 64$
    - $\Delta f = 15 \times 10^3$
    - $N_f = 2048$ (100 RBs)



5G NR Radio Frame

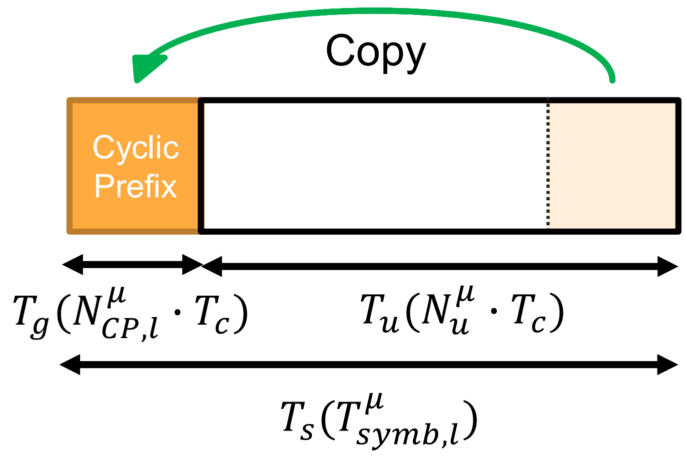


- Symbol duration
  - Useful symbol time $T_u = \frac{1}{\Delta f}$
  - Example for 15 kHz

$$T_u = \frac{1}{15\ kHz} = 6.67 \times 10^{-5}\ s = 66.67 \mu s$$

Parameter / Numerology	0	1	2	3	4
Subcarrier Spacing (kHz)	15	30	60	120	240
Slot/Subframe	1	2	4	8	16
Slot/Frame	10	20	40	80	160
Slot length (ms)	1	0.5	0.25	0.125	0.0625
OFDM Symbol Duration, T_u (μs)	66.67	33.33	16.67	8.33	4.17
Cyclic Prefix Duration, T_g (μs)	4.69	2.34	1.17	0.57	0.29
OFDM Symbol with CP, T_s (μs)	71.35	35.68	17.84	8.92	4.46

5G NR Radio Frame



- Symbol duration defined in 3GPP TS 38.211

  $\mathrm{T}^{\mu}_{symb,l} = (N^{\mu}_{u} + N^{\mu}_{CP,l})T_c$

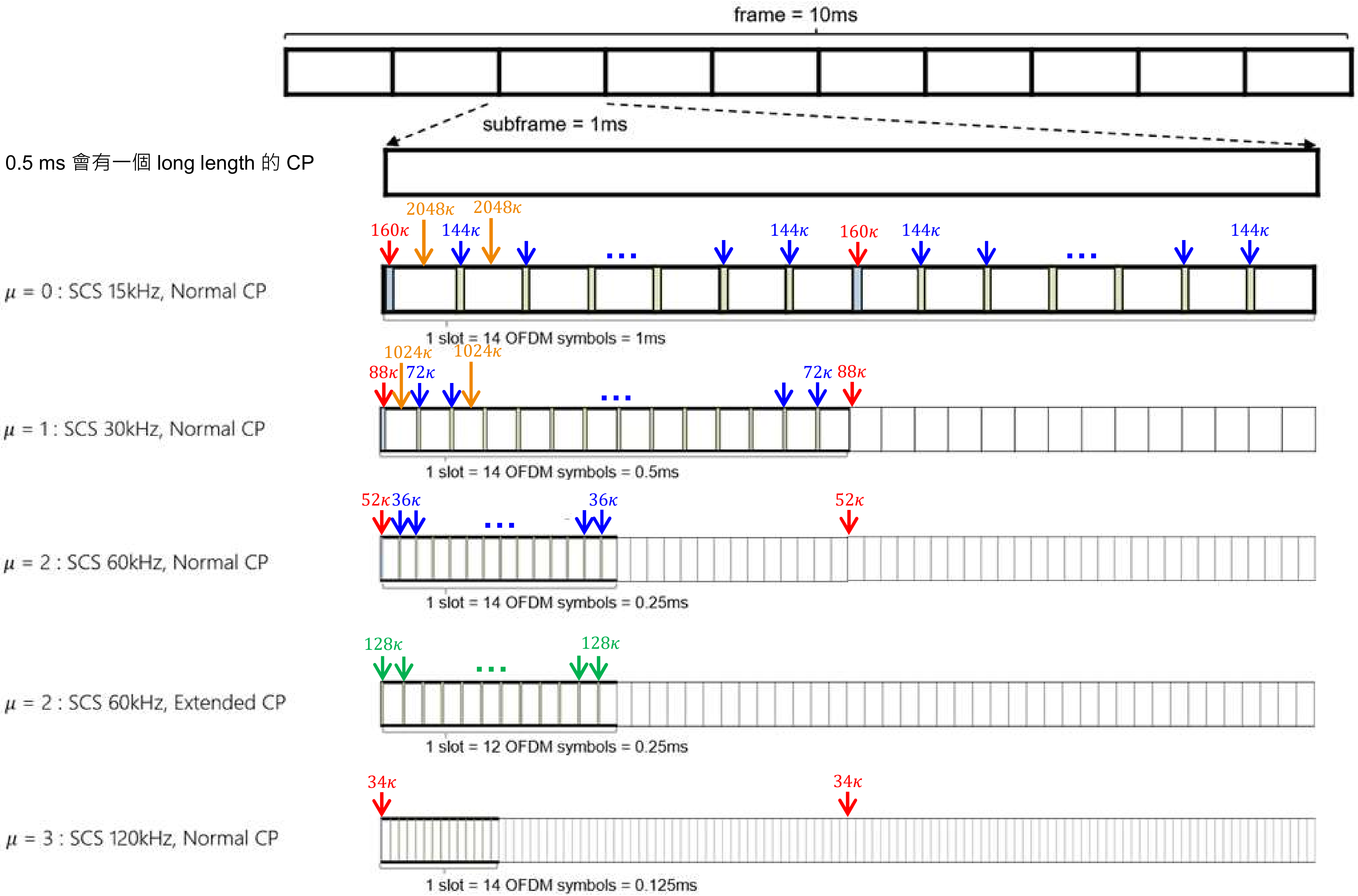
  - $N^{\mu}_{u} = 2048\kappa \cdot 2^{-\mu}$

  $$T_u = \frac{1}{\Delta f} = \frac{1}{2^{\mu} \cdot 15\ kHz} = \frac{2048 \cdot 64}{2^{\mu} \cdot 15\ kHz \cdot 2048 \cdot 64}$$

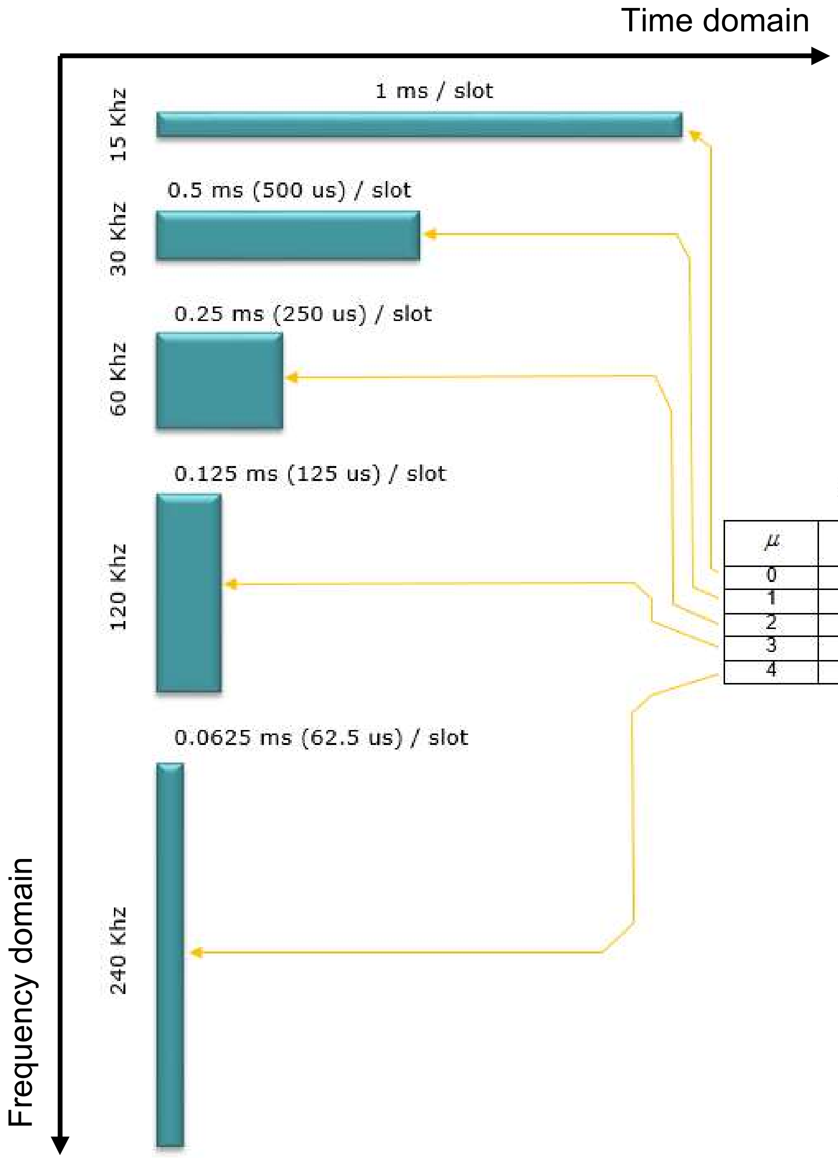
  $$= 2048\kappa \cdot 2^{-\mu} \cdot \frac{1}{15\ kHz \cdot 2048 \cdot 64} = 2048\kappa \cdot 2^{-\mu} \cdot \frac{1}{4096 \cdot 480\ kHz} = N^{\mu}_{u} \cdot T_c$$

  - $N^{\mu}_{CP,l} = \begin{cases} 512\kappa \cdot 2^{-\mu} & \text{extended cyclic prefix} \\ 144\kappa \cdot 2^{-\mu} + 16\kappa & \text{normal cyclic prefix}, l = 0 \text{ or } l = 7 \cdot 2^{\mu} \\ 144\kappa \cdot 2^{-\mu} & \text{normal cyclic prefix}, l \neq 0 \text{ and } l \neq 7 \cdot 2^{\mu} \end{cases}$

每 0.5 ms 會有一個 long length 的 CP



5G NR Radio Frame

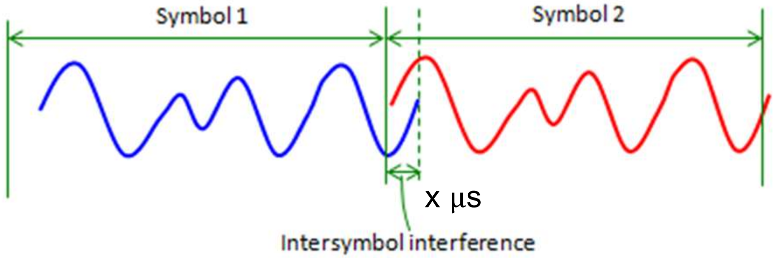


< 38.211 – Table 4.3.2-1 >

μ	N_{symb}^{slot}	$N_{slot}^{frame,\mu}$	$N_{slot}^{subframe,\mu}$
0	14	10	1
1	14	20	2
2	14	40	4
3	14	80	8
4	14	160	16

5G NR Radio Frame

- The CP duration defines how much multiple distance can be supported without affecting ISI and ICI
    - Example for 15 kHz
        - $D = c \times T_{CP} = (3 \times 10^8) \times (5.2 \times 10^{-6}) = 1560$
            - $x = 5.2 \times 10^{-6}$



Symbol 1 可能會延遲 x μs 收到，所以 Symbol 2 加上 x μs 長度的 CP，以保證 Symbol 2中的有效資料，不受 Symbol 1 的影響

Numerology	$SCS\ (kHz)$	CP for Long Symbols (μs)	Distance (m)	CP for Other Symbols (μs)	Distance (m)
0	15	5.2	1560	4.69	1407
1	30	2.86	858	2.34	703
2	60	1.69	507	1.17	351
3	120	1.11	333	0.59	175
4	240	0.81	243	0.29	87

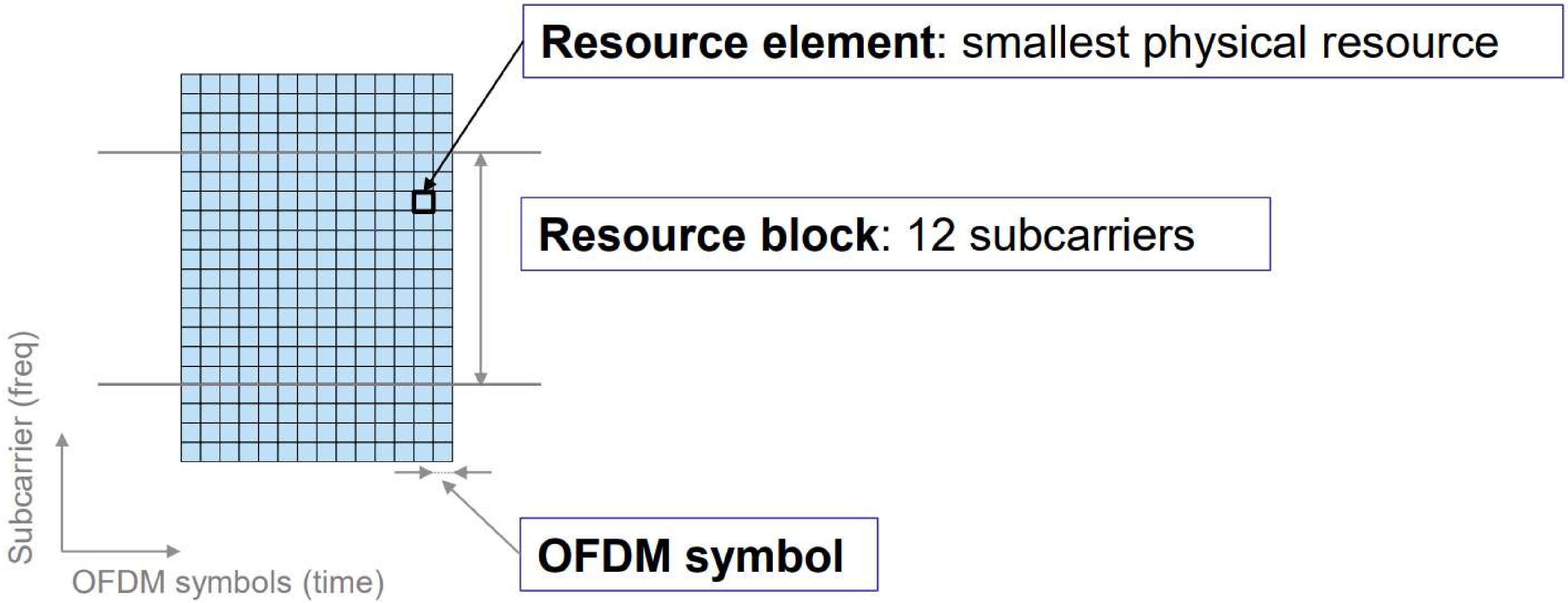
- μ 越小 ➔ CP 越長 ➔ 覆蓋越好 ➔ 單位時間內 Symbol 越少 ➔ throughput 越差

5G NR Radio Frame

- Resource Block (RB)
  - In 5G, one NR resource block contains 12 subcarrier, and its bandwidth depends on subcarrier spacing
    - 5G 在 OFDM 訊號下，每個頻寬會有非常多個子載波，為了便於管理會將每 12 個連續子載波合稱為一個 Resource Block，基地台給每位使用者的頻率資源是以 RB 為最小單位

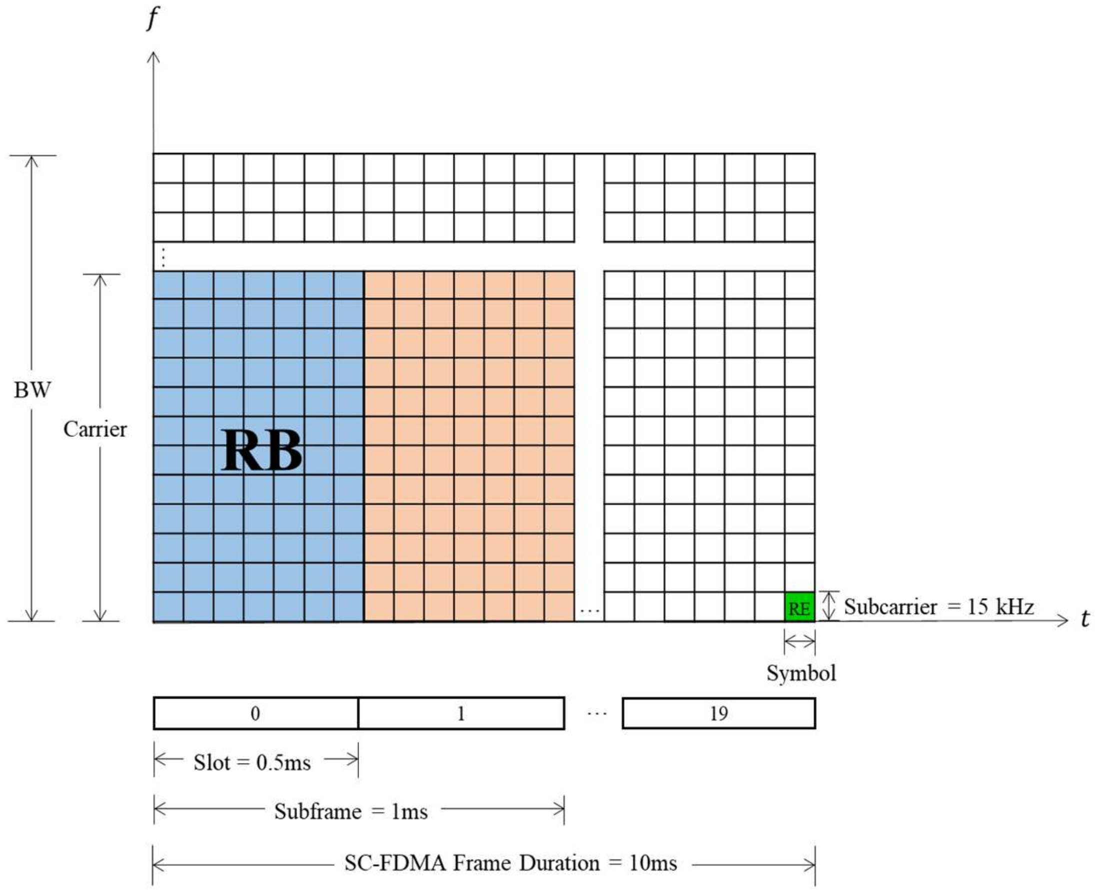
μ	$\Delta f = 15 \cdot 2^{\mu}\ kHz$	1 RB Bandwidth $= SCS \times 12$
0	15	180 kHz
1	30	360 kHz
2	60	720 kHz
3	120	1440 kHz
4	240	2880 kHz

Time Domain and Frequency Domain



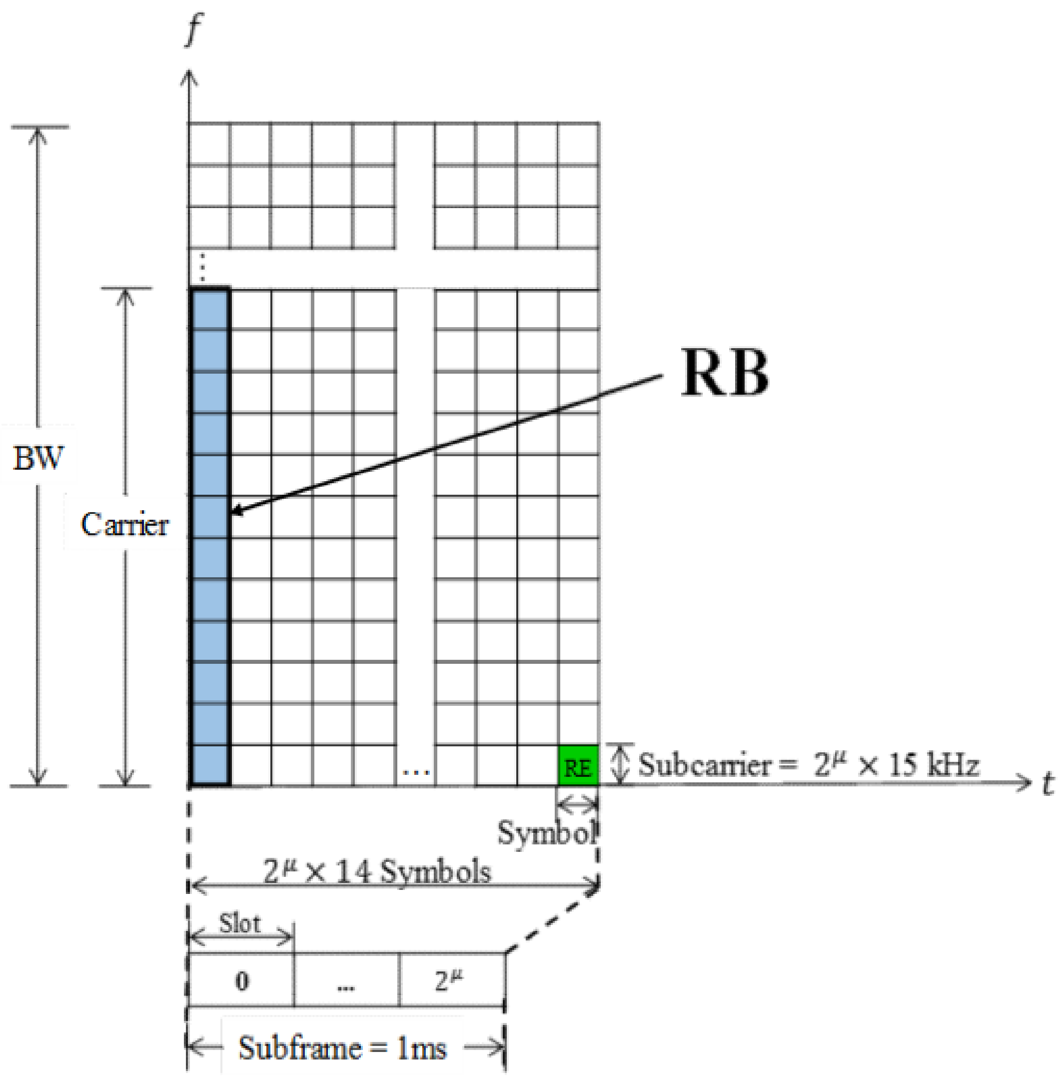
4G OFDM Signal

- Resource Element (RE)
  - 由 1 個 Subcarrier 與 1 個 Symbol 所組成
- Resource Block (RB)
  - 由 12 個 Subcarriers 與 7 Symbols 所組成
- Subcarrier Spacing
  - 15 KHz



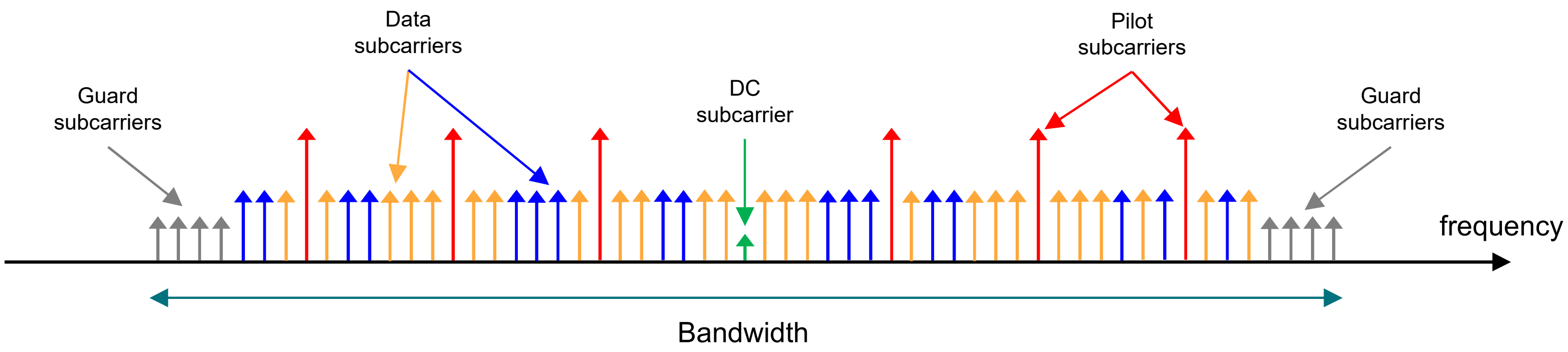
5G OFDM Signal

- Resource Element (RE)
  - 由 1 個 Subcarrier 與 1 個 Symbol 所組成
  - RE 是實體層(PHY)當中的最小單位
- Resource Block (RB)
  - 由 12 個 Subcarriers 組成
- Resource Element Group (REG)
  - 由 1 個 RB 與 1 個 Symbol 所組成
- Subcarrier Spacing
  - $15 \times 2^{\mu}\ KHz$



5G OFDM Signal

- Data Subcarriers: for data transmission
- Pilot Subcarriers: for various estimation and synchronization purposes
  - 接收端可以依照前後 OFDM Symbol 上 pilot subcarrier 相位的變化，估算出載波頻率偏移和取樣頻率偏移量，幫助接收端進行頻率的同步
- Null Subcarriers: for no transmission at all, used for guard bands and DC subcarrier
  - DC subcarrier: direct current subcarrier at center of frequency band



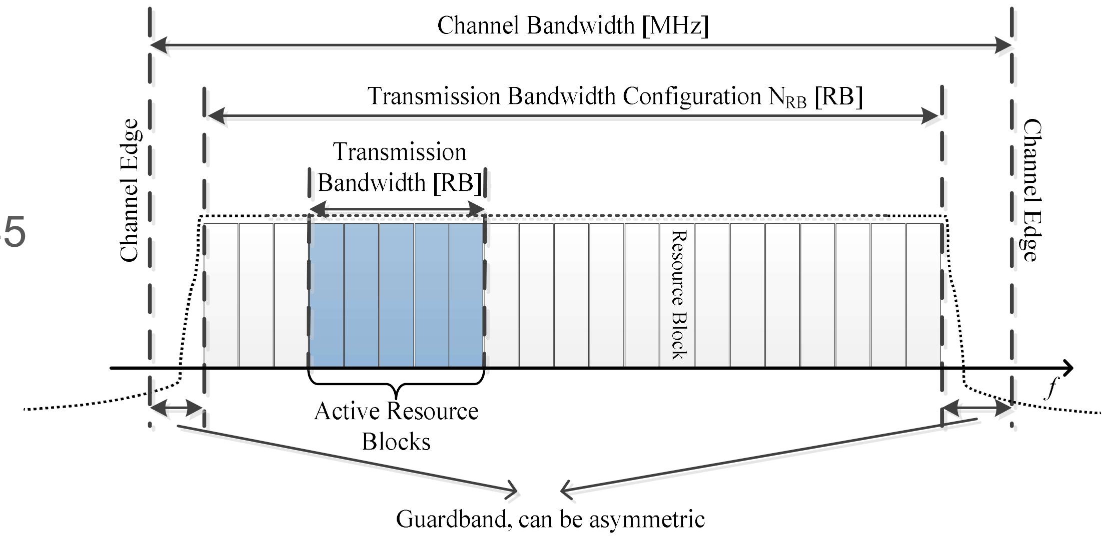
Resource Blocks

SCS (kHz)	5MHz	10MHz	15MHz	20 MHz	25 MHz	30 MHz	40 MHz	50MHz	60 MHz	80 MHz	90 MHz	100 MHz
	NRB	NRB	NRB	NRB	NRB	NRB	NRB	NRB	NRB	NRB	NRB	NRB
15	25	52	79	106	133	160	216	270	N/A	N/A	N/A	N/A
30	11	24	38	51	65	78	106	133	162	217	245	273
60	N/A	11	18	24	31	38	51	65	79	107	121	135

Table 5.3.3-1: Minimum guardband for each UE channel bandwidth and SCS (kHz)

SCS (kHz)	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz	40 MHz	50MHz	60 MHz	80 MHz	90 MHz	100 MHz
15	242.5	312.5	382.5	452.5	522.5	592.5	552.5	692.5	N/A	N/A	N/A	N/A
30	505	665	645	805	785	945	905	1045	825	925	885	845
60	N/A	1010	990	1330	1310	1290	1610	1570	1530	1450	1410	1370

- Example 1
  - $\mu = 0, \Delta f = 15\ kHz$
  - $RB_{BW} = 15\ kHz \times 12 = 180\ kHz$
  - $BW_{GuardBand}^{min} = (BW_{ChannelBand} \times 1000 - N_{RB} \times SCS \times 12)/2 - SCS/2 = \frac{50\times10^3 - 27\ \ \times 15 \times 12}{2} - \frac{15}{2} = 692.5$
  - $\cancel{N_{RB} = (BW_{ChannelBand} \times 1000 - 2 \times BW_{GuardBand}^{min} - SCS)/RB_{BW} = \frac{50\times10^3 - 2\times692.5 - 15}{180} = 270}$
- Example 2
  - $\mu = 1, \Delta f = 30\ kHz$
  - $RB_{BW} = 30\ kHz \times 12 = 360\ kHz$
  - $BW_{GuardBand}^{min} = \frac{100\times10^3 - 273\times30\times12}{2} - \frac{30}{2} = 845$
  - $\cancel{N_{RB} = \frac{10\ \ \times10^3 - 2\times845 - 30}{36} = 273}$



5G NR Throughput

$$data\ rate\ (in\ Mbps)\ in\ a\ band = 10^{-6} \cdot \left(v_{Layers} \cdot Q_m \cdot f \cdot R_{max} \cdot \frac{N_{PRB}^{BW,\mu} \cdot 12}{T_s^{u}} \cdot (1 - OH) \right) = 376\ Mbps$$

- Downlink and all symbols are DL for $\mu = 1$ (SCS 30 kHz)
- $v_{Layers} = 1$, 1 layer
- $Q_m = 6 = \log_2 64\ QAM$ (6 bits/subcarrier)
- $f = 1$, scaling factor given by higher layer parameter *scalingFactor* and can take the values 1, 0.8, 0.75, and 0.4
- $R_{max} = \frac{948}{1024}$ 編碼率 for mcs 28 of 64 QAM tabl
- $T_s^{\mu} = \frac{10^{-3}}{14 \times 2^{\mu}}$, symbol duration
- $N_{PRB}^{BW,\mu} = 273\ (BW = 100\ MHz)$
- The overhead $OH = 0.14$ for frequency range FR1 for DL

在一個 symbol 內 ($\mu = 1$ ➔ 1 ms/2 slot*14 symbol)，273 個 RBs (273*12=3276 subcarriers) 可以攜帶多少有效的 0101

RB Data Rate

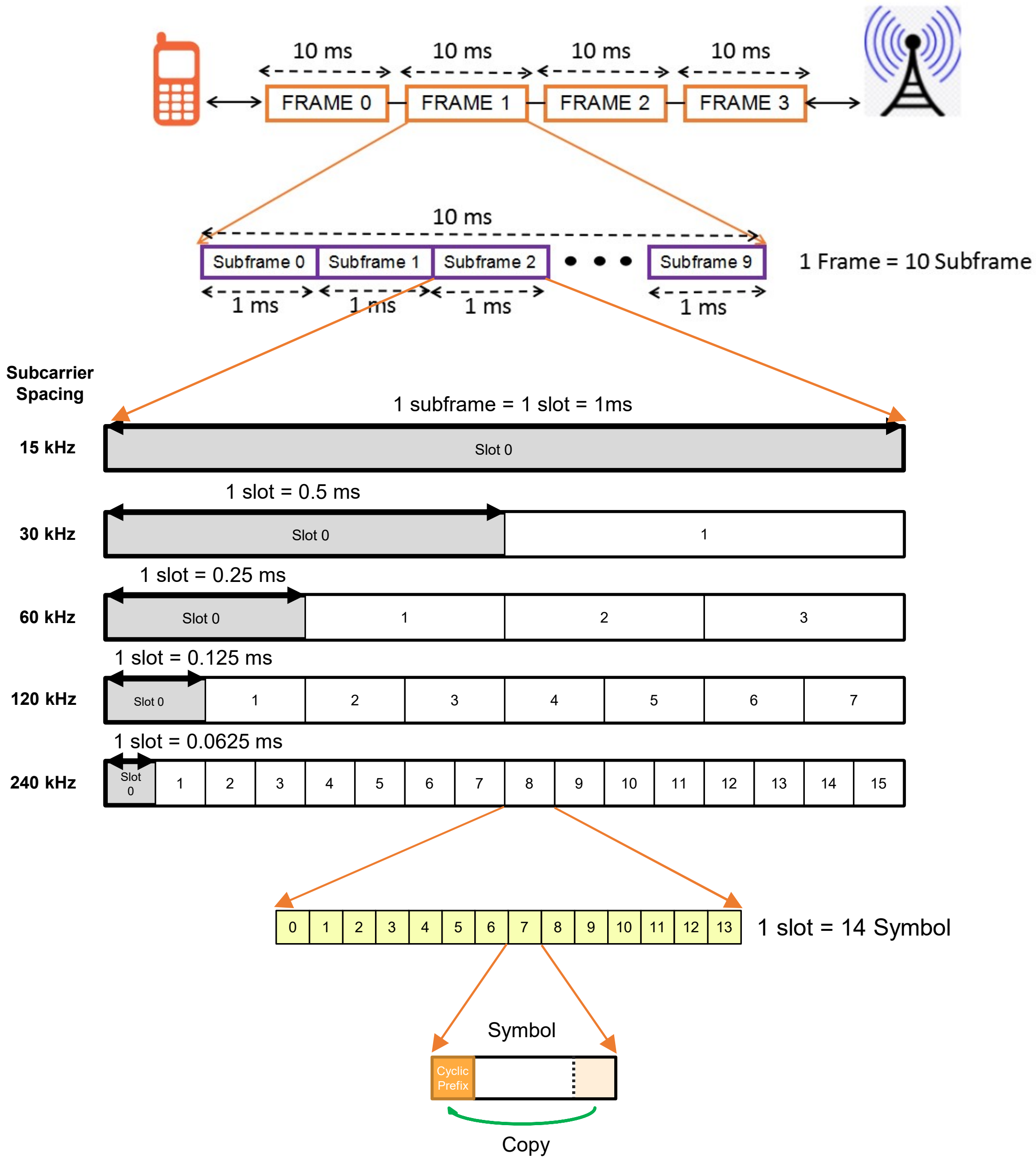
$$data\ rate/RB = 10^{-6} \cdot \left(\frac{12\ subcarriers \times Q_m}{T_s^{\mu}}\right) = 10^{-6} \cdot \frac{12 \times 6}{\frac{10^{-3}}{14 \times 2^{\mu}}} = 2.016\ Mbps$$

- $Q_m = 6 = \log_2 64\ QAM$
  - 6 bits per subcarrier
- $T_s^{\mu} = \frac{10^{-3}}{14 \times 2^{\mu}}$, symbol duration
- $Throughput = 2.016 \times 273 \times \frac{978}{1024} \times (1 - 0.14) = 376\ Mbps$

μ	**Subcarrier Spacing**	**Symbol Duration**	**Data Rate per RB**
0	15 kHz	0.071 ms	1.008 Mbps
1	30 kHz	0.036 ms	2.016 Mbps
2	60 kHz	0.016 ms	4.032 Mbps
3	120 kHz	0.009 ms	8.064 Mbps

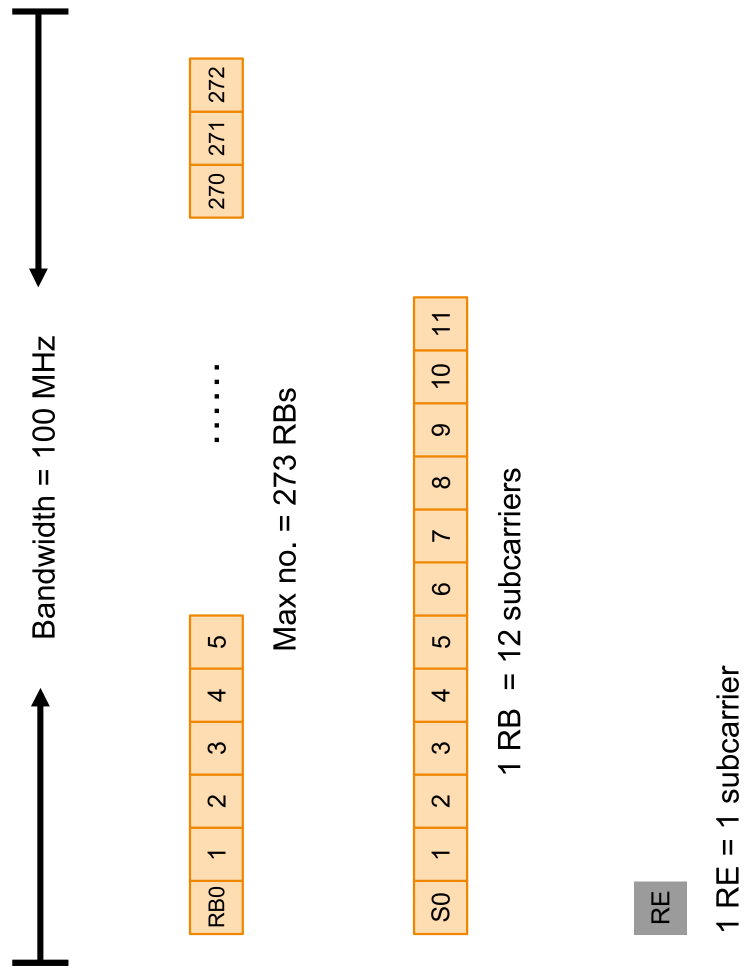
Summary

- Time domain
    - radio frame
    - subframe
    - slot
    - (OFDM) symbol
- Frequency domain
    - subcarrier
        - Data subcarrier
        - Pilot subcarrier
        - Null subcarrier
    - resource element
    - resource block



Summary

- Time domain
  - radio frame
  - subframe
  - slot
  - (OFDM) symbol
- Frequency domain
  - subcarrier
    - Data subcarrier
    - Pilot subcarrier
    - Null subcarrier
  - resource element
  - resource block



$\mu = 1$

PRACH Preamble

PRACH Preamble

- 一個 preamble 是一個長度為 L_{RA} 的序列
- preamble structure
  - Cyclic prefix + Preamble sequence + Guard period
- A preamble is send by UE to gNB over PRACH channel to obtain the UL synchronization.
  - After the cell search process, UE has obtained DL synchronization with cell, so UE can receive DL data.
- There are 64 preambles defined in each time-frequency PRACH occasion
- There are long preamble and short preamble in 5G NR
  - CP length, Sequence length, GP length, and number of repetitions are different for different format

PRACH Preamble Format

- 不同的 SCS
- 不同長度的 CP
- 不同 preamble sequence 的重複次數
- 不同長度的GP
- 應用於不同的覆蓋場景

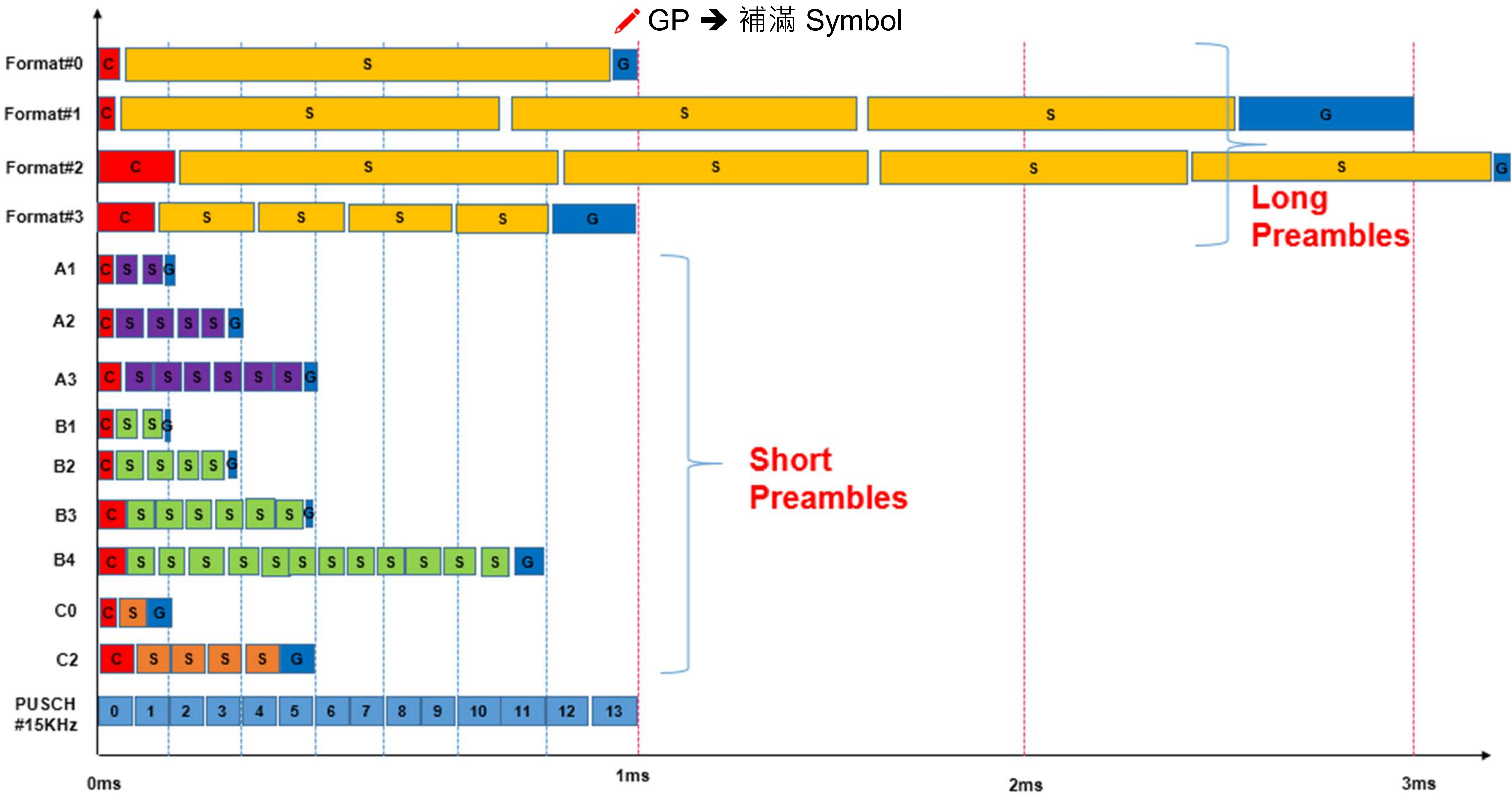
Preamble	Format	Length	SCS
Long Sequence	0, 1, 2, 3	839	1.25 KHz for format 0, 1, 2 5 kHZ for format 3
Short Sequence	A1, A2, A3, B1, B2, B3, B4, C0, C2	139	15, 30, 60 kHZ for FR1 60, 120 kHz for FR2

PRACH Preamble

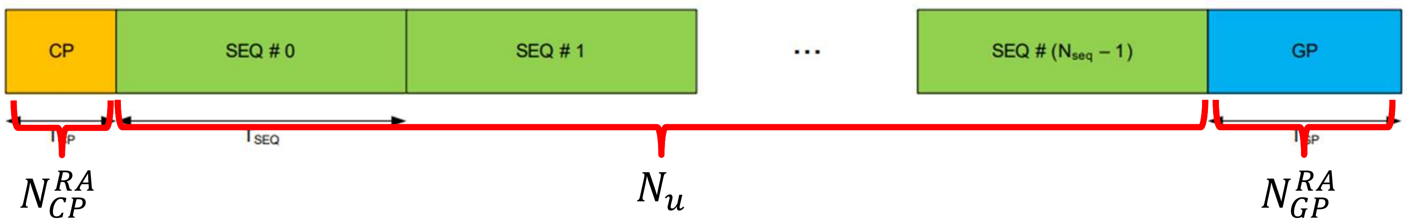
- Long preamble
  - Format 0/1/2/3
  - Sequence length (L_{RA}) = 839
  - SCS
    - Format 0/1/2 is 1.25 KHz
    - Format 3 is 5 KHz
  - LTE 僅支援部份的 long preamble，且不支援任何 short preamble
  - Long preambles can only be used for FR1 frequency bands which is below 6 GHz

PRACH Preamble

- Short preamble
  - Sequence length (L_{RA}) = 139
  - Format A1/A2/A3/B1/B2/B3/B4/C0/C2
  - SCS
    - 15 KHz, 30 KHz, 60 kHz, and 120 KHz
    - SCS of 15 KHz or 30 KHz in the case of operation below 6 GHz (FR1)
    - SCS of 60 KHz or 120 KHz in the case of operation in the higher NR frequency bands (FR2)
  - 5G NR supports mix of the “A” and “B” formats to enable additional formats like A1/B1, A2/B2, and A3/B3


GP ➔ 補滿 Symbol
Format#0
Format#1
Format#2
Format#3
A1
A2
A3
B1
B2
B3
B4
C0
C2
PUSCH
#15KHz
Long
Preambles
Short
Preambles
0ms
1ms
2ms
3ms

Preamble Format



- 3GPP TS 38.211 V15.2.0
- L_{RA} is support 571 and 1151 in V16.2.0 Release 16.

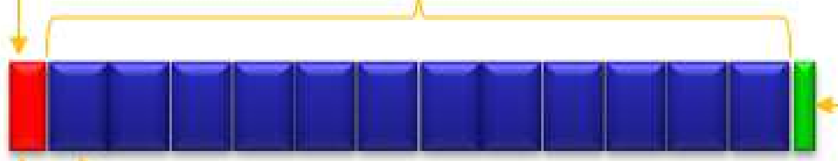
Format	L_{RA}	Δf^{RA}	N_u	N_{CP}^{RA}	N_{GP}^{RA}
0	839	$1.25\ kHz$	24576κ	3168κ	2976κ
1	839	$1.25\ kHz$	$2 \cdot 24576\kappa$	21024κ	21904κ
2	839	$1.25\ kHz$	$4 \cdot 24576\kappa$	4688κ	4528κ
3	839	$5\ kHz$	$4 \cdot 6144\kappa$	3168κ	2976κ
A1	139	$15 \cdot 2^{\mu}\ kHz$	$2 \cdot 2048\kappa \cdot 2^{-\mu}$	$288\kappa \cdot 2^{-\mu}$	0
A2	139	$15 \cdot 2^{\mu}\ kHz$	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$576\kappa \cdot 2^{-\mu}$	0
A3	139	$15 \cdot 2^{\mu}\ kHz$	$6 \cdot 2048\kappa \cdot 2^{-\mu}$	$864\kappa \cdot 2^{-\mu}$	0
B1	139	$15 \cdot 2^{\mu}\ kHz$	$2 \cdot 2048\kappa \cdot 2^{-\mu}$	$216\kappa \cdot 2^{-\mu}$	$72\kappa \cdot 2^{-\mu}$
B2	139	$15 \cdot 2^{\mu}\ kHz$	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$360\kappa \cdot 2^{-\mu}$	$216\kappa \cdot 2^{-\mu}$
B3	139	$15 \cdot 2^{\mu}\ kHz$	$6 \cdot 2048\kappa \cdot 2^{-\mu}$	$504\kappa \cdot 2^{-\mu}$	$360\kappa \cdot 2^{-\mu}$
B4	139	$15 \cdot 2^{\mu}\ kHz$	$12 \cdot 2048\kappa \cdot 2^{-\mu}$	$936\kappa \cdot 2^{-\mu}$	$792\kappa \cdot 2^{-\mu}$
C0	139	$15 \cdot 2^{\mu}\ kHz$	$2048\kappa \cdot 2^{-\mu}$	$1240\kappa \cdot 2^{-\mu}$	$1096\kappa \cdot 2^{-\mu}$
C2	139	$15 \cdot 2^{\mu}\ kHz$	$4 \cdot 2048\kappa \cdot 2^{-\mu}$	$2048\kappa \cdot 2^{-\mu}$	$2916\kappa \cdot 2^{-\mu}$

Format	L_{RA}	Δf^{RA}	N_u	N_{CP}^{RA}	Support for restricted sets
B4	139	$15 \cdot 2^{\mu}$ kHz	$12 \cdot 2048\,\kappa \cdot 2^{-\mu}$	$936\,\kappa \cdot 2^{-\mu}$	-

$$\kappa = T_s / T_c = 64$$

N_{CP}^{RA}

$N_u = 12 \times T_{SEQ}$



$$GP = 792\kappa$$
$$= (792 \times 64 \times 0.509 \times 10^{-6})ms$$
$$= 0.0258\ ms$$

T_{SEQ}

$$2048\kappa$$
$$= (2048 \times 64 \times 0.509 \times 10^{-6})ms$$
$$= 0.0667\ ms$$

T_{CP}

$$936\kappa$$
$$= (936 \times 64 \times 0.509 \times 10^{-6})ms$$
$$= 0.0305\ ms$$

Preamble

- 如何生成 64 個 PRACH preamble
  - 根據 rootSequenceIndex 及 zeroCorrelationZoneConfig 去查表，帶入公式算出
- 如何選擇正確的 PRACH 時頻資源發送所選的 preamble
  - Time domain
    - 根據 prach-ConfiguraionIndex 去查表，得到 preamble format，以及 subframe/slot/symbol 的資訊 (只允許在特定 frame 位置傳送特定格式的 preamble)
  - Frequency domain
    - 根據 msg1-FrequencyStart 及 msg1-FDM 可得到 preamble 所使用的 RB 位置與數量

A Preamble

- A Zaddoff Chu sequence is generated by using rootSequenceIndex
  - $x_{u}(i) = e^{-j\frac{\pi u i(i+1)}{L_{RA}}}, i = 0,1,\ldots,L_{RA}-1$

Table 6.3.3.1-4: Mapping from *logical index* i to sequence number u for preamble formats with $L_{\mathrm{RA}} = 139$.

rootSequenceIndex

	Sequence number u in increasing order of i																			
0 – 19	1	138	2	137	3	136	4	135	5	134	6	133	7	132	8	131	9	130	10	129
20 – 39	11	128	12	127	13	126	14	125	15	124	16	123	17	122	18	121	19	120	20	119
40 – 59	21	118	22	117	23	116	24	115	25	114	26	113	27	112	28	111	29	110	30	109
60 – 79	31	108	32	107	33	106	34	105	35	104	36	103	37	102	38	101	39	100	40	99
80 – 99	41	98	42	97	43	96	44	95	45	94	46	93	47	92	48	91	49	90	50	89
100 – 119	51	88	52	87	53	86	54	85	55	84	56	83	57	82	58	81	59	80	60	79
120 – 137	61	78	62	77	63	76	64	75	65	74	66	73	67	72	68	71	69	70	-	-
138 – 837	N/A																			

  - It's a base sequence
  - 先建出一個 base sequence，再擴充成 64 個

$$C_v = \begin{cases} vN_{CS} & v=0,1,\ldots,\lfloor L_{RA}/N_{CS}\rfloor -1, N_{CS}\neq 0 & \text{for unrestricted sets} \\ 0 & N_{CS}=0 & \text{for unrestricted sets} \\ d_{start}\lfloor v/n_{shift}^{RA}\rfloor + (v \bmod n_{shift}^{RA})N_{CS} & v=0,1,\ldots,w-1 & \text{for restricted sets type A and B} \\ \bar{\bar{d}}_{start} + (v-w)N_{CS} & v=w,\ldots,w+\bar{\bar{n}}_{shift}^{RA}-1 & \text{for restricted sets type B} \\ \bar{\bar{\bar{d}}}_{start} + (v-w-\bar{\bar{n}}_{shift}^{RA})N_{CS} & v=w+\bar{\bar{n}}_{shift}^{RA},\ldots,w+\bar{\bar{n}}_{shift}^{RA}+\bar{\bar{\bar{n}}}_{shift}^{RA}-1 & \text{for restricted sets type B} \end{cases}$$

A Preamble

- 64 different sequence are generated by doing cyclic shift of the base sequence
  - *e.g.*
    1 2 3 4 5 $\xrightarrow{\text{偏移量 } 1}$ 2 3 4 5 1
  - $x_{u,v}(n) = x_u\left((n + C_v) mod\ L_{RA}\right)$
  - The cyclic shift interval is determined by N_{cs}
  - The N_{cs} is determined by zeroCorrelationZoneConfig

➔ zeroCorrelationZoneConfig 查表得到 N_{cs}
➔ N_{cs} 帶入公式算出 C_v
➔ C_v 帶入公式產出 64 個 preamble sequence

zeroCorrelationZoneConfig	N_{CS} value for unrestricted set
0	0
1	2
2	4
3	6
4	8
5	10
6	12
7	13
8	15
9	17
10	19
11	23
12	27
13	34
14	46
15	69

Table 6.3.3.1-7: N_{CS} for preamble formats with $\Delta f^{RA} = 15 \cdot 2^{\mu}$ kHz where $\mu \in \{0,1,2,3\}$

How to Generate a Preamble

```
rach-ConfigCommon setup :
 {
    rach-ConfigGeneric
     {
       prach-ConfigurationIndex 2,
       msg1-FDM one,
       msg1-FrequencyStart 2,
       zeroCorrelationZoneConfig 6,
       preambleReceivedTargetPower -100,
       preambleTransMax n10,
       powerRampingStep dB4,
       ra-ResponseWindow sl20
     },
    ssb-perRACH-OccasionAndCB-PreamblesPerSSB four : 13,
    ra-ContentionResolutionTimer sf64,
    rsrp-ThresholdSSB 0,
    prach-RootSequenceIndex l839 : 439,
    restrictedSetConfig unrestrictedSet
 },
```

- prach-RootSequenceIndex l839 : 439
  - sequence number u = 662
- zeroCorrelationZoneConfig 6
- restrictedSetConfig unrestrictedSet
  - $v = 0,1,\ldots,\lfloor L_{RA}/N_{cs} \rfloor - 1 = 0,1,\ldots,\lfloor 839/32 \rfloor - 1 = 0,1,\ldots,25$
  - $C_v = v \cdot N_{cs} = v \cdot 32 = 0,32,64,\ldots,800$

i	Sequence number u in increasing order of i																			
420 – 439	209	630	204	635	117	722	188	651	159	680	198	641	113	726	183	656	180	659	177	662
440 – 459	196	643	155	684	214	625	126	713	131	708	219	620	222	617	226	613	230	609	232	607

Table 6.3.3.1-5: N_{CS} for preamble formats with $\Delta f^{RA} = 1.25\,\text{kHz}$.

zeroCorrelationZoneConfig	N_{CS} value		
	Unrestricted set	**Restricted set type A**	**Restricted set type B**
0	0	15	15
1	13	18	18
2	15	22	22
3	18	26	26
4	22	32	32
5	26	38	38
6	32	46	46

How to Generate a Preamble

i	Sequence number u in increasing order of i																			
420 – 439	209	630	204	635	117	722	188	651	159	680	198	641	113	726	183	656	180	659	177	662
440 – 459	196	643	155	684	214	625	126	713	131	708	219	620	222	617	226	613	230	609	232	607

- preamble_index[0]: sequence number = 662, Cv=0
- preamble_index[1]: sequence number = 662, Cv=32
- …
- preamble_index[25]: sequence number=662, Cv=800
- 通過當前的 sequence number 及 cyclic shift 只能產生 26 個 preamble ➔ 直接順移下一個 sequence number=196
- preamble_index[26]: sequence number = 196, Cv=0
- preamble_index[27]: sequence number = 196, Cv=32
- …
- preamble_index[51]: sequence number = 196, Cv=800
- 累積產生 52 個 preamble 了，再繼續順移下一個 sequence number=643
- preamble_index[52]: sequence number = 643, Cv=0
- preamble_index[53]: sequence number = 643, Cv=32
- …
- preamble_index[63]: sequence number = 643, Cv=352

How to Generate a Preamble

- $x_u(i) = e^{-j\frac{\pi u i(i+1)}{L_{RA}}}, i = 0,1,\dots,L_{RA}-1$
    - Base sequence from u=662
        - $x_{662}(0) = e^{-j\frac{\pi\cdot 662\cdot 0\cdot 1}{839}}, x_{662}(1) = e^{-j\frac{\pi\cdot 662\cdot 1\cdot 2}{839}}, \dots, x_{662}(838) = e^{-j\frac{\pi\cdot 662\cdot 838\cdot 8}{839}}$
    - …
- $x_{u,v}(n) = x_u\left((n + C_v) \bmod L_{RA}\right)$
    - u=662, Cv=0
        - $x_{662,0}(n) \Rightarrow x_{662,0}(0) = e^{-j\frac{\pi\cdot 662\cdot 0\cdot 1}{839}}, x_{662,0}(1) = e^{-j\frac{\pi\cdot 662\cdot 1\cdot 2}{839}}, \dots, x_{662,0}(838) = e^{-j\frac{\pi\cdot 662\cdot 838\cdot 839}{839}}$
    - u=662, Cv=32
        - $x_{662,1}(n) \Rightarrow x_{662,1}(0) = e^{-j\frac{\pi\cdot 662\cdot 32\cdot 3}{839}}, x_{662,1}(1) = e^{-j\frac{\pi\cdot 662\cdot 33\cdot 34}{839}}, \dots, x_{662,1}(838) = e^{-j\frac{\pi\cdot 662\cdot 31\cdot 32}{839}}$
    - …

Time Domain

- prach-ConfigurationIndex
  - determines what type of preamble format should be used and at which system frame and subframe UE can transmit PRACH Preamble
    - 決定所使用的 preamble format
    - 指定哪一個 slot/symbol 允許傳送 preamble
  - 3GPP TS 38.211 spec
    - Table 6.3.3.2-2 ➔ FR1 + FDD
    - Table 6.3.3.2-3 ➔ FR1 + TDD
    - Table 6.3.3.2-4 ➔ FR2 + TDD
    - Random access preambles can only be transmitted in the time resources given by the higher-layer parameter **prach-ConfiurationIndex**

```
rach-ConfigCommon setup :
 {
    rach-ConfigGeneric
     {
       prach-ConfigurationIndex 2,
       msg1-FDM one,
       msg1-FrequencyStart 2,
       zeroCorrelationZoneConfig 6,
       preambleReceivedTargetPower -100,
       preambleTransMax n10,
       powerRampingStep dB4,
       ra-ResponseWindow sl20
     },
    ssb-perRACH-OccasionAndCB-PreamblesPerSSB four : 13,
    ra-ContentionResolutionTimer sf64,
    rsrp-ThresholdSSB 0,
    prach-RootSequenceIndex l839 : 439,
    restrictedSetConfig unrestrictedSet
 },
```

PRACH Format and Configuration Index

- $n_{SFN}\ mod\ x = y$: 允許 UE 在每 x 個 radio frame 的第 y 個 frame 發送 preamble
  - e.g. x=16, y=1 ➔ UE 可以在 SFN=1,17,33,...上傳送 Preamble ✏ SFN (System Frame Number)➔ radio frame 的 index, 0~255
  - e.g. x=1, y=0 ➔ UE 可以在每一個 SFN 上傳送 Preamble
- Subframe number: preamble 所在的 subframe number
- Starting symbol: preamble 在 slot 中的 starting symbol index
- PRACH duration: preamble 佔多少個 symbol

PRACH Configuration Index	Preamble format	$n_{SFN}\ mod\ x = y$		Subframe number	Starting symbol	Number of PRACH slots within a subframe	$N_t^{RA,slot}$, number of time-domain PRACH occasions within a PRACH slot	N_{dur}^{RA}, PRACH duration
		x	y					
156	B4	1	0	2	0	1	1	12
158	B4	1	0	7	0	1	1	12
159	B4	1	0	9	0	1	1	12

PRACH Configuration Index	Preamble format	$n_{SFN} \bmod x = y$		Subframe number	Starting symbol	Number of PRACH slots within a subframe	$N_t^{RA,slot}$, number of time-domain PRACH occasions within a PRACH slot	N_{dur}^{RA}, PRACH duration
		x	y					
156	B4	1	0	2	0	1	1	12

Example 1

0 to 1-1 = {0}

if $\Delta f_{RA} \in \{30,120\}$ kHz

Number of PRACH slots within a subframe=1 ,then $n_{slot}^{RA} = 1$

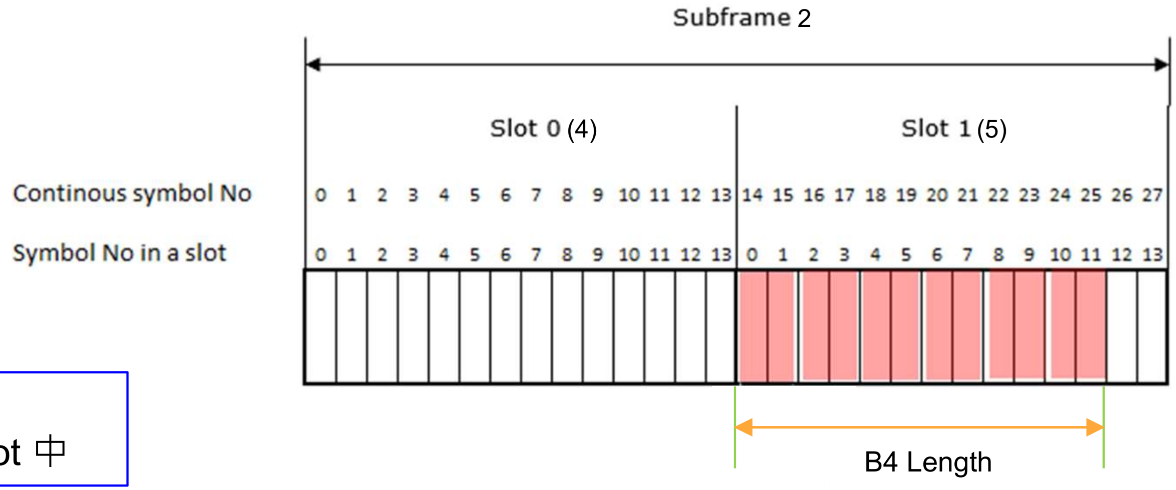
0 12 1

$$l = l_0 + n_t^{RA} N_{dur}^{RA} + 14 n_{slot}^{RA}$$

$= \{ 14 \}$

當 SCS=30 kHZ時，一個 subframe 中可以有 1~2 個 PRACH slot

- 當 $n_{slot}^{RA} = 1$，PRACH slot 會落在第 2 個slot
- 當 $n_{slot}^{RA} = 2$，PRACH slot 在兩個 slot 中都有



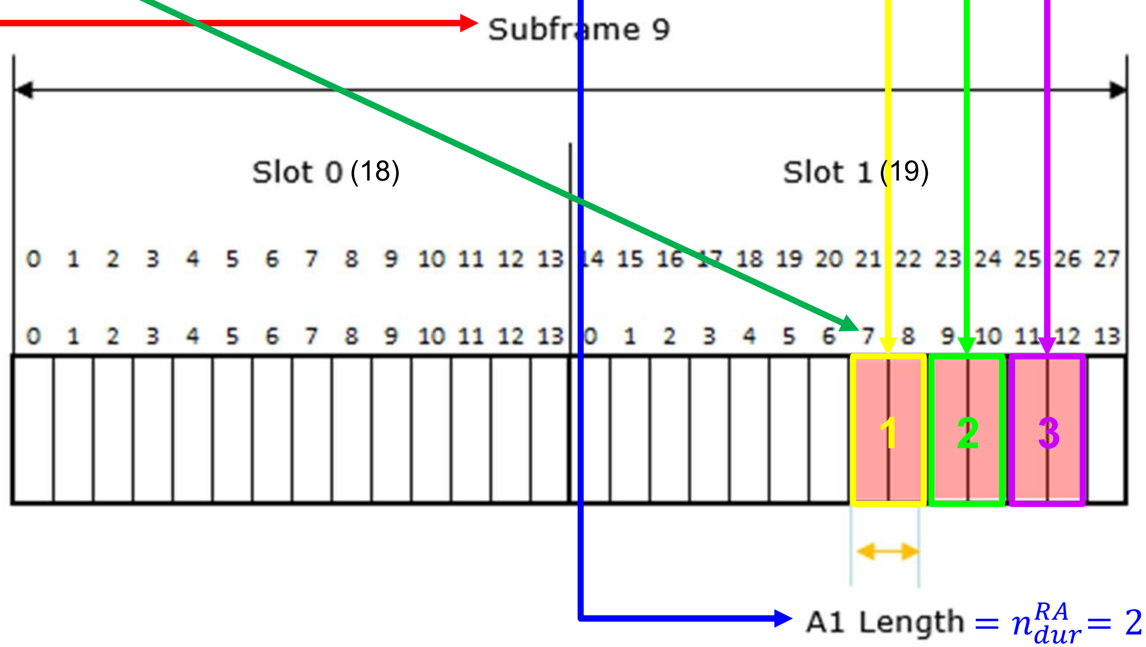
SCS 30 kHz, 1 frame ➔ 10 subframe ➔ 20 slot
PRACH preamble 落在一個 radio frame 中的第 2*2+1=5 slot 中

Example 2

PRACH Configuration Index	Preamble format	$n_{SFN} \bmod x = y$		Subframe number	Starting symbol	Number of PRACH slots within a subframe	$N_t^{RA,slot}$, number of time-domain PRACH occasions within a PRACH slot	N_{dur}^{RA}, PRACH duration
		x	y					
78	A1	1	0	9	7	1	3	2

7 + 0 to 3-1 = {0,1,2} x 2 + 14 x 1

$$l = l_0 + n_t^{RA} \mathrm{N}_{dur}^{RA} + 14 n_{slot}^{RA}$$
$$= \{21,23,25\}$$



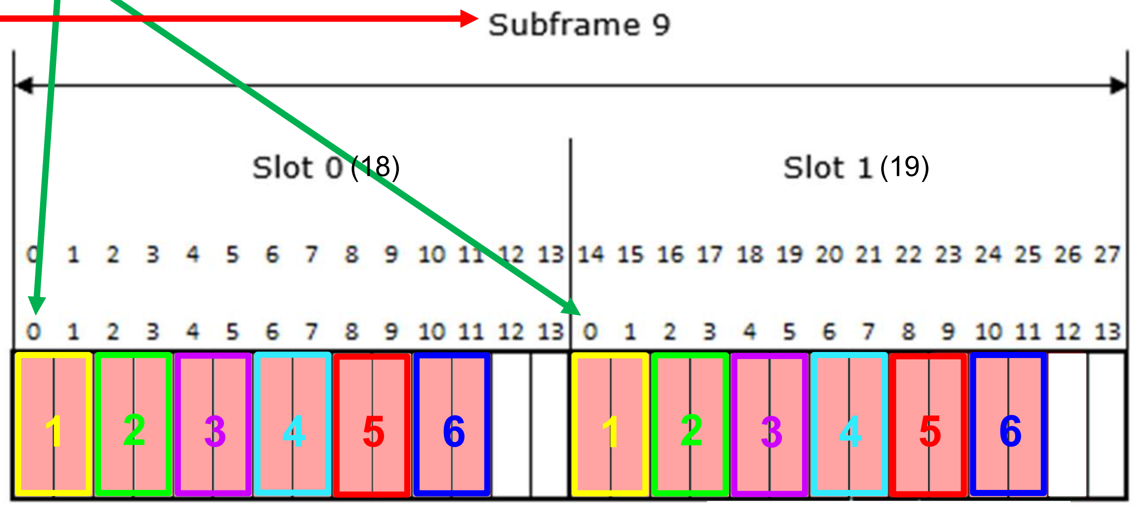
- $x = 1, y = 0$ ➔ 每個 frame 都可以帶 PRACH
- $n_{slot}^{RA} \in \{1, 2\},\ if\ SCS = 30KHz$
  if $n_{slot}^{RA} = 1$, PRACH 會在 Slot 1中
  if $n_{slot}^{RA} = 2$, PRACH 會在 Slot 0, 1 中
- Format=A1 ➔ length of A1=2
  ➔ $n_{dur}^{RA} = 2$

Example 3

PRACH Configuration Index	Preamble format	$n_{SFN}\ mod\ x = y$ x	y	Subframe number	Starting symbol	Number of PRACH slots within a subframe	$N_t^{RA,slot}$, number of time-domain PRACH occasions within a PRACH slot	N_{dur}^{RA}, PRACH duration
77	A1	1	0	9	0	2	6	2

0 + 0 to 6-1 = {0,1,2,3,4,5} x 2 + 14 x {0,1}

$$l = l_0 + n_t^{RA} N_{dur}^{RA} + 14 n_{slot}^{RA}$$
$$= \{0,2,4,6,8,10,14,16,18,20,22,24\}$$

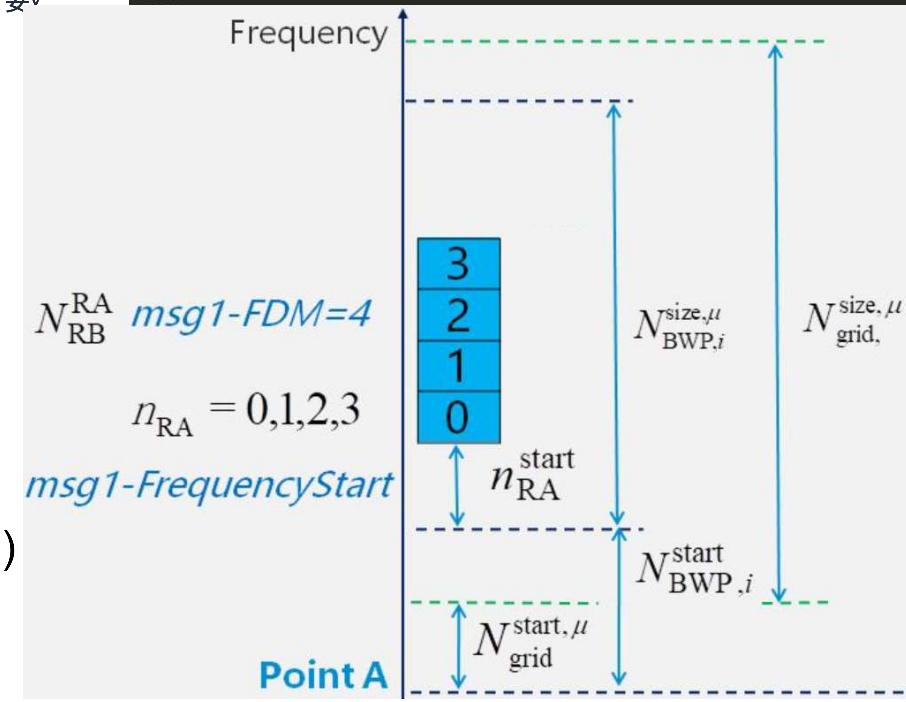


- $x = 1, y = 0$ ➔ 每個 frame 都可以帶 PRACH
- $n_{slot}^{RA} \in \{1, 2\},\ if\ SCS = 30KHz$
  if $n_{slot}^{RA} = 1$, PRACH 會在 Slot 1中
  if $n_{slot}^{RA} = 2$, PRACH 會在 Slot 0, 1 中
- Format=A1 ➔ length of A1=2
  ➔ $n_{dur}^{RA} = 2$

Frequency Domain

- Determines the frequency domain location for the PRACH preamble by
  - msg1-FDM
    - 在 frequency domain 上的 PRACH occasion 個數
      - e.g. FDM=2 ➔ 一個 time domain 上的 PRACH occasion 會對應到 frequency domain 上兩個 PRACH occasion
    - Value: 1, 2, 4, 8
      - e.g. PUSCH RBs=12, FDM=4 ➔ 在頻域上PRACH 共佔 12*4=48 個 RBs
  - msg1-FrequencyStart
    - 第一個 PRACH RB 的位置
    - Value: 0 to (max number of resource blocks - 1)

```
rach-ConfigCommon setup :
 {
    rach-ConfigGeneric
     {
       prach-ConfigurationIndex 2,
       msg1-FDM one,
       msg1-FrequencyStart 2,
       zeroCorrelationZoneConfig 6,
       preambleReceivedTargetPower -100,
       preambleTransMax n10,
       powerRampingStep dB4,
       ra-ResponseWindow sl20
     },
    ssb-perRACH-OccasionAndCB-PreamblesPerSSB four : 13,
    ra-ContentionResolutionTimer sf64,
    rsrp-ThresholdSSB 0,
    prach-RootSequenceIndex l839 : 439,
    restrictedSetConfig unrestrictedSet
 },
```



Preamble Format

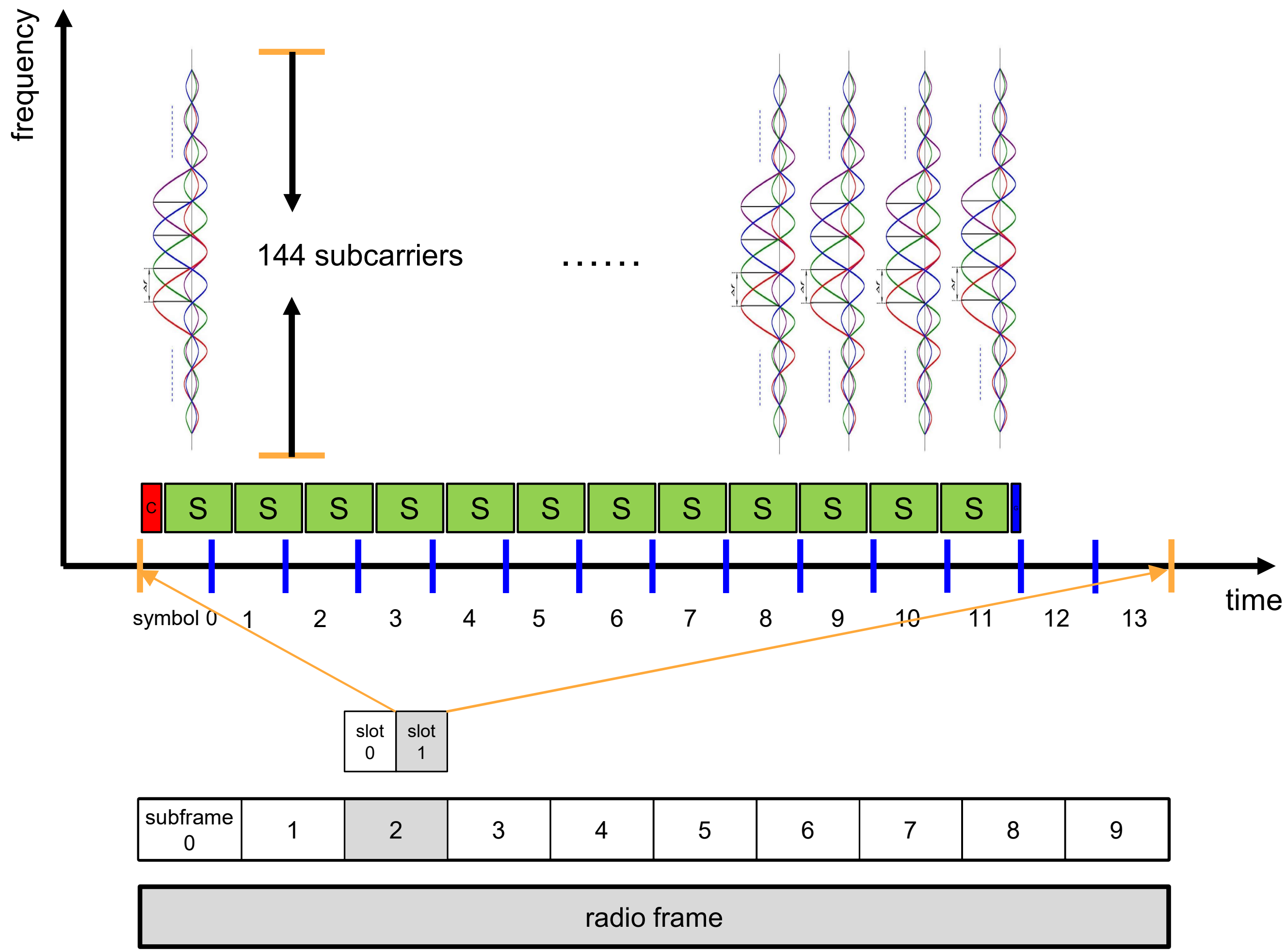
Table 6.3.3.2-1: Supported combinations of Δf^{RA} and Δf, and the corresponding value of $\bar{k}$

L_{RA}	Δf^{RA} for PRACH	Δf for PUSCH	N_{RB}^{RA}, allocation expressed in number of RBs for PUSCH	$\bar{k}$
839	1.25	15	6	7
839	1.25	30	3	1
839	1.25	60	2	133
839	5	15	24	12
839	5	30	12	10
839	5	60	6	7
139	15	15	12	2
139	15	30	6	2
139	15	60	3	2
139	30	15	24	2
139	30	30	12	2
139	30	60	6	2
139	60	60	12	2
139	60	120	6	2
139	120	60	24	2
139	120	120	12	2

反推 ➔
6 RBs=72 subcarriers
PUSCH SCS=15kHz
頻寬=72*15kHz=1.08MHz
Preamble SCS=1.25kHz
在1.08MHz頻寬中會有
1.08M/1.25k=864 subcarriers
其中，實際用839個subcarriers
上邊緣guard subcarriers=18
下邊緣guard subcarriers=7= $\bar{k}$

12 RBs=144 subcarriers
PUSCH SCS=15kHz
頻寬=144*15kHz=2.16MHz
Preamble SCS=15kHz
在2.16MHz頻寬中會有
2.16M/15k=144 subcarriers
其中，實際用139個subcarriers
上邊緣guard subcarriers=3
下邊緣guard subcarriers=2= $\bar{k}$

Summary


frequency
144 subcarriers
......
c
S S S S S S S S S S S S
time
symbol 0
1
2
3
4
5
6
7
8
9
10
11
12
13
slot 0
slot 1
subframe 0
1
2
3
4
5
6
7
8
9
radio frame

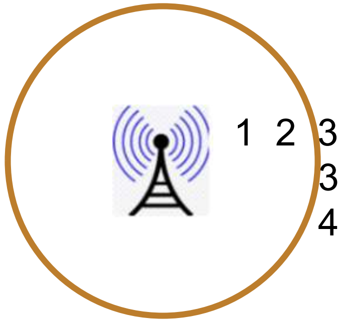
zeroCorrelationZoneConfig and Cell Radius

- 透過查表得知， zeroCorrelationZoneConfig 越大則 Ncs 越大
- Cell 覆蓋範圍越大，相對應的 Ncs 越大
  - 先設定了 Ncs ➔ UE 與 RU 距離不能超過一定距離
    - $r \leq \left(\mathrm{N}_{cs} \cdot \frac{\mathrm{T_{SEQ}}}{\mathrm{L_{RA}}} - \tau_{ds} \right) \cdot \frac{3}{20}$
  - 先預設了 UE 與 RU 距離 ➔ 挑選的 Ncs 必須大於一定數值以上
    - $\mathrm{N}_{cs} \geq \left(\frac{20}{3} r + \tau_{ds} \right) \cdot \frac{L_{RA}}{T_{SEQ}}$

zeroCorrelationZoneConfig	N_{CS} value for unrestricted set
0	0
1	2
2	4
3	6
4	8
5	10
6	12
7	13
8	15
9	17
10	19
11	23
12	27
13	34
14	46
15	69

Ncs

- $N_{cs} \geq \left(\frac{20}{3} r + \tau_{ds}\right) \cdot \frac{L_{RA}}{T_{SEQ}}$



1 2 3 4 5 6 (UE 1)
3 4 5 6 1 2 (UE 2) ➔ Ncs=2 ➔ NG
4 5 6 1 2 3 (UE 3) ➔ Ncs=3 ➔ OK

1 2 3 4 5 6 (UE 1)
4 5 6 1 2 3 (UE 2) ➔ Ncs=3 ➔ NG
5 6 1 2 3 4 (UE 3) ➔ Ncs=4 ➔ OK

$2r$ ➔ 距離
距離/光速=時間 ➔ $\frac{2r}{0.3} = \frac{20}{3} r$
τ_{ds} ➔ delay spread time
$L_{RA} = 139$ ➔ 資料總量
$T_{SEQ} = 2048\kappa \cdot 2^{-\mu}$
$\frac{L_{RA}}{T_{SEQ}}$ ➔ 單位時間內能傳送的資料數目
$\left(\frac{20}{3} r + \tau_{ds}\right) \cdot \frac{L_{RA}}{T_{SEQ}}$ ➔ 在2r距離下，單位時間內所能傳送的資料數目

- 基站為了保證每次在 random access 所配置的 subframe 中，能夠對最大 64 個 preamble sequences 分別進行正確解碼，所以 Ncs 要夠大，使得建出來的 preamble sequence 在單位時間內+有效覆蓋範圍下，不會重複/重疊

Ncs and Cell Radius

- Ncs大小會影響所需要的 preamble root sequence 數量
  - Ncs=10 => v=0, 1, ..., 139/10-1 = 0, 1, ..., 12
  - 所以要產生 64 個 preamble sequence 需要 5 個 base sequence (需要 5 個 rootSequenceIndex)
  - 總共只有 138 個 rootSequenceIndex，所以在一個區域範圍內，最多只能有 27 台 cell

zeroCorrelationZoneConfig	N_{CS} Value	Max cell radius (meter)	No. of sequences per N_{CS}	No. of root sequences for 64 preambles	Max cell number
0	0	5000	1	64	2
1	2	71	69	1	138
2	4	143	34	2	69
3	6	215	23	3	46
4	8	287	17	4	34
5	10	359	13	5	27
6	12	431	11	6	23
7	13	467	10	7	19
8	15	539	9	8	17
9	17	611	8	8	17
10	19	683	7	10	13
11	23	827	6	11	12
12	27	971	5	13	10
13	34	1223	4	16	8
14	46	1654	3	22	6
15	69	2482	2	32	4

Slot Format

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
D	D	D	S	U	D	D	D	S	U	D	D	D	S	U	D	D	D	S	U
D	D	D	S	U	U	D	D	D	D	D	D	D	S	U	U	D	D	D	D
D	D	D	S	U	U	D	S	U	U	D	D	D	S	U	U	D	S	U	U

PRACH Configuration Index	Preamble format	$n_{SFN} \bmod x = y$		Subframe number	Starting symbol	Number of PRACH slots within a subframe	$N_t^{RA,slot}$, number of time-domain PRACH occasions within a PRACH slot	N_{dur}^{RA}, PRACH duration
		x	y					
156	B4	1	0	2 $\Rightarrow 2\times2+1=5$	0	1	1	12
158	B4	1	0	7 $\Rightarrow 7\times2+1=15$	0	1	1	12
159	B4	1	0	9 $\Rightarrow 9\times2+1=19$	0	1	1	12

- 156 第 5 個 slot 可以傳 PRACH preamble ➔ slot format 第 5 個 slot 必須為 U
- 158 第 15 個 slot 可以傳 PRACH preamble ➔ slot format 第 15 個 slot 必須為 U
- 159 第 19 個 slot 可以傳 PRACH preamble ➔ slot format 第 19 個 slot 必須為 U

- Slot Format DDDSU ➔ 5(D)15(D)19(U) ➔ PRACH Config Index 可以用 159
- Slot Format DDDSUUDDDD ➔ 5(U)15(U)19(D) ➔ PRACH Config Index 可以用 156/158
- Slot Format DDDSUUDSUU ➔ 5(U)15(U)19(U) ➔ PRACH Config Index 可以用 156/158/159

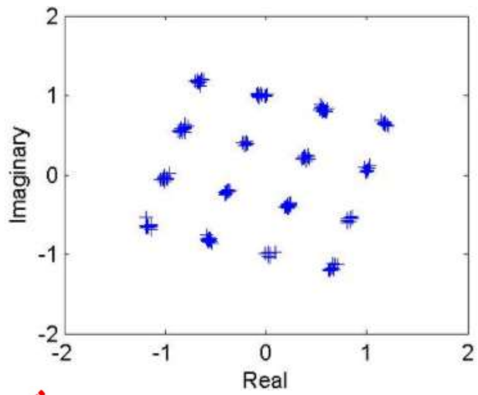
Physical Resources

Physical Resources

- Downlink
  - Physical channels
    - PDCCH
    - PDSCH
    - PBCH
  - Physical signals
    - Reference signals
      - DMRS
        - PDCCH
        - PDSCH
        - PBCH
      - PTRS
        - PDSCH
      - CSI-RS
    - Synchronization signals
      - PSS
      - SSS

- Uplink
  - Physical channels
    - PUCCH
    - PUSCH
    - PRACH
  - Physical signals
    - Reference signals
      - DMRS
        - PUCCH
        - PUSCH
      - PTRS
        - PUSCH
      - SRS

Reference Signals



Phase rotation caused by phase noise

- 參考信號是一種已知內容的信號，用來協助 UE 跟 gNB 之間的傳輸與溝通，更有效地傳送並收到更正確的數據資料的
  - 已知信號 ➔ 其頻域的位置是已知的、時域的位置是已知的、發送的內容是已知的、 發送使用的功率是已知的
- DMRS (Demodulation Reference Signals)
  - It is used by a receiver for radio channel estimation for demodulation of associated physical channel
  - 幫忙解調
- PTRS (Phase Tracking Reference Signals)
  - The PTRS plays a crucial role especially at mmWave frequencies to minimize the effect of the oscillator phase noise on system performance
  - 降低 phase noise 影響
- CSI-RS (Channel State Information Reference Signals)
  - The CSI-RS the UE receives is used to estimate the channel and report channel quality information back to the gNB
  - 用在DL，UE 利用 gNB 發來的 CSI-RS，整理分析之後再反饋給 gNB
- SRS (Sounding Reference Signal)
  - The SRS is transmitted by the UE to help the **gNB** obtain the channel state information (CSI) for each user
  - 用在UL，gNB 可以根據 CSI 內容更好的安排頻寬及波束跟 UE 溝通

Synchronization Signals

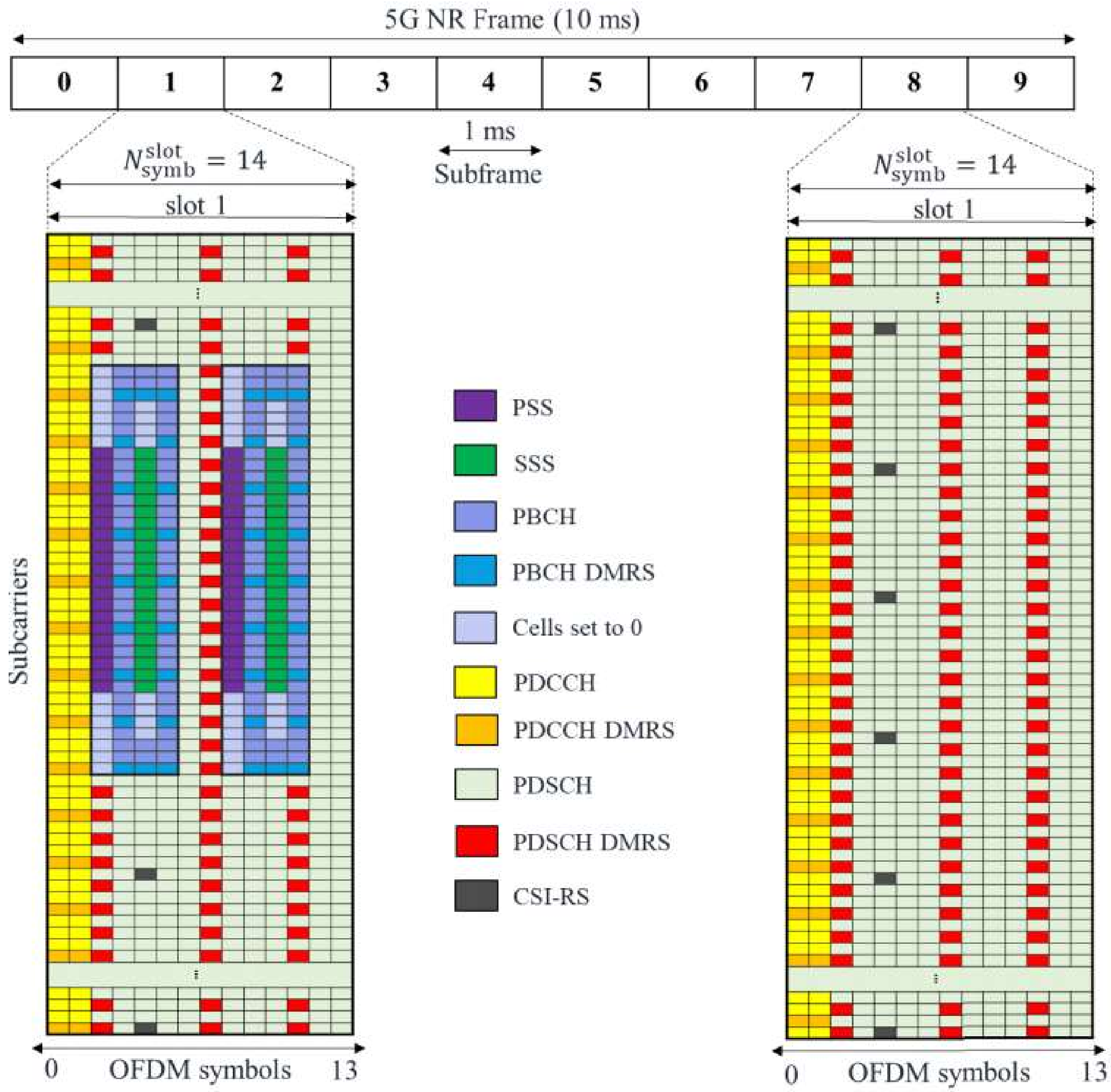
- PSS (Primary Synchronization Signal)
  - One of 3 possible sequences
  - Provides timing estimate for symbol
  - Modulation by BPSK
- SSS (Secondary Synchronization Signal)
  - One of 336 possible sequences
  - Provides cell ID (one of 3*336 = 1008)
  - Modulation by BPSK
- PSS 跟 SSS 的組合會有 3*336 = 1008 種，分別對應至 1008 個 PCI (Physical-layer cell ID)

Physical Channels

- In order to be able to carry the data across the 5G radio access network, the data and information is organised into a number of data channels.
- The 5G physical channels are used to transport information over the actual radio interface.
- 因為傳輸的資料的類型很多，所以提出幾個不同的信道，分別承載不同用途的資料，便於描述、分類、管理這些資料
- 在 OSI 架構下，延伸這些 physical channels 的概念
    - Logical channel
    - Transport channel
    - Physical channel

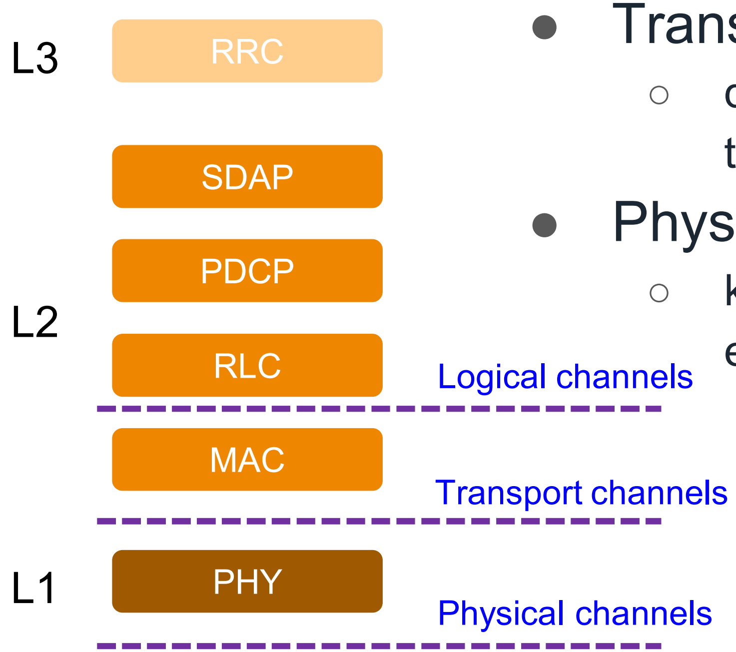
Channels and Signals

- SS/PBCH, PDCCH, and PDSCH physical channels and reference signals allocation within a frame for downlink.

