LTE PHY Spec.

Samsung Electronics

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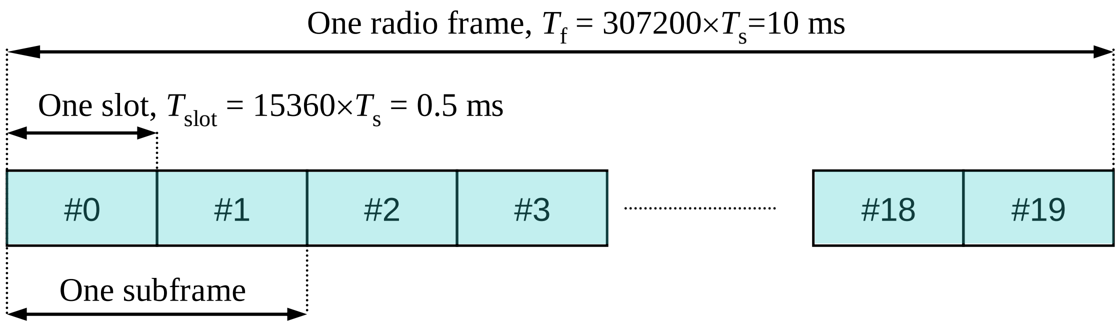
LTE L1 Specification

Downlink structure

Frame Structure

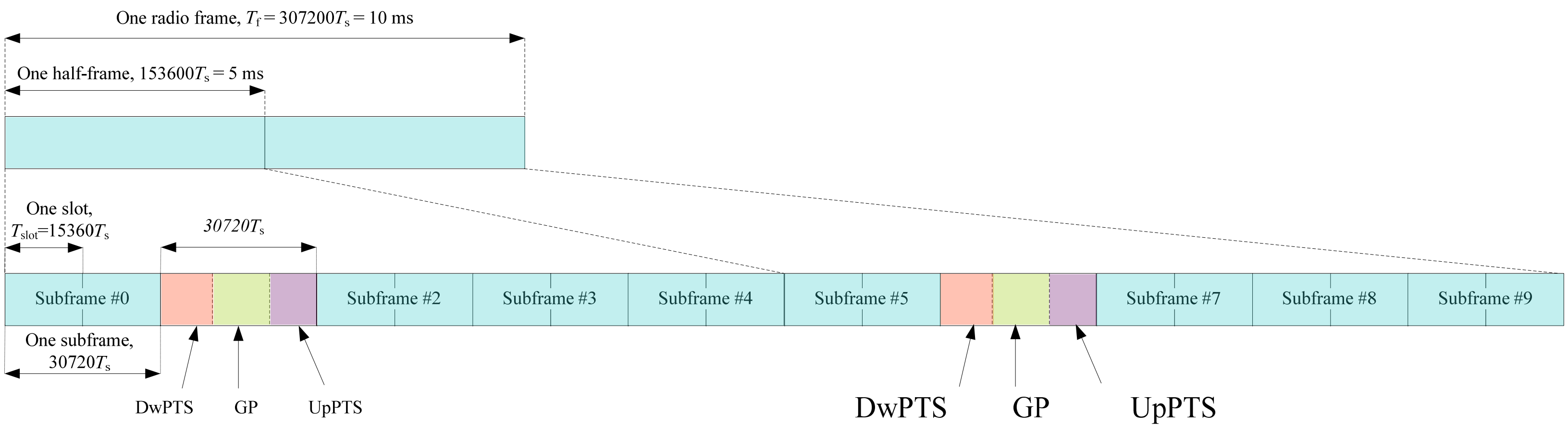
- Frame structure
  - Frame structure type 1
    - Applicable to FDD and half duplex FDD
    - Each radio frame is $T_f = 307200 \times T_s = 10\ \text{ms}$ long and consists of 20 slots of length $T_{slot} = 15360 \times T_s = 0.5\ \text{ms}$, numbered from 0 to 19($T_s = 1/(15000 \times 2048)$ seconds)



  - Frame structure type 2
    - Applicable to only TDD
    - Each radio frame consists of two half frame length $T_f = 153600 \times T_s = 5\ \text{ms}$ each and each half frame consists of 8 slots of length $T_{slot} = 15360 T_s = 0.5\ \text{ms}$ and

Frame Structure

– Frame structure type 2(Cont.)
- Three special fields, DwPTS, GP, and UpPTS in subframe #1 and #6
- Subframes 0 and 5 and DwPTS are always reserved for downlink transmission
- The lengths of DwPTS and UpPTS is given below subject to the total length of DwPTS, GP and UpPTS being equal to $30720 T_s = 1\,\text{ms}$
- Supported configurations of uplink-downlink subframe allocation are specified



Configuration	Normal cyclic prefix			Extended cyclic prefix		
	DwPTS	GP	UpPTS	DwPTS	GP	UpPTS
0	$6592 \cdot T_s$	$21936 \cdot T_s$	$2192 \cdot T_s$	$7680 \cdot T_s$	$20480 \cdot T_s$	$2560 \cdot T_s$
1	$19760 \cdot T_s$	$8768 \cdot T_s$		$20480 \cdot T_s$	$7680 \cdot T_s$	
2	$21952 \cdot T_s$	$6576 \cdot T_s$		$23040 \cdot T_s$	$5120 \cdot T_s$	
3	$24144 \cdot T_s$	$4384 \cdot T_s$		$25600 \cdot T_s$	$2560 \cdot T_s$	
4	$26336 \cdot T_s$	$2192 \cdot T_s$		$7680 \cdot T_s$	$17920 \cdot T_s$	$5120 \cdot T_s$
5	$6592 \cdot T_s$	$19744 \cdot T_s$	$4384 \cdot T_s$	$20480 \cdot T_s$	$5120 \cdot T_s$	
6	$19760 \cdot T_s$	$6576 \cdot T_s$		$23040 \cdot T_s$	$2560 \cdot T_s$	
7	$21952 \cdot T_s$	$4384 \cdot T_s$		-	-	-
8	$24144 \cdot T_s$	$2192 \cdot T_s$		-	-	-

Uplink-downlink allocations

Configuration	Switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	10 ms	D	S	U	U	U	D	S	U	U	D

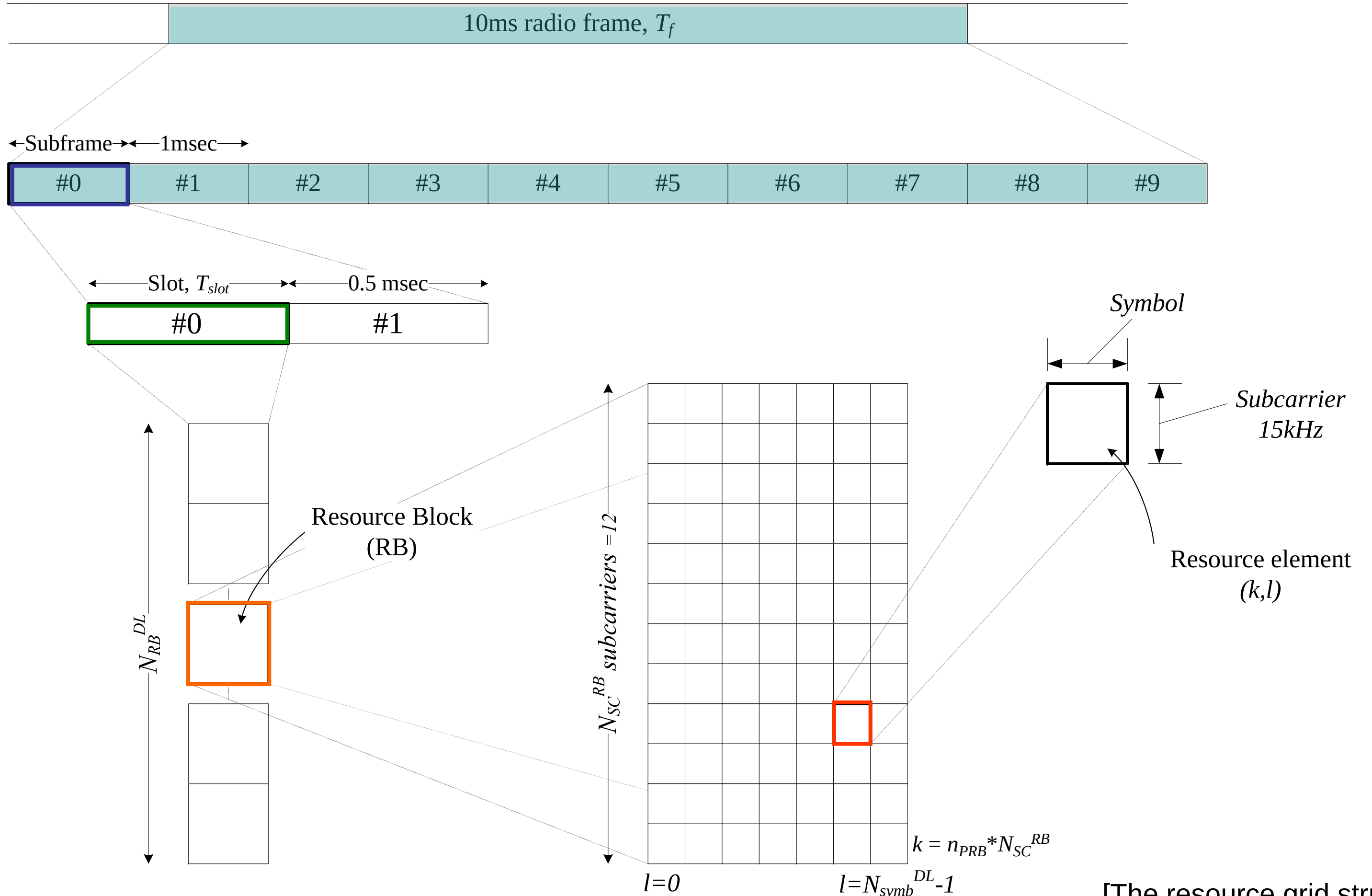
Downlink

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

- Physical signals
  - A set of Resource Elements NOT carrying information originating from higher layers
    - Reference signal
    - Synchronization signal

Resource Grid

- The transmitted signal in each slot is described by a resource grid of $N_{\mathrm{RB}}^{\mathrm{DL}} N_{\mathrm{sc}}^{\mathrm{RB}}$ subcarriers and $N_{\mathrm{symb}}^{\mathrm{DL}}$ OFDM symbols.



[The resource grid structure]

Resource Grid

- Physical resource block parameters
  - Number of symbols per slot

Configuration		RB size (number of sub-carriers)	Number of symbols per slot
Normal CP (15kHz)		12	7
Extended CP	15kHz		6
	7.5kHz	24	3

  - Number of RBs per Channel bandwidth [Ref. TS 36.104]

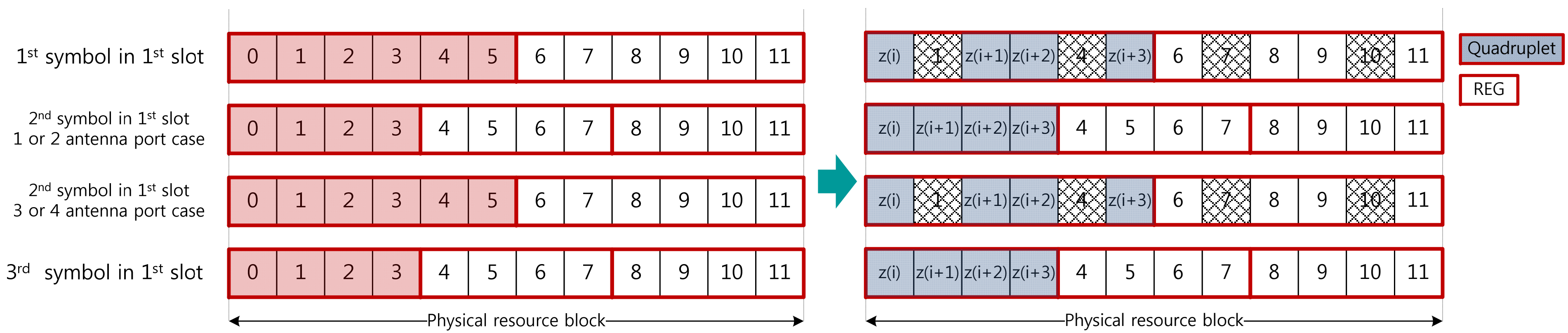
Channel bandwidth BWChannel [MHz]	1.4	3	5	10	15	20
FDD mode	6	15	25	50	75	100

Resource Grid

- In case of multi-antenna transmission,
  - There is one resource grid defined per antenna port.
  - An antenna port is defined by its associated reference signal.
  - The set of antenna ports supported depends on the reference signal configuration in the cell:
    - Cell-specific reference signals, associated with non-MBSFN transmission, support a configuration of one, two, or four antenna ports, i.e. the index , p, shall fulfil and $p=0$, $p=\{0, 1\}$, $p=\{0, 1, 2, 3\}$, respectively.
    - MBSFN reference signals, associated with MBSFN transmission, are transmitted on antenna port $p=4$.
    - UE-specific reference signals, supported in frame structure type 2 only, are transmitted on antenna port $p=5$.
  - Make sure that antenna port is not physical "Antenna"

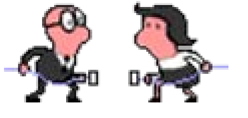
Resource Element Groups

- REGs (Resource element groups)
    - Basic RE mapping unit for downlink control information
    - Index pair of the resource element with the lowest index k in the group with all resource elements in the group having the same value of l
  - 1st symbol of 1 slot
    - Two REGs in PRB (k, l=0) with $k = k_0 + 0, k_0 + 1, \ldots, k_0 + 5$ and $k = k_0 + 6, k_0 + 7, \ldots, k_0 + 11$
  - 2nd symbol of 1 slot
    - 1 or 2 antenna port case: 3 REGs in PRB (k, l=1) with $k = k_0 + 0, k_0 + 1, \ldots, k_0 + 3$, $k = k_0 + 4, k_0 + 5, \ldots, k_0 + 7$, $k = k_0 + 8, k_0 + 9, \ldots, k_0 + 11$
    - 3 or 4 antenna port case: Same as 1st symbol of 1slot with l=1
  - 3rd symbol of 1 slot
    - Same as 1 or 2 antenna port case of 2nd symbol of 1st slot with l=2
- Mapping of symbol quadruplet $\langle z(i), z(i+1), z(i+2), z(i+3) \rangle$ onto a REG



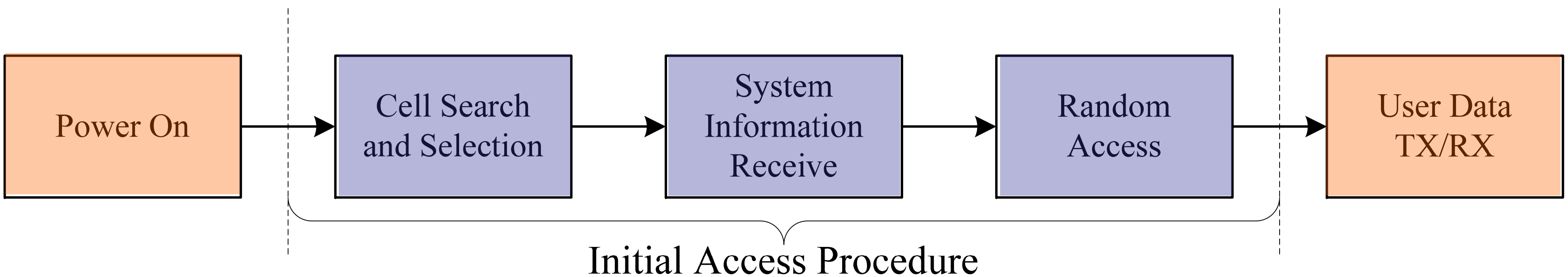
LTE L1 Specification

Initial Access



Initial Access

- Initial access procedure for LTE has three steps.
  - Cell Search
  - System Information Receive
  - Random Access



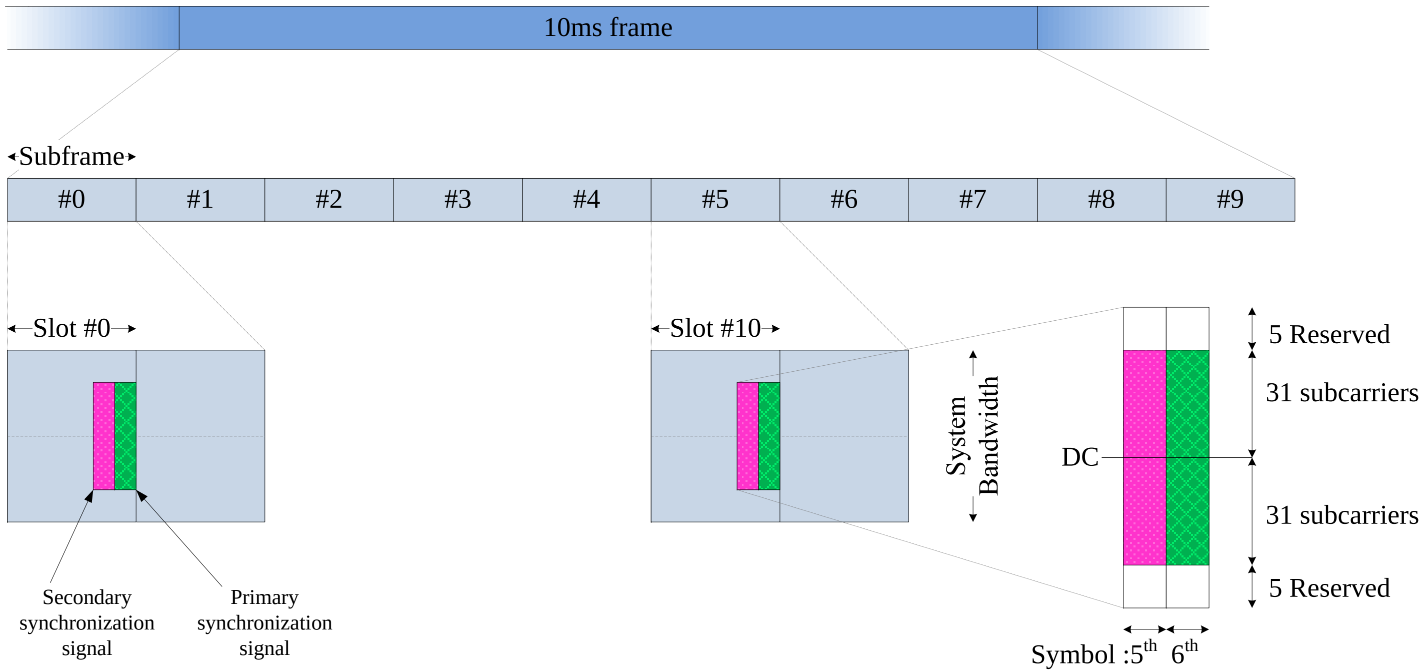
Cell search

- Cell search
  - Find a cell to connect and estimate frame timing
  - Provide the primary and secondary synchronization signals on the downlink to assist
  - Cell-specific sequences are inserted in synchronization signals
  - Support 504 unique physical-layer identities; N_{ID}^{cell} (168 unique physical-layer cell-identity groups; $N_{ID}^{(1)}$, each group containing three unique identities; $N_{ID}^{(2)}$)
- Physical-layer identity N_{ID}^{cell}

$$\boxed{N_{\mathrm{ID}}^{\mathrm{cell}} = 3N_{\mathrm{ID}}^{(1)} + N_{\mathrm{ID}}^{(2)}}$$

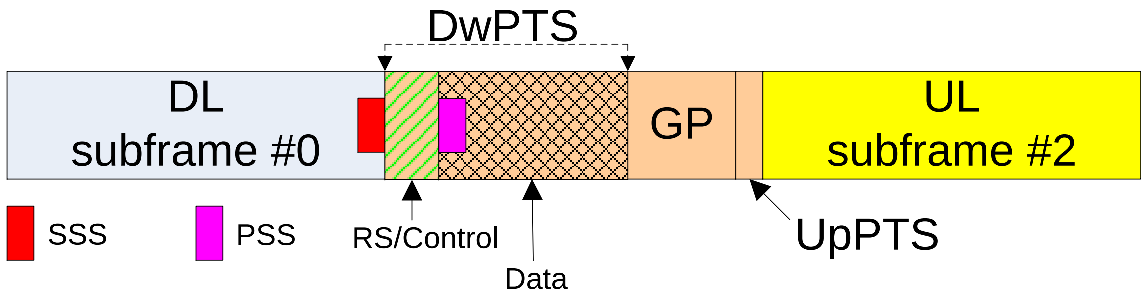
where $N_{\mathrm{ID}}^{(1)} = 0,\ldots,167$, and $N_{\mathrm{ID}}^{(2)} = 0,1,2$

Synchronization signals -FDD



- PSS
  - Using non-coherent detection, estimate 5msec timing and physical-layer identity
  - Channel estimation information for SSS
- SSS
  - Physical-layer identity (Cell ID) is obtained
  - Mapped to one of 168 cell ID groups (168 ID groups for 504 Cell IDs)
  - Radio-frame timing (10msec) identification
  - Max # of hypotheses;336 hypotheses (2x168: 2 for half frame, 168 for ID groups)
  - Can be detect RS structure information from SSS and PSS

Synchronization signals -TDD



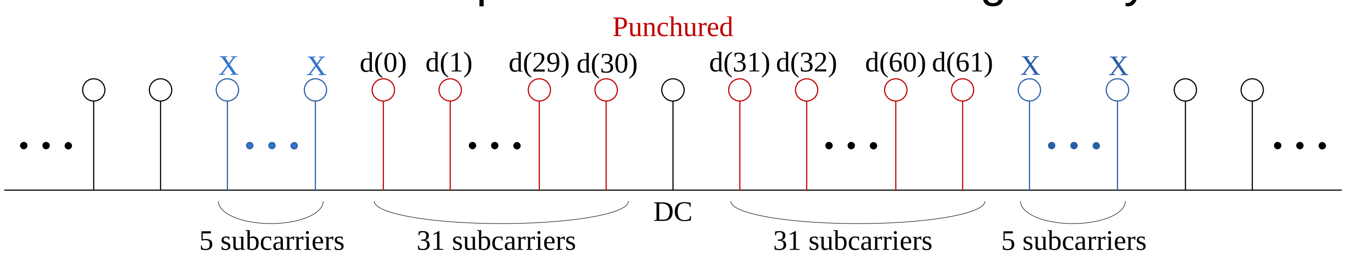
- DwPTS and Location of PSS and SSS
  - P-SCH is always transmitted in the 3rd OFDM symbol of DwPTS (subframes 1 and 6)
  - PDCCH in DwPTS (subframes 1 and 6) may span 1 or 2 OFDM symbols
  - Data is transmitted after the control region as in other DL subframes
  - Same cell specific RS patterns as in other DL subframes,
    - RS in GP are muted
- UpPTS
  - SRS transmission on UpPTS
    - Agreement on 1 SRS symbol in UpPTS.
    - Discuss further whether 2 SRS symbols in UpPTS.

Primary synchronization signal (PSS)

- Primary synchronization signal
  - Mapping of sequence is occupied 72REs in the last symbol in slot 0 and 10
  - The sequence is selected from a set of three different sequences
    - ZC sequence length =63 and PSC sequence length =62 (excluding DC)
    - The root indices u are M=n_1, M=N-n_1, M=n_2 (N=63, n_1=29, n_2=25, N-n_1=34)
    - The 32nd sample is punctured
    - Leave the remaining 10 subcarriers reserved

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

  - Partial information of reference signal configuration
  - Same synchronization structure regardless of system bandwidth
  - Identical cell search is possible without knowing the system BW



Secondary synchronization signal (SSS)

- Same frequency and slot allocation but 1 symbol prior to PSS
- Sequence generation: Combination of M-sequence based code
  - Generate a set of 31 sequences obtained as cyclic shifts of a single length 31 M-sequence generated from the primitive polynomial x^5+x^2+1 over GF(2)
  - Two short SSS codes($S_0^{(m_0)}$, $S_1^{(m_1)}$) selected from above set with m_0, m_1 cyclic shifted using cell-identity group
  - First and second sequences shall be scrambled with a binary scrambling code ($C_0(n)$, $C_1(n)$) depending on the PSS
  - Scrambling of the second sequence with a binary scrambling code ($Z_1^{(m_0)}$, $Z_1^{(m_1)}$) corresponding to the cyclic shift values of the first sequence
  - Mapping sequences to REs

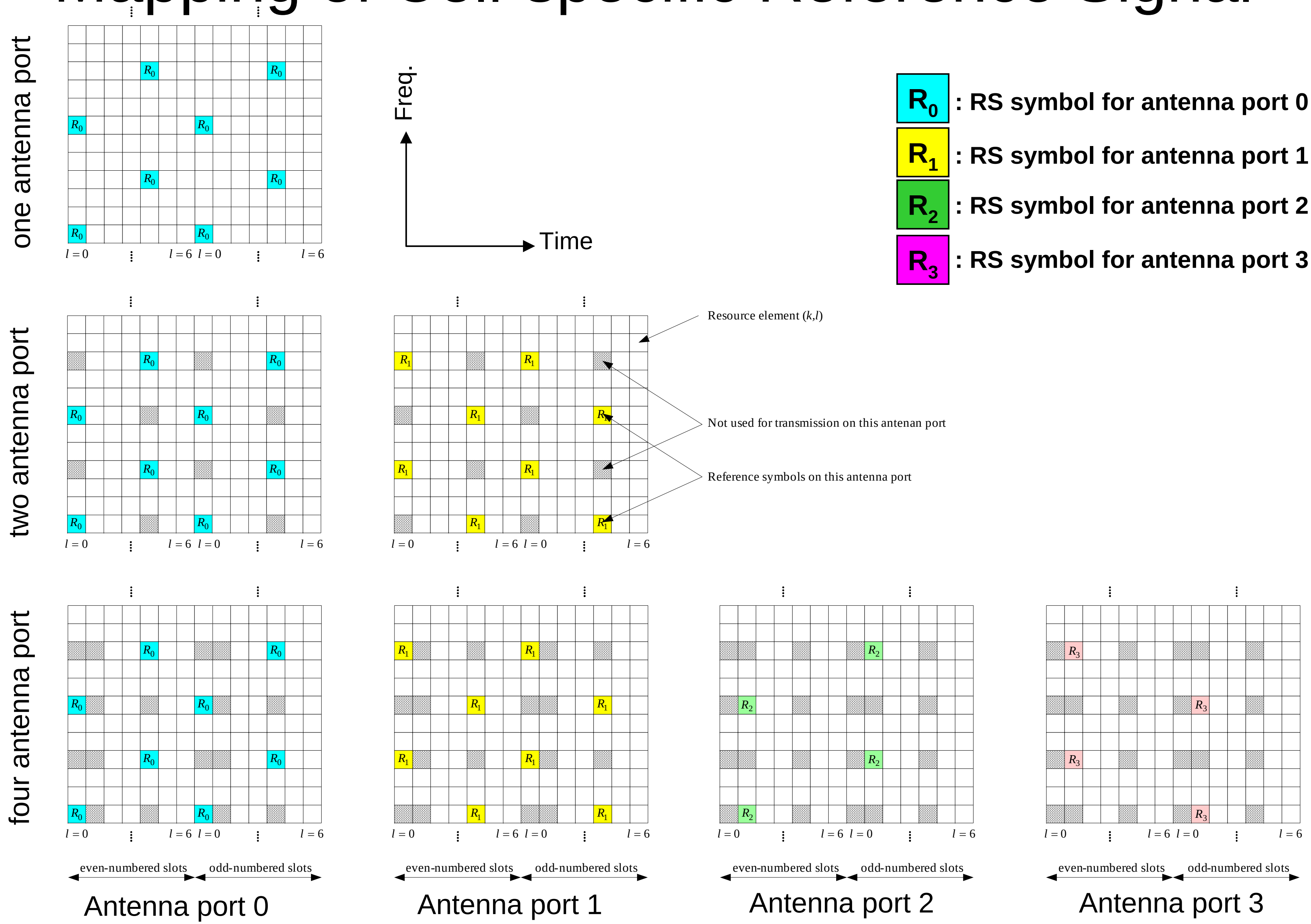
Even RE: $$d(2n) = \begin{cases} s_0^{(m_0)}(n)c_0(n) & \text{in slot } 0 \\ s_1^{(m_1)}(n)c_0(n) & \text{in slot } 10 \end{cases}$$

Odd RE: $$d(2n+1) = \begin{cases} s_1^{(m_1)}(n)c_1(n)z_1^{(m_0)}(n) & \text{in slot } 0 \\ s_0^{(m_0)}(n)c_1(n)z_1^{(m_1)}(n) & \text{in slot } 10 \end{cases}$$

Downlink Reference Signal (RS)

- Three types of downlink reference signals are defined:
  - Cell-specific reference signals, associated with non-MBSFN transmission (unicast RS)
  - MBSFN reference signals, associated with MBSFN transmission
  - UE-specific reference signals (Dedicated RS)
- There is one reference signal transmitted per downlink antenna port.
- REs used for RS transmission on any of the antenna ports in a slot shall not be used

Mapping of Cell-specific Reference Signal



Cell-specific RS

- Sequence generation
  - A one-to-one mapping between the three identities within the physical- layer identity.