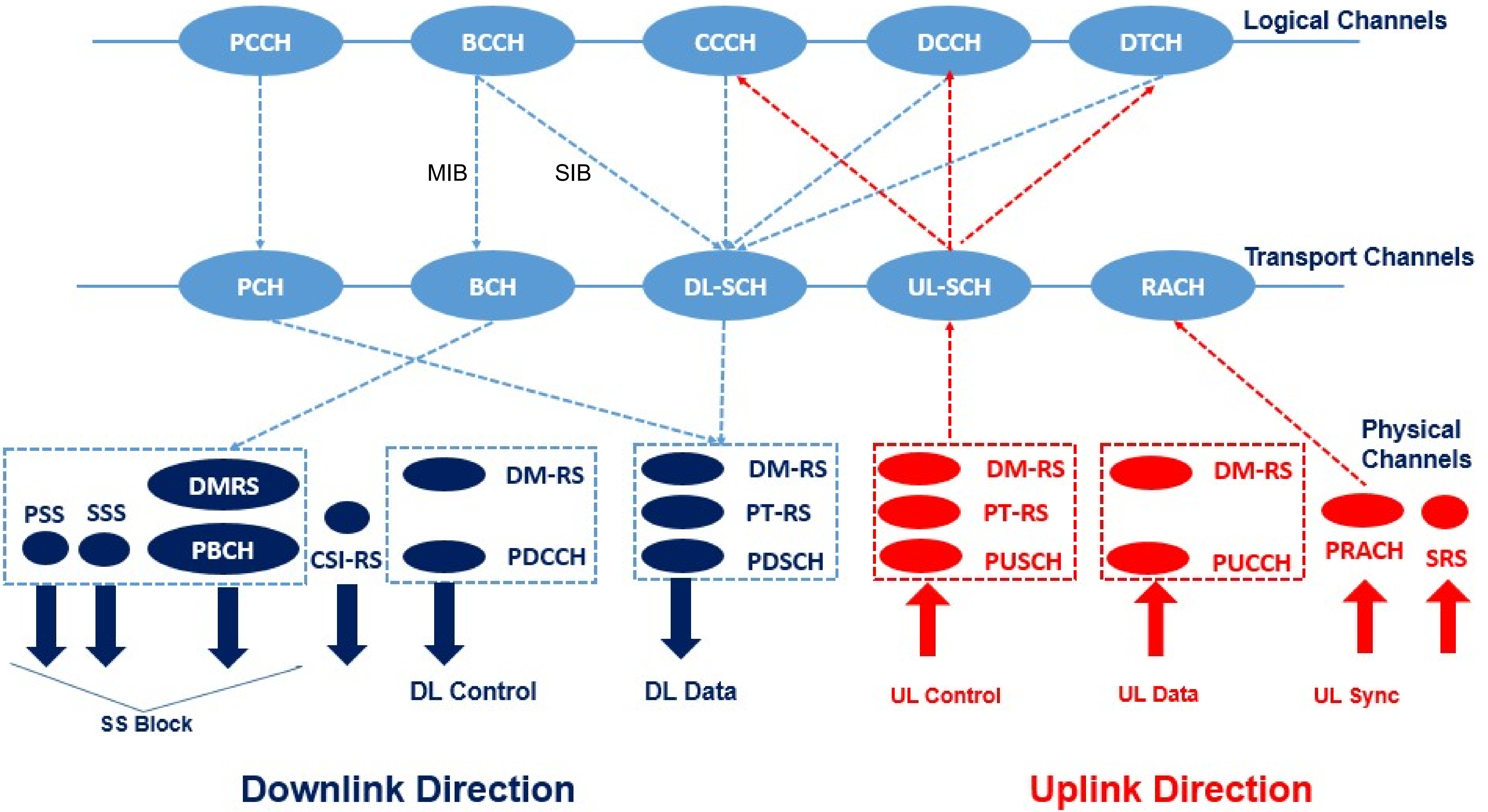


Network and Channels

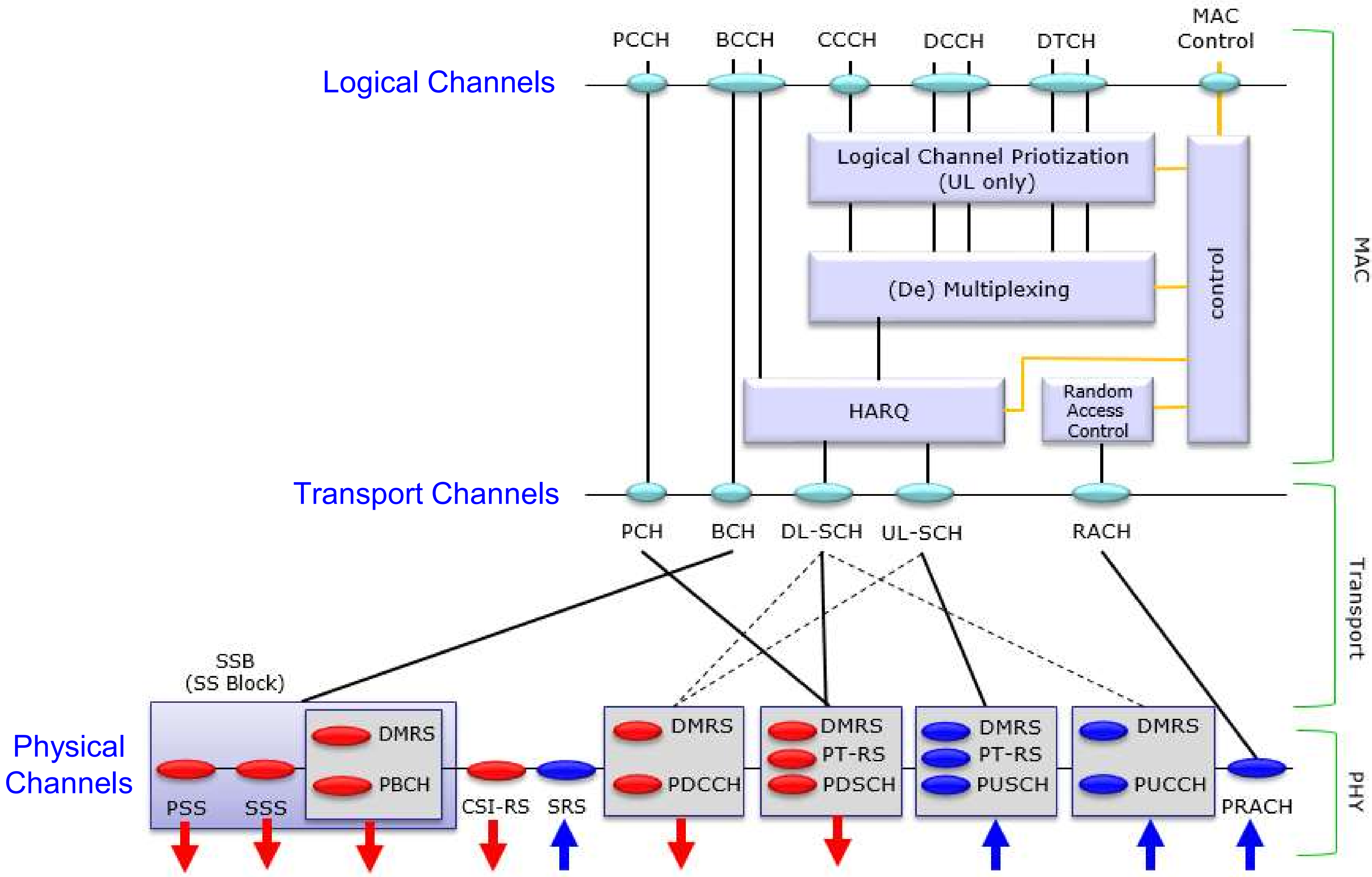
- L3 ➔ Network Layer
  - RRC
- L2 ➔ Data Link Layer
  - SDAP
  - PDCP
  - RLC
  - MAC
- L1 ➔ Physical Layer
  - PHY



- Logical channels
  - tell WHAT is the type and purpose of the data
- Transport channels
  - decide HOW the data is going to be transmitted
- Physical channels
  - know WHERE exactly the resource elements are located



Logical Channels
PCCH
BCCH
CCCH
DCCH
DTCH
MIB
SIB
Transport Channels
PCH
BCH
DL-SCH
UL-SCH
RACH
Physical Channels
PSS
SSS
DMRS
PBCH
CSI-RS
DM-RS
PDCCH
DM-RS
PT-RS
PDSCH
DM-RS
PT-RS
PUSCH
DM-RS
PUCCH
PRACH
SRS
SS Block
DL Control
DL Data
UL Control
UL Data
UL Sync
Downlink Direction
Uplink Direction



Logical Channels
PCCH
BCCH
CCCH
DCCH
DTCH
MAC Control
Logical Channel Priotization (UL only)
(De) Multiplexing
control
HARQ
Random Access Control
MAC
Transport Channels
PCH
BCH
DL-SCH
UL-SCH
RACH
Transport
SSB (SS Block)
Physical Channels
PSS
SSS
DMRS
PBCH
CSI-RS
SRS
DMRS
PDCCH
DMRS
PT-RS
PDSCH
DMRS
PT-RS
PUSCH
DMRS
PUCCH
PRACH
PHY

Physical Channels - Downlink

- PDCCH (Physical Downlink Control Channel)
  - 用於下行控制信息傳輸 (Downlink Control Information, DCI)
  - Modulation by QPSK
  - A PDCCH consists of one or more control-channel elements (CCEs)
    - 1 CCE = 6 PRBs
  - 使用 CCE 的多寡又可稱為 PDCCH aggregation level，當使用較大的 aggregation level 時可提升傳輸的可靠度，然而也會占用較多的無線資源
  - NR PDCCH 設計支援了 1, 2, 4, 8, 16 的 PDCCH aggregation level
- PDSCH (Physical Downlink Shared Channel)
  - 用於下行數據傳輸, including user data, UE-specific higher layer control messages mapped down from higher channels, system information blocks (SIBs), and paging

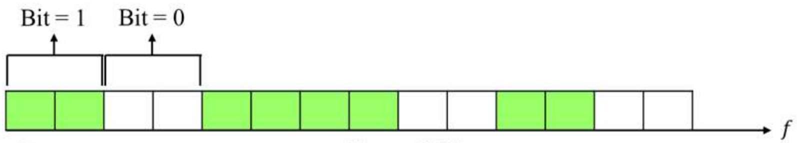
DCI (Downlink Control Information)

- 為了接收/傳送 PDSCH/PUSCH，UE 要先接收 PDCCH，其中包含的 DCI 會指示 UE 接收/傳送 PDSCH/PUSCH 所需要的所有信息
    - 資料位於 Time domain/Frequency domain 哪一個位置
        - DCI 中的 Time domain resource assignment 會指示 Time domain 位置

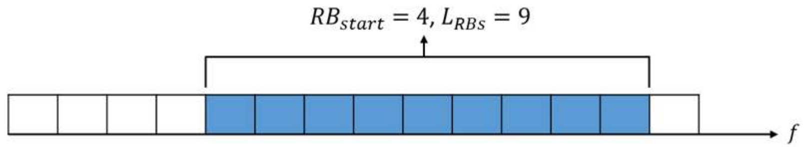
PDSCH mapping type	Normal cyclic prefix			Extended cyclic prefix		
	S	***L***	***S+L***	***S***	***L***	***S+L***
Type A	{0,1,2,3}	{3,…,14}	{3,…,14}	{0,1,2,3}	{3,…,12}	{3,…,12}
Type B	{0,…,12}	{2,4,7}	{2,…,14}	{0,…,10}	{2,4,6}	{2,…,12}

S: Starting Symbol Index
L: Number of Consecutive Symbols

        - DCI 中的 Frequency domain resource assignment 會指示 Frequency domain 位置



Bitmap = 1011010 Type 0 的 RB 分配



Type 1 的 RB 分配

    - DCI Format 0_0, Format 0_1 for Scheduling of PUSCH in one cell
    - DCI Format 1_0, Format 1_1 for Scheduling of PDSCH in one cell

Physical Channels - Downlink

- PBCH (Physical Broadcast Channel)
  - PBCH payload is of 56 bits including 24 bit CRC.
  - 用於 UE 接收 5G 所需的系統信息廣播, including MIB (24 bits) + 4 bits MSB SFN + 3 bits MSB SSB index + 1 bit half frame index
  - PBCH-DMRS
    - 協助 demodulation
    - 攜帶 SSB index (beam index)
      - NR 會向不同方向發射承載相同內容的 SSB $(\text{index} = 0 \sim L_{max} - 1)$
  - Modulation by QPSK

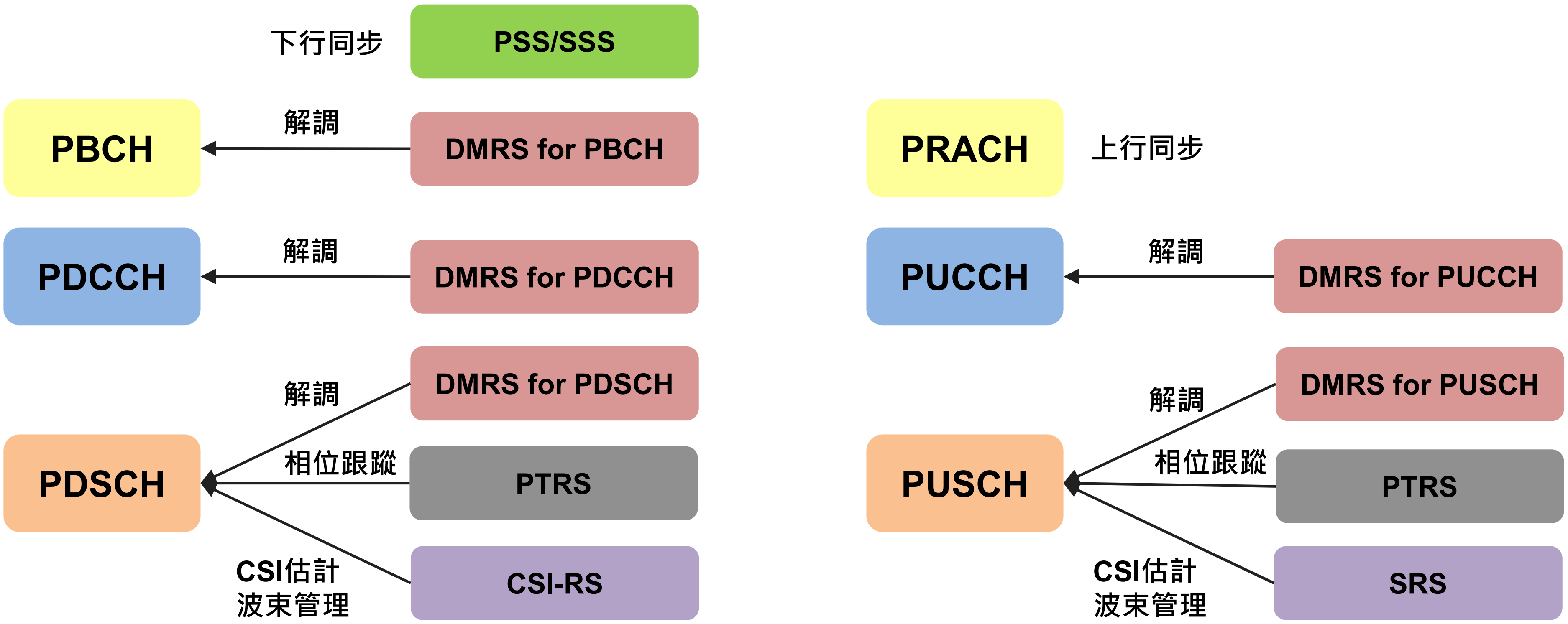
```
MIB ::= SEQUENCE {
      systemFrameNumber          BIT STRING (SIZE (6)),                6bit
      subCarrierSpacingCommon    ENUMERATED {scs15or60, scs30or120},  1bit
      ssb-SubcarrierOffset       INTEGER (0..15),                      4it
      dmrs-TypeA-Position        ENUMERATED {pos2, pos3},              1bit
      pdcch-ConfigSIB1           PDCCH-ConfigSIB1,                     8bit
      cellBarred                 ENUMERATED {barred, notBarred},       1bit
      intraFreqReselection       ENUMERATED {allowed, notAllowed},     1bit
      spare                      BIT STRING (SIZE (1))                 1bit
}
```

Physical Channels - Uplink

- PRACH (Physical Random Access Channel)
  - UE 用來請求建立連接
- PUCCH (Physical Uplink Control Channel)
  - 用於上行控制信息傳輸 (Uplink Control Information, UCI)
  - 分為 format 0, 1, 2, 3, 4
  - HARQ (Hybrid Automatic Repeat request)
    - UE 發送 HARQ-ACK/NACK 來回應，指示數據是否被成功解碼。在解碼不成功的情況下，gNB 進行重傳調度
- PUSCH (Physical Uplink Shared Channel)
  - 用於上行數據傳輸

Relationship between Channels and Signals

- Downlink
- Uplink



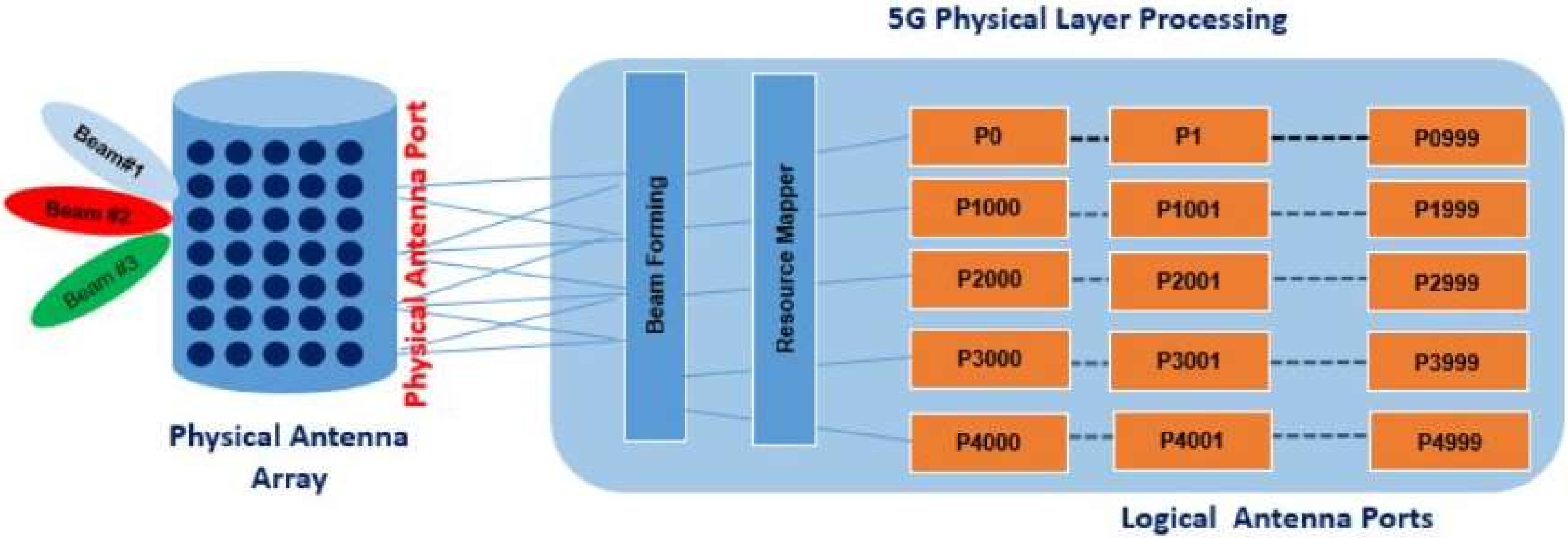
Antenna Ports and Physical Channels

- An antenna port is defined such that the channel over which a symbol on the antenna port is conveyed can be inferred from the channel over which another symbol on the same antenna port is conveyed.

	Channel/Signal	Antenna Ports
Downlink	PDSCH	Antenna ports starting with 1000
	PDCCH	Antenna ports starting with 2000
	CSI-RS	Antenna ports starting with 3000
	SS/PBCH	Antenna ports starting with 4000
Uplink	PUSCH/DMRS	Antenna ports starting with 0
	SRS	Antenna ports starting with 1000
	PUCCH	Antenna ports starting with 2000
	PRACH	Antenna port 4000

Logical Antenna Ports

- Mapping of Antenna Port to Physical Antenna Port



手機信號強度

- rsrp (Reference Signal Receiving Power) 參考信號接收功率
  - 手機對基站發出的所有 Downlink 參考信號功率值的線性平均，用來反映信號強度
  - 實際 rsrp 數值對應的信號強度會因為營運商跟手機型號而有些許差異
- $\mathrm{dB} = 10 \times log_{10} \frac{P_2}{P_1}$
  - 功率 P_2 相對於 P_1 的大小關係
    - 3 dB ➔功率 P_2 是 P_1 的 2 倍
    - -3 dB ➔功率 P_2 是 P_1 的 ½
- $\mathrm{dBW} = 10 \times log_{10} \frac{P_2}{1W}$

$$\mathrm{dBm} = 10 \times log_{10} \frac{P_2}{1mW}$$

  - 功率的絕對單位
  - 46 dBm ➔ P_2 = 40 W
  - 雙天線總功率 46 dBm，問單天線功率? ➔ 20 W or 43 dBm

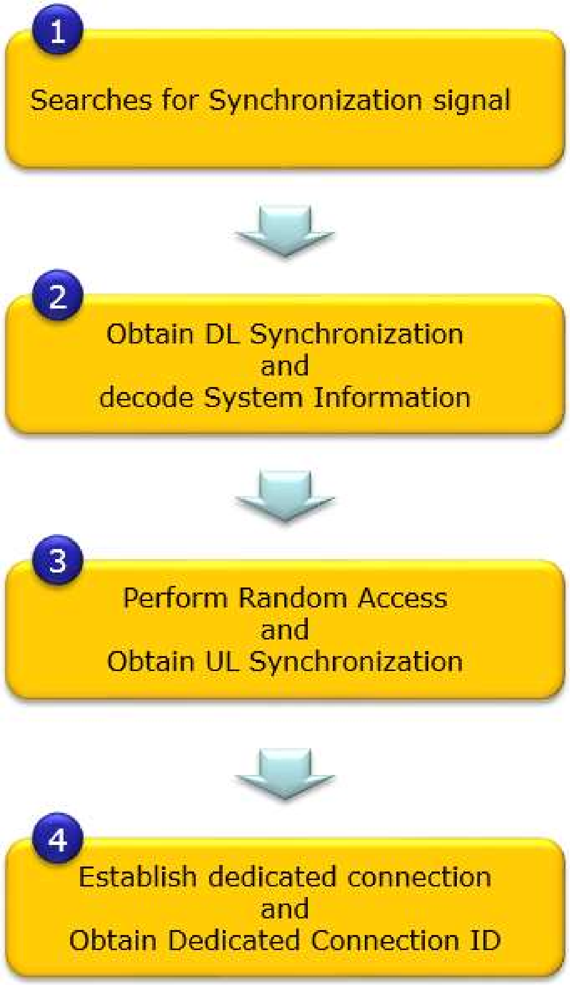
rsrp 數值 (dBm)	訊號強度
-90 以下	訊號非常良好
-91 ~ -105	訊號好
-106 ~ -120	訊號普通
-121 ~ -124	訊號極差
-125 以上	目前無訊號

Synchronization

Synchronization Process

- Downlink
  - This is the process in which UE detect the exact timing when a radio frame starts
  - Cell Search via SS Block
- Uplink
  - This is the process in which UE figure out the exact timing when it should send uplink data
  - Random Access via Preamble

Synchronization Procedure



UE 從 Cell 接收 SSB

UE 藉由 PSS 獲得 timing info，搭配 SSS 跟 PBCH 獲得 Cell 的相關訊息 ➔ DL synchronization

UE 挑選 Preamble，傳送給 Cell
➔ UL synchronization

經由幾個來回，UE 向 5GC 註冊成功，並獲得唯一 ID

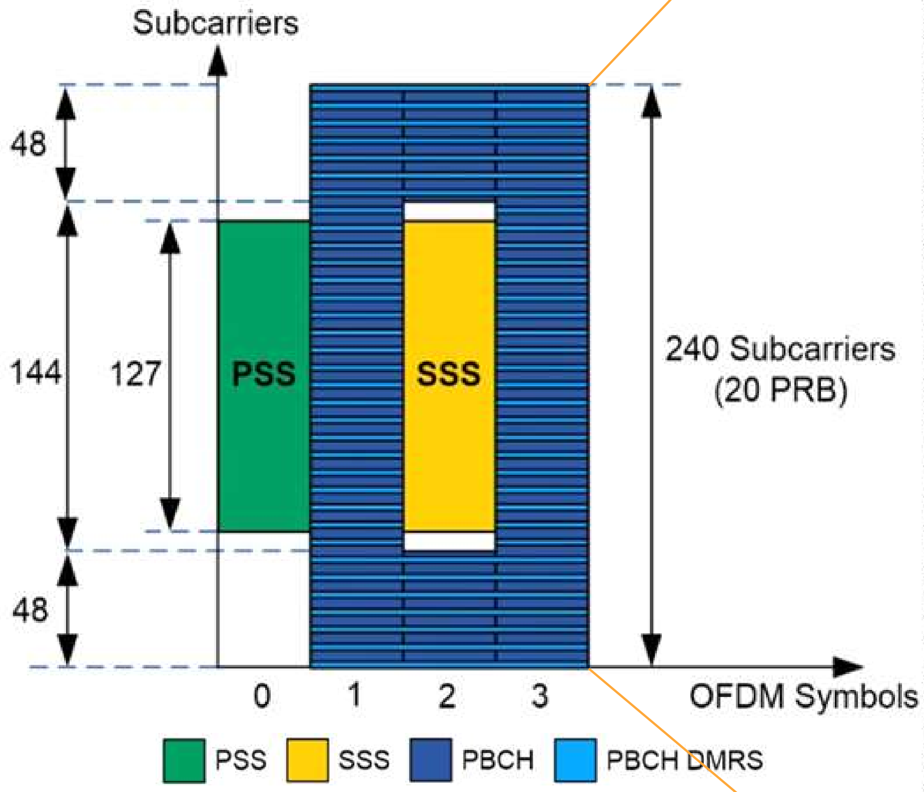
Downlink
Cell Search

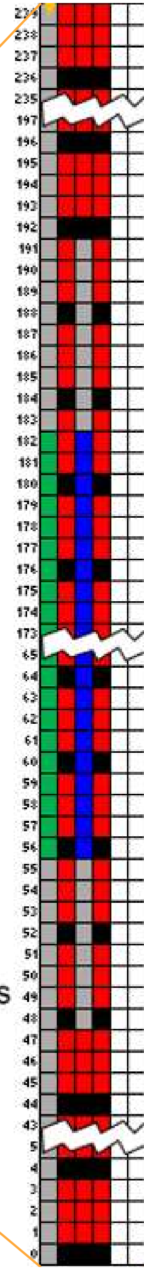
How does a phone get onto the network?

- Cell search is the procedure by which a UE acquires time and frequency synchronization with a cell and detects the Cell ID from SSB
- UE 不僅需要在開機時進行 cell search，為了支持移動性（mobility），UE 會不停地搜索 nearby cell、取得同步並估計該小區信號的接收質量，從而決定是否進行切換（handover，當UE處於RRC_CONNECTED態）或小區重選（cell re-selection，當UE處於RRC_IDLE態）

An SSB (Synchronization Signal Block)

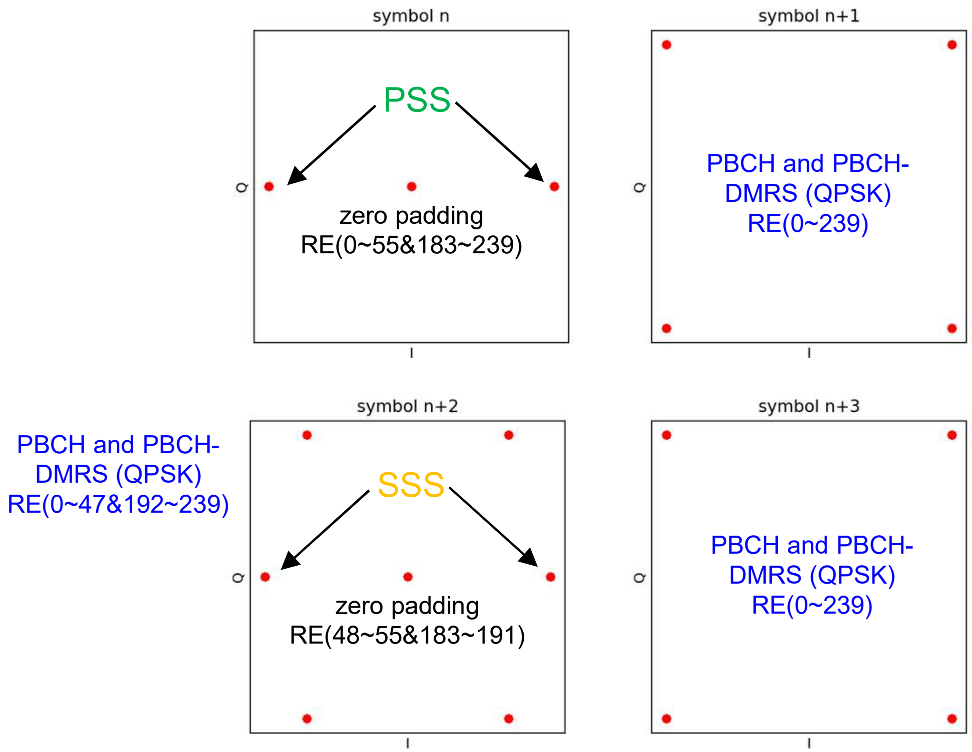
- SSB 通常指的是 SS/PBCH block，因為 SS 跟 PBCH 會打包在一起
    - PSS
    - SSS
    - PBCH
    - PBCH DMRS
- In the time domain, a SS/PBCH block consists of 4 OFDM symbols
- In the frequency domain, an SS/PBCH block consists of 240 contiguous subcarriers

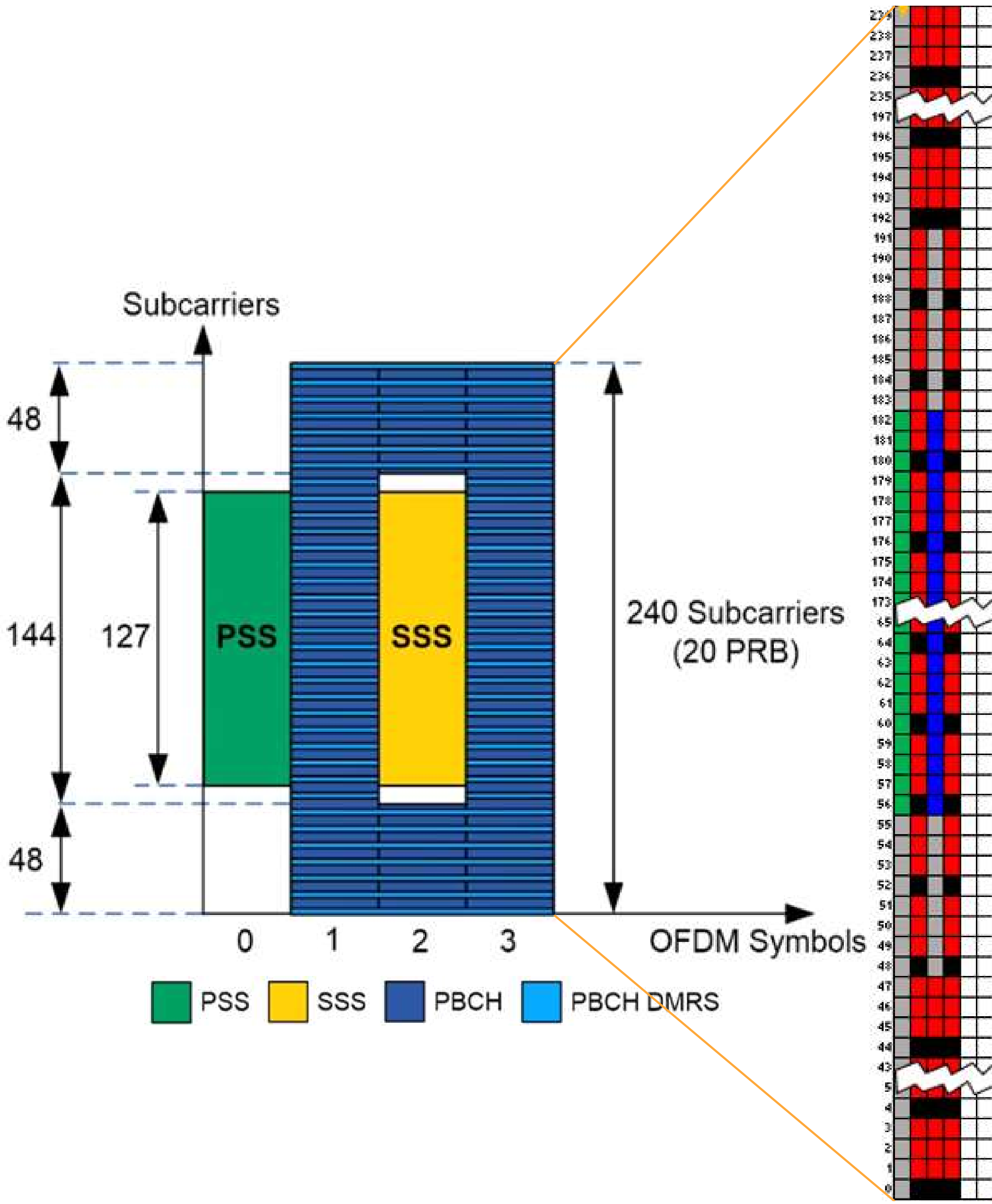




SS Block

- SSB 佔連續 4 個 symbols 和 20 RBs
- PSS 和 SSS 是一串由 1,-1 組成的已知序列
- RE 240~3275 是 PDSCH





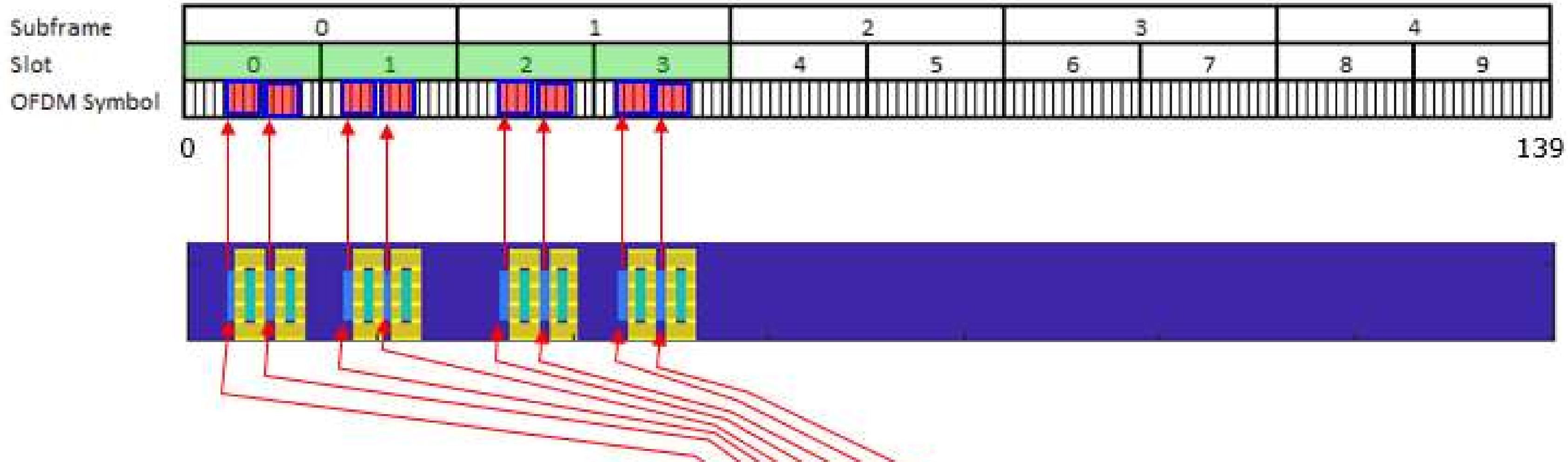
SS Burst 同步訊號叢集

- SSB 在一個 radio frame 中的分佈 (最大支援數量，實際上需用幾個SSB將會依設備波束的設計而定)

	SCS	OFDM Symbol index	f <= 3 GHz size=4	3 GHz < f <= 6GHz size=8	6 GHz < f size=64
Case A	15 KHz	{2,8}+14n	n=0,1 2,8,16,22	n=0,1,2,3 2,8,16,22,30,36,44,50	
Case B	30 kHz	{4,8,16,20}+28n	n=0 4,8,16,20	n=0,1 4,8,16,20,32,36,44,48	
Case C	30 kHz	{2,8}+14n	n=0,1 2,8,16,22	n=0,1,2,3 2,8,16,22,30,36,44,50	SS Burst
Case D	120 kHz	{4,8,16,20}+28n	SS Burst	SS Burst	n=0,1,2,3,5,6,7,8,10,11,12,13,15,16,17,18 4,8,16,20,32,36,44,48,60,64,72,76,88,92,100,104, 144,148,156,160,172,176,184,188,200,204,212,216, 228,232,240,244,284,288,296,300,312,316,324,328, 340,344,352,356,368,372,380,384,424,428,436,440, 452,456,464,468,480,484,492,496,508,512,520,524
Case E	240 kHz	{8,12,16,20,32,36,40,44}+56n			n=0,1,2,3,5,6,7,8 8,12,16,20,32,36,40,44,64,68,72,76,88,92,96,100, 120,124,128,132,144,148,152,156,176,180,184,188, 200,204,208,212,288,292,296,300,312,316,320,324, 344,348,352,356,368,372,376,380,400,404,408,412, 424,428,432,436,456,460,464,468,480,484,488,492

SS Burst

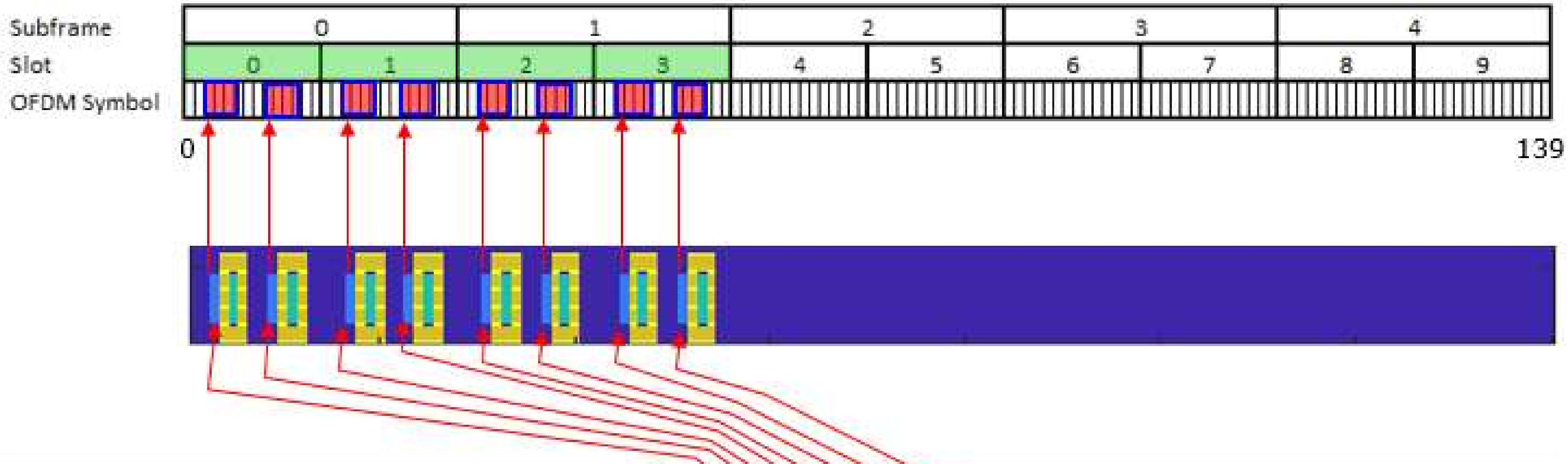
- Case B(30 kHz) and 3 GHz < f <= 6 GHz



Subcarrier Spacing	OFDM Symbol (s)	f <= 3 Ghz	3 Ghz < f <= 6 Ghz	6 Ghz < f
Case B : 30 Khz	{4,8,16,20}+28n	n = 0	n = 0,1	
		s = 4,8,16,20	s = 4,8,16,20,32,36,44,48	

SS Burst

- Case C(30 kHz) and 3 GHz < f <= 6 GHz



Subcarrier Spacing	OFDM Symbol (s)	f <= 3 Ghz	3 Ghz < f <= 6 Ghz	6 Ghz < f
Case C : 30 Khz	{2,8} + 14 n	n = 0,1	n = 0,1,2,3	
		s = 2,8,16,22	s = 2,8,16,22,30,36,44,50	

SS Block Pattern for N78/N79

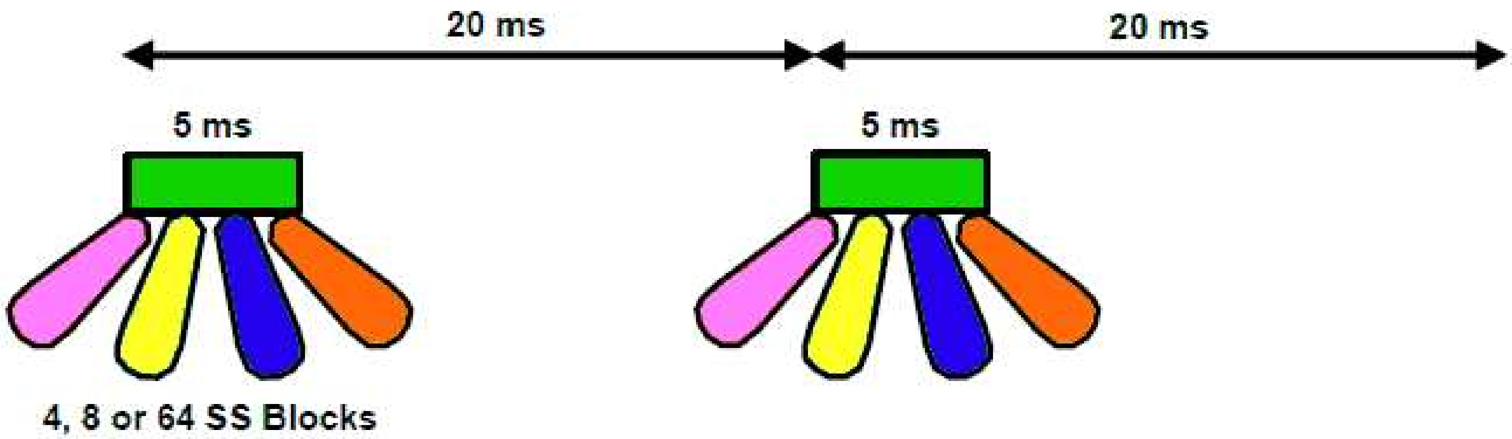
- TS 38.104

Table 5.4.3.3-1: Applicable SS raster entries per *operating band* (FR1)

NR *operating band*	SS Block SCS	SS Block pattern (note)	Range of GSCN (First – <Step size> – Last)
n78	30 kHz	Case C	7711 – <1> – 8051
n79	30 kHz	Case C	8480 – <16> – 8880

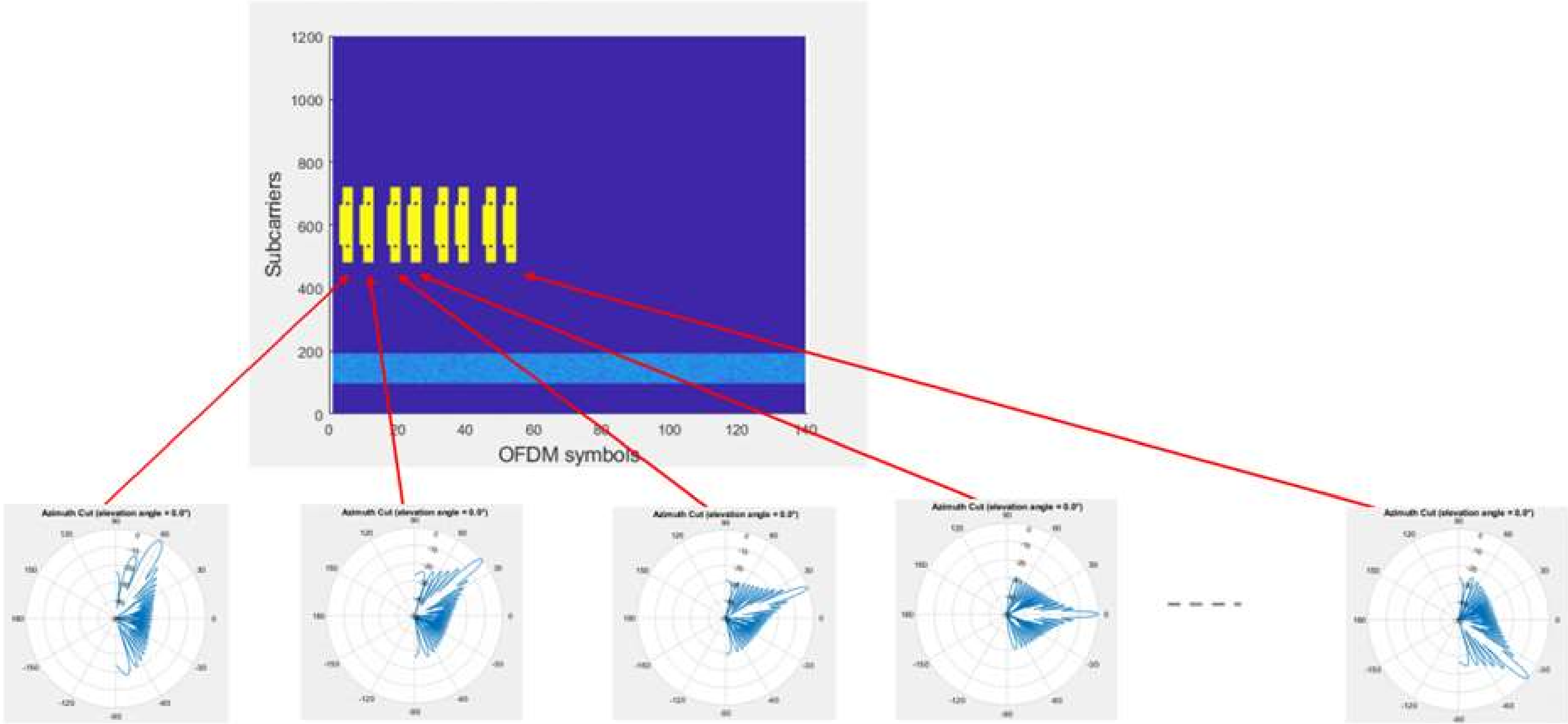
SSB in Time Domain

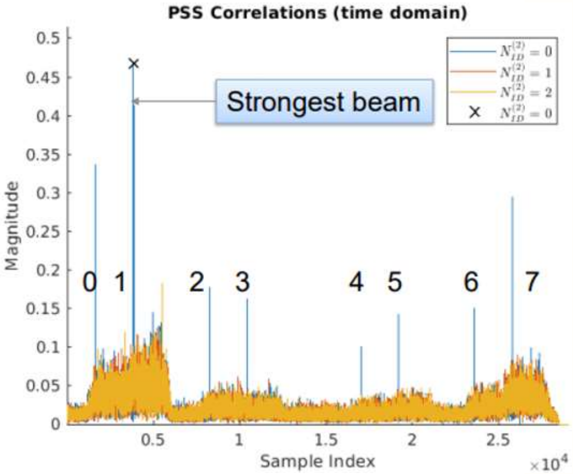
- SSB periodicity can be 5ms ~ 160ms
  - 20ms by default
  - 採用越小的周期配置有機會讓 UE 更快的搜尋到 Cell，但相對地也會多耗掉無線資源

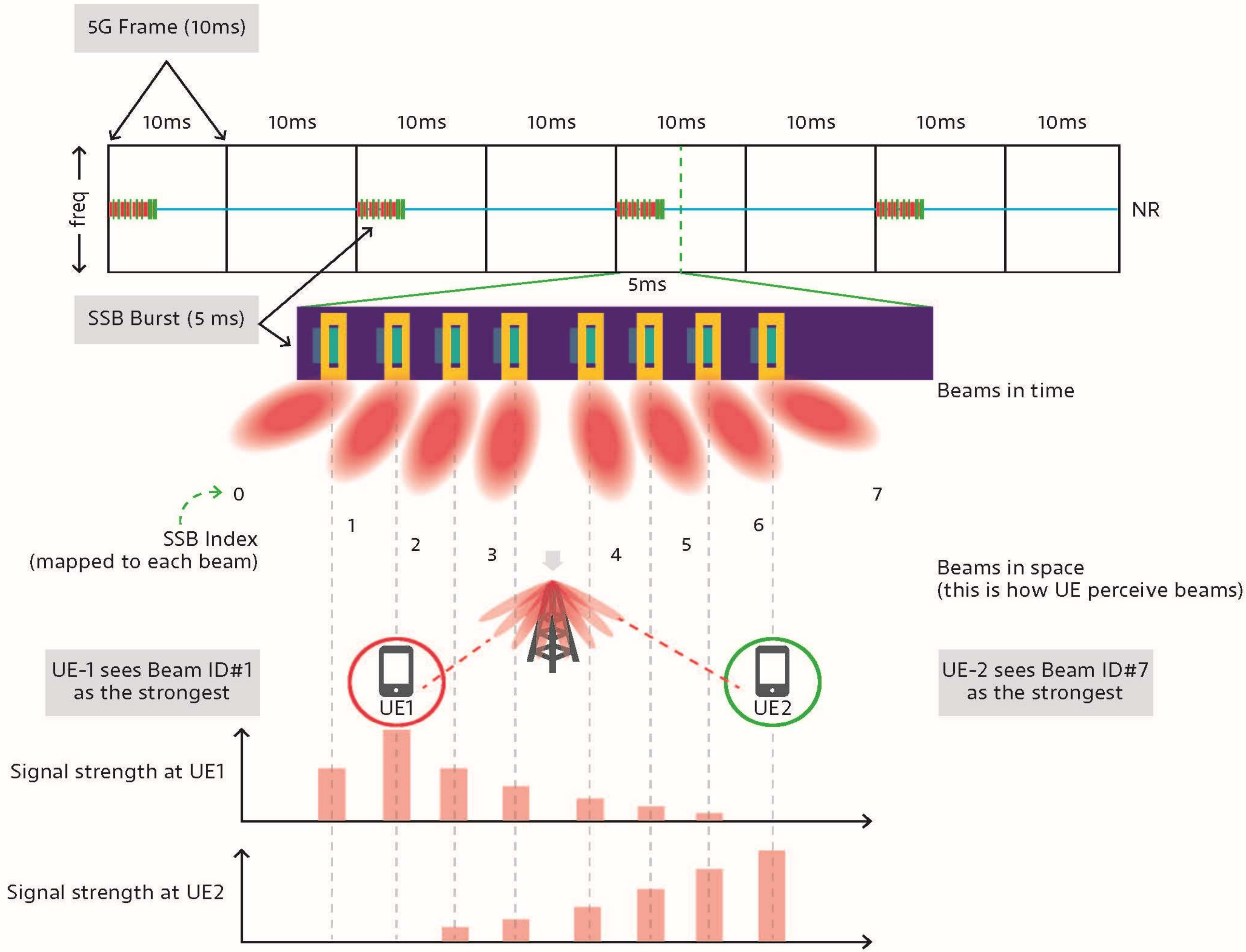


SSB and PRACH preamble

- Each SS Block is beamformed with a different pattern




PSS Correlations (time domain)
Strongest beam
$N_{ID}^{(2)} = 0$
$N_{ID}^{(2)} = 1$
$N_{ID}^{(2)} = 2$
$N_{ID}^{(2)} = 0$
0 1 2 3 4 5 6 7
Magnitude
Sample Index
$\times 10^4$


5G Frame (10ms)
10ms
10ms
10ms
10ms
10ms
10ms
10ms
10ms
freq
NR
5ms
SSB Burst (5 ms)
Beams in time
SSB Index
(mapped to each beam)
0
1
2
3
4
5
6
7
Beams in space
(this is how UE perceive beams)
UE-1 sees Beam ID#1
as the strongest
UE1
UE2
UE-2 sees Beam ID#7
as the strongest
Signal strength at UE1
Signal strength at UE2

SSB and preamble

- SSB related to downlink
- PRACH Preamble related to uplink
- 在 NR 中的隨機接入過程使用了波束
    - Cell 波束廣播
        - SSB 在時域週期內有多次發送機會，並且有相應的編號，其可分別對應不同的波束
    - UE 收到 SSB
        - 對於 UE 而言，只有當 SSB 的波束掃描信號覆蓋到 UE 時，UE 才有機會發送 preamble
        - UE 在收到 SSB 後，根據 MIB/SIB 的內容，才知道要發送的 preamble sequence 如何生成、要在什麼 time/frequency 承載 preamble 資料、要用多少功率發出 preamble…
    - Cell 收到 preamble
        - 當 gNB 收到 UE 的 preamble 時，就知道下行最佳波束，換句話說，就是知道哪個波束指向了 UE，接下來的 DL data 都會透過該方向的波束進行傳輸
        - preamble 是一串固定內容的序列，不會包含 beam index 資訊 ➔ 透過在特定 time occasion + frequency occasion + preamble 就可以對應出 SSB index

SSB and preamble

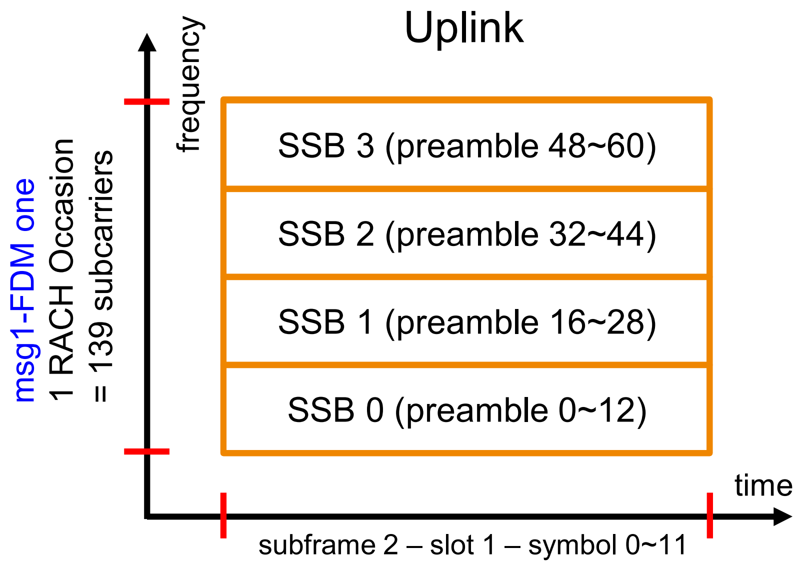
- ssb-perRACH-OccasionAndCB-PreamblePerSSB
  - ssb-perRACH-Occasion
    - 1 個 RO 對應 4 個 SSB
  - CB-PreamblePerSSB
    - 1 個 SSB 對應 13 個 contention-based 的 preamble
  - ssb-perRACH-Occasion*CB-PreamblePerSSB <= 64

➔ UE 送出 preamble 20 的序列 ➔ cell 就知道 SSB index=1

```
rach-ConfigCommon setup :
 {
   rach-ConfigGeneric
    {
      prach-ConfigurationIndex 2,
      msg1-FDM one,
      msg1-FrequencyStart 2,
      zeroCorrelationZoneConfig 6,
      preambleReceivedTargetPower -100,
      preambleTransMax n10,
      powerRampingStep dB4,
      ra-ResponseWindow sl20
    },
   ssb-perRACH-OccasionAndCB-PreamblesPerSSB four : 13,
   ra-ContentionResolutionTimer sf64,
   rsrp-ThresholdSSB 0,
   prach-RootSequenceIndex l839 : 439,
   restrictedSetConfig unrestrictedSet
 },
```

```
oneEighth   ENUMERATED {n4,n8,n12,n16,n20,n24,n28,n32,n36,n40,n44,n48,n52,n56,n60,n64},
oneFourth   ENUMERATED {n4,n8,n12,n16,n20,n24,n28,n32,n36,n40,n44,n48,n52,n56,n60,n64},
oneHalf     ENUMERATED {n4,n8,n12,n16,n20,n24,n28,n32,n36,n40,n44,n48,n52,n56,n60,n64},
one         ENUMERATED {n4,n8,n12,n16,n20,n24,n28,n32,n36,n40,n44,n48,n52,n56,n60,n64},
two         ENUMERATED {n4,n8,n12,n16,n20,n24,n28,n32},
four        INTEGER (1..16),
eight          INTEGER (1..8),
sixteen        INTEGER (1..4)
```

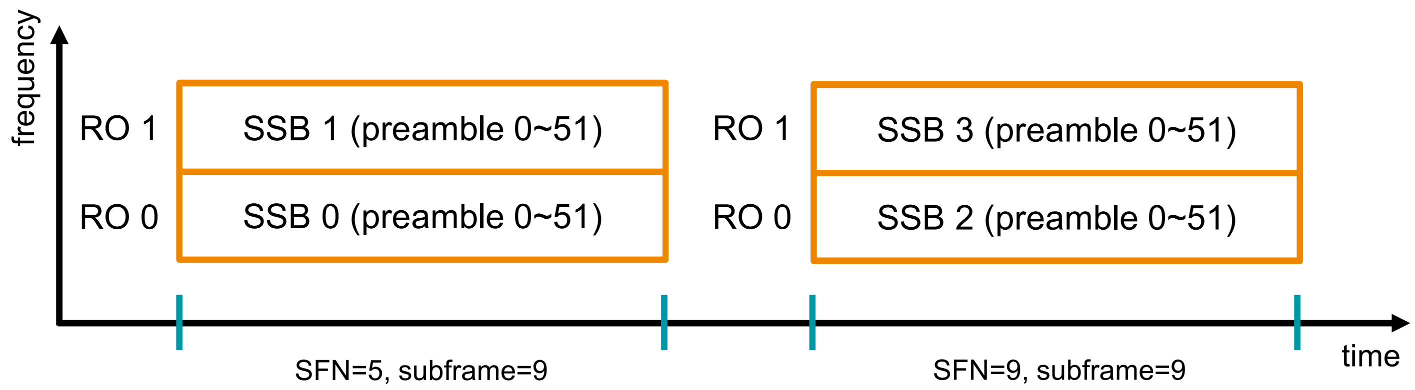
four/13 ➔ 4*13=52 個 CB-preambles
➔ 64-52=12 個 CF-preambles



- 如果 cell 發出的 SSB 只有 4 個，照如此配置，在 time domain 中只需要 1 個 PRACH occasion
- 如果 cell 發出的 SSB 有 8 個
  - FDM=1, ssb-perRACH-Occasion=4, PO=2
  - FDM=2, ssb-perRACH-Occasion=4, PO=1
  - FDM=1, ssb-perRACH-Occasion=8, PO=1
  - …

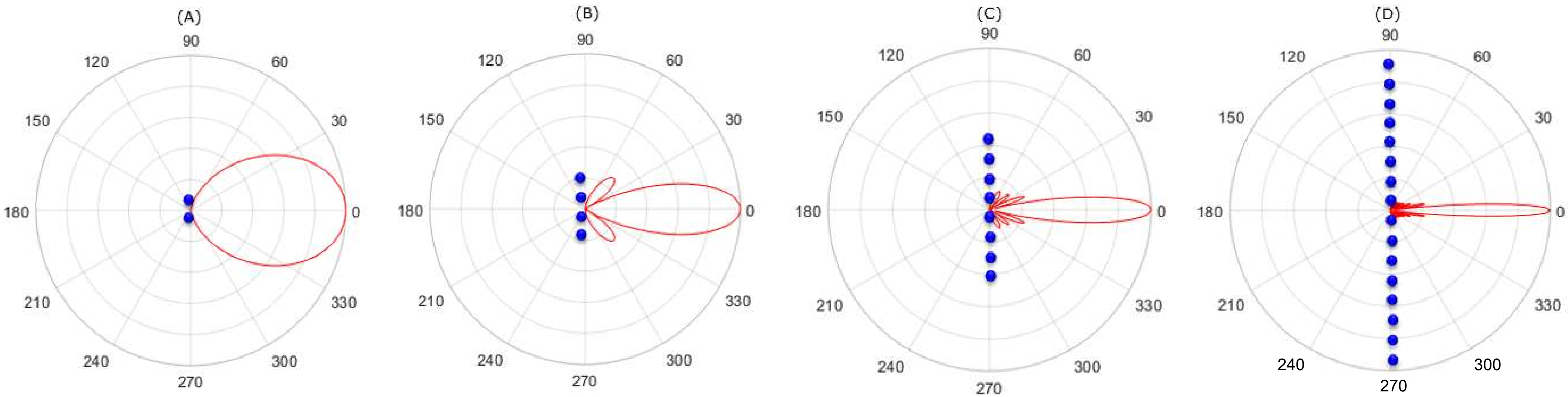
SSB and preamble

- ssb-perRACH-OccasionAndCB-PreamblePerSSB one : 52
- Msg1-FDM two
  ➔ UE 送出 preamble 20 的序列無法判斷出 SSB index
  ➔ 要再加上 time/frequency 上 RACH occasion 的資訊



BeamForming

- 一個天線的時候，電磁波的輻射方向是360度傳播的，但是一個天線陣列可以實現電磁波單方向傳播。天線個數越多，電磁波傳播方向越集中。



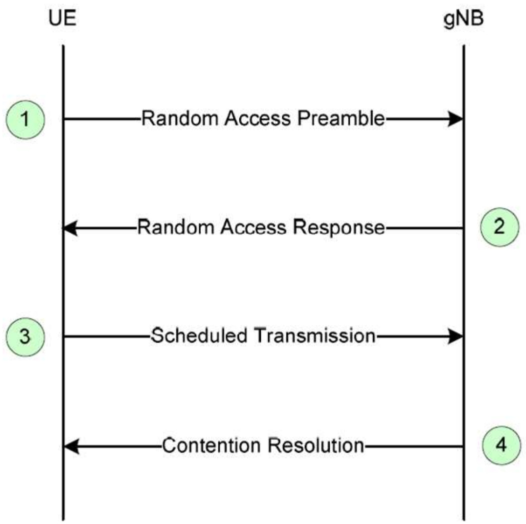
DL Sychronization

- UE 收到 SSB
    - 從 PBCH 中的 MIB 可以得知 SFN
    - 從 PSS 中可以定位出 time/frequency information
    - 透過 PBCH-DMRS 得知 beam index
    - 根據 spec，可以知道該 SSB 的 symbol index
- 有了這些信息，UE 便可以輕鬆定位某個 SFN 或者這個 SFN 內某個 slot 的邊界在哪裡，也就完成了 frame 同步
- Since UE already have all the details of the predefined sync signal, it can search and detect the data from the stream of data reaching the UE.
- Because the sync signal is located in the predefined location in time, UE can detect the exact timing from the decoded sync signal.

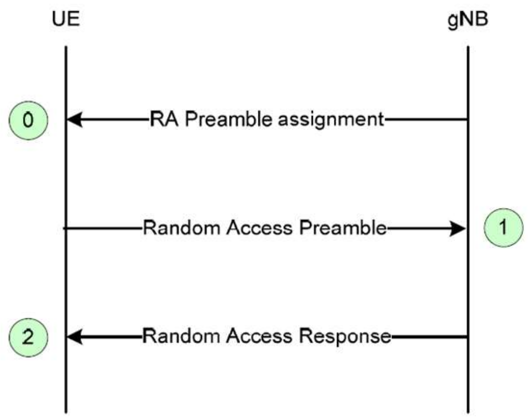
Uplink
Random Access

PRACH Preamble

- Contention Based - 基於競爭的隨機接入
  - 當一個 UE 準備進行 RA 時，會先在 64 個 preamble 中選出一個，如果有多 UE 在同一個 cell 裡面，就有可能選中相同的 preamble
- Contention Free - 非競爭的隨機接入
  - 由 gNB 指派特定的 preamble 給 UE 後，UE 再發起 RA



(a) Contention-Based



(b) Contention-Free

Random Access (RA)

- The purpose of RA
  - UL sychronizaion
  - Register UE to 5GC
- 在傳送 preamble 前的處理，也是 5G NR 與 4G LTE 在 RA 最大的不同
  - When NR operates on beam forming mode, UE needs to detect and select the best beam for RACH process.
  - Before the initiation of RA procedure, physical layer at UE receives set of PBCH/SS blocks.
  - Based on RSRP measurement of SS/PBCH blocks decides on 1 PBCH/SS index and then performs RA procedure.
  - The relationship between SS/PSCH block and PRACH resources is totally based on higher layer parameter ssb-perRACH-OccasionAndCB-PreamblesPerSSB.

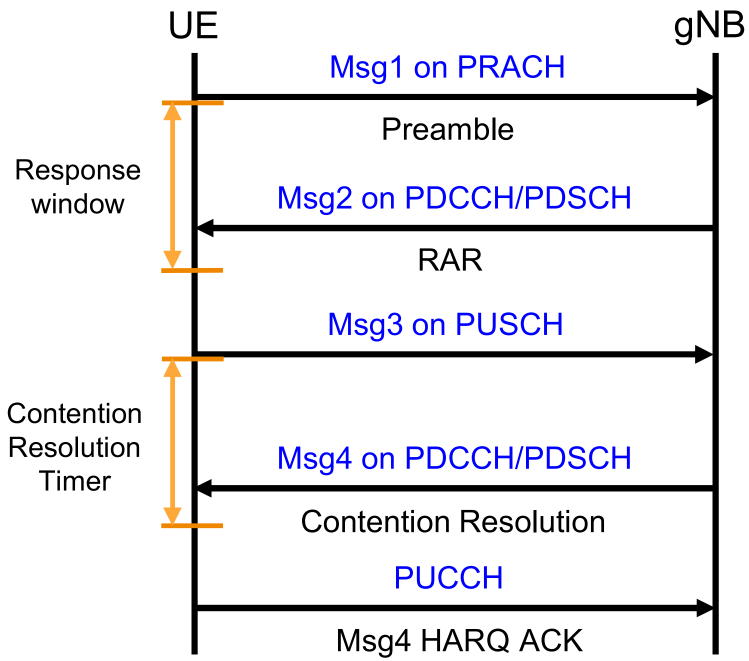
Random Access (RA)

- The random access procedure is triggered by
  - Initial access from RRC_IDLE
  - RRC Connection Re-establishment procedure
  - DL or UL data arrival during RRC_CONNECTED when UL synchronization status is "non-synchronized"
  - UL data arrival during RRC_CONNECTED when there are no PUCCH resources for SR available
  - SR failure
  - Request by RRC upon synchronous reconfiguration (e.g. handover)
  - Transition from RRC_INACTIVE
  - To establish time alignment for a secondary TAG
  - Request for Other SI
  - Beam failure recovery
- 根據不同的情境，分別採用 CBRA or CFRA

Random Access (RA) Procedure

- UE 發送 preamble
  - 根據 trigger 原因的不同，會採用 CBRA or CFRA
- gNB 發送RAR (Random Access Response)
  - 基站接收 preamble 解調後，得以估計其與 UE 之間的傳輸時延 TA (timing alignment)，校準 UL timing
  - 如果 UE 沒有在 RA 響應窗口內接收到響應或未能驗證響應，則響應失敗
- UE 發送 Msg3
  - 會根據 TA 調整發送 Msg3 的時間
  - Msg3 和 Msg4 主要是用於解決 preamble 的碰撞機制
- gNB 發送 contention resolution
  - UE 收到 Msg4 之後，就完成了 RRC 連線，正式向基站完成了註冊

```
rach-ConfigCommon setup :
 {
   rach-ConfigGeneric
    {
      prach-ConfigurationIndex 2,
      msg1-FDM one,
      msg1-FrequencyStart 2,
      zeroCorrelationZoneConfig 6,
      preambleReceivedTargetPower -100,
      preambleTransMax n10,
      powerRampingStep dB4,
      ra-ResponseWindow sl20
    },
   ssb-perRACH-OccasionAndCB-PreamblesPerSSB four : 13,
   ra-ContentionResolutionTimer sf64,
   rsrp-ThresholdSSB 0,
   prach-RootSequenceIndex l839 : 439,
   restrictedSetConfig unrestrictedSet
 },
```



```
rach-ConfigCommon setup :
 {
   rach-ConfigGeneric
    {
      prach-ConfigurationIndex 2,
      msg1-FDM one,
      msg1-FrequencyStart 2,
      zeroCorrelationZoneConfig 6,
      preambleReceivedTargetPower -100,
      preambleTransMax n10,
      powerRampingStep dB4,
      ra-ResponseWindow sl20
    },
   ssb-perRACH-OccasionAndCB-PreamblesPerSSB four : 13,
   ra-ContentionResolutionTimer sf64,
   rsrp-ThresholdSSB 0,
   prach-RootSequenceIndex l839 : 439,
   restrictedSetConfig unrestrictedSet
 },
```

Random Access Msg2

- Msg2 包含以下資訊
  - BI (backoff Indicator)
    - 如果 Msg1 需要重發時的間隔時間
  - RAPID (Random Access Preamble ID)
    - 用來比對跟 UE➔gNB 的 preamble 是否 match
  - RAR
    - Timing Advance Command
      - gNB 與 UE 間的時間偏移量 (TA)
    - UL Grant
      - 用於Msg3，包括 PUSCH 時頻域的資源分配、MCS、Msg3 的功率控制和 CSI request
    - TC-RNTI (Temporary Cell-Radio Network Temporary Identify)
      - C-RNTI 是 UE 與 RRC 連接和調度的唯一識別碼，在確認無競爭情況且正式完成註冊前，視作為 TC-RNTI
- 若是 Msg2 接收或是資料比對失敗，會觸發 Msg1 重傳，重傳的次數由 preambleTransMax 決定，並且，重傳 Msg1 的功率會根據 powerRampinStep 增加

Foxconn DU Configuration

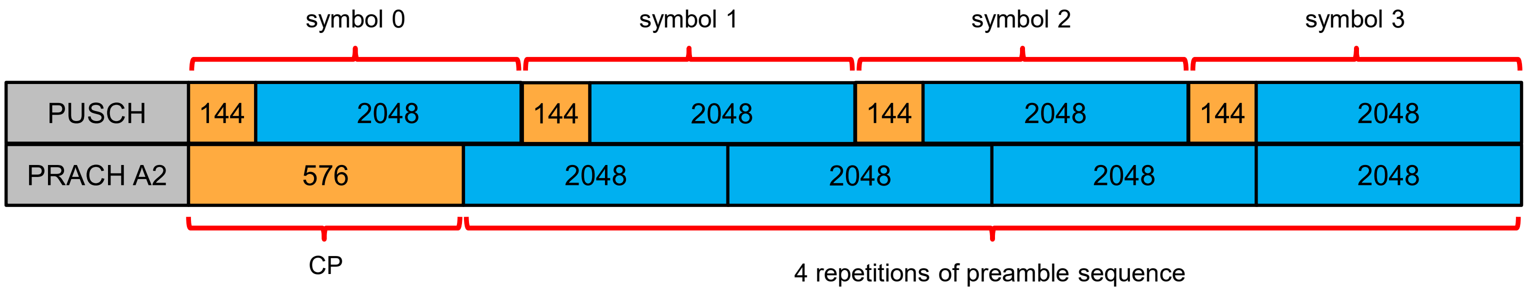
- <cyclicPrefixType>cyclicPrefix_NORMAL</cyclicPrefixType>
- <isPhaseTrackingRefSigEnb>false</isPhaseTrackingRefSigEnb>
- <numSsb>1</numSsb>
- <ssPbchBurstSetSize>1</ssPbchBurstSetSize>
- <totalNumOfRachPreamble>63</totalNumOfRachPreamble>
- <ssbsPerRach>SSB_ONE</ssbsPerRach>
- <cbPreamblePerSsb>4</cbPreamblePerSsb>
- <subCarrierSpacing>scs_KHz30</subCarrierSpacing>
- <carrierBw>273</carrierBw>
- <prachCfgIdx>159</prachCfgIdx>
- <msg1Fdm>1</msg1Fdm>
- <msg1FreqStart>0</msg1FreqStart>
- <zeroCorrelationZoneCfg>6</zeroCorrelationZoneCfg>
- <rootSeqType>rootSeqId_L139Int</rootSeqType>
- <rootSeqVal>0</rootSeqVal>
- <msg1Scs>msg1Scs_KHz30</msg1Scs>
- <csiEnable>false</csiEnable>

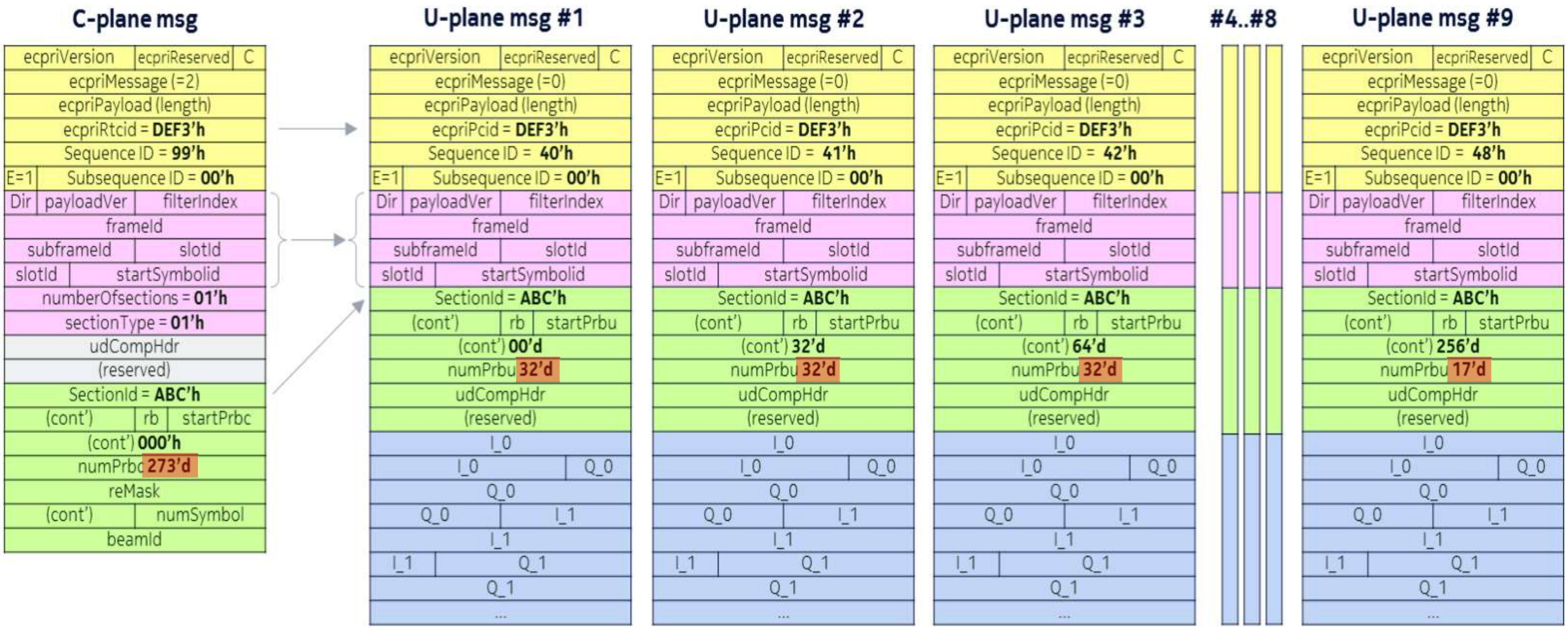
C-Plane Protocol

Introduction

- Either eCPRI or IEEE 1914.3 is used as an encapsulation mechanism for the C-plane messages
- C-Plane messages are not concatenated with U-Plane messages within same Ethernet frame
- The main purpose of C-plane messages is to transmit data-associated control information required for processing of user data (e.g., scheduling and beamforming commands)

- 根據不同的 Preamble format，其資料可能會跨多個 symbol
- O-RU must be informed by C-plane how to correctly execute CP extraction and FFT




C-plane msg
ecpriVersion | ecpriReserved | C
ecpriMessage (=2)
ecpriPayload (length)
ecpriRtcid = DEF3'h
Sequence ID = 99'h
E=1 | Subsequence ID = 00'h
Dir | payloadVer | filterIndex
frameId
subframeId | slotId
slotId | startSymbolid
numberOfsections = 01'h
sectionType = 01'h
udCompHdr
(reserved)
SectionId = ABC'h
(cont') | rb | startPrbc
(cont') 000'h
numPrbc 273'd
reMask
(cont') | numSymbol
beamId
U-plane msg #1
ecpriVersion | ecpriReserved | C
ecpriMessage (=0)
ecpriPayload (length)
ecpriPcid = DEF3'h
Sequence ID = 40'h
E=1 | Subsequence ID = 00'h
Dir | payloadVer | filterIndex
frameId
subframeId | slotId
slotId | startSymbolid
SectionId = ABC'h
(cont') | rb | startPrbu
(cont') 00'd
numPrbu 32'd
udCompHdr
(reserved)
I_0
I_0 | Q_0
Q_0
Q_0 | I_1
I_1
I_1 | Q_1
Q_1
...
U-plane msg #2
ecpriVersion | ecpriReserved | C
ecpriMessage (=0)
ecpriPayload (length)
ecpriPcid = DEF3'h
Sequence ID = 41'h
E=1 | Subsequence ID = 00'h
Dir | payloadVer | filterIndex
frameId
subframeId | slotId
slotId | startSymbolid
SectionId = ABC'h
(cont') | rb | startPrbu
(cont') 32'd
numPrbu 32'd
udCompHdr
(reserved)
I_0
I_0 | Q_0
Q_0
Q_0 | I_1
I_1
I_1 | Q_1
Q_1
...
U-plane msg #3
ecpriVersion | ecpriReserved | C
ecpriMessage (=0)
ecpriPayload (length)
ecpriPcid = DEF3'h
Sequence ID = 42'h
E=1 | Subsequence ID = 00'h
Dir | payloadVer | filterIndex
frameId
subframeId | slotId
slotId | startSymbolid
SectionId = ABC'h
(cont') | rb | startPrbu
(cont') 64'd
numPrbu 32'd
udCompHdr
(reserved)
I_0
I_0 | Q_0
Q_0
Q_0 | I_1
I_1
I_1 | Q_1
Q_1
...
#4..#8
U-plane msg #9
ecpriVersion | ecpriReserved | C
ecpriMessage (=0)
ecpriPayload (length)
ecpriPcid = DEF3'h
Sequence ID = 48'h
E=1 | Subsequence ID = 00'h
Dir | payloadVer | filterIndex
frameId
subframeId | slotId
slotId | startSymbolid
SectionId = ABC'h
(cont') | rb | startPrbu
(cont') 256'd
numPrbu 17'd
udCompHdr
(reserved)
I_0
I_0 | Q_0
Q_0
Q_0 | I_1
I_1
I_1 | Q_1
Q_1
...

C-plane Section Type

Section Type	Target Scenario	Remarks
0	Unused Resource Blocks or symbols in Downlink or Uplink	Indicates to O-RU that certain Resource Blocks or symbols will not be used (idle periods, guard periods). Likewise, there are no associated U-Plane messages containing IQ data for this Section Type. The purpose is to inform the O-RU that transmissions may be halted during the specified idle interval for e.g. power-savings or to provide an interval for calibration.
1	Most DL/UL radio channels*	Here “most” refers to channels not requiring time or frequency offsets such as are needed for mixed-numerology channels
3	PRACH and mixed-numerology channels*	Channels requiring time or frequency offsets or different-than-nominal SCS values
5	UE scheduling information (UE-ID assignment to section)	Provides scheduling information for UE-IDs
6	Channel information	Sends UE-specific channel information from the O-DU to the O-RU
7	LAA	Messages communicated between O-DU and the O-RU in both directions to configure LBT for PDSCH/DRS transmission and to report the LBT outcome.