  - Reference sequences

$$\boxed{r_{l,n_s}(i) = \left(1 - 2 \cdot c(2i)\right) + j\left(1 - 2 \cdot c(2i+1)\right), \quad i = 0,1,\ldots,2N_{\mathrm{RB}}^{\max,\mathrm{DL}} - 1}$$

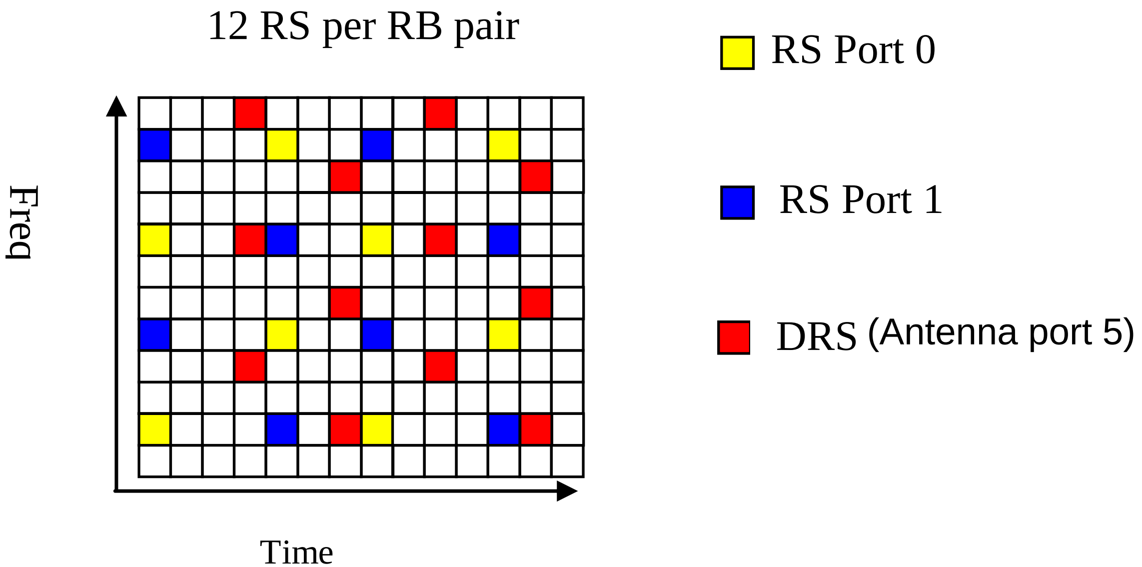
    - n_s is the slot number within a radio frame and l is the OFDM symbol number within the slot

  - Mapping to RE
    - Cell-specific cyclic shifting with physical-layer cell-identity groups

$$\boxed{v_{\mathrm{shift}} = N_{\mathrm{ID}}^{(1)} \bmod 6}$$

Dedicated RS

- Dedicated RS
  - DRS (antenna port 5) pattern for normal CP
    - DRS pattern with 12 DRS per RB pair
    - Support of DRS operation is a UE capability of FDD/TDD
    - DRS pattern for extended CP for 12 RS per RB: FFS
  - CQI estimation
    - CQI estimation (DL) is always based on Common RS (CRS)



[Dedicated RS with common RS]

System Information Receive

- PBCH
  - Master information block of system information is transmitted on Primary broadcast channel

- Dynamic BCH
  - After successful reception of PBCH, UE can read D-BCH in PDSCH (including PCFICH and PDCCH) which carries system information not including in PBCH

PBCH

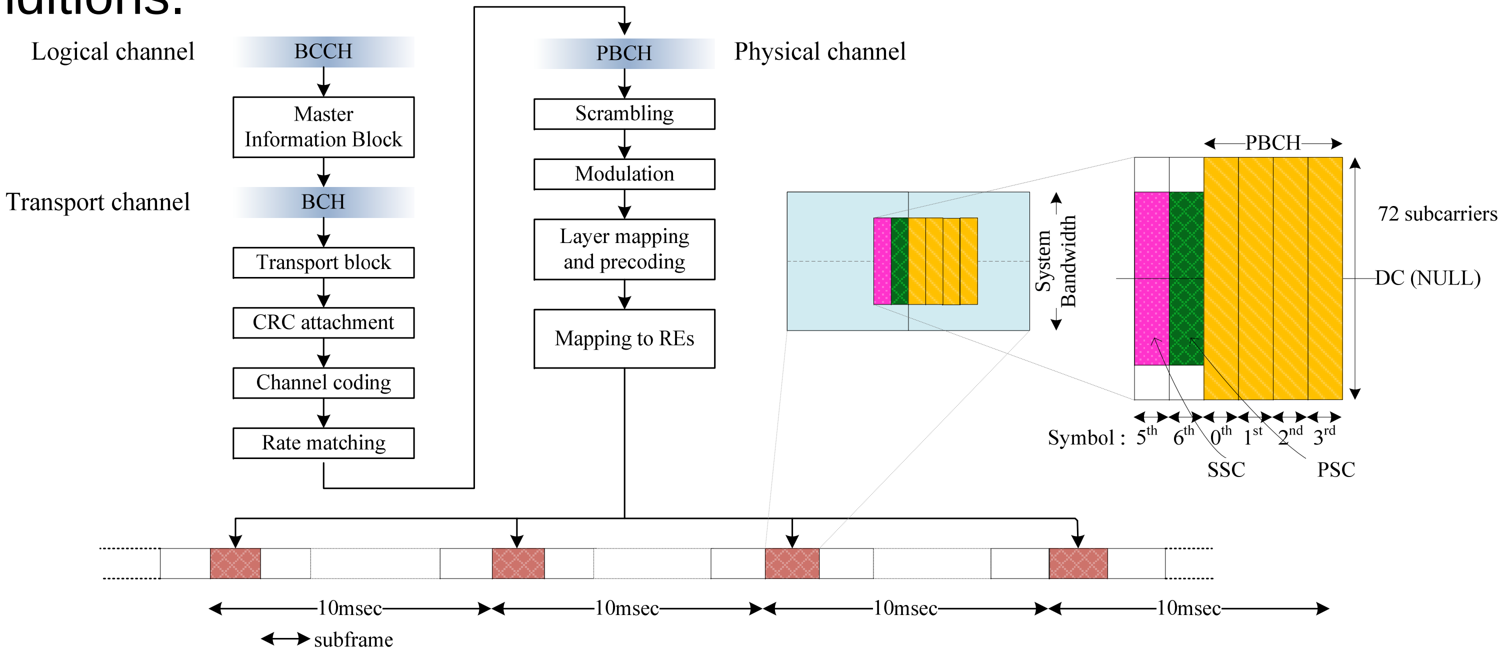
- PBCH
  - Master information block of system information is transmitted on Primary broadcast channel
- Cell-specific scrambled prior to modulation
- Modulation: QPSK
- Mapping to resource elements
  - Set of values for the RE index *k* is

$$k = \frac{N_{\mathrm{RB}}^{\mathrm{DL}} N_{\mathrm{sc}}^{\mathrm{RB}}}{2} - 36 + k', \qquad k' = 0,1,\ldots,71$$

  - Values for the symbol index is 0, 1, 2, 3 in slot 1 of subframe 0
- Including system information (RAN2 conclusions)
  - L1 parameters (e.g. DL system bandwidth, etc.)
  - System Frame Number (SFN)
  - PHICH duration (1 bit)
  - PHICH resource (2 bits)
  - FFS…

PBCH

- The coded BCH transport block is mapped to four subframes (subframe #0) within a 40 ms interval
- 40 ms timing is blindly detected, i.e. there is no explicit signaling indicating 40 ms timing.
- Coded BCH mapped to 4 OFDM symbols within a subframe
- Each subframe is assumed to be self-decodable, i.e the BCH can be decoded from a single reception, assuming sufficiently good channel conditions.



PBCH

- No explicit bits in the PBCH to signal the number of TX antennas at the eNB
- PBCH encoding chain includes CRC masking dependent on the number of configured TX antennas at the eNodeB
- PBCH is mapped into RE assuming RS from 4 antennas are used at the eNB transmitter, irrespective of the actual number of TX antenna

# of TX antennas	PBCH CRC Mask
1	<0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0>
2	<1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1>
4	<0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1>

- TX diversity scheme
  - 336 hypotheses on SSC, and SFBC based TX diversity scheme
    - For 2 TX antennas SFBC
    - For 4 TX antennas based on SFBC + FSTD
  - No antenna information carried on SSC for SFBC

PCFICH

- CCFI (Control format indication)
  - Information about the number of OFDM symbols (1, 2 or 3) used for transmission of PDCCHs in a subframe.
- PCFICH carries CCFI.
  - The number of bits: 32 bits
  - Cell-specific scrambling prior to modulation.
  - Modulation: QPSK
  - Mapping to resource elements: four groups of four contiguous REs not used for RS in the first OFDM symbol
    - Spread over the whole system bandwidth
    - Same mapping for 1, 2 and 4 antennas

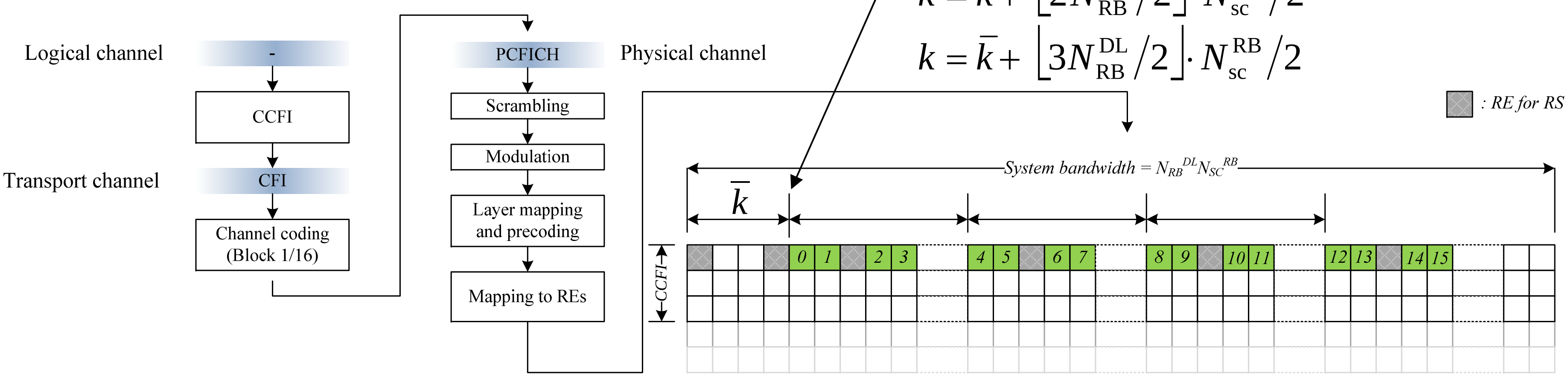
$$\bar{k} = \left(N_{\mathrm{sc}}^{\mathrm{RB}}/2\right)\cdot\left(N_{\mathrm{ID}}^{\mathrm{cell}} \bmod 2N_{\mathrm{RB}}^{\mathrm{DL}}\right)$$

$$k = \bar{k}$$

$$k = \bar{k} + \left\lfloor N_{\mathrm{RB}}^{\mathrm{DL}}/2 \right\rfloor \cdot N_{\mathrm{sc}}^{\mathrm{RB}}/2$$

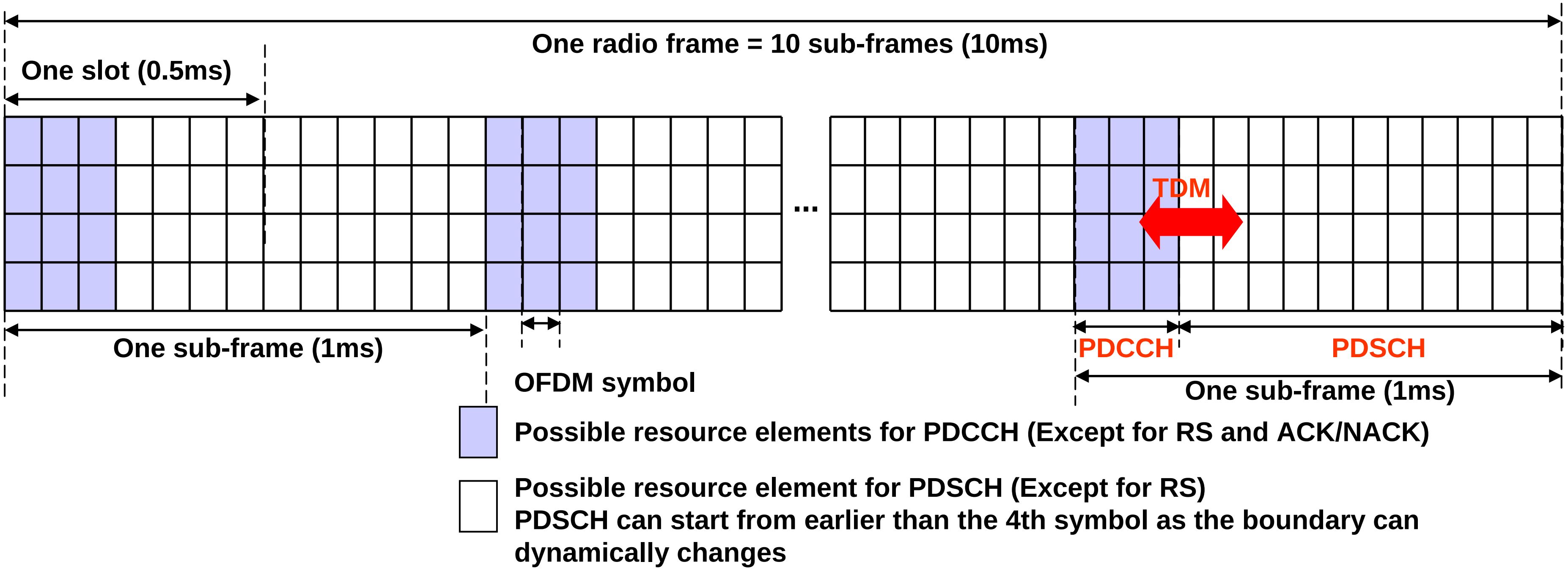
$$k = \bar{k} + \left\lfloor 2N_{\mathrm{RB}}^{\mathrm{DL}}/2 \right\rfloor \cdot N_{\mathrm{sc}}^{\mathrm{RB}}/2$$

$$k = \bar{k} + \left\lfloor 3N_{\mathrm{RB}}^{\mathrm{DL}}/2 \right\rfloor \cdot N_{\mathrm{sc}}^{\mathrm{RB}}/2$$



PDCCH

- The physical downlink control channel carries scheduling assignments
- A physical control channel is transmitted on an aggregation of one or several control channel elements, where a control channel element (CCE) corresponds to a set of resource elements
  - 1PDCCH = 1, 2, 4, 8 CCEs
  - 1 CCE = 9 REGs
- Multiple PDCCHs can be transmitted in a sub-frame
- The PDCCH supports multiple formats
- Maximum number of blind decoding for LTE_ACTIVE users is 44 in total

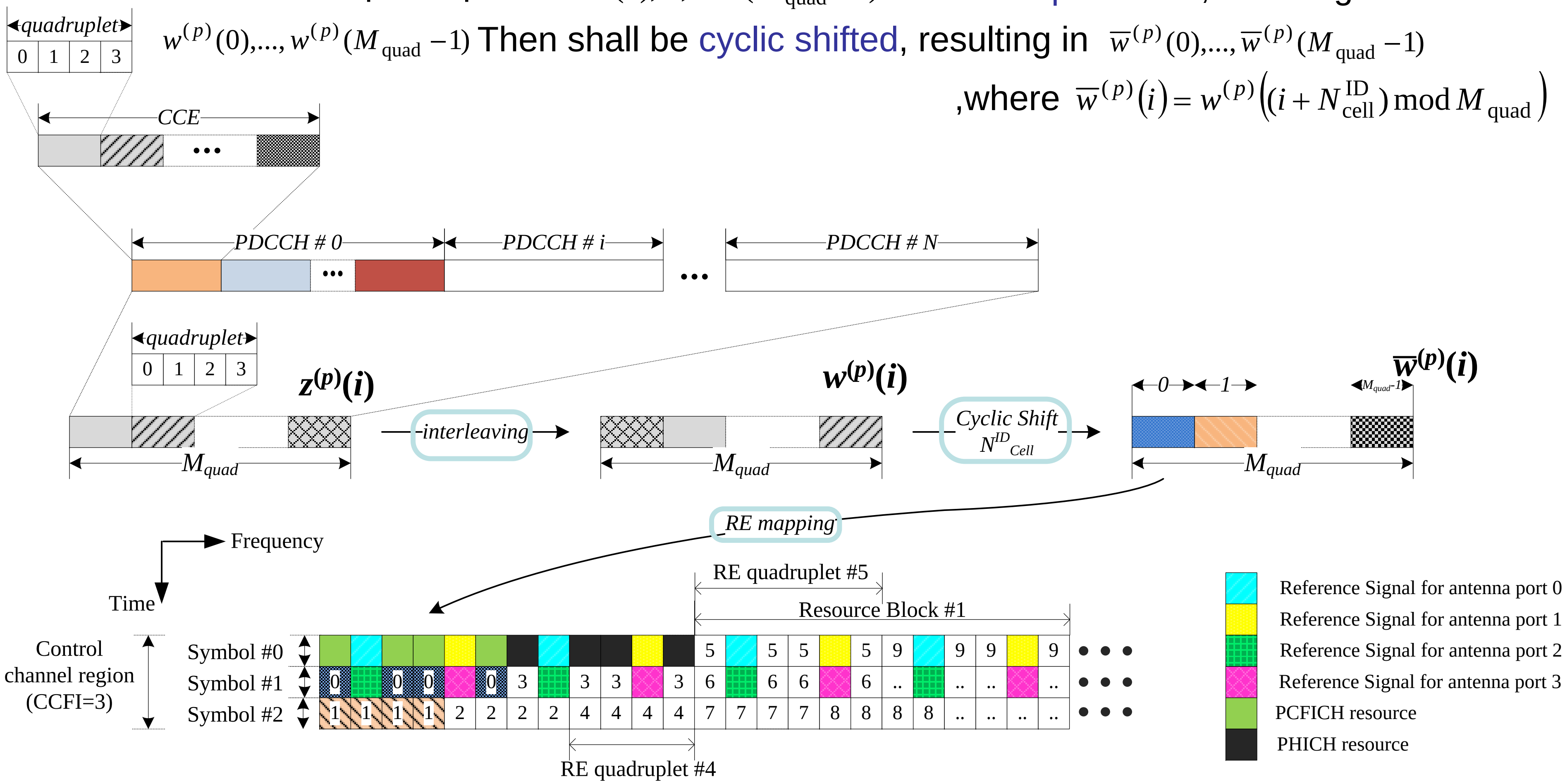


PDCCH

- Modulation: QPSK
- Mapping to resource elements

The block of quadruplets $z^{(p)}(0),\dots,z^{(p)}(M_{\text{quad}}-1)$ shall be permuted, resulting in $w^{(p)}(0),\dots,w^{(p)}(M_{\text{quad}}-1)$ Then shall be cyclic shifted, resulting in $\overline{w}^{(p)}(0),\dots,\overline{w}^{(p)}(M_{\text{quad}}-1)$

,where $\overline{w}^{(p)}(i)=w^{(p)}\left((i+N_{\text{cell}}^{\text{ID}}) \bmod M_{\text{quad}}\right)$

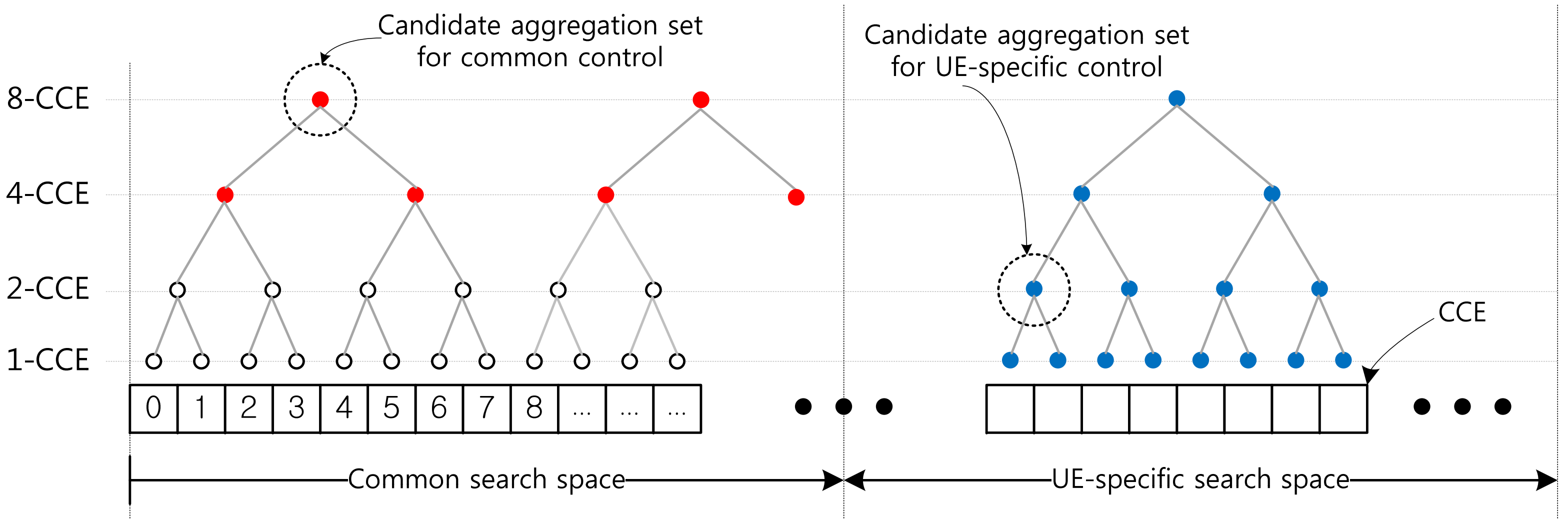


PDCCH

- DCI format [Detailed in TS36.212]
  - DCI format 0 is used for the transmission of UL-SCH assignments
  - DCI format 1 is used for the transmission of DL-SCH assignments for SIMO operation
  - DCI format 1A is used for a compact transmission of DL-SCH assignments for SIMO operation
  - DCI format 1B is used to support closed-loop single-rank transmission with possibly contiguous resource allocation
  - DCI format 1C is for downlink transmission of paging, RACH response and dynamic BCCH scheduling
  - DCI format 2 is used for the transmission of DL-SCH assignments for MIMO operation
  - DCI format 3 is used for the transmission of TPC commands for PUCCH and PUSCH with 2-bit power adjustments
  - DCI format 3A is used for the transmission of TPC commands for PUCCH and PUSCH with single bit power adjustments

PDCCH

- Aggregation of CCE
  - Tree-based aggregation with 1, 2, 4, 8 CCE
    - 1-CCE start on any CCE position (i=0,1,2,3,4,...)
    - 2-CCE every second location (i=0,2,4,6,...)
    - 4-CCE on every fourth (i=0, 4, 8, ...)
    - 8-CCE on every eight position (i=0, 8, ...)
  - The number of available CCEs in a cell depends on
    - Semi-static: bandwidth, #antenna ports, PHICH conf, ...
    - Dynamic: PCFICH value



PDCCH

- Common search space
  - Common search space corresponds to CCEs 0-15 (four decoding candidates on level-4, CCEs 0-3, 4-7, 8-11, 12-15 and two decoding candidates on level-8, CCEs 0-7, 8-15
  - Monitored by all UEs in the cell
  - Can be used for any PDCCH signalling (not restricted to ’common’ PDCCH, can be used to resolve ’blocking’)
    - Format 1C
    - Format 0/1A/3A
  - May overlap with UE-specific search space
  - Aggregation levels
    - 4-CCE and 8-CCE
  - Number of blind decodes spent on common search space = 12

PDCCH

- UE-specific search space
  - 32 blind decoding attempts
  - Aggregation levels 1, 2, 4, 8
  - Decoding attempts per payload size (assuming 2 payload sizes per aggregation level)
    - 6 decoding attempts of 1-CCE aggregation
    - 6 decoding attempts of 2-CCE aggregation
    - 2 decoding attempts of 4-CCE aggregation
    - 2 decoding attempts of 8-CCE aggregation
    - FFS if the above can be changed with RRC signalling (max 2 configurations in total)
  - DCI formats, semi-static configuration of one of the alternatives
    - 0/1A, 1 (”non-spatial-multiplexing”)
    - 0/1A, 2 (”spatial multiplexing”)
    - 0/1A, 1B(“rank-1 precoding”)

PDCCH

- Starting point of UE-specific search space to monitor given by ”hashing function”

  – Z_k=Y_k mod floor(N_{CCE}/L_{PDCCH})Input to hashing function
    - Z_k : PDCCH search space starting position in subframe #K for CCE aggregation level L_{PDCCH}
    - N_{CCE} : Number of CCEs in subframe #K
    - L_{PDCCH} : CCE aggregation Level

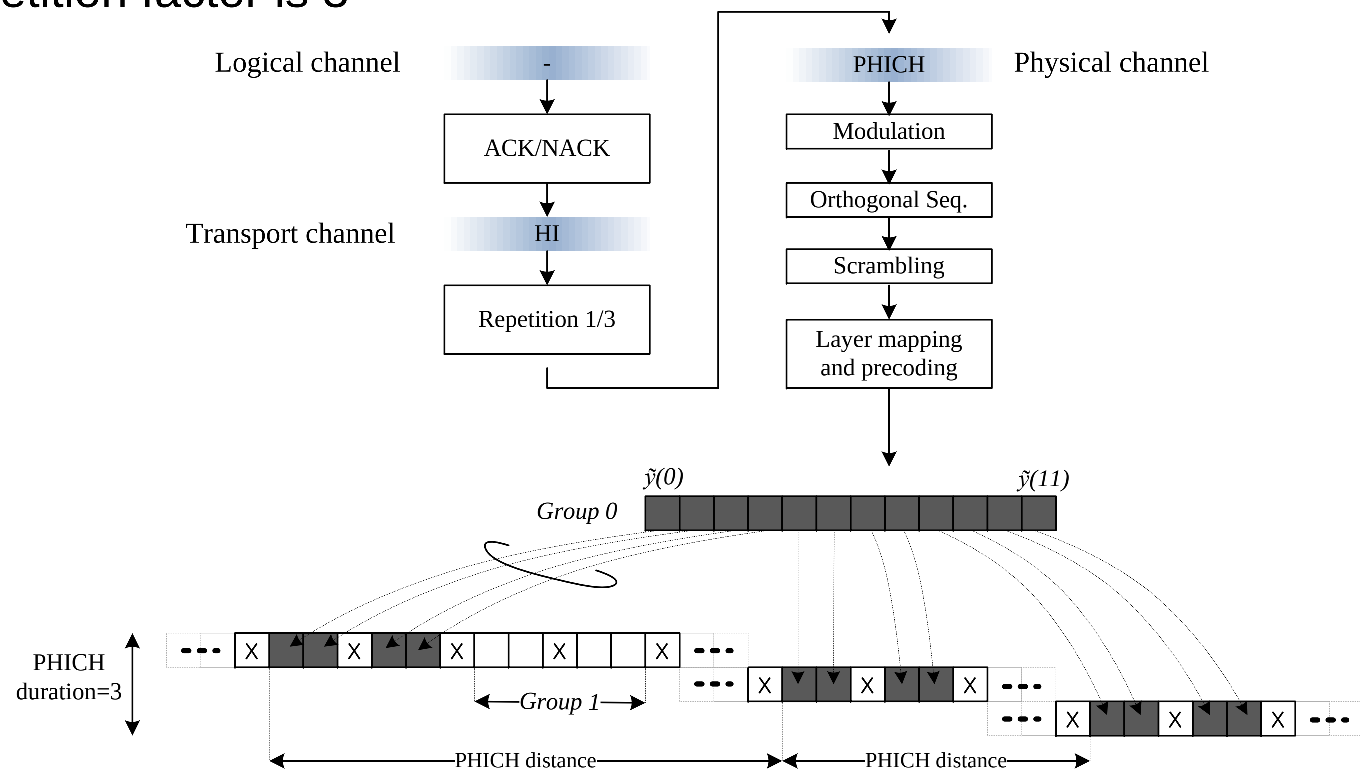
  – Y_K = A*Y_{K-1} mod D, for K={1, 1, 2, …, 9}
    - Y-1 = {UE=ID}x=UE_ID*16 + subframe_number
    - All ‘0’ UE-ID forbidden
    - A=39827, D=65537

LTE L1 Specification

Downlink data transmission

PHICH

- PHICH carries the downlink hybrid-ARQ ACK/NACK
- PHICH group
  - 1 PHICH group = 8 PHICHs (Normal CP)
  - 1 PHICH group = 4 PHICHs (Extended CP)
- Repetition factor is 3



PHICH

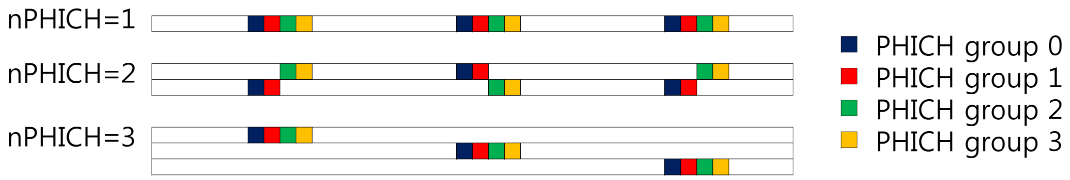
- The amount of PHICH resources signaled by 2 bits on PBCH
  - The four combinations on PBCHG correspond to the number N of PHICH groups as

$$N = \begin{cases} ceil\left[N_h (N_{\mathrm{RB}}^{\mathrm{DL}} / 8)\right] & \text{for normal CP} \\ 2 * ceil\left[N_h (N_{\mathrm{RB}}^{\mathrm{DL}} / 8)\right] & \text{for extended CP} \end{cases}$$

    - N_h is signalled on the PBCH as 1/6, ½, 1, or 2

PHICH

- PHICH mapping
  - Time and frequency location of PHICH



  - Cell specific mapping
    - Assigned resource-element group number $\bar{n}_i$ is given by below
    - *I* is PHICH index of PHICH group

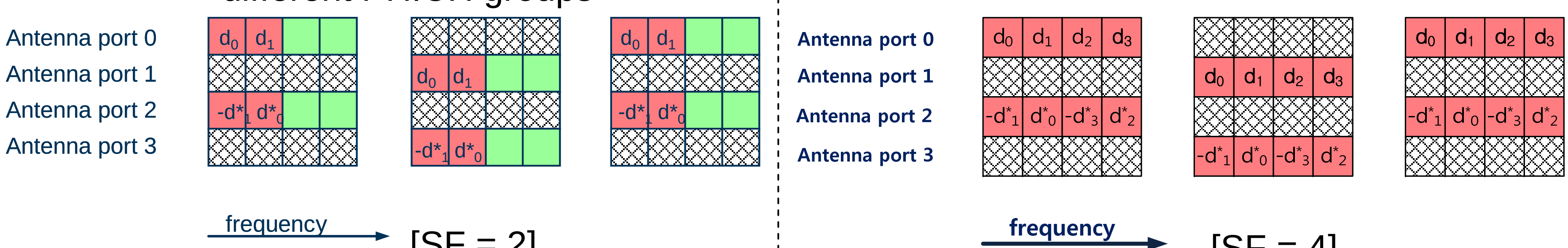
$$\bar{n}_i = \begin{cases} \left(\left\lfloor N_{ID}^{cell} \cdot n_{l_i'} / n_k \right\rfloor + m'\right) \bmod n_{l_i'} & i = 0 \\ \left(\left\lfloor N_{ID}^{cell} \cdot n_{l_i'} / n_k \right\rfloor + m' + \left\lfloor n_i' / 3 \right\rfloor\right) \bmod n_{l_i'} & i = 1 \\ \left(\left\lfloor N_{ID}^{cell} \cdot n_{l_i'} / n_k \right\rfloor + m' + \left\lfloor 2n_i' / 3 \right\rfloor\right) \bmod n_{l_i'} & i = 2 \end{cases}$$