C-plane Section Type

- Section Type 0: used for indicating idle or guard periods from O-DU to O-RU
- Section Type 1: used for most Downlink and Uplink radio channels
    - When PRACH having same SCS as other UL channel, type 1 can alternatively be used
- Section Type 3: used for PRACH and mixed-numerology channels
- Section Type 5: used for UE scheduling information
- Section Type 6: used for sending channel information for a specific UE ID
- Section Type 7: used to support LAA

Section Type	O-DU support	O-RU support
0	Optional	Mandatory
1	Mandatory	Mandatory
3	Mandatory	Mandatory
5	Optional	Optional
6	Optional	Optional
7	Optional	Optional

- LAA (Licensed Assisted Access) 授權輔助存取
  - 在非授權頻段中傳送 5G 訊號
  - 由授權頻段載波作為 Primary Cell(PCell)，非授權頻段載波只能作為 Secondary Cell(SCell) 的一種**載波聚合技術**
- LBT (Listen Before Talk)
  - 為了避免信道訪問的衝突(實現頻譜共享)以及實現信道訪問的優先級控制
  - Downlink LBT 針對 DU
    - 在任何情況下都要在進行下行傳輸前做 LBT
- DRS (Discovery Reference Signal) 探索參考訊號
- Dynamic Spectrum Sharing (DSS)
  - allows different technologies (4G LTE and 5G NR) share same frequency carrier dynamically
  - This version of the specification supports DSS via using dedicated eAxC ids (i.e. endpoints) for LTE and NR or via using Section Extension = 9 for DSS

C-plane and U-plane

- Coupling of C-Plane and U-Plane
  - O-DU may configure O-RU the used method via M-Plane
    - via sectionId, used by default
    - via Frequency and Time
    - via Frequency and Time with Priorities
- 同樣 section type 的 C-plane，可以包在同一個 message 中

C-plane Fields

- Transport Layer (eCPRI header)
- Application Layer (eCPRI Payload)
  - Common Header Fields
  - Section Fields

Section Type 1 : DL/UL control msgs									
0 (msb)	1	2	3	4	5	6	7 (lsb)	# of bytes	
transport header, see section 3.1.3 eCPRI header								8	Octet 1
dataDirection	payloadVersion			filterIndex				1	Octet 9
frameId								1	Octet 10
subframeId				slotId Common header				1	Octet 11
slotId		startSymbolid						1	Octet 12
numberOfsections								1	Octet 13
sectionType = 1								1	Octet 14
udCompHdr								1	Octet 15
reserved								1	Octet 16
sectionId								1	Octet 17
sectionId				rb	symInc	startPrbc		1	Octet 18
startPrbc								1	Octet 19
numPrbc								1	Octet 20
reMask[11:4] Section Fields 1								1	Octet 21
reMask[3:0]				numSymbol				1	Octet 22
ef = 1	beamId[14:8]							1	Octet 23
beamId[7:0]								1	Octet 24
section extensions as indicated by “ef”								var	Octet 25
...									
sectionId								1	Octet N
sectionId				rb	symInc	startPrbc		1	N+1
startPrbc								1	N+2
numPrbc								1	N+3
reMask[11:4] Section Fields 2								1	N+4
reMask[3:0]				numSymbol				1	N+5
ef = 0	beamId[14:8]							1	N+6
beamId[7:0]								1	N+7
section extensions as indicated by “ef”								var	N+8
									Octet M

	Section Type 0	Section Type 1	Section Type 3	Section Type 5	Section Type 6	Section Type 7
Common Header Field	dataDirection	dataDirection	dataDirection	dataDirection	dataDirection	dataDirection
	payloadVersion	payloadVersion	payloadVersion	payloadVersion	payloadVersion	payloadVersion
	filterIndex	filterIndex	filterIndex	filterIndex	filterIndex	filterIndex
	frameId	frameId	frameId	frameId	frameId	frameId
	subframeId	subframeId	subframeId	subframeId	subframeId	subframeId
	slotID	slotID	slotID	slotID	slotID	slotID
	startSymbolid	startSymbolid	startSymbolid	startSymbolid	startSymbolid	startSymbolid
	numberOfsections	numberOfsections	numberOfsections	numberOfsections	numberOfsections	numberOfsections
	sectionType=0	sectionType=1	sectionType=3	sectionType=5	sectionType=6	sectionType=7
	timeOffset		timeOffset			
	frameStructure		frameStructure			
	cpLength		cpLength			
		udCompHdr	udCompHdr	udCompHdr		
					numberOfUEs	
Section Field	sectionId	sectionId	sectionId	sectionId		
	rb	rb	rb	rb	rb	
	symInc	symInc	symInc	symInc	symInc	
	startPrbc	startPrbc	startPrbc	startPrbc	startPrbc	
	numPrbc	numPrbc	numPrbc	numPrbc	numPrbc	
	reMask	reMask	reMask	reMask		
	numSymbol	numSymbol	numSymbol	numSymbol		
	ef	ef	ef	ef	ef	
		beamId	beamId			
			freqOffset			
				ueId	ueId	
					regularizationFactor	
					ciIsample	
					ciQsample	
						laaMsgType
						laaMsgLen
						Payload by laaMsgType

Information Elements - Common

- dataDirection [all]
  - 0=Rx(UL), 1=Tx(DL)
- payloadVersion [all]
  - 001, for current specification version
- filterIndex [all]
  - Filter index is commanded from O-DU to O-RU
  - it is not mandatory to command special filters, and 0000b is also allowed for PRACH

Value of IE "filter Index"	Usage	PRACH preamble formats	Minimum filter pass band
0000b	standard channel filter	N/A	
0001b	UL filter for PRACH preamble formats	LTE-0, LTE-1, LTE-2, LTE-3, NR-0, NR-1, NR-2	839 x 1.25kHz = 1048.75 kHz
0010b		NR-3	839 x 5 kHz = 4195 kHz
0011b		NR-A1, NR-A2, NR-A3, NR-B1, NR-B2, NR-B3, NR-B4, NR-C0, NR-C2	139 x Δf^{RA} (See SCS in **Table 5-11**)
0100b	UL filter for NPRACH	LTE-NB0, LTE-NB1	48 x 3.75kHz = 180 kHz
0101b	UL filter for PRACH preamble formats	LTE-4	139 x 7.5kHz = 1042.5 kHz
0110b…111b	Reserved		

Information Elements - Common

- frameId [all]
  - frame number modulo 256 (2.56 seconds period with 10 ms/frame)
- subframeId [all]
  - the counter for 1 ms sub-frames within 10 ms frame
- slotId [all]
  - the slot number within a 1 ms sub-frame
- startSymbolid [all]
  - the symbol number(within a slot) of the earliest symbol
- numberOfSections [all]
  - the number of data section descriptions included in this C-plane message
- sectionType [all]
  - determines the characteristics of U-plane data

Information Elements - Common

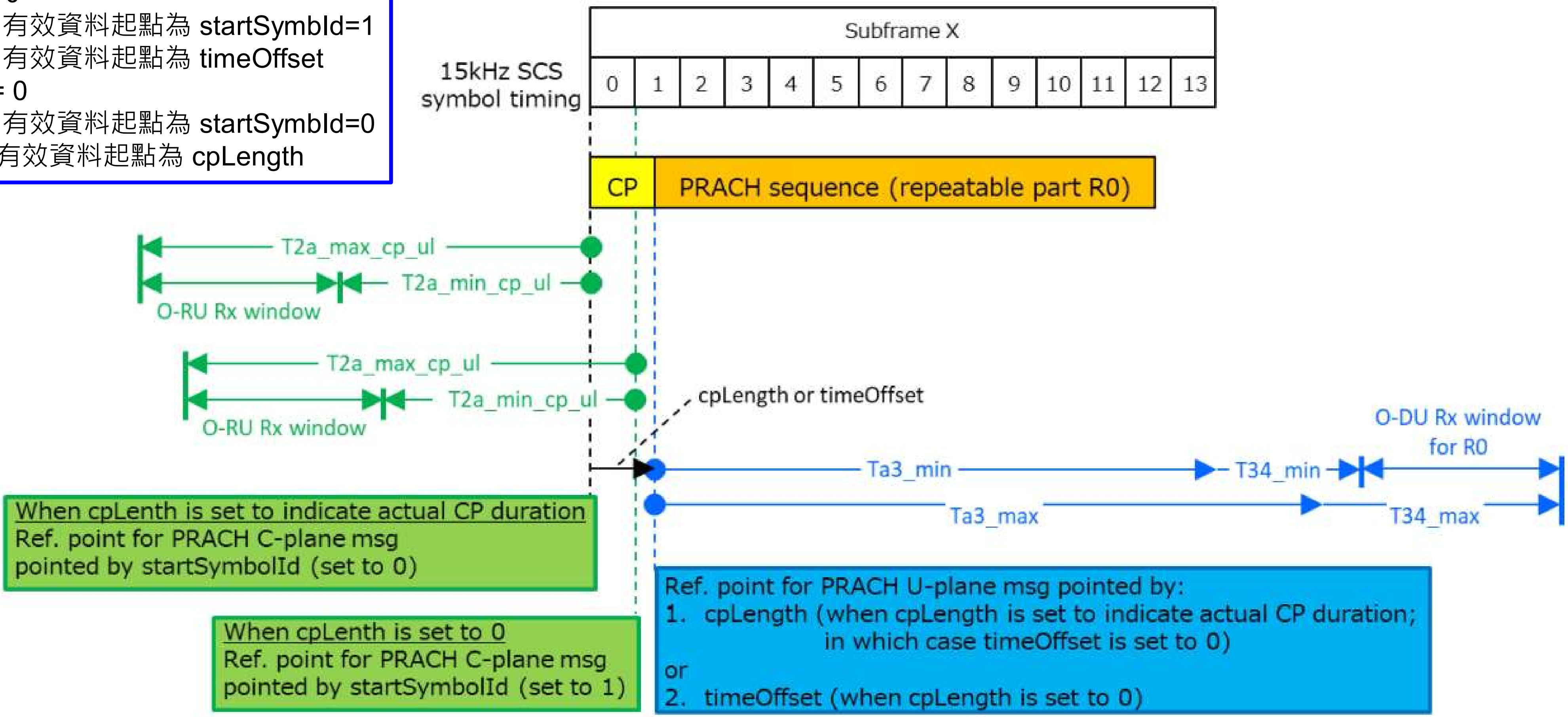
- udCompHdr (user data compression header) [1,3,5]
  - For U-plane, udCompHdr information instructs the O-RU (on DL) and O-DU (on UL) how to interpret and decompress the received U-Plane data
  - For C-plane, udCompHdr only has meaning for UL U-Plane data to instruct the O-RU to decide the data compression method
- numberOfUEs [6]
  - the number of Ues
  - This allows the parser to determine when the last UE’s data has been parsed
- timeOffset [0,3]
  - defines the time_offset from the start of the slot to the start of the Cyclic Prefix
  - time_offset = timeOffset * Ts
- cpLength [0,3]
  - defines the length CP_length of the Cyclic Prefix
  - CP_length = cpLength * Ts

cpLength and timeOffset

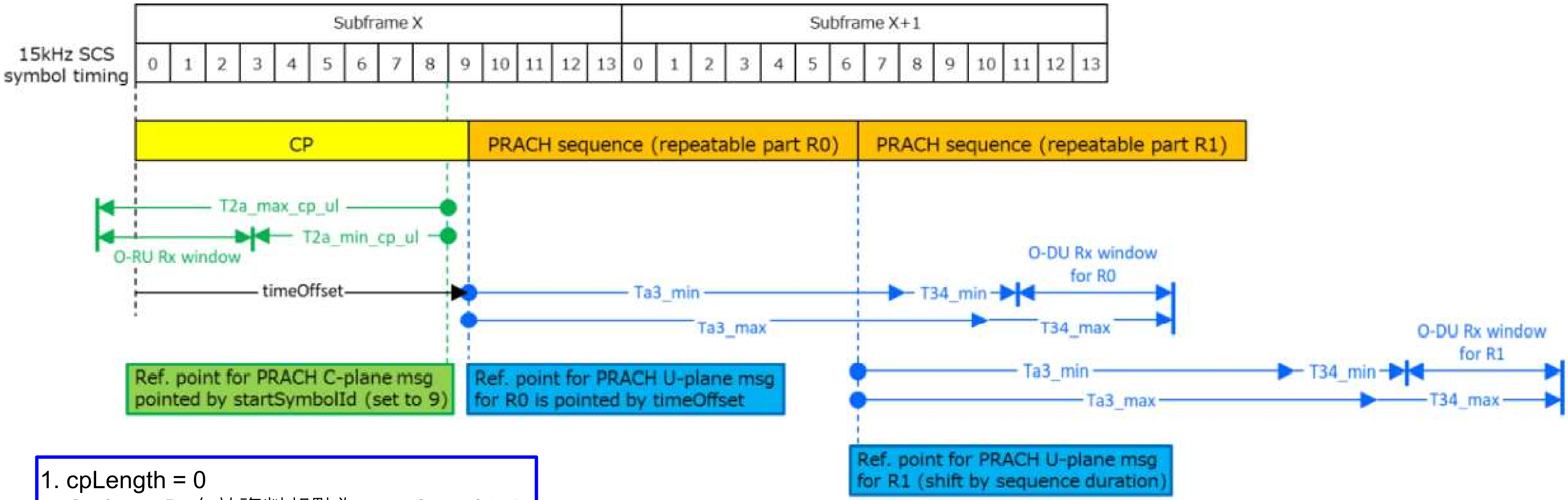
- For the first PRACH repetition
  - If cpLength is set to a non-zero value in the PRACH C-plane
    - the reference point for PRACH U-plane message is pointed by timeOffset (pointing to the start of PRACH cyclic prefix) + cpLength
  - if cpLength is set to zero in the PRACH C-plane
    - the reference point for PRACH U-plane message is pointed by timeOffset (pointing to the start of the PRACH repetition (after PRACH cyclic prefix))

PRACH format 0

1. cpLength = 0
   C-plane ➔ 有效資料起點為 startSymbId=1
   U-plane ➔ 有效資料起點為 timeOffset
2. cpLength != 0
   C-plane ➔ 有效資料起點為 startSymbId=0
   U-plane ➔有效資料起點為 cpLength

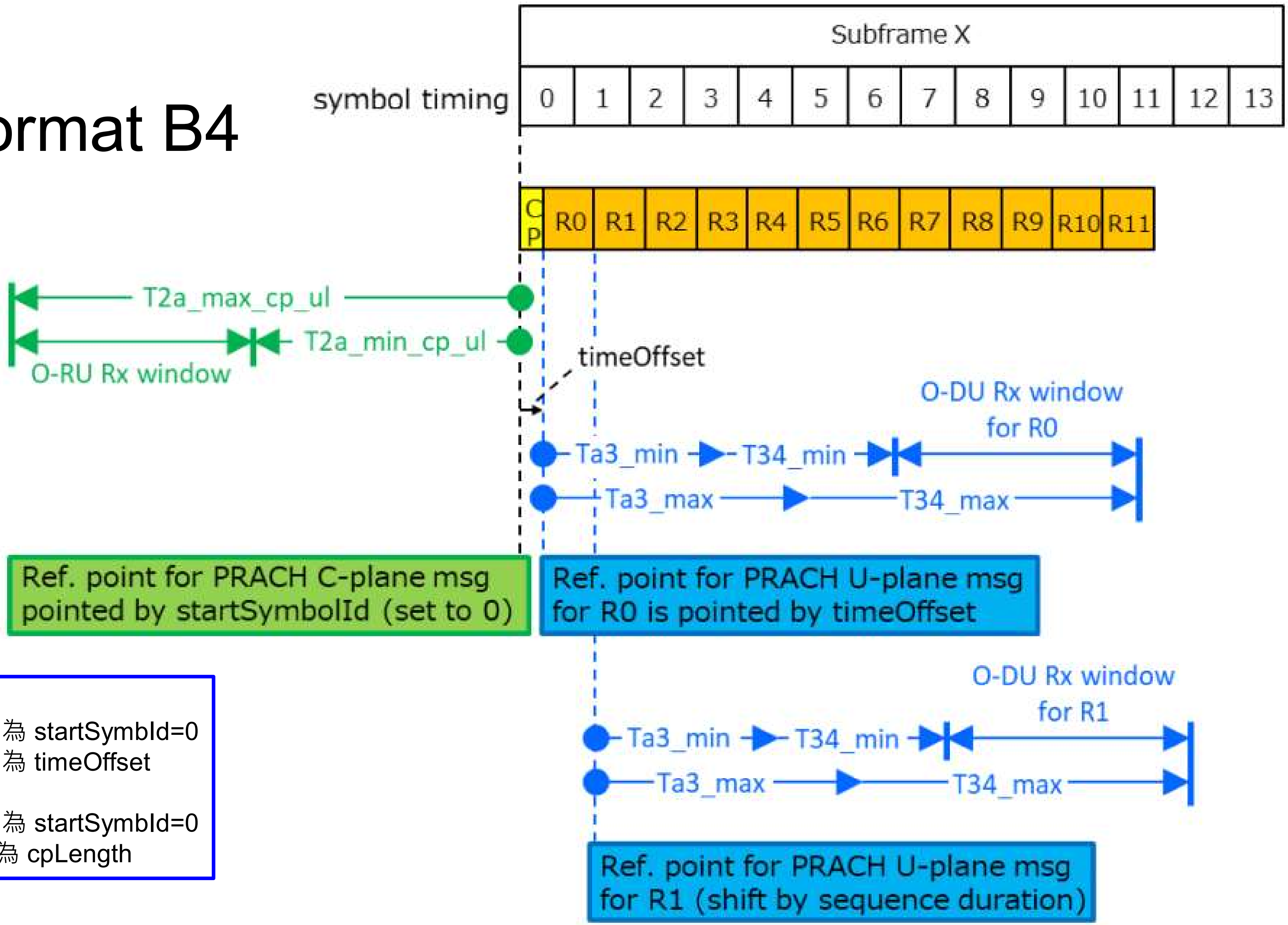


PRACH format 1



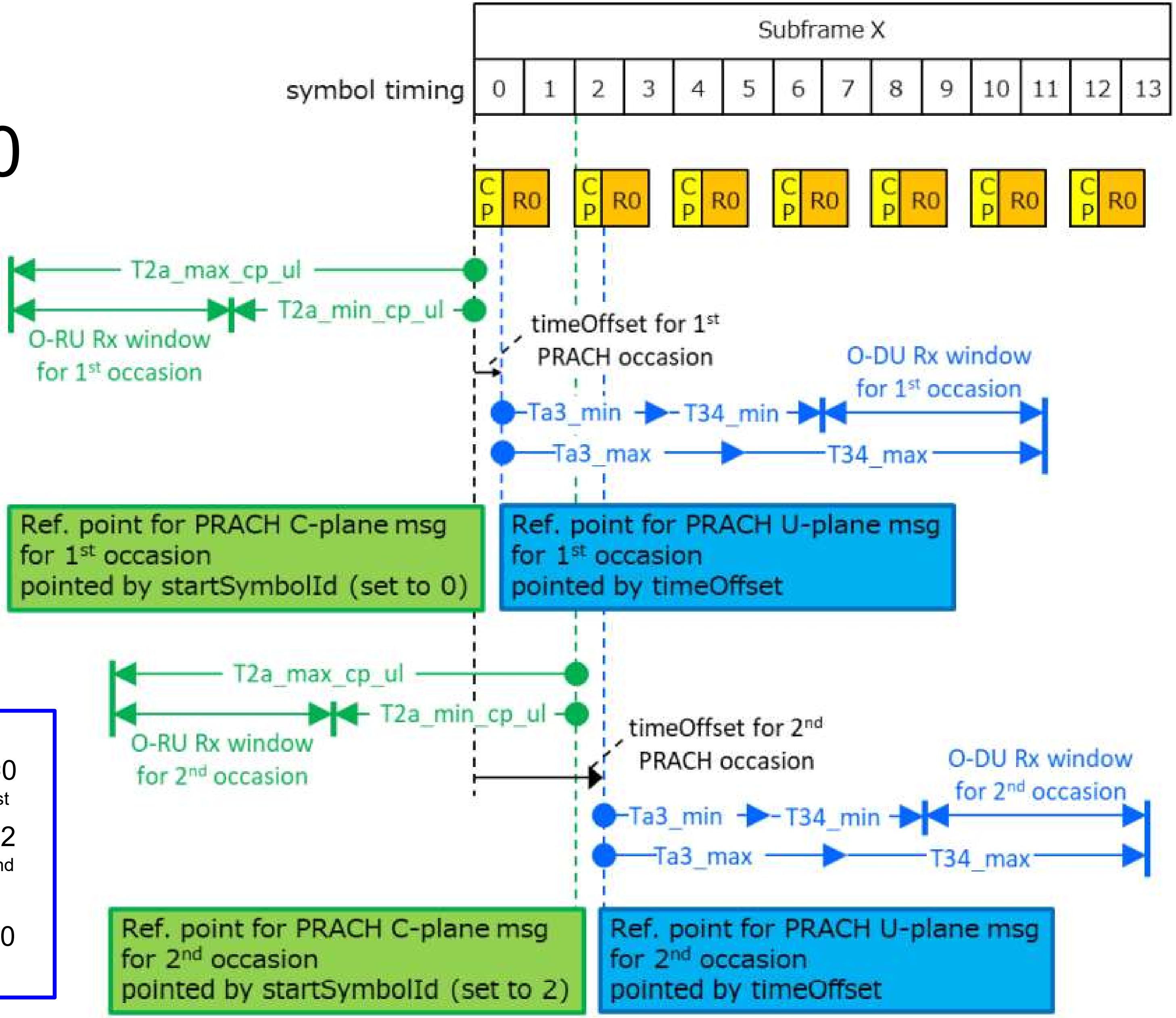
1. cpLength = 0
   C-plane ➔ 有效資料起點為 startSymbId=9
   U-plane ➔ 有效資料起點為 timeOffset
2. cpLength != 0
   C-plane ➔ 有效資料起點為 startSymbId=0
   U-plane ➔有效資料起點為 cpLength

PRACH format B4

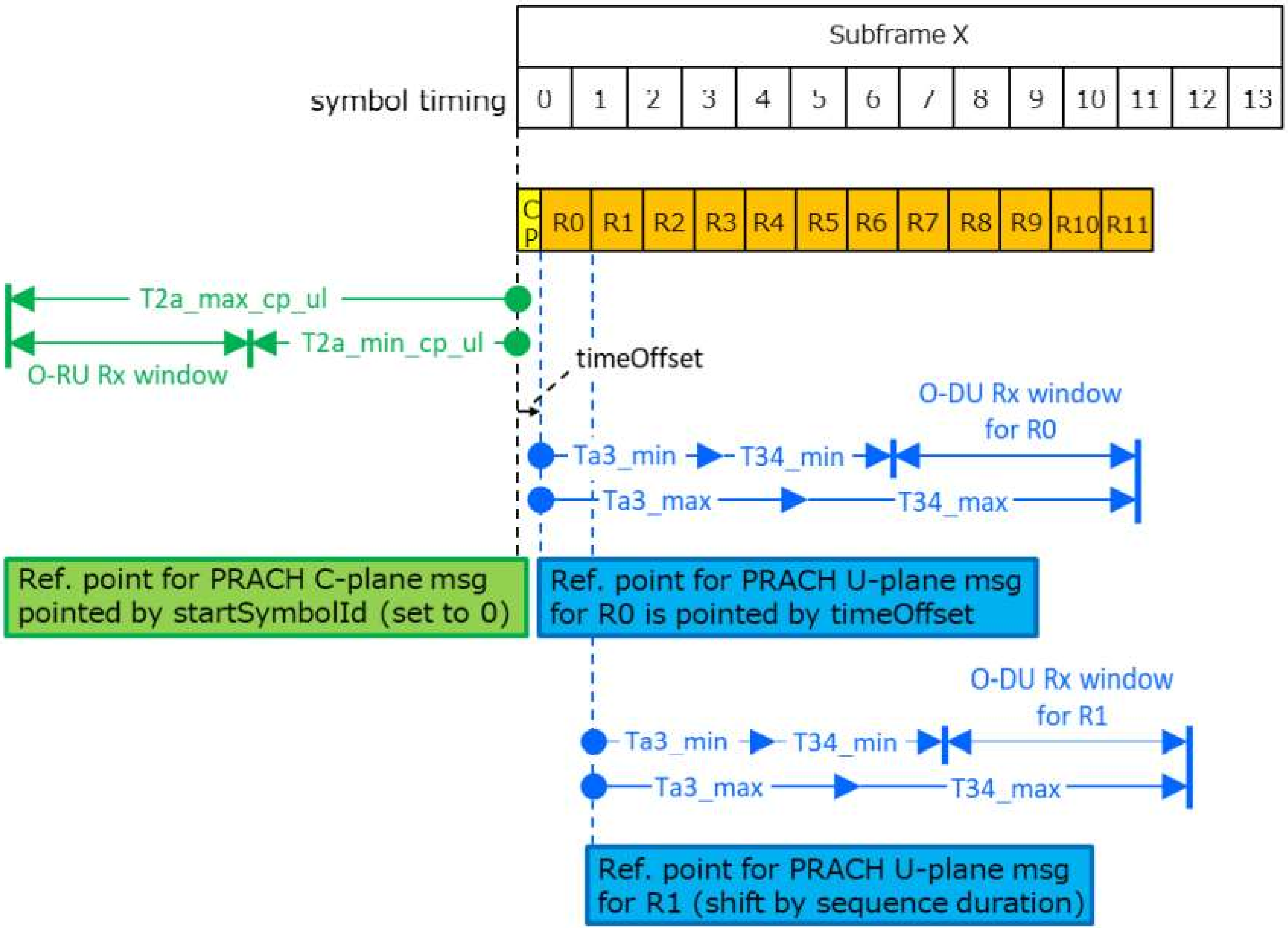


1. cpLength = 0
   C-plane ➔ 有效資料起點為 startSymbId=0
   U-plane ➔ 有效資料起點為 timeOffset
2. cpLength != 0
   C-plane ➔ 有效資料起點為 startSymbId=0
   U-plane ➔有效資料起點為 cpLength

PRACH format C0



1. cpLength = 0
   - 1^{st} C-plane ➔ 有效資料起點為 startSymbId=0
   - 1^{st} U-plane ➔ 有效資料起點為 timeOffset_1^{st}
   - 2^{nd} C-plane ➔ 有效資料起點為 startSymbId=2
   - 2^{nd} U-plane ➔ 有效資料起點為 timeOffset_2^{nd}
2. cpLength != 0
   - R0 C-plane ➔ 有效資料起點為 startSymbId=0
   - R0 U-plane ➔有效資料起點為 cpLength



Subframe X
symbol timing
0 1 2 3 4 5 6 7 8 9 10 11 12 13
CP R0 R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11
T2a_max_cp_ul
T2a_min_cp_ul
O-RU Rx window
timeOffset
O-DU Rx window for R0
Ta3_min
T34_min
Ta3_max
T34_max
Ref. point for PRACH C-plane msg pointed by startSymbolId (set to 0)
Ref. point for PRACH U-plane msg for R0 is pointed by timeOffset
O-DU Rx window for R1
Ta3_min
T34_min
Ta3_max
T34_max
Ref. point for PRACH U-plane msg for R1 (shift by sequence duration)

Information Elements - Common

- frameStructure [0,3]
  - Indicates FFT/iFFT size and numerology

0 (msb)	1	2	3	4	5	6	7 (lsb)	Number of Octets	
FFT Size				μ (Subcarrier spacing)				1	Octet 1

  - FFT size

Value of IE "FFT_size"	FFT/iFFT size
0000b	Reserved (no FFT/iFFT processing)
0001b…0110b	Reserved
0111b	128
1000b	256
1001b	512
1010b	1024
1011b	2048
1100b	4096
1101b	1536
1110,1111b	Reserved

Information Elements - Common

- numerology

Value of IE "SCS"	3GPP "μ"	Subcarrier spacing Δf	Number of slots per 1ms sub-frame: N_{slot}	Slot length
0000b	0	15kHz	1	1ms
0001b	1	30kHz	2	500μs
0010b	2	60kHz	4	250μs
0011b	3	120kHz	8	125μs
0100b	4	240kHz	16	62.5μs
0101b…1011b	NA	Reserved	Reserved	Reserved
1100b	NA	1.25kHz	1	1ms
1101b	NA	3.75kHz (LTE-specific)	1	1ms
1110b	NA	5kHz	1	1ms
1111b	NA	7.5kHz (LTE-specific)	1	1ms

Information Elements - Sections

- sectionId [0,1,3,5]
  - CU-plane coupling via sectionId
    - used to map U-Plane data sections to the corresponding C-Plane message
    - sectionIds are specific to a slot, so sectionId values may be “reused” for each slot
  - CU-plane coupling via frequency and time
    - sectionId=4095
- rb (resource block indicator) [0,1,3,5,6]
  - indicates if every RB is used or every other RB is used
  - rb=0, startPrbc=1, numPrbc=3 ➔ 1, 2, 3 PRBs are used
  - rb=1, startPrbc=1, numPrbc=3 ➔ 1, 3, 5 PRBs are used

Information Elements - Sections

- symInc (symbol number increment command) [0,1,3,5,6]
  - indicate if the symbol number should be incremented to the next symbol
  - If symInc[s] = 0 then symbol[s] = symbol[s-1], else symbol[s] = symbol[s-1] + numSymbols[s-1]
- startPrbc (start PRB/c-plane) [0,1,3,5,6]
  - the starting PRB of a data section (指定 section 中 u-plane 的起始 PRB index)
  - Values of startPrbc and numPrbc must ensure that data sections must never overlap
- numPrbc [0,1,3,5,6]
  - define the number of contiguous PRBs
  - Field length: 8 bits ➔ 如果需要配置的 PRBs 數量大於 255，會切割成多個 data section 來設定
  - If numPrbc=00000000 ➔ 配置所有的 PRBs according to the specified SCS and carrier bandwidth ➔ rb and startPrbc are don’t care (不管設什麼值，都看成是 rb=0, startPrbc=0)
- numSymbol [0,1,3,5]
  - define the number of symbols, or number of PRACH repetitions in the case of PRACH
  - value range: 0001~1110

Information Elements - Sections

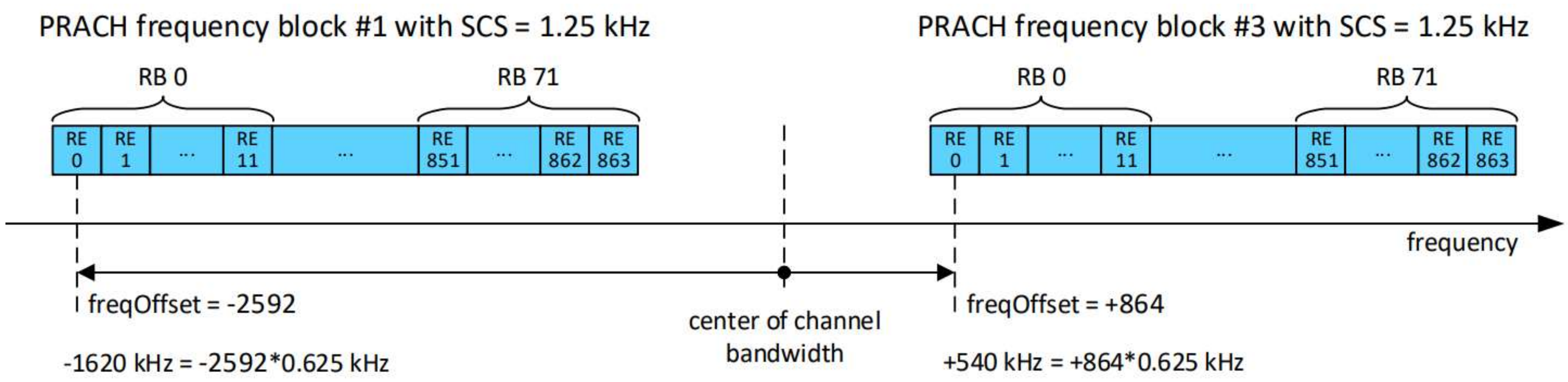
- reMask (resource block indicator) [0,1,3,5]
  - defines the Resource Element mask within an PRB to indicate if the section control is applicable to the RE sent in U-Plane messages
  - 0=not applicable, 1=applicable
  - 在 C-plane message 可以定義多個 section block ➔ 不同的 block 的 sectionId 可以一樣 ➔ 相同 sectionId 的 block 會有相同的 rb, startPrbc, numPrbc, udCompHdr, numSymbol ➔ 其所對應的 U-plane 會用到同一塊的 PRB ➔ 相同 sectionId 搭配不同的 reMask 可以使得同一塊 PRB 中的不同 RE 分配給不同的 U-plane 使用
  - Field length: 12 bits ➔ 一個 PRB 中會有 12 個 RE
- ef (extension flag) [0,1,3,5,6]
  - 0 ➔ no Section Extensions
  - 1 ➔ one or more Section Extensions are included in this section

Information Elements - Sections

- beamId [1,3]
  - define the beam pattern to be applied to the U-Plane data
  - beamId = 0 means no beamforming operation will be performed
  - No beamforming operation implies that the RU shall not apply any phase or amplitude weights to the U-plane data
- ueId [5,6]
  - provide a label for the UE for which the section contents apply
- regularizationFactor [6]
  - provides a signed value to support MMSE operation within the O-RU when beamforming weights are supported in the O-RU
- ciIsample (channel information I values) [6]
  - These values are the channel information complex values relayed from the O-DU to the O-RU
- ciQsample (channel information Q values) [6]
  - These values are the channel information complex values relayed from the O-DU to the O-RU

Information Elements - Sections

- freqOffset [3]
  - defines the frequency offset with respect to the carrier center frequency
  - Value range
    - 0x000000=no offset
    - 0x000001 – 0x7FFFFF = positive frequency offset
    - 0x800000 – 0xFFFFFF = negative frequency offset



Information Elements - Sections

- laaMsgType [7]
  - defines the LAA message type being conveyed within the Section Type 7 C-Plane message
- laaMsgLen [7]
  - defines number of 32-bit words in the LAA section

laaMsgType	lssMsgType definition	lssMsgType meaning
0000b	LBT_PDSCH_REQ	O-DU to O-RU request to obtain a PDSCH channel
0001b	LBT_DRS_REQ	O-DU to O-RU request to obtain the channel and send DRS
0010b	LBT_PDSCH_RSP	O-RU to O-DU response, channel acq success or failure
0011b	LBT_DRS_RSP	O-RU to O-DU response, DRS sending success or failure
0100b	LBT_Buffer_Error	O-RU to O-DU response, reporting buffer overflow
0101b	LBT_CWCONFIG_REQ	O-DU to O-RU request, congestion window configuration
0110b	LBT_CWCONFIG_RSP	O-RU to O-DU response, congestion window config. response
0100b – 1111b	reserved for future methods	

Information Elements - Section Extensions

- extType (5.7.6)
  - There are 17 extension types
  - beamforming weights, beamforming attributes, Multiple-eAxC designation, …
- extLen
  - provides the length of the section extension in units of 32-bit words
  - Field length: 8 bits (Section Extension 1~`0) or 16 bits (Section Extension 11~17)

Section Extensions

- ExtType=6 [1,3,5]
  - Non-contiguous PRB allocation in time and frequency domain
    - enables allocation of non-contiguous sets of PRBs
    - This will reduce significantly the C-Plane overhead

<table>
<tr><td>ef</td><td colspan="3">extType = 0x06</td><td>1</td><td>Octet N</td></tr>
<tr><td colspan="4">extLen = 0x02 (2 words)</td><td>1</td><td>N+1</td></tr>
<tr><td>repetition</td><td colspan="2">rbgSize [2:0]</td><td>rbgMask [27:24]</td><td>1</td><td>N+2</td></tr>
<tr><td colspan="4">rbgMask [23:16]</td><td>1</td><td>N+3</td></tr>
<tr><td colspan="4">rbgMask[15:8]</td><td>1</td><td>N+4</td></tr>
<tr><td colspan="4">rbgMask[7:0]</td><td>1</td><td>N+5</td></tr>
<tr><td colspan="2">priority[1:0]</td><td colspan="2">symbolMask[13:8]</td><td>1</td><td>N+6</td></tr>
<tr><td colspan="4">symbolMask[7:0]</td><td>1</td><td>N+7</td></tr>
</table>

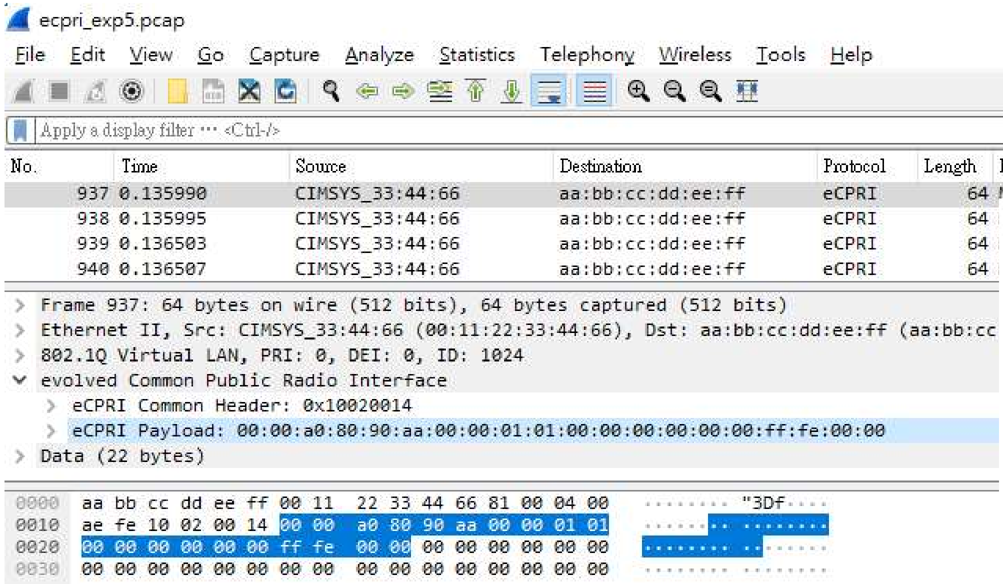
Section Extensions

- rbgSize (resource block group size)
  - indicate the size in number of PRBs of the resource block groups allocated by the bit mask
  - 000b: reserved, 001b: 1, 010b: 2, 011b: 3, 100b: 4, 101b: 6, 110b: 8, 111b: 16
- rbgMask
  - a bit mask where each bit indicates whether a corresponding resource block group is allocated
- symbolMask
  - each bit indicates whether the rbgMask applies to a given symbol in the slot
  - Field length: 14 bits

#	sectionId	symbolMask	startPrbc	numPrbc	reMask	beamId	Note
1	100	0110110	0	4	111111	100	UE1
2	101	1001000	0	4	110110	100	UE1
3	101	1001000	0	4	001000	1	Reference signal
4	101	1001000	0	4	000001	2	Reference signal

eCPRI Package

- Radio frame ➔ 0xaa
  - subframe
    - 0➔937~940
    - 1➔941~946
    - 2➔947~952,955~978
    - 3➔953,954,979,980
    - 4➔981~984
    - 5➔985~988
    - 6➔989~994
    - 7➔995~998
    - 8➔999~1002
    - 9➔1003~1006



Ethernet Frame Index	Radio frame ID SFN
…	…
867~936	0xa9
937~1006	0xaa
1007~1076	0xab
…	…

No.	Time
937	0.135990
938	0.135995
939	0.136503
940	0.136507
941	0.136997
942	0.137002
	10 ms
1001	0.144516
1002	0.144522
1003	0.144992
1004	0.144997
1005	0.145499
1006	0.145504
1007	0.145996

All packages for 0xaa frame

No.	Time
955	0.139032
956	0.139036
957	0.139042
958	0.139043
959	0.139052
960	0.139056
961	0.139114
962	0.139120
963	0.139121
964	0.139185
965	0.139189
966	0.139190
	0.5 ms
967	0.139246
968	0.139250
969	0.139251
970	0.139252
971	0.139260
972	0.139326
973	0.139330
974	0.139391
975	0.139395
976	0.139396
977	0.139457
978	0.139461

All packages for Preamble

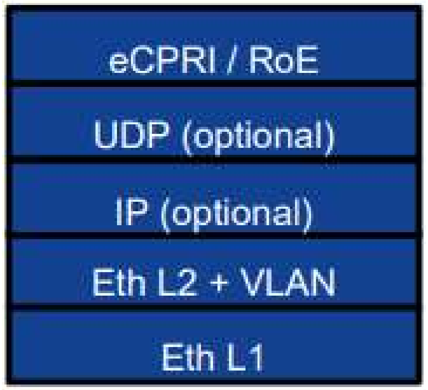
Ethernet Frame ID	Sequence ID	RU PORT ID	Subframe	Slot (global index)	(cp)invalid Symbol (up)symbol ID	Data Direction	Data Type
937	a0	0	0	0 (0) D	14	DL	cp
938	a0	1	0	0 (0)	14	DL	cp
939	a1	0	0	1 (1) D	14	DL	cp
940	a1	1	0	1 (1)	14	DL	cp
941	a2	0	1	0 (2) D	14	DL	cp
942	a2	1	1	0 (2)	14	DL	cp
943	a3	0	1	1 (3) S	6	DL	cp
944	a3	1	1	1 (3)	6	DL	cp
945	fc	0	1	1 (3)	4	UL	cp
946	fc	1	1	1 (3)	4	UL	cp
947	fd	0	2	0 (4) U	14	UL	cp
948	fd	1	2	0 (4)	14	UL	cp
949	fe	0	2	1 (5) U	14	UL	cp
950	fe	1	2	1 (5)	14	UL	cp
951	aa	2	2	1 (5)	12	UL (Preamble)	cp
952	aa	3	2	1 (5)	12	UL (Preamble)	cp
953	a4	0	3	0 (6) D	14	DL	cp
954	a4	1	3	0 (6)	14	DL	cp
955	1c	2	2	1	0	UL	up
956	1d	3	2	1	0	UL	up
957	1f	2	2	1	1	UL	up
958	20	3	2	1	1	UL	up

Ethernet Frame ID	Sequence ID	RU PORT ID	Subframe	Slot (global index)	(cp)invalid Symbol (up)symbol ID	Data Direction	Data Type
955	1c	2	2	1	0	UL	up
956	1d	3	2	1	0	UL	up
957	1f	2	2	1	1	UL	up
958	20	3	2	1	1	UL	up
959	22	2	2	1	2	UL	up
960	23	3	2	1	2	UL	up
961	25	2	2	1	3	UL	up
962	26	3	2	1	3	UL	up
963	28	2	2	1	4	UL	up
964	29	3	2	1	4	UL	up
965	2b	2	2	1	5	UL	up
966	2c	3	2	1	5	UL	up
967	2e	2	2	1	6	UL	up
968	2f	3	2	1	6	UL	up
969	31	2	2	1	7	UL	up
970	32	3	2	1	7	UL	up
971	34	2	2	1	8	UL	up
972	35	3	2	1	8	UL	up
973	37	2	2	1	9	UL	up
974	38	3	2	1	9	UL	up
975	3q	2	2	1	10	UL	up
976	3b	3	2	1	10	UL	up
977	3d	2	2	1	11	UL	up
978	3e	3	2	1	11	UL	up

Ethernet Frame ID	Sequence ID	RU PORT ID	Subframe	Slot (global index)	(cp)invalid Symbol (up)symbol ID	Data Direction	Data Type
979	a5	0	3	1 (7) D	14	DL	cp
980	a5	1	3	1 (7)	14	DL	cp
981	a6	0	4	0 (8) D	14	DL	cp
982	a6	1	4	0 (8)	14	DL	cp
983	a7	0	4	1 (9) D	14	DL	cp
984	a7	1	4	1 (9)	14	DL	cp
985	a8	0	5	0 (10) D	14	DL	cp
986	a8	1	5	0 (10)	14	DL	cp
987	a9	0	5	1 (11) D	14	DL	cp
988	a9	1	5	1 (11)	14	DL	cp
989	aa	0	6	0 (12) D	14	DL	cp
990	aa	1	6	0 (12)	14	DL	cp
991	ab	0	6	1 (13) S	6	DL	cp
992	ab	1	6	1 (13)	6	DL	cp
993	ff	0	6	1 (13)	4	UL	cp
994	ff	1	6	1 (13)	4	UL	cp
995	00	0	7	0 (14) U	14	UL	cp
996	00	1	7	0 (14)	14	UL	cp
997	01	0	7	1 (15) U	14	UL	cp
998	01	1	7	1 (15)	14	UL	cp
999	ac	0	8	0 (16) D	14	DL	cp
1000	ac	1	8	0 (16)	14	DL	cp
1001	ad	0	8	1 (17) D	14	DL	cp
1002	ad	1	8	1 (17)	14	DL	cp
1003	ae	0	9	0 (18) D	14	DL	cp
1004	ae	1	9	0 (19)	14	DL	cp
1005	af	0	9	1 (19) D	14	DL	cp
1006	af	1	9	1 (19)	14	DL	cp

C-plane Message Sample – Section type 1

- ethernet header
  - dst mac ➔ 0xaa bb cc dd ee ff
  - src mac ➔ 0x00 11 22 33 44 66
  - vlan tag(TPID+PCP+CFI+VID) ➔ 0x81 00 04 00
    - the Default TPID value in IEEE 802.1Q is 0x8100
    - VID ➔ 0x400 (u-plane: 0x402)
  - eCPRI over Ethernet with Ethertype = 0xaefe



Preamble (8 Bytes)	Destination MAC Address (6 Bytes)	Source MAC Address (6 Bytes)	VLAN Tag (4 Bytes)	Type/Length (Ethertype) (2 Bytes)	Payload (46…1500 Bytes)	FCS (4 Bytes)	IFG (12 Bytes)

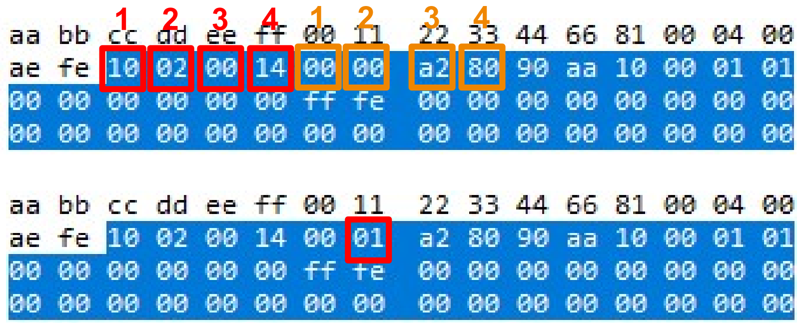
Figure 3-1 : Native Ethernet frame with VLAN

TPID (Tag Protocol Identify): 16 bits
PCP (Priority Code Point): 3 bits
CFI (Canonical Format Indicator): 1 bit ➔ 指定 MAC 位址是否為標準格式
VID (VLAN Identifier): 12 bits

```
aa bb cc dd ee ff 00 11  22 33 44 66 81 00 04 00
ae fe 10 02 00 14 00 00  a2 80 90 aa 10 00 01 01
00 00 00 00 00 00 ff fe  00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00
```

C-plane Message Sample – Section type 1

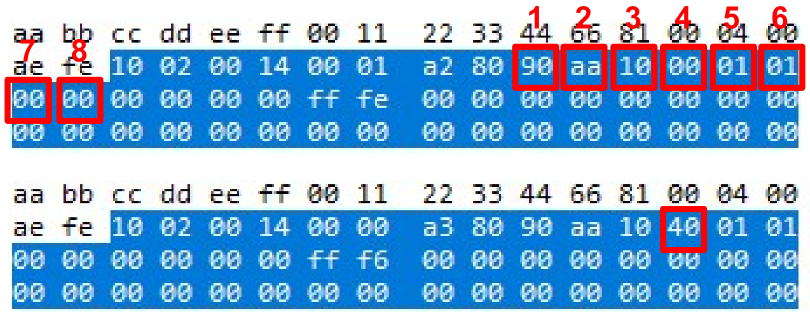
- eCPRI
  - ecpri header
    - Byte 1
      - bit 0~3 ➔ ecpriVersion (固定是0001)
      - bit 4~6 ➔ reserved (000)
      - bit 7 ➔ concatenation (0, by default)
    - Byte 2 ➔ message type (0x02 control data)
    - Byte 3~4 ➔ ecpri payload size (0x0014=20 bytes)
  - ecpri payload
    - Byte 1~2 ➔ ecpriRtcid
      - bit 0~3 ➔ DU_Port_ID
      - bit 4~7 ➔ BandSector_ID
      - bit 8~11 ➔ CC_ID
      - bit 12~15 ➔ RU_Port_ID (0x00/0x01)
    - Byte 3~4 (0xa280=1010 0010 1000 0000 ➔ sequence=a2, E=1, subsequence=0)
      - bit 0~7 ➔ sequence ID (0xa2)
      - bit 8 ➔ E-bit (c-plane不能fragmentation, E=1)
      - bit 9~15 ➔ subsequence ID (0x0)
    - Common header field
    - Section field



C-plane Message Sample – Section type 1

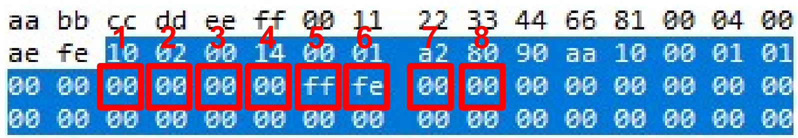
- Common header
  - Byte 1 (DL=0x90, UL=0x10, preamble=0x13)
    - bit 0 ➔ dataDirection (DL=1, UL=0)
    - bit 1~3 ➔ payload version (固定是001)
    - bit 4~7 ➔ filterIndex (0000 for standard filter, 0011 for preamble)
  - Byte 2 ➔ frame ID (0xaa)=SFN(0~255)
  - Byte 3
    - bit 0~3 ➔ subframe ID
    - bit 4~7 ➔ slot ID
  - Byte 4
    - bit 0~1 ➔ slot ID
    - bit 2~7 ➔ start symbol ID
    - 0x1000=0001 0000 0000 0000 ➔ subframe 1, slot 0, symbol 0
    - 0x1040=0001 0000 0100 0000 ➔ subframe 1, slot 1, symbol 0
  - Byte 5 ➔ numberOfSections (0x01 一個)
  - Byte 6 ➔ sectionType (0x01)
  - Byte 7 ➔ user data compression header(0x00➔ no compression)
  - Byte 8 ➔ reserved

Section Type	Common Header Length (bytes)
0	12
1	8
3	12
5	8
6	8
7	8



C-plane Message Sample – Section type 1

- Section field
  - Byte 1 ➔ sectionId
  - Byte 2
    - bit 0~3 ➔ sectionId (0x0 ➔ no paired U-Plane message)
    - bit 4 ➔ rb (0x0 ➔ RB連續使用)
    - bit 5 ➔ symInc (0x0 ➔ 不累計)
    - bit 6~7 ➔ startPrbc
  - Byte 3 ➔ startPrbc (0x0)
  - Byte 4 ➔ numPrbc (0x0: all PRBs in the specified SCS and carrier bandwidth are used)
  - Byte 5 ➔ reMask
  - Byte 6
    - bit 0~3 ➔ reMask (0xfff: all REs in the block applicable)
    - bit 4~7 ➔ numSymbol (0xe=14 symbols)
  - Byte 7
    - bit 0 ➔ ef (0x0 ➔ 沒有extension data)
    - bit 1~7 ➔ beamID
  - Byte 8 ➔ beamID (0x0: no beamforming operation is performed to U-plane data)



C-plane Message Sample – Section type 3

- eCPRI
  - ecpri header
    - Byte 1
      - bit 0~3 ➔ ecpriVersion (固定是0001)
      - bit 4~6 ➔ reserved (000)
      - bit 7 ➔ concatenation (0, by default)
    - Byte 2 ➔ message type (0x02 control data)
    - Byte 3~4 ➔ ecpri payload size (0x001c=28 bytes)
  - ecpri payload
    - Byte 1~2 ➔ ecpriRtcid
      - bit 0~3 ➔ DU_Port_ID
      - bit 4~7 ➔ BandSector_ID
      - bit 8~11 ➔ CC_ID
      - bit 12~15 ➔ RU_Port_ID (0x02/0x03)
    - Byte 3~4 ➔ Sequence ID (0xaa80)
    - Common header field
    - Section field

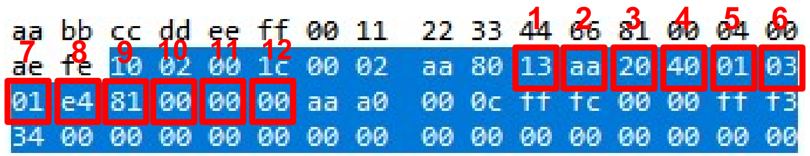
```
          1  2  3  4  1  2   3  4
aa bb cc dd ee ff 00 11  22 33 44 66 81 00 04 00
ae fe 10 02 00 1c 00 02  aa 80 13 aa 20 40 01 03
01 e4 81 00 00 00 aa a0  00 0c ff fc 00 00 ff f3
34 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00
```

```
aa bb cc dd ee ff 00 11  22 33 44 66 81 00 04 00
ae fe 10 02 00 1c 00 03  aa 80 13 aa 20 40 01 03
01 e4 81 00 00 00 aa a0  00 0c ff fc 00 00 ff f3
34 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00
```

C-plane Message Sample – Section type 3

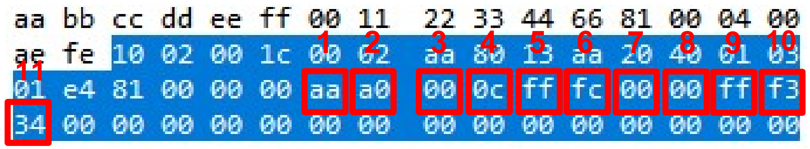
- Common header
  - Byte 1 (DL=0x90, UL=0x10, preamble=0x13)
    - bit 0 ➔ dataDirection (DL=1, UL=0)
    - bit 1~3 ➔ payload version (固定是001)
    - bit 4~7 ➔ filterIndex (0000 for standard filter, 0011 for preamble)
  - Byte 2 ➔ frame ID (0xaa)=SFN(0~255)
  - Byte 3
    - bit 0~3 ➔ subframe ID
    - bit 4~7 ➔ slot ID
  - Byte 4
    - bit 0~1 ➔ slot ID
    - bit 2~7 ➔ start symbol ID
    - 0x2040=0010 0000 0100 0000 ➔ subframe 2, slot 1, symbol 0
  - Byte 5 ➔ numberOfSections (0x01 一個)
  - Byte 6 ➔ sectionType (0x03)
  - Byte 7~8 ➔ timeOffset (0x01e4=484*Ts)
  - Byte 9 ➔ frameStructure (0x81=1000 0001 ➔ $\mu = 1$, FFT size=256(實際subcarriers使用量=139)
  - Byte 10~11 ➔ cpLength (0x0)
  - Byte 12 ➔ user data compression header (0x0)

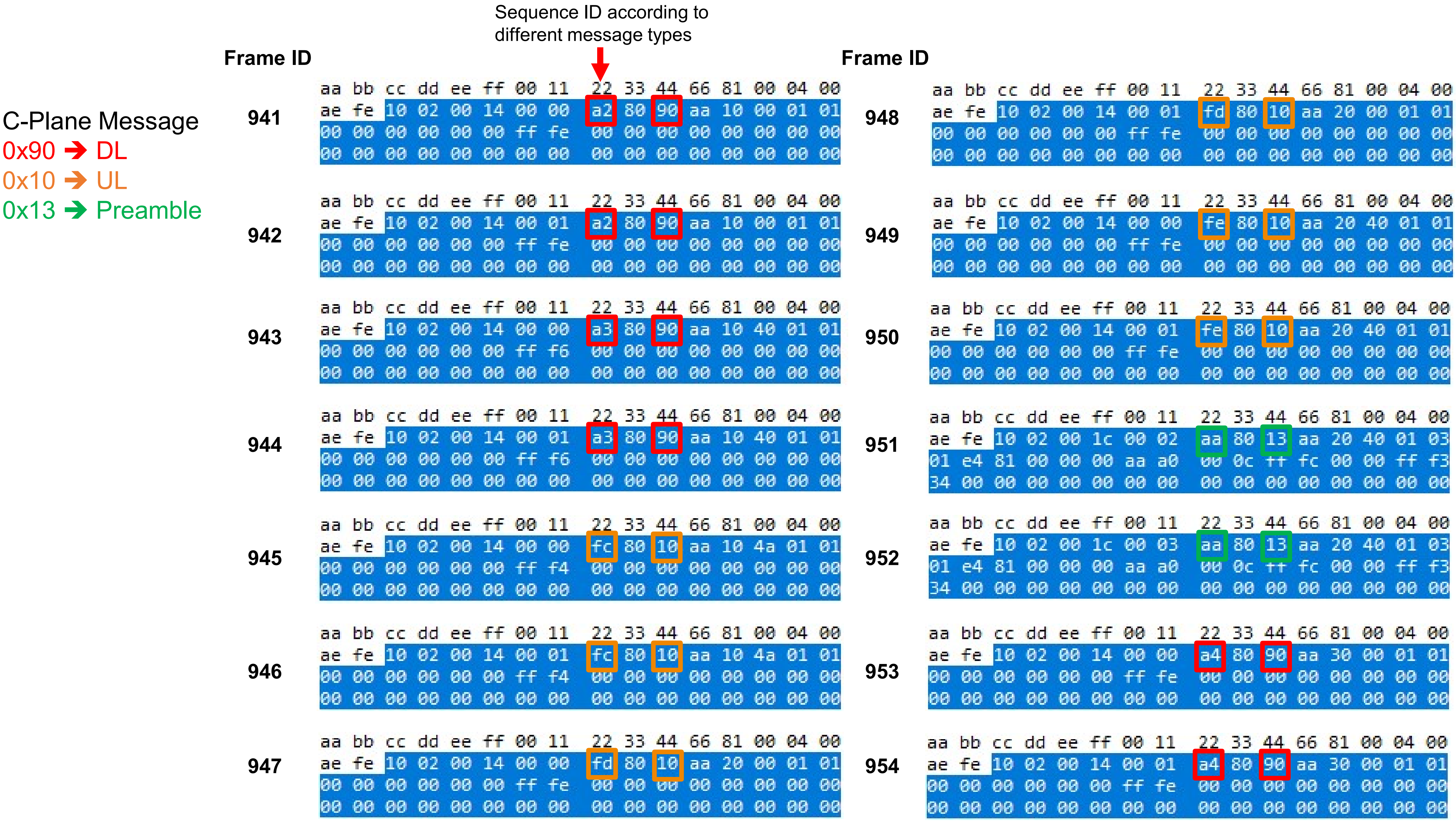
PRACH Configuration Index	Preamble format	$n_{SFN} \bmod x = y$		Subframe number	Starting symbol	Number of PRACH slots within a subframe	$N_t^{RA,slot}$, number of time-domain PRACH occasions within a PRACH slot	N_{dur}^{RA}, PRACH duration
		x	y					
156	B4	1	0	2	0	1	1	12



C-plane Message Sample – Section type 3

- Section field
  - Byte 1 ➔ sectionId
  - Byte 2
    - bit 0~3 ➔ sectionId (0xaaa ➔ 對應到 U-Plane message)
    - bit 4 ➔ rb (0x0)
    - bit 5 ➔ symInc
    - bit 6~7 ➔ startPrbc
  - Byte 3 ➔ startPrbc (0x0)
  - Byte 4 ➔ numPrbc (0x0c: 12 PRBs)
  - Byte 5 ➔ reMask
  - Byte 6
    - bit 0~3 ➔ reMask (0xfff: all REs in the block applicable)
    - bit 4~7 ➔ numSymbol (0xc=12 symbols ➔ B4 會用到 12 symbols)
  - Byte 7
    - bit 0 ➔ ef (0x0 ➔ 沒有extension data)
    - bit 1~7 ➔ beamID
  - Byte 8 ➔ beamID (0x0: no beamforming operation is performed to U-plane data)
  - Byte 9~11 ➔ freqOffset (0xfff334)





C-Plane Message
0x90 → DL
0x10 → UL
0x13 → Preamble
Sequence ID according to different message types
Frame ID
941
aa bb cc dd ee ff 00 11 22 33 44 66 81 00 04 00
ae fe 10 02 00 14 00 00 a2 80 90 aa 10 00 01 01
00 00 00 00 00 00 ff fe 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
942
aa bb cc dd ee ff 00 11 22 33 44 66 81 00 04 00
ae fe 10 02 00 14 00 01 a2 80 90 aa 10 00 01 01
00 00 00 00 00 00 ff fe 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
943
aa bb cc dd ee ff 00 11 22 33 44 66 81 00 04 00
ae fe 10 02 00 14 00 00 a3 80 90 aa 10 40 01 01
00 00 00 00 00 00 ff f6 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
944
aa bb cc dd ee ff 00 11 22 33 44 66 81 00 04 00
ae fe 10 02 00 14 00 01 a3 80 90 aa 10 40 01 01
00 00 00 00 00 00 ff f6 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
945
aa bb cc dd ee ff 00 11 22 33 44 66 81 00 04 00
ae fe 10 02 00 14 00 00 fc 80 10 aa 10 4a 01 01
00 00 00 00 00 00 ff f4 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
946
aa bb cc dd ee ff 00 11 22 33 44 66 81 00 04 00
ae fe 10 02 00 14 00 01 fc 80 10 aa 10 4a 01 01
00 00 00 00 00 00 ff f4 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
947
aa bb cc dd ee ff 00 11 22 33 44 66 81 00 04 00
ae fe 10 02 00 14 00 00 fd 80 10 aa 20 00 01 01
00 00 00 00 00 00 ff fe 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
Frame ID
948
aa bb cc dd ee ff 00 11 22 33 44 66 81 00 04 00
ae fe 10 02 00 14 00 01 fd 80 10 aa 20 00 01 01
00 00 00 00 00 00 ff fe 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
949
aa bb cc dd ee ff 00 11 22 33 44 66 81 00 04 00
ae fe 10 02 00 14 00 00 fe 80 10 aa 20 40 01 01
00 00 00 00 00 00 ff fe 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
950
aa bb cc dd ee ff 00 11 22 33 44 66 81 00 04 00
ae fe 10 02 00 14 00 01 fe 80 10 aa 20 40 01 01
00 00 00 00 00 00 ff fe 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
951
aa bb cc dd ee ff 00 11 22 33 44 66 81 00 04 00
ae fe 10 02 00 1c 00 02 aa 80 13 aa 20 40 01 03
01 e4 81 00 00 00 aa a0 00 0c ff fc 00 00 ff f3
34 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
952
aa bb cc dd ee ff 00 11 22 33 44 66 81 00 04 00
ae fe 10 02 00 1c 00 03 aa 80 13 aa 20 40 01 03
01 e4 81 00 00 00 aa a0 00 0c ff fc 00 00 ff f3
34 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
953
aa bb cc dd ee ff 00 11 22 33 44 66 81 00 04 00
ae fe 10 02 00 14 00 00 a4 80 90 aa 30 00 01 01
00 00 00 00 00 00 ff fe 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
954
aa bb cc dd ee ff 00 11 22 33 44 66 81 00 04 00
ae fe 10 02 00 14 00 01 a4 80 90 aa 30 00 01 01
00 00 00 00 00 00 ff fe 00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00

Section Type 1

```
aa bb cc dd ee ff 00 11  22 33 44 66 81 00 40 00
ae fe 10 02 00 14 00 01  a2 80 90 aa 10 00 01 01
00 00 00 00 00 00 ff fe  00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00
```

0	1	2	3	4	5	6	7	# of bytes	index
Destination MAC Address								6	1
Source MAC Address								6	7
TPID							Ethernet Header	2	13
PCP			CFI	VLAN ID				1	15
VLAN ID								1	16
eCPRI Ethernet Type								2	17
ecpriVersion				ecpriReserved			concatenation	1	19
eCPRI Message Type								1	20
eCPRI Payload Size							eCPRI Header	2	21
DU Port ID				BandSector ID				1	23
CC ID (Component-Carrier)				RU Port ID				1	24
Subsequence ID								2	25
dataDirection	Payload Version			Filter Index				1	27
Radio Frame ID								1	28
Subframe ID				Slot ID				1	29
Slot ID		Start Symbol ID					Common Header Field	1	30
Number of Sections								1	31
Section Type=1								1	32
User Data Compression Header								1	33
reserved								1	34

Section Type 1

0	1	2	3	4	5	6	7	# of bytes	Index
ecpriVersion				ecpriReserved			concatenation	1	19
eCPRI Message Type								1	20
eCPRI Payload Size						eCPRI Header		2	21
DU Port ID				BandSector ID				1	23
CC ID (Component-Carrier)				RU Port ID				1	24
Subsequence ID								2	25
dataDirection	Payload Version			Filter Index				1	27
Radio Frame ID								1	28
Subframe ID				Slot ID				1	29
Slot ID		Start Symbol ID				Common Header Field		1	30
Number of Sections								1	31
Section Type=1								1	32
User Data Compression Header								1	33
reserved								1	34
Section ID								1	35
Section ID				rb	symInc	startPrbc		1	36
startPrbc								1	37
numPrbc						Section Field		1	38
reMask								1	39
reMask				numSymbol				1	40
ef	Beam ID							1	41
Beam ID								1	42

```
aa bb cc dd ee ff 00 11  22 33 44 66 81 00 40 00
ae fe 10 02 00 14 00 01  a2 80 90 aa 10 00 01 01
00 00 00 00 00 00 ff fe  00 00 00 00 00 00 00 00
00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00
```

Section Type 3

0	1	2	3	4	5	6	7	# of bytes	Index
ecpriVersion				ecpriReserved			concatenation	1	19
eCPRI Message Type								1	20
eCPRI Payload Size								2	21
DU Port ID				BandSector ID				1	23
CC ID (Component-Carrier)				RU Port ID				1	24
Subsequence ID								2	25
dataDirection	Payload Version			Filter Index				1	27
Radio Frame ID								1	28
Subframe ID				Slot ID				1	29
Slot ID		Start Symbol ID						1	30
Number of Sections								1	31
Section Type=3								1	32
timeOffset								2	33
frameStructure								1	35
cpLength								2	36
User Data Compression Header								1	38
Section ID								1	39
Section ID				rb	symInc	startPrbc		1	40
startPrbc								1	41
numPrbc								1	42
reMask								1	43
reMask				numSymbol				1	44
ef	Beam ID							1	45
Beam ID								1	46
freqOffset								3	47

eCPRI Header

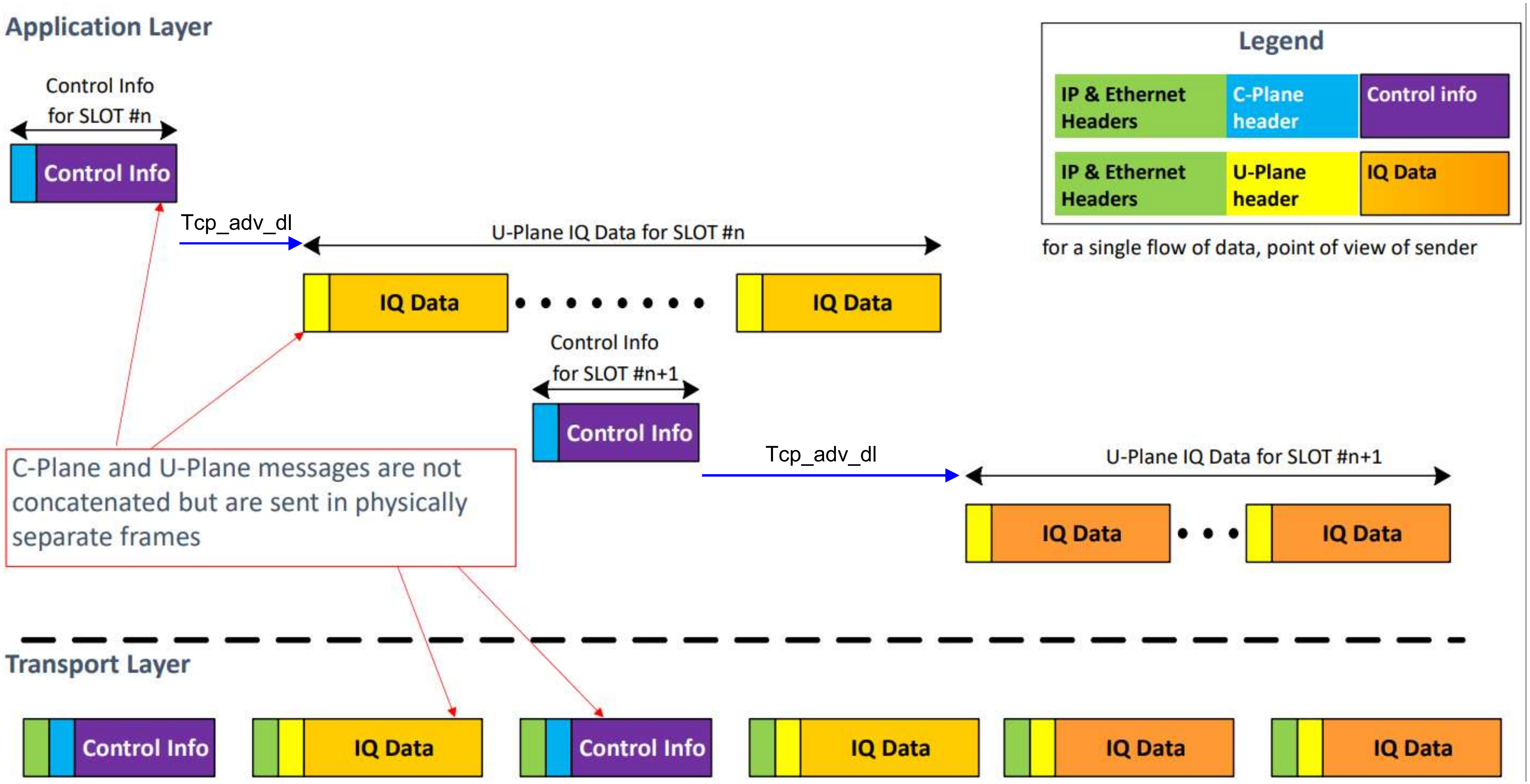
Common Header Field

Section Field

```
aa bb cc dd ee ff 00 11  22 33 44 66 81 00 40 00
ae fe 10 02 00 1c 00 02  aa 80 13 aa 20 40 01 03
01 e4 00 00 00 00 aa ac  00 0c ff fc 00 00 ff f3
34 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00
```

U-Plane Protocol

IQ Data Transfer Procedure



CU-Plane Contents

- A C-plane message is sent and described according to a slot.
  - 一個 slot 裡面有幾個 symbol
  - 那些 symbol，如何被使用 ➔ DL/UL
  - For example，一個 slot 會用一個以上的 C-Plane message 來描述
- A U-plane message is sent and described according to RB in a symbol.
  - 一個 symbol 裡面有幾個 RBs
  - 那謝 RBs 如何被使用，攜帶什麼 IQ data
  - For example，一個 symbol 中的 273 RBs 會用一個以上的 U-Plane message 來描述

U-plane Section Type

- No U-plane messages are associated with Section Type 0/6/7
- ~~Section Type 0: used for indicating idle or guard periods from O-DU to O-RU~~
- Section Type 1: used for most Downlink and Uplink radio channels
    - When PRACH having same SCS as other UL channel, type 1 can alternatively be used
- Section Type 3: used for PRACH and mixed-numerology channels
- Section Type 5: used for UE scheduling information
- ~~Section Type 6: used for sending channel information for a specific UE ID~~
- ~~Section Type 7: used to support LAA~~

U-plane Fields

- Transport Layer (eCPRI header)
- Application Layer (eCPRI Payload)
  - Common Header Fields
  - Section Header Fields
  - PRB Fields

0 (msb)	1	2	3	4	5	6	7 (lsb)	# of bytes	
transport header, see section 3.1.3						eCPRI header		8	Octet 1
dataDirection	payloadVersion			filterIndex				1	Octet 9
frameId						Common header		1	Octet 10
subframeId				slotId				1	Octet 11
slotId		symbolid						1	Octet 12
sectionId								1	Octet 13
sectionId				rb	symInc	startPrbu		1	Octet 14
startPrbu								1	Octet 15
numPrbu						Section Field 1		1	Octet 16
udCompHdr (not always present)								0/1	Octet 17
reserved (not always present)								0/1	Octet 18
udCompLen (not always present)								0/2	Octet 17/19
udCompParam (not always present)								0/1/2	Octet 17/19/21
iSample (1^{st} RE in the PRB)								1*	K= 17/19/20/21/23
qSample (1^{st} RE in the PRB)						PRB Field 1		1*	K+1*
...									
iSample (12^{th} RE in the PRB)								1*	K+22*
qSample (12^{st} RE in the PRB)								1*	K+23*
udCompParam (not always present)								1/1/2	K+24*
iSample (1^{st} RE in the PRB)								1*	K+24/25/26*
qSample (1^{st} RE in the PRB)						PRB Field 2		1*	K+25/26/27*
...									
iSample (12^{th} RE in the PRB)								1*	K+46/47/48*
qSample (12^{st} RE in the PRB)								1*	K+47/48/49*
...									

Information Elements - Common

- dataDirection
- payloadVersion
- filterIndex
- frameId
- subframeId
- slotId
- symbolId

Information Elements - Section

- sectionId
- rb
- symInc
- startPrbu
- numPrbu
- udCompHdr (user data compression parameter)
- udCompLen (PRB field length)

Information Elements - Section

- udCompHdr: 8 bits (This field is absent from U-Plane messages when the static IQ 7 format and compression method is configured via the M-Plane)
  - udIqWidth (0~3 bit)
    - IQ data 的 bit 數
  - udCompMeth (4~7 bit)

udIqWidth	Bit width of each I and each Q
0000-1111b	16 for udIqWidth=0, otherwise equals udIqWidth e.g. udIqWidth = 0000b means I and Q are each 16 bits wide; e.g. udIQWidth = 0001b means I and Q are each 1 bit wide; e.g. udIqWidth = 1111b means I and Q are each 15 bits wide

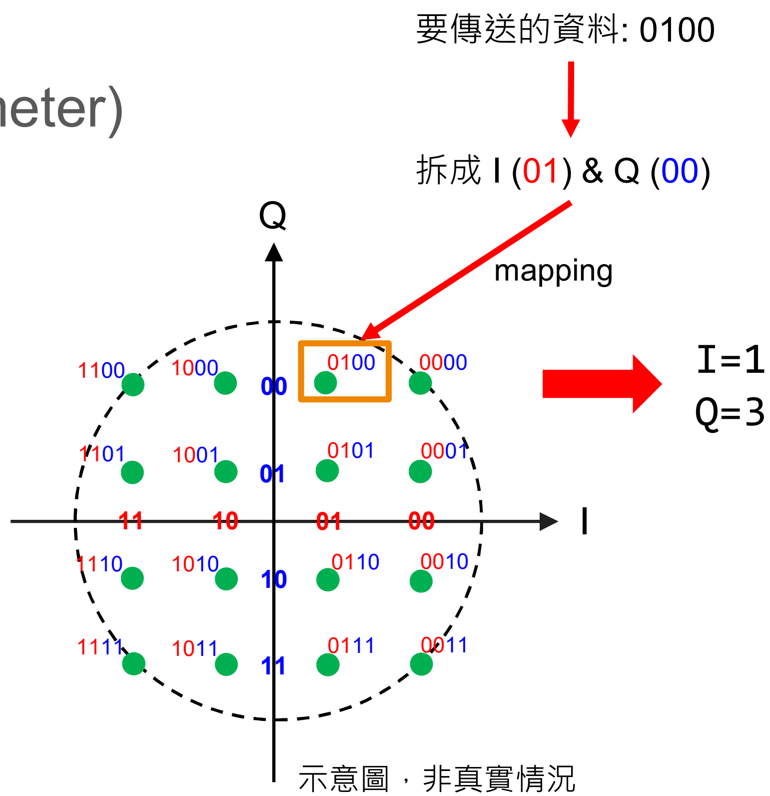
udCompMeth	compression method	udIqWidth meaning
0000b	no compression	bitwidth of each uncompressed I and Q value
0001b	block floating point (BFP)	bitwidth of each I and Q mantissa value
0010b	block scaling	bitwidth of each I and Q scaled value
0011b	μ-law	bitwidth of each compressed I and Q value
0100b	modulation compression	bitwidth of each compressed I and Q value
0101b	BFP + selective RE sending	bitwidth of each compressed I and Q value
0110b	mod-compr + selective RE sending	bitwidth of each compressed I and Q value
0111b – 1111b	reserved for future methods	depends on the specific compression method

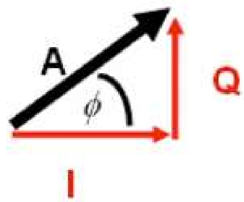
Information Elements - Section

- udCompLen
  - the total number of octets including padding in the PRB fields
  - The maximum supported PRB field length is $2^{16} - 1$
  - This field is only present when udCompMeth is 0x0101 or 0x0110

Information Elements - PRB

- udCompParam (user data compression parameter)
- iSample
  - 1~16 bits
- qSample
  - 1~16 bits





$$S(t) = A\cos(2\pi f t + \varphi) = \sqrt{I^2 + Q^2}\cos\left(2\pi f t + \tan^{-1}\left(\frac{Q}{I}\right)\right)$$

EVM Measurement (rms)

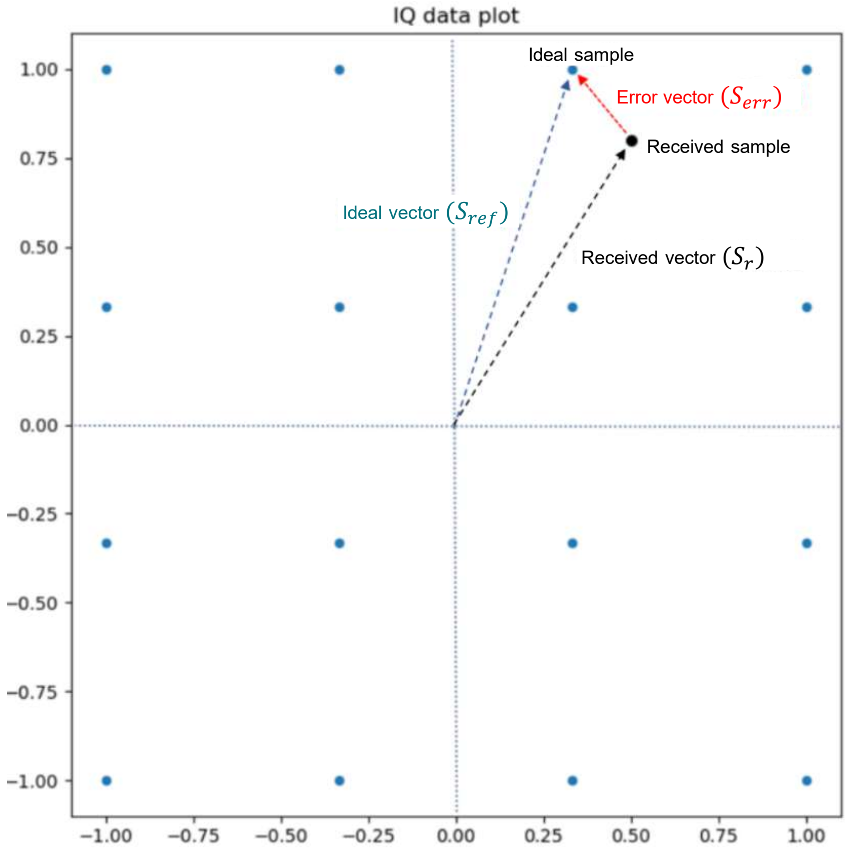
$$EVM(\%) = \frac{\sqrt{\frac{1}{N}\sum_{n=0}^{N-1}\left|S_{ref}(n) - S_r(n)\right|^2}}{\sqrt{\frac{1}{N}\sum_{n=0}^{N-1}\left|S_{ref}(n)\right|^2}} \times 100\%$$

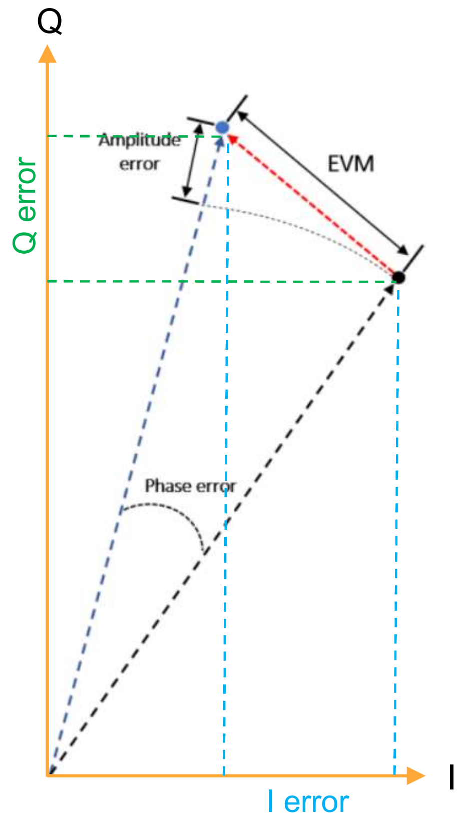
$$= \frac{\sqrt{\frac{1}{N}\sum_{n=0}^{N-1}\left|S_{err}(n)\right|^2}}{\sqrt{\frac{1}{N}\sum_{n=0}^{N-1}\left|S_{ref}(n)\right|^2}} \times 100\%$$

$$= \frac{\sqrt{\frac{1}{N}\sum_{n=0}^{N-1}\left(I_{err}(n)^2 + Q_{err}(n)^2\right)}}{\sqrt{\frac{1}{N}\sum_{n=0}^{N-1}\left(I_{ref}(n)^2 + Q_{ref}(n)^2\right)}} \times 100\%$$

- N is the number of samples
- S_{ref} is the reference vector
- S_r is the received vector
- S_{err} is the error vector

➔ 計算所有收到的 IQ sample 的誤差平均

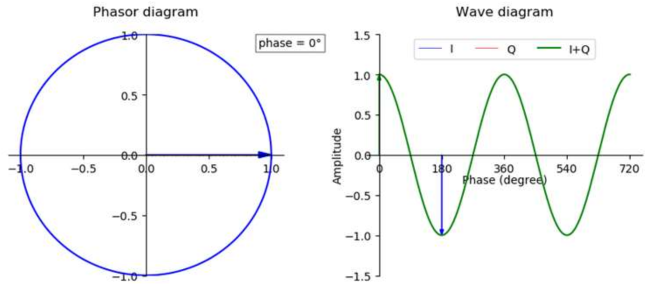




$EVM(dB) = 20 \times log\frac{EVM(\%)}{100(\%)}$, e.g. 3% 的 EVM 用對數表示為 -30.5 dB

Definition of IQ Power in dBFS

- The unit dBFS is a logarithmic measurement unit which assigns 0 dBFS as the maximum power level
  - For example, a power level of -15 dBFS indicates that the measured power is 15 dB below the maximum subcarrier power
- IQ power level in dBFS



$$= 10 \cdot \log_{10}(I^2 + Q^2) - 10 \cdot \log_{10}(FS)$$

$$= 10 \cdot \log_{10}\left(\frac{I^2+Q^2}{FS}\right)$$

  - FS is the full-scale reference value of one I or Q value squared
    - for example, with a signed 9-bit mantissa and a 4-bit exponent $FS = \left(2^{2^4-1} \cdot 2^{9-1}\right)^2 = 2^{46}$
      - 9-bit mantissa ➔ I/Q 有 9 bits
      - 4-bit exponent ➔ compression’s parameter

U-plane Message Sample

- ethernet header
  - dst mac ➔ 0x00 11 22 33 44 66
  - src mac ➔ 0xaa bb cc dd ee ff
  - vlan tag(TPID+PCP+CFI+VID) ➔ 0x81 00 04 02
    - the Default TPID value in IEEE 802.1Q is 0x8100
    - VID ➔ 0x402 (c-plane: 0x400)
  - eCPRI over Ethernet with Ethertype = 0xaefe

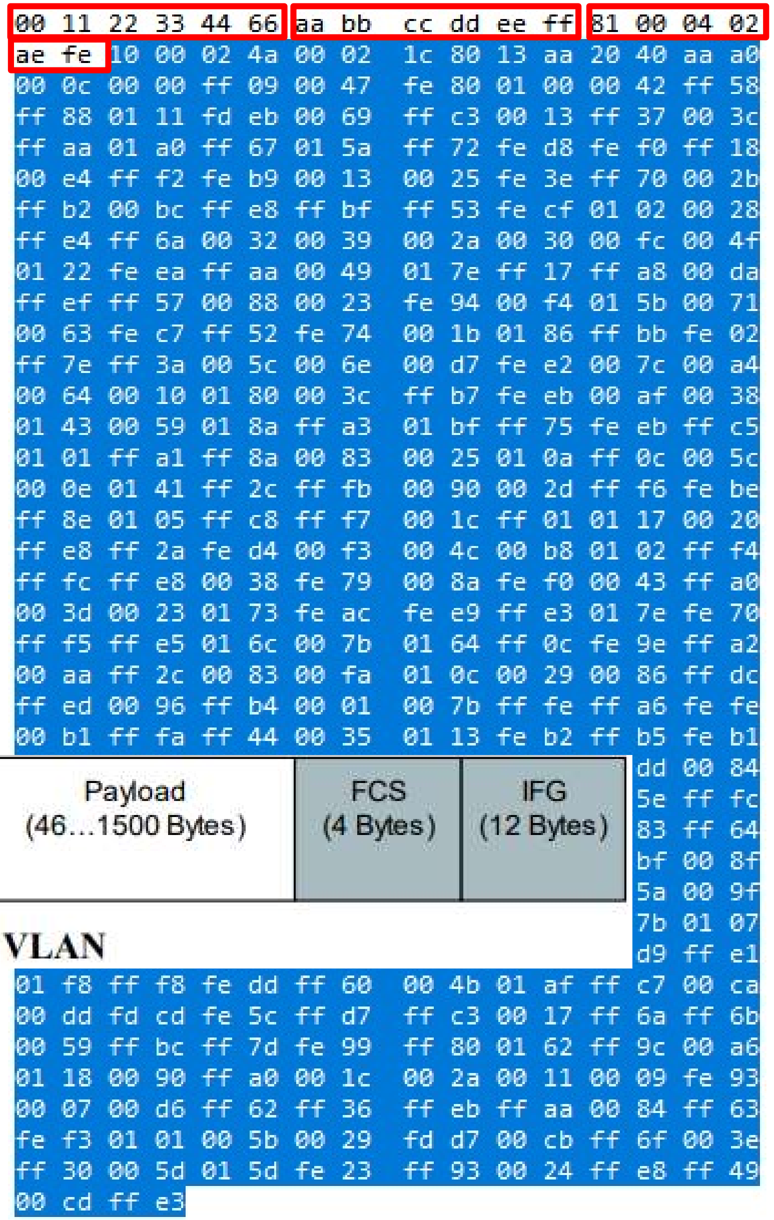


Figure 3-1 : Native Ethernet frame with VLAN

U-plane Message Sample

- eCPRI header
  - ecpri header
    - Byte 1
      - bit 0~3 ➔ ecpriVersion (固定是0001)
      - bit 4~6 ➔ reserved (000)
      - bit 7 ➔ concatenation (0, by default)
    - Byte 2 ➔ message type (0x00 user data)
    - Byte 3~4 ➔ ecpri payload size (0x024a=586 bytes)
  - ecpri payload
    - Byte 1~2 ➔ ecpriPcid
      - bit 0~3 ➔ DU_Port_ID
      - bit 4~7 ➔ BandSector_ID
      - bit 8~11 ➔ CC_ID
      - bit 12~15 ➔ RU_Port_ID (0x02/0x03)
    - Byte 3~4 (0x1c80=0001 1100 1000 0000)
      - bit 0~7 ➔ sequence ID (0x1c)
      - bit 8 ➔ E-bit (E=1，沒有fragmentation)
      - bit 9~15 ➔ subsequence ID (0x0)


```
00 11 22 33 44 66 aa bb  cc dd ee ff 81 00 04 02
ae fe 10 00 02 4a 00 02  1c 80 13 aa 20 40 aa a0
00 0c 00 00 ff 09 00 47  fe 80 01 00 00 42 ff 58
ff 88 01 11 fd eb 00 69  ff c3 00 13 ff 37 00 3c
ff aa 01 a0 ff 67 01 5a  ff 72 fe d8 fe f0 ff 18
00 e4 ff f2 fe b9 00 13  00 25 fe 3e ff 70 00 2b
ff b2 00 bc ff e8 ff bf  ff 53 fe cf 01 02 00 28
ff e4 ff 6a 00 32 00 39  00 2a 00 30 00 fc 00 4f
01 22 fe ea ff aa 00 49  01 7e ff 17 ff a8 00 da
ff ef ff 57 00 88 00 23  fe 94 00 f4 01 5b 00 71
00 63 fe c7 ff 52 fe 74  00 1b 01 86 ff bb fe 02
ff 7e ff 3a 00 5c 00 6e  00 d7 fe e2 00 7c 00 a4
00 64 00 10 01 80 00 3c  ff b7 fe eb 00 af 00 38
01 43 00 59 01 8a ff a3  01 bf ff 75 fe eb ff c5
01 01 ff a1 ff 8a 00 83  00 25 01 0a ff 0c 00 5c
00 0e 01 41 ff 2c ff fb  00 90 00 2d ff f6 fe be
ff 8e 01 05 ff c8 ff f7  00 1c ff 01 01 17 00 20
ff e8 ff 2a fe d4 00 f3  00 4c 00 b8 01 02 ff f4
ff fc ff e8 00 38 fe 79  00 8a fe f0 00 43 ff a0
00 3d 00 23 01 73 fe ac  fe e9 ff e3 01 7e fe 70
ff f5 ff e5 01 6c 00 7b  01 64 ff 0c fe 9e ff a2
00 aa ff 2c 00 83 00 fa  01 0c 00 29 00 86 ff dc
ff ed 00 96 ff b4 00 01  00 7b ff fe ff a6 fe fe
00 b1 ff fa ff 44 00 35  01 13 fe b2 ff b5 fe b1
00 f2 ff a4 01 9b fe be  ff 8d ff ad ff dd 00 84
00 7b 00 cc fe ef ff 4c  ff f2 ff a7 01 5e ff fc
fe ae 00 7c ff dc ff fb  ff fe 00 53 fe 83 ff 64
00 09 00 0a ff 7f ff 83  01 58 01 53 00 bf 00 8f
00 86 00 7a 00 3c fd 6b  ff c7 ff 8f fe 5a 00 9f
fd f2 ff d2 fe ba ff 4b  00 bf ff a8 00 7b 01 07
00 c6 fe 20 ff f6 01 bd  01 6c fe f6 ff d9 ff e1
01 f8 ff f8 fe dd ff 60  00 4b 01 af ff c7 00 ca
00 dd fd cd fe 5c ff d7  ff c3 00 17 ff 6a ff 6b
00 59 ff bc ff 7d fe 99  ff 80 01 62 ff 9c 00 a6
01 18 00 90 ff a0 00 1c  00 2a 00 11 00 09 fe 93
00 07 00 d6 ff 62 ff 36  ff eb ff aa 00 84 ff 63
fe f3 01 01 00 5b 00 29  fd d7 00 cb ff 6f 00 3e
ff 30 00 5d 01 5d fe 23  ff 93 00 24 ff e8 ff 49
00 cd ff e3
```