PHICH

- Orthogonal sequence of SF = 4 for normal CP and SF =2 for extended CP case

Sequence index $n_{\mathrm{PHICH}}^{\mathrm{seq}}$	Orthogonal sequence: Normal cyclic prefix $N_{\mathrm{SF}}^{\mathrm{PHICH}}=4$	Orthogonal sequence: Extended cyclic prefix $N_{\mathrm{SF}}^{\mathrm{PHICH}}=2$
0	$[+1\ \ +1\ \ +1\ \ +1]$	$[+1\ \ +1]$
1	$[+1\ \ -1\ \ +1\ \ -1]$	$[+1\ \ -1]$
2	$[+1\ \ +1\ \ -1\ \ -1]$	$[+j\ \ +j]$
3	$[+1\ \ -1\ \ -1\ \ +1]$	$[+j\ \ -j]$
4	$[+j\ \ +j\ \ +j\ \ +j]$	-
5	$[+j\ \ -j\ \ +j\ \ -j]$	-
6	$[+j\ \ +j\ \ -j\ \ -j]$	-
7	$[+j\ \ -j\ \ -j\ \ +j]$	-

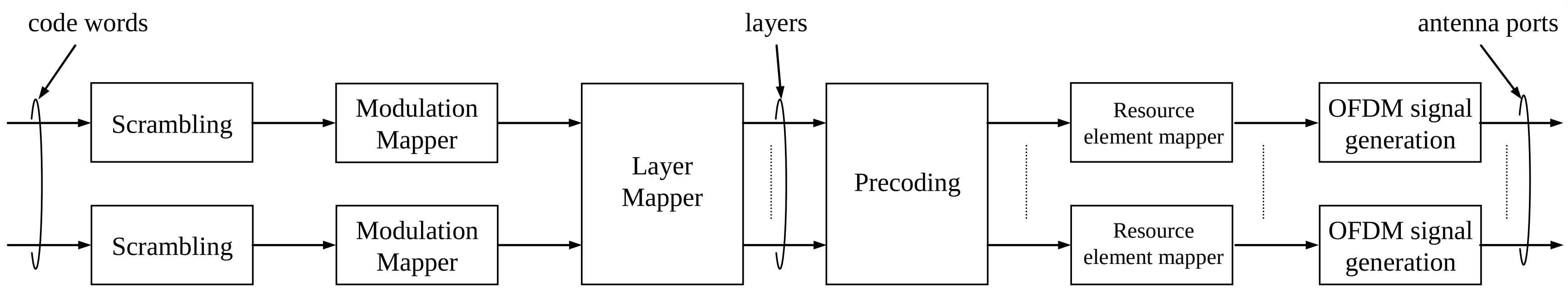
- Example of extended CP case (SF = 2) and TX=4 case
  – d_0 and d_1 represent the SF=2 spread ACK/NAK symbol, red and green are two different PHICH groups



[SF = 2] [SF = 4]

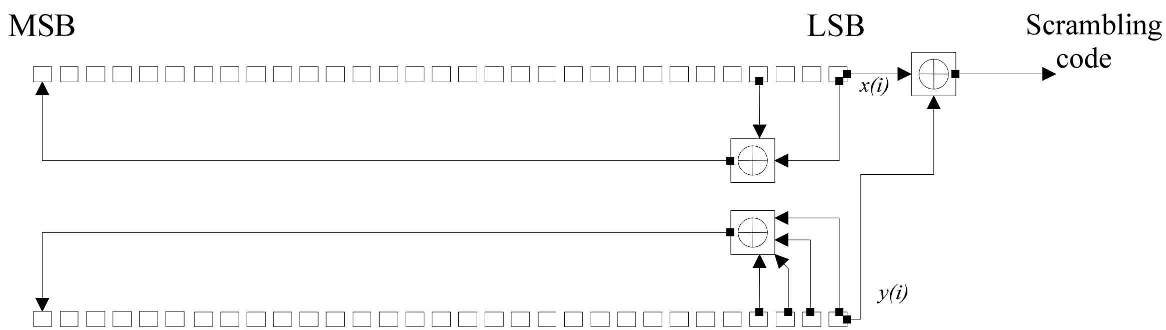
DL Physical Channel Processing

- The baseband signal representing a downlink physical channel is defined in terms of the following steps:
  - Scrambling of coded bits
  - Modulation of scrambled bits to generate complex-valued modulation symbols
  - Mapping of the complex-valued modulation symbols onto one or several transmission layers
  - Pre-coding of the complex-valued modulation symbols on each layer for transmission on the antenna ports
  - Mapping of complex-valued modulation symbols for each antenna port to resource elements
  - Generation of complex-valued time-domain OFDM signal for each antenna port



Scrambling

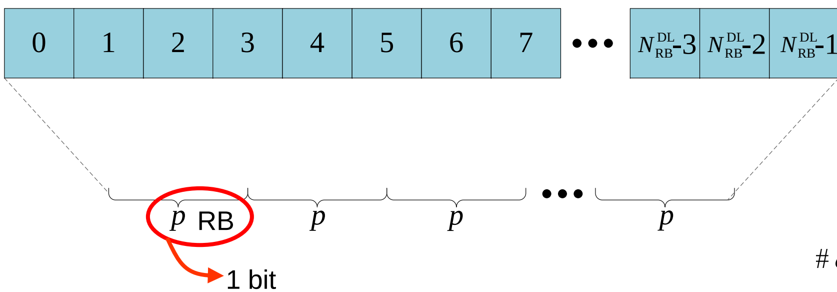
- Sequence generation
  - The scrambling sequence generator shall be initialised at the start of each subframe, where the initialisation value of c_{init}
- Generation register
  - Fill the top register with the following fixed pattern x(0)=1(MSB),and x(1)=…=x(30)=0.
  - Fill the lower register with the initialisation sequence based on below

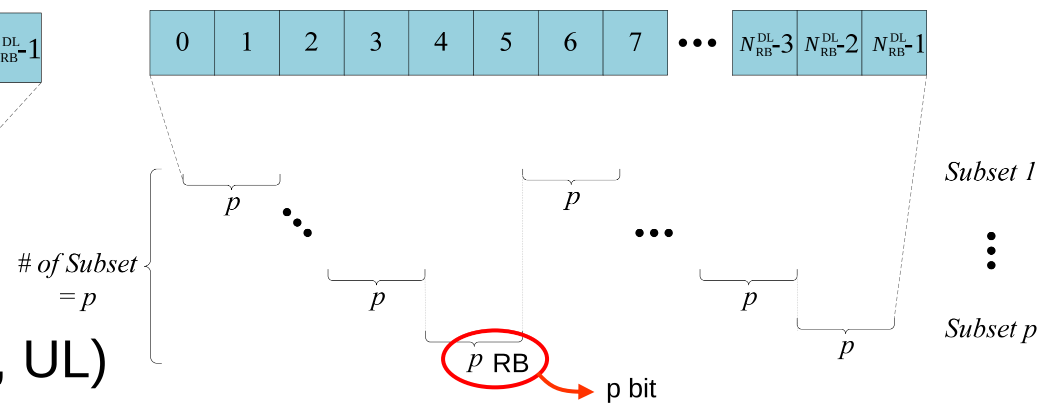


- PDSCH & PMCH: $c_{\mathrm{init}} = \begin{cases} n_{\mathrm{RNTI}} \cdot 2^{14} + q \cdot 2^{13} + \lfloor n_s/2 \rfloor \cdot 2^9 + N_{\mathrm{ID}}^{\mathrm{cell}} & \text{for PDSCH} \\ \lfloor n_s/2 \rfloor \cdot 2^9 + N_{\mathrm{ID}}^{\mathrm{MBSFN}} & \text{for PMCH} \end{cases}$
- PBCH: $c_{\mathrm{init}} = N_{\mathrm{ID}}^{\mathrm{cell}}$ (Re-initialization is performed every 4 subframes)
- PCFICH, PDCCH, PHICH: $c_{\mathrm{init}} = \lfloor n_s/2 \rfloor \cdot 2^9 + N_{\mathrm{ID}}^{\mathrm{cell}}$

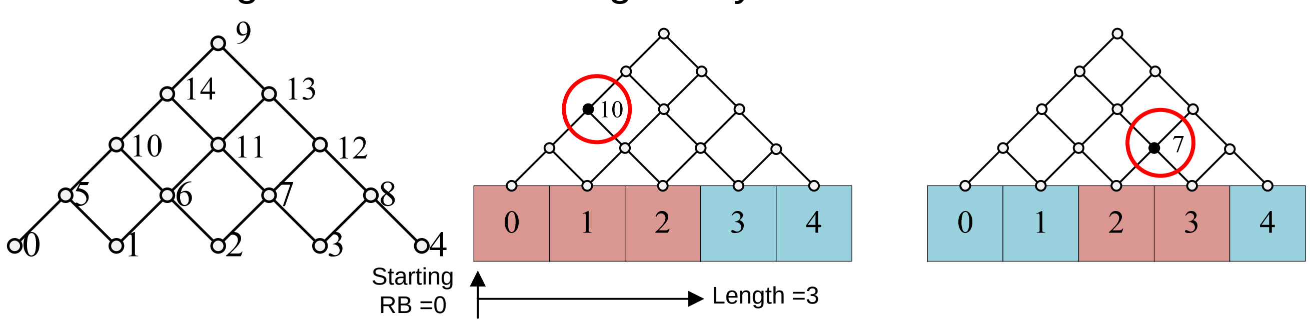
PDSCH

- Resource allocation of PDSCH [Detailed in TS36.213]
  - Non-compact assignment (DL only)
    - Bitmap approach 1 (Group-wise bitmap)
    - Bitmap approach 2 (bitmap within subset)





  - Compact assignment (DL, UL)
    - Resource indication value (RIV) corresponding to a starting resource block and a length in terms of contiguously allocated resource blocks



LTE L1 Specification

MBSFN

MBSFN Sub-frame Structure

Frequency domain in sub-carrier units

Sub-frame | Slot | Slot

R1	C	C	R2	C	C	R1	C	C	R2	C	C	R1	C	C	R2
R3	C	C	R4	C	C	R3	C	C	R4	C	C	R3	C	C	R4
MR	D	MR	D	MR	D	MR	D	MR	D	MR	D	MR	D	MR	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	MR	D	MR	D	MR	D	MR	D	MR	D	MR	D	MR	D	MR
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
MR	D	MR	D	MR	D	MR	D	MR	D	MR	D	MR	D	MR	D
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D

R0 : Unicast RS for antenna port 0

R1 : Unicast RS for antenna port 1

C : Unicast control

R2 : Unicast RS for antenna port 2

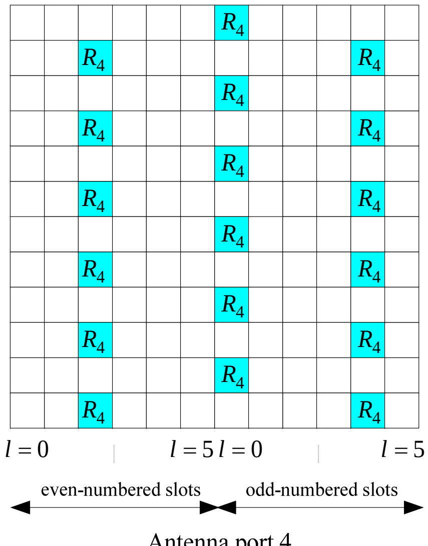
R3 : Unicast RS for antenna port 3

D : MBSFN data

MR : MBSFN RS for antenna port 4

MBSFN RS and PMCH

- RS structure for MBSFN(MBMS Single Frequency



Sub-frame for MBSFN transmission

➔ Adopt the unicast CP structure and RS sequence type for the first and second (in case it is a unicast one) symbol of MBSFN sub-frames

MBSFN data from different MBSFN areas are NOT multiplexed within the same sub-frame within a cell to avoid multiple MBSFN RSs

Sequence generation

$$r_{l,n_s}(i) = (1-2\cdot c(2i)) + j(1-2\cdot c(2i+1)), \quad i = 0,1,\ldots,6N_{\mathrm{RB}}^{\max,\mathrm{DL}}-1$$

– The pseudo-random sequence generator shall be initialised with

$$c_{\mathrm{init}} = 2^{13}\cdot l' + 2^{9}\cdot \lfloor n_s/2 \rfloor + N_{\mathrm{ID}}^{\mathrm{MBSFN}} + 1$$

at the start of each OFDM symbol where $l' = (n_s \bmod 2)\cdot N_{\mathrm{symb}}^{\mathrm{DL}} + l$ is the OFDM symbol number with a subframe

– PHICH duration in MBSFN subframes, semi-statically configured
  - Supported PHICH durations in MBSFN subframes: 1 and 2 OS

– No need to specify power boosting and frequency shifting

PCFICH and PMCH in MBSFN

- PCFICH
  - Transmit PCFICH in every subframe, including MBSFN subframes on mixed carrier
  - The PCFICH correctly reflects the control region, also in MBSFN sub frames.
  - The PCFICH value in MBSFN subframes shall be the same as the valu e provided by higher layers for MBSFN UEs

- PMCH
  - Only transmitted in sub-frames allocated for MBSFN transmissions
    - Only TDM on sub-frame basis of data transmission
  - Multiplexing of MBSFN and Non-MBSFN data
  - No transmit diversity for MBSFN and the transmission shall use antenna port 4
  - Not to transmitted in subframe 0 and 5 on a carrier supporting a mix of PDSCH and PMCH

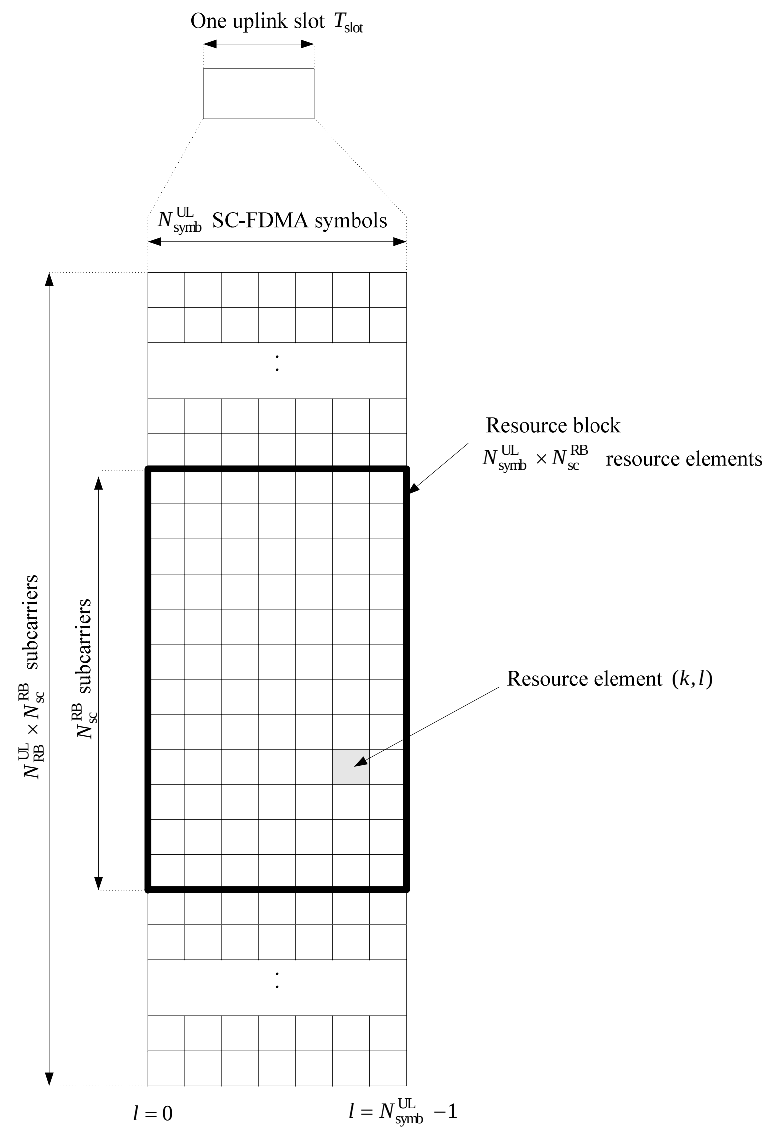
LTE L1 Specification

Uplink structure

Uplink Overview - Uplink Structure

- Slot structure and resource grid
  - The transmitted signal in each slot is described by
    - $N_{RB}^{UL} N_{sc}^{RB}$ subcarriers
    - N_{symb}^{UL} SC-FDMA symbols
  - Resource block (RB)
    - $N_{symb}^{UL} \times N_{sc}^{RB}$ resource elements (REs)
    - Corresponds to a slot and 180kHz
  - CP length is signaled by higher layers

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



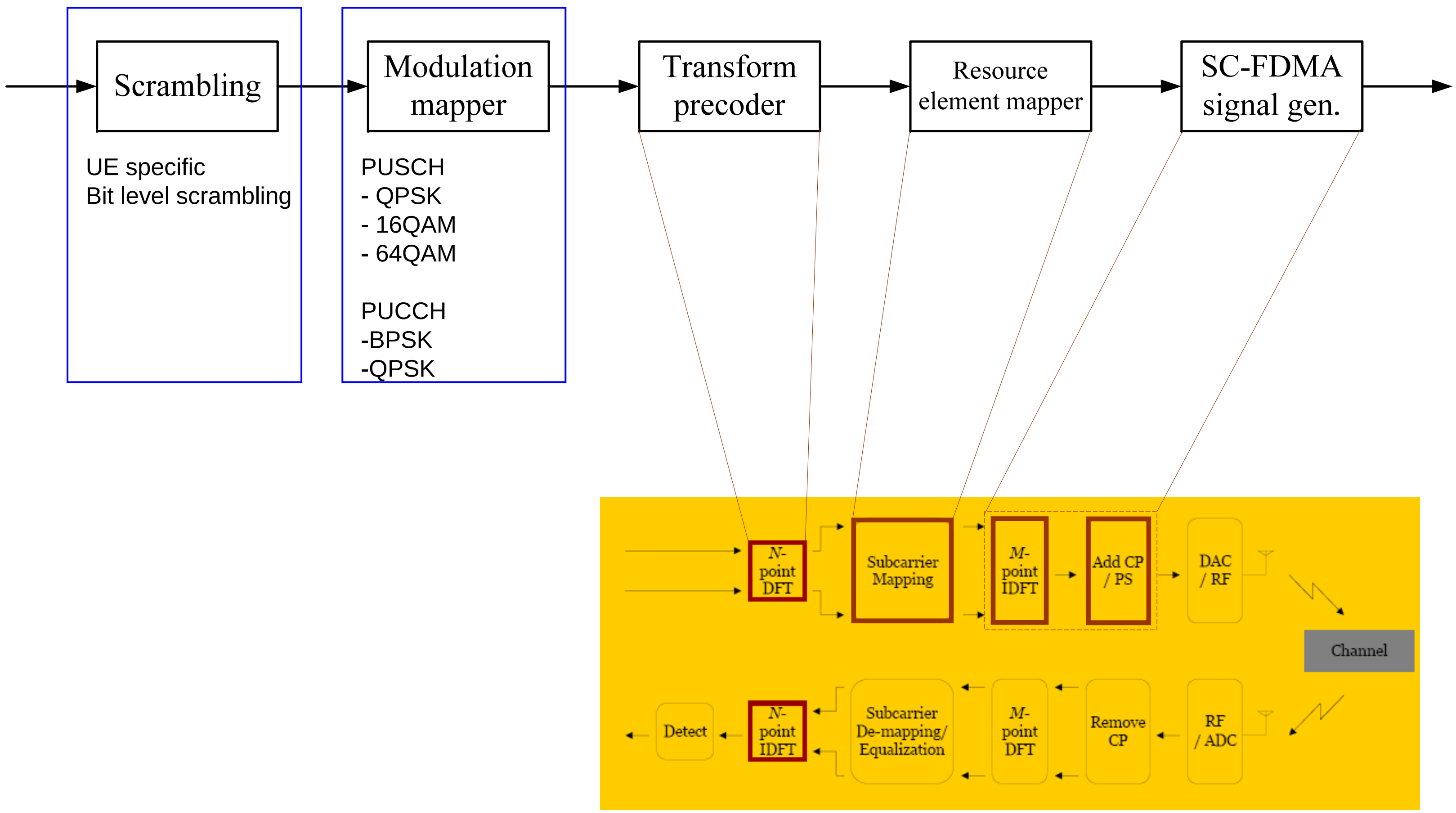
Uplink Overview - Uplink Physical Channels

- Physical channels
  - Physical Uplink Shared Channel (PUSCH)
    - Uplink data with localized transmission
      - Localized transmission w/o frequency hopping
      - Localized transmission with frequency hopping
    - Frequency hopping is available on both slot basis and subframe basis
  - Physical Uplink Control Channel (PUCCH)
    - ACK/NACK, CQI/PMI, SR transmission
    - PUCCH transmission
      - Via frequency bands towards both edges
      - Frequency hopping at the slot boundary
  - UCI transmission with PUSCH
    - CQI/PMI is multiplexed with PUSCH and mapped into PUSCH bands
    - ACK/NAK is multiplexed with PUSCH by puncturing the data
    - SR would be transmitted through RRC signalling (RAN2)
  - Physical Random Access Channel (PRACH)

- Physical Signals
  - Reference signal (RS)
    - Demodulation RS (DM RS)
    - Sounding RS (SRS)

PUSCH Processing

- SC-FDMA in uplink transmission
  - DM RS may be generated directly in frequency domain



Transform precoding

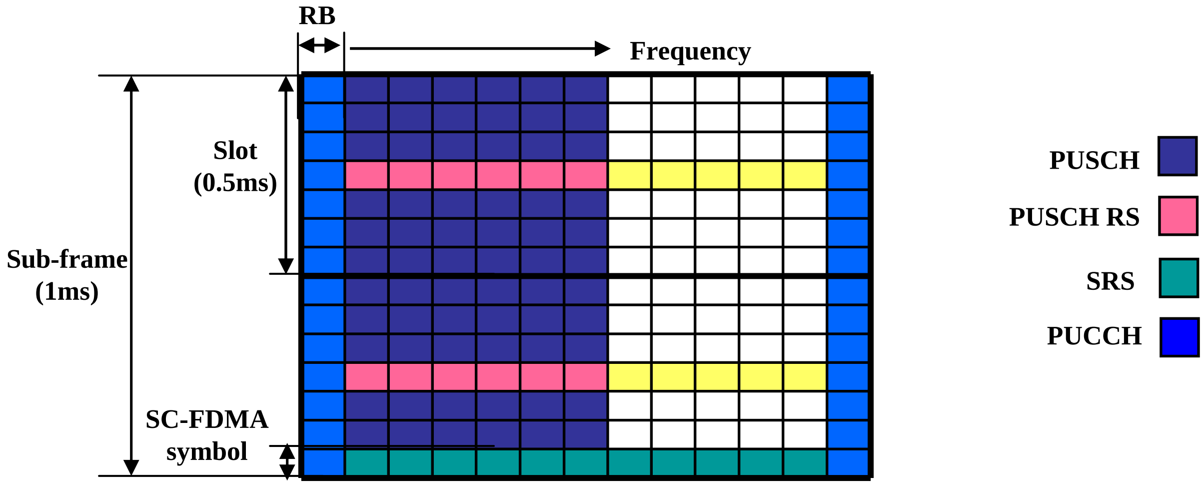
- The block of complex-valued symbols $d(0),\ldots,d(M_{\text{symb}}-1)$
- $M_{\text{sc}}^{\text{PUSCH}}$ represents the number of scheduled subcarriers used for PUSCH transmission in an SC-FDMA symbol

$$M_{\text{sc}}^{\text{PUSCH}} = N_{\text{sc}}^{\text{RB}} \cdot 2^{\alpha_2} \cdot 3^{\alpha_3} \cdot 5^{\alpha_5} \le N_{\text{sc}}^{\text{RB}} \cdot N_{\text{RB}}^{\text{UL}}$$

$$z(l \cdot M_{\text{sc}}^{\text{PUSCH}} + k) = \frac{1}{\sqrt{M_{\text{sc}}^{\text{PUSCH}}}} \sum_{i=0}^{M_{\text{sc}}^{\text{PUSCH}}-1} d(l \cdot M_{\text{sc}}^{\text{PUSCH}} + i) e^{-j\frac{2\pi ik}{M_{\text{sc}}^{\text{PUSCH}}}}$$

$$k = 0,\ldots, M_{\text{sc}}^{\text{PUSCH}} - 1$$

$$l = 0,\ldots, M_{\text{symb}} \big/ M_{\text{sc}}^{\text{PUSCH}} - 1$$



One example configuration for normal CP

- PUSCH transmission
  - 1 bit indication in UL grant whether frequency hopping or not
  - Localized transmission w/o frequency hopping
  - Localized transmission with frequency hopping
    - Hopping based on the hopping information in UL grant
    - Hopping according to a predefined hopping pattern

- Inter/Intra Subframe PUSCH Hopping
  - Set of PRBs to be used for transmission are given by UL scheduling grant
    - If hopping with predefined hopping pattern is enabled, a predefined pattern is used
  - When grant is absent, e.g., in cases of persistent scheduling and HARQ retransmission, UE follows the indication for hopping mode in the initial grant
  - A single bit signaled by higher layers indicates whether PUSCH frequency hopping is inter-subframe only or both intra and inter-subframe

PUSCH Hopping

- Example for predefined hopping for PUSCH with 20 RBs and M=4

PRB index	$f_{hop}(i)=0$, $f_m(i)=0$ (i=0)	$f_{hop}(i)=1$, $f_m(i)=0$ (i=8)	$f_{hop}(i)=3$, $f_m(i)=1$ (i=16)	$f_{hop}(i)=2$, $f_m(i)=0$ (i=24)	$f_{hop}(i)=1$, $f_m(i)=1$ (i=32)
0	0	15	9	10	19
1	1	16	8	11	18
2	2	17	7	12	17
3	3	18	6	13	16
4	4	19	5	14	15
5	5	0	14	15	4
6	6	1	13	16	3
7	7	2	12	17	2
8	8	3	11	18	1
9	9	4	10	19	0
10	10	5	19	0	9
11	11	6	18	1	8
12	12	7	17	2	7
13	13	8	16	3	6
14	14	9	15	4	5
15	15	10	4	5	14
16	16	11	3	6	13
17	17	12	2	7	12
18	18	13	1	8	11
19	19	14	0	9	10

Subband

: Sub-band hopping (← Cyclic shift in sub-band units) only

: Both sub-band hopping and mirroring within a sub-band

- Grant format
  - Grant size is the same as for a localized allocation
    - Includes 1 bit to indicate whether hopping mode or non-hopping mode
    - Hopping resource allocation (1st slot) is 0-2 bits smaller than non-hopping resource allocation
  - Hopping resource allocation for the 2nd slot uses those 0-2 bits
    - 0 bit: mirroring over non-PUCCH RBs
    - 1 bit: 0 = floor(N_RB/2), 1 = follow hopping pattern
    - 2 bits: 00= floor(N_RB/4), 01 = -floor(N_RB/4), 10 = N_RB/2, 11 = follow the predefined hopping pattern
    - N_RB is the actual number of PRB for PUSCH

PUSCH Hopping

- PUSCH hopping based on predefined pattern
  - Number of sub-bands for hopping pattern is equal to M
  - The predefined cell-specific hopping pattern is used
  - M=1: Only mirroring over whole PUSCH band
  - M>1: Hopping patterns defined based on inter-sub band hopping and mirroring on/off
  - All sub-band sizes should be equal

- Inter subframe PUSCH hopping
  - For Inter subframe hopping via grant, the hopping allocation in the 1st slot corresponds to even retransmission number and one in the 2nd slot corresponds to odd retransmission number
  - When hopping pattern is used, the hopping pattern is indexed by subframe number (instead of slot number)

PUCCH Format

- Format 1 (SR only with On-off Keying (OOK))
- Format 1a and 1b (ACK/NACK only)
  - Format 1a: BPSK ACK/NACK for 1 Codeword
  - Format 1b: QPSK ACK/NACK for 2 Codewords
- Format 2 (CQI only with QPSK)
- Format 2a and 2b (CQI + ACK/NACK)

PUCCH format	Modulation scheme	Number of bits per subframe, M_{bit}
1	N/A	N/A
1a	BPSK	1
1b	QPSK	2
2	QPSK	20
2a	QPSK+BPSK	21
2b	QPSK+QPSK	22

Normal CP

Number of PUCCH demodulation reference symbols per slot

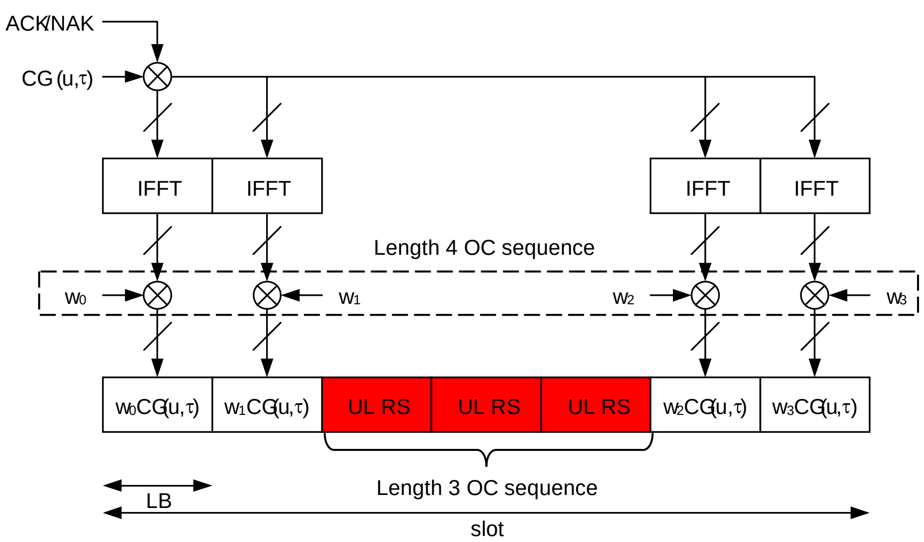
PUCCH format	Normal cyclic prefix	Extended cyclic prefix
1, 1a, 1b	3	2
2	2	1
2a, 2b	2	N/A