U-plane Message Sample

- Common header
  - Byte 1 (DL=0x90, UL=0x10, preamble=0x13)
    - bit 0 ➔ dataDirection (DL=1, UL=0)
    - bit 1~3 ➔ payload version (固定是001)
    - bit 4~7 ➔ filterIndex (0000 for standard filter, 0011 for preamble)
  - Byte 2 ➔ frame ID (0xaa)=SFN(0~255)
    - For frame 0xaa, preamble data 落在 955~978
  - Byte 3
    - bit 0~3 ➔ subframe ID
    - bit 4~7 ➔ slot ID
  - Byte 4
    - bit 0~1 ➔ slot ID
    - bit 2~7 ➔ start symbol ID
    - 0x2040=0010 0000 0100 0000 ➔ subframe 2, slot 1, symbol 0
    - ~0x204b=0010 0000 0100 1011 ➔ subframe 2, slot 1, symbol 11

PRACH Configuration Index	Preamble format	$n_{SFN} \bmod x = y$		Subframe number	Starting symbol	Number of PRACH slots within a subframe	$N_t^{RA,slot}$, number of time-domain PRACH occasions within a PRACH slot	N_{dur}^{RA}, PRACH duration
		x	y					
156	B4	1	0	2	0	1	1	12


```
00 11 22 33 44 66 aa bb  cc dd ee ff 81 00 04 02
ae fe 10 00 02 4a 00 02  1c 80 13 aa 20 40 aa a0
00 0c 00 00 ff 09 00 47  fe 80 01 00 00 42 ff 58
ff 88 01 11 fd eb 00 69  ff c3 00 13 ff 37 00 3c
ff aa 01 a0 ff 67 01 5a  ff 72 fe d8 fe f0 ff 18
00 e4 ff f2 fe b9 00 13  00 25 fe 3e ff 70 00 2b
ff b2 00 bc ff e8 ff bf  ff 53 fe cf 01 02 00 28
ff e4 ff 6a 00 32 00 39  00 2a 00 30 00 fc 00 4f
01 22 fe ea ff aa 00 49  01 7e ff 17 ff a8 00 da
ff ef ff 57 00 88 00 23  fe 94 00 f4 01 5b 00 71
00 63 fe c7 ff 52 fe 74  00 1b 01 86 ff bb fe 02
ff 7e ff 3a 00 5c 00 6e  00 d7 fe e2 00 7c 00 a4
00 64 00 10 01 80 00 3c  ff b7 fe eb 00 af 00 38
01 43 00 59 01 8a ff a3  01 bf ff 75 fe eb ff c5
01 01 ff a1 ff 8a 00 83  00 25 01 0a ff 0c 00 5c
00 0e 01 41 ff 2c ff fb  00 90 00 2d ff f6 fe be
ff 8e 01 05 ff c8 ff f7  00 1c ff 01 01 17 00 20
ff e8 ff 2a fe d4 00 f3  00 4c 00 b8 01 02 ff f4
ff fc ff e8 00 38 fe 79  00 8a fe f0 00 43 ff a0
00 3d 00 23 01 73 fe ac  fe e9 ff e3 01 7e fe 70
ff f5 ff e5 01 6c 00 7b  01 64 ff 0c fe 9e ff a2
00 aa ff 2c 00 83 00 fa  01 0c 00 29 00 86 ff dc
ff ed 00 96 ff b4 00 01  00 7b ff fe ff a6 fe fe
00 b1 ff fa ff 44 00 35  01 13 fe b2 ff b5 fe b1
00 f2 ff a4 01 9b fe be  ff 8d ff ad ff dd 00 84
00 7b 00 cc fe ef ff 4c  ff f2 ff a7 01 5e ff fc
fe ae 00 7c ff dc ff fb  ff fe 00 53 fe 83 ff 64
00 09 00 0a ff 7f ff 83  01 58 01 53 00 bf 00 8f
00 86 00 7a 00 3c fd 6b  ff c7 ff 8f fe 5a 00 9f
fd f2 ff d2 fe ba ff 4b  00 bf ff a8 00 7b 01 07
00 c6 fe 20 ff f6 01 bd  01 6c fe f6 ff d9 ff e1
01 f8 ff f8 fe dd ff 60  00 4b 01 af ff c7 00 ca
00 dd fd cd fe 5c ff d7  ff c3 00 17 ff 6a ff 6b
00 59 ff bc ff 7d fe 99  ff 80 01 62 ff 9c 00 a6
01 18 00 90 ff a0 00 1c  00 2a 00 11 00 09 fe 93
00 07 00 d6 ff 62 ff 36  ff eb ff aa 00 84 ff 63
fe f3 01 01 00 5b 00 29  fd d7 00 cb ff 6f 00 3e
ff 30 00 5d 01 5d fe 23  ff 93 00 24 ff e8 ff 49
00 cd ff e3
```

U-plane Message Sample

- Section filed
  - Byte 1 ➔ section ID
  - Byte 2
    - bit 0~3 ➔ section ID (0xaaa ➔ 對應到 c-plane)
    - bit 4 ➔ rb
    - bit 5 ➔ symInc
    - bit 6~7 ➔ startPrbu
  - Byte 3 ➔ startPrbu (0x0)
  - Byte 4 ➔ numPrbu (0x0c=12 PRBs)
  - Byte 5 ➔ udCompHdr (0x0 ➔ I/Q are 16 bits)
  - Byte 6 ➔ reserved
- 0xaa a0 00 0c

  = 1010 1010 1010 0000 0000 0000 0000 1100

  Section ID=2730, startPrbu=0, numPrbu=12

```
00 11 22 33 44 66 aa bb  cc dd ee ff 81 00 04 02
ae fe 10 00 02 4a 00 02  1c 80 13 aa 20 40 aa a0
00 0c 00 00 ff 09 00 47  fe 80 01 00 00 42 ff 58
ff 88 01 11 fd eb 00 69  ff c3 00 13 ff 37 00 3c
ff aa 01 a0 ff 67 01 5a  ff 72 fe d8 fe f0 ff 18
00 e4 ff f2 fe b9 00 13  00 25 fe 3e ff 70 00 2b
ff b2 00 bc ff e8 ff bf  ff 53 fe cf 01 02 00 28
ff e4 ff 6a 00 32 00 39  00 2a 00 30 00 fc 00 4f
01 22 fe ea ff aa 00 49  01 7e ff 17 ff a8 00 da
ff ef ff 57 00 88 00 23  fe 94 00 f4 01 5b 00 71
00 63 fe c7 ff 52 fe 74  00 1b 01 86 ff bb fe 02
ff 7e ff 3a 00 5c 00 6e  00 d7 fe e2 00 7c 00 a4
00 64 00 10 01 80 00 3c  ff b7 fe eb 00 af 00 38
01 43 00 59 01 8a ff a3  01 bf ff 75 fe eb ff c5
01 01 ff a1 ff 8a 00 83  00 25 01 0a ff 0c 00 5c
00 0e 01 41 ff 2c ff fb  00 90 00 2d ff f6 fe be
ff 8e 01 05 ff c8 ff f7  00 1c ff 01 01 17 00 20
ff e8 ff 2a fe d4 00 f3  00 4c 00 b8 01 02 ff f4
ff fc ff e8 00 38 fe 79  00 8a fe f0 00 43 ff a0
00 3d 00 23 01 73 fe ac  fe e9 ff e3 01 7e fe 70
ff f5 ff e5 01 6c 00 7b  01 64 ff 0c fe 9e ff a2
00 aa ff 2c 00 83 00 fa  01 0c 00 29 00 86 ff dc
ff ed 00 96 ff b4 00 01  00 7b ff fe ff a6 fe fe
00 b1 ff fa ff 44 00 35  01 13 fe b2 ff b5 fe b1
00 f2 ff a4 01 9b fe be  ff 8d ff ad ff dd 00 84
00 7b 00 cc fe ef ff 4c  ff f2 ff a7 01 5e ff fc
fe ae 00 7c ff dc ff fb  ff fe 00 53 fe 83 ff 64
00 09 00 0a ff 7f ff 83  01 58 01 53 00 bf 00 8f
00 86 00 7a 00 3c fd 6b  ff c7 ff 8f fe 5a 00 9f
fd f2 ff d2 fe ba ff 4b  00 bf ff a8 00 7b 01 07
00 c6 fe 20 ff f6 01 bd  01 6c fe f6 ff d9 ff e1
01 f8 ff f8 fe dd ff 60  00 4b 01 af ff c7 00 ca
00 dd fd cd fe 5c ff d7  ff c3 00 17 ff 6a ff 6b
00 59 ff bc ff 7d fe 99  ff 80 01 62 ff 9c 00 a6
01 18 00 90 ff a0 00 1c  00 2a 00 11 00 09 fe 93
00 07 00 d6 ff 62 ff 36  ff eb ff aa 00 84 ff 63
fe f3 01 01 00 5b 00 29  fd d7 00 cb ff 6f 00 3e
ff 30 00 5d 01 5d fe 23  ff 93 00 24 ff e8 ff 49
00 cd ff e3
```

U-plane Message Sample

- PRB fields (preamble)
  - Total data in a symbol
    = (I/Q are each 2 bytes)/RE * 12 REs/PRB * 12 PRBs/symbol
    = (2 * 2) * 12 * 12 = 576 bytes

0 (msb)	1	2	3	4	5	6	7 (lsb)	Number of Octets	
…									
udCompParam								1	Octet N
I_{15}	I_{14}	I_{13}	I_{12}	I_{11}	I_{10}	I_9	I_8	1	N+1
I_7	I_6	I_5	I_4	I_3	I_2	I_1	I_0	1	N+2
Q_{15}	Q_{14}	Q_{13}	Q_{12}	Q_{11}	Q_{10}	Q_9	Q_8	1	N+3
Q_7	Q_6	Q_5	Q_4	Q_3	Q_2	Q_1	Q_0	1	N+4
…									
I_{15}	I_{14}	I_{13}	I_{12}	I_{11}	I_{10}	I_9	I_8	1	N+45
I_7	I_6	I_5	I_4	I_3	I_2	I_1	I_0	1	N+46
Q_{15}	Q_{14}	Q_{13}	Q_{12}	Q_{11}	Q_{10}	Q_9	Q_8	1	N+47
Q_7	Q_6	Q_5	Q_4	Q_3	Q_2	Q_1	Q_0	1	N+48
udCompParam								1	Octet M
I_{15}	I_{14}	I_{13}	I_{12}	I_{11}	I_{10}	I_9	I_8	1	M+1
I_7	I_6	I_5	I_4	I_3	I_2	I_1	I_0	1	M+2
Q_{15}	Q_{14}	Q_{13}	Q_{12}	Q_{11}	Q_{10}	Q_9	Q_8	1	M+3
Q_7	Q_6	Q_5	Q_4	Q_3	Q_2	Q_1	Q_0	1	M+4
…									
I_{15}	I_{14}	I_{13}	I_{12}	I_{11}	I_{10}	I_9	I_8	1	M+45
I_7	I_6	I_5	I_4	I_3	I_2	I_1	I_0	1	M+46
Q_{15}	Q_{14}	Q_{13}	Q_{12}	Q_{11}	Q_{10}	Q_9	Q_8	1	M+47
Q_7	Q_6	Q_5	Q_4	Q_3	Q_2	Q_1	Q_0	1	M+48
…									

RE 0 for I-data
RB 0
RE 11 for Q-data
RE 0 for I-data
RB 1
RE 11 for Q-data


```
00 11 22 33 44 66 aa bb  cc dd ee ff 81 00 04 02
ae fe 10 00 02 4a 00 02  1c 80 13 aa 20 40 aa a0
00 0c 00 00 ff 09 00 47  fe 80 01 00 00 42 ff 58
ff 88 01 11 fd eb 00 69  ff c3 00 13 ff 37 00 3c
ff aa 01 a0 ff 67 01 5a  ff 72 fe d8 fe f0 ff 18
00 e4 ff f2 fe b9 00 13  00 25 fe 3e ff 70 00 2b
ff b2 00 bc ff e8 ff bf  ff 53 fe cf 01 02 00 28
ff e4 ff 6a 00 32 00 39  00 2a 00 30 00 fc 00 4f
01 22 fe ea ff aa 00 49  01 7e ff 17 ff a8 00 da
ff ef ff 57 00 88 00 23  fe 94 00 f4 01 5b 00 71
00 63 fe c7 ff 52 fe 74  00 1b 01 86 ff bb fe 02
ff 7e ff 3a 00 5c 00 6e  00 d7 fe e2 00 7c 00 a4
00 64 00 10 01 80 00 3c  ff b7 fe eb 00 af 00 38
01 43 00 59 01 8a ff a3  01 bf ff 75 fe eb ff c5
01 01 ff a1 ff 8a 00 83  00 25 01 0a ff 0c 00 5c
00 0e 01 41 ff 2c ff fb  00 90 00 2d ff f6 fe be
ff 8e 01 05 ff c8 ff f7  00 1c ff 01 01 17 00 20
ff e8 ff 2a fe d4 00 f3  00 4c 00 b8 01 02 ff f4
ff fc ff e8 00 38 fe 79  00 8a fe f0 00 43 ff a0
00 3d 00 23 01 73 [illegible] e3 01 7e fe 70
ff f5 ff e5 01 6c 00 7b  01 64 ff 0c fe 9e ff a2
00 aa ff 2c 00 83 00 fa  01 0c 00 29 00 86 ff dc
ff ed 00 96 ff b4 00 01  00 7b ff fe ff a6 fe fe
00 b1 ff fa ff 44 00 35  01 13 fe b2 ff b5 fe b1
00 f2 ff a4 01 9b fe be  ff 8d ff ad ff dd 00 84
00 7b 00 cc fe ef ff 4c  ff f2 ff a7 01 5e ff fc
fe ae 00 7c ff dc ff fb  ff fe 00 53 fe 83 ff 64
00 09 00 0a ff 7f ff 83  01 58 01 53 00 bf 00 8f
00 86 00 7a 00 3c fd 6b  ff c7 ff 8f fe 5a 00 9f
fd f2 ff d2 fe ba ff 4b  00 bf ff a8 00 7b 01 07
00 c6 fe 20 ff f6 01 bd  01 6c fe f6 ff d9 ff e1
01 f8 ff f8 fe dd ff 60  00 4b 01 af ff c7 00 ca
00 dd fd cd fe 5c ff d7  ff c3 00 17 ff 6a ff 6b
00 59 ff bc ff 7d fe 99  ff 80 01 62 ff 9c 00 a6
01 18 00 90 ff a0 00 1c  00 2a 00 11 00 09 fe 93
00 07 00 d6 ff 62 ff 36  ff eb ff aa 00 84 ff 63
fe f3 01 01 00 5b 00 29  fd d7 00 cb ff 6f 00 3e
ff 30 00 5d 01 5d fe 23  ff 93 00 24 ff e8 ff 49
00 cd ff e3
```


576 bytes

Data Bytes for 1 RB

- 6 bits for I ➔ 12 bits for (I, Q)
  ➔ 12 bits for 1 subcarrier ➔ 12*12=144 bits=18 bytes for 1 RB

Table D-1. IQ data samples bit-ordering (6-bit IQ bitwidth example)

0 (msb)	1	2	3	4	5	6	7 (lsb)	Number of Octets	
…									
udCompParam								1	Octet N
I_5	I_4	I_3	I_2	I_1	I_0	Q_5	Q_4	1	N+1
Q_3	Q_2	Q_1	Q_0	…				1	N+2
…									
			…	I_5	I_4	I_3	I_2	1	N+17
I_1	I_0	Q_5	Q_4	Q_3	Q_2	Q_1	Q_0	1	N+18
udCompParam								1	Octet M
I_5	I_4	I_3	I_2	I_1	I_0	Q_5	Q_4	1	M+1
Q_3	Q_2	Q_1	Q_0	…				1	M+2
…									
			…	I_5	I_4	I_3	I_2	1	M+17
I_1	I_0	Q_5	Q_4	Q_3	Q_2	Q_1	Q_0	1	M+18
…									

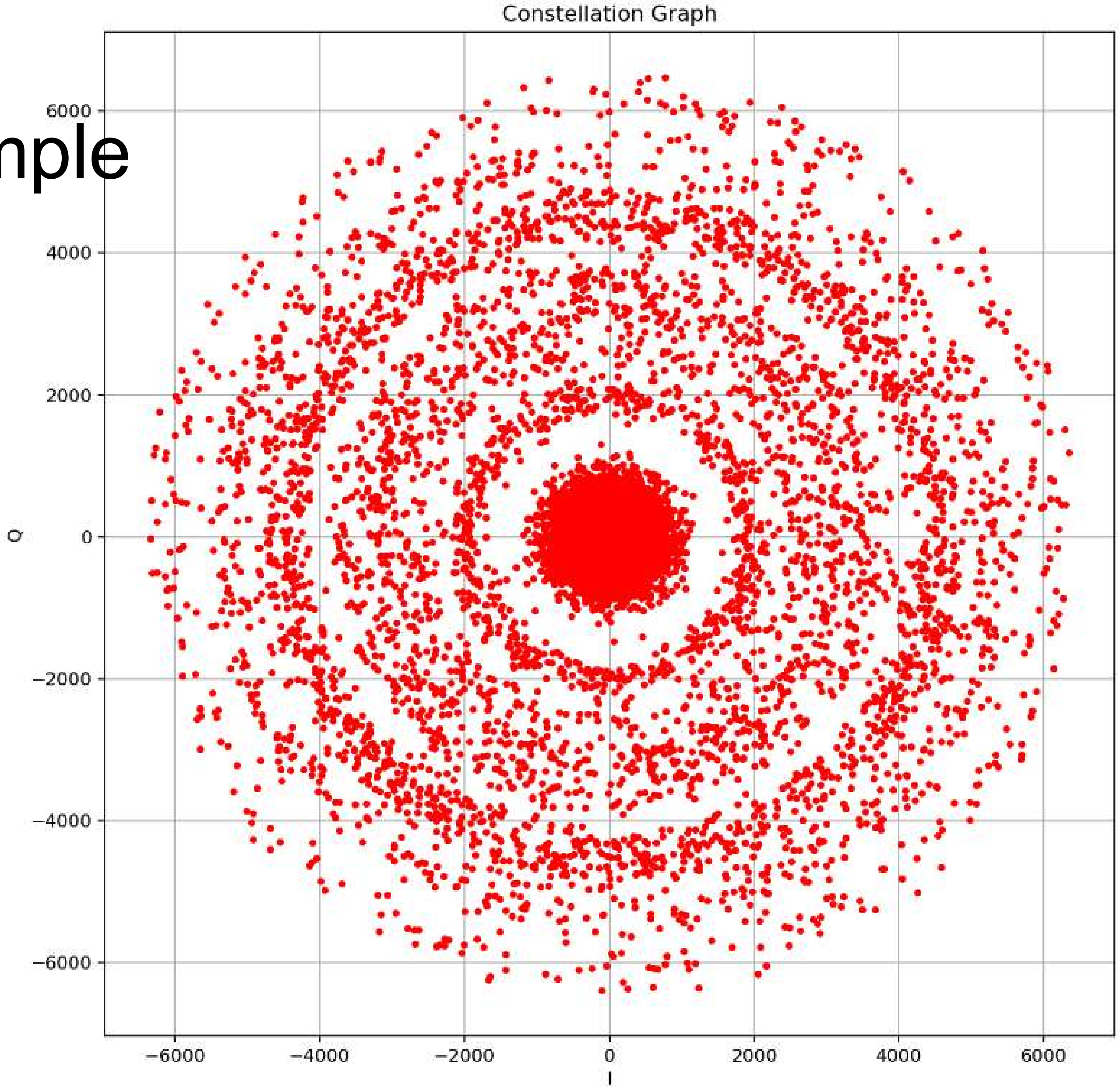
U-plane Message Sample

- Preamble U-plane ➔ 12 RBs totally
- PRB 0 (big endian + signed number)
  - ff 09 ➔ 第 1 個subcarrier 的 I ➔ -247
  - 00 47 ➔ 第 1 個subcarrier 的 Q ➔ 71
  - fe 80 ➔ 第 2 個subcarrier 的 I ➔ -384
  - 01 00 ➔ 第 2 個subcarrier 的 Q ➔ 256
  - 00 42 ➔ 第 3 個subcarrier 的 I ➔ 66
  - ff 58 ➔ 第 3 個subcarrier 的 Q ➔ -168
  - ff 88 ➔ 第 4 個subcarrier 的 I ➔ -120
  - 01 11 ➔ 第 4 個subcarrier 的 Q ➔ 273
  - fd eb ➔ 第 5 個subcarrier 的 I ➔ -533
  - 00 69 ➔ 第 5 個subcarrier 的 Q ➔ 105
  - ff c3 ➔ 第 6 個subcarrier 的 I ➔ -61
  - 00 13 ➔ 第 6 個subcarrier 的 Q ➔ 19
  - …


```
00 11 22 33 44 66 aa bb  cc dd ee ff 81 00 04 02
        RB0
ae fe 10 0[illegible] [illegible] 4a 00 02  1c 80 13 aa 20 40 aa a0
00 0c 00 00 ff 09 00 47  fe 80 01 00 00 42 ff 58
ff 88 01 11 fd eb 00 69  ff c3 00 13 ff 37 00 3c
ff aa 01 a0 ff 67 01 5a  ff 72 fe d8 fe f0 ff 18
00 e4 ff f2 fe b9 00 13  00 25 fe 3e ff 70 00 2b
ff b2 00 bc ff e8 ff bf  ff 53 fe cf 01 02 00 28
ff e4 ff 6a 00 32 00 39  00 2a 00 30 00 fc 00 4f
01 22 fe ea ff aa 00 49  01 7e ff 17 ff a8 00 da
ff ef ff 57 00 88 00 23  fe 94 00 f4 01 5b 00 71
00 63 fe c7 ff 52 fe 74  00 1b 01 86 ff bb fe 02
ff 7e ff 3a 00 5c 00 6e  00 d7 fe e2 00 7c 00 a4
00 64 00 10 01 80 00 3c  ff b7 fe eb 00 af 00 38
01 43 00 59 01 8a ff a3  01 bf ff 75 fe eb ff c5
01 01 ff a1 ff 8a 00 83  00 25 01 0a ff 0c 00 5c
00 0e 01 41 ff 2c ff fb  00 90 00 2d ff f6 fe be
ff 8e 01 05 ff c8 ff f7  00 1c ff 01 01 17 00 20
ff e8 ff 2a fe d4 00 f3  00 4c 00 b8 01 02 ff f4
ff fc ff e8 00 38 fe 79  00 8a fe f0 00 43 ff a0
00 3d 00 23 01 73 fe ac  fe e9 ff e3 01 7e fe 70
ff f5 ff e5 01 6c 00 7b  01 64 ff 0c fe 9e ff a2
00 aa ff 2c 00 83 00 fa  01 0c 00 29 00 86 ff dc
ff ed 00 96 ff b4 00 01  00 7b ff fe ff a6 fe fe
00 b1 ff fa ff 44 00 35  01 13 fe b2 ff b5 fe b1
00 f2 ff a4 01 9b fe be  ff 8d ff ad ff dd 00 84
00 7b 00 cc fe ef ff 4c  ff f2 ff a7 01 5e ff fc
fe ae 00 7c ff dc ff fb  ff fe 00 53 fe 83 ff 64
00 09 00 0a ff 7f ff 83  01 58 01 53 00 bf 00 8f
00 86 00 7a 00 3c fd 6b  ff c7 ff 8f fe 5a 00 9f
fd f2 ff d2 fe ba ff 4b  00 bf ff a8 00 7b 01 07
00 c6 fe 20 ff f6 01 bd  01 6c fe f6 ff d9 ff e1
01 f8 ff f8 fe dd ff 60  00 4b 01 af ff c7 00 ca
00 dd fd cd fe 5c ff d7  ff c3 00 17 ff 6a ff 6b
00 59 ff bc ff 7d fe 99  ff 80 01 62 ff 9c 00 a6
        RB11
01 18 00 9[illegible] [illegible] a0 00 1c  00 2a 00 11 00 09 fe 93
00 07 00 d6 ff 62 ff 36  ff eb ff aa 00 84 ff 63
fe f3 01 01 00 5b 00 29  fd d7 00 cb ff 6f 00 3e
ff 30 00 5d 01 5d fe 23  ff 93 00 24 ff e8 ff 49
00 cd ff e3
```

U-plane Message Sample

- eCPRI raw data to IQ samples
- 直出不校正
- 星座圖 via matplotlib



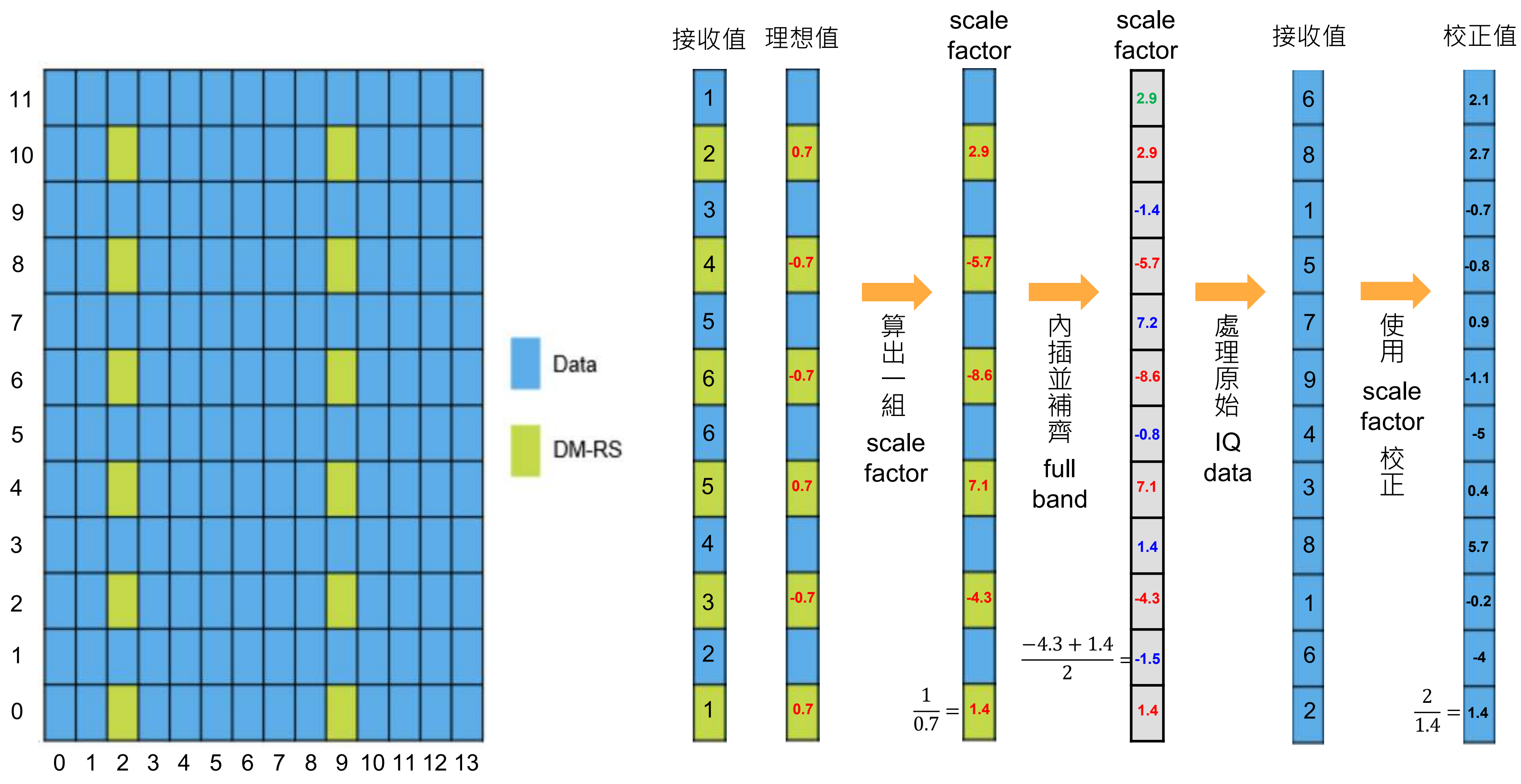
How to Generate DMRS Sequence

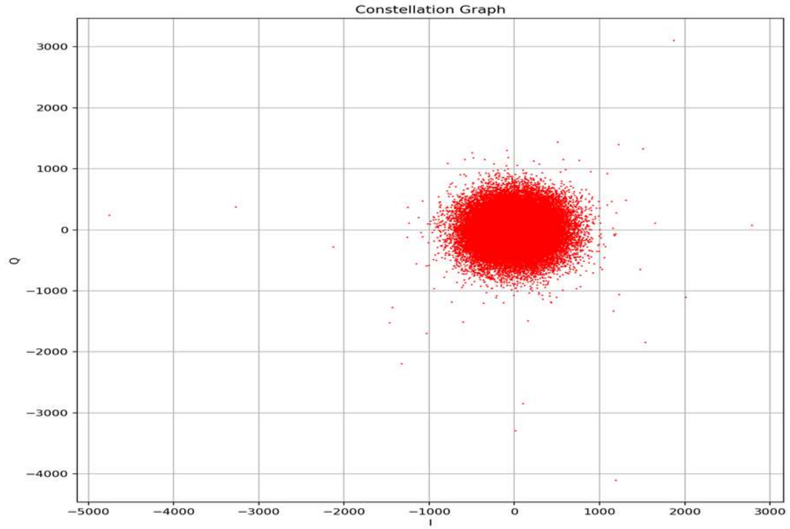
- DMRS Sequence $r(n) = \frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2n)\right) + j\frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2n+1)\right)$

  假設需要 1638 個，n就帶入 0~1637去算

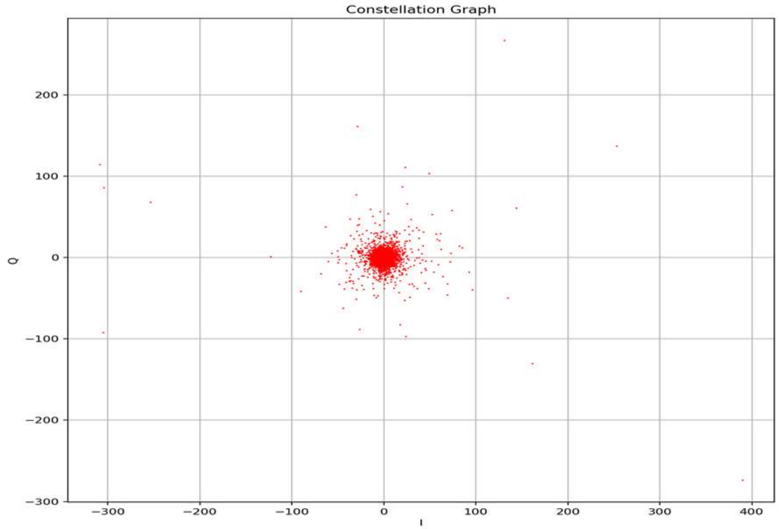
  - $c(n) = \left(x_1(n + N_c) + x_2(n + N_c)\right) \: mod \: 2, N_c = 1600$
  - $x_1(n + 31) = \left(x_1(n+3) + x_1(n)\right) \: mod \: 2$
    - $x_1(n)$ ➔ $x_1(0) = 1, x_1(n) = 0, n = 1,2, \ldots, 30$
      - $x_1(0\sim30) = [1\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0]$
      - $x_1(31)$ 之後就帶公式算，需要多少就算多少個出來
  - $x_2(n + 31) = \left(x_2(n+3) + x_2(n+2) + x_2(n+1) + x_2(n)\right) \: mod \: 2$
    - $c_{init} = \sum_{i=0}^{30} x_2(i) \cdot 2^i$
      - $c_{init} = \left(2^{17}\left(N_{symb}^{slot} n_{s,f}^{\mu} + l + 1\right)\left(2N_{ID}^{n_{SCID}} + 1\right) + 2\mathrm{N}_{\mathrm{ID}}^{n_{SCID}} + n_{SCID}\right) \: mod \: 2^{31}$
      - $c_{init} = x_2(0) \cdot 2^0 + x_2(1) \cdot 2^1 + x_2(2) \cdot 2^2 + x_2(3) \cdot 2^3 + \ldots + x_2(30) \cdot 2^{30}$
        - For example, c_{init} 算出來為 $[1\ 1\ 1\ 0\ 1\ 1\ 0\ 1\ 1\ 1\ 1\ 1\ 0\ 0\ 0\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 0\ 1\ 1\ 1\ 1\ 1\ 1\ 1]$
          則 $x_2(0\sim30)$ 為 c_{init} 的顛倒 $[1\ 1\ 1\ 1\ 1\ 1\ 1\ 0\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 0\ 0\ 0\ 1\ 1\ 1\ 1\ 1\ 0\ 1\ 1\ 0\ 1\ 1\ 1]$

- DMRS 是一串已知內容的序列 $r(n)=\frac{1}{\sqrt{2}}\left(1-2\cdot c(2n)\right)+j\frac{1}{\sqrt{2}}\left(1-2\cdot c(2n+1)\right)$
- symbol 2 DMRS 負責校正 symbol 0~6、 symbol 9 DMRS 負責校正 symbol 7~13
- The format of all elements are I+Qi，方便起見，以下例子皆簡化為一實數

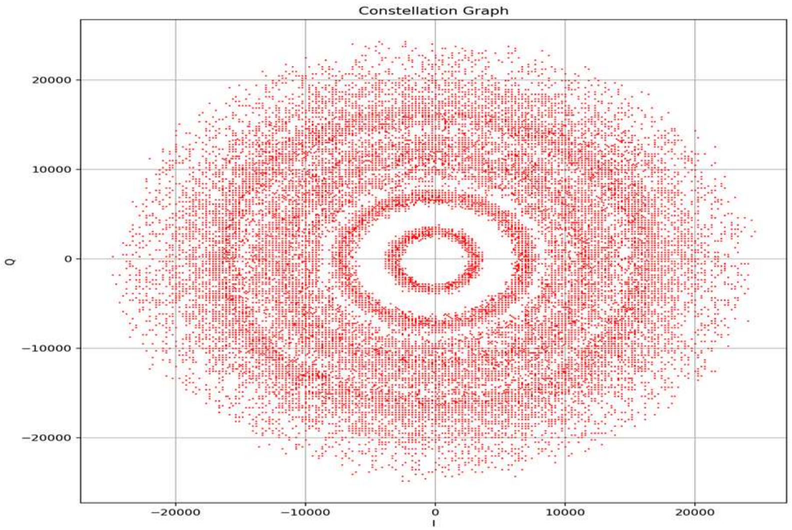




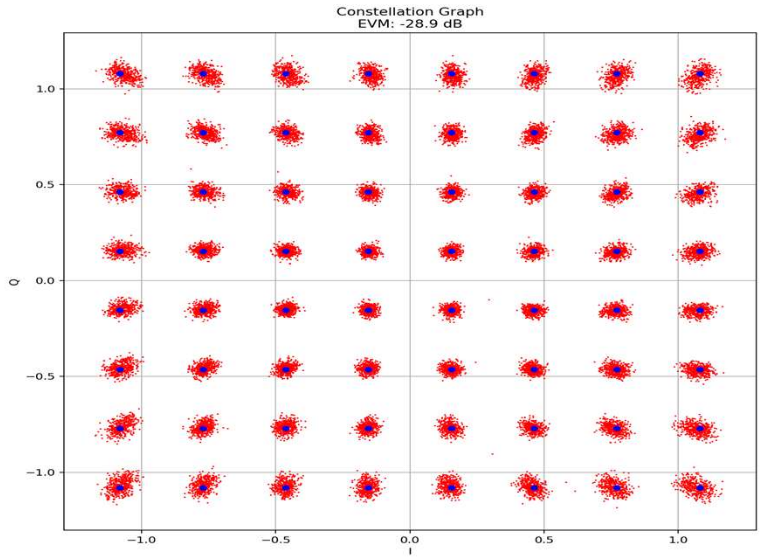
BLER + no Correction



BLER + Correction



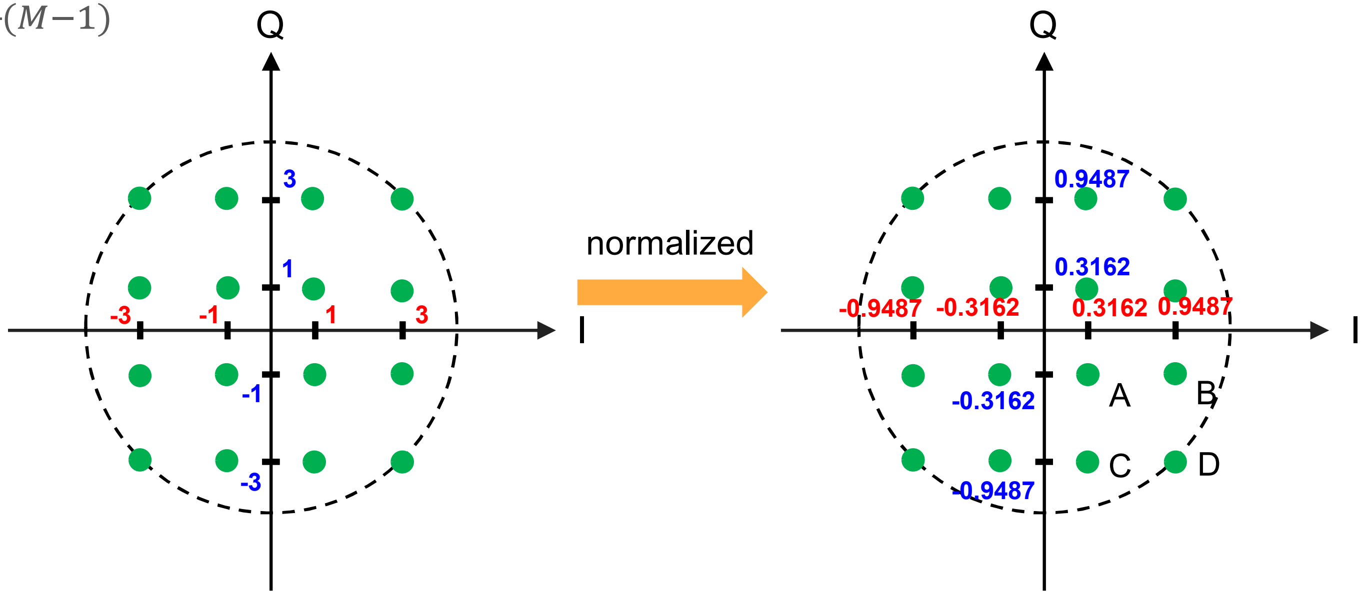
no BLER + no Correction



no BLER + Correction

Normalized Constellation Diagram

- The average of all amplitude in the normalized constellation will be equal to ONE.
- |A|+|B|+|C|+|D|=4
  - |A|=$\sqrt{0.3162^2+-0.3162^2}$、|B|=$\sqrt{0.9487^2+-0.3162^2}$
    |C|=$\sqrt{0.3162^2+-0.9487^2}$、|D|=$\sqrt{0.9487^2+-0.9487^2}$
- Normalizing Factor $=\frac{1}{\sqrt{\frac{2}{3}(M-1)}}$, M=4, 16, 64, 256



Modulation - QAM

- QPSK

$$d(i)=\frac{1}{\sqrt{2}}\left[\left(1-2b(2i)\right)+j\left(1-2b(2i+1)\right)\right]$$

- 16QAN

$$d(i)=\frac{1}{\sqrt{10}}\left\{\left(1-2b(4i)\right)\left[2-\left(1-2b(4i+2)\right)\right]+j\left(1-2b(4i+1)\right)\left[2-\left(1-2b(4i+3)\right)\right]\right\}$$

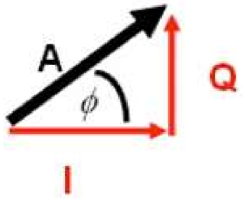
- 64QAN

$$d(i)=\frac{1}{\sqrt{42}}\left\{(1-2b(6i))\left[4-(1-2b(6i+2))\left[2-(1-2b(6i+4))\right]\right]+j(1-2b(6i+1))\left[4-(1-2b(6i+3))\left[2-(1-2b(6i+5))\right]\right]\right\}$$

- 256QAM

$$\begin{aligned}d(i)=\frac{1}{\sqrt{170}}\Big\{&(1-2b(8i))\left[8-(1-2b(8i+2))\left[4-(1-2b(8i+4))\left[2-(1-2b(8i+6))\right]\right]\right]\\&+j(1-2b(8i+1))\left[8-(1-2b(8i+3))\left[4-(1-2b(8i+5))\left[2-(1-2b(8i+7))\right]\right]\right]\Big\}\end{aligned}$$

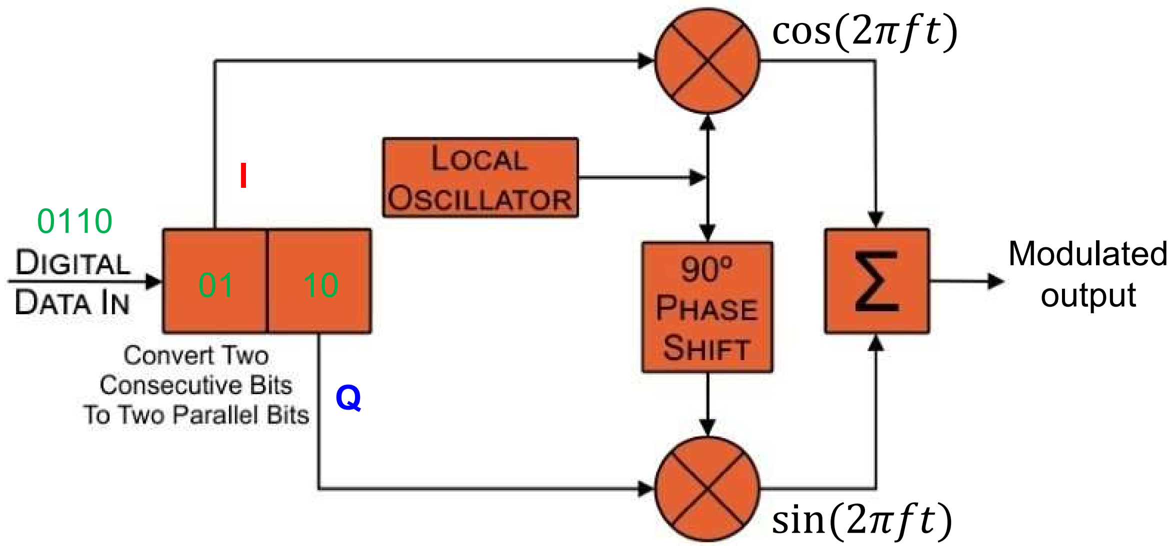
IQ Data Modulation in RU

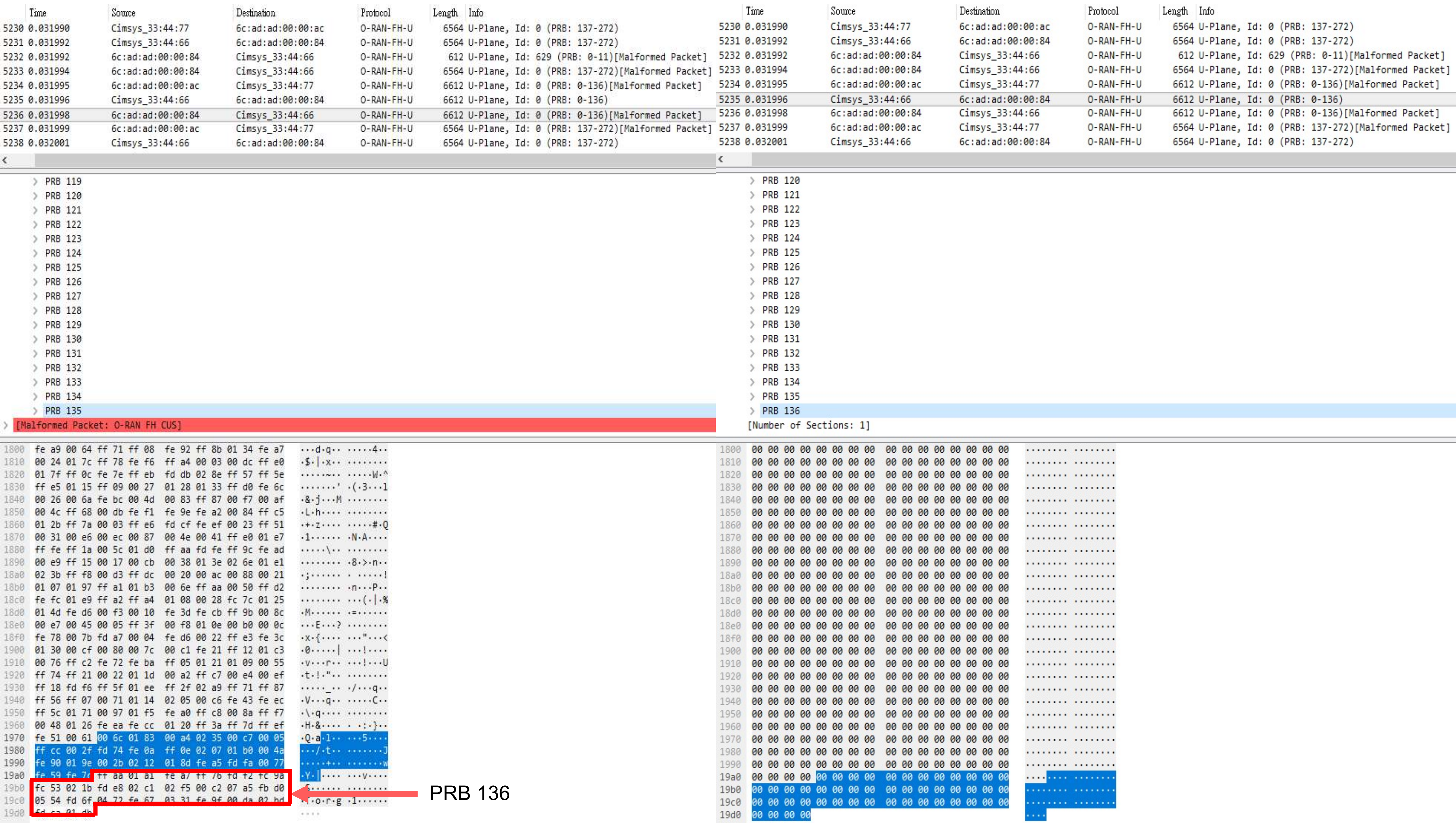


$$I = A\cos(\varphi)$$
$$Q = A\sin(\varphi)$$

在星座圖上
I：振幅=$A\cos(\varphi)$ 、相位=0° or 180°
Q：振幅=$A\sin(\varphi)$ 、相位=90° or 270°

$$\begin{aligned} S(t) &= A\cos(2\pi f t + \varphi) \\ &= A\cos(2\pi f t)\cos(\varphi) - A\sin(2\pi f t)\sin(\varphi) \\ &= I\cos(2\pi f t) - Q\sin(2\pi f t) \end{aligned}$$

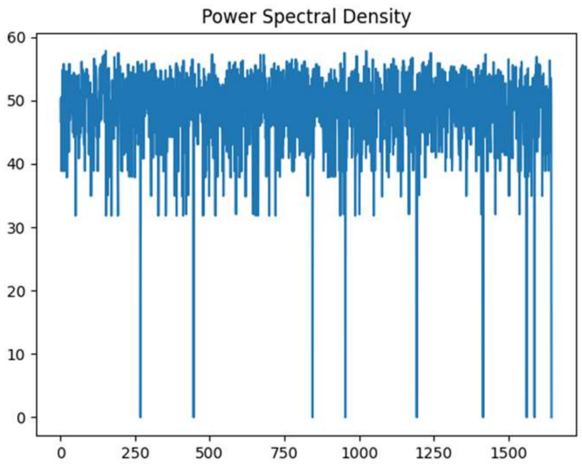



Time Source Destination Protocol Length Info
5230 0.031990 Cimsys_33:44:77 6c:ad:ad:00:00:ac O-RAN-FH-U 6564 U-Plane, Id: 0 (PRB: 137-272)
5231 0.031992 Cimsys_33:44:66 6c:ad:ad:00:00:84 O-RAN-FH-U 6564 U-Plane, Id: 0 (PRB: 137-272)
5232 0.031992 6c:ad:ad:00:00:84 Cimsys_33:44:66 O-RAN-FH-U 612 U-Plane, Id: 629 (PRB: 0-11)[Malformed Packet]
5233 0.031994 6c:ad:ad:00:00:84 Cimsys_33:44:66 O-RAN-FH-U 6564 U-Plane, Id: 0 (PRB: 137-272)[Malformed Packet]
5234 0.031995 6c:ad:ad:00:00:ac Cimsys_33:44:77 O-RAN-FH-U 6612 U-Plane, Id: 0 (PRB: 0-136)[Malformed Packet]
5235 0.031996 Cimsys_33:44:66 6c:ad:ad:00:00:84 O-RAN-FH-U 6612 U-Plane, Id: 0 (PRB: 0-136)
5236 0.031998 6c:ad:ad:00:00:84 Cimsys_33:44:66 O-RAN-FH-U 6612 U-Plane, Id: 0 (PRB: 0-136)[Malformed Packet]
5237 0.031999 6c:ad:ad:00:00:ac Cimsys_33:44:77 O-RAN-FH-U 6564 U-Plane, Id: 0 (PRB: 137-272)[Malformed Packet]
5238 0.032001 Cimsys_33:44:66 6c:ad:ad:00:00:84 O-RAN-FH-U 6564 U-Plane, Id: 0 (PRB: 137-272)
PRB 119
PRB 120
PRB 121
PRB 122
PRB 123
PRB 124
PRB 125
PRB 126
PRB 127
PRB 128
PRB 129
PRB 130
PRB 131
PRB 132
PRB 133
PRB 134
PRB 135
[Malformed Packet: O-RAN FH CUS]
PRB 136
PRB 120
PRB 121
PRB 122
PRB 123
PRB 124
PRB 125
PRB 126
PRB 127
PRB 128
PRB 129
PRB 130
PRB 131
PRB 132
PRB 133
PRB 134
PRB 135
PRB 136
[Number of Sections: 1]

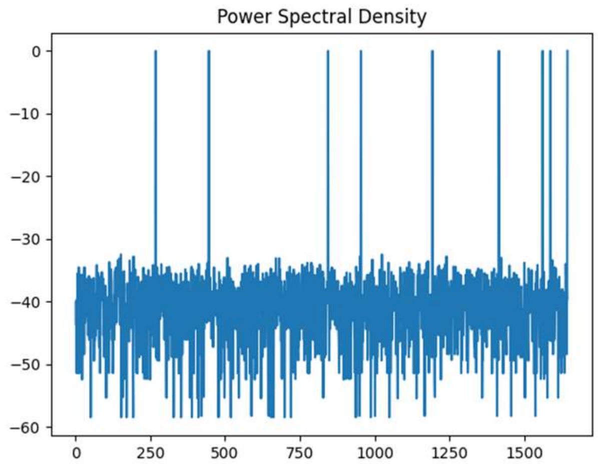
- I/Q rms
  - rms (Root Mean Square)

    I rms $= \sqrt{\frac{1}{N}\sum_{i=1}^{N} I_i^2}$

    Q rms $= \sqrt{\frac{1}{N}\sum_{i=1}^{N} Q_i^2}$
- Power level
  - a. $10 \cdot \log_{10}(I^2 + Q^2)$
  - b. $10 \cdot \log_{10}\left(\frac{I^2+Q^2}{FS}\right)$
    - $FS = 2^{30}$



a



b

Question

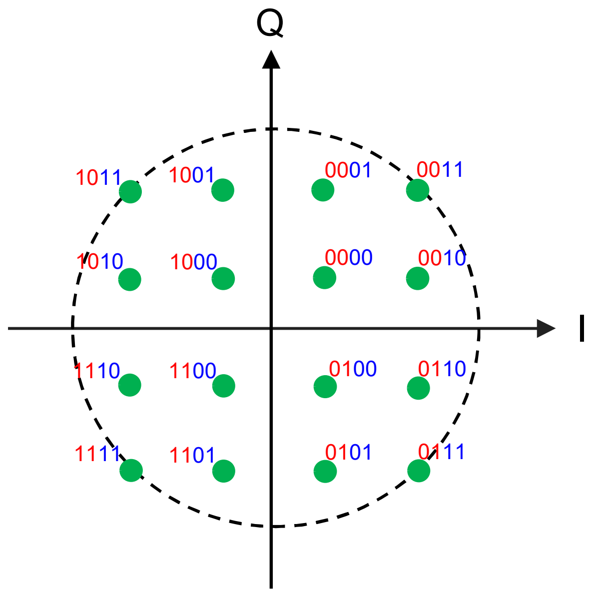
0 (msb)	1	2	3	4	5	6	7 (lsb)	Number of Octets	
…									
udCompParam								1	Octet N
I_{15}	I_{14}	I_{13}	I_{12}	I_{11}	I_{10}	I_9	I_8	1	N+1
I_7	I_6	I_5	I_4	I_3	I_2	I_1	I_0	1	N+2
Q_{15}	Q_{14}	Q_{13}	Q_{12}	Q_{11}	Q_{10}	Q_9	Q_8	1	N+3
Q_7	Q_6	Q_5	Q_4	Q_3	Q_2	Q_1	Q_0	1	N+4
…									
I_{15}	I_{14}	I_{13}	I_{12}	I_{11}	I_{10}	I_9	I_8	1	N+45
I_7	I_6	I_5	I_4	I_3	I_2	I_1	I_0	1	N+46
Q_{15}	Q_{14}	Q_{13}	Q_{12}	Q_{11}	Q_{10}	Q_9	Q_8	1	N+47
Q_7	Q_6	Q_5	Q_4	Q_3	Q_2	Q_1	Q_0	1	N+48

RE 0 for I-data

RB 0

RE 11 for Q-data

- Q1
  - 一個 RB 有 12 個 subcarriers
  - 256 QAM，一個 subcarrier 最多代表 8 bits
  - I+Q data in eCPRI 為什麼能有 32 bits?
- Q2
  - 256 QAM IQ 平面上，I/Q 各佔 4 bits
  - i.e. IQ 只需要 4 bits 就能描述了，為什麼會用到 16 bits
- Q3
  - I rms = $\sqrt{\frac{1}{N}\sum_{i=1}^{N} I_i^2}$
  - 為什麼不計算 $\frac{1}{N}\sum_{i=1}^{N} I_i$ 就好



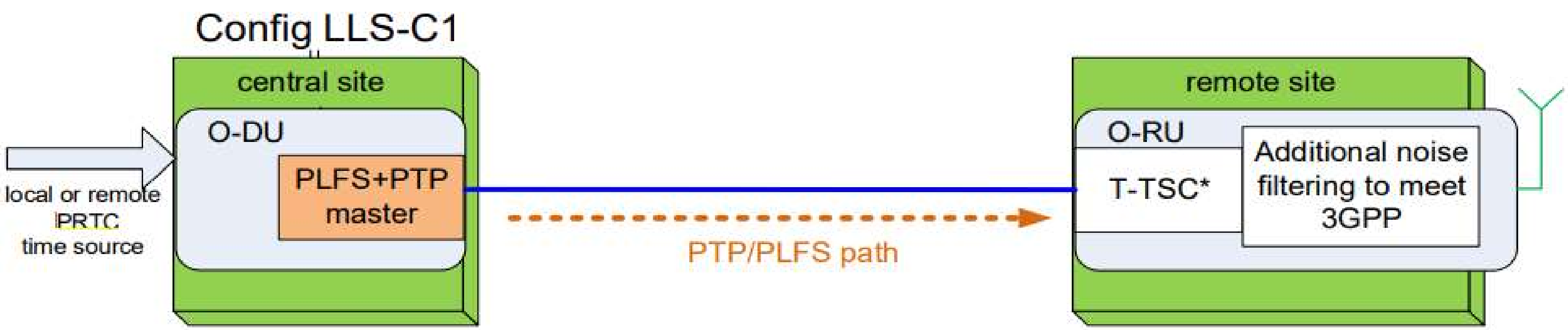
S-Plane Protocol

S-plane

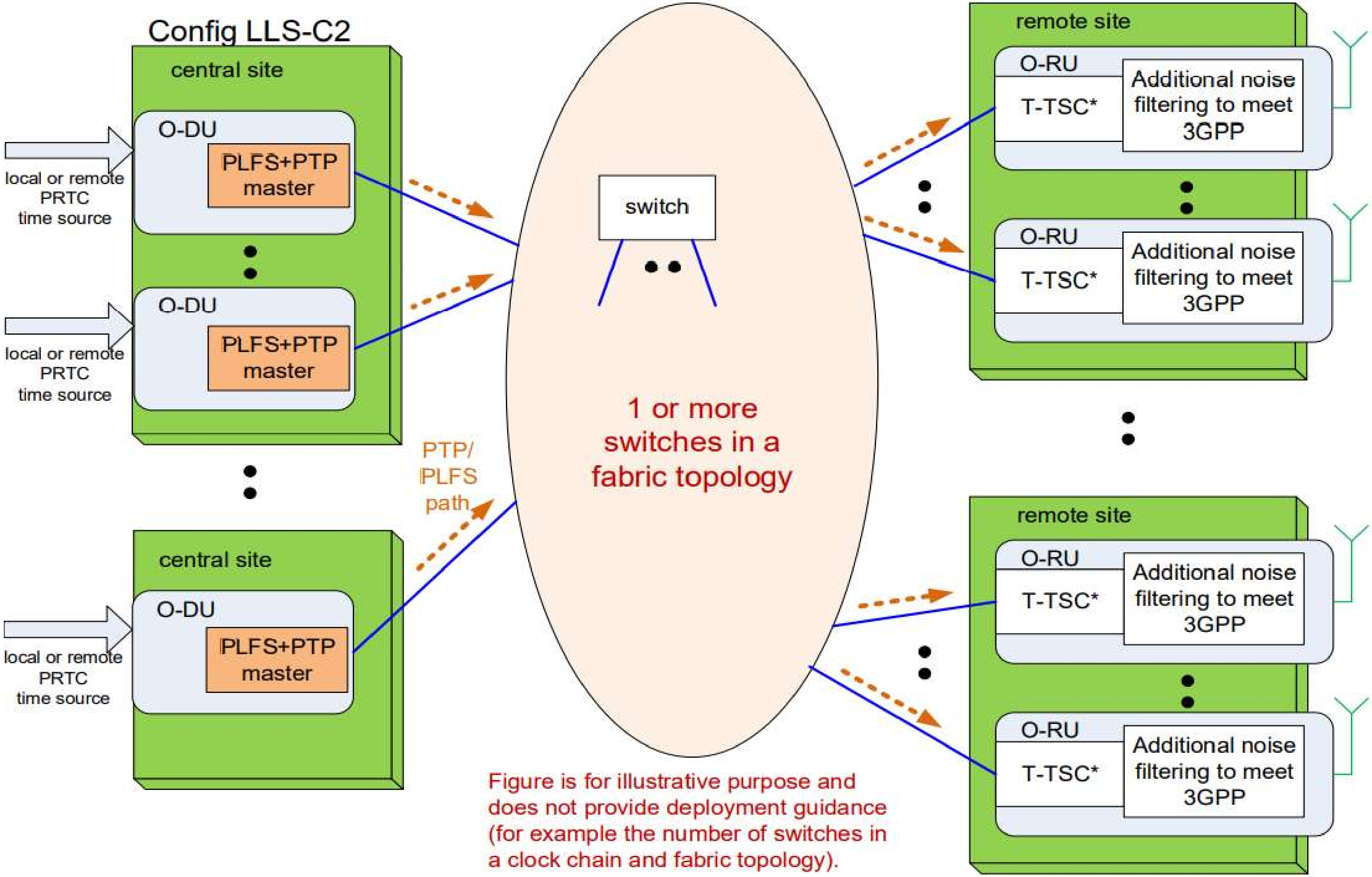
- O-RAN 基於 SyncE (Synchronous Ethernet) 及 PTP (IEEE Precision Time Protocol) 並以 Ethernet 做為時間與頻率的傳遞媒介，有四種 topology：C1、C2、C3、C4 ➔ 針對 O-RU 的同步源來區分
  - C1 是 O-DU 與 O-RU 點對點連接，並以 O-DU 為 SyncE 與 PTP 的同步源，使 O-RU 與之同步
  - C2 以 O-DU 為同步源，使 O-RUs 透過一個或多個 Ethernet switch 與 O-DU 進行同步
  - C3 的架構與 C2 相同，差別在於 C3 的 O-DUs 與 O-RUs 皆扮演 Slave Clock，以 PRTC/T-GM 為同步源，經過中間的 Ethernet switch，使 O-DUs 與 O-RUs 與之同步
  - C4 是 O-RU 自行連接 PRTC (typically a GNSS receiver)，而 fronthaul network 不需支援 PTP 及 SyncE

C1

- 是 O-DU 與 O-RU 點對點連接，並以 O-DU 為 SyncE 與 PTP 的同步源，使 O-RU 與之同步
    - O-DU may be synchronized from either a local or remote PTRC

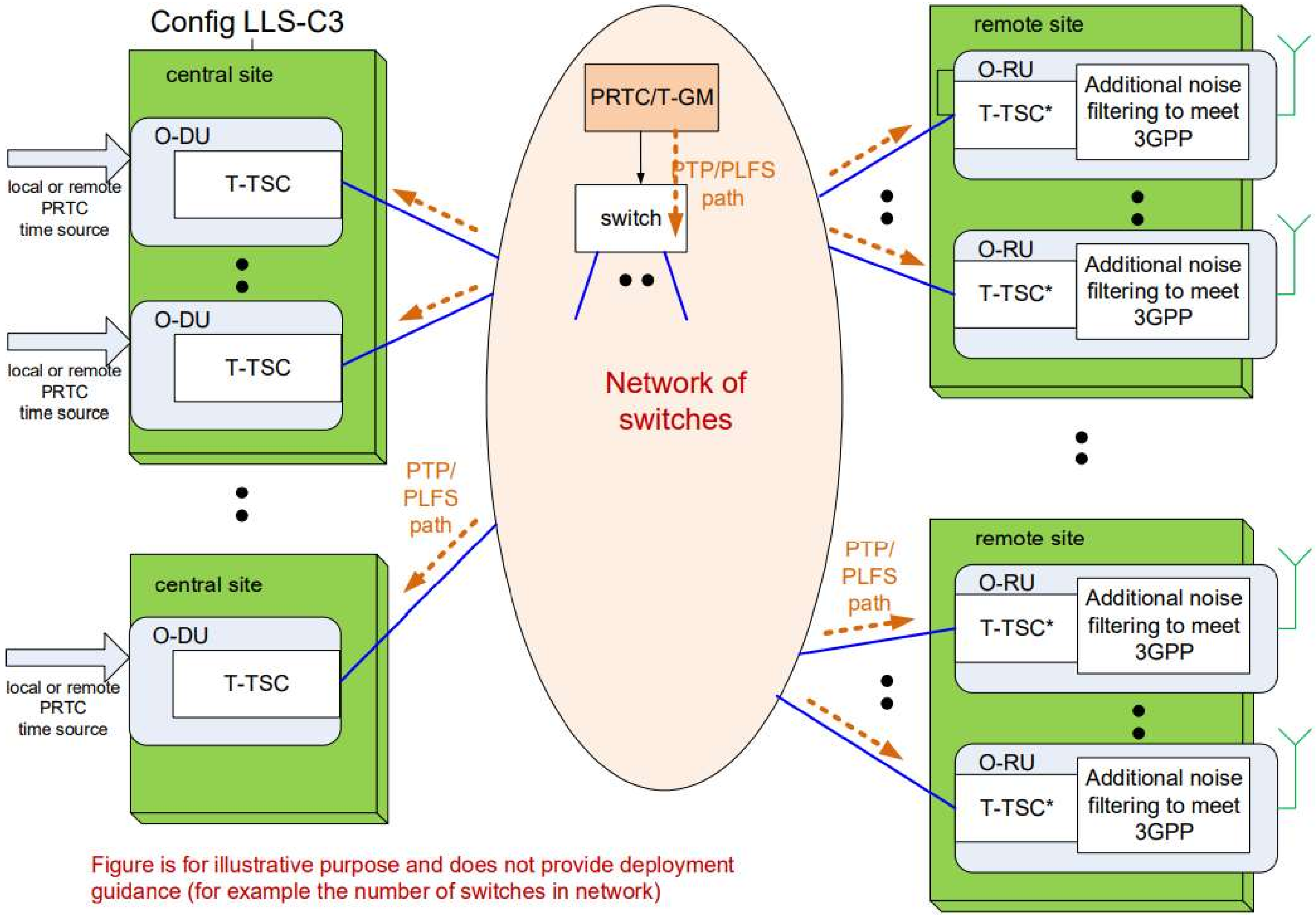


C2



- 以 O-DU 為同步源，使 O-RUs 透過一個或多個 Ethernet switch 與 O-DU 進行同步
- One O-DU shall serve as active GrandMaster to all O-RUs

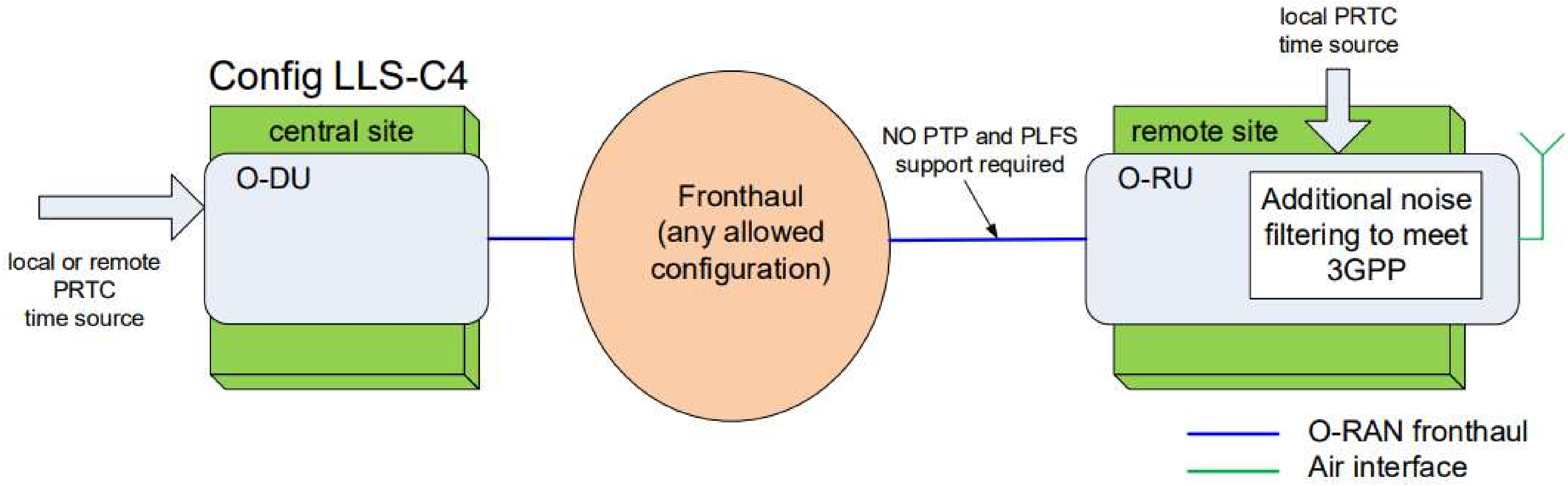
C3



- O-DUs 與 O-RUs 皆扮演 Slave Clock，以 PRTC/T-GM 為同步源，經過中間的 Ethernet switch，使 O-DUs 與 O-RUs 與之同步

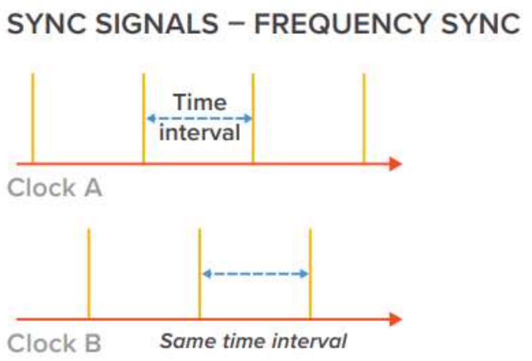
C4

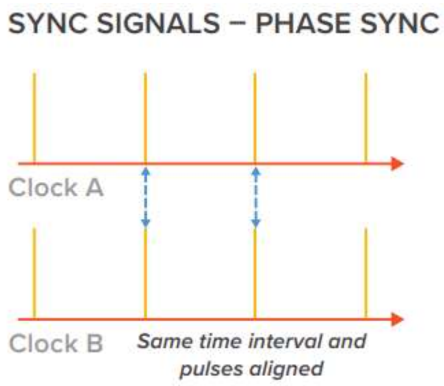
- O-RU 自行連接 PRTC (typically a GNSS receiver)

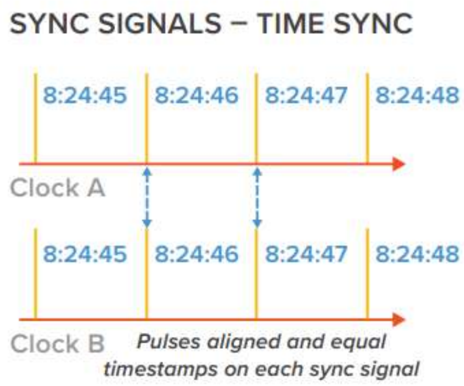


3 Basic Components of Network Synchronization

- Frequency Synchronization
  - Leading edge of the pulses are at same pace, but not at the identical moment
  - 讓 A 與 B 的時間走的一樣快，始終保持一個恆定的差，但是 A 與 B 的時間可能不一樣
- Phase Synchronization
  - Leading edge of the pulses are at the identical moment
  - 讓連續流逝的時間的某一瞬間是一致的
- Time Synchronization
  - Leading edge of the pulses are at the identical moment and identical time
  - 某一瞬間的時間，是一致的







Synchronization Technology

- GPS (Global Positioning System)
  - 通過電磁波攜帶頻率和相位信息，實現時間同步
  - 能精確到微秒 (us)
- NTP (Network Time Protocol)
  - NTP 協議較被廣泛用於 LAN 和 WAN 上的時間同步
  - 只能精確到毫秒 (ms)
- PTP (Precision Time Protocol)
  - A kind of 乙太網路同步技術
  - Defined in ITU-T G.8265, G.8275
  - 能精確到微秒 (us)
- SyncE
  - A kind of 乙太網路同步技術
  - Defined in ITU-T G.8261, G.8262, G.8264
  - Used for frequency synchronization
  - SyncE頻率同步+PTP時間同步，比單純用 PTP 時間同步，精度更高

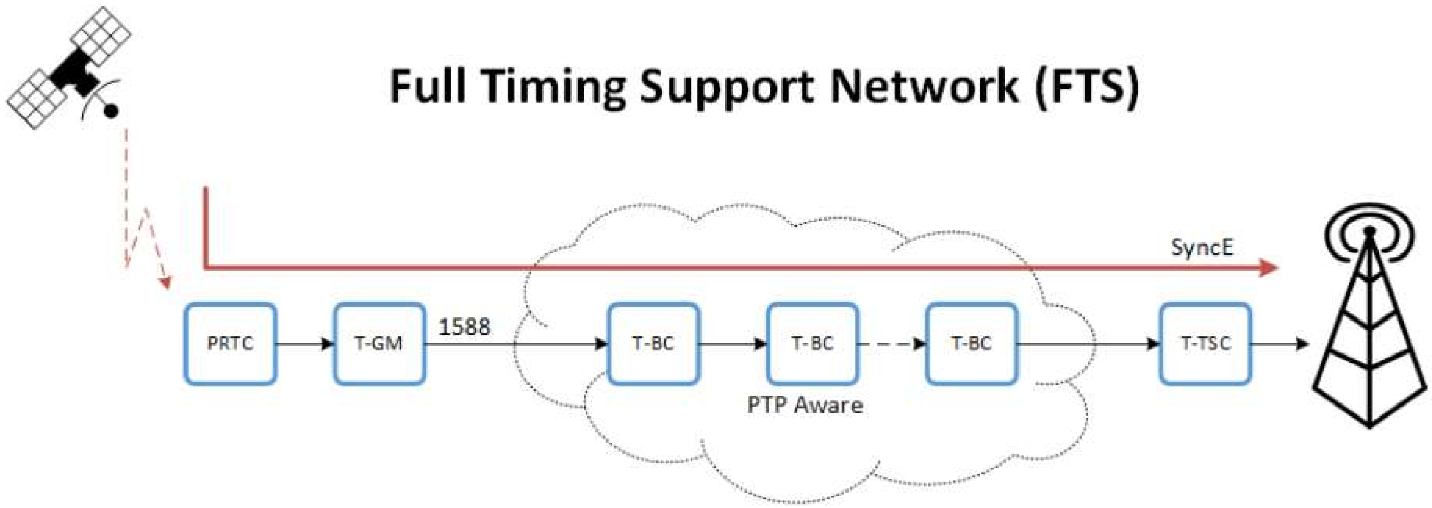
ITU-T Specifications for PTP

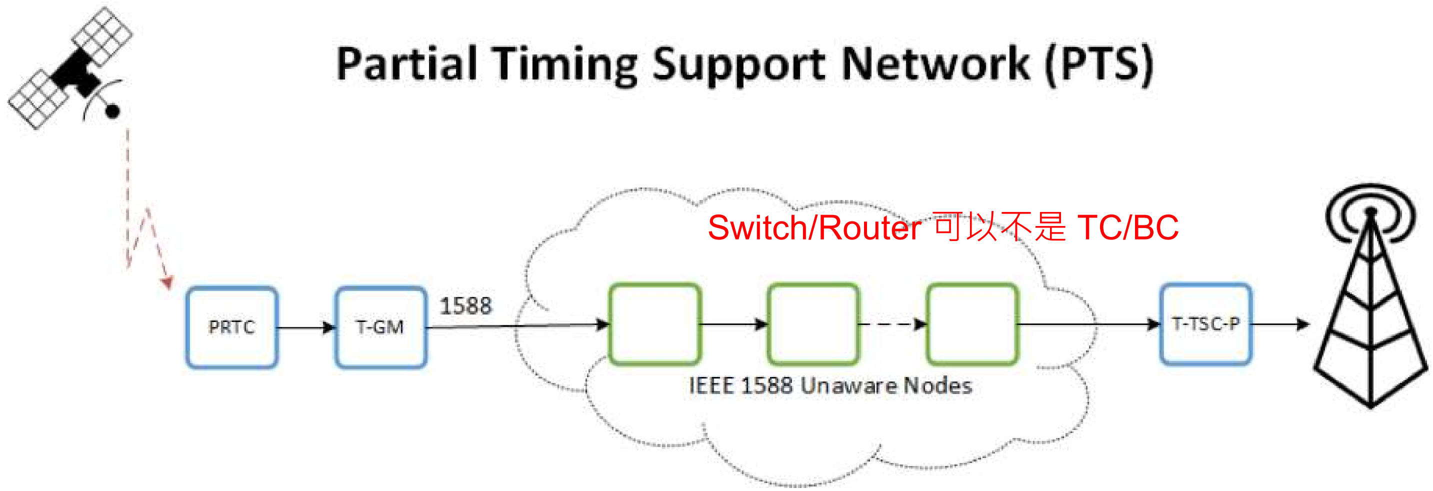
- G.8265.1
  - Precision time protocol telecom profile for frequency synchronization
- G.8275.1
  - Precision time protocol telecom profile for time/phase synchronization with full timing support from the network
  - multicast
- G.8275.2
  - Precision time protocol telecom profile for time/phase synchronization with partial timing support from the network
  - unicast

Timing Support

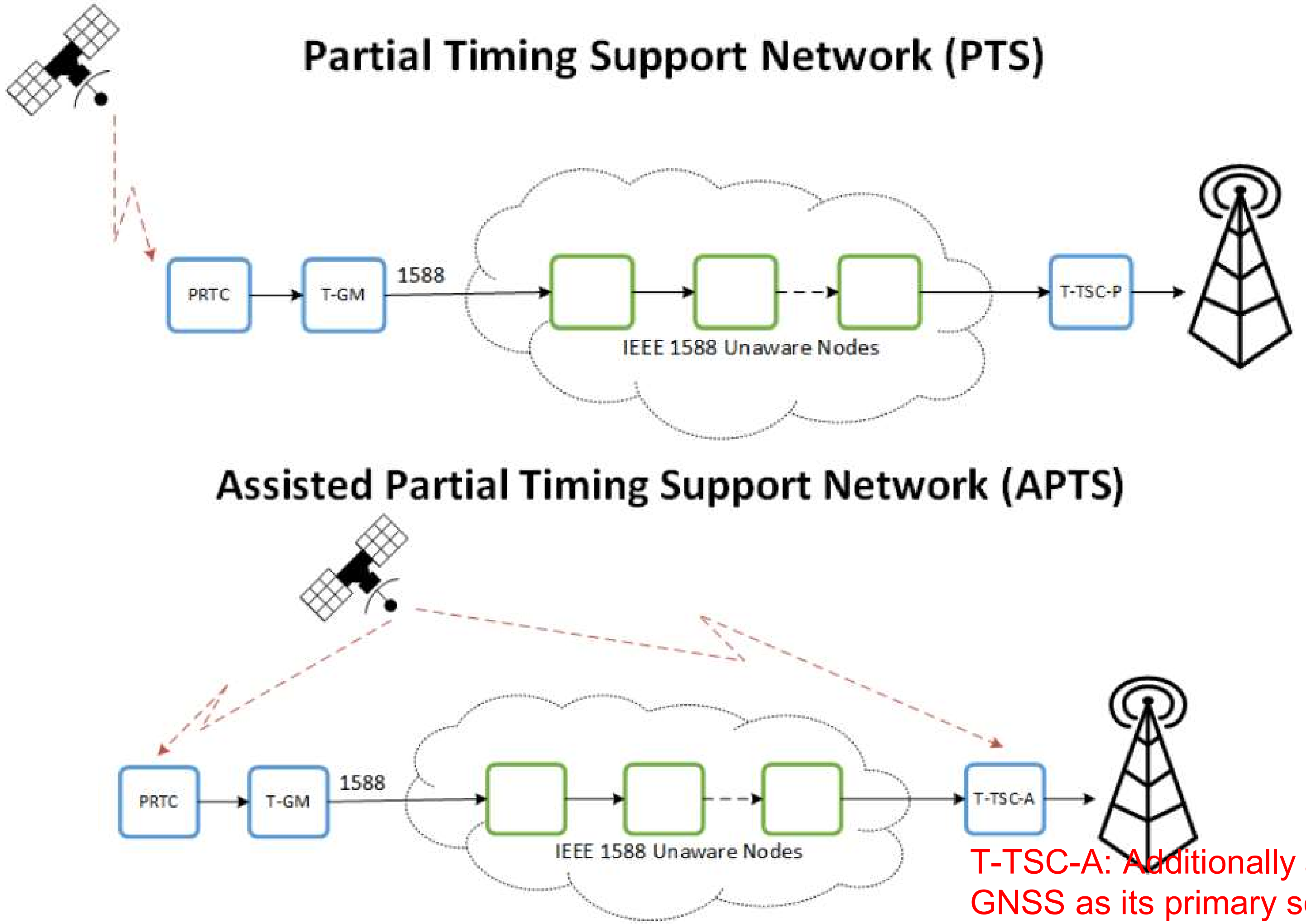
- G.8275.1
  - Full timing support
  - G.8275.1 is aimed at new build networks
- G.8275.2
  - Partial timing support
    - PTS
    - APTS
  - G.8275.2 is aimed at operation over existing networks
    - 在既有的網路環境，添加 PTP 設備，但那些舊有的 switch/router 未必具有 PTP 能力

ITU-T G.8275 Networks





ITU-T G.8275.2 Networks

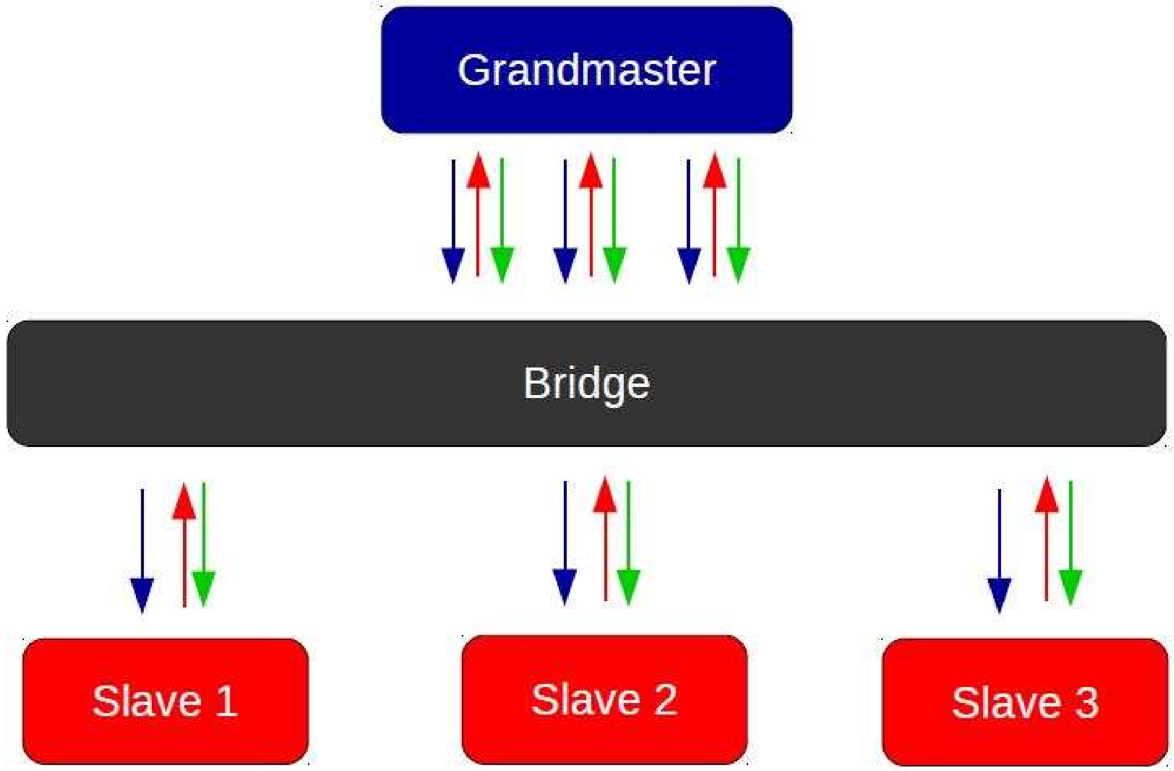


T-TSC-A: Additionally access to a GNSS as its primary source of time.

PTP Transmission Mode

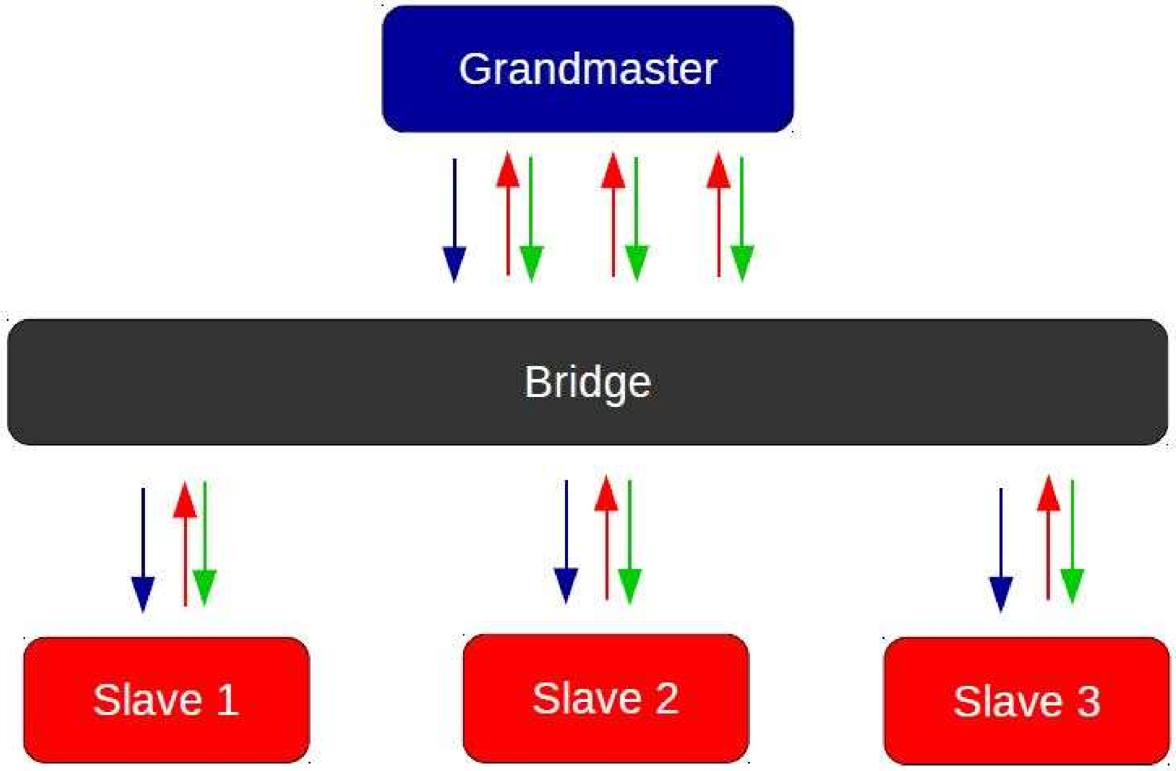
- There are three transmission modes
  - Multicast mode
  - Unicast mode
  - Multicast/Hybrid mode
    - Announce、Sync/Follow_up via Multicast mode
    - Delay_Req/Delay_Resp via Unicast mode

PTP Transmission



- *This diagram shows the timing messages exchanged among a grandmaster clock and three slave clocks, using unicast PTP. The bridge may be a transparent clock or a switch or router with no PTP capability. Color code: blue=Sync, red=delay request, green=delay response.*

PTP Transmission



- *This diagram shows the timing messages exchanged among a grandmaster clock and three slave clocks, using mixed multicast/unicast PTP. The bridge may be a transparent clock or a switch or router with no PTP capability. Color code: blue=Sync, red=delay request, green=delay response.*

PTP Domain

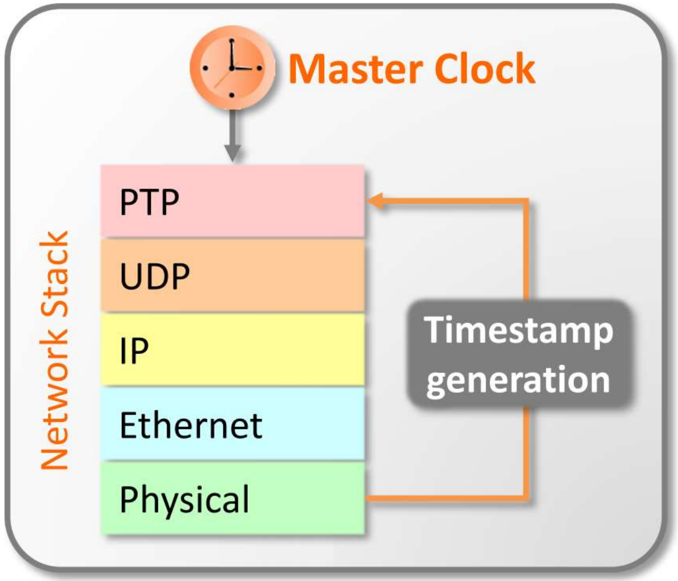
- 每個 domain 是獨立的，一個 domain 內只會有一個 Master Clock (0-255)
    - G.8275.1
        - 24, by default
        - the range of applicable PTP domain numbers is {24 – 43}
    - G.8275.2
        - 44, by default
        - the range of applicable PTP domain numbers is {44 – 63}

PTP Device Port

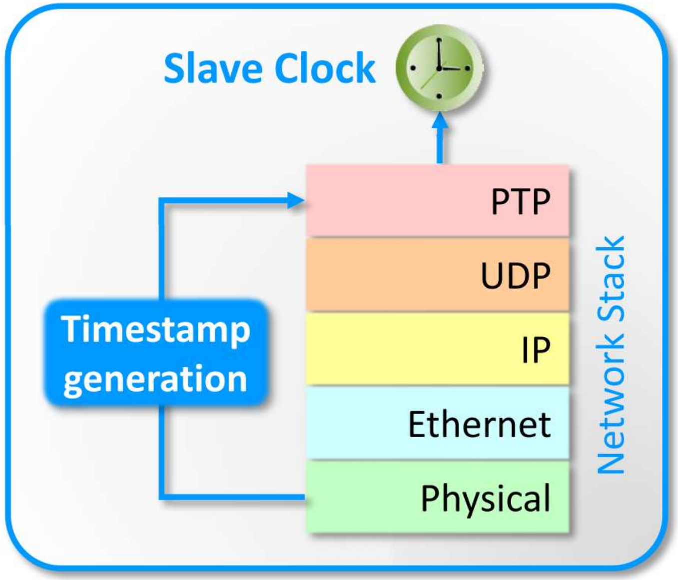
- Port
  - Master Port
    - 發佈同步時間的端口
  - Slave Port
    - 接收同步時間的端口
  - Passive Port
    - 既不接收同步時間、也不對外發布同步時間的端口，只存在於BC上
- Relationship
  - Master-Slaves
    - Master clock ➔發佈同步時間的 clock
    - Slave clock ➔ 接收同步時間的 clock

1-step sync message

- Sync message 的封包，是一層一層準備、包裝起來的
- 當封包經由 Physical 準備送出去時，必須即時動態更新 timestamp (t1) 到 PTP payload 中



- 當 Slave 收到 sync message，會一層一層拆開，取出 PTP payload，此外，會將 Physical layer 接收到封包時的 timestamp (t2) 記錄下來，與 PTP payload 中的 t1 做計算

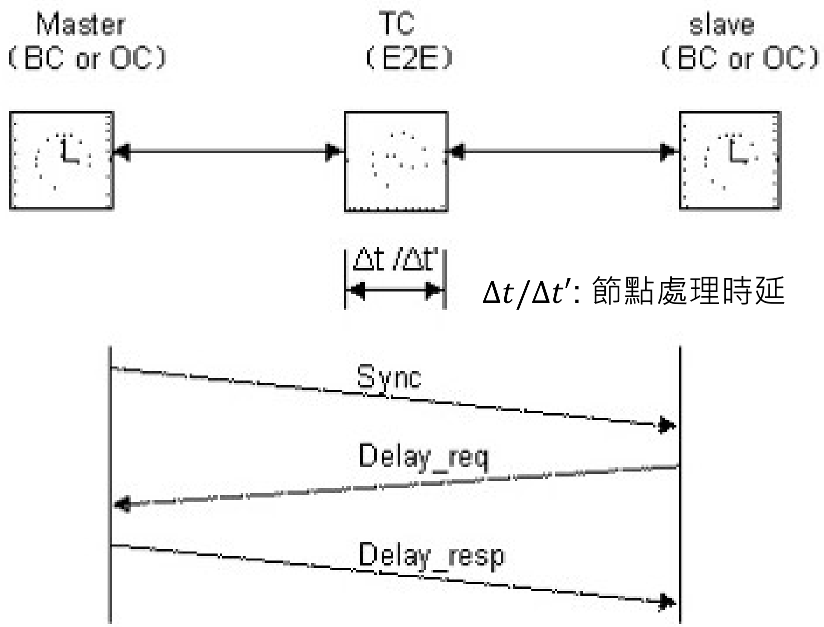


PTP Node Type Defined in IEEE 1588

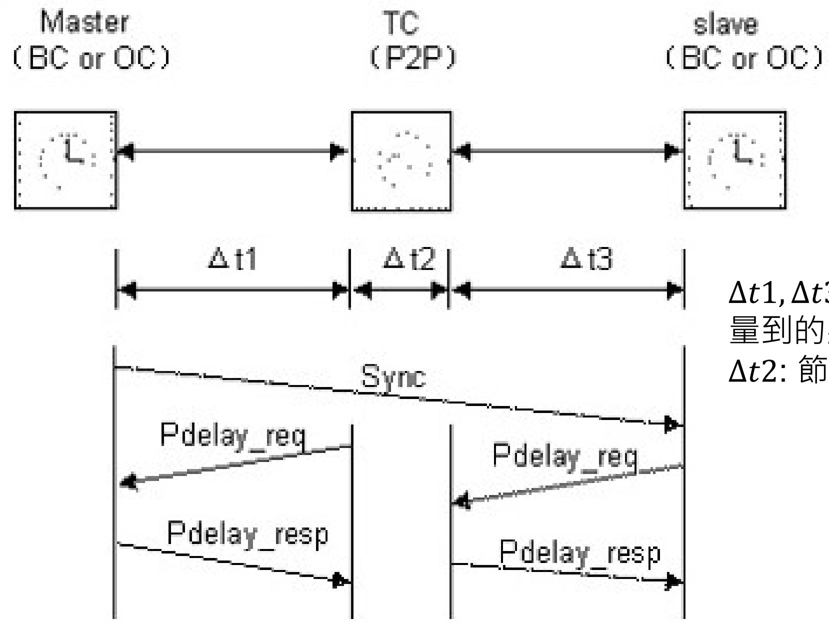
- OC (Ordinary Clock)
  - A single port device that can be a Master or Slave clock.
- BC (Boundary Clock)
  - A multi port device that can be Master and Slave clocks.
- TC (Transparent clock)
  - A multi port device that is not a Master or Slave clock but a bridge between the two to FORWARD and CORRECT PTP messages.
    - End-to-End
      - Handle all PTP messages with addition of the bridge residence time into a correction field
      - 封包停留 TC 時間
    - Peer-to-Peer
      - Handle Sync and Follow_Up messages only with addition of the bridge residence time + the peer-to-peer link delay into a correction field.
      - 封包停留 TC 時間 + 每一段 link 的延遲時間

PTP Node Type Defined in IEEE 1588

- TC (Transparent clock)



End-to-End

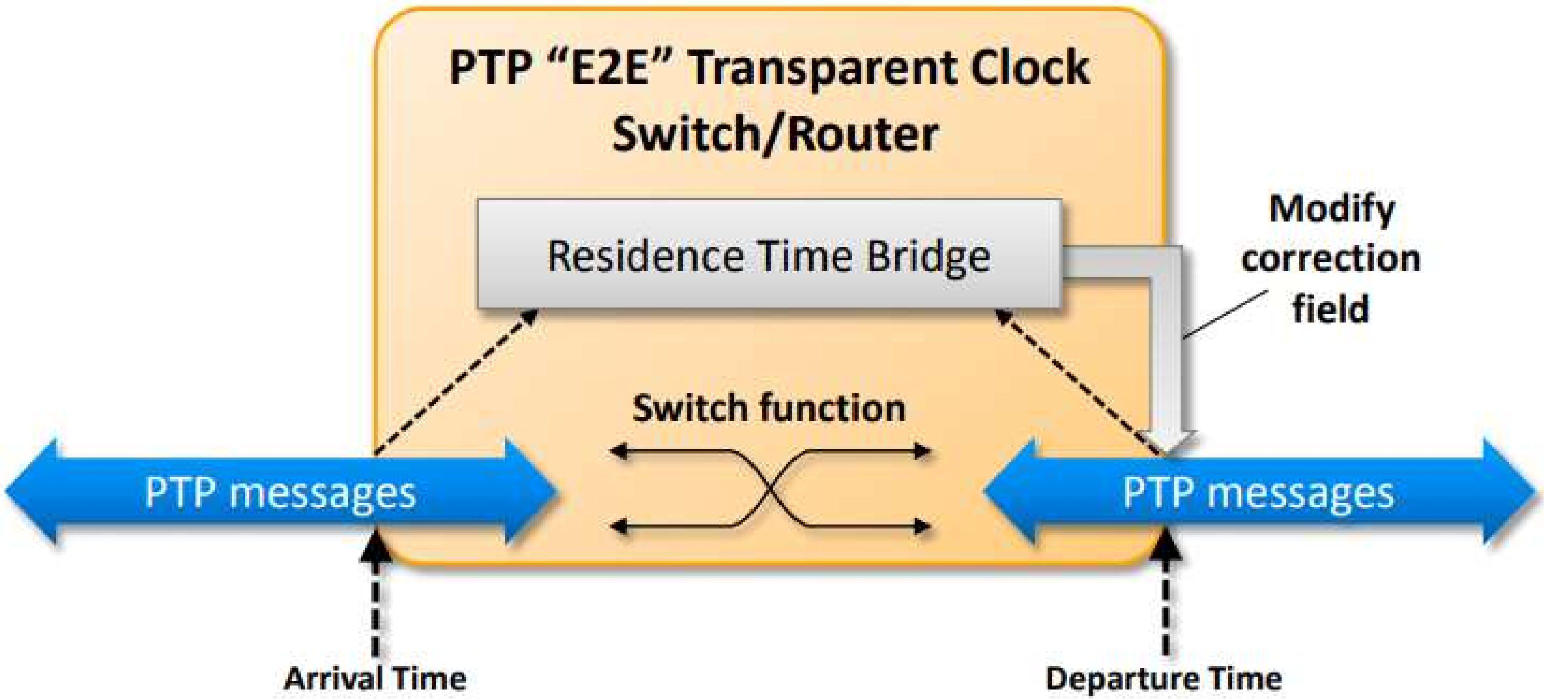


$\Delta t1, \Delta t3$: P2P機制測量到的線路時延
$\Delta t2$: 節點處理時延

Peer-to-Peer

End-to-End Transparent Clock

- 技術性跟 1-step 一樣高，必須在封包離開的瞬間，計算出停留的時間，並更新到 PTP header correction field 中



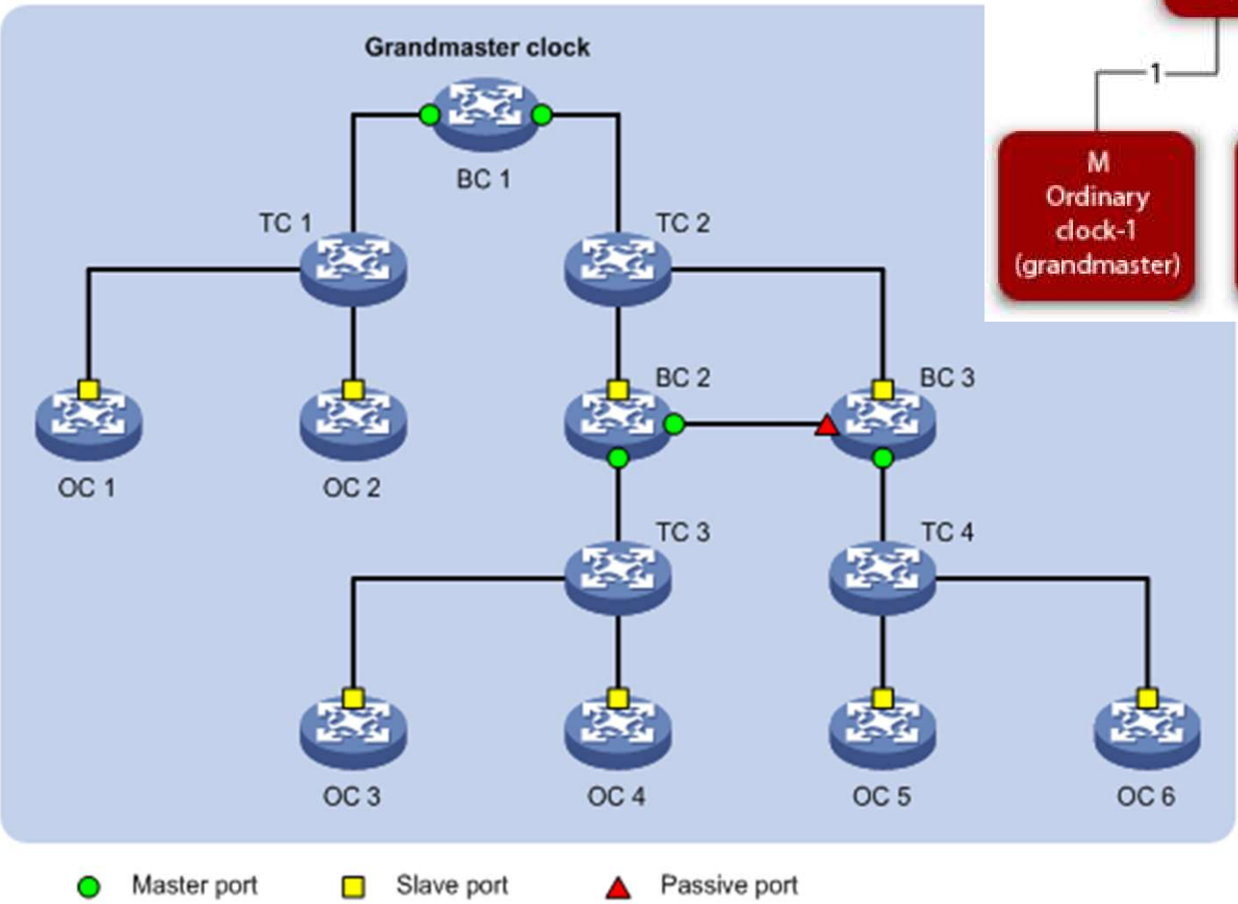
PTP Node Type Defined in ITU-T

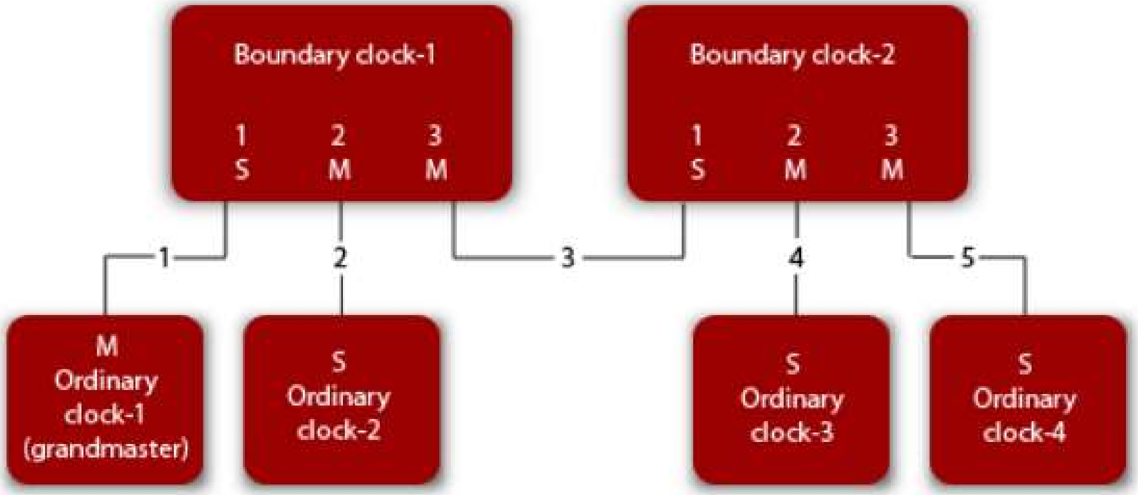
Table 1 – Mapping between [ITU-T G.8275] and PTP clock types

Clock type from [ITU-T G.8275]	Description	Clock type from [IEEE 1588]
T-GM	Master-only ordinary clock (master with a single PTP port, always a GM, cannot be slaved to another PTP clock)	OC
	Master-only boundary clock (master with multiple PTP ports, always a GM, cannot be slaved to another PTP clock)	BC
T-BC	Boundary clock (may become a GM, or may be slaved to another PTP clock)	BC
T-TSC	Slave-only ordinary clock (always a slave, cannot become a GM)	OC
T-TC	Transparent clock	End-to-end TC

PTP Node

Example 1





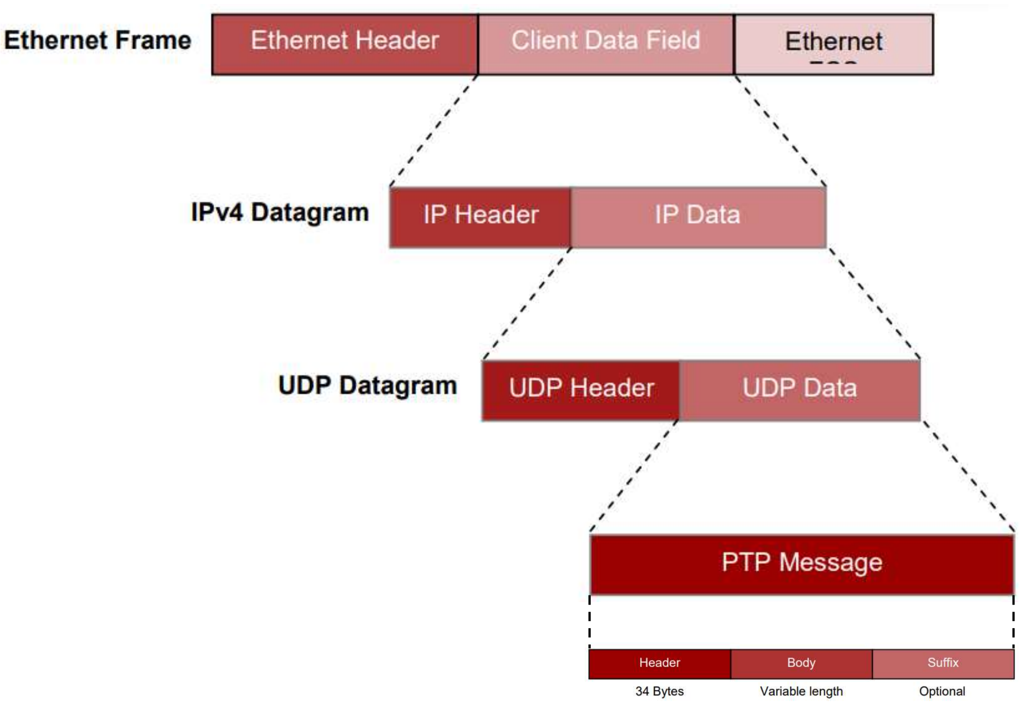
Example 2

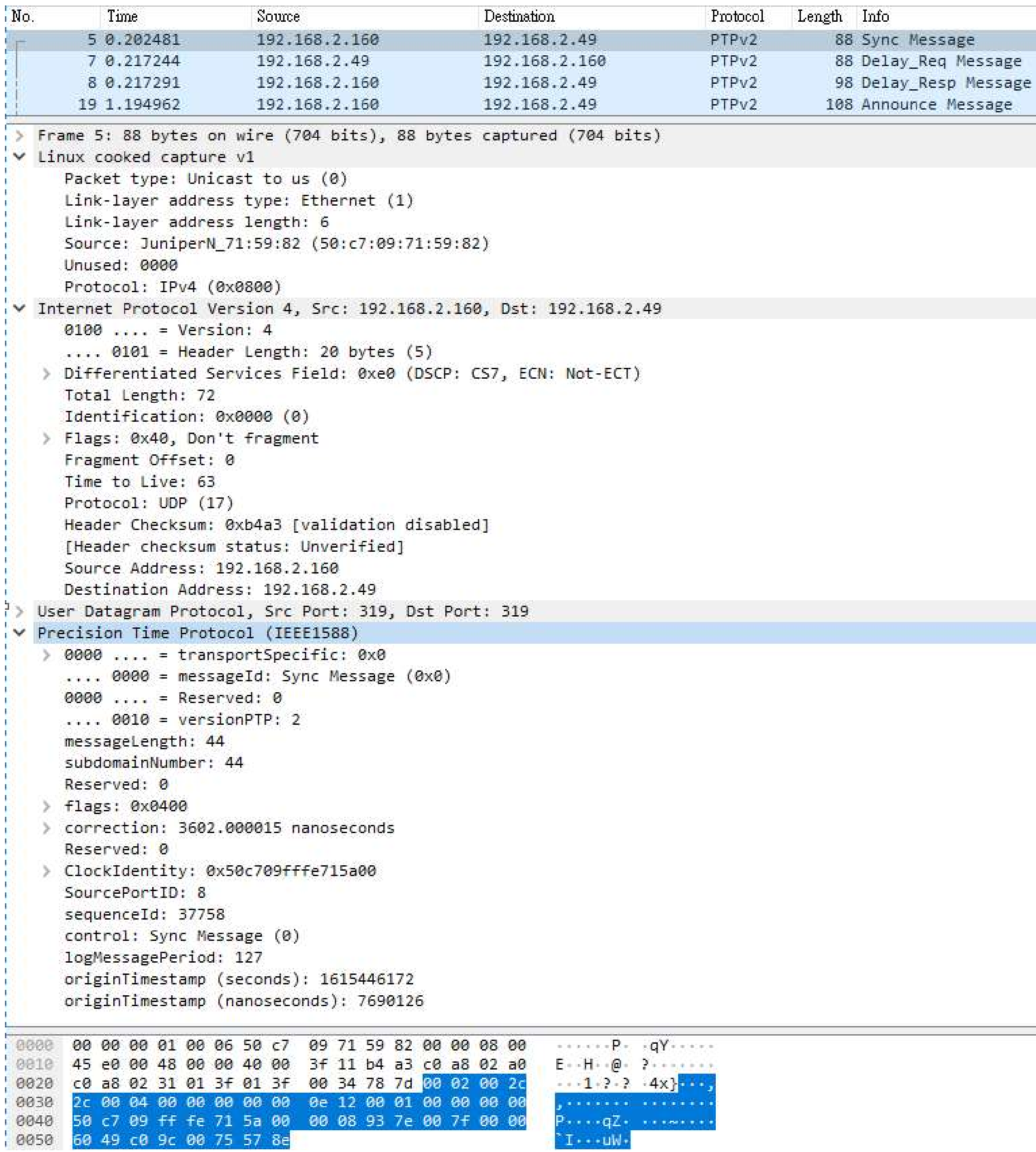
Message Rates

- G.8275.1
  - Sync messages (if used, Follow_up messages will have the same rate)
    - nominal rate: 16 packets-per-second
  - Delay_Req/Delay_Resp messages
    - nominal rate: 16 packets-per-second
  - Announce messages
    - nominal rate: 8 packets-per-second
- G.8275.2
  - Sync messages (if used, Follow_up messages will have the same rate)
    - Sync messages (if used, Follow_up messages will have the same rate)
      - minimum rate: 1 packet-per-second, maximum rate: 128 packets-per-second.
    - Delay_Req/Delay_Resp messages
      - minimum rate: 1 packet-per-second, maximum rate: 128 packets-per-second.
    - Announce messages
      - minimum rate: 1 packet-per-second, maximum rate: 8 packets-per-second
    - Signalling messages
      - no rate is specified

PTP Package

- The detail information can be observed from wireshark





PTP Messages

- Singalling
- Announce
- Sync
- Follow_Up
- Delay_Req
- Delay_Resp
- Pdelay_Req
- Pdelay_Resp
- Pdelay_Pesp_Follow_Up
- Managemant

PTP Message Header Format

- 34 bytes

0	1	2	3	4	5	6	7	# of bytes	index
transportSpecific				messageType (Sync/Delay_Req/…)				1	0
Reserved				versionPTP=0010				1	1
messageLength								2	2
domainNumber=24/44								1	4
Reserved								1	5
Flags (UNICAST? TWO_STEP?...)								2	6
correctionField (used for TC)								8	8
Reserved								4	16
ClockIdentity (Master/Slave Clock ID)								8	20
sourcePortIdentity (Master port or Slave port)								2	28
sequenceID (不同type各自序號)								2	30
controlField (=messageType)								1	32
logMessageInterval								1	33

PTP – Announce Message

- 30 bytes, sent every second periodically from Master Clock to Slave Clock
  - logAnnounceInterval=0
- indicates the capabilities of a clock to the other clocks on the same domain
  - 如果 domain 中沒有指定 Master Clock，會透過 Announce message 自動挑選出來

0	1	2	3	4	5	6	7	# of bytes	index
header								34	0
originTimestamp (=t1? or =0?, second 6 bytes + nanoseconds 4 bytes)								10	34
currentUtcOffset (Master's TAI-UTC in seconds)								2	44
Reserved								1	46
grandmasterPriority1 (值越小優先權越高)								1	47
grandMasterClockQuality (The time is accurate to within xxx us/ns)								4	48
grandmasterPriority2								1	52
grandmasterIdentity (=clockIdentity)								8	53
stepsRemoved								2	61
timeSource (0x20=GPS, 0xa0=INTERNAL_OSCILLATOR)								1	63

PTP – Sync Message

- 10 bytes, sent every second periodically from Master Clock to Slave Clock
  - logSyncInterval=0
- contains the Master time t1 when the Sync message was sent
  - If the Master clock is a two-step clock, the timestamp in the Sync will be set to zero

0	1	2	3	4	5	6	7	# of bytes	index
header								34	0
originTimestamp (=t1, second 6 bytes + nanoseconds 4 bytes)								10	34

PTP – Follow_Up Message

- 10 bytes, sent from Master Clock to Slave Clock
- contains the Master time t1 when the Sync message was sent

0	1	2	3	4	5	6	7	# of bytes	index
header								34	0
preciseOriginTimestamp (=t1, second 6 bytes + nanoseconds 4 bytes)								10	34

PTP – Delay_Req Message

- 10 bytes, sent from Slave Clock to Master Clock
- timestamp=0

0	1	2	3	4	5	6	7	# of bytes	index
header								34	0
originTimestamp (=0, second 6 bytes + nanoseconds 4 bytes)								10	34

PTP – Delay_Resp Message

- 20 bytes, sent from Master Clock to Slave Clock
- timestamp=0

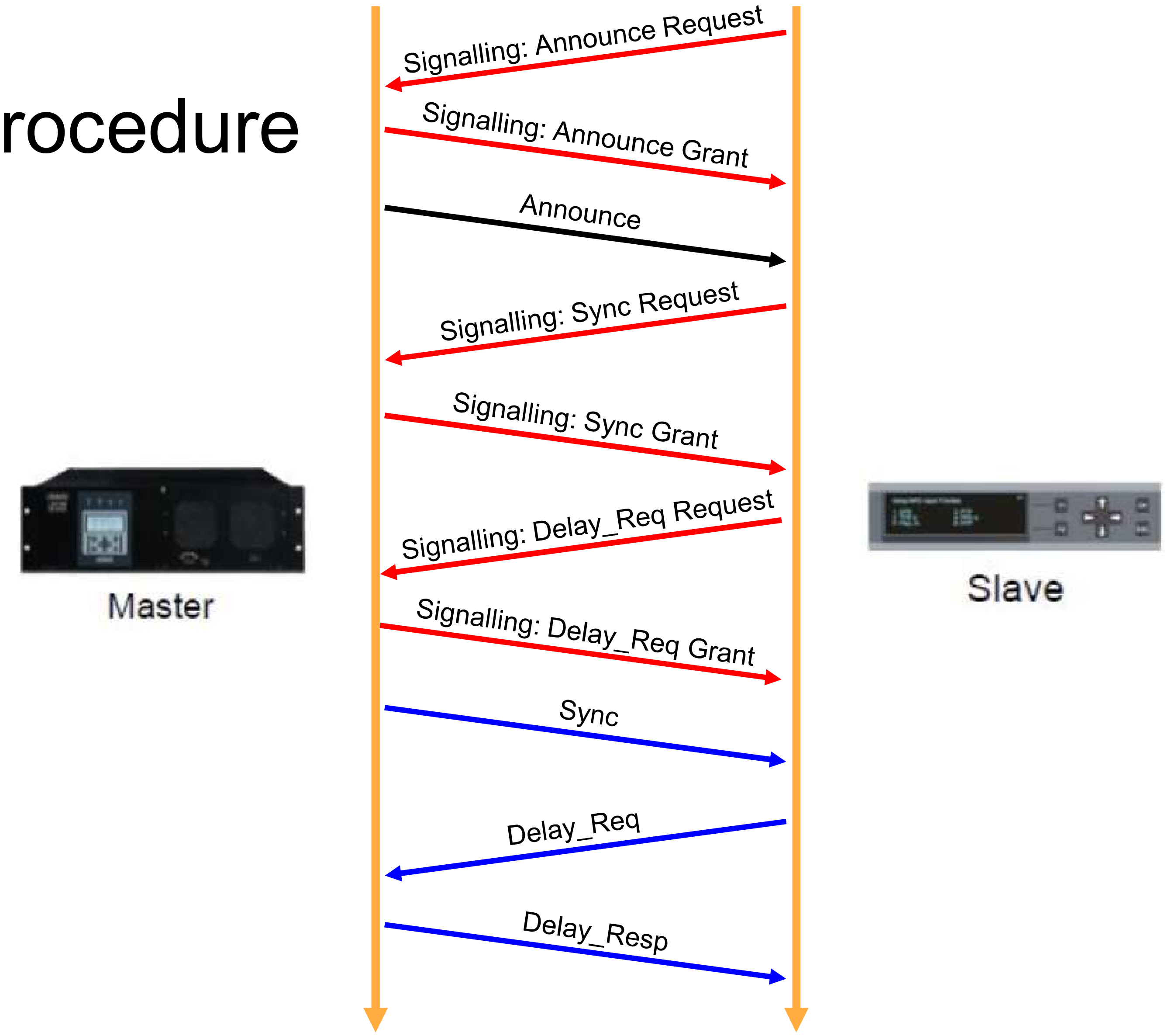
0	1	2	3	4	5	6	7	# of bytes	index
header								34	0
receiveTimestamp (=t4, second 6 bytes + nanoseconds 4 bytes)								10	34
requestingPortIdentity (slave clock ID + slave port ID)								10	44

PTP – Signalling Message

- 10+N bytes, sent every 4 seconds periodically between Slave Clock and Master Clock
- from Slave to Master
  - tlv=Request unicast transmission
    - request Announce ➔ period: every 1 seconds, rate: 1 packets/sec
    - request Sync ➔ period: every 1 seconds, rate: 1 packets/sec
    - request Delay_Req
- from Master to Slave
  - tlv=grant unicast transmission

0	1	2	3	4	5	6	7	# of bytes	index
header								34	0
targetPortIdentity (clock ID + port ID)								10	34
One or more TLVs (Type, Length, Value Identity)								N	44

Synchronization Procedure



Hardware Support for PTP in the NIC

- Software Timestamp
  - SOF_TIMESTAMPING_SOFTWARE
  - SOF_TIMESTAMPING_TX_SOFTWARE
  - SOF_TIMESTAMPING_RX_SOFTWARE
- Hardware Timestamp
  - SOF_TIMESTAMPING_RAW_HARDWARE
  - SOF_TIMESTAMPING_TX_HARDWARE
  - SOF_TIMESTAMPING_RX_HARDWARE

```
# ethtool -T enp0s3
Time stamping parameters for enp0s3:
Capabilities:
        software-transmit     (SOF_TIMESTAMPING_TX_SOFTWARE)
        software-receive      (SOF_TIMESTAMPING_RX_SOFTWARE)
        software-system-clock (SOF_TIMESTAMPING_SOFTWARE)
PTP Hardware Clock: none
Hardware Transmit Timestamp Modes: none
Hardware Receive Filter Modes: none
```

```
# ethtool -T enp134s0f0
Time stamping parameters for enp134s0f0:
Capabilities:
    hardware-transmit     (SOF_TIMESTAMPING_TX_HARDWARE)
    software-transmit     (SOF_TIMESTAMPING_TX_SOFTWARE)
    hardware-receive      (SOF_TIMESTAMPING_RX_HARDWARE)
    software-receive      (SOF_TIMESTAMPING_RX_SOFTWARE)
    software-system-clock (SOF_TIMESTAMPING_SOFTWARE)
    hardware-raw-clock    (SOF_TIMESTAMPING_RAW_HARDWARE)
PTP Hardware Clock: 1
Hardware Transmit Timestamp Modes:
    off                   (HWTSTAMP_TX_OFF)
    on                    (HWTSTAMP_TX_ON)
Hardware Receive Filter Modes:
    none                  (HWTSTAMP_FILTER_NONE)
    all                   (HWTSTAMP_FILTER_ALL)
```

PTP Tools

- Two processes
    - 使用 ptp4l 指令，將 local NIC 中的 PHC (PTP Hardware Clock) 做為 slave mode，同步為 master (Switch BC) 的時間
        - 若是使用 software timestamp，會直接將 master clock 時間同步到系統時間
    - 使用 phc2sys 指令，將 local NIC 中的 PHC 時間，同步到系統時間
        - 若是使用 software timestamp，則不需要執行 phc2sys

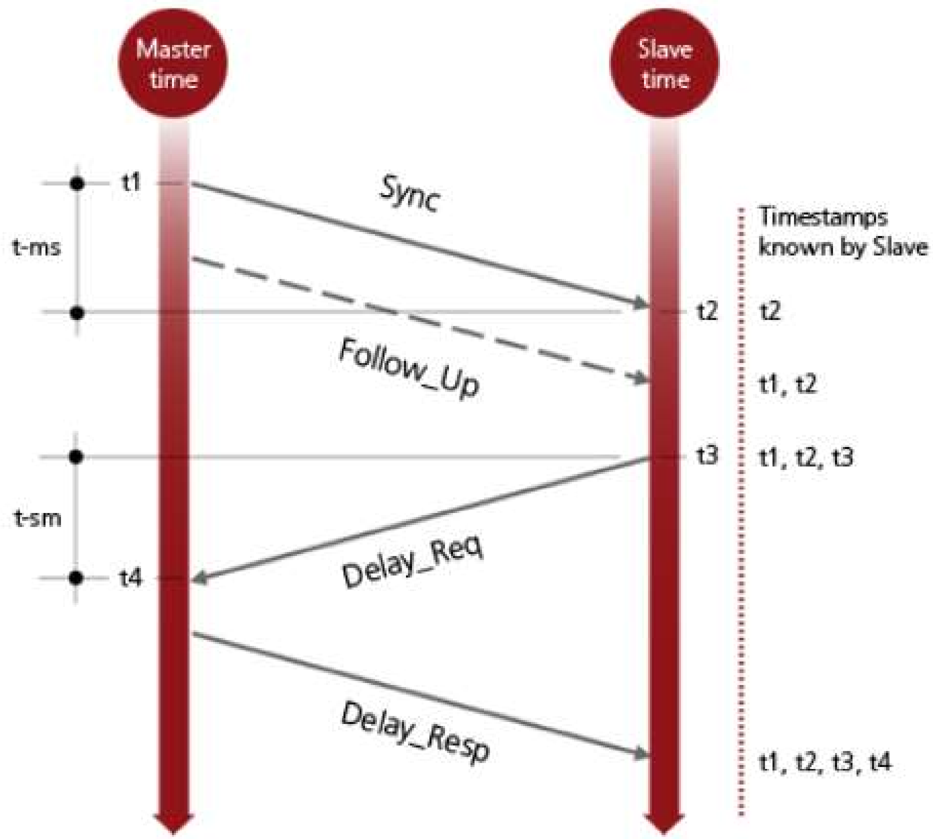
```
# ptp4l -i enp134s0f0 -m -s -f ptp4l.conf
 -i [dev]  interface device to use
 -m        print messages to stdout
 -s        slave only mode
 -f [file] read configuration from 'file’
```

```
# phc2sys -s enp134s0f0 -w -m -n 44
 -s [dev|name]  master clock
 -w             wait for ptp4l
 -m             print messages to stdout
 -n [num]       domain number
```

```
# ptp4l -i enp134s0f0 –m ➔ master clock
# ptp4l -i enp134s0f0 –m –S ➔ software timestamp
```

Delay Request-Response Mechanism

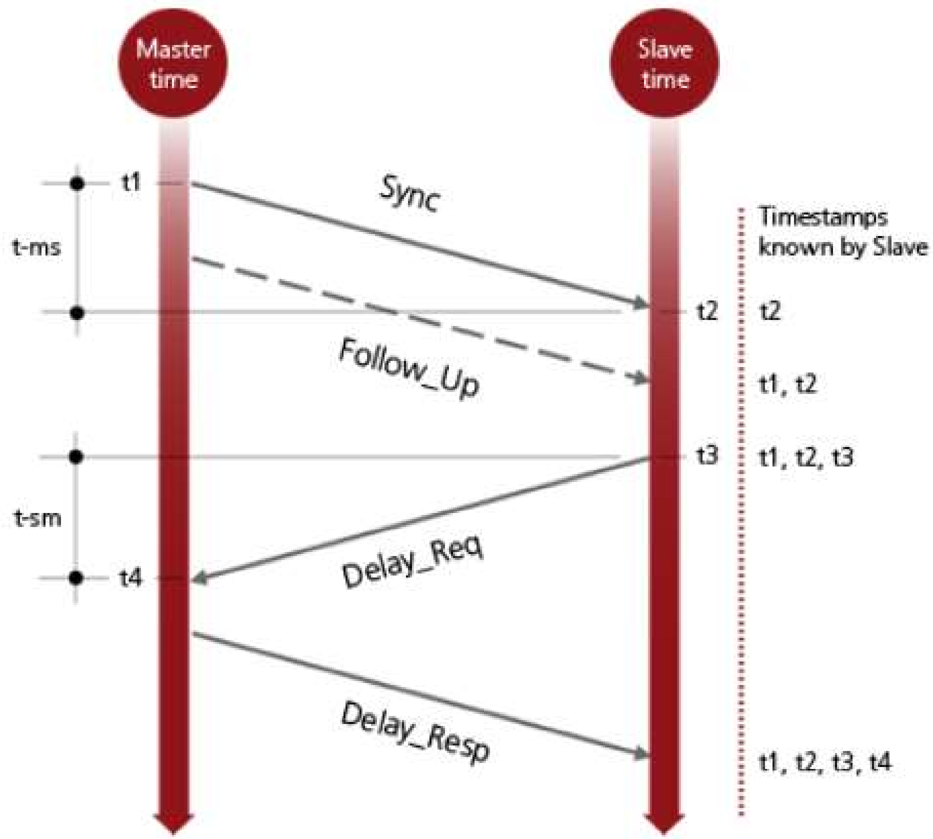
- t1 ➔ Master Time at point of sending Sync
- t2 ➔ Slave Time at Point of receiving Sync
- t3 ➔ Slave time at point at sending Delay_Req
- t4 ➔ Master time at point of receiving Delay_Req



Delay Request-Response Mechanism

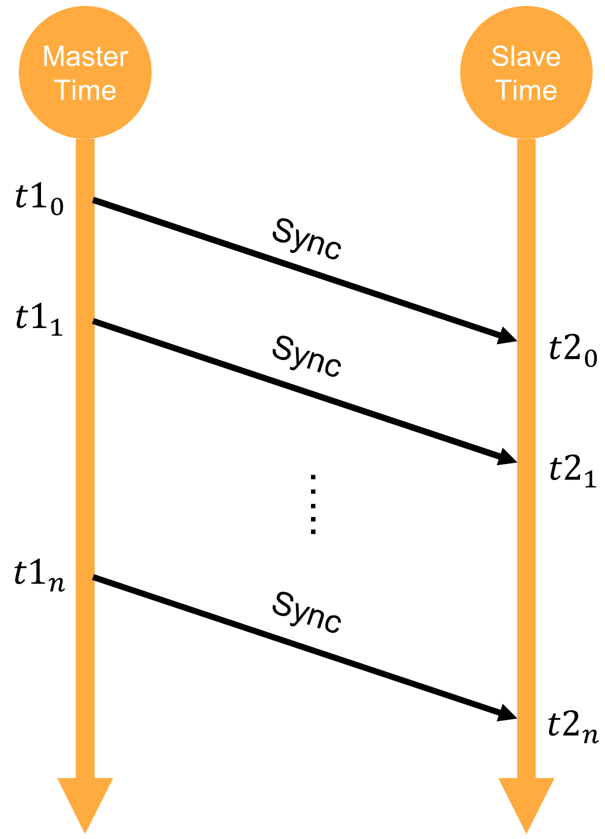
- Two types
  - 1-step
    - 透過 Sync 把 t1 告知 Slave
    - 透過 Delay_Resp 把 t4 告知 Slave
  - 2-step
    - 在 Sync 傳送時，還不知道 t1，所以在 Sync 傳送之後，再透過 Follow_Up 告知 Slave
    - 透過 Delay_Resp 把 t4 告知 Slave
- 當 Slave 得知 t1, t2, t3, t4 後

$$The\ mean\ propagation\ delay = \frac{(t2 - t1) + (t4 - t3)}{2}$$



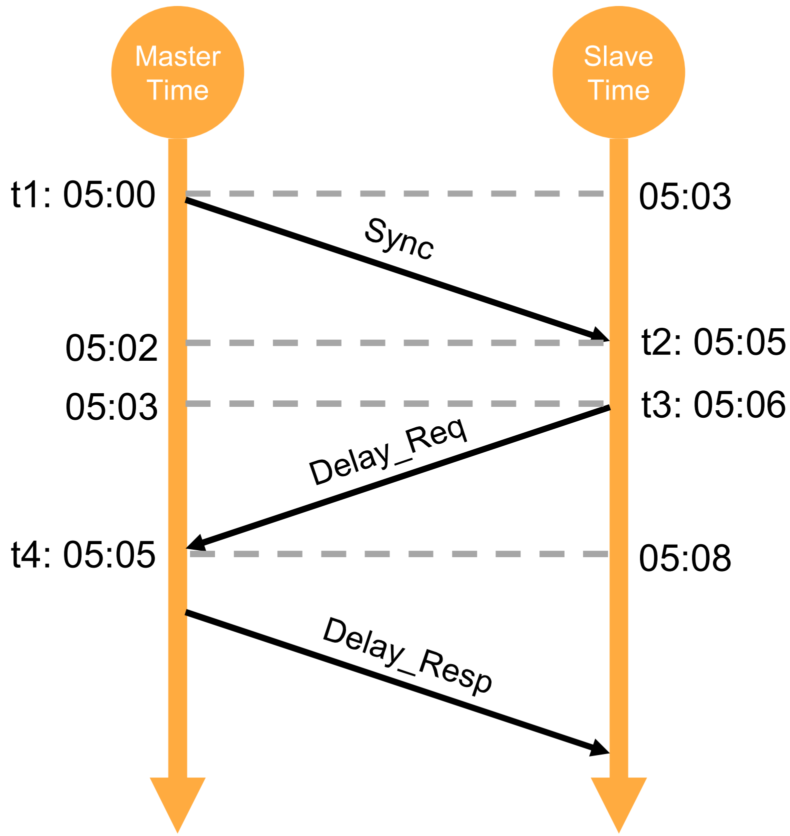
Synchronization Procedure

- 頻率同步
    - 通過 Master 和 Slave 之間的 Sync message 來實現
    - Master 週期性發送 Sync message 給 Slave
        - 透過 $t1_n - t1_{n-1}$ 與 $t2_n - t2_{n-1}$，調整 Slave 的 Frequency 快慢
- Or do frequency synchronization via SyncE



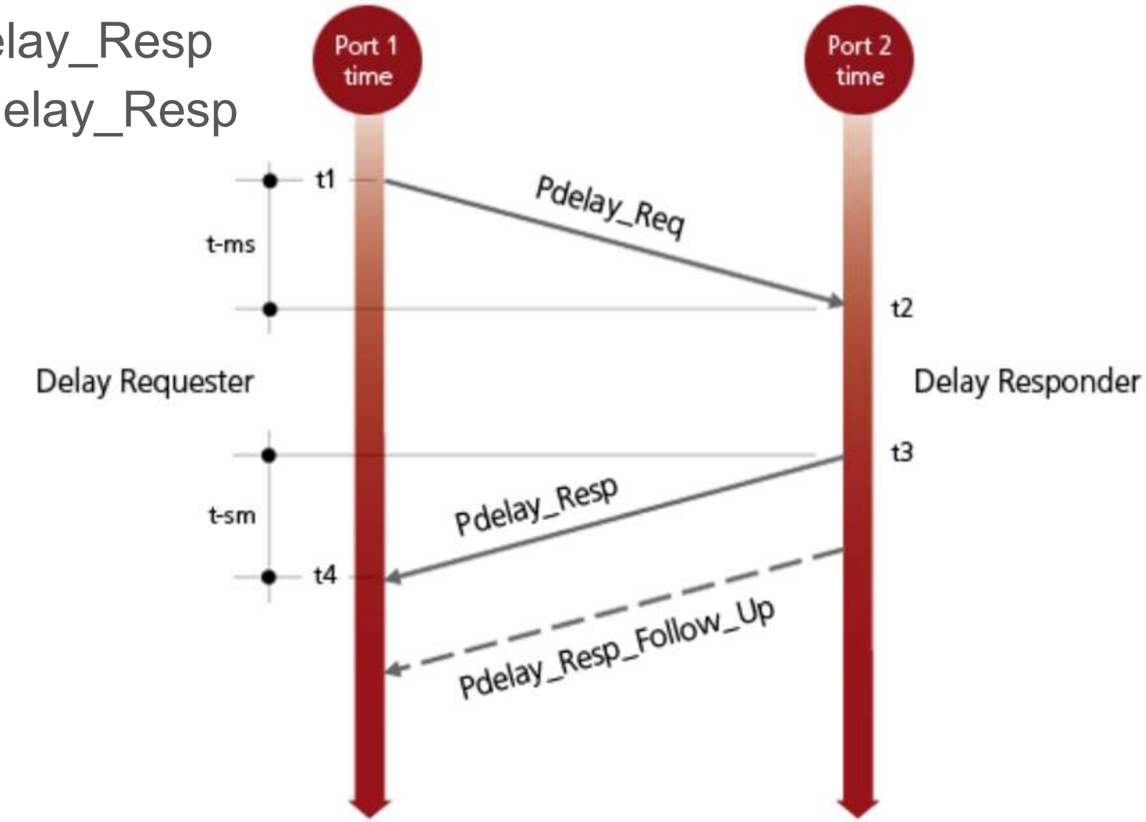
Synchronization Procedure

- 時間同步
  - $The\ mean\ propagation\ delay = \frac{(t2-t1)\quad(t4-t3)}{2}$
    ➔ Master-Slave 之間的傳輸時間
    ➔ $delay = \frac{(5)+(-1)}{2} = 2$
    在 t2 收到 t1=05:00，加上 delay 2
    ➔ Master 在 t2 時刻的時間應為 05:00+2=05:02
    ➔ Slave t2=05:05 必須校正(-3)為 05:02
  - $The\ time\ offset = \frac{(t2-t1)\quad(t3-t4)}{2} = \frac{(5)+(1)}{2} = 3$



Peer-to-Peer Delay Mechanism

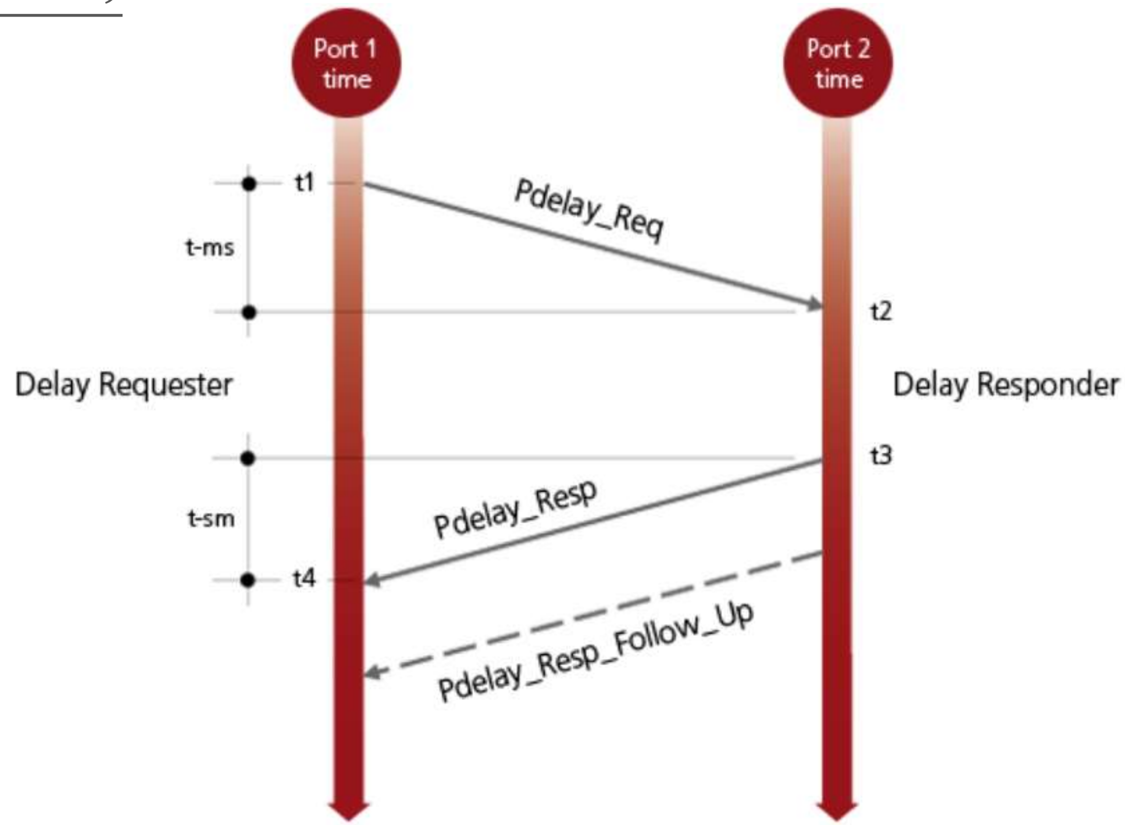
- t1 ➔ Port 1 time at point of sending Pdelay_Req
- t2 ➔ Port 2 time at point of receiving Pdelay_Req
- t3 ➔ Port 2 time at point of sending Pdelay_Resp
- t4 ➔ Port 1 time at point of receiving Pdelay_Resp



Peer-to-Peer Delay Mechanism

- Calculate delay based on Port 1

$$The\ mean\ link\ propagation\ delay = \frac{(t2 - t1) + (t4 - t3)}{2}$$



1-step vs 2-step

- 1-step
  - 更簡單，Slave 只需要收一種 type 封包，並可以更快的處理同步的程序
  - 在某些特別協議的網路環境(PRP, HSR)，Sync/Follow_Up messages 封包有可能會不依照順序到達 Slave，導致處理上較複雜
  - 技術含量較高
    - 第一動，產生 PTP Sync message package
    - 第二動，在發送出封包前瞬間，動態修改封包中的 timestemp
    - 因為第二動造成的處理延遲，所以 1-step 只能適用於 10 Gigabit 以下的 Ethernet 連接
- 2-step
  - 更容易實作，只需要將 t1 包在第二動作的 message 裡
  - 不需要在 Sync message 離開時將 timestamp 寫入，這可以使 2-step 主時鐘在硬件方面更便宜
  - 靈活性更好，Sync message 是 key point，但有效的資料不需要跟隨著這一個 key point message 傳送出去，有什麼新增或修改的 feature，不需要動到 Sync
  - 如果使用 10 Gigabit 或更高的 Ethernet 連接，2-Step 也是唯一的選擇，因為以更高 bitrates 編碼消息的時間有限

PTP Sample

- offset
  - Slave 與 Master 的時間差
- state
  - s0: unlock
  - s1: synchronizing
  - s2: lock
- freq
  - 時鐘的頻率調整(ppb)
- delay
  - Master 與 Slave 間的傳輸時間

```
ptp4l[4193.585]: selected /dev/ptp0 as PTP clock
ptp4l[4193.585]: port 1: INITIALIZING to LISTENING on INIT_COMPLETE
ptp4l[4193.585]: port 0: INITIALIZING to LISTENING on INIT_COMPLETE
ptp4l[4196.458]: port 1: new foreign master 94c691.fffe.a2b95e-1
ptp4l[4199.743]: selected local clock 1c1b0d.fffe.2c13e5 as best master
ptp4l[4200.458]: selected best master clock 94c691.fffe.a2b95e
ptp4l[4200.458]: port 1: LISTENING to UNCALIBRATED on RS_SLAVE
ptp4l[4202.458]: master offset 93404955449589 s0 freq      +0 path delay     11406
ptp4l[4203.458]: master offset 93404955466370 s1 freq  +16781 path delay     11500
ptp4l[4204.458]: master offset          149 s2 freq  +16930 path delay     11500
ptp4l[4204.458]: port 1: UNCALIBRATED to SLAVE on MASTER_CLOCK_SELECTED
ptp4l[4205.458]: master offset        -1265 s2 freq  +15560 path delay     13062
ptp4l[4206.458]: master offset        -1090 s2 freq  +15356 path delay     14625
ptp4l[4207.458]: master offset        -1532 s2 freq  +14587 path delay     16430
ptp4l[4208.458]: master offset            7 s2 freq  +15666 path delay     17981
ptp4l[4209.458]: master offset          757 s2 freq  +16418 path delay     17981
ptp4l[4210.458]: master offset         1266 s2 freq  +17154 path delay     18108
ptp4l[4211.458]: master offset         1301 s2 freq  +17569 path delay     18108
ptp4l[4212.458]: master offset          565 s2 freq  +17223 path delay     18379
ptp4l[4213.458]: master offset          173 s2 freq  +17001 path delay     18556
ptp4l[4214.458]: master offset           13 s2 freq  +16893 path delay     18614
```

Physical Resource

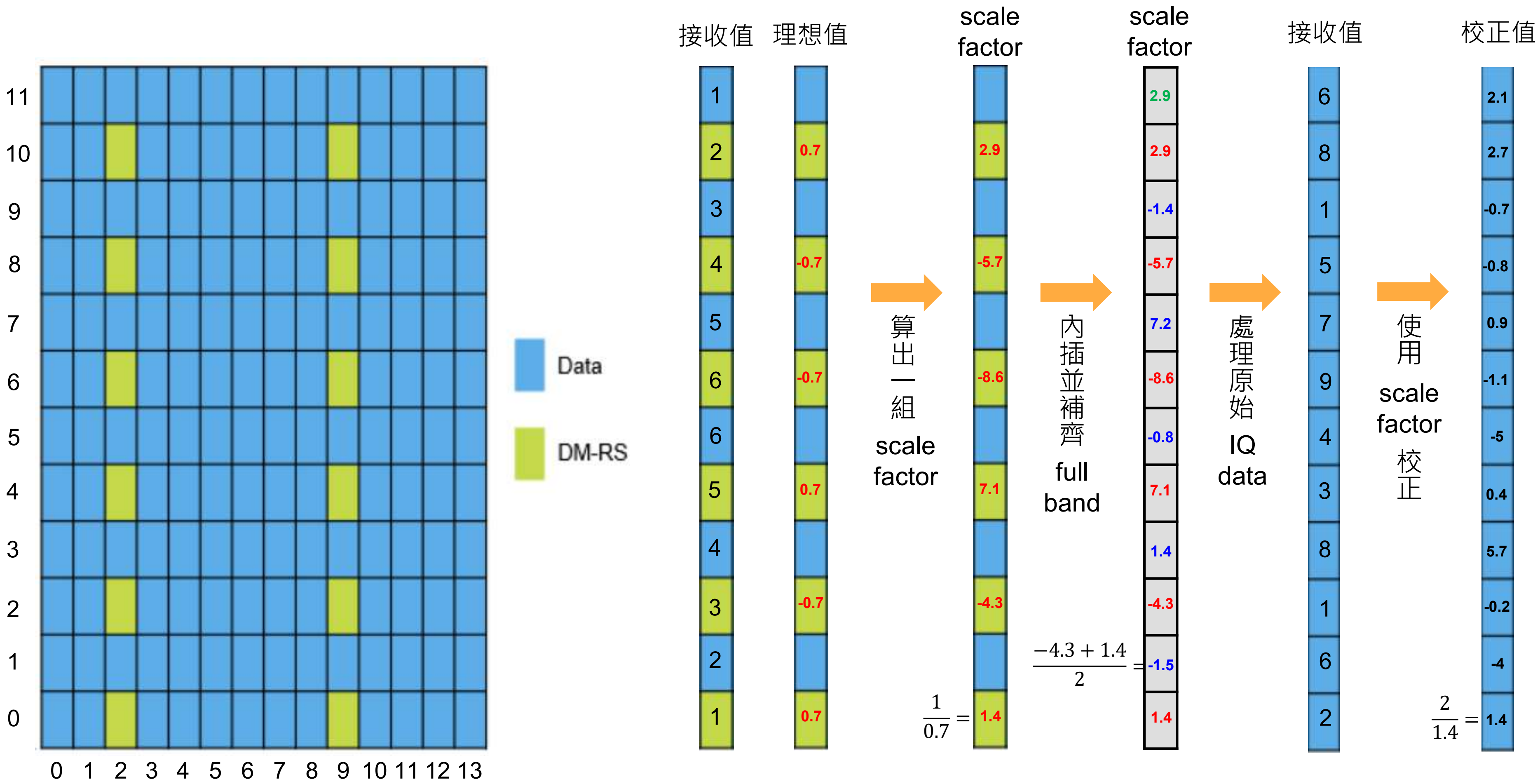
How to Generate DMRS Sequence

- DMRS Sequence $r(n) = \frac{1}{\sqrt{2}}\big(1-2\cdot c(2n)\big) + j\frac{1}{\sqrt{2}}\big(1-2\cdot c(2n+1)\big)$

  假設需要 1638 個，n就帶入 0~1637去算

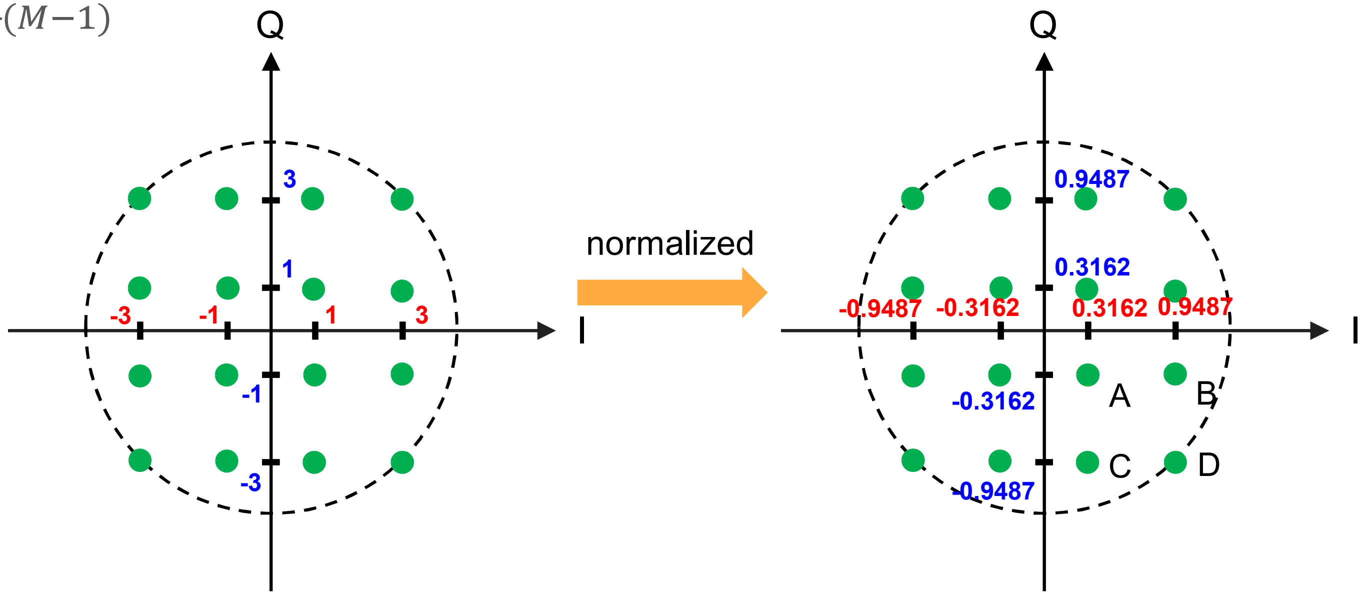
  - $c(n) = \big(x_1(n+N_c) + x_2(n+N_c)\big)\ mod\ 2, N_c = 1600$
    - DMRS 序列由 $\pm\frac{1}{\sqrt{2}} \pm \frac{1}{\sqrt{2}}j$ 所組成 (note that $|r(n)| = 1$)
  - $x_1(n+31) = \big(x_1(n+3) + x_1(n)\big)\ mod\ 2$
    - $x_1(n) \rightarrow x_1(0) = 1, x_1(n) = 0, n = 1,2,\ldots,30$
      - $x_1(0\sim30) = [1\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0]$
      - $x_1(31)$ 之後就帶公式算，需要多少就算多少個出來
  - $x_2(n+31) = \big(x_2(n+3) + x_2(n+2) + x_2(n+1) + x_2(n)\big)\ mod\ 2$
    - $c_{init} = \sum_{i=0}^{30} x_2(i) \cdot 2^i$
      - $c_{init} = \left(2^{17}\left(\overset{14}{N_{symb}^{slot}}\overset{\text{slot\_idx}}{n_{s,f}^{\mu}} + \overset{\text{symbol\_idx}}{l} + 1\right)\left(2N_{ID}^{n_{SCID}} + 1\right) + 2\mathrm{N}_{\mathrm{ID}}^{n_{SCID}} + n_{SCID}\right)\ mod\ 2^{31}$
      - $c_{init} = x_2(0)\cdot 2^0 + x_2(1)\cdot 2^1 + x_2(2)\cdot 2^2 + x_2(3)\cdot 2^3 + \ldots + x_2(30)\cdot 2^{30}$
        - For example, c_{init} 算出來為 $[1\ 1\ 1\ 0\ 1\ 1\ 0\ 1\ 1\ 1\ 1\ 1\ 0\ 0\ 0\ 0\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 0\ 1\ 1\ 1\ 1\ 1\ 1\ 1]$
          則 $x_2(0\sim30)$ 為 c_{init} 的顛倒 $[1\ 1\ 1\ 1\ 1\ 1\ 1\ 0\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 0\ 0\ 0\ 0\ 1\ 1\ 1\ 1\ 1\ 0\ 1\ 1\ 0\ 1\ 1\ 1]$

- DMRS 是一串已知內容的序列 $r(n)=\frac{1}{\sqrt{2}}\left(1-2\cdot c(2n)\right)+j\frac{1}{\sqrt{2}}\left(1-2\cdot c(2n+1)\right)$
- symbol 2 DMRS 負責校正 symbol 0~6、 symbol 9 DMRS 負責校正 symbol 7~13
- The format of all elements are I+Qi，方便起見，以下例子皆簡化為一實數

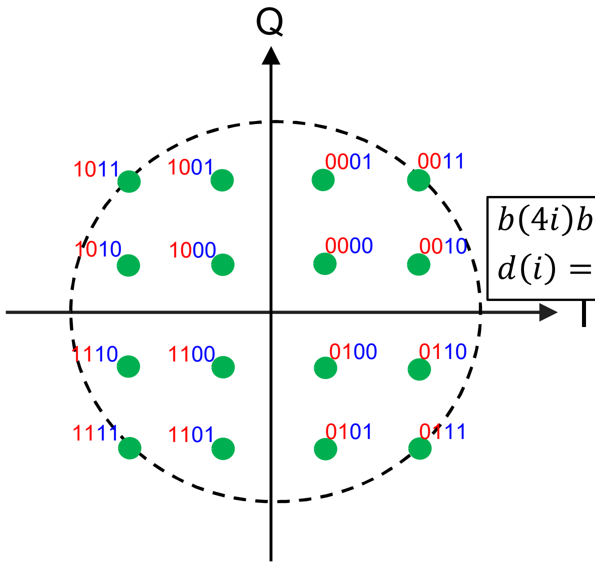


Normalized Constellation Diagram

- The average of all amplitude in the normalized constellation will be equal to ONE.
- |A|+|B|+|C|+|D|=4
  - |A|=$\sqrt{0.3162^2 + -0.3162^2}$、|B|=$\sqrt{0.9487^2 + -0.3162^2}$
    |C|=$\sqrt{0.3162^2 + -0.9487^2}$、|D|=$\sqrt{0.9487^2 + -0.9487^2}$
- Normalizing Factor $= \frac{1}{\sqrt{\frac{2}{3}(M-1)}}$, M=4, 16, 64, 256



Modulation - QAM



$$b(4i)b(4i+1)b(4i+2)b(4i+3) = 0010$$
$$d(i) = \frac{3}{\sqrt{10}} + \frac{1}{\sqrt{10}}j$$

- QPSK

$$d(i) = \frac{1}{\sqrt{2}}\left[(1-2b(2i)) + j(1-2b(2i+1))\right]$$

- 16QAM

$$d(i) = \frac{1}{\sqrt{10}}\left\{(1-2b(4i))\left[2-(1-2b(4i+2))\right] + j(1-2b(4i+1))\left[2-(1-2b(4i+3))\right]\right\}$$

- 64QAM

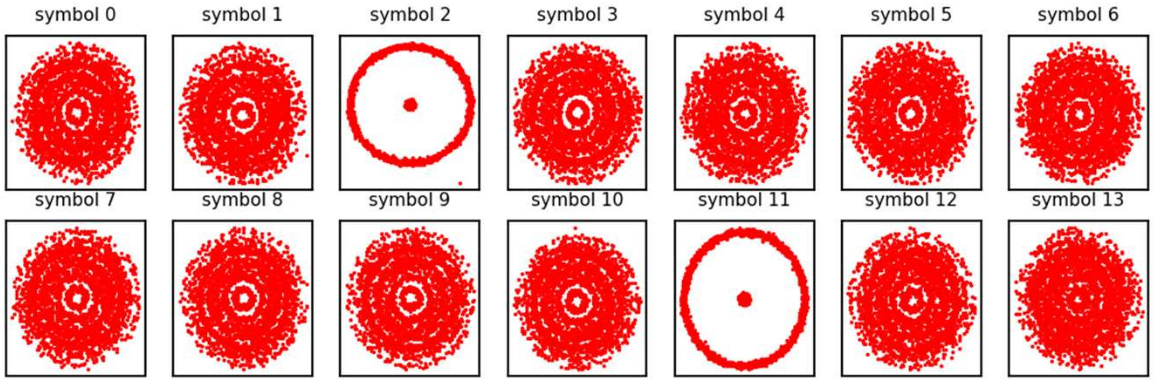
$$d(i) = \frac{1}{\sqrt{42}}\left\{(1-2b(6i))\left[4-(1-2b(6i+2))\left[2-(1-2b(6i+4))\right]\right] + j(1-2b(6i+1))\left[4-(1-2b(6i+3))\left[2-(1-2b(6i+5))\right]\right]\right\}$$

- 256QAM

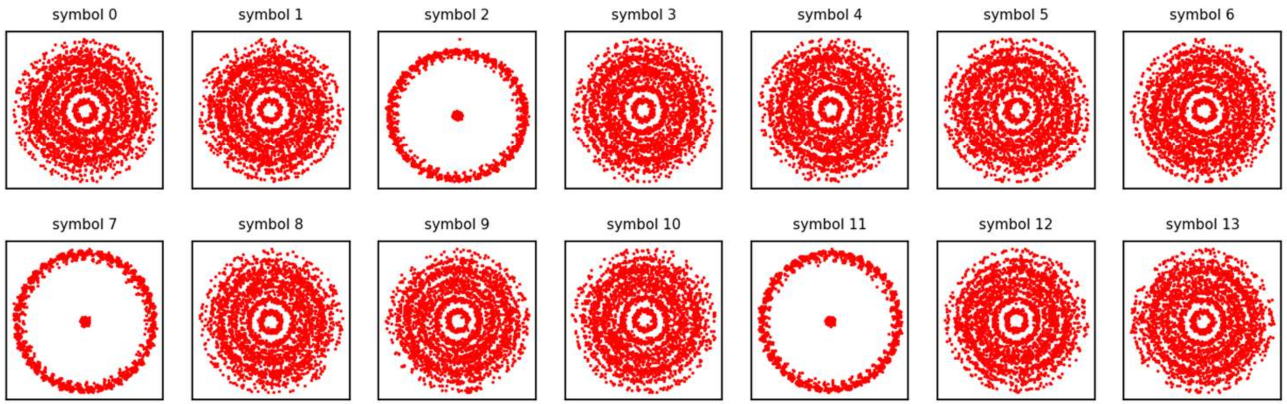
$$d(i) = \frac{1}{\sqrt{170}}\left\{(1-2b(8i))\left[8-(1-2b(8i+2))\left[4-(1-2b(8i+4))\left[2-(1-2b(8i+6))\right]\right]\right]\right.$$
$$\left. + j(1-2b(8i+1))\left[8-(1-2b(8i+3))\left[4-(1-2b(8i+5))\left[2-(1-2b(8i+7))\right]\right]\right]\right\}$$

Demodulation

- Position of DMRS (uplink)



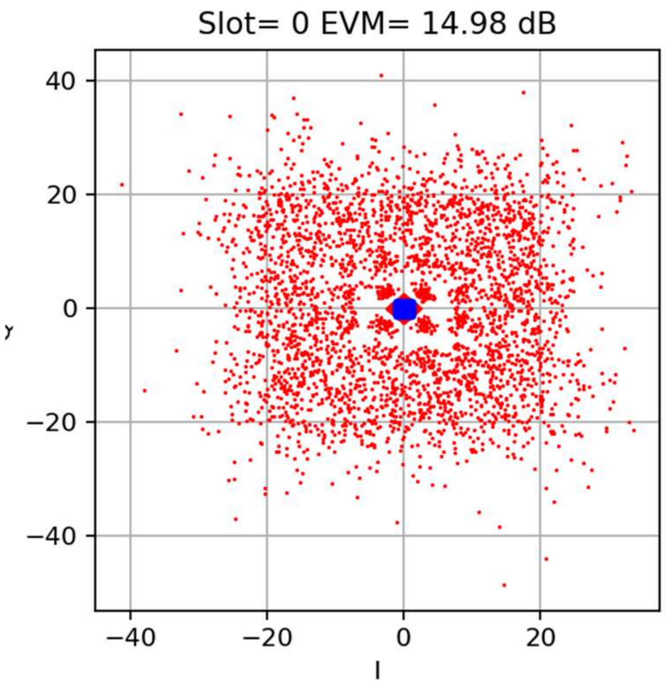
DMRS = 2

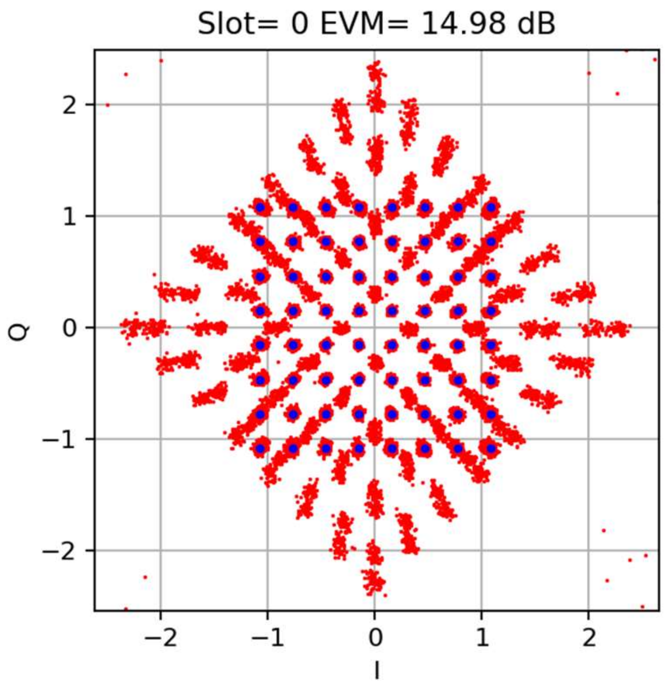


DMRS = 3

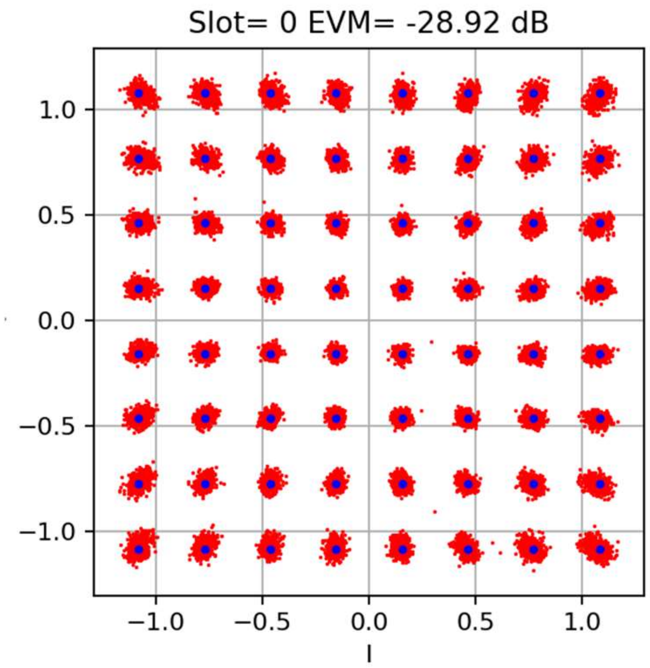
Demodulation

- 如果 $\mathrm{N_{ID}^{n_{SCID}}}$(Scrambling_ID) 或 n_{SCID} 設定錯誤，解出來的 IQ 如下
- 如果 DCI 中沒有 $\mathrm{N_{ID}^{n_{SCID}}}$ 、n_{SCID} 的資訊，取值如下
  - $n_{SCID} = 0$
  - $\mathrm{N_{ID}^{n_{SCID}}} = cell\ ID$

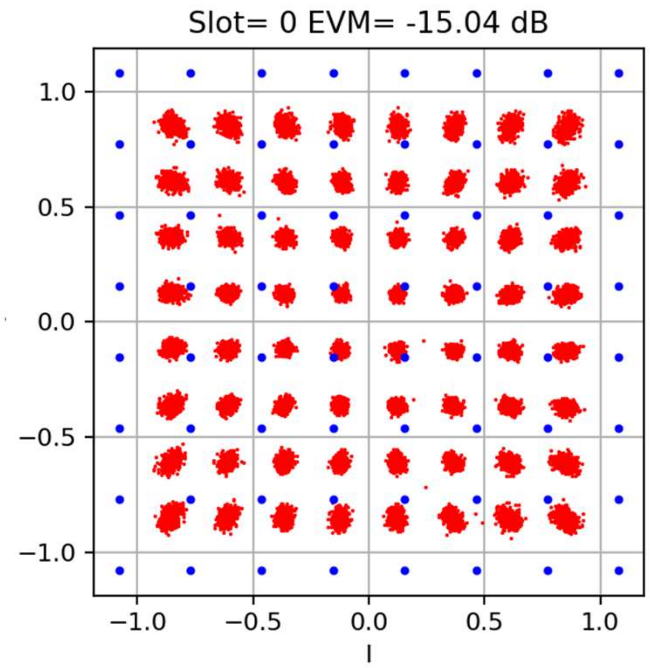




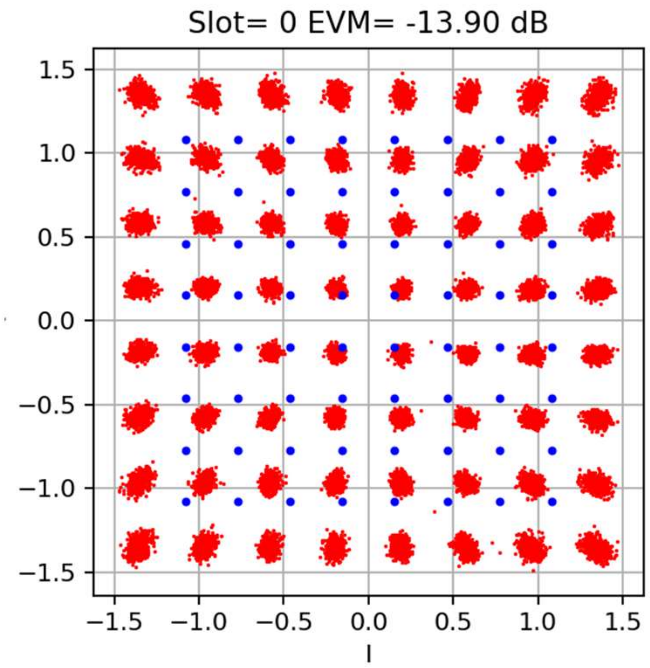
Power Boost for DMRS



PowerBoost=3



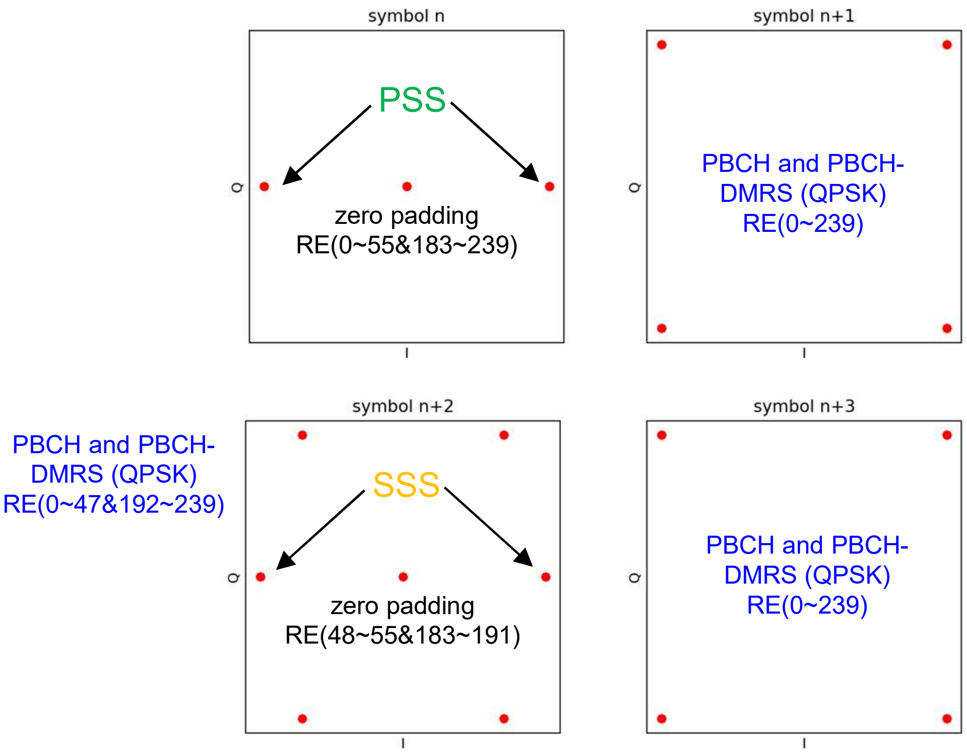
PowerBoost=1

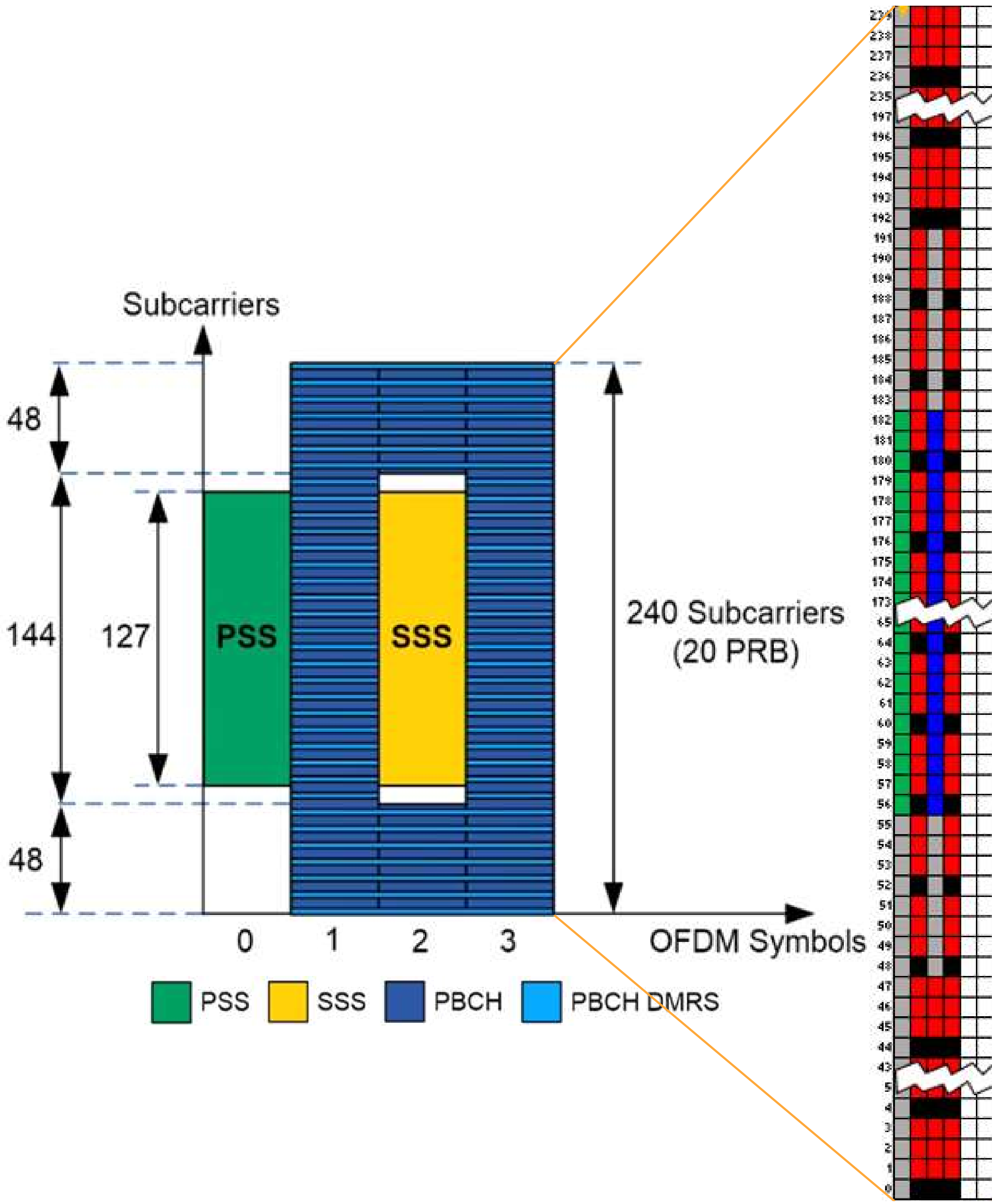


PowerBoost=5

SS Block

- SSB 佔連續 4 個 symbols 和 20 RBs
- PSS 和 SSS 是一串由 1,-1 組成的已知序列
- RE 240~3275 是 PDSCH





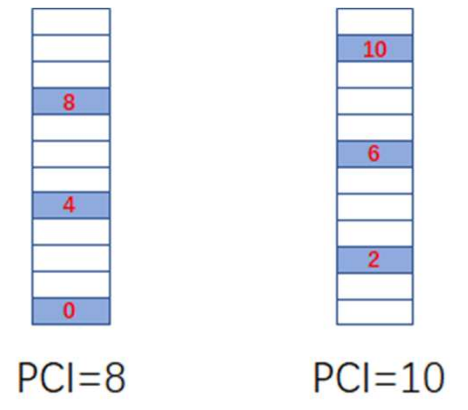
PSS and SSS

- $N_{ID}^{cell} = 3N_{ID}^{(1)} + N_{ID}^{(2)}, N_{ID}^{(1)} \in \{1,2,\ldots,335\}$ and $N_{ID}^{(2)} \in \{0,1,2\}$
  - $N_{ID}^{(1)}$ is SSS index and $N_{ID}^{(2)}$ is PSS index
  - There are 1008 unique PCIs
- PSS
  - There are 3 different PSS sequences
  - $d_{PSS}(n) = 1 - 2x(m)$
    - $m = \left(n + 43N_{ID}^{(2)}\right) mod\ 127, 0 \le n < 127$
    - $x(i+7) = \left(x(i+4) + x(i)\right) mod\ 2$
      - $x(6\sim0) = [1\ 1\ 1\ 0\ 1\ 1\ 0]$
- SSS
  - There are 336 different SSS sequences
  - $d_{SSS}(n) = \left[1 - 2x_0\left((n+m_0) mod\ 127\right)\right]\left[1 - 2x_1\left((n+m_1) mod\ 127\right)\right]$
    - $m_0 = 15\left\lfloor \frac{N_{ID}^{(1)}}{112} \right\rfloor + 5N_{ID}^{(2)}\ and\ m_1 = N_{ID}^{(1)}\ mod\ 112, 0 \le n < 127$
    - $x_0(i+7) = \left(x_0(i+4) + x_0(i)\right) mod\ 2$
    - $x_1(i+7) = \left(x_1(i+4) + x_1(i)\right) mod\ 2$
      - $x_0(6\sim0) = [0\ 0\ 0\ 0\ 0\ 0\ 1]\ and\ x_1(6\sim0) = [0\ 0\ 0\ 0\ 0\ 0\ 1]$

PBCH-DMRS

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
DM-RS for PBCH	1, 3	$0+v, 4+v, 8+v, \ldots, 236+v$
	2	$0+v, 4+v, 8+v, \ldots, 44+v$ $192+v, 196+v, \ldots, 236+v$

- $v = N_{ID}^{cell}\ mod\ 4$ (PCI mod 4)