Demodulation reference signal location for different PUCCH formats

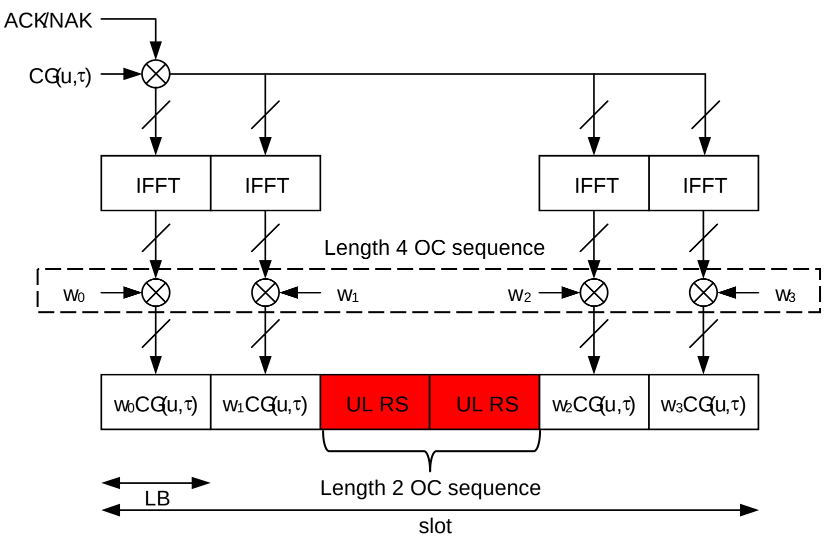
PUCCH format	Set of values for l	
	Normal cyclic prefix	Extended cyclic prefix
1, 1a, 1b	2, 3, 4	2, 3
2, 2a, 2b	1, 5	3

PUCCH Format 1a and 1b (For ACK/NACK Only Case)

- UE ACK/NACK signals are distinguished by both Computer Generated (CG) CAZAC (Constant Amplitude Zero Auto-Correlation) sequences with different cyclic shift values and Walsh/DFT orthogonal sequences
- For non-persistent scheduling, the ACK/NACK resource is linked to the lowest CCE of the control channel used for scheduling
- UL ACK/NACK resource due to persistent scheduling is explicitly signalled once when the persistent scheduling information for data is sent to the UE



Normal CP case



Extended CP case

Orthogonal Sequence for PUCCH

Length-4 orthogonal sequences for PUCCH formats 1/1a/1b

Sequence index $n_{oc}(n_s)$	**Orthogonal sequences** $[w(0) \quad \cdots \quad w(N_{SF}^{PUCCH}-1)]$
0	$[+1 \quad +1 \quad +1 \quad +1]$
1	$[+1 \quad -1 \quad +1 \quad -1]$
2	$[+1 \quad -1 \quad -1 \quad +1]$

Length-3 orthogonal sequences for PUCCH formats 1/1a/1b

Sequence index $n_{oc}(n_s)$	**Orthogonal sequences** $[w(0) \quad \cdots \quad w(N_{SF}^{PUCCH}-1)]$
0	$[1 \quad 1 \quad 1]$
1	$[1 \quad e^{j2\pi/3} \quad e^{j4\pi/3}]$
2	$[1 \quad e^{j4\pi/3} \quad e^{j2\pi/3}]$

ACK/NACK Channelization

Resource allocation: 18 ACK/NACK channels with normal CP $\Delta_{\text{shift}}^{\text{PUCCH}} = 2$

Cell specific cyclic shift offset		RS orthogonal cover			ACK/NACK orthogonal cover		
$\delta_{\text{offset}}^{\text{PUCCH}}=1$	$\delta_{\text{offset}}^{\text{PUCCH}}=0$	$\overline{n}_{OC}=0$	$\overline{n}_{OC}=1$	$\overline{n}_{OC}=2$	$n_{OC}=0$	$n_{OC}=1$	$n_{OC}=2$
$n_{CS}=1$	$n_{CS}=0$	$n'=0$		12	$n'=0$		12
2	1		6			6	
3	2	1		13	1		13
4	3		7			7	
5	4	2		14	2		14
6	5		8			8	
7	6	3		15	3		15
8	7		9			9	
9	8	4		16	4		16
10	9		10			10	
11	10	5		17	5		17
0	11		11			11	

$$\Delta_{\text{shift}}^{\text{PUCCH}} \in \begin{cases} \{1,2,3\} & \text{for normal cyclic prefix} \\ \{1,2,3\} & \text{for extended cyclic prefix} \end{cases}$$

Cell-specific Cyclic shift value of CAZAC sequence

$$\delta_{\text{offset}}^{\text{PUCCH}} \in \{0,1,\ldots,\Delta_{\text{shift}}^{\text{PUCCH}}-1\}$$

Cell specific cyclic shift offset

n_{OC} **Orthogonal sequence index for ACK/NACK**

$\overline{n}_{OC}$ **Orthogonal sequence index for RS**

n_{CS} **Cyclic shift value of a CAZAC sequence**

n' **ACK/NACK resource index used for the channelization in a RB**

ACK/NACK Channelization

- Channelization for PUCCH format 1/1a/1b in a RB with a mix of formats 1/1a/1b and 2/2a/2b
  - ACK/NACKs and CQIs from different UEs are mixed within a RB
  - ACK/NACK and CQI boundary can be known via semi-static signaling through broadcast channel

	Orthogonal cover		
Cyclic shift	**OC_{index}=0**	**OC_{index}=1**	**OC_{index}=2**
0			
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			

ACK/NACK

CQI

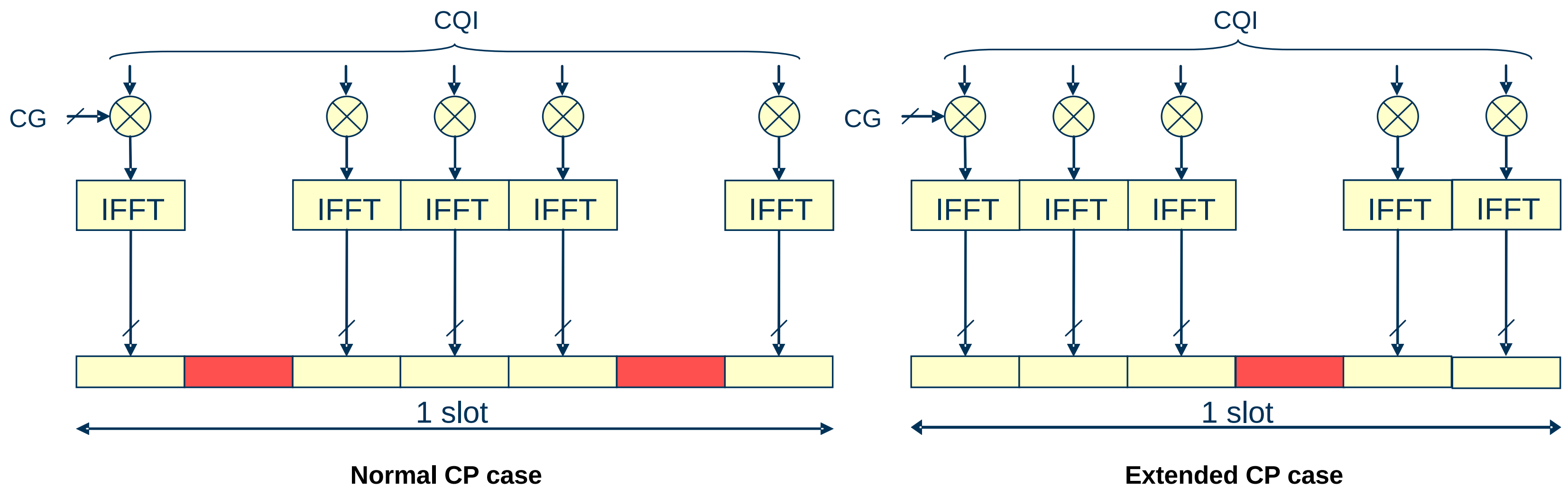
Guard shifts

CS Hopping and CS/OC Re-mapping

- Cell specific CS hopping on symbol basis
  - Inter-cell interference randomization
- Slot-level CS/OC re-mapping
  - Intra-cell interference randomization
  - The mapping between ACK/NACK channels and resources (k) is varied on slot basis

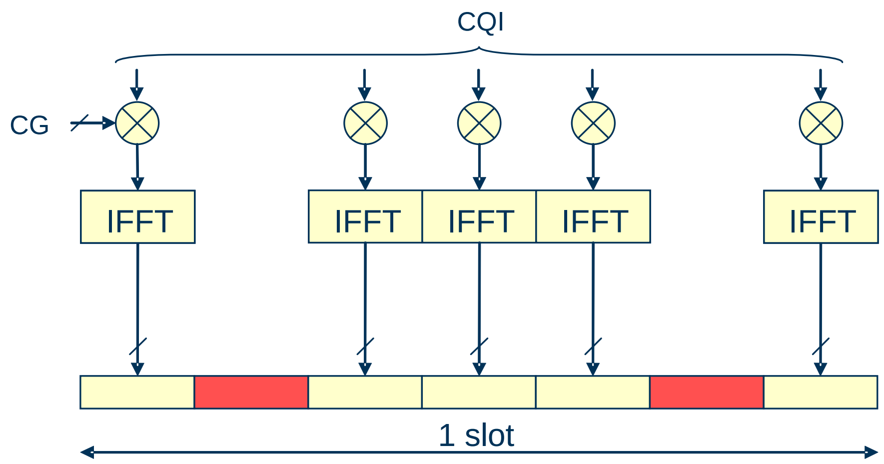
PUCCH Format 2

- Cases
  - CQI only
  - CQI+ACK/NACK with expended CP
- Bit scrambled by UE specific scrambling sequence
  - Initialization of scrambling sequence generator is same with that of PUSCH
- QPSK, (20, A) simplex code
- Cyclic Shift (CS) based orthogonality of CG CAZAC sequence
- CS hopping on symbol basis



PUCCH Format 2a and 2b (ACK/NACK and CQI from a UE)

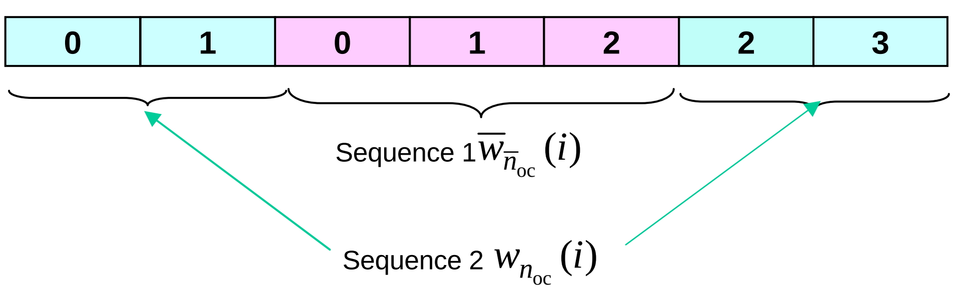
- Formats 2a and 2b are supported for the normal CP only
  - CQI
    - Bit scrambled by UE specific scrambling sequence
    - Initialization of scrambling sequence generator is same with that of PUSCH
    - QPSK, (20,A) simplex code
  - ACK/NACK
    - BPSK (2a) or QPSK (2b) modulation for the 2^{nd} RS symbol in each slot
  - Format 2a: QPSK CQI + BPSK ACK/NACK
  - Format 2b: QPSK CQI + QPSK ACK/NACK



Normal CP case

PUCCH Format 1 (Scheduling Request Only)

- On-off keying (OOK)
  - On (transmission of SR): request to be scheduled
- The length 7 sequence is split into two orthogonal sequences
  - Sequence 1: Length 3 $\overline{w}_{\overline{n}_{\mathrm{oc}}}(i)$
  - Sequence 2: Length 4 $w_{n_{\mathrm{oc}}}(i)$
- No reference signals are transmitted
- Channelization structure is same with that of PUCCH format 1a/1b
- Multiplexing of SR with CQI and/or ACK/NAK on PUCCH
  - CQI: Drop CQI when SR is transmitted
  - ACK/NAK: Support multiplexing of SR and ACK/NAK
    Positive SR (d(0)=1) → the ACK/NACK is transmitted using the SR resource
    Negative SR → the ACK/NACK is transmitted using the ACK/NACK resource

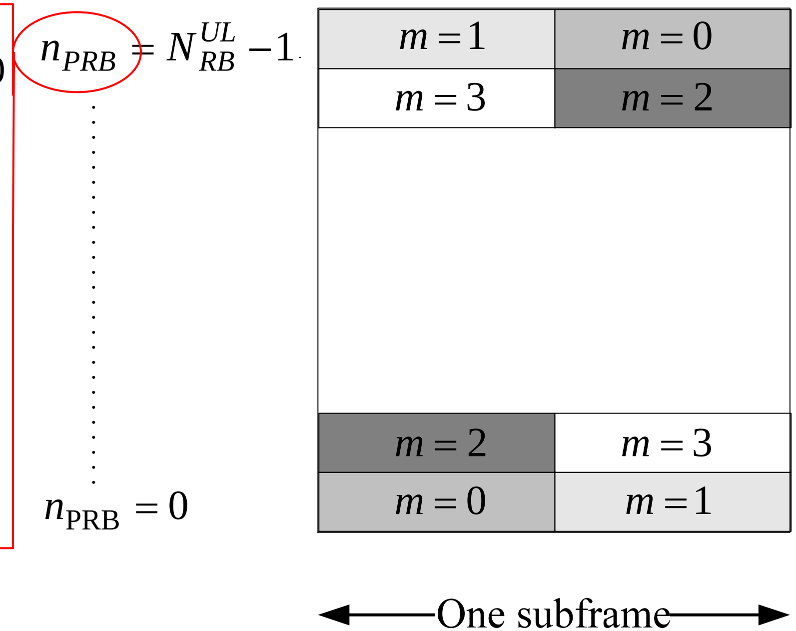


Mapping PUCCH to Physical Resources

- PRBs to be used for transmission of PUCCH in slot n_s

$$n_{\mathrm{PRB}} = \begin{cases} \left\lfloor \dfrac{m}{2} \right\rfloor & \text{if } (m + n_s \bmod 2) \bmod 2 = 0 \\ N_{\mathrm{RB}}^{\mathrm{UL}} - 1 - \left\lfloor \dfrac{m}{2} \right\rfloor & \text{if } (m + n_s \bmod 2) \bmod 2 = 1 \end{cases}$$