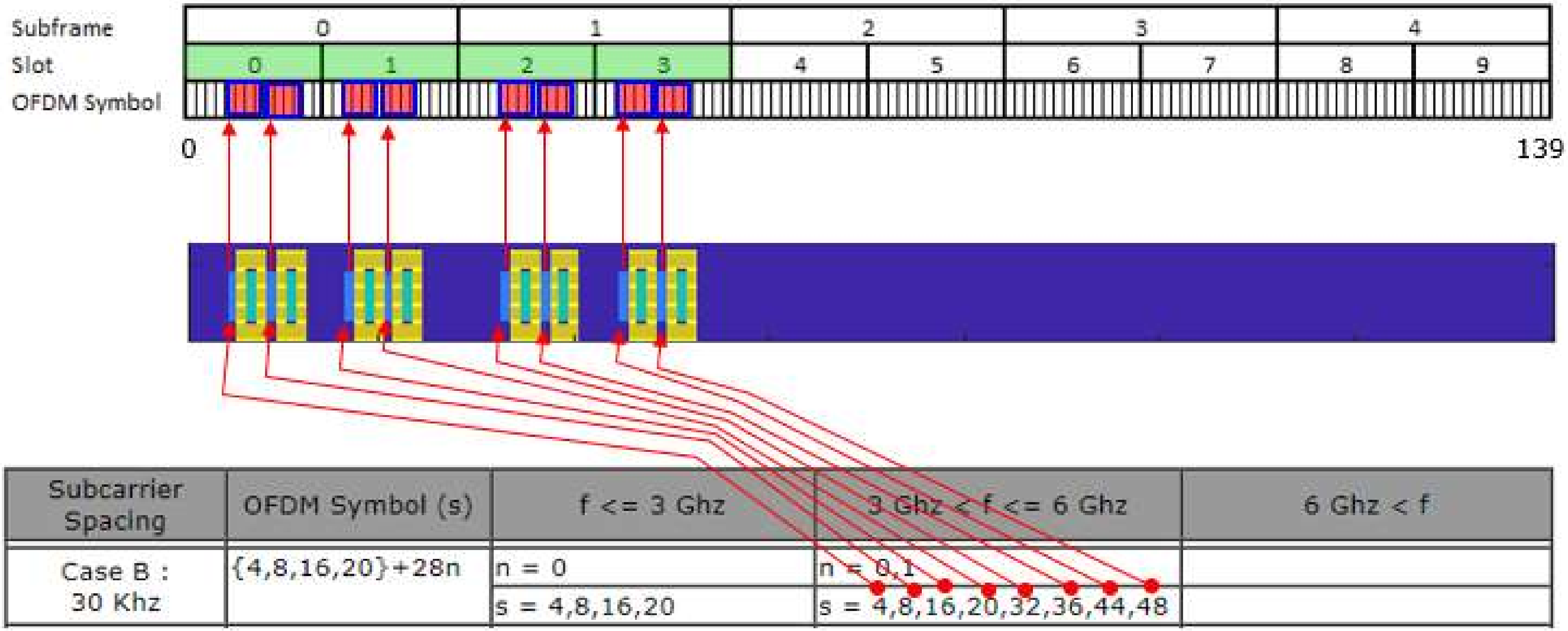
- Based on the design of different Physical layer signals (PSS, DMRS & SRS), channels (PUSCH, PUCCH) and time-frequency allocation, PCI planning must consider following Mod to reduce interference.
  - PCI Mod 3
  - PCI Mod 4
  - PCI Mod 30

PCI Impact on Network Performance

- Based on the design of different Physical layer signals (PSS, DMRS & SRS), channels (PUSCH, PUCCH) and time-frequency allocation, PCI planning must consider following Mod to reduce interference
  - PCI Mod 3 ➔ same PSS
  - PCI Mod 4 ➔ same position of PBCH-DMRS
  - PCI Mod 30 ➔ same ZC root sequence of DMRS and SRS for PUSCH

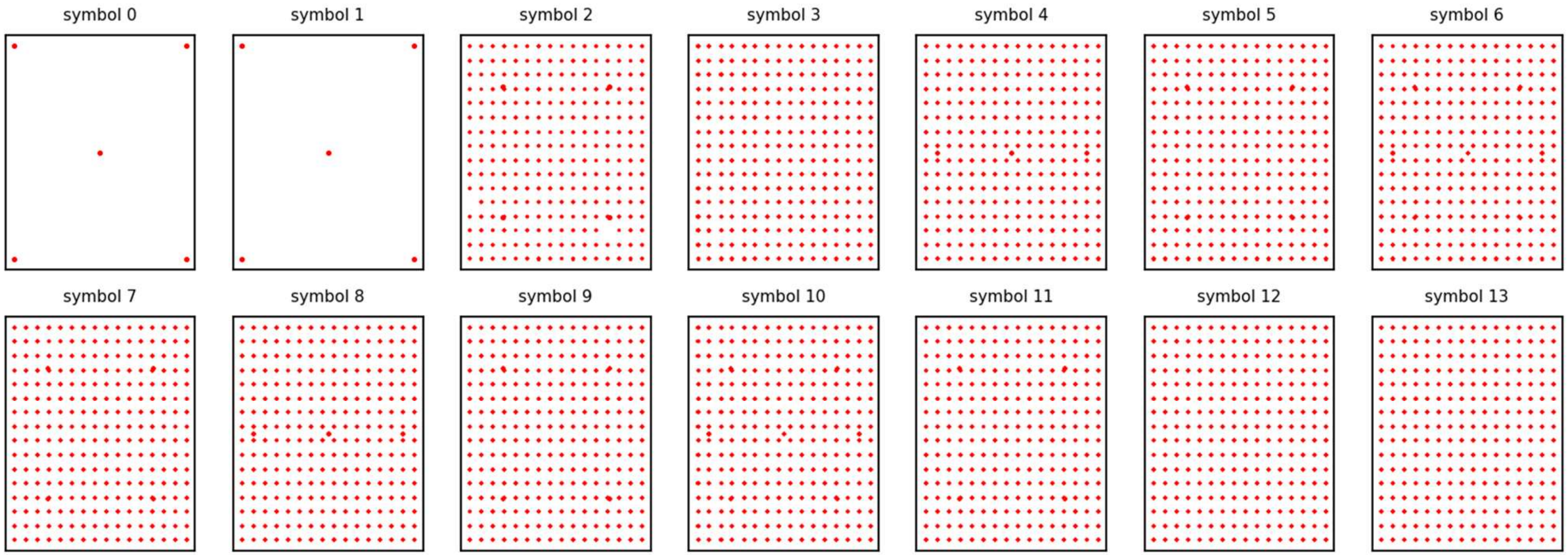
SS Burst

- Case B(30 kHz) and 3 GHz < f <= 6 GHz



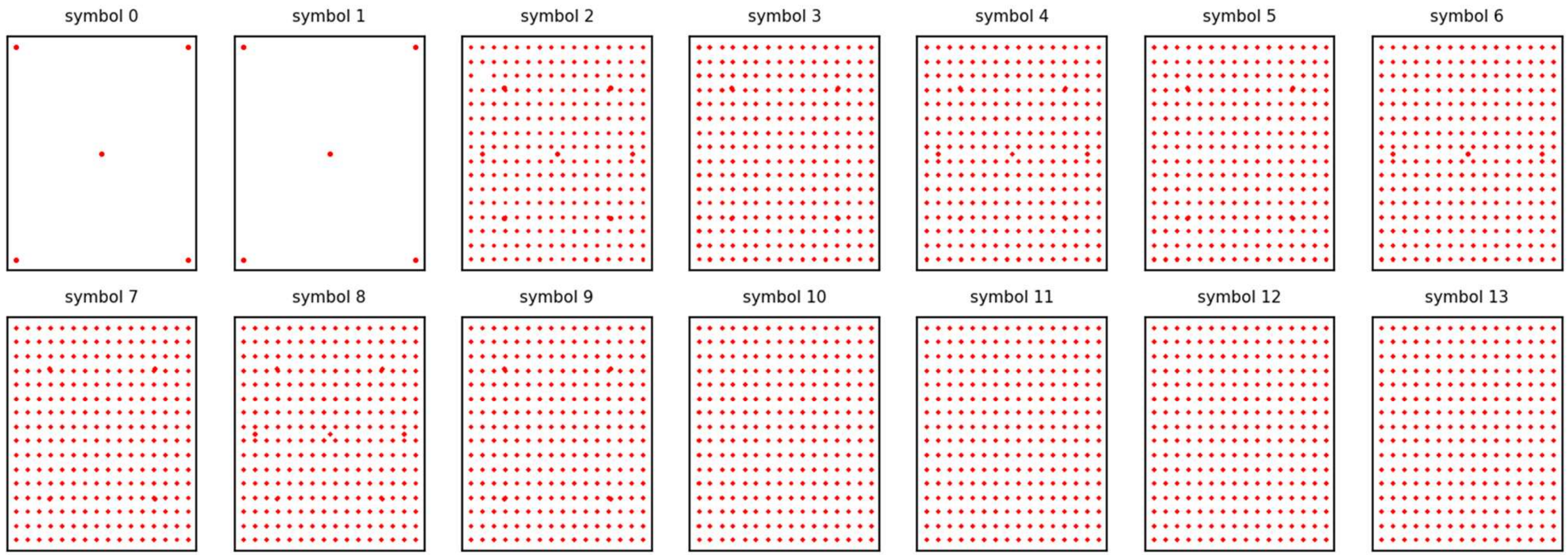
IQ in ant_0_256qam.bin

- Slot 0
  - There are 2 SSB on symbol 4~7 and 8~11



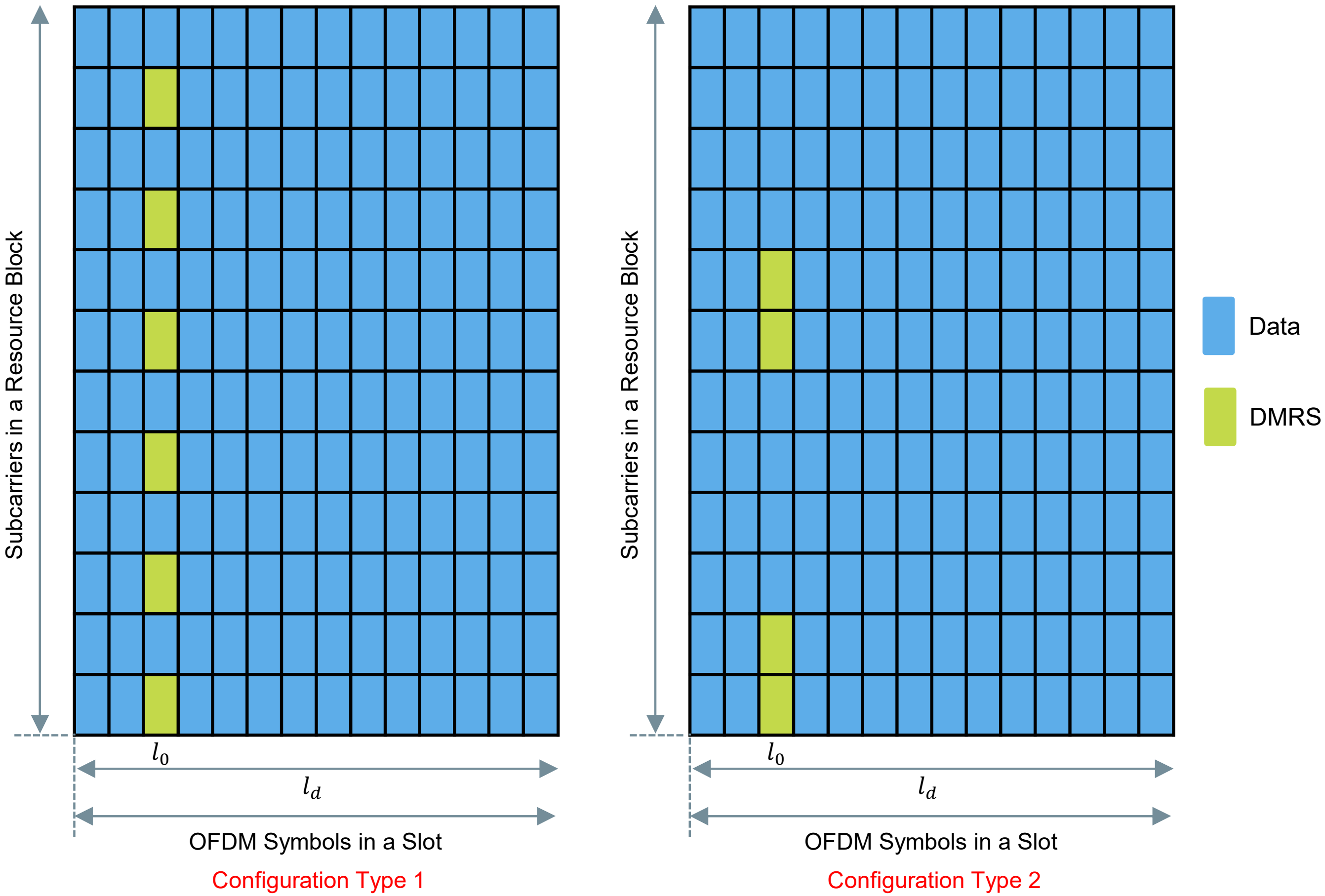
IQ in ant_0_256qam.bin

- Slot 1
  - There are 2 SSB on symbol 2~5 and 6~9



DMRS

- Configuration
  - type1, type 2
- Length
  - Single(1), Double(2)
- AdditionalPosition
  - 0, 1, 2, 3
- TypeAPosition
  - 2, 3

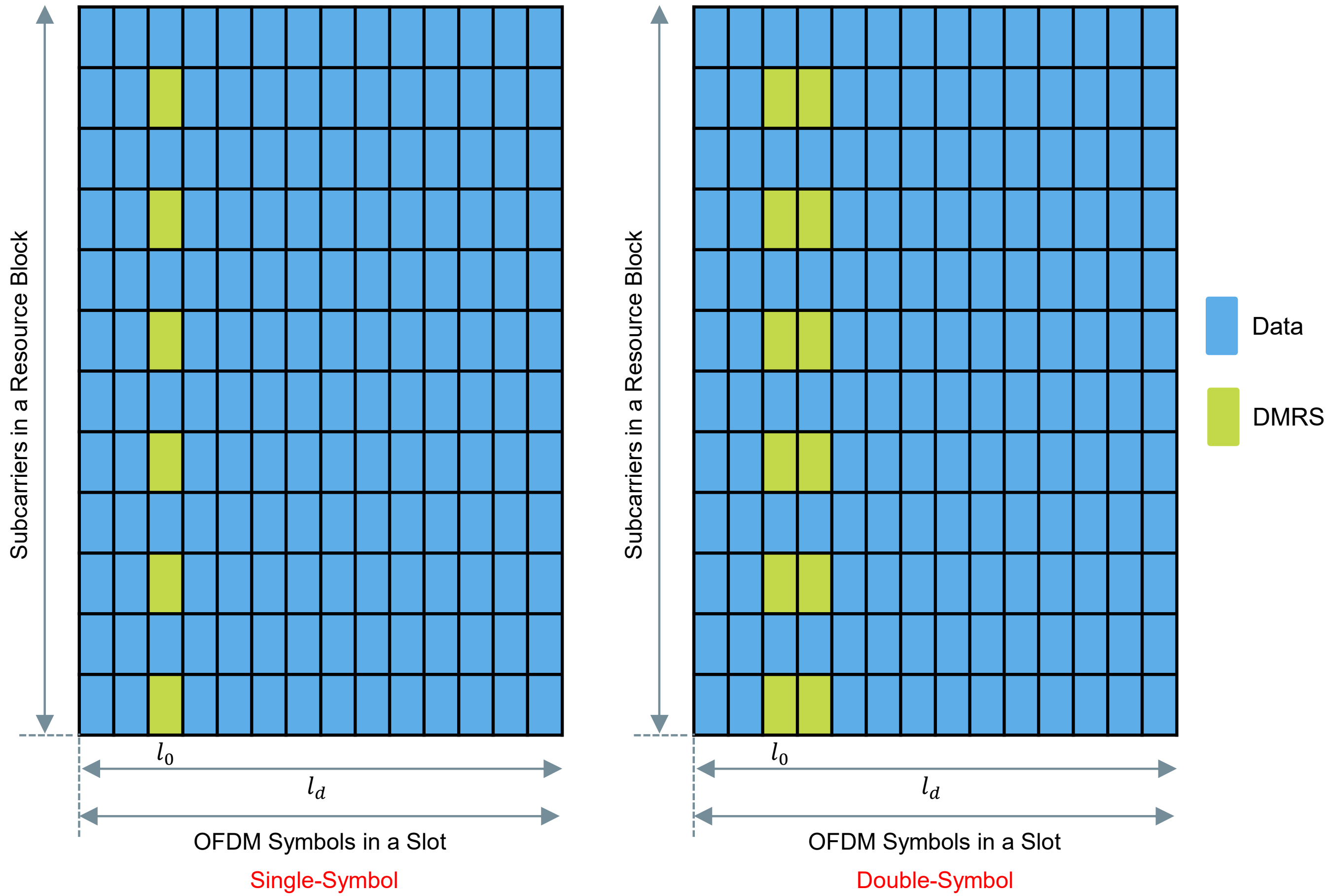


類型1更適合低信噪比、頻域選擇性較高的場景，類型2更適合高信噪比、時延擴展較小的場景

DMRS

- Configuration
  - type1, type 2
- Length
  - Single(1), Double(2)
- AdditionalPosition
  - 0, 1, 2, 3
- TypeAPosition
  - 2, 3

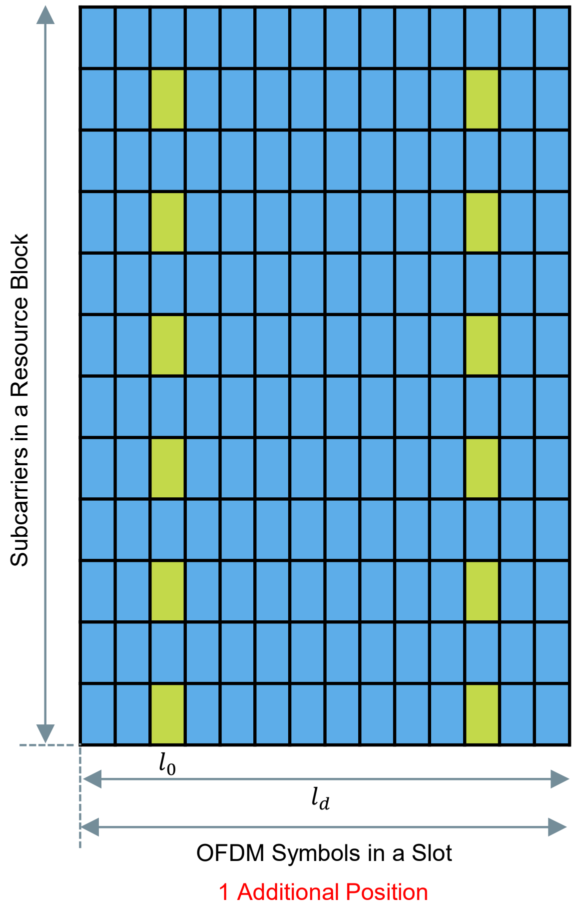
為避免干擾，不同的 antenna port 會交錯分佈 DMRS，當 antenna port 數量多時，就需要使用 double-symbol

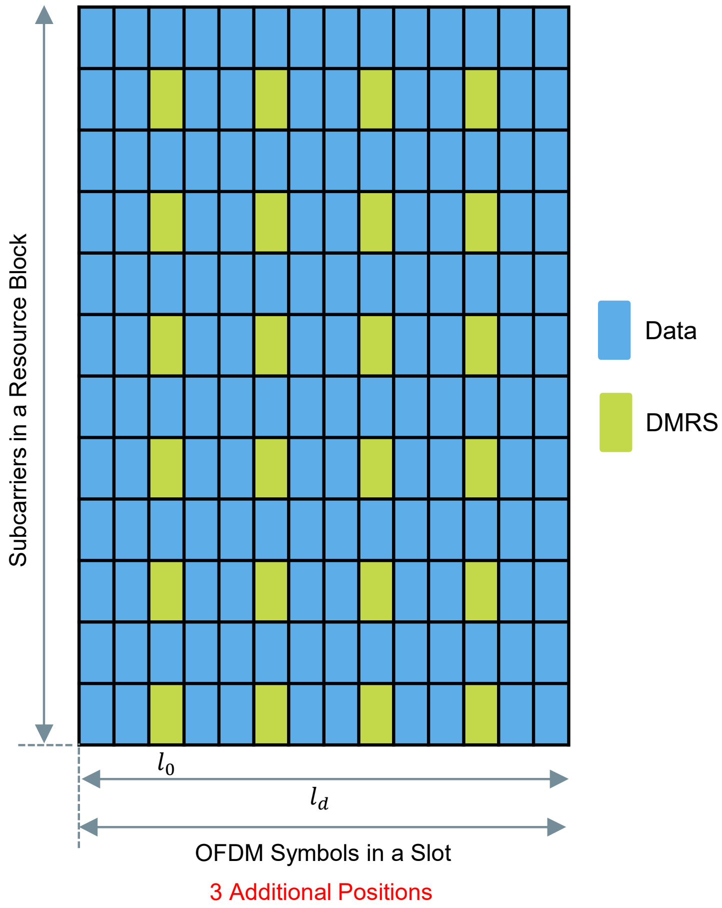


DMRS

- Configuration
  - type1, type 2
- Length
  - Single(1), Double(2)
- AdditionalPosition
  - 0, 1, 2, 3
- TypeAPosition
  - 2, 3

e.g. 兩組 DMRS，代表 0~6 symbols 由 DMRS1 輔助 domod，7~13 symbols 由 DMRS2 輔助 domod。

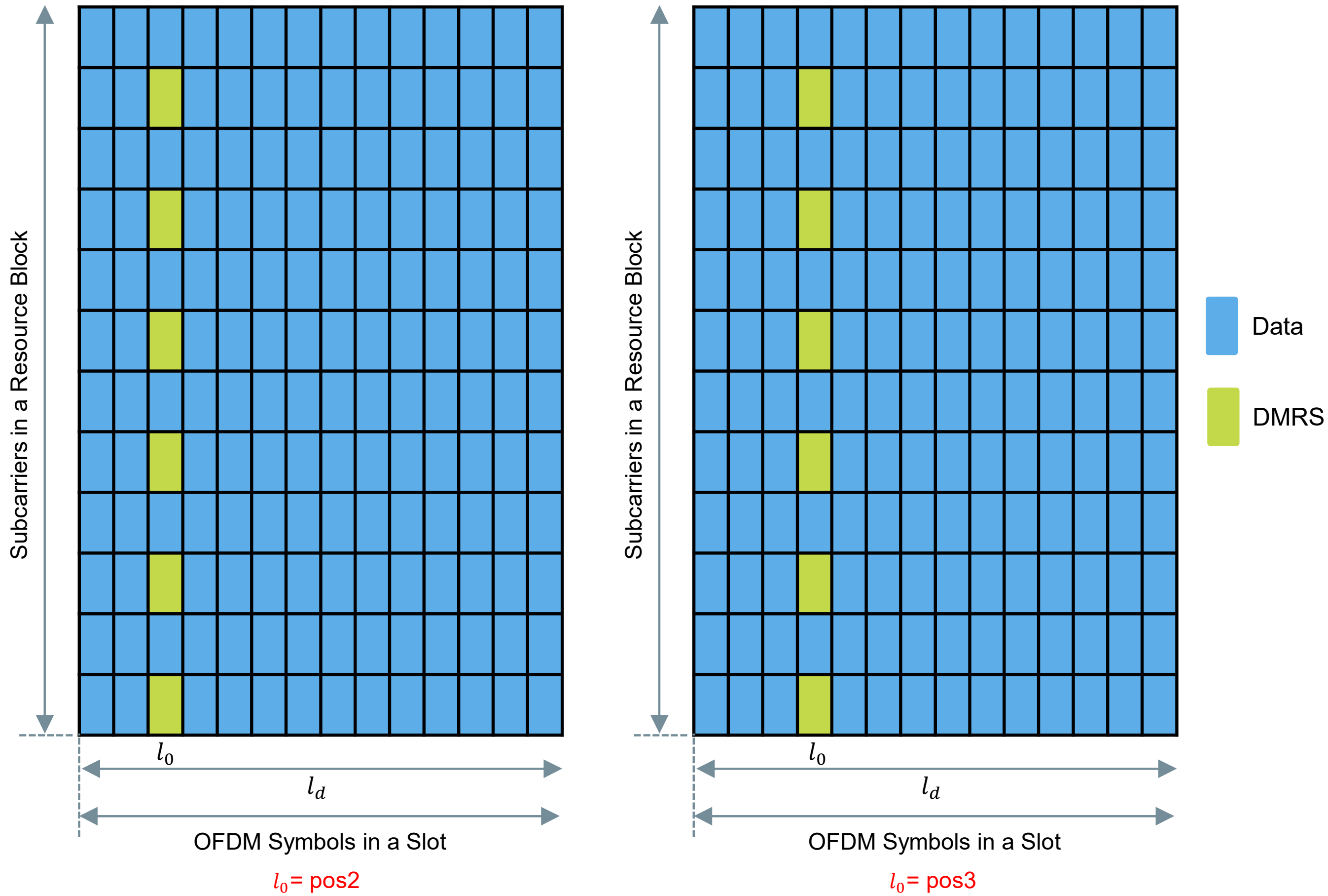




DMRS

- Configuration
  - type1, type 2
- Length
  - Single(1), Double(2)
- AdditionalPosition
  - 0, 1, 2, 3
- TypeAPosition
  - 2, 3

e.g. 當 PDSCH start symbol=3，DMRS 的 TypeAPosition 就只能是 3



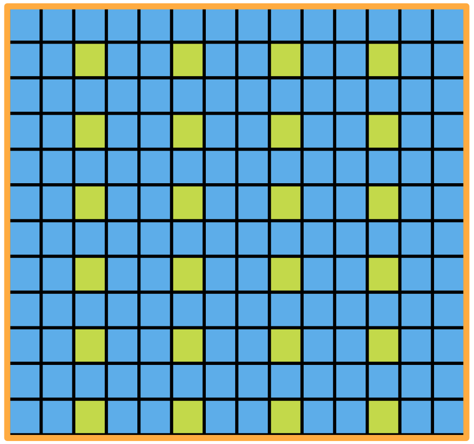
DMRS

- DMRS for
  - PBCH
  - PDCCH
  - PDSCH
  - PUCCH
  - PUSCH

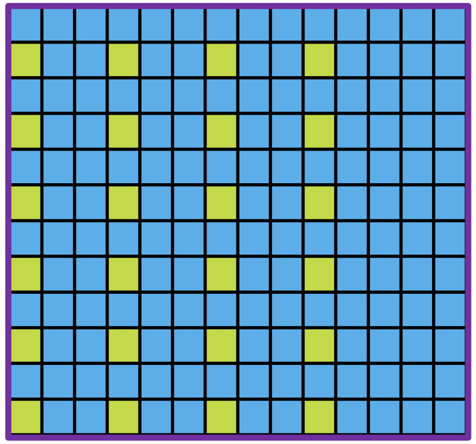
DMRS for PDSCH and PUSCH

- Sequence
  - $r(n) = \frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2n)\right) + j\frac{1}{\sqrt{2}}\left(1 - 2 \cdot c(2n+1)\right)$
  - $c_{init} = \left(2^{17}\left(N_{symb}^{slot} n_{s,f}^{\mu} + l + 1\right)\left(2N_{ID}^{n_{SCID}} + 1\right) + 2\mathrm{N}_{\mathrm{ID}}^{n_{SCID}} + n_{SCID}\right) \; mod \; 2^{31}$
- Position on time domain
- Position on frequency domain

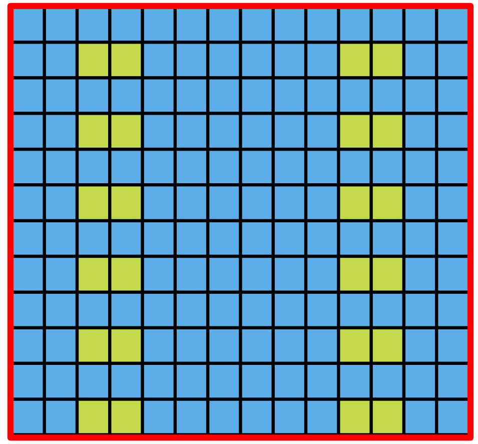
PUSCH – Time Domain Physical Resource Mapping



(a)



(b)



(c)

Duration in symbols	DM-RS positions $\bar{l}$							
	PUSCH mapping type A				PUSCH mapping type B			
	dmrs-AdditionalPosition				*dmrs-AdditionalPosition*			
	0	**1**	**2**	**3**	**0**	**1**	**2**	**3**
<4	-	-	-	-	l_0	l_0	l_0	l_0
4	l_0	l_0	l_0	l_0	l_0	l_0	l_0	l_0
5	l_0	l_0	l_0	l_0	l_0	l_0, 4	l_0, 4	l_0, 4
6	l_0	l_0	l_0	l_0	l_0	l_0, 4	l_0, 4	l_0, 4
7	l_0	l_0	l_0	l_0	l_0	l_0, 4	l_0, 4	l_0, 4
8	l_0	l_0, 7	l_0, 7	l_0, 7	l_0	l_0, 6	l_0, 3, 6	l_0, 3, 6
9	l_0	l_0, 7	l_0, 7	l_0, 7	l_0	l_0, 6	l_0, 3, 6	l_0, 3, 6
10	l_0	l_0, 9	l_0, 6, 9	l_0, 6, 9	l_0	l_0, 8	l_0, 4, 8	l_0, 3, 6, 9
11	l_0	l_0, 9	l_0, 6, 9	l_0, 6, 9	l_0	l_0, 8	l_0, 4, 8	l_0, 3, 6, 9
12	l_0	l_0, 9	l_0, 6, 9	l_0, 5, 8, 11	l_0	l_0, 10	l_0, 5, 10	l_0, 3, 6, 9
13	l_0	l_0, 11	l_0, 7, 11	l_0, 5, 8, 11	l_0	l_0, 10	l_0, 5, 10	l_0, 3, 6, 9
14	l_0	l_0, 11	l_0, 7, 11	l_0, 5, 8, 11 (a)	l_0	l_0, 10	l_0, 5, 10	l_0, 3, 6, 9 (b)

single-symbol

Duration in symbols	DM-RS positions $\bar{l}$							
	PUSCH mapping type A				PUSCH mapping type B			
	dmrs-AdditionalPosition				*dmrs-AdditionalPosition*			
	0	**1**	**2**	**3**	**0**	**1**	**2**	**3**
<4	-	-			-	-		
4	l_0	l_0			-	-		
5	l_0	l_0			l_0	l_0		
6	l_0	l_0			l_0	l_0		
7	l_0	l_0			l_0	l_0		
8	l_0	l_0			l_0	l_0, 5		
9	l_0	l_0			l_0	l_0, 5		
10	l_0	l_0, 8			l_0	l_0, 7		
11	l_0	l_0, 8			l_0	l_0, 7		
12	l_0	l_0, 8			l_0	l_0, 9		
13	l_0	l_0, 10			l_0	l_0, 9		
14	l_0	l_0, 10 (c)			l_0	l_0, 9		

double-symbol

PUSCH – Frequency Domain Physical Resource Mapping

$$\tilde{a}_{k,l}^{(\tilde{p}_j,\mu)} = w_{\mathrm{f}}(k')\, w_{\mathrm{t}}(l')\, r(2n+k')$$

$$k = \begin{cases} 4n+2k'+\Delta & \text{Configuration type 1} \\ 6n+k'+\Delta & \text{Configuration type 2} \end{cases}$$

$$k' = 0,1$$

$$l = \bar{l} + l'$$

$$n = 0,1,\ldots$$

$$j = 0,1,\ldots,\upsilon-1$$

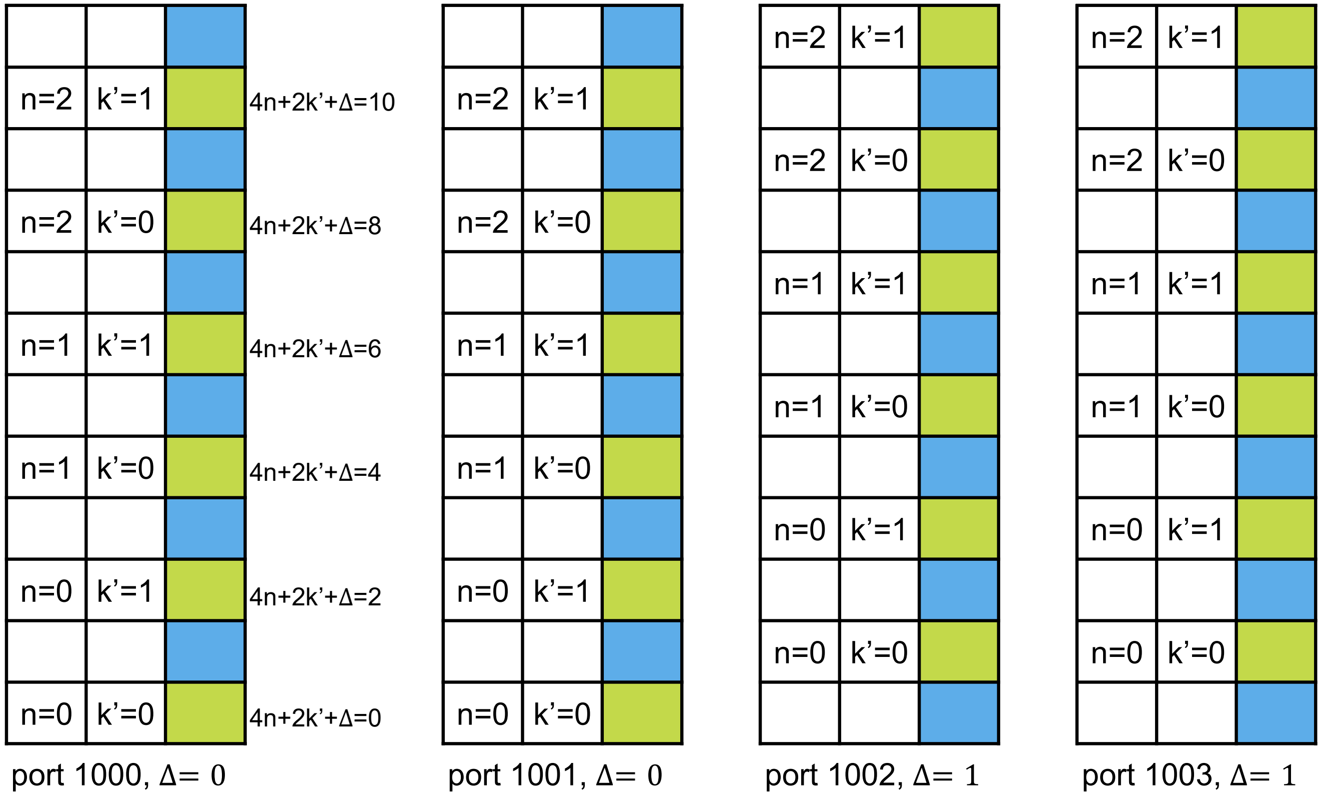


Table 6.4.1.1.3-1: Parameters for PUSCH DM-RS configuration type 1.

$\tilde{p}$	CDM group	Δ	$w_{\mathrm{f}}(k')$		$w_{\mathrm{t}}(l')$	
			$k'=0$	$k'=1$	$l'=0$	$l'=1$
0	0	0	+1	+1	+1	+1
1	0	0	+1	-1	+1	+1
2	1	1	+1	+1	+1	+1
3	1	1	+1	-1	+1	+1
4	0	0	+1	+1	+1	-1
5	0	0	+1	-1	+1	-1
6	1	1	+1	+1	+1	-1
7	1	1	+1	-1	+1	-1

	Channel/Signal	Antenna Ports
Downlink	PDSCH	Antenna ports starting with 1000
	PDCCH	Antenna ports starting with 2000
	CSI-RS	Antenna ports starting with 3000
	SS/PBCH	Antenna ports starting with 4000
Uplink	PUSCH/DMRS	Antenna ports starting with 0
	SRS	Antenna ports starting with 1000
	PUCCH	Antenna ports starting with 2000
	PRACH	Antenna port 4000

PUSCH – Frequency Domain Physical Resource Mapping

$$\tilde{a}_{k,l}^{(\tilde{p}_j,\mu)} = w_{\mathrm{f}}(k')\, w_{\mathrm{t}}(l')\, r(2n+k')$$

$$k = \begin{cases} 4n+2k'+\Delta & \text{Configuration type 1} \\ 6n+k'+\Delta & \text{Configuration type 2} \end{cases}$$

$$k' = 0,1$$

$$l = \bar{l} + l'$$

$$n = 0,1,\ldots$$

$$j = 0,1,\ldots,\upsilon-1$$

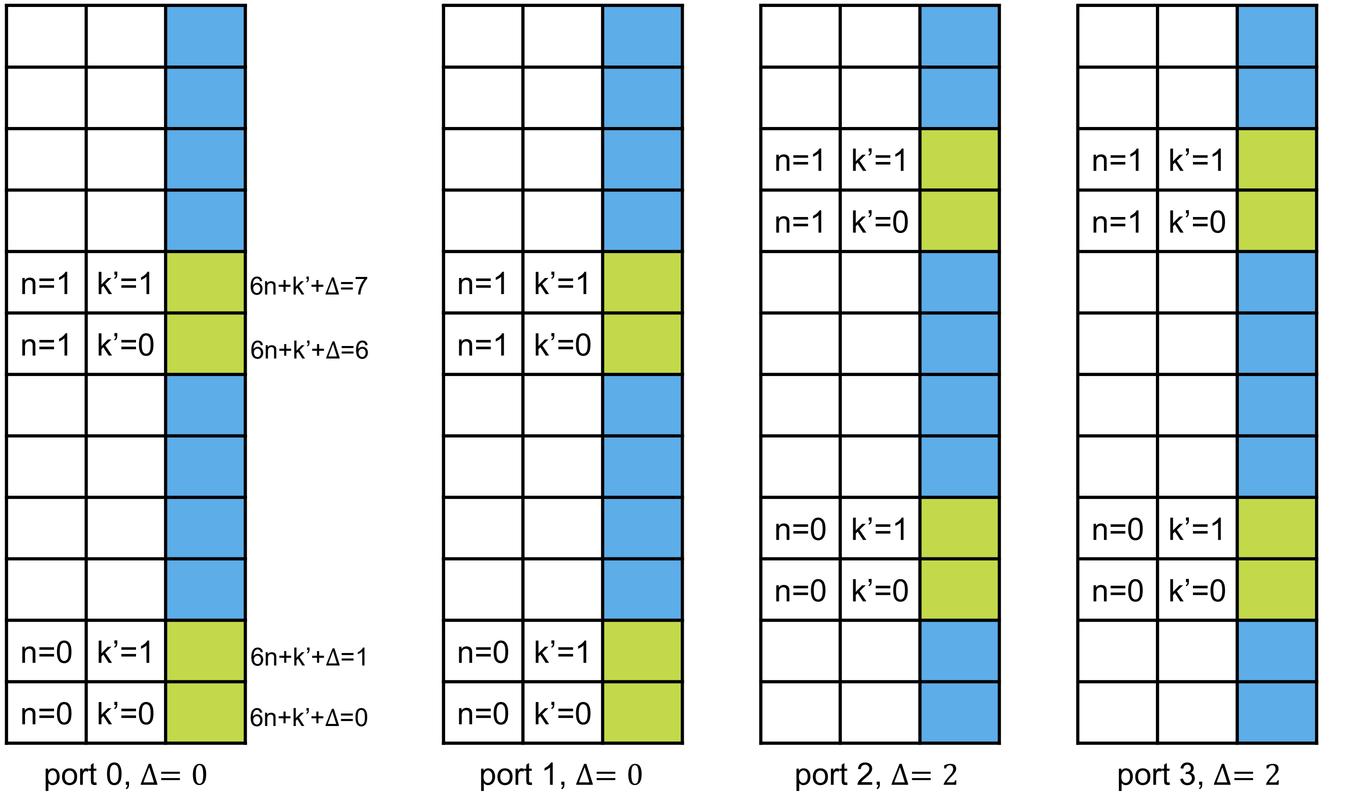


Table 6.4.1.1.3-2: Parameters for PUSCH DM-RS configuration type 2.

$\tilde{p}$	CDM group	Δ	$w_{\mathrm{f}}(k')$		$w_{\mathrm{t}}(l')$	
			$k'=0$	$k'=1$	$l'=0$	$l'=1$
0	0	0	+1	+1	+1	+1
1	0	0	+1	-1	+1	+1
2	1	2	+1	+1	+1	+1
3	1	2	+1	-1	+1	+1
4	2	4	+1	+1	+1	+1
5	2	4	+1	-1	+1	+1
6	0	0	+1	+1	+1	-1
7	0	0	+1	-1	+1	-1
8	1	2	+1	+1	+1	-1
9	1	2	+1	-1	+1	-1
10	2	4	+1	+1	+1	-1
11	2	4	+1	-1	+1	-1

Table 6.4.1.1.3-5: PUSCH DM-RS time index l'.

DM-RS duration	l'	*Supported antenna ports $\tilde{p}$*	
		Configuration type 1	*Configuration type 2*
single-symbol DM-RS	0	0 – 3	0 – 5
double-symbol DM-RS	0, 1	0 – 7	0 – 11

PDSCH – Time Domain
Physical Resource Mapping

Duration in symbols	DM-RS positions $\bar{l}$							
	PDSCH mapping type A				PDSCH mapping type B			
	dmrs-AdditionalPosition				*dmrs-AdditionalPosition*			
	0	***1***	***2***	***3***	***0***	***1***	***2***	***3***
2	-	-	-	-	l_0	l_0		
3	l_0	l_0	l_0	l_0	-	-		
4	l_0	l_0	l_0	l_0	l_0	l_0		
5	l_0	l_0	l_0	l_0	-	-		
6	l_0	l_0	l_0	l_0	l_0	l_0,4		
7	l_0	l_0	l_0	l_0	l_0	l_0,4		
8	l_0	l_0, 7	l_0, 7	l_0, 7	-	-		
9	l_0	l_0, 7	l_0, 7	l_0, 7	-	-		
10	l_0	l_0, 9	l_0, 6, 9	l_0, 6, 9	-	-		
11	l_0	l_0, 9	l_0, 6, 9	l_0, 6, 9	-	-		
12	l_0	l_0, 9	l_0, 6, 9	l_0, 5, 8, 11	-	-		
13	l_0	l_0, 11	l_0, 7, 11	l_0, 5, 8, 11	-	-		
14	l_0	l_0, 11	l_0, 7, 11	l_0, 5, 8, 11	-	-		

single-symbol

Duration in symbols	DM-RS positions $\bar{l}$					
	PDSCH mapping type A			PDSCH mapping type B		
	dmrs-AdditionalPosition			dmrs-AdditionalPosition		
	0	**1**	**2**	**0**	**1**	**2**
<4				-	-	
4	l_0	l_0		-	-	
5	l_0	l_0		-	-	
6	l_0	l_0		l_0	l_0	
7	l_0	l_0		l_0	l_0	
8	l_0	l_0		-	-	
9	l_0	l_0		-	-	
10	l_0	l_0, 8		-	-	
11	l_0	l_0, 8		-	-	
12	l_0	l_0, 8		-	-	
13	l_0	l_0, 10		-	-	
14	l_0	l_0, 10		-	-	

double-symbol

PDSCH – Frequency Domain Physical Resource Mapping

$$\tilde{a}_{k,l}^{(\tilde{p}_j,\mu)} = w_{\mathrm{f}}(k')\,w_{\mathrm{t}}(l')\,r(2n+k')$$

$$k = \begin{cases} 4n+2k'+\Delta & \text{Configuration type 1} \\ 6n+k'+\Delta & \text{Configuration type 2} \end{cases}$$

$$k' = 0,1$$

$$l = \bar{l} + l'$$

$$n = 0,1,\ldots$$

$$j = 0,1,\ldots,\upsilon-1$$

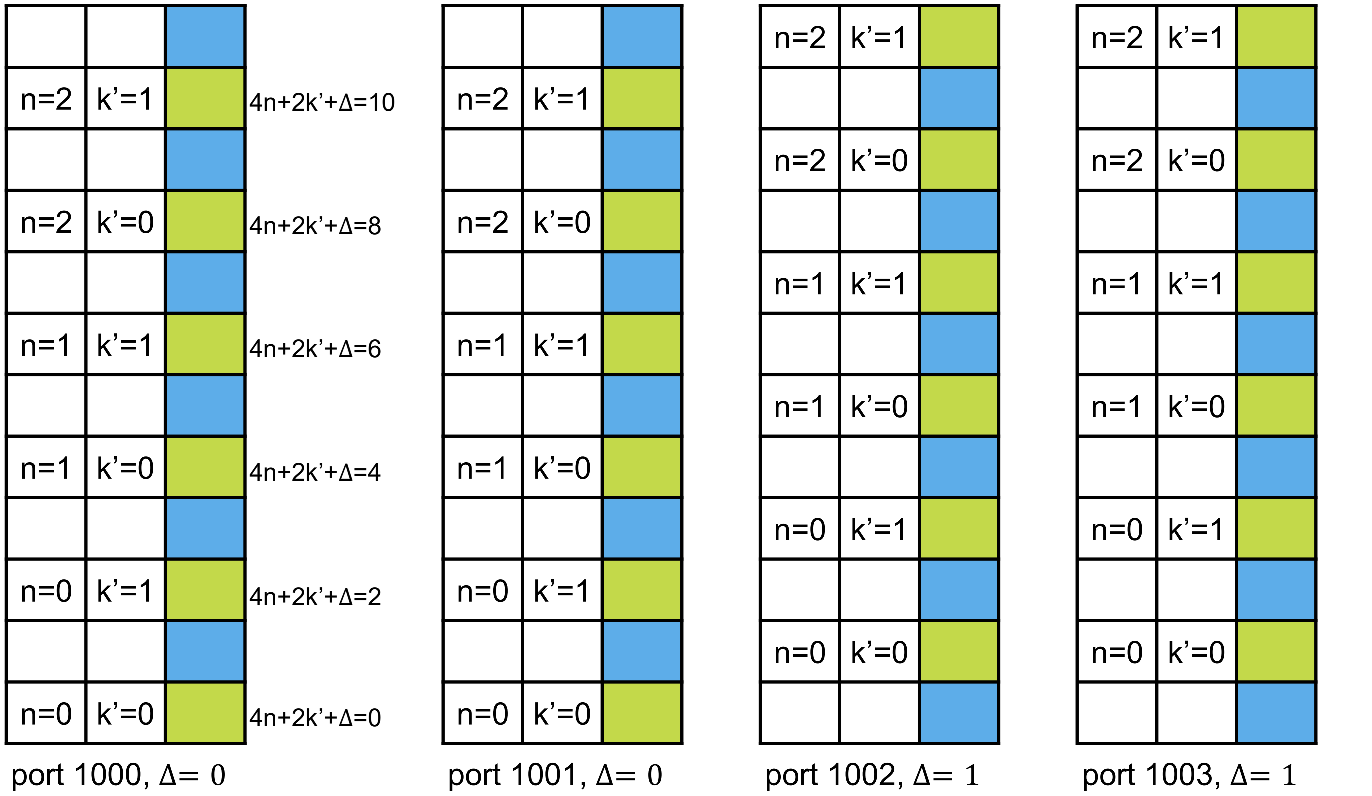


Table 7.4.1.1.2-1: Parameters for PDSCH DM-RS configuration type 1.

p	CDM group λ	Δ	$w_{\mathrm{f}}(k')$		$w_{\mathrm{t}}(l')$	
			$k'=0$	$k'=1$	$l'=0$	$l'=1$
1000	0	0	+1	+1	+1	+1
1001	0	0	+1	-1	+1	+1
1002	1	1	+1	+1	+1	+1
1003	1	1	+1	-1	+1	+1
1004	0	0	+1	+1	+1	-1
1005	0	0	+1	-1	+1	-1
1006	1	1	+1	+1	+1	-1
1007	1	1	+1	-1	+1	-1

	Channel/Signal	Antenna Ports
Downlink	PDSCH	Antenna ports starting with 1000
	PDCCH	Antenna ports starting with 2000
	CSI-RS	Antenna ports starting with 3000
	SS/PBCH	Antenna ports starting with 4000
Uplink	PUSCH/DMRS	Antenna ports starting with 0
	SRS	Antenna ports starting with 1000
	PUCCH	Antenna ports starting with 2000
	PRACH	Antenna port 4000

PDSCH – Frequency Domain Physical Resource Mapping

$$\tilde{a}_{k,l}^{(\tilde{p}_j,\mu)} = w_{\mathrm{f}}(k')\,w_{\mathrm{t}}(l')\,r(2n+k')$$

$$k = \begin{cases} 4n+2k'+\Delta & \text{Configuration type 1} \\ 6n+k'+\Delta & \text{Configuration type 2} \end{cases}$$

$$k' = 0,1$$

$$l = \bar{l} + l'$$

$$n = 0,1,...$$

$$j = 0,1,...,\upsilon-1$$

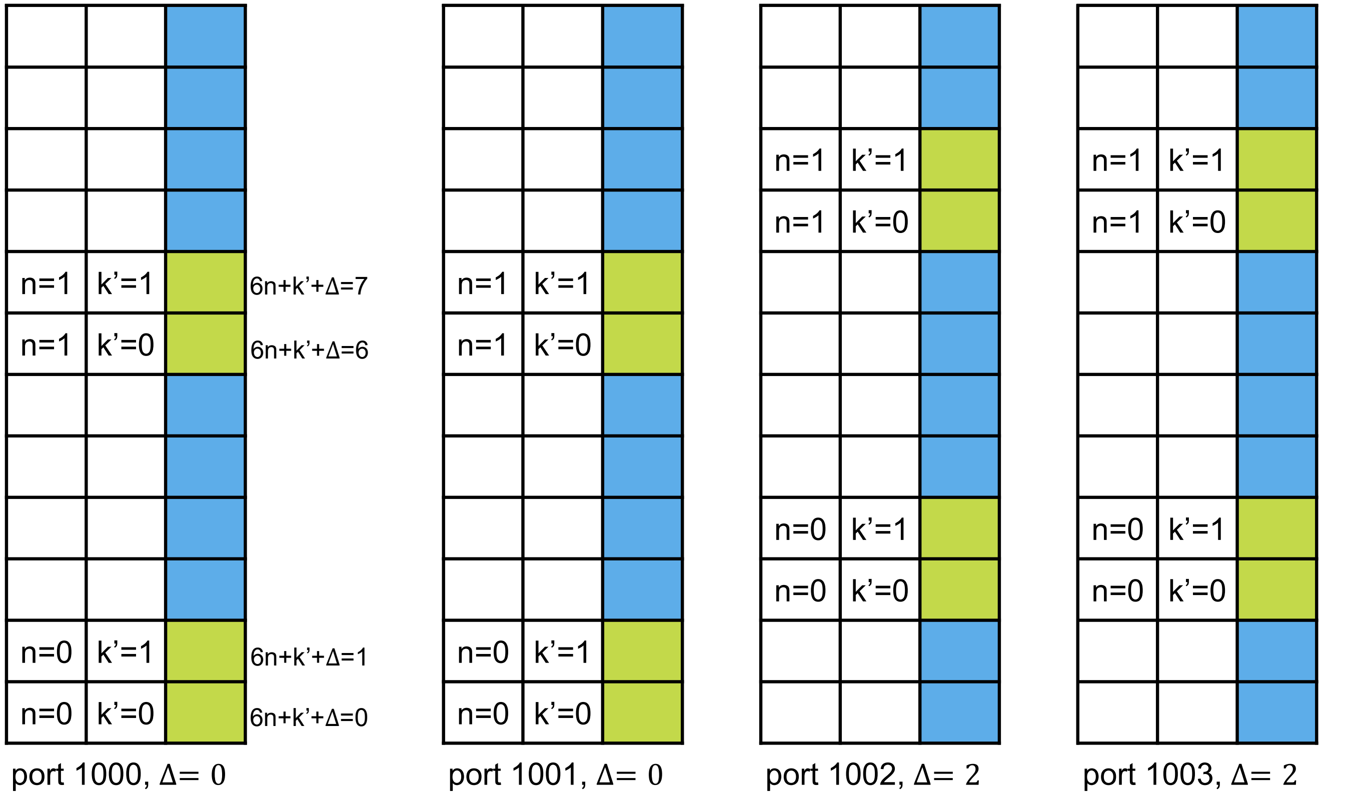


Table 7.4.1.1.2-2: Parameters for PDSCH DM-RS configuration type 2.

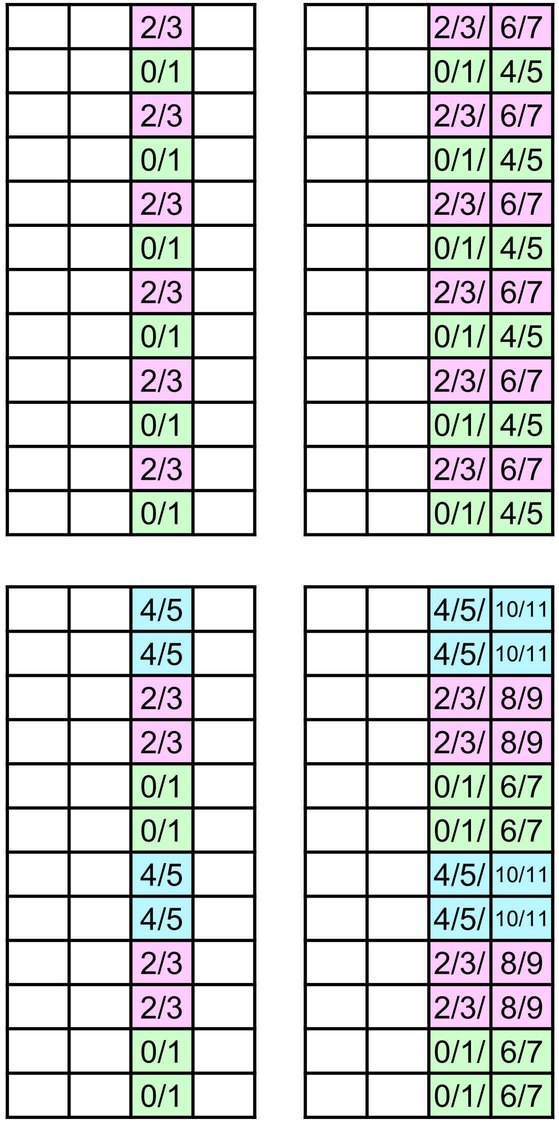
p	CDM group λ	Δ	$w_{\mathrm{f}}(k')$		$w_{\mathrm{t}}(l')$	
			$k'=0$	$k'=1$	$l'=0$	$l'=1$
1000	0	0	+1	+1	+1	+1
1001	0	0	+1	-1	+1	+1
1002	1	2	+1	+1	+1	+1
1003	1	2	+1	-1	+1	+1
1004	2	4	+1	+1	+1	+1
1005	2	4	+1	-1	+1	+1
1006	0	0	+1	+1	+1	-1
1007	0	0	+1	-1	+1	-1
1008	1	2	+1	+1	+1	-1
1009	1	2	+1	-1	+1	-1
1010	2	4	+1	+1	+1	-1
1011	2	4	+1	-1	+1	-1

Table 6.4.1.1.3-5: PUSCH DM-RS time index l'.

DM-RS duration	l'	*Supported antenna ports $\tilde{p}$*	
		Configuration type 1	***Configuration type 2***
single-symbol DM-RS	0	0 – 3	0 – 5
double-symbol DM-RS	0, 1	0 – 7	0 – 11

DMRS and Antenna Port

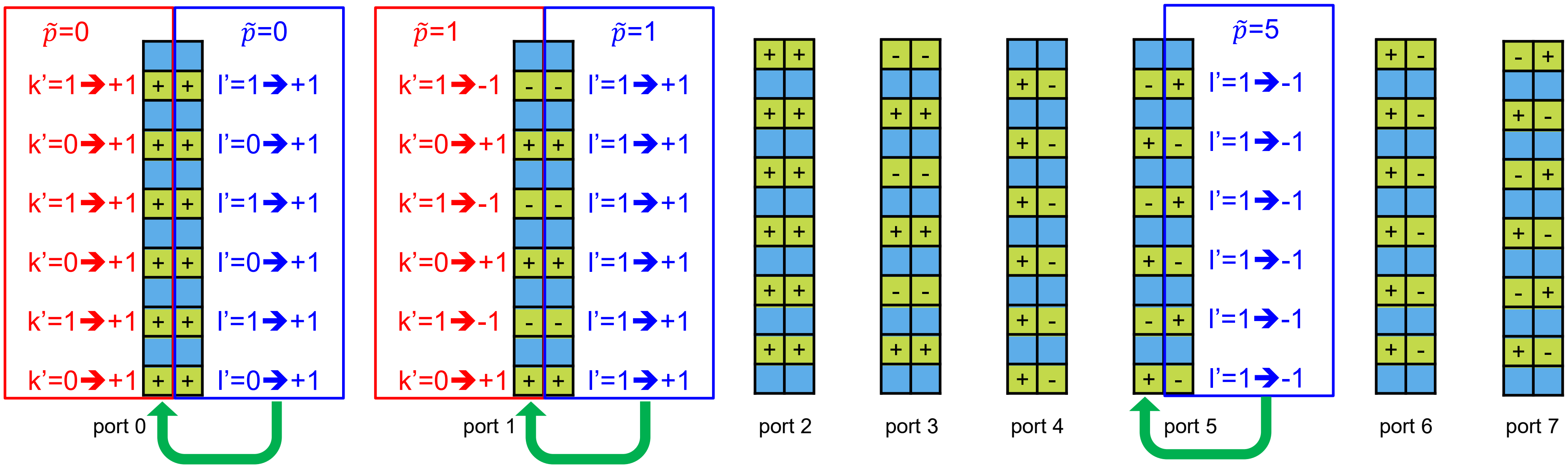
- type 1 在 single-symbol 情況下，最多支持 4 個 antenna port，port 01 和 23 分別在不同的 CDM group，每個 CDM group 內，比如 port 0 和 1，又通過頻域的 OCC 來實現正交，從而實現 4 個 port 的正交
- type 1 在 double-symbol 情況下，最多支持 8 個 antenna port，除了頻域 OCC 外，還可以時域 OCC 來實現正交
- type 2 在 single-symbol 情況下，最多支持 6 個 antenna port ，共三個 CDM group，每個 group 內又通過頻域 OCC 實現正交。
- type 2 在 double-symbol 情況下，最多支持 12 個 antenna port ，除了頻域OCC 外，還可以時域 OCC，從而支持更多的 port



DMRS Type 1 & Double-symbol with OCC

Table 6.4.1.1.3-1: Parameters for PUSCH DM-RS configuration type 1.

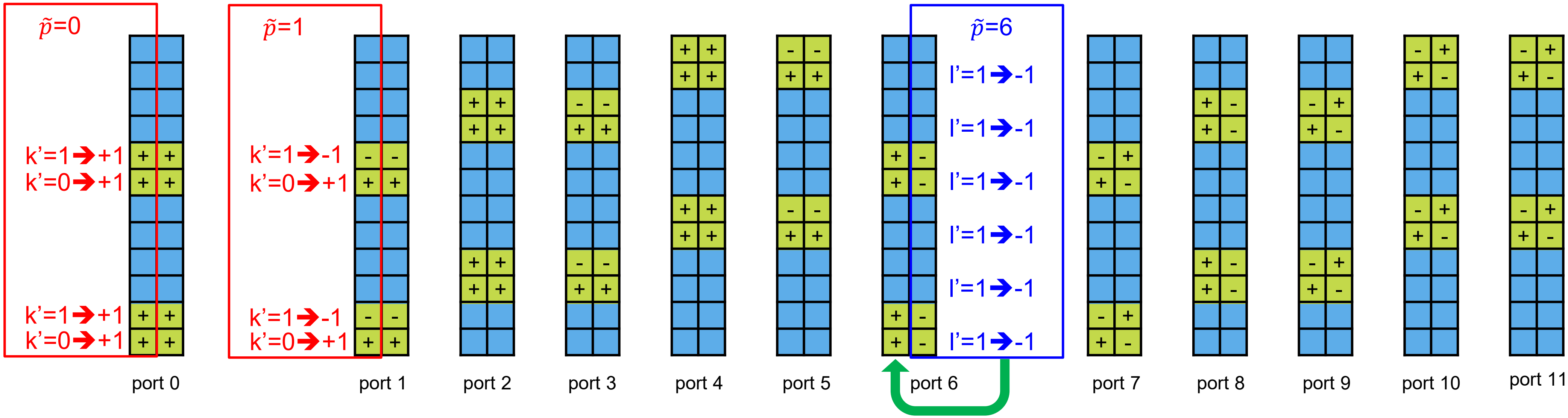
$\tilde{p}$	CDM group	Δ	處理 Frequency Domain $w_f(k')$		處理 Time Domain $w_t(l')$	
			$k'=0$	$k'=1$	$l'=0$	$l'=1$
0	0	0	+1	+1	+1	+1
1	0	0	+1	-1	+1	+1
2	1	1	+1	+1	+1	+1
3	1	1	+1	-1	+1	+1
4	0	0	+1	+1	+1	-1
5	0	0	+1	-1	+1	-1
6	1	1	+1	+1	+1	-1
7	1	1	+1	-1	+1	-1



DMRS Type 2 & Double-symbol with OCC

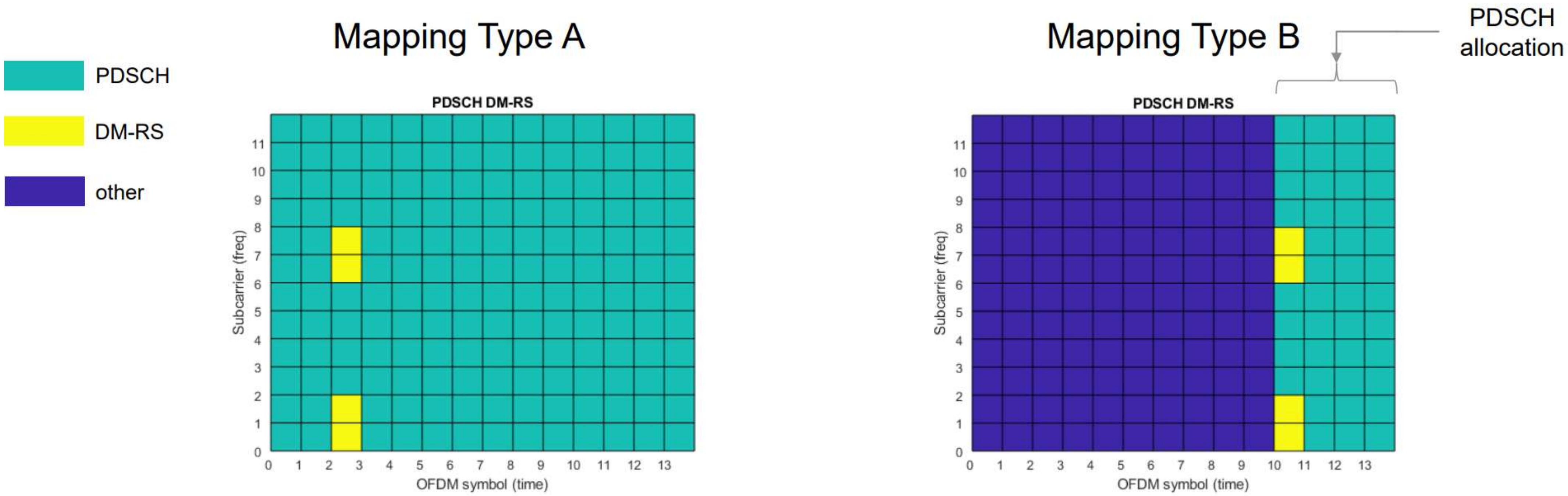
Table 6.4.1.1.3-2: Parameters for PUSCH DM-RS configuration type 2.

$\tilde{p}$	CDM group	Δ	處理 Frequency Domain		處理 Time Domain	
			$k'=0$	$k'=1$	$l'=0$	$l'=1$
0	0	0	+1	+1	+1	+1
1	0	0	+1	-1	+1	+1
2	1	2	+1	+1	+1	+1
3	1	2	+1	-1	+1	+1
4	2	4	+1	+1	+1	+1
5	2	4	+1	-1	+1	+1
6	0	0	+1	+1	+1	-1
7	0	0	+1	-1	+1	-1
8	1	2	+1	+1	+1	-1
9	1	2	+1	-1	+1	-1
10	2	4	+1	+1	+1	-1
11	2	4	+1	-1	+1	-1



PDSCH Mapping Type

- Two types of mapping



- First DM-RS in symbol 2 or 3 of the slot

- DM-RS in first symbol of the allocation
- PUSCH partially mapped to slot

PDSCH Mapping Type

PDSCH mapping type	Normal cyclic prefix			Extended cyclic prefix		
	S	***L***	***S+L***	***S***	***L***	***S+L***
Type A	{0,1,2,3}	{3,…,14}	{3,…,14}	{0,1,2,3}	{3,…,12}	{3,…,12}
Type B	{0,…,12}	{2,4,7}	{2,…,14}	{0,…,10}	{2,4,6}	{2,…,12}

- The information is carried by DCI
  - Type A
    - The PDSCH-DMRS location is fixed to symbol 2 or 3
      - S = 3 is applicable only if dmrs-TypeA-Position = 3
  - Type B
    - The PDSCH-DMRS location is fixed to the first symbol of the allocated PDSCH
    - PDSCH Length can only be 2 or 4 or 7(6)
      - MiniSlot used for URLLC application with very low latency

PUSCH Mapping Type

PDSCH mapping type	Normal cyclic prefix			Extended cyclic prefix		
	S	***L***	***S+L***	***S***	***L***	***S+L***
Type A	0	{4,…,14}	{4,…,14}	0	{4,…,12}	{4,…,12}
Type B	{0,…,13}	{1,…,14}	{1,…,14}	{0,…,12}	{1,…,12}	{1,…,12}

- The information is carried by DCI
  - Type A
    - The PUSCH-DMRS location is fixed to symbol 2 or 3
    - PUSCH Starting Symbol is always 0
  - Type B
    - The PUSCH-DMRS location is fixed to the first symbol of the allocated PUSCH

PUCCH Format

- format 0
- format 1
- format 2
- format 3
- format 4

- 3GPP TS 38.213

Table 9.2.1-1: PUCCH resource sets before dedicated PUCCH resource configuration

Index	PUCCH format	First symbol	Number of symbols	PRB offset RB_{BWP}^{offset}	Set of initial CS indexes
0	0	12	2	0	{0, 3}
1	0	12	2	0	{0, 4, 8}
2	0	12	2	3	{0, 4, 8}
3	1	10	4	0	{0, 6}
4	1	10	4	0	{0, 3, 6, 9}
5	1	10	4	2	{0, 3, 6, 9}
6	1	10	4	4	{0, 3, 6, 9}
7	1	4	10	0	{0, 6}
8	1	4	10	0	{0, 3, 6, 9}
9	1	4	10	2	{0, 3, 6, 9}
10	1	4	10	4	{0, 3, 6, 9}
11	1	0	14	0	{0, 6}
12	1	0	14	0	{0, 3, 6, 9}
13	1	0	14	2	{0, 3, 6, 9}
14	1	0	14	4	{0, 3, 6, 9}
15	1	0	14	$\lfloor N_{BWP}^{size}/4 \rfloor$	{0, 3, 6, 9}

- BWP
    - bandwidth part
- CORESET
    - control resource set

- MSI(Minimum System Information) contains
  - MIB(Master Information Block)
    - MIB provides all the required information to UE for decoding SIB1
  - SIB1(System Information Block #1)
    - RMSI(Remaining Minimum System Information)
    - SIB1 carries the critical information required for the UE to **access the cell**
- OSI(Other System Information) contains
  - SIB2 ~ SIB9
- In **O-RAN** architecture, the DU is responsible for generating the content of both the **MIB** and **SIB1**
- MIB provides all the required information to UE for decoding SIB1
- SIB 1 is **cell-specific** information
  - carries the critical information required for the UE to **access the cell**

eAxC
BandSector and CC

eAxC (extended Antenna-Carrier)

- Include 4 fields

0 (msb)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15 (lsb)

DU_Port_ID	BandSector_ID	CC_ID	RU_Port_ID

  - What is BandSector?
    - distinguishes bands and sectors supported by the O-RU
  - What is CC (component carrier)?
    - distinguishes Carrier Components supported by the O-RU

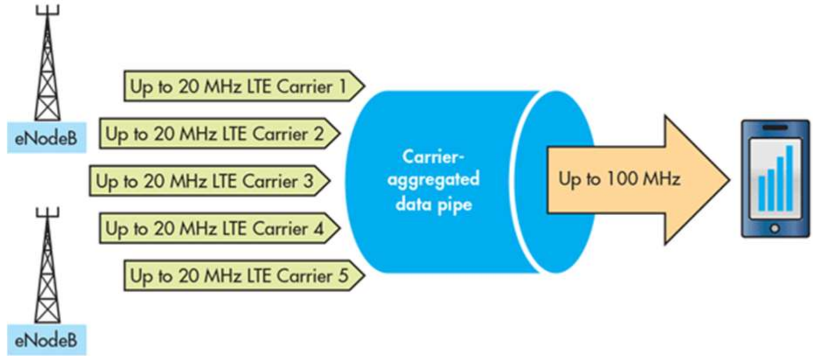
What is Carrier Aggregation?

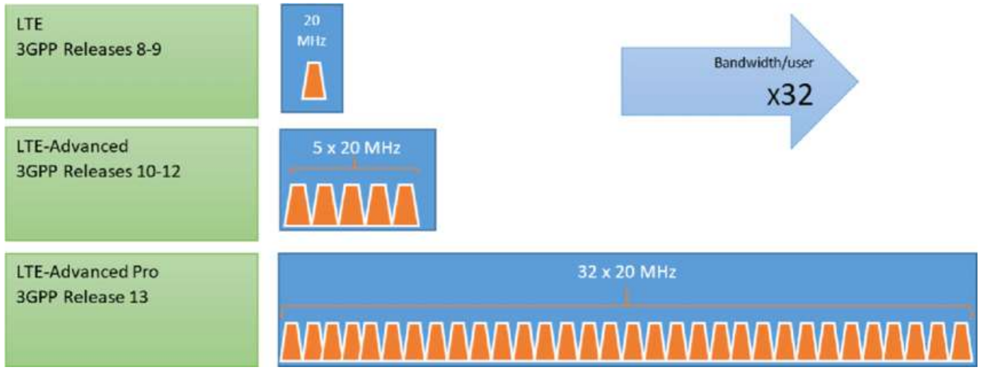
- 一般來說，要提升網速或者容量
  - **建更多的基站**：這樣一來同一個基站下搶資源的人就少了，網速自然就上去了。但缺點是投入太大了，運營商肯定不會做虧本的買賣
  - **提升頻譜效率**：在每赫茲的頻譜上傳更多的資料！
    - 用更好的 modulation model、用更好的通訊元件，達到更佳的 QAM 數
    - 多天線技術 (MIMO) 提升頻譜使用效率
  - **增加頻譜頻寬**：從 2G 到 5G，載波的頻寬不斷增大，從 2G 的 200K，再到 3G 的 5M，4G 的 20M，在 5G 時代達到了 100M（Sub-6 頻段）乃至 400M（毫米波頻段）！
    - 單個載波的頻寬太小，那就集結多個載波頻寬，一起傳資料 ➔ **載波聚合**

- MIMO
  - 頻寬不變，同時傳送多數據流
  - 道路寬度不變，但是畫成多線道，透過對數據的一些處理，盡量減低互相干擾
- Carrier Aggregation
  - 聚合多頻寬傳送資料
  - 一條道路依舊維持 n 條數據流，但徵收多條道路 (拓寬道路)

What is Carrier Aggregation?

- e.g. 4G 單載波最大頻寬為 20 MHz，5 個 CC 集合可以達到 100 MHz
- 4G 目前可支援 32 個 CC、 5G 目前可支援 16 個 CC





What is Component Carrier?

- For 5G NR, maximum Component Carrier bandwidth is 100 MHz for FR1 and 400 MHz for FR2

所有支援的 channel bandwidth

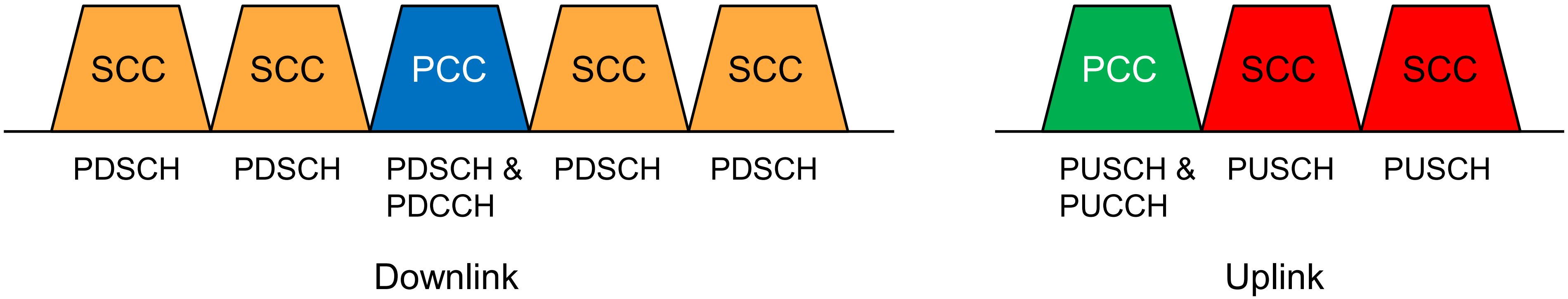
Frequency Range 1 [編輯]

頻段	雙工方式[A 1]	*f*（MHz）	常用名	頻段子集	上行信道（MHz）[A 2]	下行信道（MHz）[A 3]	雙工間隔（MHz）	信道帶寬（MHz）[5]
n78	TDD	3500	C-Band	n77	3300 – 3800		不適用	10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100
n79	TDD	4700	C-Band		4400 – 5000		不適用	40, 50, 60, 80, 100

- 在 SCS 30 kHz + 最大頻寬 100 MHz 條件下
    - Frequency domain 下，最多會有 273 RBs = 3276 subcarriers
    - Time domain 下，為一電磁波
    - 在這 100 MHz 頻寬內的載波，稱為 Component Carrier
- When Carrier Aggregation is used, there are a number of serving cells, one for each Component Carrier

PCC and SCC

- Component Carrier are divided into two categories
  - Primary Component Carrier ➔ 對應到 PCell
  - Secondary Component Carrier ➔ 對應到 SCell
- RRC Connection and Registration only performed on PCC
- Control channels (PDSCH and PUCCH) on PCC
- Data channels (PDSCH and PUSCH) on all component carriers



Cell Types for Carrier Aggregation

- Primary Cell (Pcell)
  - 主小區是工作在主頻帶上的小區
  - UE 在該小區進行初始連接建立過程，或開始連接重建立過程。在切換過程中該小區被指示為主小區
- Secondary Cell (Scell)
  - 輔小區是工作在輔頻帶上的小區
  - 一旦 RRC 連接建立，輔小區就可能被配置以提供額外的無線資源
- Serving Cell
  - 處於 RRC_CONNECTED state 的 UE，如果沒有配置 CA，則只有一個 Serving Cell，即Pcell
  - 如果配置了 CA，則 Serving Cell 集合是由 PCell 和 SCell 組成

Carrier Aggregation - 3 Modes

NR operating band	Uplink (UL) *operating band* BS receive / UE transmit F_{UL_low} – F_{UL_high}	Downlink (DL) *operating band* BS transmit / UE receive F_{DL_low} – F_{DL_high}
n77	3300 MHz – 4200 MHz	3300 MHz – 4200 MHz
n78	3300 MHz – 3800 MHz	3300 MHz – 3800 MHz
n79	4400 MHz – 5000 MHz	4400 MHz – 5000 MHz

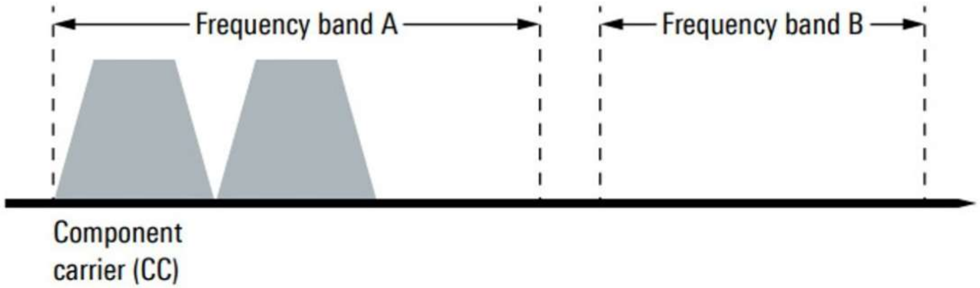
Table 5.2A.1-1: Intra-band contiguous CA operating bands in FR1

NR CA Band	NR Band (Table 5.2-1)
CA_n77	n77
CA_n78	n78
CA_n79	n79

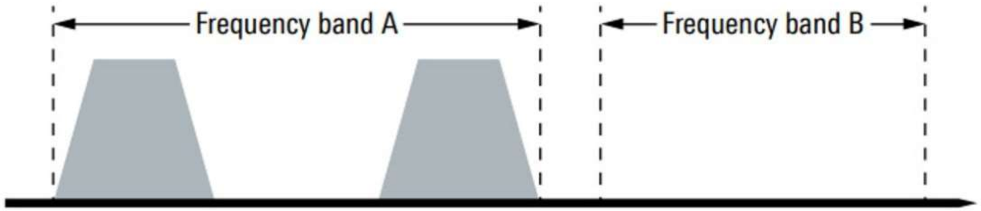
Table 5.2A.2-1: Inter-band CA operating bands involving FR1 (two bands)

NR CA Band	NR Band (Table 5.2-1)
CA_n3A-n77A	n3, n77
CA_n3A-n78A	n3, n78
CA_n3A-n79A	n3, n79
CA_n8A-n75A	n8, n75
CA n8-n78A	n8, n78
CA_n8A-n79A	n8, n79
CA_n28A-n75A[2]	n28, n75
CA_n28A_n78A	n28, n78
CA_n41A-n78A	n41, n78
CA_n75A-n78A[1]	n75, n78
CA_n77A-n79A	n77, n79
CA_n78A-n79A	n78, n79

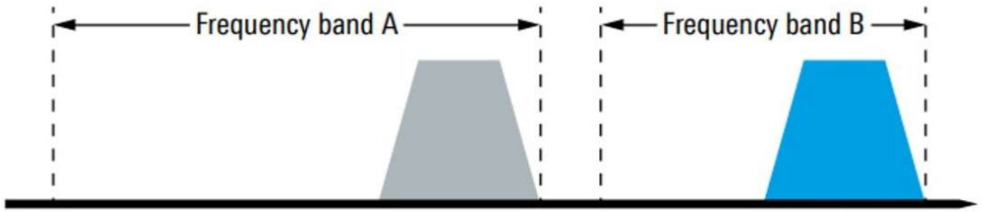
Contiguous intra-band carrier aggregation



Non-contiguous intra-band carrier aggregation



Non-contiguous inter-band carrier aggregation



Carrier Aggregation Bandwidth Class

- 定義 CA 的等級
  - 單個 band 內有多少個連續的 CC
  - 單個 band 內總頻寬會達到多少

Table 5.3A.5-1: CA bandwidth classed

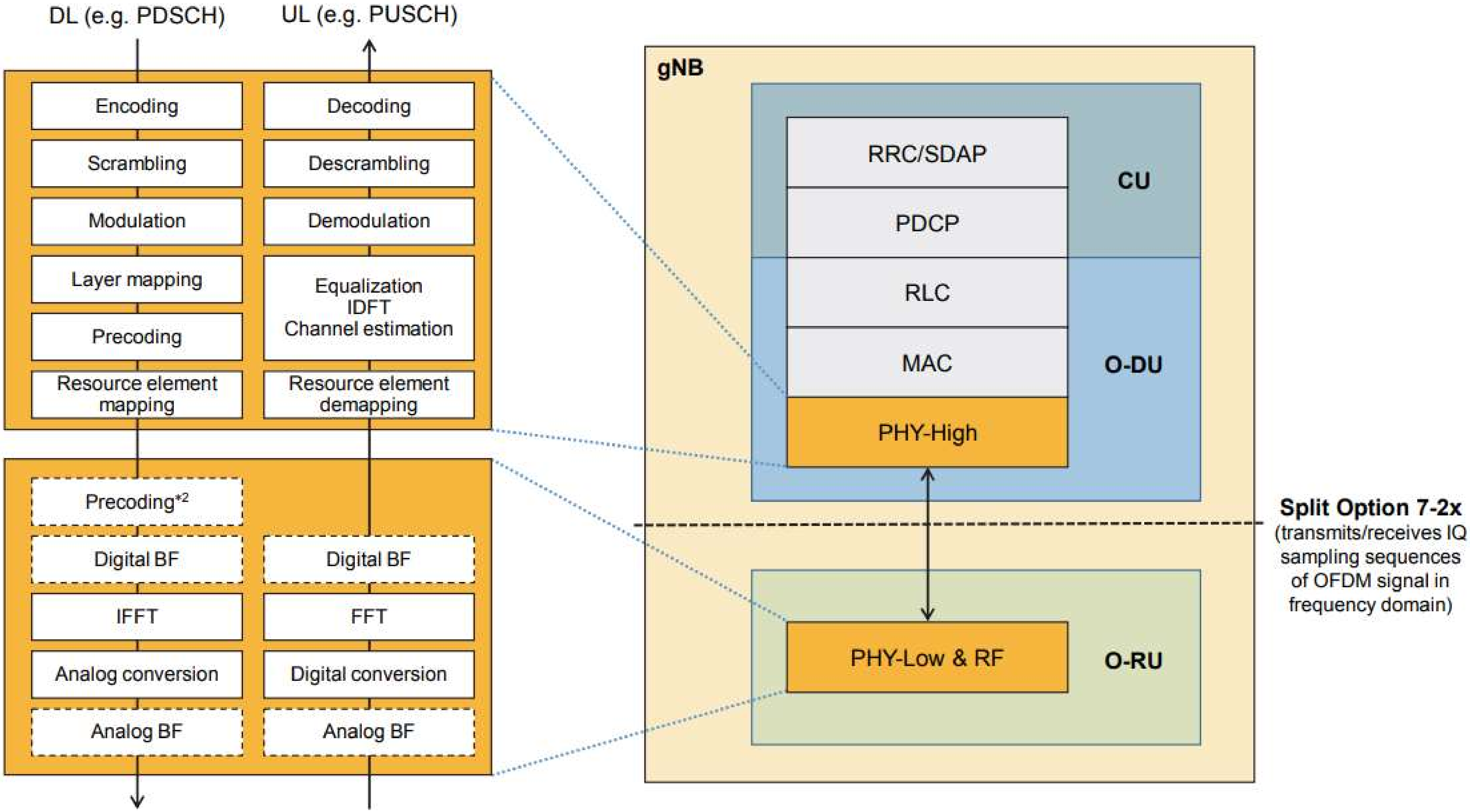
NR CA bandwidth class	Aggregated channel bandwidth	Number of contiguous CC
A	$BW_{Channel\_CA} \le BW_{Channel,max}$	1
B	$20\ MHz \le BW_{Channel\_CA} \le 50\ MHz$	2
C	$100\ MHz < BW_{Channel\_CA} \le 2 \times BW_{Channel,max}$	2
D	$200\ MHz < BW_{Channel\_CA} \le 3 \times BW_{Channel,max}$	3
E	$300\ MHz < BW_{Channel\_CA} \le 4 \times BW_{Channel,max}$	4
F	$50\ MHz < BW_{Channel\_CA} \le 100\ MHz$	2
G	$100\ MHz < BW_{Channel\_CA} \le 150\ MHz$	3
H	$150\ MHz < BW_{Channel\_CA} \le 200\ MHz$	4
I	$200\ MHz < BW_{Channel\_CA} \le 250\ MHz$	5
J	$250\ MHz < BW_{Channel\_CA} \le 300\ MHz$	6
K	$300\ MHz < BW_{Channel\_CA} \le 350\ MHz$	7
L	$350\ MHz < BW_{Channel\_CA} \le 400\ MHz$	8

Example for CA configuration

- CA_n77C
  - Intra-band in n77
  - # CC = 2
  - 100 M < Total BW <= 200 M
- CA_n77D
  - Intra-band in n77
  - # CC = 3
  - 200 M < Total BW <= 300 M
- …
- CA_n8A-n78B
  - Inter-band with n8 & n78
  - # CC = 1 in n8
  - # CC = 2 in n78
  - 100 M < Total BW in n8 <= 200 M
  - 200 M < Total BW in n78 <= 300 M

Table A-: NR CA configurations and bandwidth combination sets defined for intra-band contiguous CA

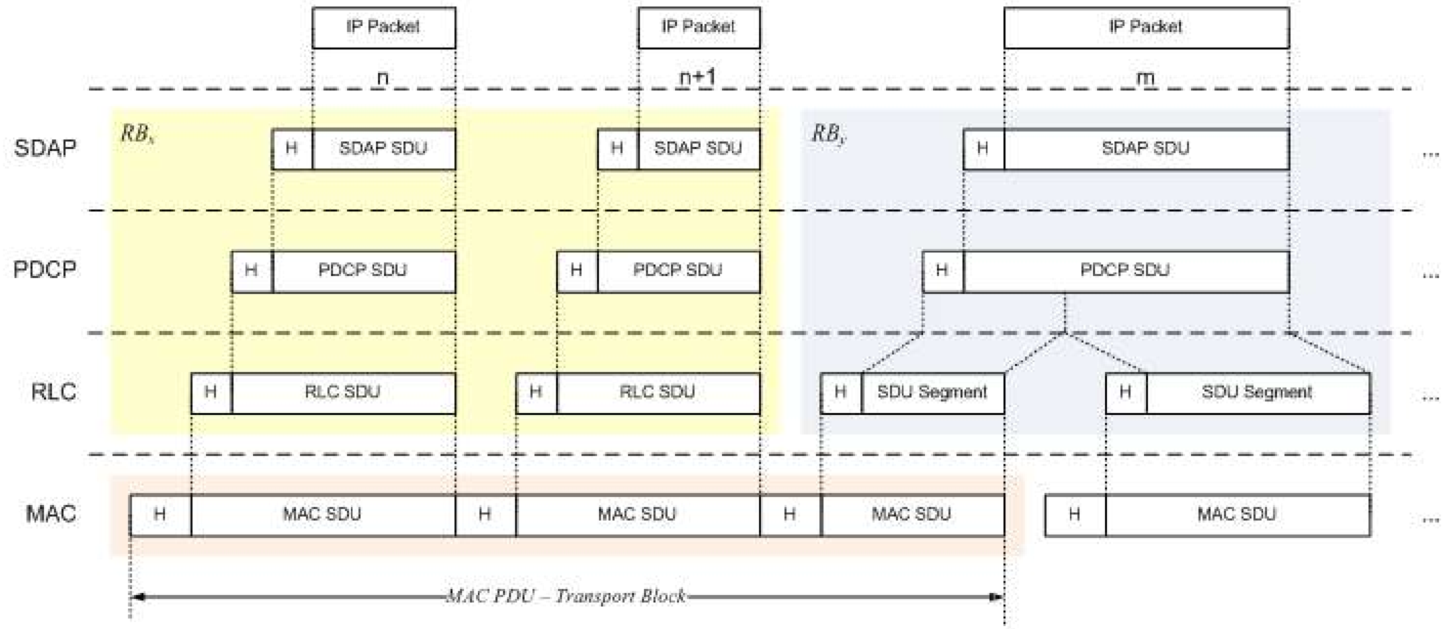
E-UTRA CA configuration / Bandwidth combination set							
NR CA configuration	Uplink CA configurations	Component carriers in order of increasing carrier frequency					Aggregated bandwidth (MHz)
		Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	Channel bandwidths for carrier (MHz)	
CA_n77C CA_n78C CA_n79C		50	60				110
		60	60				120
		50	80				130
		60	80				140
		50	100				150
		60	100				160
		80	80				
		80	100				180
		100	100				200
CA_n77D, CA_n78D, CA_n79D		50	60	100			210
		60	60	100			220
		50	80	100			230
		60	80	100			240
		50	100	100			250
		80	80	100			260
		80	90	100			270
		80	100	100			280
		90	100	100			290
		100	100	100			300

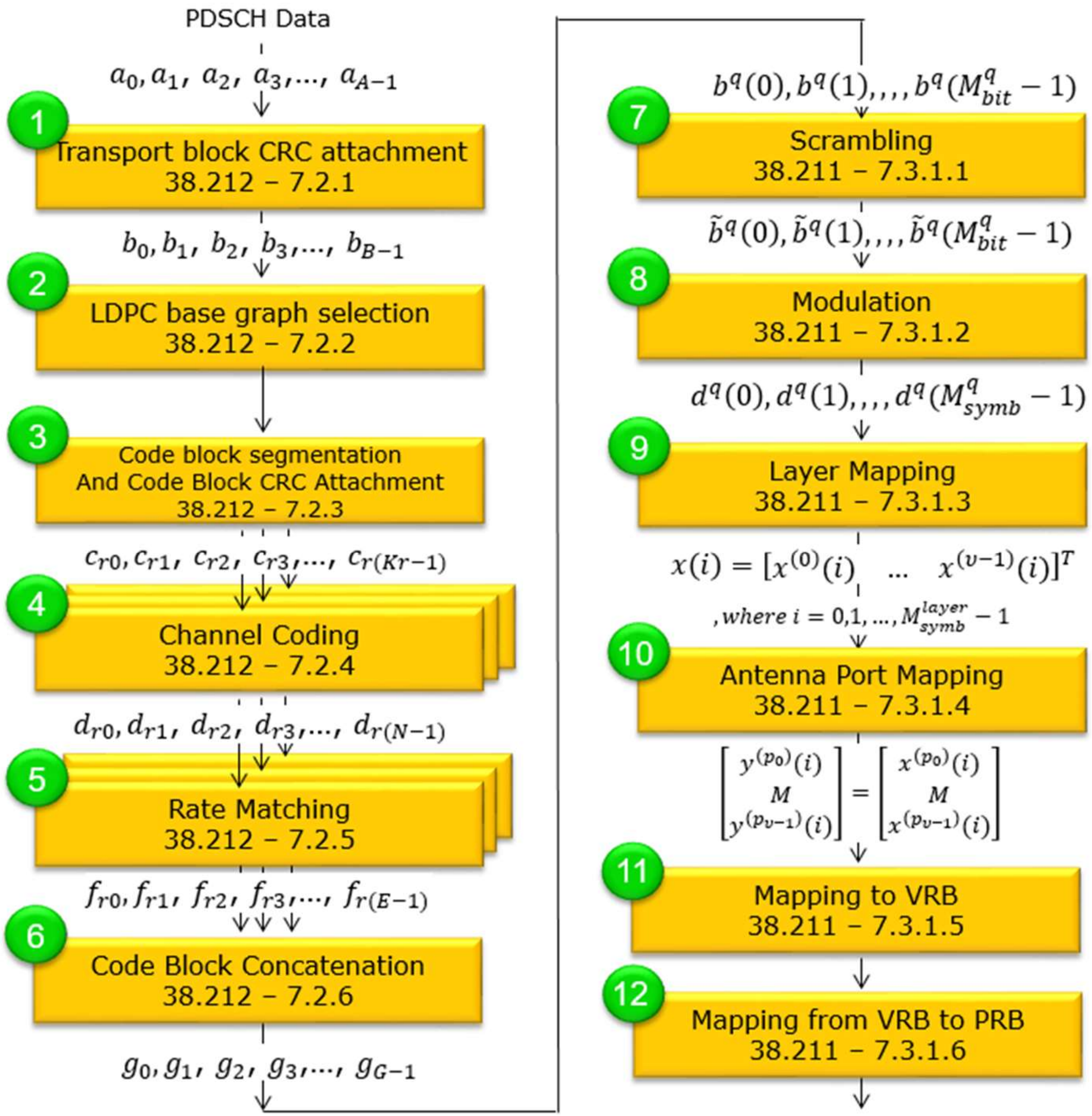


DL (e.g. PDSCH)
UL (e.g. PUSCH)
Encoding
Scrambling
Modulation
Layer mapping
Precoding
Resource element mapping
Decoding
Descrambling
Demodulation
Equalization
IDFT
Channel estimation
Resource element demapping
Precoding*2
Digital BF
IFFT
Analog conversion
Analog BF
Digital BF
FFT
Digital conversion
Analog BF
gNB
RRC/SDAP
PDCP
RLC
MAC
PHY-High
CU
O-DU
PHY-Low & RF
O-RU
Split Option 7-2x
(transmits/receives IQ sampling sequences of OFDM signal in frequency domain)

MAC (Medium Access Control)

- MAC layer organizes the data into the transport block and transmits it to the physical layer
    - The maximum transport block size is 1,277,992 bits

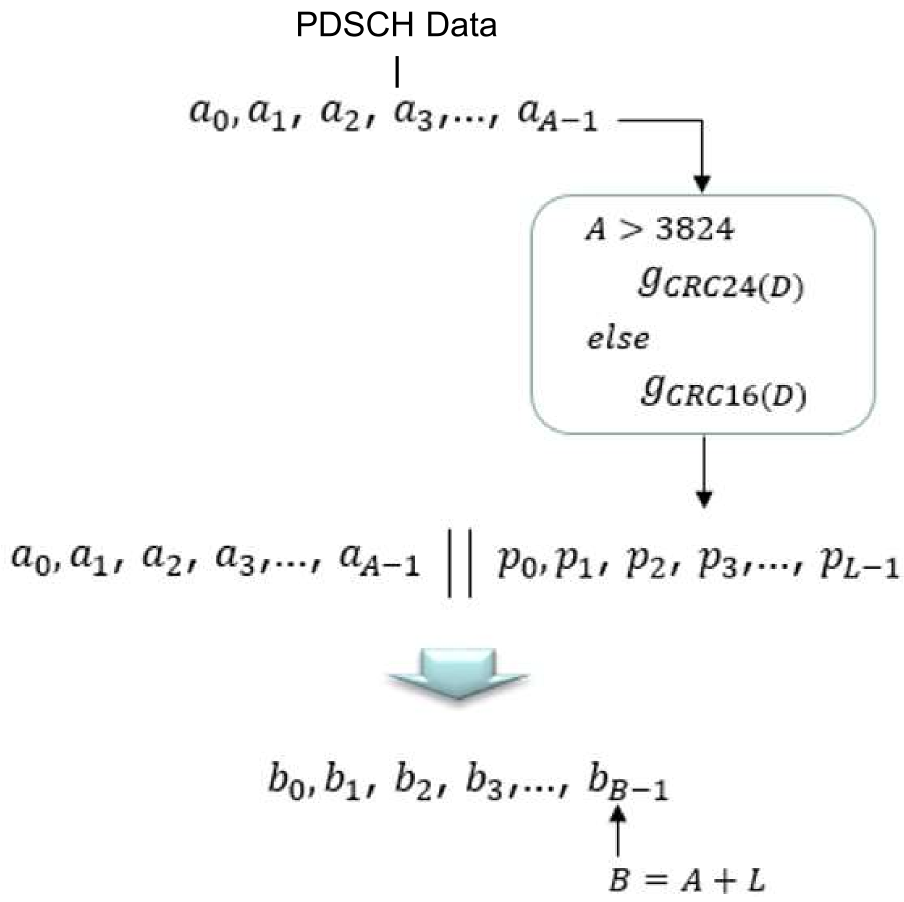




PDSCH Data
$a_0, a_1, a_2, a_3, \ldots, a_{A-1}$
1
Transport block CRC attachment
38.212 – 7.2.1
$b_0, b_1, b_2, b_3, \ldots, b_{B-1}$
2
LDPC base graph selection
38.212 – 7.2.2
3
Code block segmentation
And Code Block CRC Attachment
38.212 – 7.2.3
$c_{r0}, c_{r1}, c_{r2}, c_{r3}, \ldots, c_{r(Kr-1)}$
4
Channel Coding
38.212 – 7.2.4
$d_{r0}, d_{r1}, d_{r2}, d_{r3}, \ldots, d_{r(N-1)}$
5
Rate Matching
38.212 – 7.2.5
$f_{r0}, f_{r1}, f_{r2}, f_{r3}, \ldots, f_{r(E-1)}$
6
Code Block Concatenation
38.212 – 7.2.6
$g_0, g_1, g_2, g_3, \ldots, g_{G-1}$
$b^q(0), b^q(1), , , , b^q(M^q_{bit} - 1)$
7
Scrambling
38.211 – 7.3.1.1
$\tilde{b}^q(0), \tilde{b}^q(1), , , , \tilde{b}^q(M^q_{bit} - 1)$
8
Modulation
38.211 – 7.3.1.2
$d^q(0), d^q(1), , , , d^q(M^q_{symb} - 1)$
9
Layer Mapping
38.211 – 7.3.1.3
$x(i) = [x^{(0)}(i) \quad \ldots \quad x^{(v-1)}(i)]^T$
$, where\ i = 0, 1, \ldots, M^{layer}_{symb} - 1$
10
Antenna Port Mapping
38.211 – 7.3.1.4
$\begin{bmatrix} y^{(p_0)}(i) \\ M \\ y^{(p_{v-1})}(i) \end{bmatrix} = \begin{bmatrix} x^{(p_0)}(i) \\ M \\ x^{(p_{v-1})}(i) \end{bmatrix}$
11
Mapping to VRB
38.211 – 7.3.1.5
12
Mapping from VRB to PRB
38.211 – 7.3.1.6

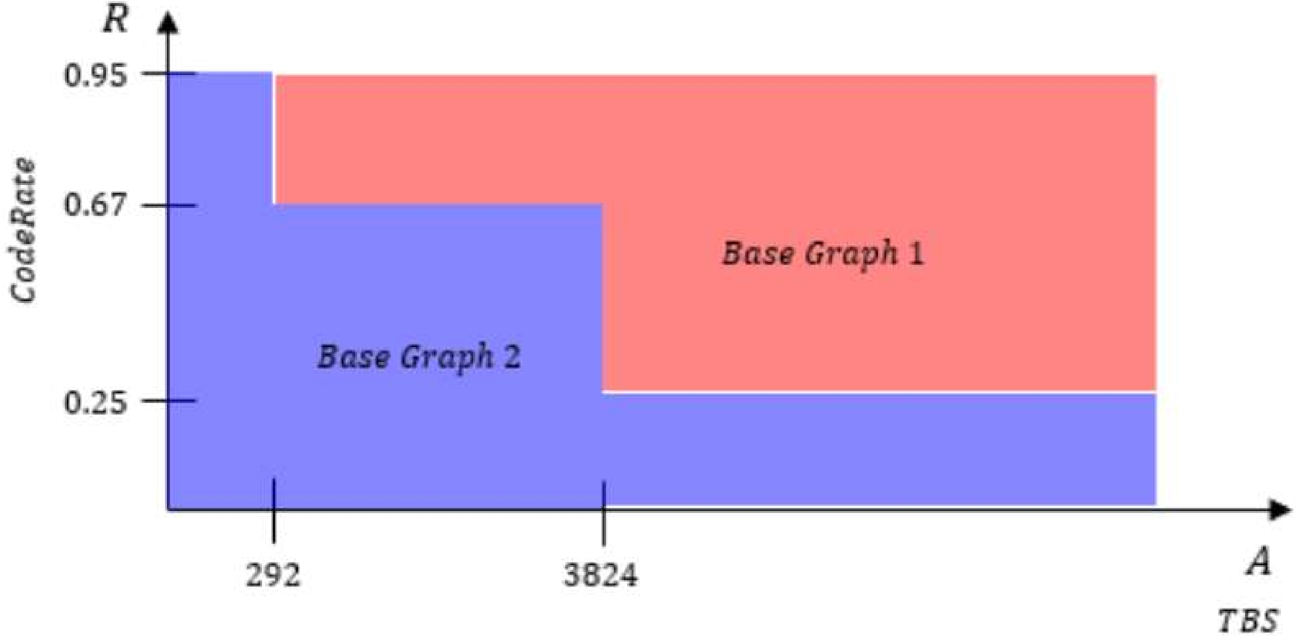
(1) Transport Block CRC Attachment

- A: the transport block size
- L: the CRC length
    - if A $\leq$ 3824 bits，L = 16 bits
    - if A $>$ 3824 bits，L = 24 bits



(2) LDPC Base Graph Selection

- NR supports 2 LDPC base graphs
  - Low-density parity-check code 低密度奇偶檢查碼
- LDPC Base Graph type is determined by Transport Block Size (A) and Code Rate (R)



Code Rate

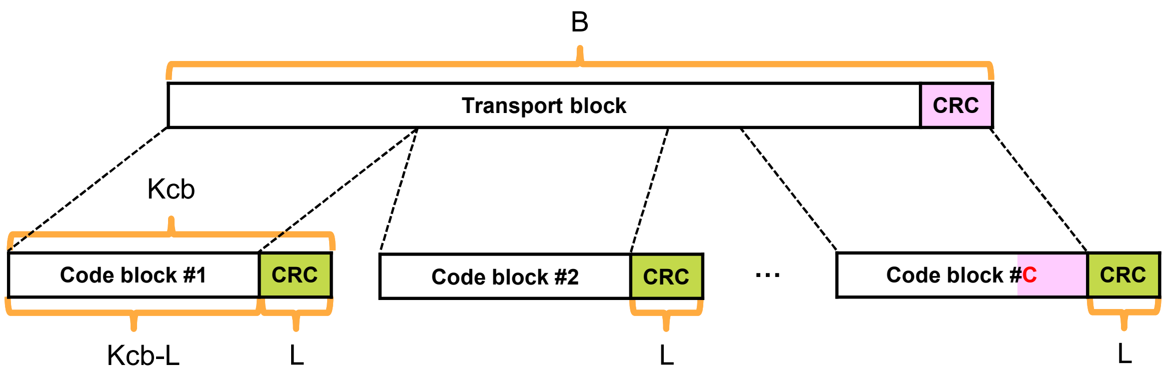
- code rate (k/n)
  - 總資料長度為 n bits，其中 k bits 為真實資料，即會有 n-k bits 是無效資料
- code rate for PDSCH = [A+24(CRC bits)]/(Bit number after Rate Matching)
  - A: TBS
  - 24: CRC for transport block
- code rate 越低，包含的 redundancy message 越多，糾錯的能力越强，抗干擾的能力越强，傳輸的有效數據越小

Spectral efficiency = (Code Rate) * Qm
= 單個子載波能承載的有效bits

MCS Index I_{MCS}	Modulation Order Q_m	Target code Rate R x [1024]	Spectral efficiency
0	2	120	0.2344
1	2	157	0.3066
2	2	193	0.3770
3	2	251	0.4902
4	2	308	0.6016
5	2	379	0.7402
6	2	449	0.8770
7	2	526	1.0273
8	2	602	1.1758
9	2	679	1.3262
10	4	340	1.3281
11	4	378	1.4766
12	4	434	1.6953
13	4	490	1.9141
14	4	553	2.1602
15	4	616	2.4063
16	4	658	2.5703
17	6	438	2.5664
18	6	466	2.7305
19	6	517	3.0293
20	6	567	3.3223
21	6	616	3.6094
22	6	666	3.9023
23	6	719	4.2129
24	6	772	4.5234
25	6	822	4.8164
26	6	873	5.1152
27	6	910	5.3320
28	6	948	5.5547
29	2	reserved	
30	4	reserved	
31	6	reserved	

(3) Code Block Segmentation and CRC Attachment

- Determine the max size of the code block (Kcb)
  - For LDPC base graph type 1 : Kcb = 8448 bits
  - For LDPC base graph type 2 : Kcb = 3840 bits
- Determine the number of code blocks (C)
  - if B < Kcb
    - L = 0 (CRC length for code block)
    - C = 1
    - 總資料長度 = B
  - else
    - L = 24
    - C = $\left\lceil \frac{B}{Kcb-L} \right\rceil$
    - 總資料長度 = B + CxL
  - 實際上一個 code block size = 總資料長度/C
- 每個 CB 各自加上 CRC，在 HARQ 機制下重送時，可以讓接收端只針對錯誤的 CB 重新解碼
- BLER (Block Error Rate) - 出錯的 code block 在所有發送的 block 中所佔的百分比



(4) Channel Coding

- 不同 channel 會使用不同的 coding scheme

Table 5.3-1: Usage of channel coding scheme for TrCHs

TrCH	Coding scheme
UL-SCH	LDPC
DL-SCH	
PCH	
BCH	Polar code

Table 5.3-2: Usage of channel coding scheme for control information

Control Information	Coding scheme
DCI	Polar code
UCI	Block code
	Polar code

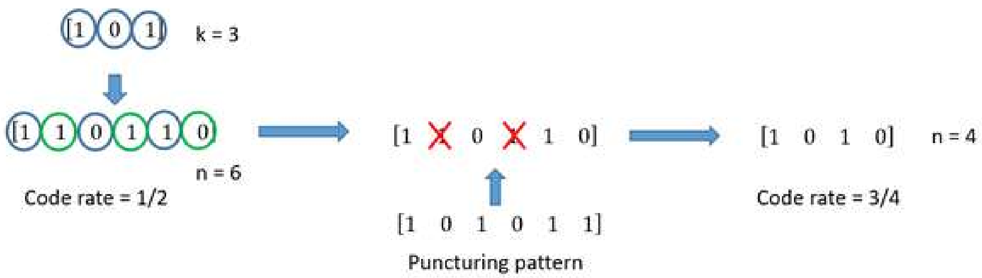
- This step “Channel Coding” 就是指說要將 data 進行 encode

Encoded PDSCH via LDPC

- 不同的 LDPC Graph 會使用不同的矩陣進行 LDPC 編碼
  - Base Graph 1 (BG1)
    - With Matrix size 46X68 entries ➔ For Large Transport Block
  - Base Graph 2 (BG2)
    - With matrix size 42X52 entries ➔ For Smaller Transport Block
- Each code block is individually LDPC encoded
- Encode/Decode??? orz…

(5) Rate Matching

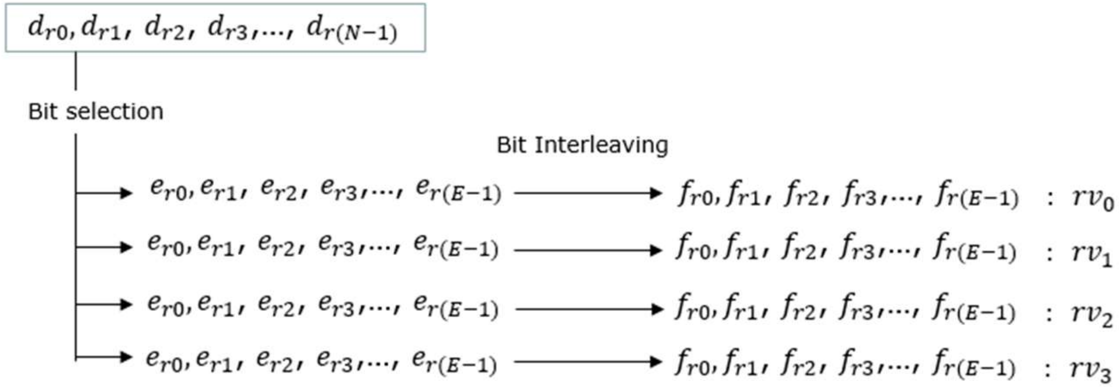
- Rate matching is used to adjust **the incoming bits to available resources**
  - 在不同的時間間隔內，傳輸信道的數據量大小並不是一成不變，但所配置的物理信道的時頻資源卻是固定的，因此， 需要將 bit stream 進行一定的調整從而符合物理信道的承載能力
    - if available resource are A bits and input data are B bits
      - A>B ➔ repeat some of the bits to fill the remaining resources ➔ repetition
      - B>A ➔ just transmit A bits and skip the remaining B-A bits ➔ puncturing
  - The rate matching for LDPC code is defined per code block and consists of bit selection and bit interleaving.



(5) Rate Matching

- Bit Selection

```
k = 0;
j = 0;

while k < E

    if d_{(k_0+j) mod N_cb} ≠ <NULL>

        e_k = d_{(k_0+j) mod N_cb};

        k = k + 1;

    end if

    j = j + 1;

end while
```



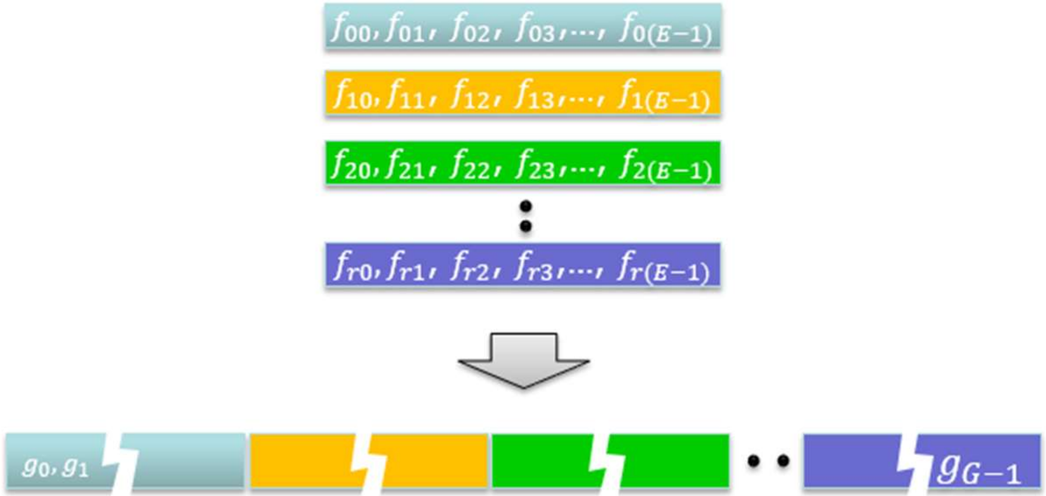
- Bit Interleaving
  - bit sequence $e_0, e_1, \dots, e_{E-1}$ is interleaved to bit sequence $f_0, f_1, \dots, f_{E-1}$
  - suppose that E = 9, $\mathrm{Q}_m = 3\ (64\ QAM)$

```
for j = 0 to E/Q_m - 1

    for i = 0 to Q_m - 1

        f_{i+j·Q_m} = e_{i·E/Q_m+j};

    end for

end for
```

- $f_0 = e_0\ (j = 0, i = 0)$
- $f_1 = e_3\ (j = 0, i = 1)$
- $f_2 = e_6\ (j = 0, i = 2)$
- $f_3 = e_1\ (j = 1, i = 0)$
- $f_4 = e_4\ (j = 1, i = 1)$
- $f_5 = e_7\ (j = 1, i = 2)$
- $f_6 = e_2\ (j = 2, i = 0)$
- $f_7 = e_5\ (j = 2, i = 1)$
- $f_8 = e_8\ (j = 2, i = 2)$

(6) Code Block Concatenation

- 將 Step 5 的 output data 全都接在一起，形成一個 Codeword
- 一個 Codeword 會在一個 TTI 中發送
- 一個 TTI 最多可以發送兩個 Codewords



(7) Scrambling

- 利用 c(n) 序列，將 $b^{(q)}(i)$ 進行擾亂
- 有加密的涵義，接收者如果不知道 scrambling ID 算出 scrambling sequence，就推導不出原始資料
- UL Scrambling 可以區分用戶，DL Scrambling 可以區分 cell
    - 假設兩個 cell/user 傳送的資料相近，干擾就會比較嚴重
    - 不同的 cell/user 會有不同的 scrambling sequence，透過 scrambling 將資料內容完全打亂，可以降低干擾

CRNTI

$n_{\mathrm{ID}} \in \{0,1,\ldots,1023\}$ equals the dataScramblingIdentity PDSCH if configured in PDSCH-Config

$n_{\mathrm{ID}} = N_{\mathrm{ID}}^{\mathrm{cell}}$ otherwise

$$c_{\mathrm{init}} = n_{\mathrm{RNTI}} \cdot 2^{15} + q \cdot 2^{14} + n_{\mathrm{ID}}$$

$$x_1(n+31) = \left(x_1(n+3) + x_1(n)\right) \bmod 2$$

$$x_2(n+31) = \left(x_2(n+3) + x_2(n+2) + x_2(n+1) + x_2(n)\right) \bmod 2$$

$$c(n) = \left(x_1(n+N_C) + x_2(n+N_C)\right) \bmod 2$$

$$\tilde{b}^{(q)}(i) = \left(b^{(q)}(i) + c^{(q)}(i)\right) \bmod 2$$

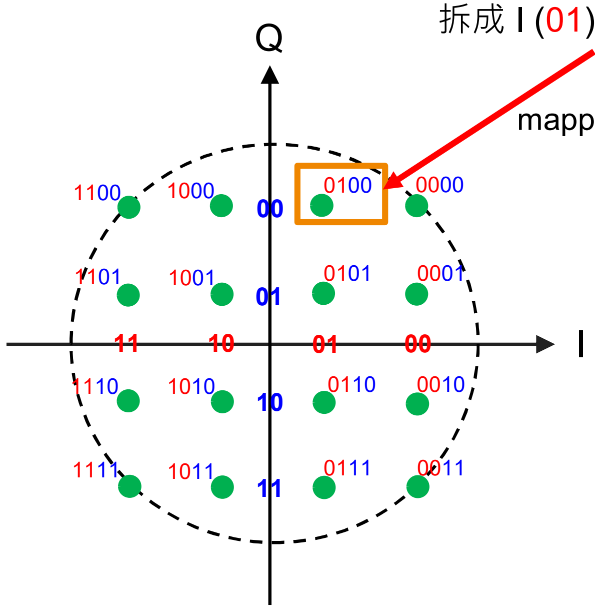
(8) Modulation

- Binary Sequence $\tilde{b}^{(q)}(0), \dots, \tilde{b}^{(q)}\left(M_{bit}^{(q)} - 1\right)$ $\xrightarrow{\text{Modulation}}$ Complex Number Sequence $d^{(q)}(0), \dots, d^{(q)}\left(M_{symb}^{(q)} - 1\right)$

要傳送的資料: $\tilde{b}^{(q)}(i) = 0010$

拆成 I (01) & Q (00)

mapping



I=1
Q=3

$d^{(q)}(i) = 1 + 3j$

(9) Layer Mapping

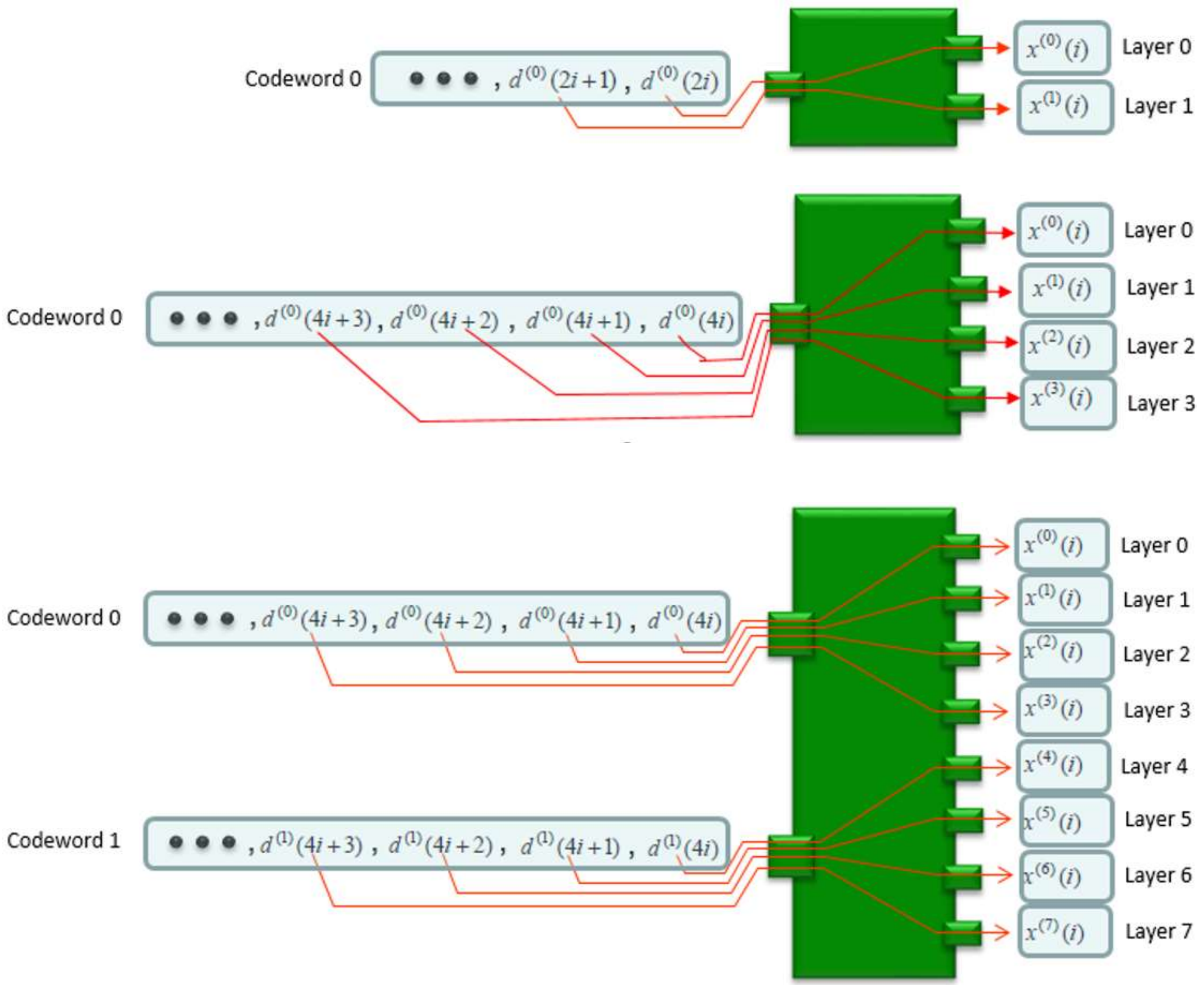
- $d^{(q)}(0), \ldots, d^{(q)}\left(M_{symb}^{(q)} - 1\right)$ for codeword q
- Layer 1 ~ 4 只有一個 codeword
- Layer 5 ~ 8 會有兩個 codewords

Table 7.3.1.3-1: Codeword-to-layer mapping for spatial multiplexing.

Number of layers	Number of codewords	Codeword-to-layer mapping $i = 0,1,\ldots,M_{\text{symb}}^{\text{layer}} - 1$	
1	1	$x^{(0)}(i) = d^{(0)}(i)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}$
2	1	$x^{(0)}(i) = d^{(0)}(2i)$ $x^{(1)}(i) = d^{(0)}(2i+1)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/2$
3	1	$x^{(0)}(i) = d^{(0)}(3i)$ $x^{(1)}(i) = d^{(0)}(3i+1)$ $x^{(2)}(i) = d^{(0)}(3i+2)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/3$
4	1	$x^{(0)}(i) = d^{(0)}(4i)$ $x^{(1)}(i) = d^{(0)}(4i+1)$ $x^{(2)}(i) = d^{(0)}(4i+2)$ $x^{(3)}(i) = d^{(0)}(4i+3)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/4$
5	2	$x^{(0)}(i) = d^{(0)}(2i)$ $x^{(1)}(i) = d^{(0)}(2i+1)$ $x^{(2)}(i) = d^{(1)}(3i)$ $x^{(3)}(i) = d^{(1)}(3i+1)$ $x^{(4)}(i) = d^{(1)}(3i+2)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/2 = M_{\text{symb}}^{(1)}/3$
6	2	$x^{(0)}(i) = d^{(0)}(3i)$ $x^{(1)}(i) = d^{(0)}(3i+1)$ $x^{(2)}(i) = d^{(0)}(3i+2)$ $x^{(3)}(i) = d^{(1)}(3i)$ $x^{(4)}(i) = d^{(1)}(3i+1)$ $x^{(5)}(i) = d^{(1)}(3i+2)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/3 = M_{\text{symb}}^{(1)}/3$
7	2	$x^{(0)}(i) = d^{(0)}(3i)$ $x^{(1)}(i) = d^{(0)}(3i+1)$ $x^{(2)}(i) = d^{(0)}(3i+2)$ $x^{(3)}(i) = d^{(1)}(4i)$ $x^{(4)}(i) = d^{(1)}(4i+1)$ $x^{(5)}(i) = d^{(1)}(4i+2)$ $x^{(6)}(i) = d^{(1)}(4i+3)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/3 = M_{\text{symb}}^{(1)}/4$
8	2	$x^{(0)}(i) = d^{(0)}(4i)$ $x^{(1)}(i) = d^{(0)}(4i+1)$ $x^{(2)}(i) = d^{(0)}(4i+2)$ $x^{(3)}(i) = d^{(0)}(4i+3)$ $x^{(4)}(i) = d^{(1)}(4i)$ $x^{(5)}(i) = d^{(1)}(4i+1)$ $x^{(6)}(i) = d^{(1)}(4i+2)$ $x^{(7)}(i) = d^{(1)}(4i+3)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/4 = M_{\text{symb}}^{(1)}/4$

(9) Layer Mapping

- 每個 layer 的資料內容是不一樣的
- 幾個 layer 就相當於有幾條並行的數據流

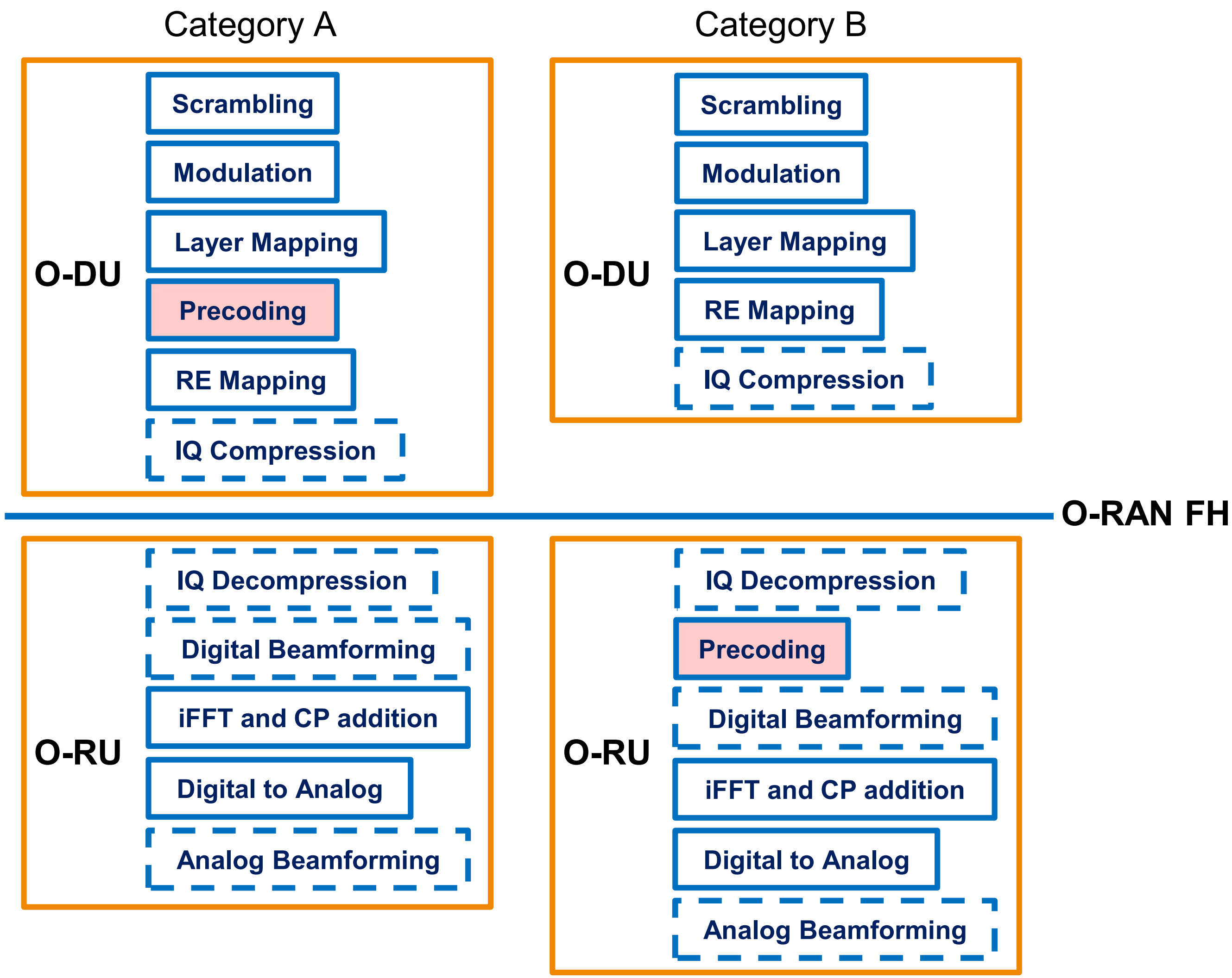


(9.5) Precoding

- 沒有 Precoding，那 layer 跟 port 就是一對一，沒有對上 layer 的 port 帶的資料就是 0
- Layer Mapping + Precoding (= MIMO)
    - 可以將資料分配到多個 Antenna port 進行傳送，在不增加頻寬的條件下，大幅的提高頻譜使用率
        - 每個 port 傳送不同資料 ➔ spatial multiplexing ➔ 增加頻譜效率，提高傳輸數據量
    - 透過多個 Antenna port 發送相同的資料，可增強資料的傳輸品質
        - 每個 port 傳送一樣資料 ➔ transmit diversity ➔ 抗衰落，提高訊號傳輸的可靠性
            - 只會有一個 codeword (如果有兩個 codewords，無法生成一樣的資料到 antenna port)
    - 38.211 中指定義了 spatial multiplexing type

O-RU Category

- Category A
  - The function of precoding is implemented in DU.
  - Precoding in RU is not supported.
- Category B
  - The function of precoding is implemented in RU.
  - Precoding in RU is supported.



Rank

- DU Configuration
  - dlRank
  - ulRank

  → Layer? Rank?

  - dlNumAntPorts
  - ulNumOfAntPorts

  → Antenna Port

- What is **RANK**?
  - 一個矩陣中，線性獨立的最大行數 or 列數
  - $A = \begin{bmatrix} 3 & 0 & 2 & 2 \\ -6 & 42 & 24 & 54 \\ 21 & -21 & 0 & -15 \end{bmatrix} \sim \begin{bmatrix} 3 & 0 & 2 & 2 \\ 0 & 42 & 28 & 58 \\ 0 & 0 & 0 & 0 \end{bmatrix}$ ➔ rank(A)=2
    - 想像成 3 條四元一次聯立方程式，經過化簡，其實第 3 條可由前 2 條組成
  - $A = \begin{bmatrix} 3 & 0 & 2 & 2 \\ -6 & 42 & 24 & 54 \\ 21 & -21 & 0 & -15 \end{bmatrix} \sim \begin{bmatrix} 3 & 0 & 0 & 0 \\ -6 & 42 & 0 & 0 \\ 21 & -21 & 0 & 0 \end{bmatrix}$ ➔ rank(A)=2
    - 列向量跟行向量的結果會是一樣的

Precoding Matrix

- port $\geq$ layer

TPMI index	W (ordered from left to right in increasing order of TPMI index)							
0 – 7	$\frac{1}{2}\begin{bmatrix}1\\0\\0\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\1\\0\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\0\\1\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0\\0\\0\\1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\0\\1\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\0\\-1\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\0\\j\\0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1\\0\\-j\\0\end{bmatrix}$

1 layer & 4 port

Rank=1

TPMI index	W (ordered from left to right in increasing order of TPMI index)			
0 – 3	$\frac{1}{2}\begin{bmatrix}1&0\\0&1\\0&0\\0&0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\0&0\\0&1\\0&0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0\\0&0\\0&0\\0&1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}0&0\\1&0\\0&1\\0&0\end{bmatrix}$

2 layer & 4 port

Rank=2

TPMI index	W (ordered from left to right in increasing order of TPMI index)			
0 – 3	$\frac{1}{2}\begin{bmatrix}1&0&0\\0&1&0\\0&0&1\\0&0&0\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0&0\\0&1&0\\1&0&0\\0&0&1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1&0&0\\0&1&0\\-1&0&0\\0&0&1\end{bmatrix}$	$\frac{1}{2\sqrt{3}}\begin{bmatrix}1&1&1\\1&-1&1\\1&1&-1\\1&-1&-1\end{bmatrix}$

3 layer & 4 port

Rank=3

TPMI index	W (ordered from left to right in increasing order of TPMI index)			
0 – 3	$\frac{1}{2}\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1&1&0&0\\0&0&1&1\\1&-1&0&0\\0&0&1&-1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1&1&0&0\\0&0&1&1\\j&-j&0&0\\0&0&j&-j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1&1&1&1\\1&-1&1&-1\\1&1&-1&-1\\1&-1&-1&1\end{bmatrix}$

4 layer & 4 port

Rank=4

Settings of Layer and Antenna Port

- DL
  - 當 Port 設定等於 Layer
    - 可以簡單地將 layer data 一對一 mapping 到 port 進行傳送
    - 可以透過 precoding，將 layer data 進行重組再 mapping 到 port 進行傳送
  - 當 Port 設定大於 Layer
    - 若是沒有進行 precoding，只會有 # Layer 路的 port 有資料，其餘的 port 傳送資料為 0
    - 可以透過 precoding，將 layer data mapping 到多路的 port
- UL
  - 當 Port 設定大於 Layer
    - 在 RU 端，因為 Port 開的多，所以接收資料的可靠度或訊號可能會比較好
    - 資料從 RU 端送到 DU 端，一樣只會透過 # Layer 路的 port

Precoding

- 將 Layer 上的資料進行編碼，再映射到對應的天線上發送
    - 編碼 ➔ 將 input data (codeword) 跟 precoding matrix 做運算
- $\begin{bmatrix} y^{(p_0)}(i) \\ \vdots \\ y^{(p_{\rho-1})}(i) \end{bmatrix} = W \begin{bmatrix} x^{(0)}(i) \\ \vdots \\ x^{(v-1)}(i) \end{bmatrix}$
    - Layer number = v
    - Layer data: $x^{(0)}(i)$, …, $x^{(v-1)}(i)$
    - Precoding matrix = W
    - Antenna ports = $\{p_0, \dots, p_{\rho-1}\}$
    - Antenna port data: $y^{(p_0)}(i)$, …,$y^{(p_{\rho-1})}(i)$

Precoding Example 1

- Codeword=1，layer=1，port=2
- # Precoding=2
  - 此時兩根天線傳送相同的訊號

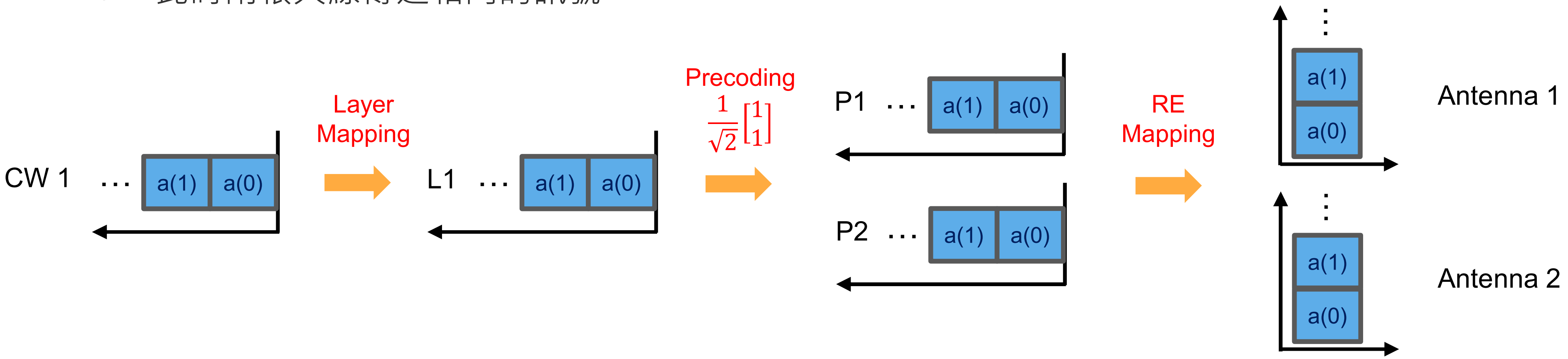


Table 6.3.1.5-1: Precoding matrix W for single-layer transmission using two antenna ports.

TPMI index	W (ordered from left to right in increasing order of TPMI index)							
0 – 5	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\0\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}0\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-	-

Precoding Example 2

- Codeword=2，layer=2，port=2
- # Precoding=0
  - 此時 Antenna 1 傳送 CW 1，Antenna 2 傳送 CW 2

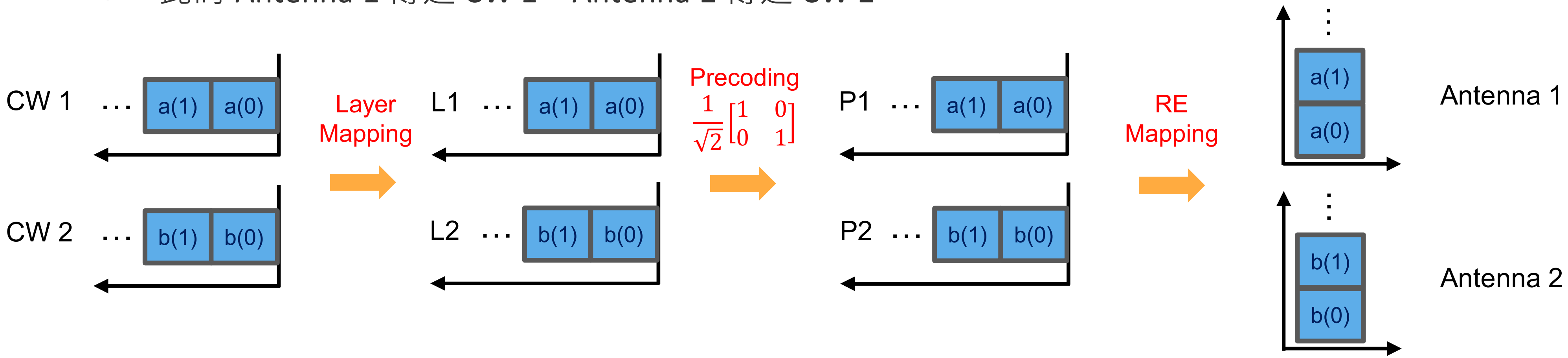


Table 6.3.1.5-4: Precoding matrix W for two-layer transmission using two antenna ports with transform precoding disabled.

TPMI index	W (ordered from left to right in increasing order of TPMI index)			
0 – 2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\j & -j\end{bmatrix}$	

Precoding Example 3

- Codeword=2，layer=2，port=2
- # Precoding=1
  - Precoding 混合了兩個 Layer 的訊號，因此 Antenna 1 與 Antenna 2 傳送的訊號混合了 CW 1 與 CW 2

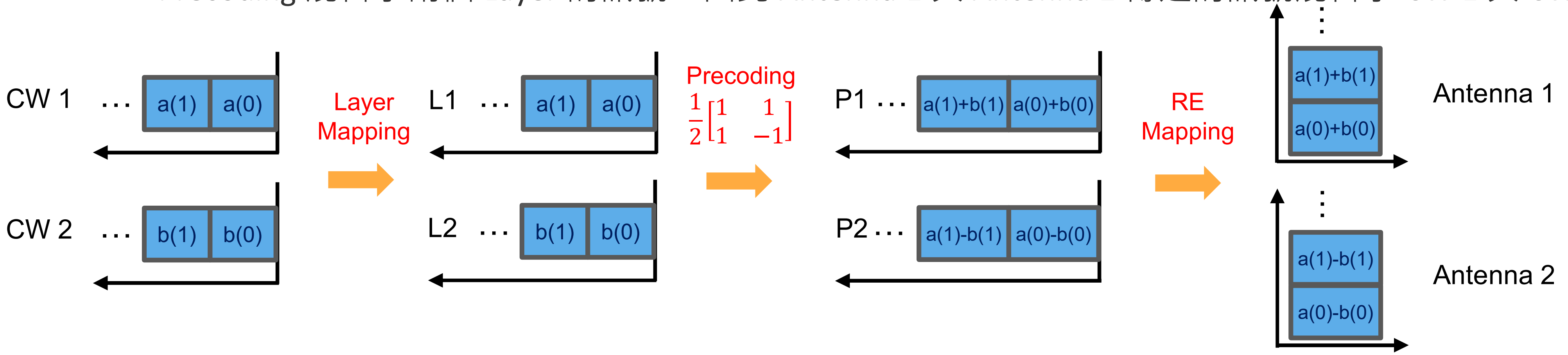


Table 6.3.1.5-4: Precoding matrix W for two-layer transmission using two antenna ports with transform precoding disabled.

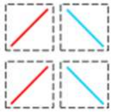
TPMI index	W (ordered from left to right in increasing order of TPMI index)			
0 – 2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\ 1 & -1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\ j & -j\end{bmatrix}$	

Coherence between Antenna Port

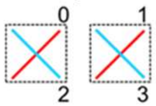
Table 6.3.1.5-7: Precoding matrix W for four-layer transmission using four antenna ports.

	W (ordered from left to right in increasing order of TPMI index)				
TPMI index	0	1	2	3	4
	$\frac{1}{2}\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1 & 1 & 0 & 0\\ 0 & 0 & 1 & 1\\ 1 & -1 & 0 & 0\\ 0 & 0 & 1 & -1\end{bmatrix}$	$\frac{1}{2\sqrt{2}}\begin{bmatrix}1 & 1 & 0 & 0\\ 0 & 0 & 1 & 1\\ j & -j & 0 & 0\\ 0 & 0 & j & -j\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1 & 1 & 1\\ 1 & -1 & 1 & -1\\ 1 & 1 & -1 & -1\\ 1 & -1 & -1 & 1\end{bmatrix}$	$\frac{1}{4}\begin{bmatrix}1 & 1 & 1 & 1\\ 1 & -1 & 1 & -1\\ j & j & -j & -j\\ j & -j & -j & j\end{bmatrix}$

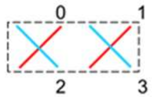
Subclause 6.3.1.5 of [TS 38.211]



Non coherence



Partial coherence



Full coherence

(10) Antenna Port Mapping

- When CSI is not applied, the data maps to physical antenna port
- When CSI is applied, the data from layer mapper are first mapped to each of CSI antenna port as shown below

CSI Antenna Port Number

Layer Number (index)

$$\begin{bmatrix} y^{(3000)}(i) \\ M \\ y^{(3000+P-1)}(i) \end{bmatrix} = W(i) \begin{bmatrix} x^{(0)}(i) \\ M \\ x^{(\nu-1)}(i) \end{bmatrix}$$

Number of CSI-RS Ports

This matrix is determined by reportQuantity in RRC CSI ReportConfig

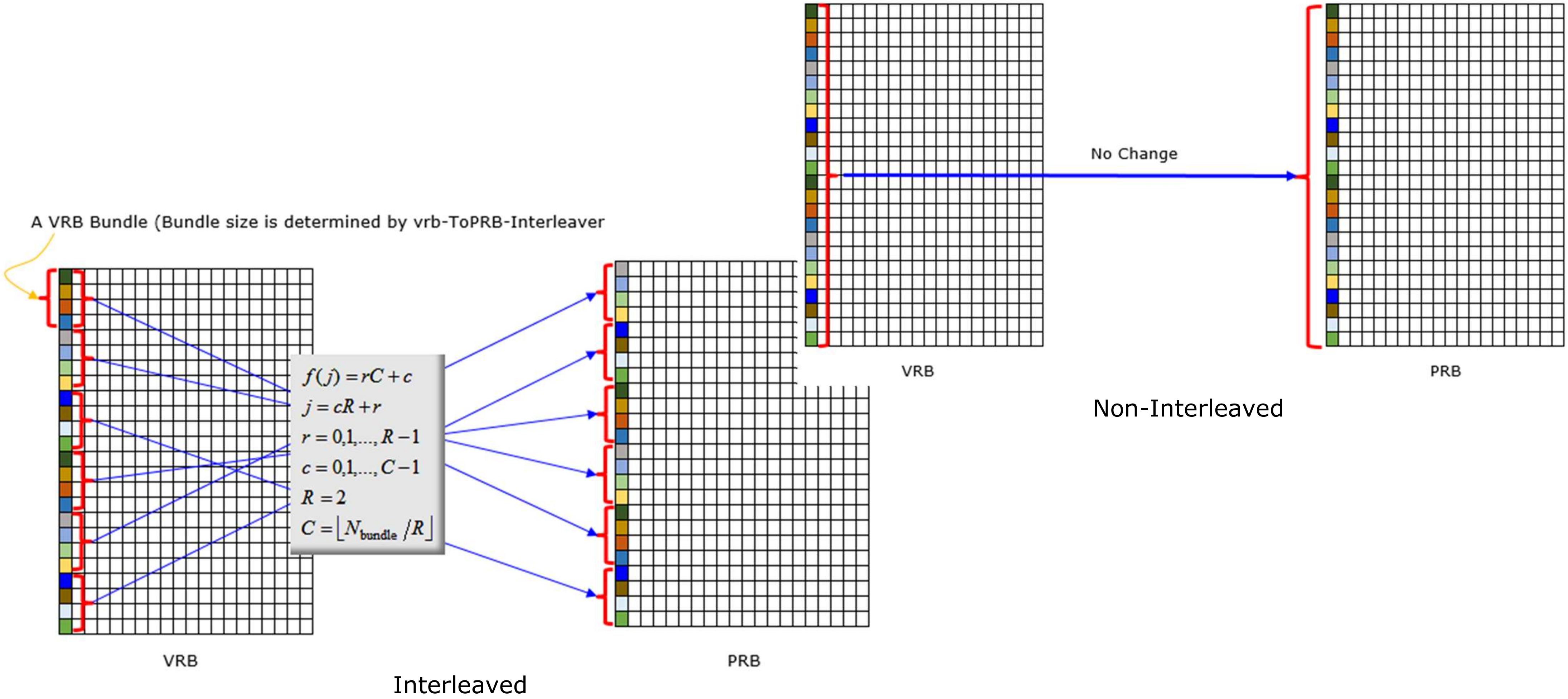
$$P \in [1,2,4,8,12,16,24,32]$$

	Channel/Signal	Antenna Ports
Downlink	PDSCH	Antenna ports starting with 1000
	PDCCH	Antenna ports starting with 2000
	CSI-RS	Antenna ports starting with 3000
	SS/PBCH	Antenna ports starting with 4000
Uplink	PUSCH/DMRS	Antenna ports starting with 0
	SRS	Antenna ports starting with 1000
	PUCCH	Antenna ports starting with 2000
	PRACH	Antenna port 4000

(11) Mapping to VRB

- 把所有 PDSCH IQ 數組，一個一個填進 RE，由 lowest frequency to higher frequency，except for
  - REs assigned for DMRS associated with the PDSCH to be transmitted
  - REs assigned for DMRS intended for other co-scheduled UEs
  - REs for non-zero-power CSI-RS, except for non-zero-power CSI-RSs configured by the higher-layer parameter CSI-RS-Resource-Mobility in the MeasObjectNR IE.
  - REs for PTRS
  - REs declared as 'not available for PDSCH

(12) Mapping from VRB to PRB



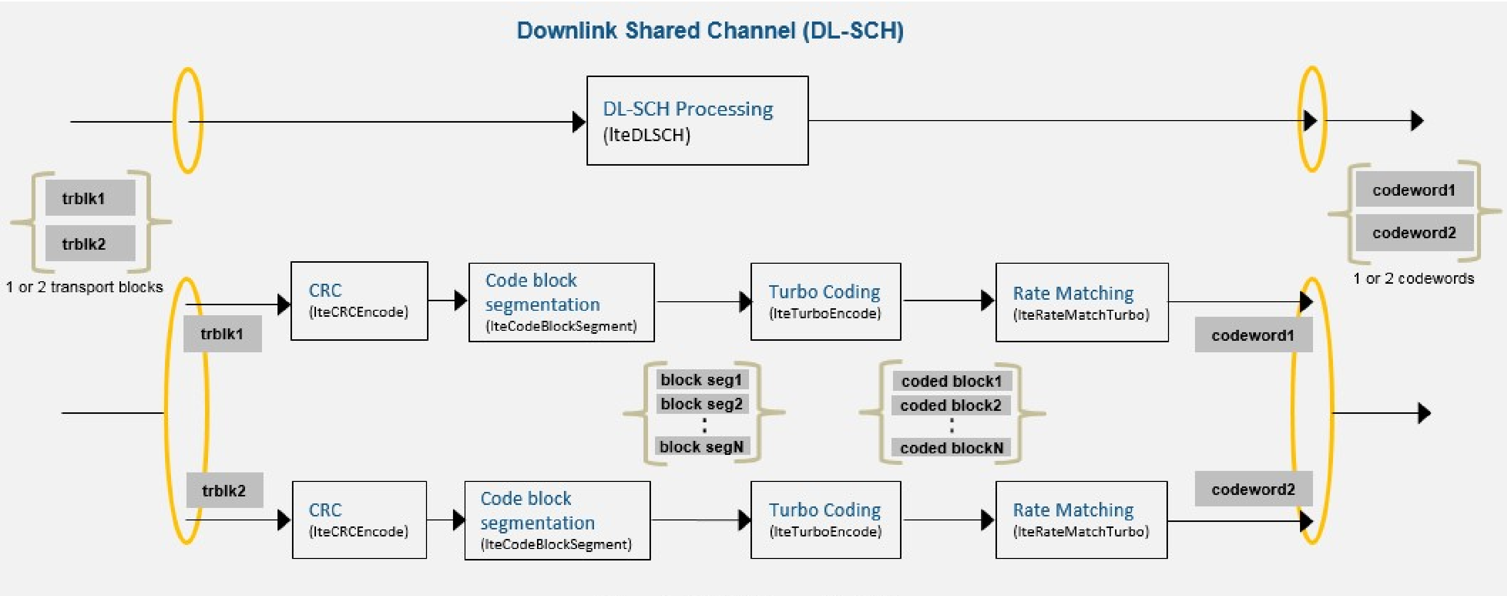


Figure 1: DL-SCH Processing Chain

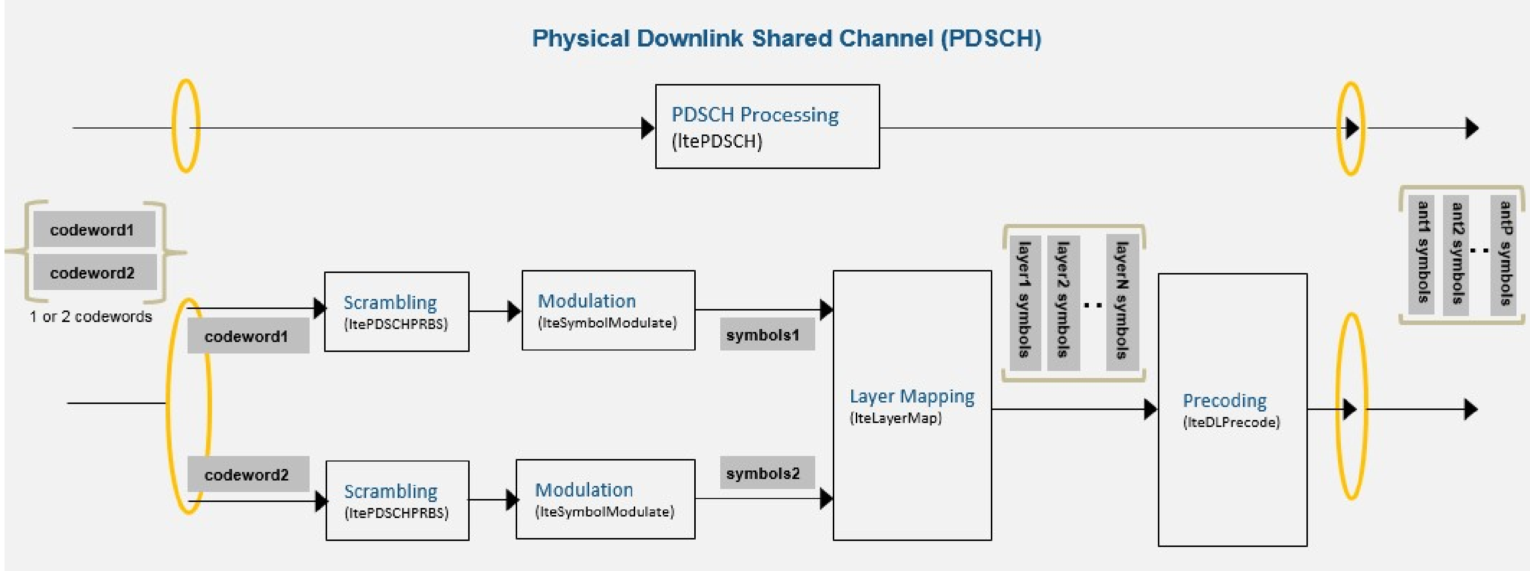


Figure 2: PDSCH Processing Chain

HARQ

資料重傳

- 5G 的重傳機制包含
  - RLC layer 中的 ARQ 機制
    - 提供可靠的數據傳輸
  - MAC layer 中的 HARQ 機制
    - 提供快速重傳
  - 丟失或出錯數據的重傳，主要是由 MAC 的 HARQ 機制處理，並由 RLC 的 ARQ 機制進行補充
- ARQ vs. HARQ
  - ARQ
    - 重傳對象是 PDU
    - 採 Go-back-N protocol
  - HARQ
    - 重傳對象是 CBG
    - 採 Stop-and-Wait protocol

What is HARQ?

- HARQ (Hybrid Automatic Repeat reQuest, 混合自動重傳請求)，包含
  - FEC (Forward Error Correction，前向糾錯)
  - ARQ (Automatic Repeat reQuest，自動重傳請求)

HARQ

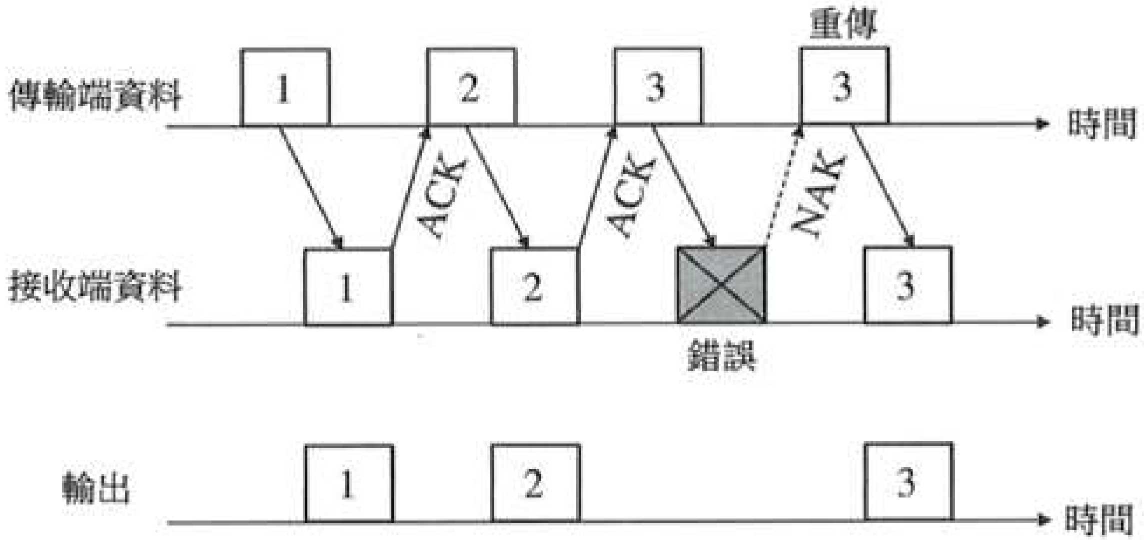
- HARQ (Hybrid Automatic Repeat reQuest, 混合自動重傳請求)，包含
  - FEC (Forward Error Correction，前向糾錯)
    - 通過添加冗餘信息，使得接收端能夠糾正一部分錯誤，從而減少重傳的次數
    - 無法糾正的錯誤，再通過 ARQ 機制請求發送端重發數據
  - ARQ (Automatic Repeat reQuest，自動重傳請求)
    - 接收端會透過 CRC 檢查數據內容
      - 無錯 ➔ 發送 ACK (Acknowledgement) 回發送端
      - 有錯+無法糾正 ➔ 發送 NACK (Negative Acknowledgement) 回發送端
- HARQ with Soft Combining
  - 當封包有錯時，先將數據保存在 HARQ buffer 內，等待接收到新數據時，與之合併，共同為正確解碼盡一分力
    - HARQ 搭配 Soft Combining 將錯誤的封包暫存於緩衝器內，並將其與重傳的資料合併，此為 PHY 中的功能

HARQ

- HARQ 優點
  - 可以不用每次都大費周章地預先準確估測通道，或想盡辦法將被雜訊影響嚴重的訊息正確解碼，直接讓傳送端重送資料便可大幅增加正確解碼的機率
- 傳送端將原始資料封包 (Information Bits) 加上循環冗餘校驗 CRC 後透過 Turbo Encoder 編碼產生數據封包 (Coded Bits)
  - Chase Combining (CC)
    - 重傳的資料與第一次傳送的資料是一樣的，都是同一包 Coded Bits
  - Incremental Redundancy (IR)
    - 每次重傳的資料都不一樣
      - 傳送端在傳送前會將 Coded Bits 透過 Circular Buffer 用 Puncturing 的方式分成四種 RV (Redundancy Version)
      - 第一次傳送 r.v.=0，若有需要重傳，會依序再傳 r.v.=2、r.v.=3 及 r.v.=1 的部分
      - 若傳送四次合併之後仍無法正確解碼，會全部捨棄再從頭重傳一遍

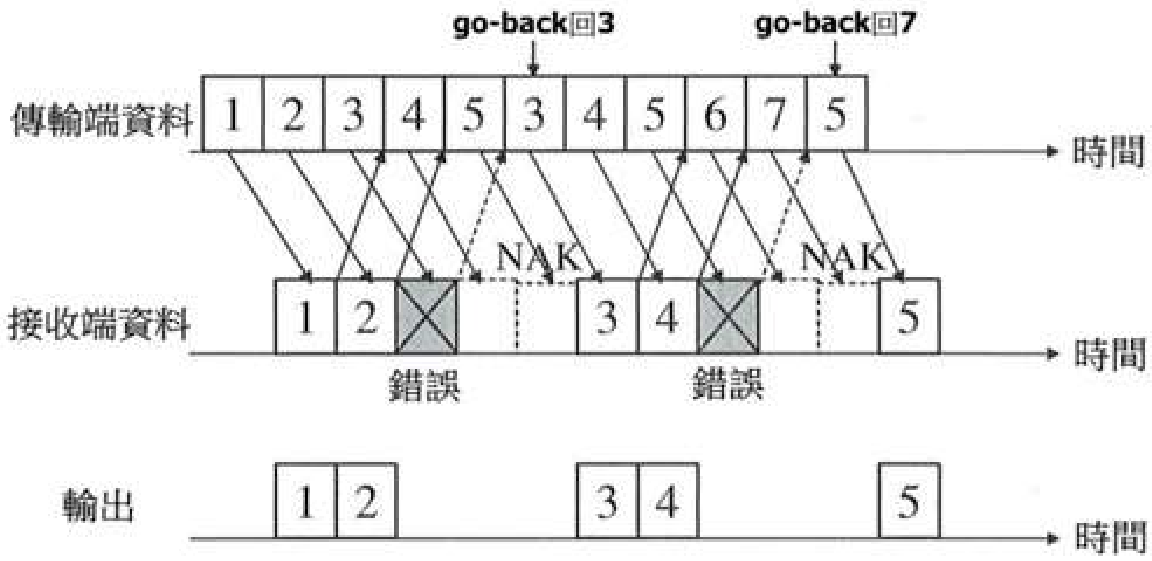
Protocols of HARQ

- Stop-and-Wait
  - 發送端每傳送一筆資料封包就先暫時停下來，待其收到接收端傳回的 ACK/NACK，或者在特定時間後尚未收到 ACK/NACK 時才決定傳新資料/重傳



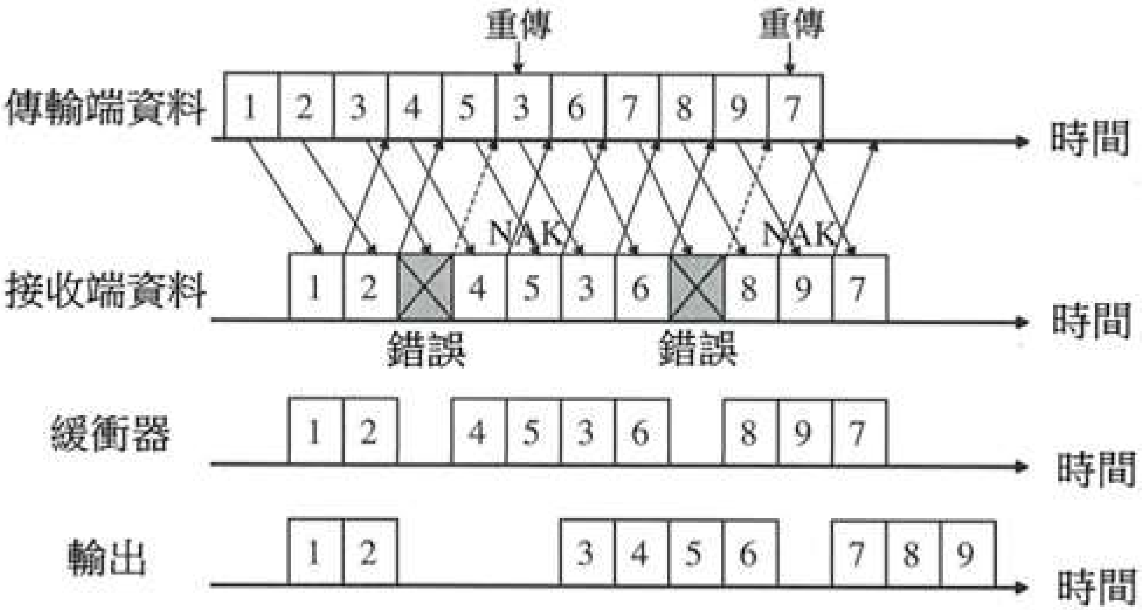
Protocols of HARQ

- Go-back-N
  - 發送端持續不斷地傳送資料封包，若收到 ACK 時不改變其動作，但收到 NACK 時會跳回錯誤的資料封包再依序重傳一次
  - 接收端在回傳 NACK 後便捨棄接下來收到的封包，待前一次傳錯的資料正確解碼後，才開始繼續依序儲存資料封包



Protocols of HARQ

- Selective-repeat
  - 發送端收到 NACK 時僅重傳錯誤的那份資料封包，而非重新依序重傳
  - 接收端在回傳 NACK 後並非捨棄接下來收到的封包而是存在 Buffer 中，待資料全部接收(正確解碼)完成後再重新依序排列



HARQ Process

- HARQ 使用 stop-and-wait protocol 來發送數據
- 同時，會有多個 HARQ processes 在處理資料
    - 當一個 HARQ process 在等待確認信息時，發送端可以使用另一個 HARQ process 繼續發送數據
- 這些 HARQ processes 共同組成了一個 HARQ entity
- 每個 HARQ process 在一個 TTI 只處理一個 TB
- 每個 HARQ process 在接收端都需要有獨立的 HARQ buffer，以便對接收到的數據進行 soft combining
- NDI (New Data Indicator)
    - 每個 HARQ process 會保存一個 NDI 值，該值使用 1 bit 來指示被調度的數據是新傳還是重傳
    - 如果同一 HARQ process 的 NDI 值與之前相比不同，表示當前傳輸的是一個新的 TB
    - 否則，表示當前傳輸的是同一個 TB 的重傳

HARQ Process

- NR R15 每個上下行支援最大 16 個 HARQ processes
  - by default, # HARQ process = 8 for DL
  - by default, # HARQ process = 16 for UL
  - length of HARQ process ID = 4 bits
- 5G 不支援跨 cell 的 HARQ
- HARQ-ACK 信息既可以在 PUCCH 上承載，也可以在 PDCCH 上承載
- 對於上行數據發送，如果需要重傳，gNB 不向 UE 發送 ACK/NACK 信息，而是直接調度 UE 進行數據重傳

HARQ – bbu-cli

- bbu-cli --config cell {0|1|2} maxDlHqTx 2
- bbu-cli --config cell {0|1|2} maxUlHqTx 2
    - range 1~15
    - 最大重傳次數

AMC

AMC (Adaptive Modulation and Coding)

- 根據 UE 和 gNodeB 提供的訊息，動態選擇最佳的 MCS，使其適應在系統限制範圍內和通道條件
  - adaptive modulation
    - 在 bandwidth 固定的情況下，根據 channel state，選擇不同的 modulation
    - 不同的 modulation 在單個子載波能傳遞的 bits 數目不同
  - adaptive coding
    - 根據 channel state，選擇不同的編碼技術
    - 在 channel coding 過程中添加不同長度的 redundancy bits
    - redundancy bits 越多，檢錯和糾錯的能力越強。
  - Channel 條件差 ➔ 選擇較小的 MCS
  - Channel 條件好 ➔ 選擇較大的 MCS

AMC

- 無論 DL/UL，MCS 的選擇都是由 gNB 根據 channel quality 來決定的
    - Downlink
        - Outer loop
            - gNB 根據 UE 接收到的 DL Data 的 ACK/NACK，來推測 channel 的質量，主動調整 CQI 值
            - UE 回復 NACK，代表 channel quality 差，所以調低 CQI
        - Inner loop
            - gNB 根據 UE 對 DMRS 的測量值 CQI 的上報，來決定 channel 的質量
            - DMRS 為已知內容的序列，UE 可以透過比對收到的 DMRS 與理論值來判定 channel quality

channel estimation: 看看發送端傳送的數據 (參考信號)，接收端是否能正確收到

CQI Table

- gNB 根據收到的 CQI 值進行查表，找到對應的 modulation 方式、編碼率率以及編碼效率，動態選擇 MCS

Table 5.2.2.1-2: 4-bit CQI Table

CQI index	modulation	code rate x 1024	efficiency
0	out of range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

Table 5.2.2.1-3: 4-bit CQI Table 2

CQI index	modulation	code rate x 1024	efficiency
0	out of range		
1	QPSK	78	0.1523
2	QPSK	193	0.3770
3	QPSK	449	0.8770
4	16QAM	378	1.4766
5	16QAM	490	1.9141
6	16QAM	616	2.4063
7	64QAM	466	2.7305
8	64QAM	567	3.3223
9	64QAM	666	3.9023
10	64QAM	772	4.5234
11	64QAM	873	5.1152
12	256QAM	711	5.5547
13	256QAM	797	6.2266
14	256QAM	885	6.9141
15	256QAM	948	7.4063

AMC

- 無論 DL/UL，MCS 的選擇都是由 gNB 根據 channel quality 來決定的
  - Uplink
    - Outer loop
      - gNB 根據 UL Data 的 ACK/NACK，以及對 BLER 的要求，來推測 channel 的質量，主動調整 OLLA (Outer Loop Link Adaption) Offset 值
    - Inner loop
      - gNB 直接根據測量的信噪比 SNR，來推測 channel 的質量

- SNR/SINR (Signal to Interference plus Noise Ratio)
  - 接收到的有用信號的強度與干擾信號的強度的比值

AMC – bbu-cli

- bbu-cli --config cell {0|1|2} AMC
  - on
  - off

PC

PC (Power Control, 功率控制)

- CLPC (Closed Loop Power Control)
  - gNodeB 在收到 UE 發送的訊號後，經量測可得到功率大小
  - 接著再反饋 UE，該增加/減少多少發送功率
  - 可以在持續地溝通過程中，調整功率
- OLPC (Open Loop Power Control)
  - gNodeB 會發送特定 power 的 reference signal，以及 UE 可傳輸的最大 power (via SSB)
  - UE 收到 reference signal 後，經過量測，可以推算出從 gNodeB 到 UE 的功率衰減量
  - 再參考最大 power，推算出該向 gNodeB 發射多大功率的訊號

PC

- PRACH 的 power control 採用 OLPC
  - 從 OLPC 主要就是 UE 可以知道 Path Loss
- UE 發出 Preamble (Msg1) 到底要用多少功率?
  - $\mathrm{P}_{\mathrm{PRACH}} = \min\{P_{CMAX}, P_{PRACH,target} + PL\}\ dBm$
  - ssbPwr ➔ gNB 會用多少 power 打出 SSB
  - preambleRcvdTgtPwr ➔ gNB 預計希望接收的 preamble power
    - 從收到 SSB 的 power，可以計算出 path loss
    - 從 path loss 跟 preambleRcvdTgtPwr，UE 可以知道 preamble 要打出多少功率
- UE 發出 Msg3 到底要用多少功率?
  - msg3-DeltaPreamble
    - msg3 Power = PRACH Power + (2 x msg3-DeltaPreamble)
- UE 發出 PUCCH/PUSCH 到底要用多少功率?
  - p0nominal ➔ gNB 預計希望接收的 UL power
    - 從 path loss 跟 p0nominal，UE 可以知道 UL data 要打出多少功率

PC for PRACH

Table 7.3-2: DELTA_PREAMBLE values for short preamble formats.

Preamble Format	DELTA_PREAMBLE values (dB)
A1	$8 + 3 \times \mu$
A2	$5 + 3 \times \mu$
A3	$3 + 3 \times \mu$
B1	$8 + 3 \times \mu$
B2	$5 + 3 \times \mu$
B3	$3 + 3 \times \mu$
B4	$3 \times \mu$
C0	$11 + 3 \times \mu$
C2	$5 + 3 \times \mu$

- $P_{PRACH} = \min\{P_{CMAX}, P_{PRACH,target} + PL\}\ dBm$
  - P_{CMAX} is depend on UE category and usually consider as **23dBm**
  - $P_{PRACH,target} = preambleReceivedTargetPower + DELTA\_PREAMBLE$
    $+(PREAMBLE\_POWER\_RAMPING\_COUNTER - 1) * PREAMBLE\_POWER\_RAMPING\_STEP$
    $= -100 + 3 + (1 - 1) * 2 = -97$
    - $preambleReceivedTargetPower$ ➔ 在 DU 中定義
      - bbu-cli --config cell {0|1|2} preambleRcvdTgtPwr -100
        - range: -202 ~ -60
    - $DELTA\_PREAMBLE$ ➔ 根據 preamble format 查表
      - DELTA_PREAMBLE = 3
        - B4 and μ=1
    - $PREAMBLE\_POWER\_RAMPING\_COUNTER$
      - 傳送 preamble 的 counter，初始傳送值為 1，每次重傳加 1
    - $PREAMBLE\_POWER\_RAMPING\_STEP$ ➔在 DU 中定義
      - <pwrRampingStep>pwrRampingStep_dB2</pwrRampingStep>
      - 每重傳一次 preamble，會加大多少 power
        - 總共允許重傳幾次
        - <preambleTransMax>preambleTransMax_n200</preambleTransMax>

```
rach-ConfigCommon setup :
 {
   rach-ConfigGeneric
    {
      prach-ConfigurationIndex 2,
      msg1-FDM one,
      msg1-FrequencyStart 2,
      zeroCorrelationZoneConfig 6,
      preambleReceivedTargetPower -100,
      preambleTransMax n10,
      powerRampingStep dB4,
      ra-ResponseWindow sl20
    },
   ssb-perRACH-OccasionAndCB-PreamblesPerSSB four : 13,
   ra-ContentionResolutionTimer sf64,
   rsrp-ThresholdSSB 0,
   prach-RootSequenceIndex 1839 : 439,
   restrictedSetConfig unrestrictedSet
 },
```

PC for PRACH

- $\mathrm{P}_{\mathrm{PRACH}} = \min\{P_{CMAX}, P_{PRACH,target} + PL\}\ dBm$
  - PL (Path Loss) = referenceSignalPower - HigherlayerfilteredRSRP
    - referenceSignalPower
      - determined by powerControlOffsetSS
        - value: -3, 0, 3, 6
      - determined by ss-PBCH-BlockPower ➔在 DU 中定義
        - bbu-cli --config cell {0|1|2} nSsbPwr -30
          - range: -60 ~ 50
    - HigherlayerfilteredRSRP
      - the RSRP measured when sending PRACH
      - 就是 UE 收到 SSB 時測量到的 RSRP
    - gNB 發出的 SSB power 說好了是 nSsbPwr，但是 UE 收到時的 power 是 rsrp，所以中間衰減了 ➔ nSsbPwr - rsrp

PC for PRACH

- UE 要用多少 power 打出 preamble (Msg1)

  $= \mathrm{P_{PRACH}} = \min\{P_{CMAX}, P_{PRACH,target} + PL\}\ dBm$

  $= \min\{23, -97 + (-30 - rsrp)\}\ dBm$
- UE 要用多少 power 打出 preamble (Msg3)
  - msg3 Power = PRACH Power + (2 x msg3-DeltaPreamble)
    - msg3-DeltaPreamble ➔ 在 DU 中定義
      - <msg3deltaPreamble>0</msg3deltaPreamble>
        - range: -1 ~ 6

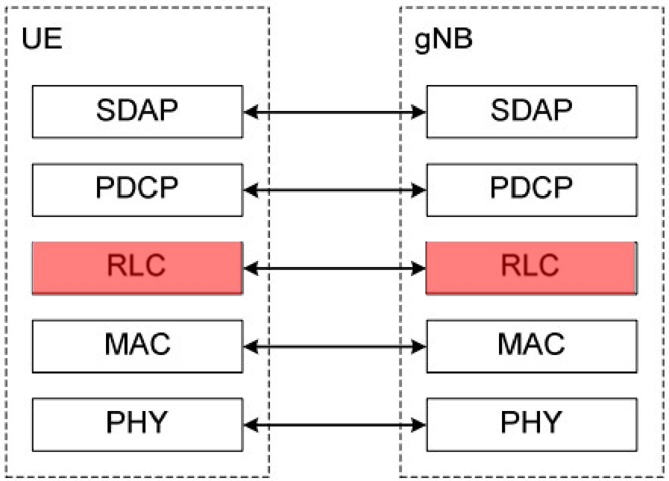
PC for PUSCH

- UE 要用多少 power 打出 UL data?
  - PUSCH
    - bbu-cli --config cell {0|1|2} p0nominal_pusch -82
  - PUCCH
    - bbu-cli --config cell {0|1|2} p0nominal_pusch -82
    - Default level for P0 for PUCCH is much lower than for PUSCH because it is a much more robust channel with low bit rate requirements.

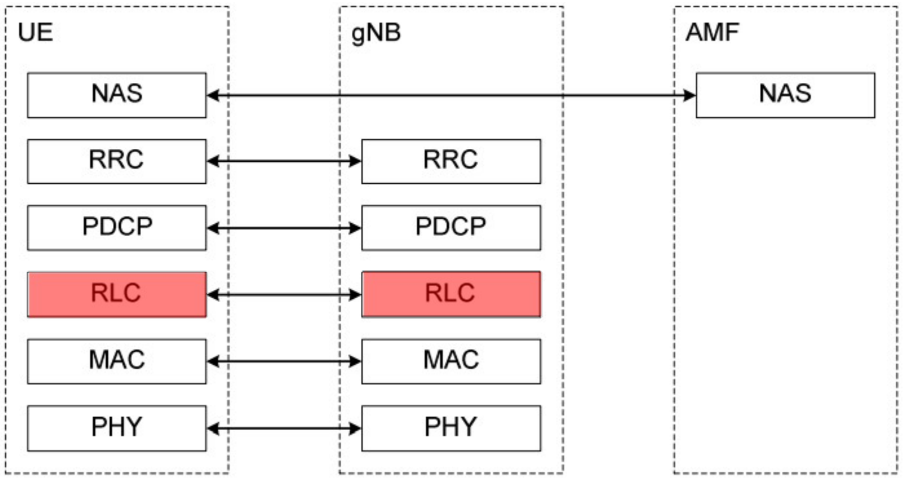
RLC

RLC (Radio Link Control)

- 對 PDCP Layer 的 PDU 數據進行處理成 SDU，然後交給 MAC Layer
  - 確保封包順序
  - 移除重覆封包與重傳
  - 封包的切割與重組



User Plane Protocol Stack



Control Plane Protocol Stack

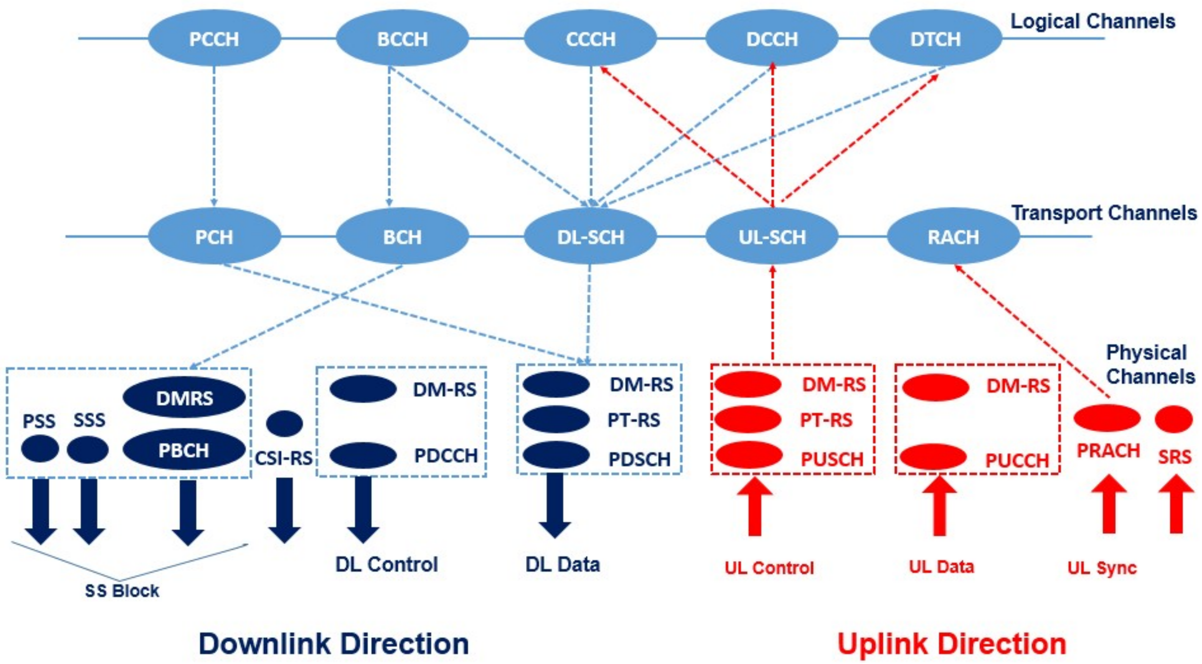
RLC Mode

- Acknowledged Mode (AM)
  - 只有在此模式下，才支援 ARQ
- Unacknowledged Mode (UM)
- Transparent Mode (TM)
  - RLC 不處理數據，直接 bypass

	RLC Header	PDU 排序	Buffer	檢測重複 SDU	SDU 分段、串接、重組	ARQ
TM	No	Not support	Only Tx	Not support	Not support	Not support
UM	Yes	Support	Both Tx and Rx	Support	Support	Not support
AM	Yes	Support	Both Tx and Rx	Support	Support	Support

RLC Mode

- Each of logical channels use a specific RLC mode
  - BCCH, PCCH, CCCH use RLC TM only
  - DCCH use RLC AM only
  - DTCH use RLC UM or AM (Which mode is used for each DTCH channel ? This is determined by RRC message)



RLC Mode – bbu-cli

- bbu-cli --config cell {0|1|2} rlcMode
  - RLC_AM
  - RLC_TM
  - RLC_UM_TX_ONLY
  - RLC_UM_RX_ONLY
  - RLC_UM_BIDIRECTIONAL
- bbu-cli --config cell {0|1|2}
  - snFieldLenUlAm
    - size12
    - size18
  - snFieldLenDlAm
    - size12
    - size18

Q: 不同的 logical channel 有固定的 RLC mode，那 DU 設定的這個 rlcMode，是設定什麼部份?!

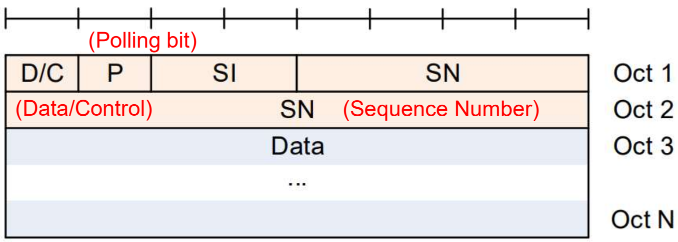
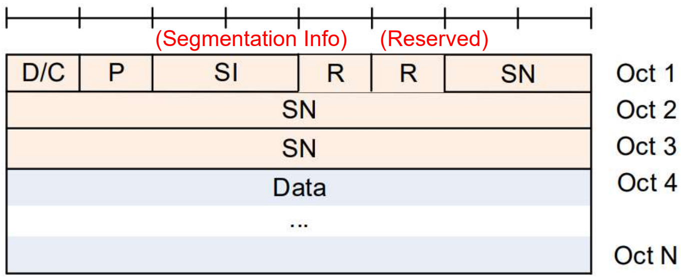


Figure 6.2.2.4-1: AMD PDU with 12 bit SN (No SO)

(AM Data)

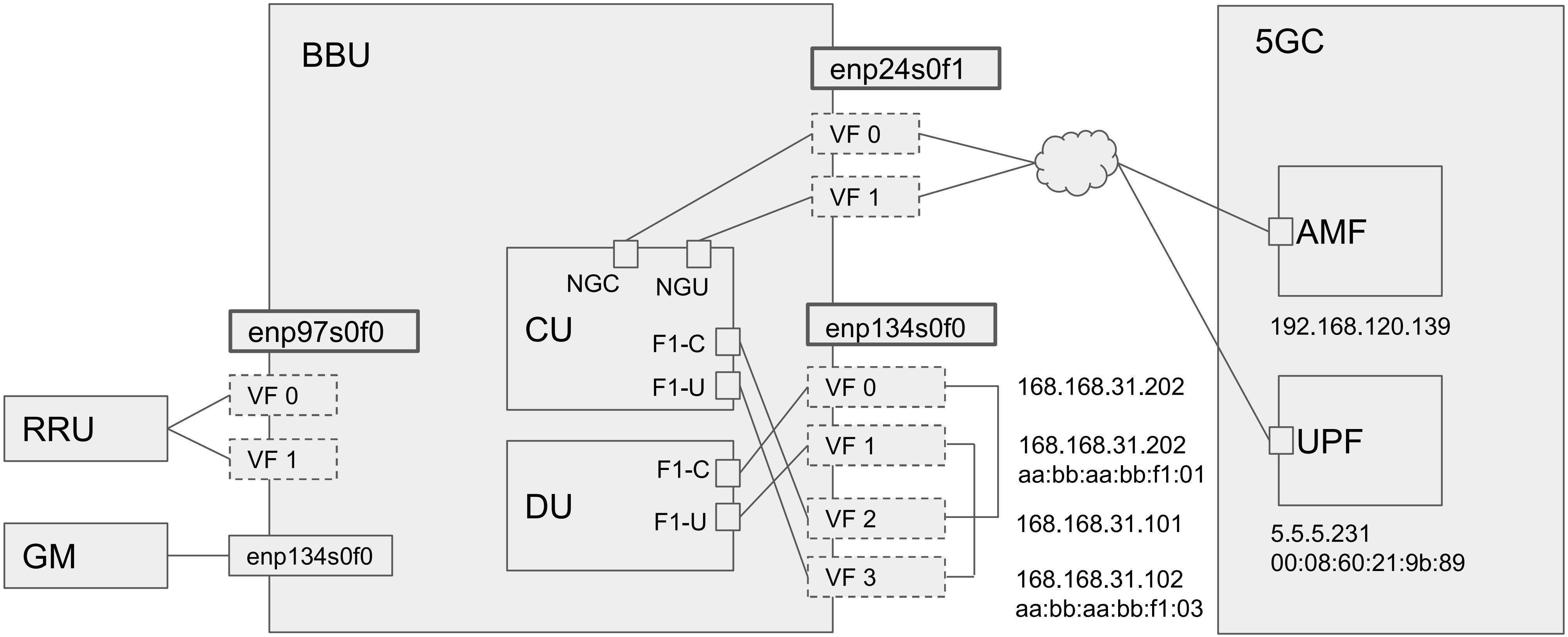


(Segment Offset)

Figure 6.2.2.4-2: AMD PDU with 18 bit SN (No SO)

DPDK Mode
for MidHaul and BackHaul

BBU Topology

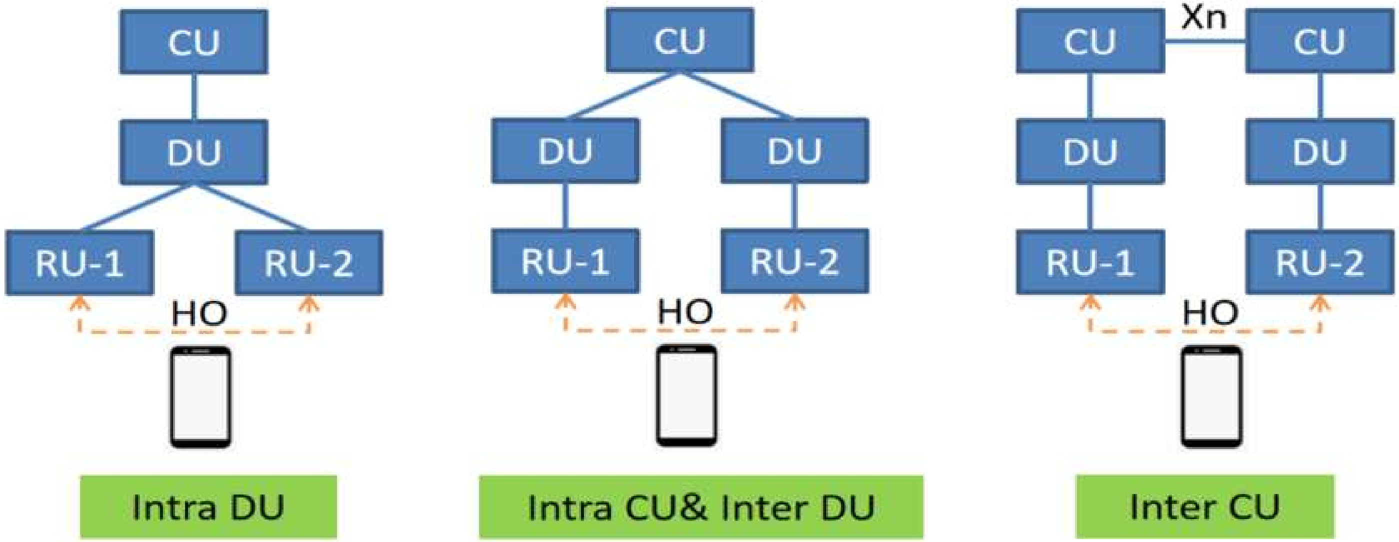


Handover

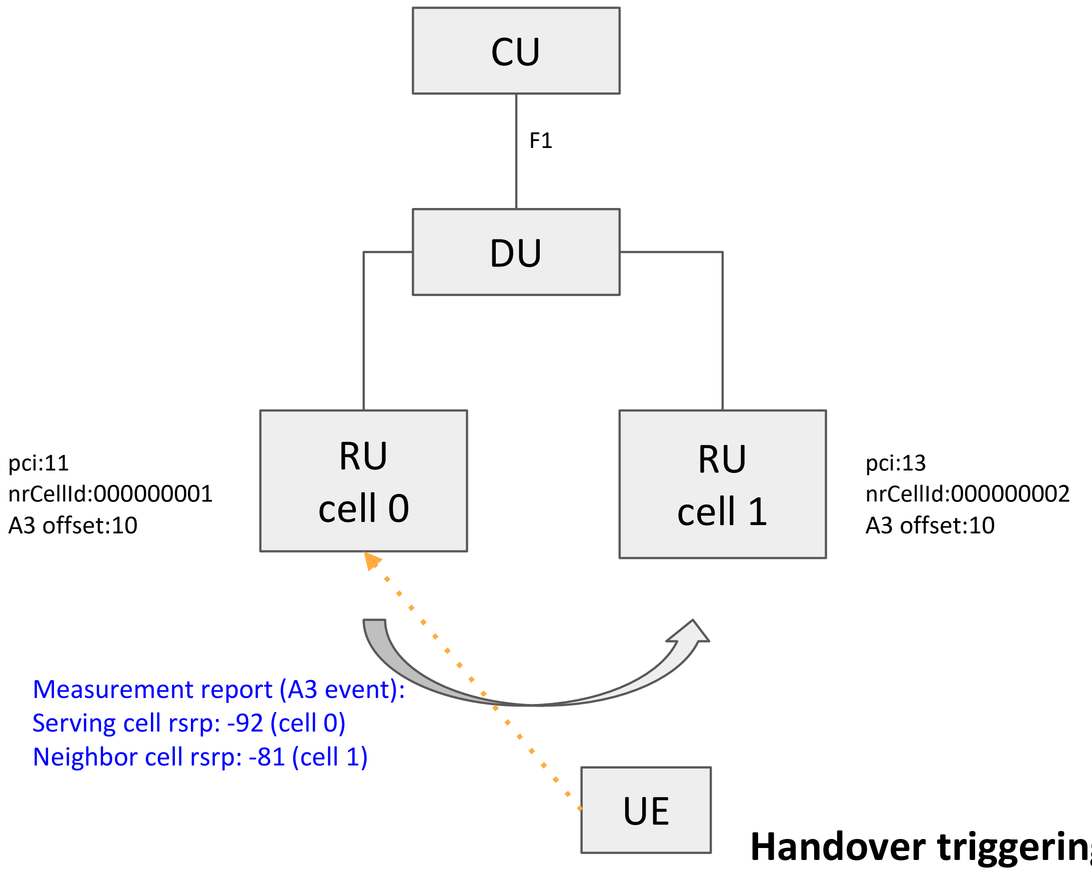
s1c/s1u 是 4g 的 eNB 到 4g 核心網(EPC) 的連線
ngc/ngu 是 5g 的 gNB 到 5g 核心網(5GC) 的連線
x2c/x2u 是 NSA 的 BBU 之間的連線
xnc/xnu 是 SA 的 BBU 之間的連線

BBU Handover Type

- Support 3 Handover (HO) Type
  - Intra-DU
  - Intra-CU and inter-DU
  - Xn based Inter-CU



Intra-DU

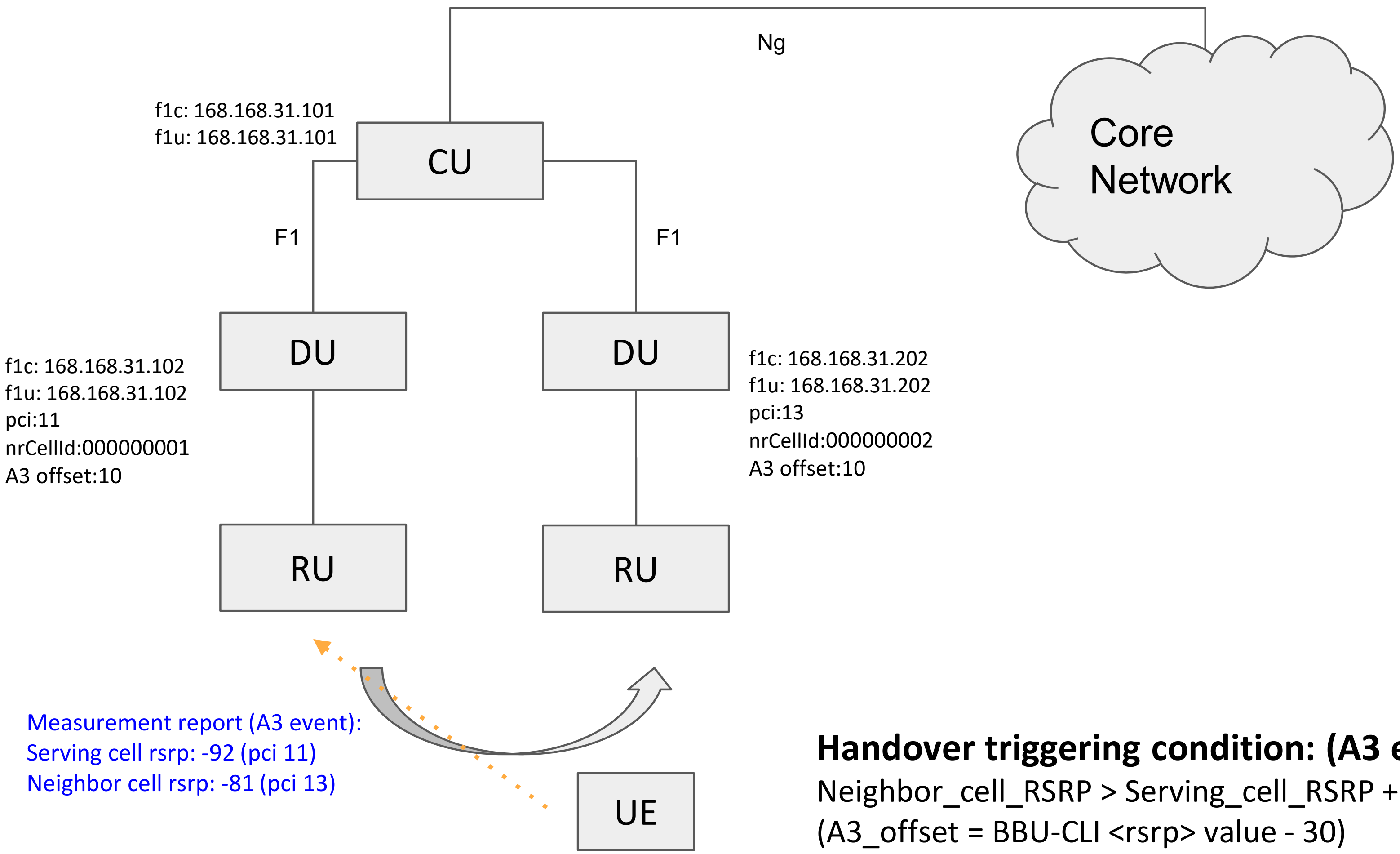


Handover triggering condition: (A3 event report)

Neighbor_cell_RSRP > Serving_cell_RSRP + A3_offset

(A3_offset = BBU-CLI <rsrp> value - 30)

Intra-CU and inter-DU

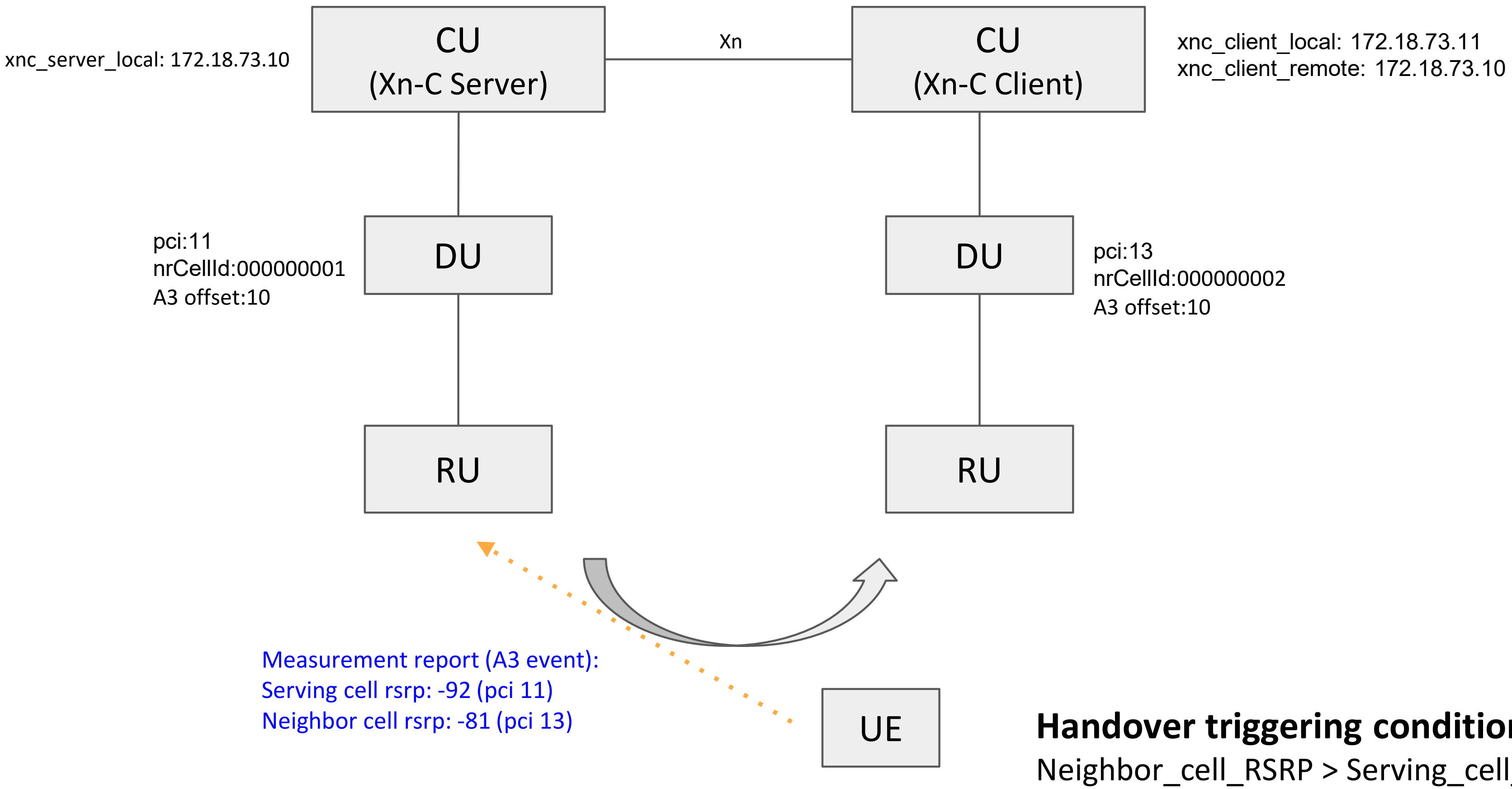


Handover triggering condition: (A3 event report)

Neighbor_cell_RSRP > Serving_cell_RSRP + A3_offset

(A3_offset = BBU-CLI <rsrp> value - 30)

Xn based Inter-CU



Handover triggering condition: (A3 event report)

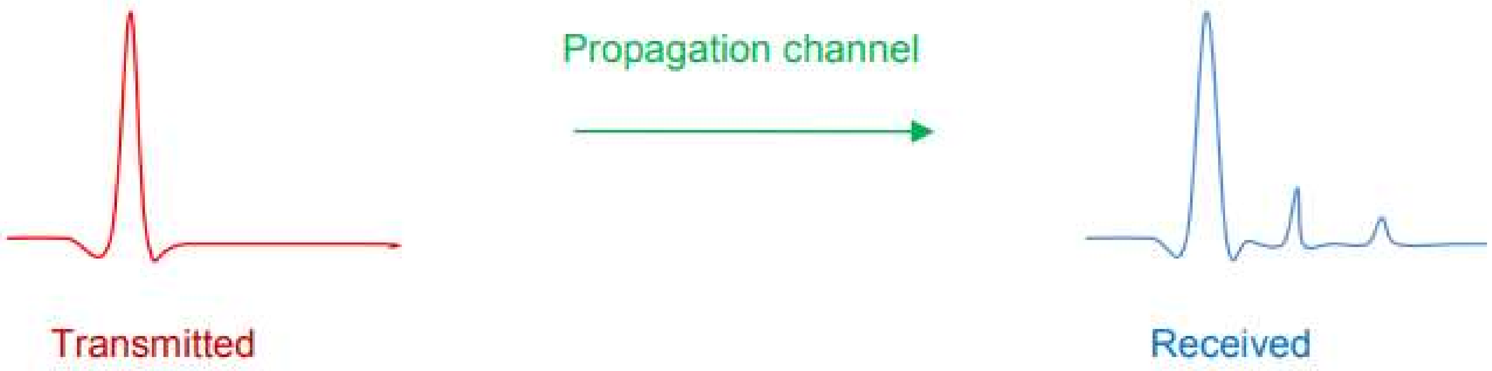
Neighbor_cell_RSRP > Serving_cell_RSRP + A3_offset

(A3_offset = BBU-CLI <rsrp> value - 30)

CFR/CIR

Channel Sounding

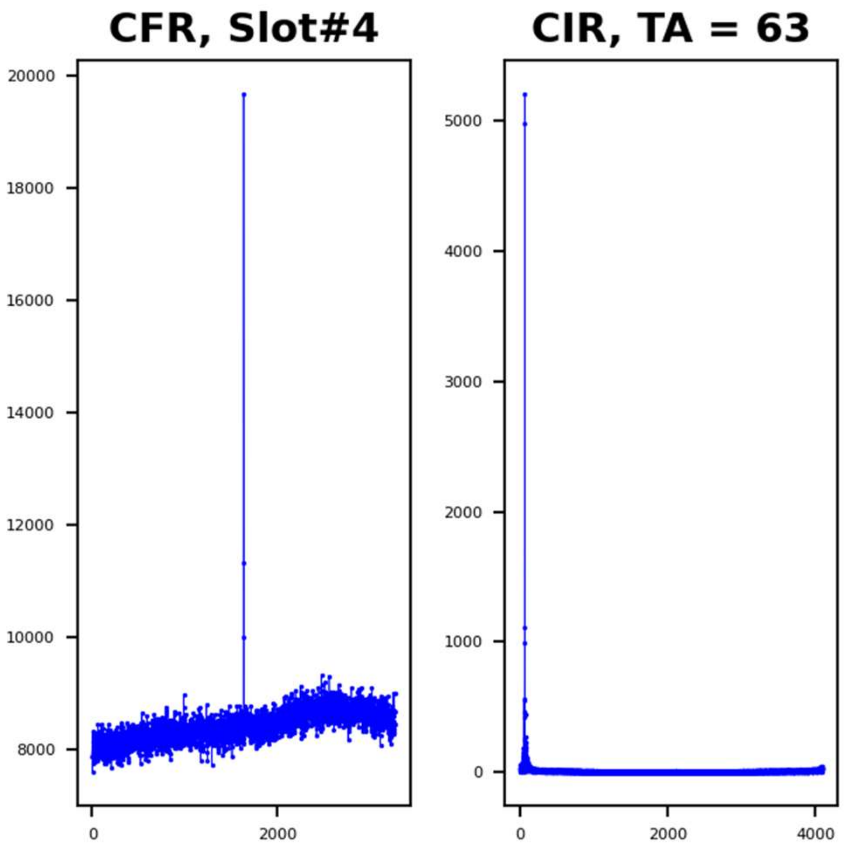
- 信道探測是一種評估無線通信（尤其是MIMO系統）的無線電環境的技術。由於地形和障礙物的影響，無線信號會沿多條路徑傳播。為了最小化或使用多徑效應，工程師使用通道探測來處理多維時空信號並估計通道特性



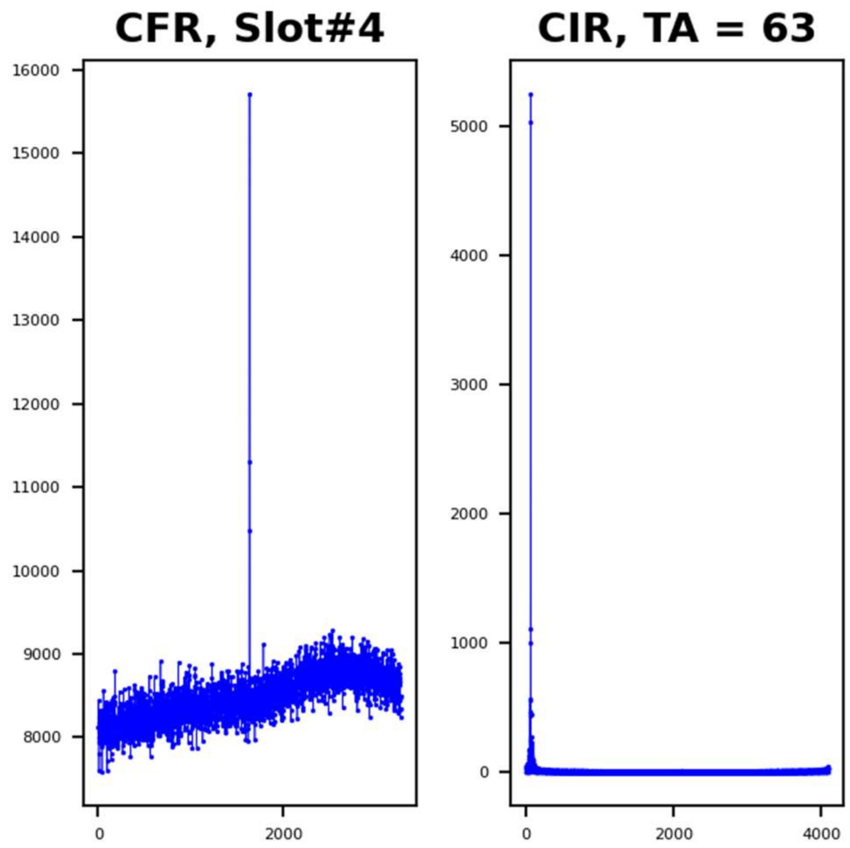
CFR/CIR

- 由 DMRS 所在的 symbol 來計算 channel sounding
  - CFR (Channel Frequency Response)
    - CFR = $|(DMRS\_IQ_{received}/DMRS_{ideal})|$
  - CIR (Channel Impulse Response)
    - CIR = $|IFFT(DMRS\_IQ_{received}/DMRS_{ideal})|$

CFR/CIR

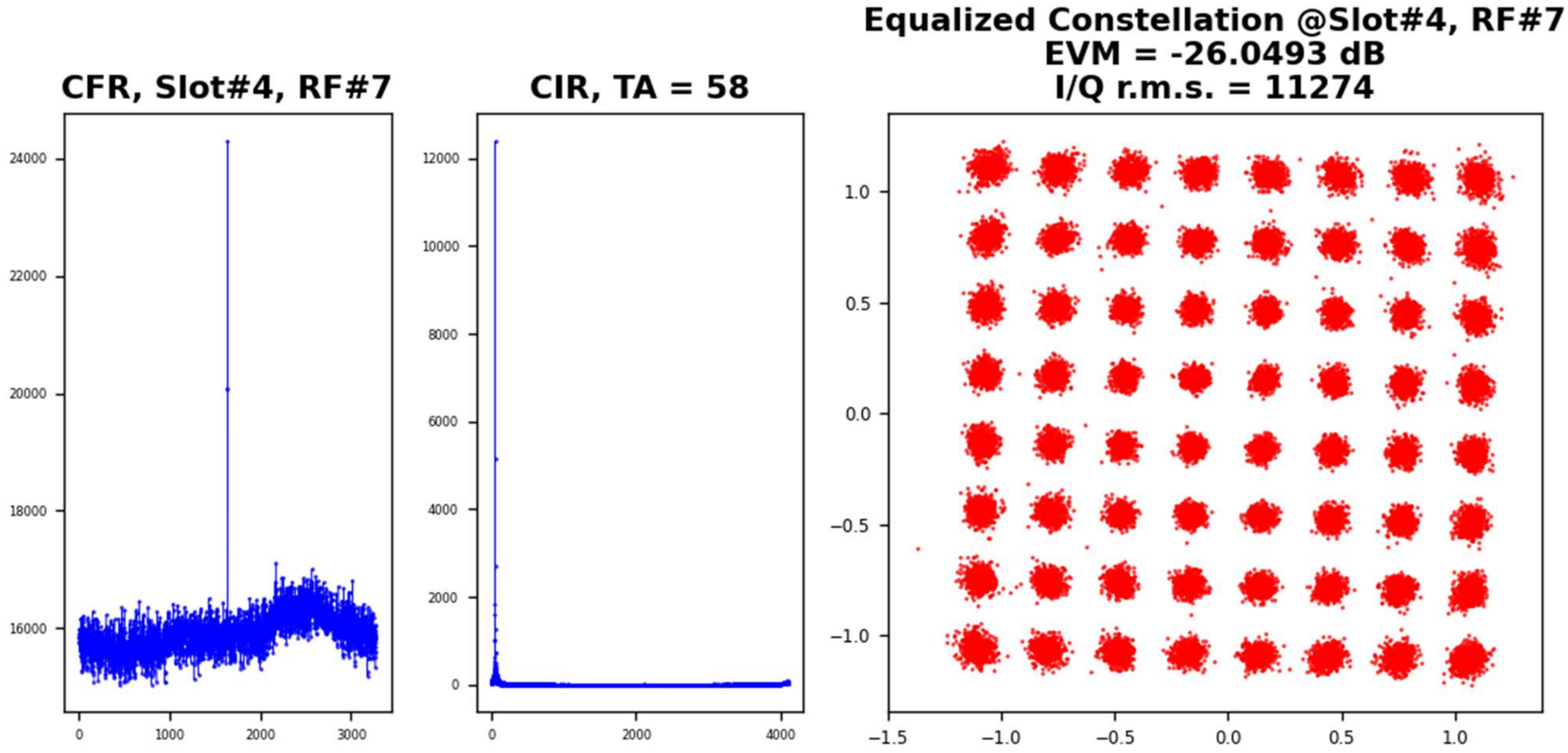


Symbol 2

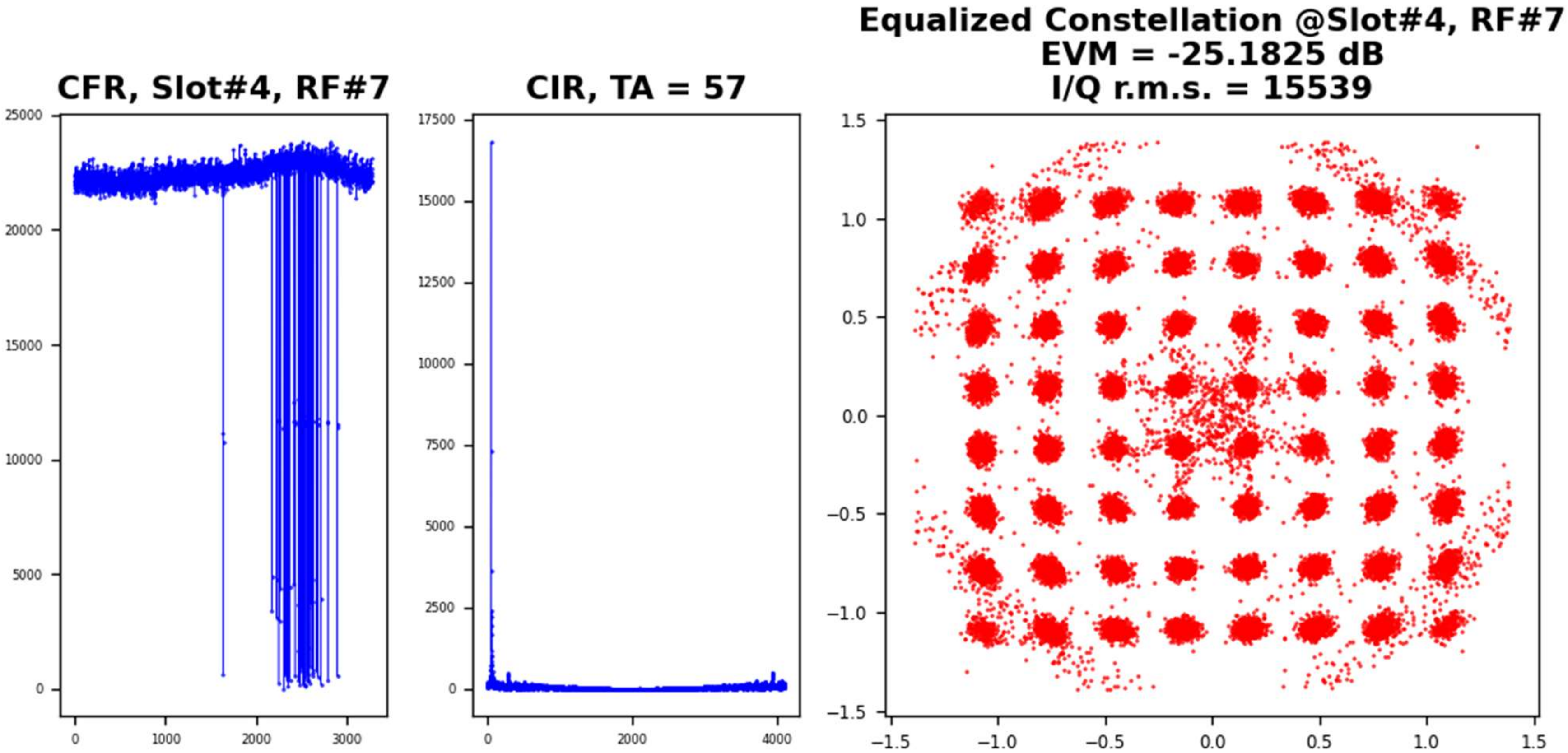


Symbol 11

When Uplink Power is -20 dBm



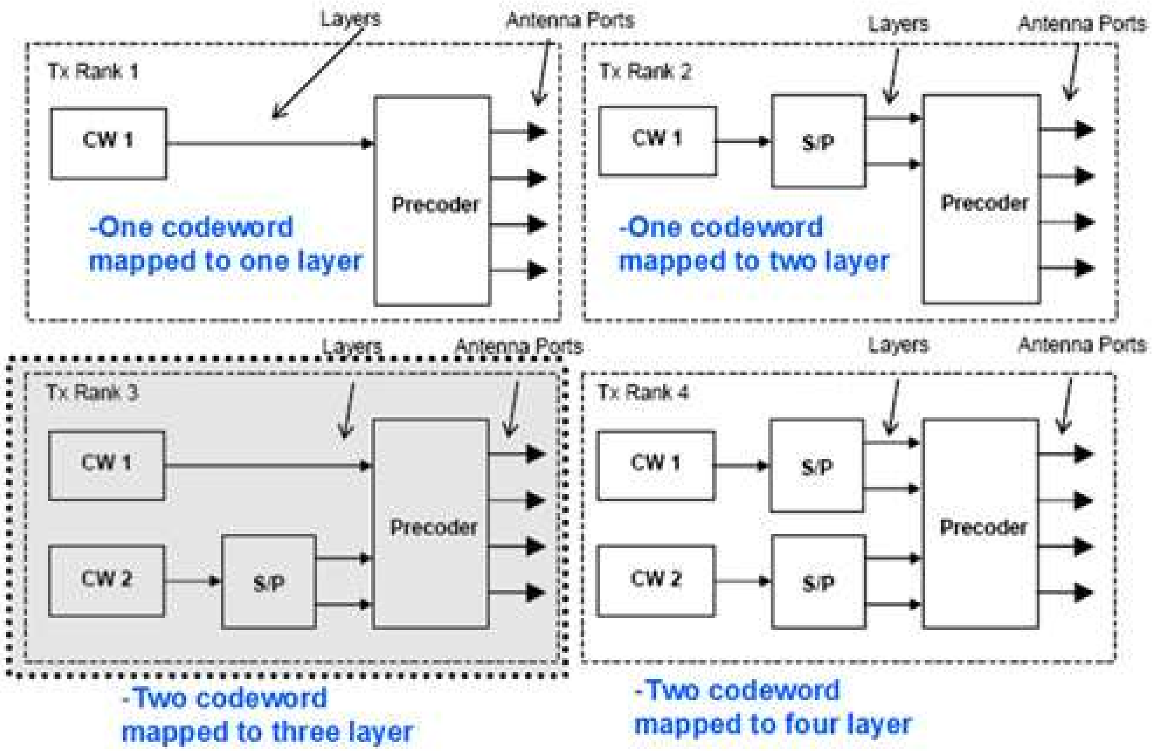
When Uplink Power is -17 dBm



Backup

- https://note-on-clouds.blogspot.com/2015/12/lte-harq-and-rlc.html

Delay	long		short	
Channel (error rate)	good	bad	good	bad
RLC AM	ON	ON	OFF	Cond. ON
HARQ	X	X	ON	ON


Layers
Antenna Ports
Tx Rank 1
CW 1
Precoder
-One codeword
mapped to one layer
Layers
Antenna Ports
Tx Rank 2
CW 1
S/P
Precoder
-One codeword
mapped to two layer
Layers
Antenna Ports
Tx Rank 3
CW 1
CW 2
S/P
Precoder
Layers
Antenna Ports
Tx Rank 4
CW 1
S/P
CW 2
S/P
Precoder
-Two codeword
mapped to three layer
-Two codeword
mapped to four layer

Item	Frequency Range 1 (FR1)	Frequency Range 2 (FR2)
Known As	Sub 6 GHz	mmWave
Frequency Range	450 MHz - 6000 MHz	24250 MHz - 52600 MHz
Duplex Mode	FDD, TDD	TDD
Subcarrier Spacing	15, 30, 60 KHz	60, 120 KHz
Bandwidth	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 100 MHz	50, 100, 200, 400 MHz
MIMO	DL: 8x8 UL: 4x4	DL: 2x2 UL: 2x2
MIMO Method	Spatial Multiplexing for higher Throughput	Beamforming for better SNR
Radio Frame Duration	10ms	
Subframe Duration	1ms	
Modulation	pi/2-BPSK, BPSK, QPSK, 16QAM, 64QAM, 256QAM	
Access	DL: CP-OFDM UL: CP-OFDM, DFT-s-OFDM	
Carrier Aggregation	16 carriers maximum	
Channel Coding	Polar Codes, LDPC Codes	

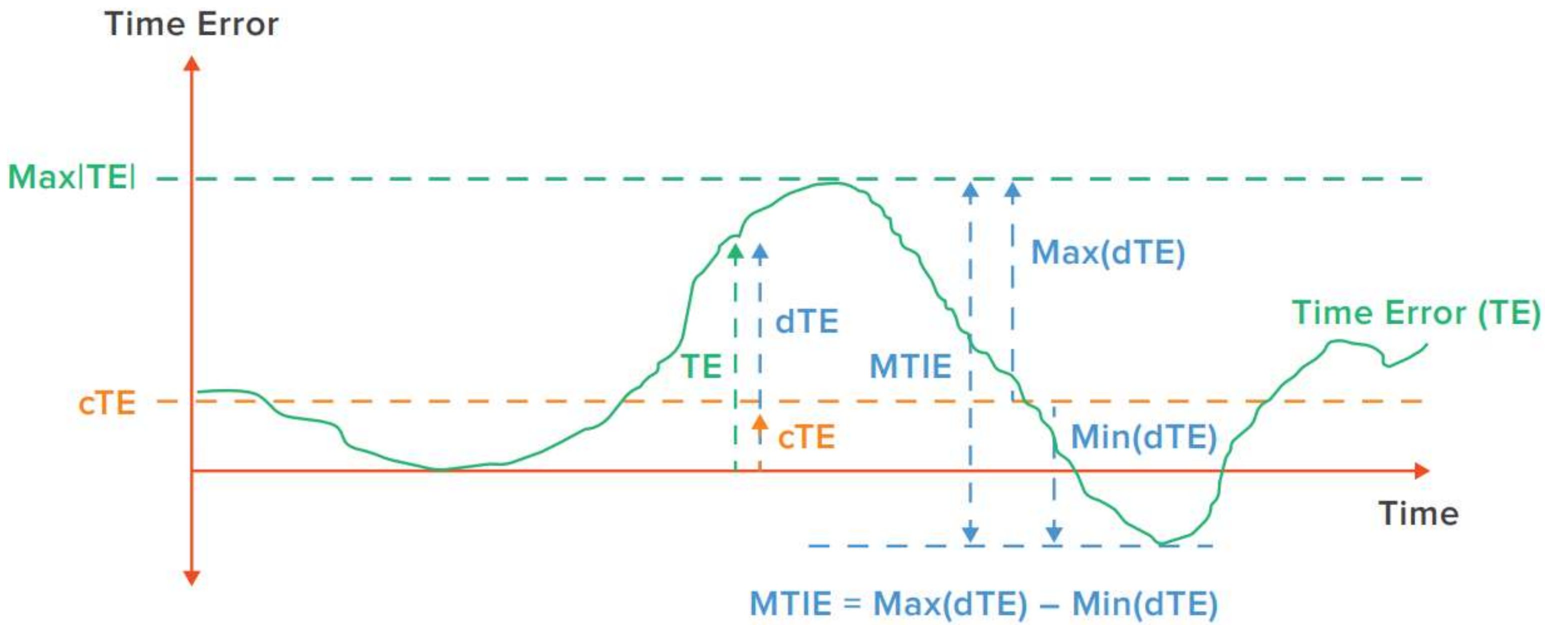
Item	Downlink	Uplink
Data Channels	PDSCH, PCH	PUSCH, PRACH
Control Channels	PDCCH	PUCCH (HARQ/CSI/SR)
Synchronization Signals	PSS, SSS, PBCH	-
Reference Signals	DMRS, PTRS, CSIRS	DMRS, PTRS, SRS

	SCS (kHz)	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz	40 MHz	50 MHz	60 MHz	80 MHz	90 MHz	100 MHz	200 MHz	400 MHz	# of BWs	3GPP Suggested RBs for all supported BWs	# of OFDM Types	# of Modulations	# of Sampling Rates	# of CCs	ALL Test Cases with all possible RB Sweep
		N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}							
FR1	15	25	52	79	106	133	160	216	270	N/A	N/A	N/A	N/A	N/A	N/A	8	8	2	6	1	1	768
	30	11	24	38	51	65	78	106	133	162	217	245	273	N/A	N/A	12	8	2	6	1	1	1,152
	60	N/A	11	18	24	31	38	51	65	79	107	121	135	N/A	N/A	11	8	2	6	1	1	1,056
FR2	60	N/A	N/A	N/A	N/A	N/A	N/A	N/A	66	N/A	N/A	N/A	132	264	N/A	3	6	2	6	2	1	432
	120	N/A	N/A	N/A	N/A	N/A	N/A	N/A	32	N/A	N/A	N/A	66	132	264	4	6	2	6	2	1	576
															Total		36					3,984

- IEEE-1588 defines profile as “The set of allowed Precision Time Protocol (PTP) features applicable to a device”

Time Error

- Time Error measures the time difference between two clocks
  - TE (Time Error)
  - cTE (constant Time Error)
  - dTE (dynamic Time Error)

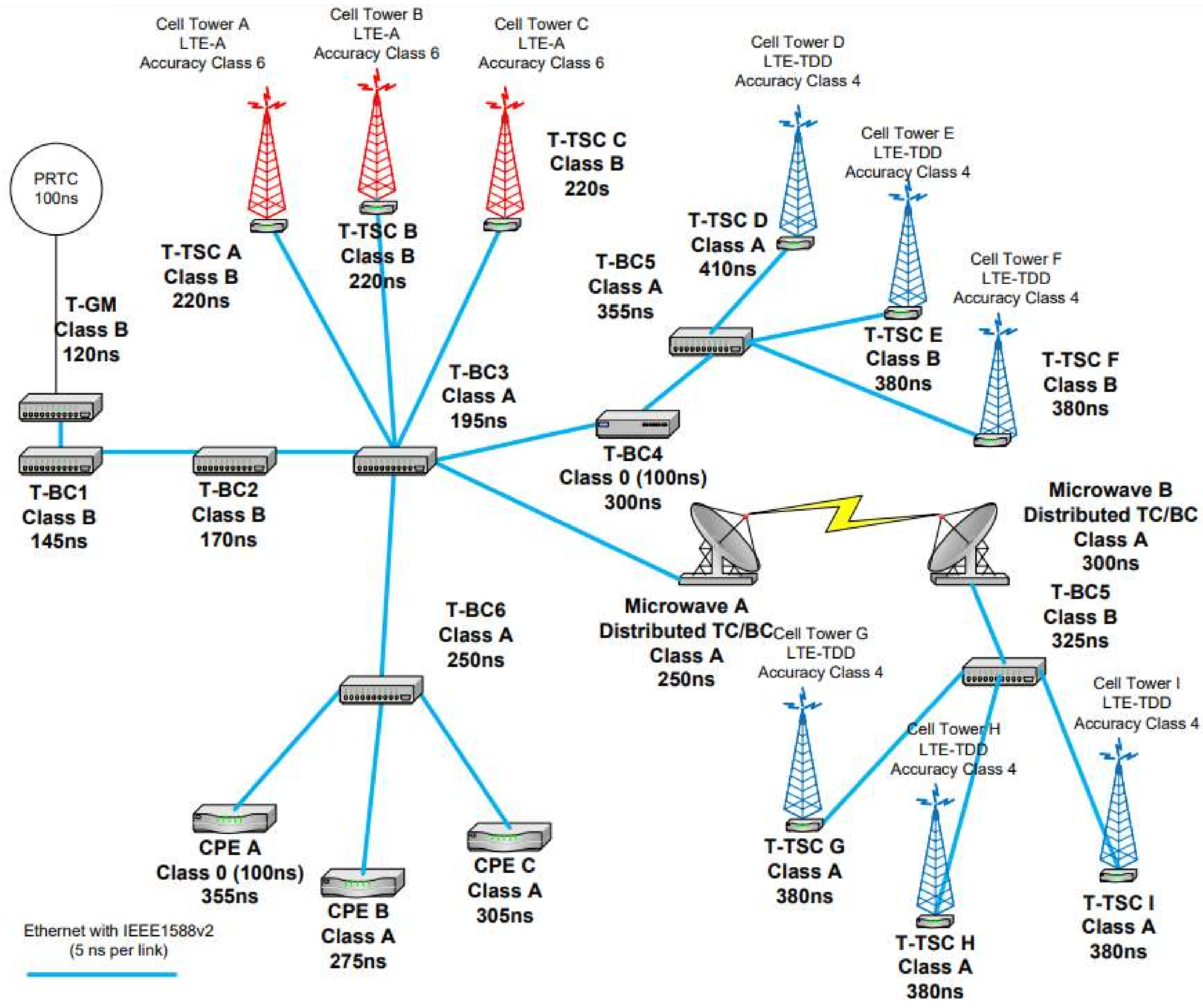


ITU-T G.8273.2 PTP T-BC Classes

Parameter	Conditions	Class A	Class B	Class C	Class D
Max|TE|	Unfiltered 1,000 second measurement	100 ns	70 ns	30 ns	-
Max|TE_L|	0.1 Hz low-pass filter, 1,000 s	-	-	-	5ns
cTE	Averaged over 1,000 s	±50 ns	±20 ns	±10 ns	-
dTE_L MTIE	0.1 Hz low-pass filter, constant temp, 1,000 s	40 ns	40 ns	10 ns	-
	0.1 Hz low-pass filter, variable temp, 10,000 s	40 ns	40 ns	-	-
dTE_L TDEV	0.1 Hz low-pass filter, constant temp, 1,000 s	4 ns	4ns	2 ns	-
dTE_H peak-to-peak	0.1 Hz high-pass filter, constant temp, 1,000 s	70 ns	70 ns	-	-

ITU-T G.8265.1/G.8275.1/G.8275.2

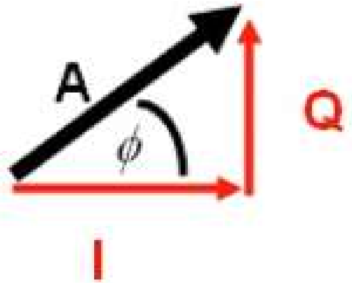
PTP Options/Attributes	G.8265.1	G.8275.1	G.8275.2
Domain Number	default : 4, range: {4-23}	default : 24, range: {24-43}	default : 44, range: {44-63}
Types of Clocks	Ordinary clocks (i.e. Grandmasters, slave-only clocks)	- Ordinary clocks (i.e. Grandmasters, slave-only clocks) - Boundary clocks - End-to-end transparent clocks	- Ordinary clocks (i.e. Grandmasters, slave-only clocks) - Boundary clocks
Time Transfer	- One-way - Two-way	- Two-way	- Two-way
Type of clocks	One-step and two-step	One-step and two-step	One-step and two-step
Transport Mode	Unicast - IEEE1588-2008 Annex D IPv4/UDP stack - IEEE1588-2008 Annex E IPv6/UDP stack	Multicast - IEEE1588-2008 Annex F - Transport of PTP over OTN (based on G.7041 and G.709)	Unicast - IEEE1588-2008 Annex D IPv4/UDP stack - IEEE1588-2008 Annex E IPv6/UDP stack
Path delay measurement	delay request/delay response mechanism	delay request/delay response mechanism	delay request/delay response mechanism
PTP Message rate (packets/s)	Sync /Follow-up – min rate:1/16, max rate: 128 Delay_Request/Delay_Response – min rate:1/16, max rate: 128 Announce – min rate:1/16, max rate: 128	Sync /Follow-up – fixed rate of 16 Delay_Request/Delay_Response – fixed rate of 16 Announce – fixed rate of 8	Sync /Follow-up – min rate:1, max rate: 128 Delay_Request/Delay_Response – min rate:1, max rate: 128 Announce – min rate:1, max rate: 128 Signaling messages – no rate is specified
BMCA	Alternate BMCA	alternate BMCA based on the IEEE 1588 default BMCA	alternate BMCA based on the IEEE 1588 default BMCA


Cell Tower A
LTE-A
Accuracy Class 6
Cell Tower B
LTE-A
Accuracy Class 6
Cell Tower C
LTE-A
Accuracy Class 6
Cell Tower D
LTE-TDD
Accuracy Class 4
Cell Tower E
LTE-TDD
Accuracy Class 4
Cell Tower F
LTE-TDD
Accuracy Class 4
PRTC
100ns
T-TSC A
Class B
220ns
T-TSC B
Class B
220ns
T-TSC C
Class B
220s
T-TSC D
Class A
410ns
T-BC5
Class A
355ns
T-TSC E
Class B
380ns
T-TSC F
Class B
380ns
T-GM
Class B
120ns
T-BC3
Class A
195ns
T-BC1
Class B
145ns
T-BC2
Class B
170ns
T-BC4
Class 0 (100ns)
300ns
Microwave B
Distributed TC/BC
Class A
300ns
T-BC6
Class A
250ns
Microwave A
Distributed TC/BC
Class A
250ns
Cell Tower G
LTE-TDD
Accuracy Class 4
T-BC5
Class B
325ns
Cell Tower I
LTE-TDD
Accuracy Class 4
Cell Tower H
LTE-TDD
Accuracy Class 4
CPE A
Class 0 (100ns)
355ns
CPE B
Class A
275ns
CPE C
Class A
305ns
T-TSC G
Class A
380ns
T-TSC H
Class A
380ns
T-TSC I
Class A
380ns
Ethernet with IEEE1588v2
(5 ns per link)

- https://blog.csdn.net/qq_33206497/article/details/9041561
- https://zh.codeprj.com/blog/ac90821.html
- https://www.shangmayuan.com/a/cf5411b6cc0146ce82b7592b.html
- https://www.techplayon.com/5gnr/
- https://www.2cm.com.tw/2cm/zh-tw/tech/9C0D1859282042B0998967B2AD6B3A6A
- https://www.rfwireless-world.com/Tutorials/5G-tutorial.html

$$Cos\,(\alpha + \beta) = Cos\,(\alpha)Cos\,(\beta) - Sin\,(\alpha)Sin\,(\beta)$$

$$ACos(2\pi f_c t + \phi) = ACos(2\pi f_c t)Cos(\phi) - ASin(2\pi f_c t)Sin(\phi)$$



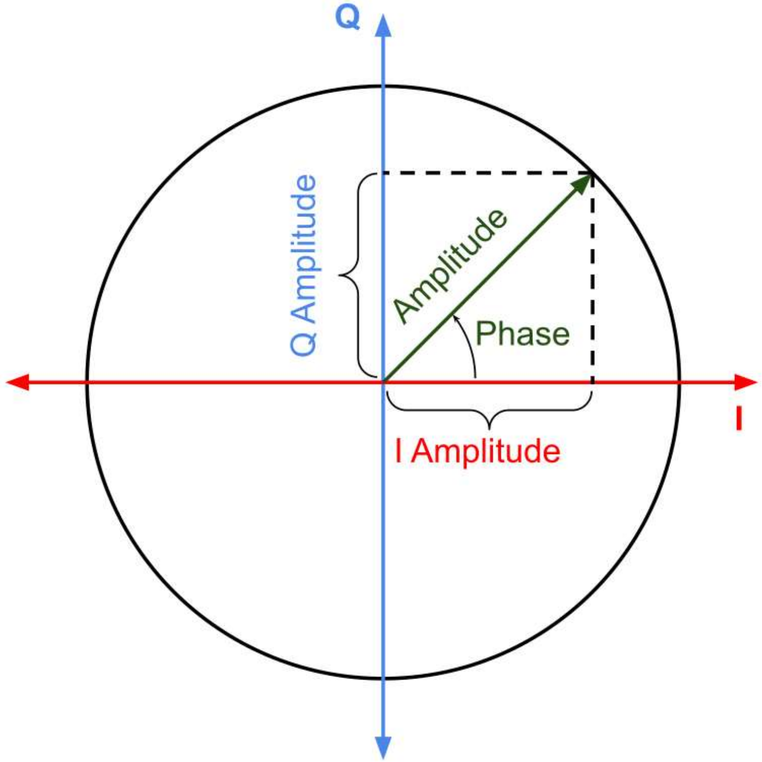
$$I = ACos(\phi)$$

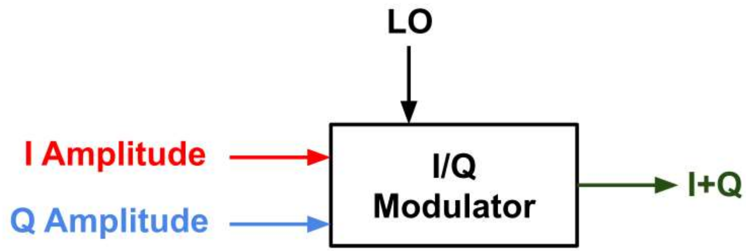
$$Q = ASin(\phi)$$

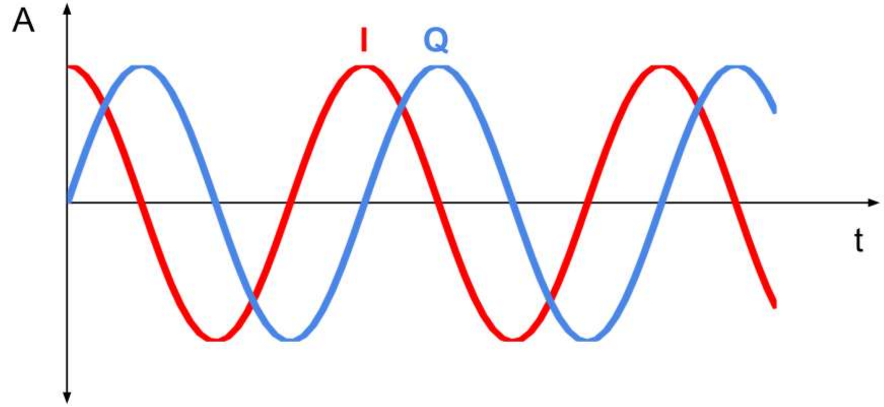
$$ACos\,(2\pi f_c t + \phi) = ICos\,(2\pi f_c t) - QSin(2\pi f_c t)$$

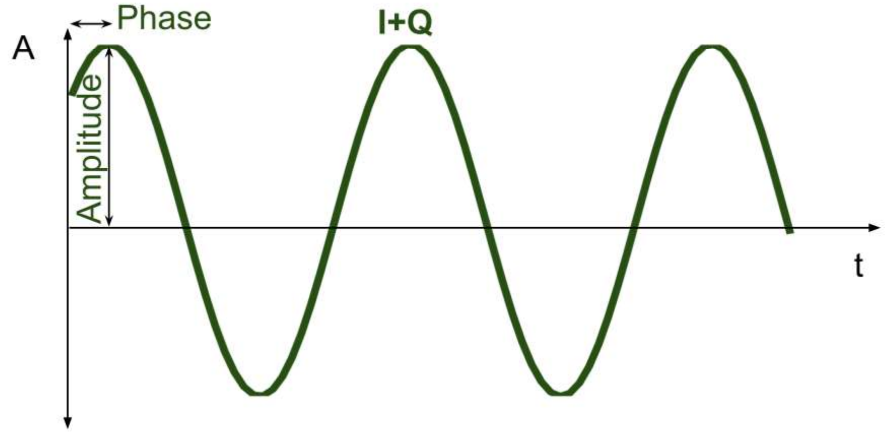
I = Amplitude of the "In-Phase Carrier"

Q = Amplitude of the "Quadrature Phase Carrier"

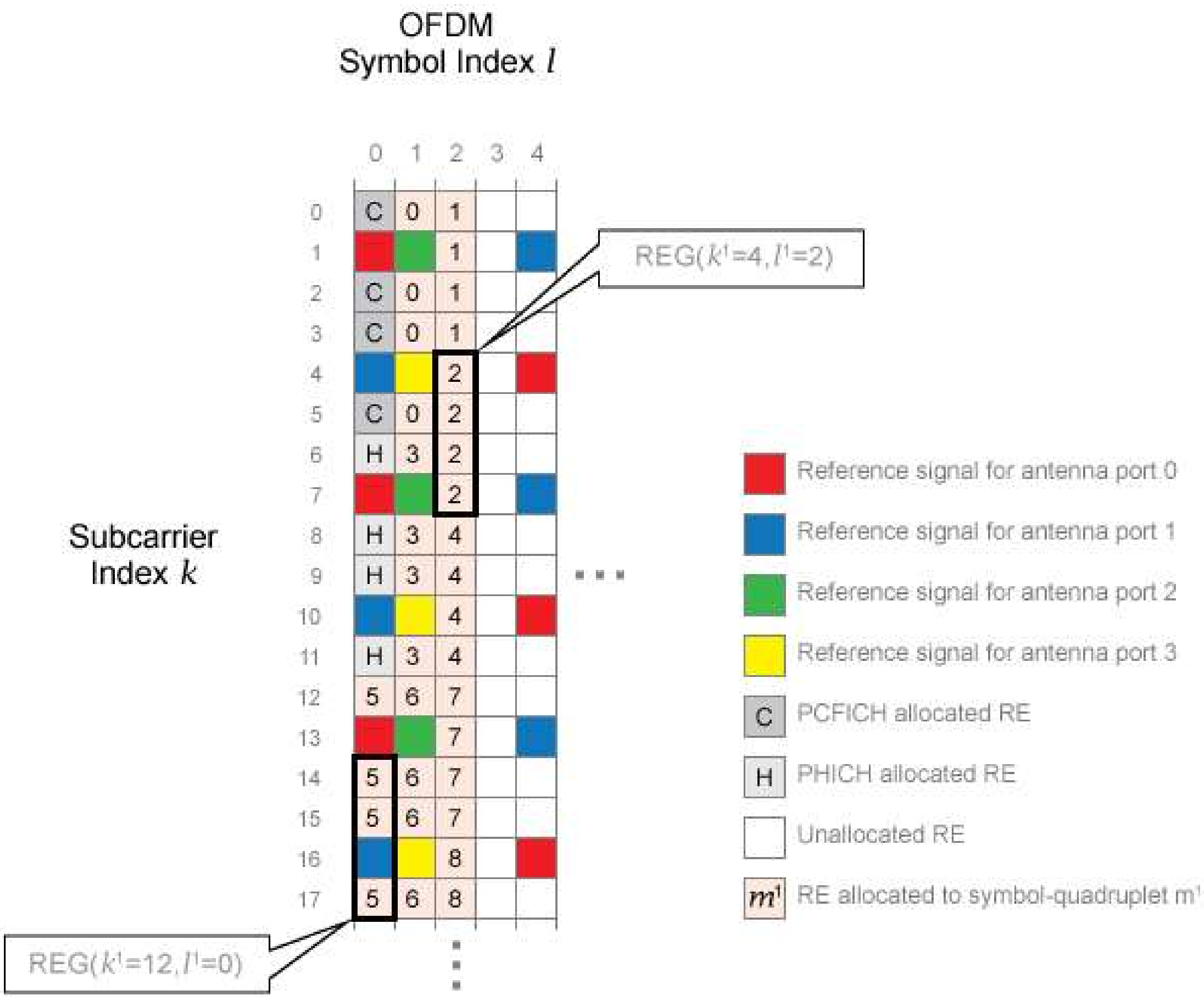




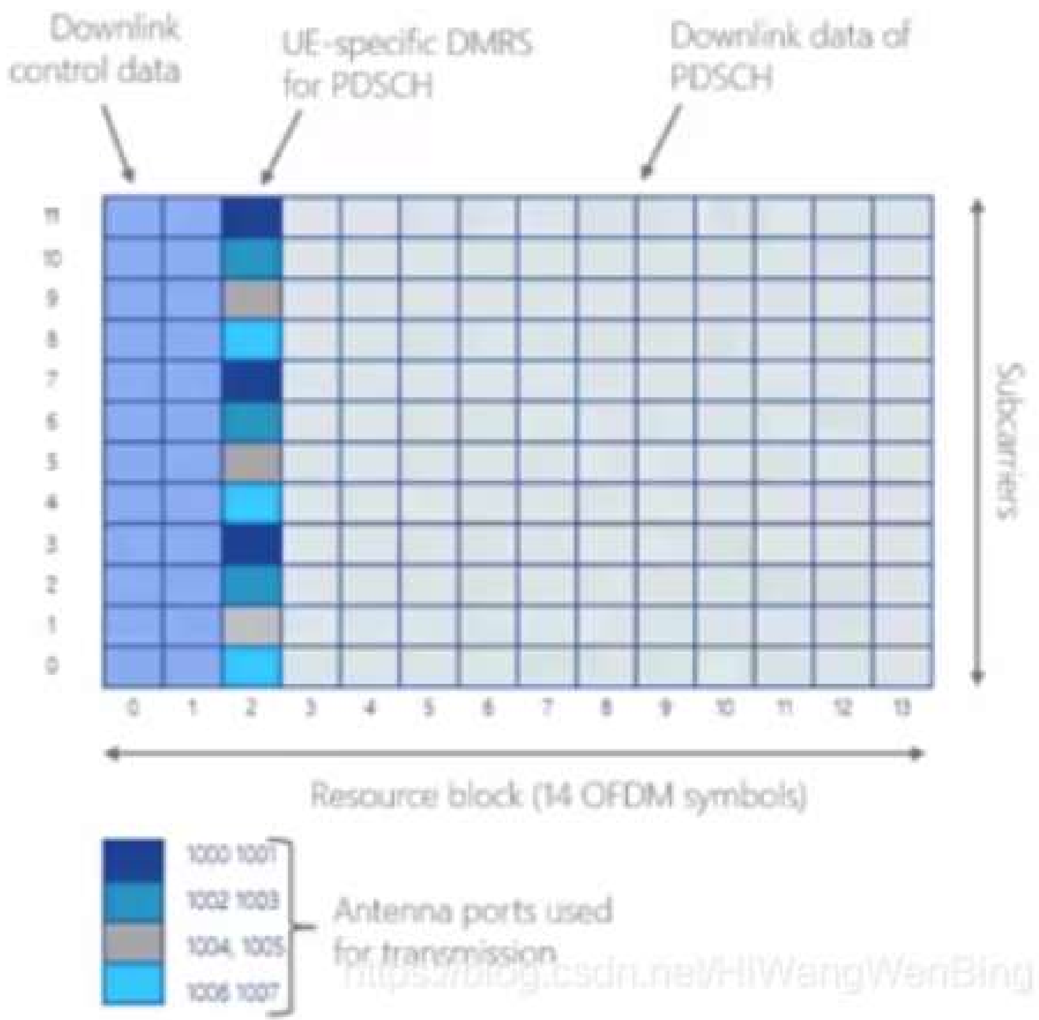




I Amplitude (V)	Q Amplitude (V)	I+Q	
		Amplitude (V)	Phase (°)
1	0	1	0
0	1	1	90
-1	0	1	180
0	-1	1	270



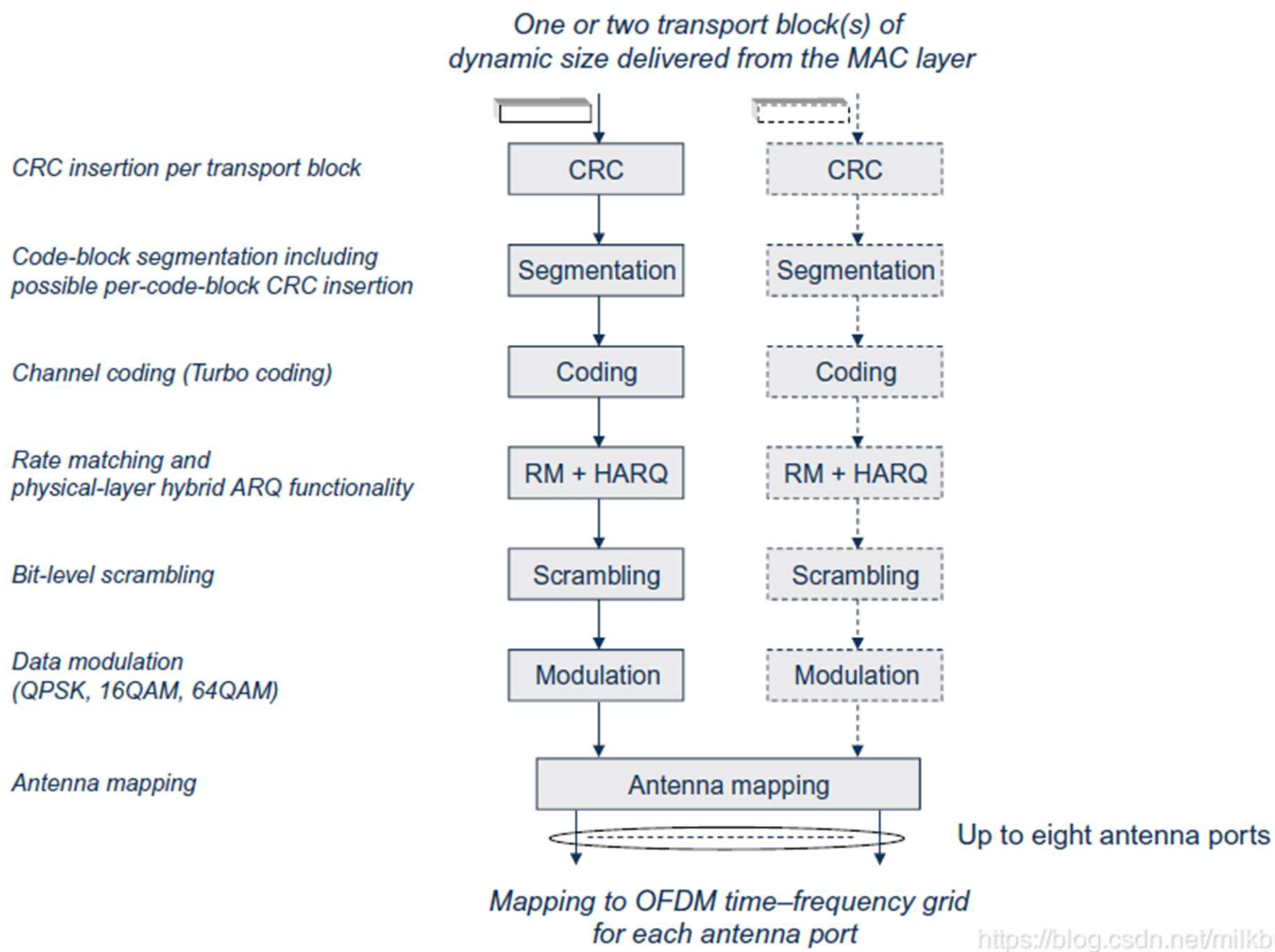
OFDM
Symbol Index l
Subcarrier
Index k
REG(k'=4, l'=2)
REG(k'=12, l'=0)
Reference signal for antenna port 0
Reference signal for antenna port 1
Reference signal for antenna port 2
Reference signal for antenna port 3
PCFICH allocated RE
PHICH allocated RE
Unallocated RE
RE allocated to symbol-quadruplet m'



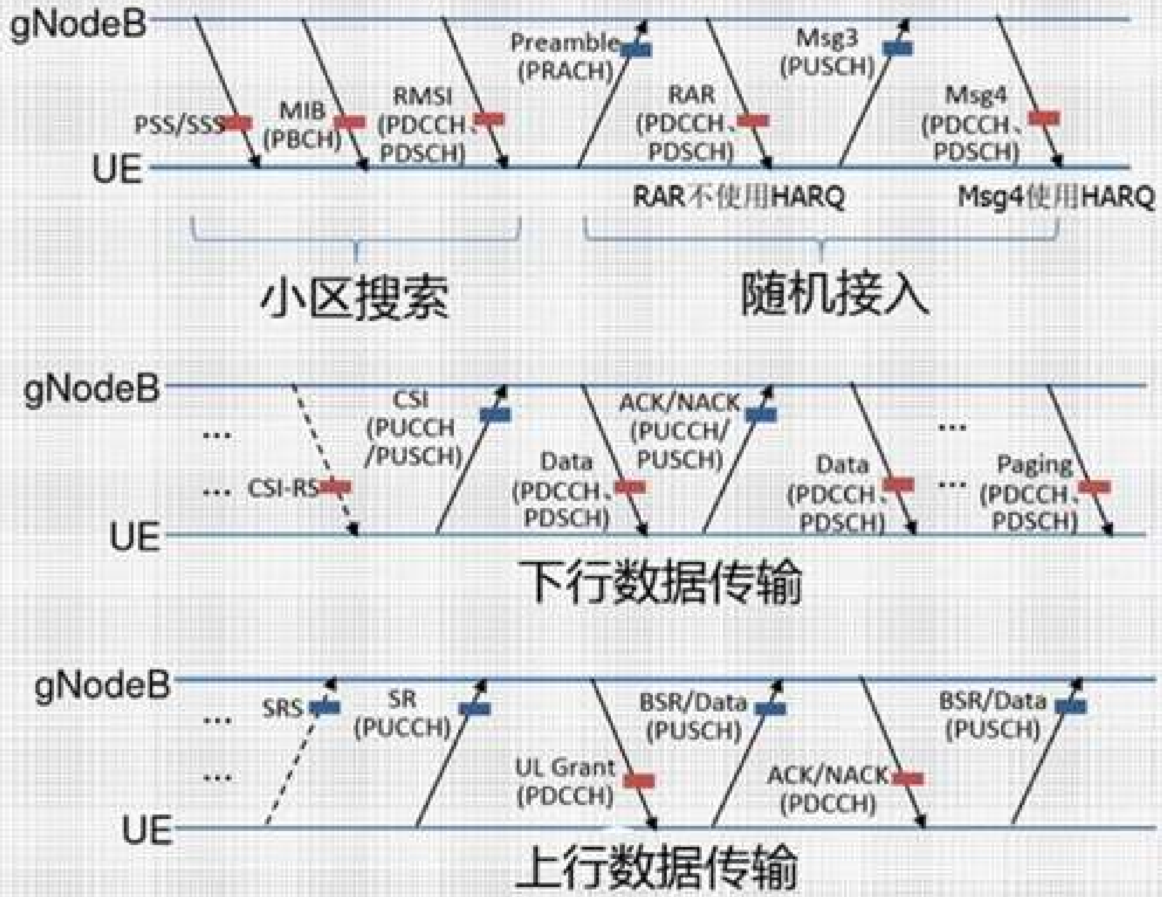
在每个**RB**资源块中，除了时域符号0-2之外，其他时频资源都可以用于PDSCH信道，传输业务数据。

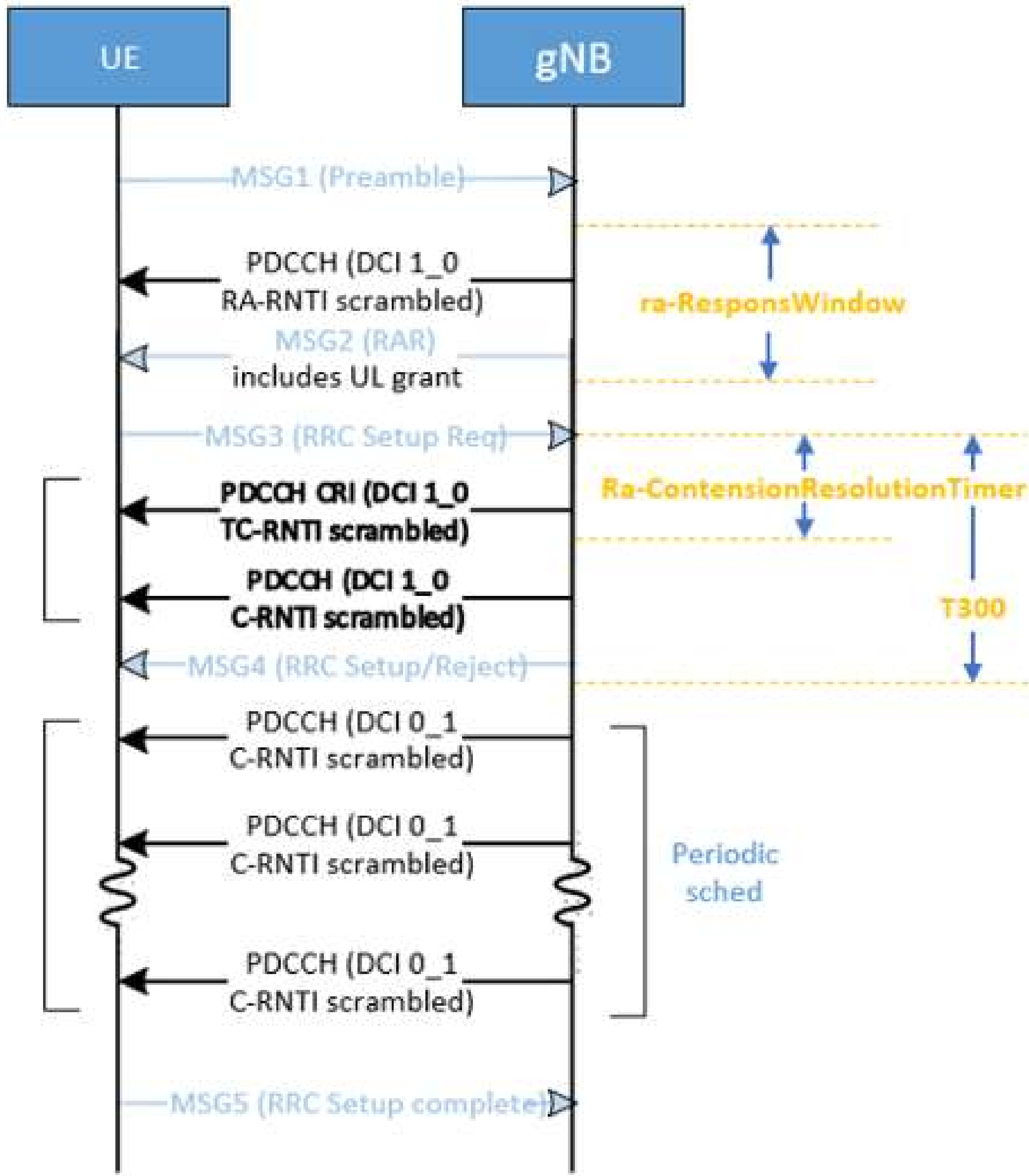
PDSCH信道与PDCCH在同一个子帧中，反应更加的及时。

- Transmission mode 1: Single-antenna transmission.
- Transmission mode 2: Transmit diversity.
- Transmission mode 3: Open-loop codebook-based precoding in the case of more than one layer, transmit diversity in the case of rank-one transmission.
- Transmission mode 4: Closed-loop codebook-based precoding.
- Transmission mode 5: Multi-user-MIMO version of transmission mode 4.
- Transmission mode 6: Special case of closed-loop codebook-based precoding limited to single layer transmission.
- Transmission mode 7: Release-8 non-codebook-based precoding supporting only single-layer transmission.
- Transmission mode 8: Release-9 non-codebook-based precoding supporting up to two layers.
- Transmission mode 9: Release-10 non-codebook-based precoding supporting up to eight layers.


One or two transport block(s) of
dynamic size delivered from the MAC layer
CRC insertion per transport block
CRC
CRC
Code-block segmentation including
possible per-code-block CRC insertion
Segmentation
Segmentation
Channel coding (Turbo coding)
Coding
Coding
Rate matching and
physical-layer hybrid ARQ functionality
RM + HARQ
RM + HARQ
Bit-level scrambling
Scrambling
Scrambling
Data modulation
(QPSK, 16QAM, 64QAM)
Modulation
Modulation
Antenna mapping
Antenna mapping
Up to eight antenna ports
Mapping to OFDM time–frequency grid
for each antenna port

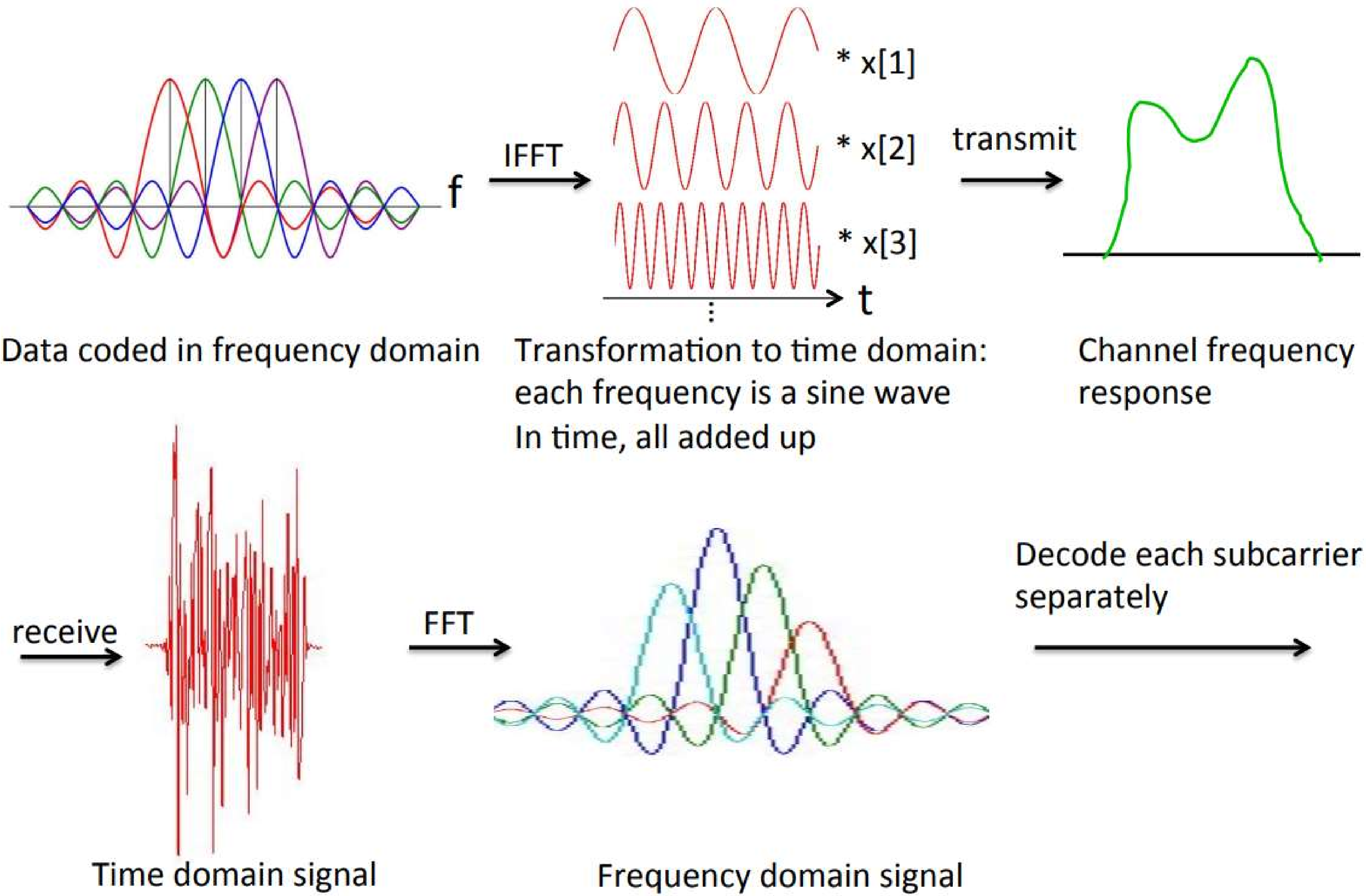
- **小区搜索涉及的物理信道**
  - PSS/SSS -> PBCH -> PDCCH -> PDSCH
- **随机接入涉及的物理信道**
  - PRACH -> PDCCH -> PDSCH -> PUSCH
- **下行数据传输涉及的物理信道**
  - PDCCH -> PDSCH -> PUCCH/PUSCH
- **上行数据传输涉及的物理信道**
  - PUCCH -> PDCCH -> PUSCH





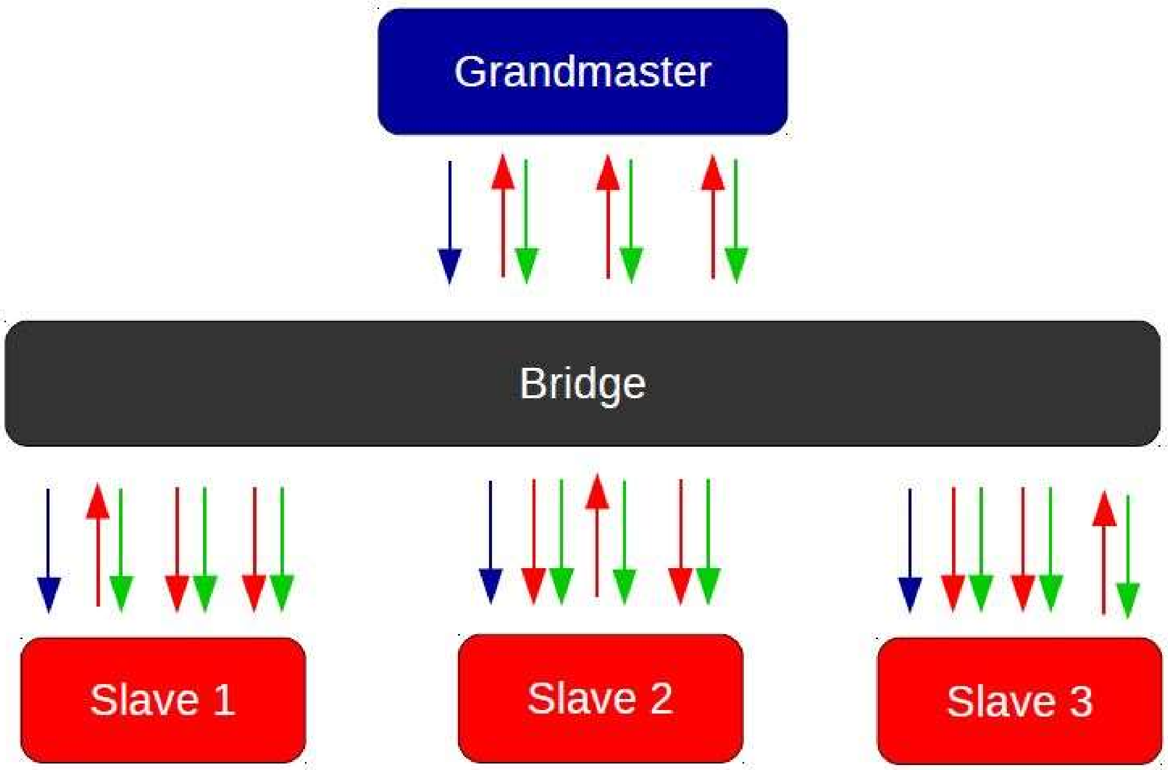
UE
gNB
MSG1 (Preamble)
PDCCH (DCI 1_0
RA-RNTI scrambled)
ra-ResponsWindow
MSG2 (RAR)
includes UL grant
MSG3 (RRC Setup Req)
PDCCH CRI (DCI 1_0
TC-RNTI scrambled)
Ra-ContensionResolutionTimer
PDCCH (DCI 1_0
C-RNTI scrambled)
T300
MSG4 (RRC Setup/Reject)
PDCCH (DCI 0_1
C-RNTI scrambled)
PDCCH (DCI 0_1
C-RNTI scrambled)
Periodic
sched
PDCCH (DCI 0_1
C-RNTI scrambled)
MSG5 (RRC Setup complete)

NRCellDU	rachRootSequence	First root sequence number for RACH preamble generation. Specification: 3GPP TS 38.211 Default: 1 Range: {0 .. 137}	
NRCellDU	preambleRecTargetPower	Target power level at network receiver side. Unit: 1 dBm Resolution: 2 Specification: 3GPP TS 38.331, 3GPP TS 38.321 Default: -110 Range: {-202 .. -60}	
NRCellDU	preambleTransMax	Maximum number of RA preamble transmissions performed before declaring a failure. Specification: 3GPP TS 38.331, 3GPP TS 38.322 Default: 10 Range: {3, 4, 5, 6, 7, 8, 10, 20, 50, 100, 200}	
Rrc	T300	UE timer to supervise response to RRC Connection Request. Provided to UE by SIB1. Unit: 1 ms Default: 1000 Range: {100, 200, 300, 400, 600, 1000, 1500, 2000}	



f
IFFT
* x[1]
* x[2]
* x[3]
t
transmit
Data coded in frequency domain
Transformation to time domain:
each frequency is a sine wave
In time, all added up
Channel frequency response
receive
FFT
Decode each subcarrier separately
Time domain signal
Frequency domain signal

PTP Topology



- *This diagram shows the timing messages exchanged among a grandmaster clock and three slave clocks using multicast end-to-end PTP. The bridge may be a transparent clock or a switch or router with no PTP capability. Color code: blue=Sync, red=delay request, green=delay response.*
    - The overhead on every slave is heavy

Question

- 為什麼由 DL 轉換到 UL 時，要有 GP
- 為什麼由 UL 轉換到 DL 時，不需 GP

- 由於基地台(eNode B, eNB)功率較強且為同步，若其同時由傳送模式(DL)轉成接收模式(UL)時，可能還會接收到別的Cell的eNB所傳而非手機端(User Equipment, UE)所須傳送的資料，為避免這種非所需資料的干擾，所以在DL→UL Subframe中間加一個含有GP的Special Subframe當作緩衝。
- 相較於eNB來說，UE的功率小了許多，UE自傳送模式(UL)轉成接收模式(DL)時，其訊號幾乎不會傳到隔壁Cell造成干擾，因此UL→DL Subframe時並沒有加入GP作為緩衝，但設計上仍會在UL Subframe最後一小段時間不傳送任何資料做較簡易的保護。