- Mapping order:
  From RBs in outer edge to RBs in inner edge
- PUCCH format 2/2a/2b first
- Secondly mixed ACK/NACK and CQI format
- PUCCH format 1/1a/1b



PUCCH Format 1/1a/1b

$$m = \begin{cases} N_{\mathrm{RB}}^{(2)} & \text{if } n_{\mathrm{PUCCH}}^{(1)} < c \cdot N_{\mathrm{cs}}^{(1)} / \Delta_{\mathrm{shift}}^{\mathrm{PUCCH}} \\ \left\lfloor \dfrac{n_{\mathrm{PUCCH}}^{(1)} - c \cdot N_{\mathrm{cs}}^{(1)} / \Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}}{c \cdot N_{\mathrm{sc}}^{\mathrm{RB}} / \Delta_{\mathrm{shift}}^{\mathrm{PUCCH}}} \right\rfloor + N_{\mathrm{RB}}^{(2)} + \left\lceil \dfrac{N_{\mathrm{cs}}^{(1)}}{8} \right\rceil & \text{otherwise} \end{cases}$$

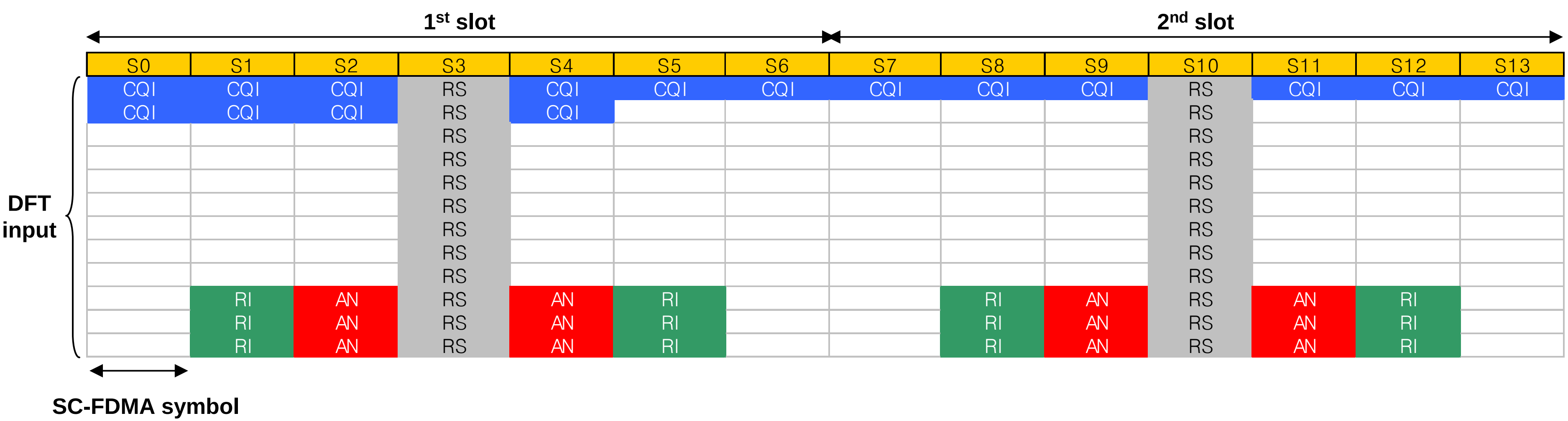
$$c = \begin{cases} 3 & \text{normal cyclic prefix} \\ 2 & \text{extended cyclic prefix} \end{cases}$$

PUCCH Format 2/2a/2b

$$m = \left\lfloor n_{\mathrm{PUCCH}}^{(2)} / \mathrm{N}_{\mathrm{sc}}^{\mathrm{RB}} \right\rfloor$$

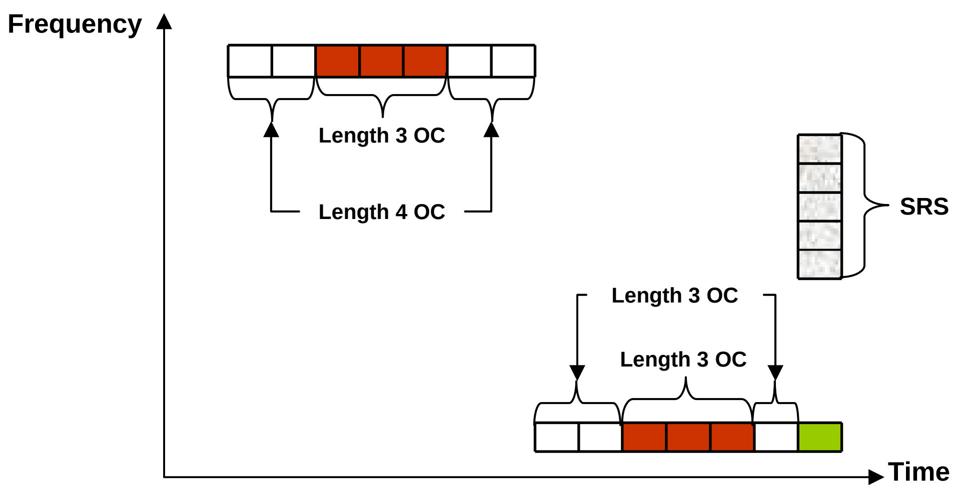
Multiplexing of Control and Data on PUSCH

- ACK/NACK mapping consecutive to RS, CQI time-first mapping in TS36.212
  - A/N resources punctured into data starting from the bottom of the figure below
  - Max number of resources for A/N: 4 SC-FDMA symbols
  - In case of 2 bits A/N,. (3,2) simplex coding is done
  - CQI resources placed at the beginning of the data resources
    - CQI payload less than or equal to 11 bits: (32,A) simplex code
    - CQI payload larger than bits: Tail biting convolutional code
  - RI bits placed next to the A/N bits in PUSCH, irrespective whether A/N is present or not
  - In case of 2 bits RI, (3,2) simplex coding is done



PUCCH Interaction with SRS for a UE

- ACK/NACK interaction with SRS
  - Option1: One ACK/NAK symbol is punctured
  - Option2: SRS transmission is dropped
  - Both Option 1and 2 are supported
  - The use of option 1 or 2 is configurable on cell basis
- CQI interaction with SRS
  - SRS transmission is dropped
- SRS interaction with SR
  - SRS transmission is dropped



DM RS for PUSCH

- For each UE, DM RS for PUSCH is transmitted over bandwidths where its PUSCH is scheduled
- PUSCH DM RS in MIMO
  - SIMO: FDM between UEs
  - MU-MIMO: RSs of different UEs are orthogonalized by allocating different cyclic shift for each UE
- Different cyclic shifts can be used in different slots of a subframe
- For extended CP, PUSCH DM RS is located at the 3rd symbol

$$n_{cs} = \left(\underbrace{n_{\mathrm{DMRS}}^{(1)}}_{\text{Broadcasted value}} + \underbrace{n_{\mathrm{DMRS}}^{(2)}}_{\text{Included in UL grant For MU-MIMO}} + \underbrace{n_{\mathrm{PRS}}}_{}\right) \bmod 12$$

Given by the pseudo-random sequence *c*(*i*)
Application of *c*(*i*) is cell specific

Cyclic shift field in UL grant	$n_{\mathrm{DMRS}}^{(2)}$
000	0
001	2
010	3
011	4
100	6
101	8
110	9
111	10

Sounding Reference Signal (SRS) Subframe Configuration

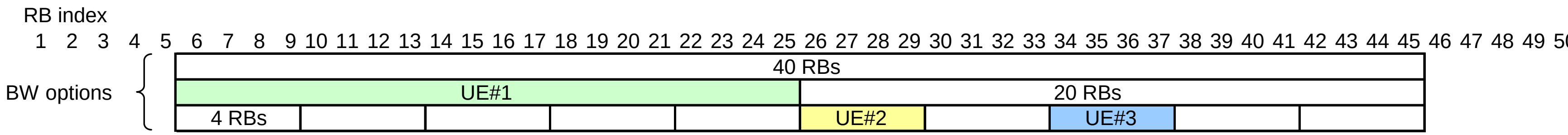
- Cell-specific configuration in 4 bits
- Every 1, 2, 5, 10, inf. subframes have one SRS subframe

Configuration	Binary	Configuration Period (subframes)	Transmission offset (subframes)
0	0000	1	{0}
1	0001	2	{0}
2	0010	2	{1}
3	0011	5	{0}
4	0100	5	{1}
5	0101	5	{2}
6	0110	5	{3}
7	0111	5	{0,1}
8	1000	5	{2,3}
9	1001	10	{0}
10	1010	10	{1}
11	1011	10	{2}
12	1100	10	{3}
13	1101	10	{0,1,2,3,4,6,8}
14	1110	10	{0,1,2,3,4,5,6,8}
15	1111	Inf	N/A

SRS Bandwidth Configuration (1)

- SRS transmission bandwidths (CR030 R1-082264)
  - Multiple SRS BW trees are predefined for each uplink system operating bandwidth

10 MHz bandwidth



Tree layer l	B_l	N_l	n_{l}, UE#1	n_{l}, UE#2	n_{l}, UE#3
0	12x40	1	0	0	0
1	12x20	2	0	1	1
2	12x4	5	-	0	2

- Cell specific 3 bits are broadcasted to indicate one of 8 SRS BW configurations
  - One SRS BW configuration has Max. SRS BW and predefined SRS BW trees
- UE specific 2 bits are given from higher layers to indicate one of 4 SRS BWs
  - For each SRS BW configurations, there exist 1~4 SRS BWs

SRS Bandwidth Configuration (2)

SRS bandwidth configuration and SRS bandwidth for 6~40 RB uplink system BW

SRS bandwidth configuration	SRS-Bandwidth $b = 0$		SRS-Bandwidth $b = 1$		SRS-Bandwidth $b = 2$		SRS-Bandwidth $b = 3$	
	$m_{SRS,b}$	N_b	$m_{SRS,b}$	N_b	$m_{SRS,b}$	N_b	$m_{SRS,b}$	N_b
0	36	1	12	3	N/A	1	4	3
1	32	1	16	2	8	2	4	4
2	24	1	N/A	1	N/A	1	4	6
3	20	1	N/A	1	N/A	1	4	5
4	16	1	N/A	1	N/A	1	4	4
5	12	1	N/A	1	N/A	1	4	3
6	8	1	N/A	1	N/A	1	4	2
7	4	1	N/A	N/A	N/A	N/A	N/A	N/A

SRS bandwidth configuration and SRS bandwidth for 80~110 RB uplink system BW

SRS bandwidth configuration	SRS-Bandwidth $b = 0$		SRS-Bandwidth $b = 1$		SRS-Bandwidth $b = 2$		SRS-Bandwidth $b = 3$	
	$m_{SRS,b}$	N_b	$m_{SRS,b}$	N_b	$m_{SRS,b}$	N_b	$m_{SRS,b}$	N_b
0	96	1	48	2	24	2	4	6
1	96	1	32	3	16	2	4	4
2	80	1	40	2	20	2	4	5
3	72	1	24	3	12	2	4	3
4	64	1	32	2	16	2	4	4
5	60	1	20	3	N/A	1	4	5
6	48	1	24	2	12	2	4	3
7	48	1	16	3	8	2	4	2

SRS Generation

- SRS sequence index is derived from PUCCH DM RS base sequence index

$$r^{\mathrm{SRS}}(n) = r_{u,v}^{(\alpha)}(n)$$

$$\alpha = 2\pi \frac{\text{cyclic\_shift\_value\_SRS}}{8}$$

Configured for each UE by high layers (3bits)

- Repetition factor: RPF=2 only
- Transmission power is obtained from the offset relative to PUSCH DM RS transmission power
- Position of the SRS in time domain: Last SC-FDMA symbol of a subframe
- Mapping to physical resources is done as following equations

$$a_{2k+k_0,l} = \begin{cases} \beta_{\mathrm{SRS}} r^{\mathrm{SRS}}(k) & k = 0,1,\ldots,M_{\mathrm{sc},b}^{\mathrm{RS}} - 1 \\ 0 & \text{otherwise} \end{cases}$$

$$k_0 = k_0' + \sum_{b=0}^{B_{\mathrm{SRS}}} 2M_{\mathrm{sc},b}^{\mathrm{RS}} n_b$$

k_0 : Frequency domain starting position of SRS

$M_{\mathrm{sc},b}^{\mathrm{RS}} = m_{\mathrm{SRS},b} N_{\mathrm{sc}}^{\mathrm{RB}} / 2$: Length of SRS sequence at level b

$m_{\mathrm{SRS},b}$: SRS bandwidth in RB unit

k_0' : Offset value depending on transmission comb

n_b : Frequency position index for SRS bandwidth

SRS Hopping Pattern

- Predefined frequency hopping pattern for SRS transmission

$$n_b = \begin{cases} 0 & b = 0 \\ F_b(n_{SRS}) + n_{b,RRC} \bmod N_b & \text{otherwise} \end{cases}$$

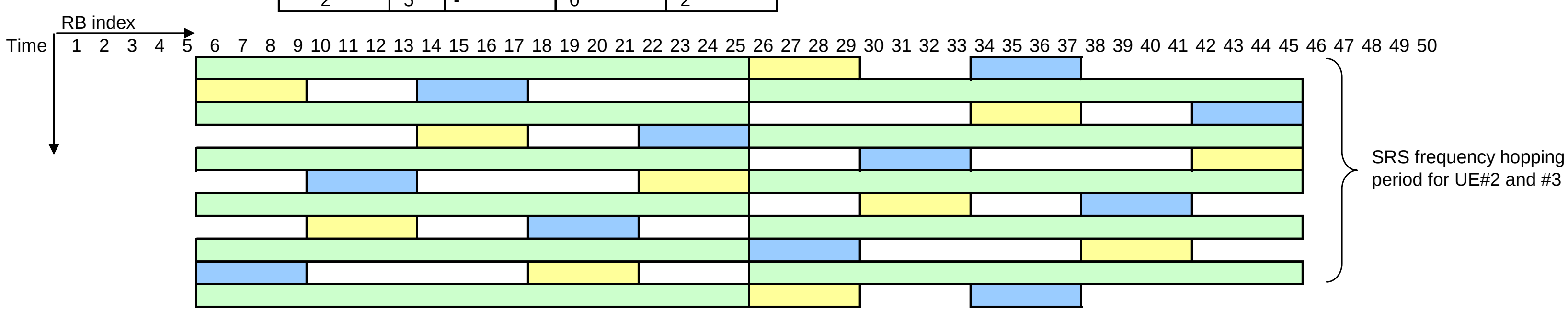
$$F_b(n_{SRS}) = \begin{cases} N_b/2 \left\lfloor \dfrac{n_{SRS} \bmod \Pi_{b'=0}^{b} N_{b'}}{\Pi_{b'=0}^{b-1} N_{b'}} \right\rfloor + \left\lfloor \dfrac{n_{SRS} \bmod \Pi_{b'=0}^{b} N_{b'}}{2\Pi_{b'=0}^{b-1} N_{b'}} \right\rfloor & \text{if } N_b \text{ even} \\ \lfloor N_b/2 \rfloor \lfloor n_{SRS} / \Pi_{b'=0}^{b-1} N_{b'} \rfloor & \text{if } N_b \text{ odd} \end{cases}$$

n_{SRS} : Number of prior SRS transmissions

N_b : Number of branches on assigned tree level b

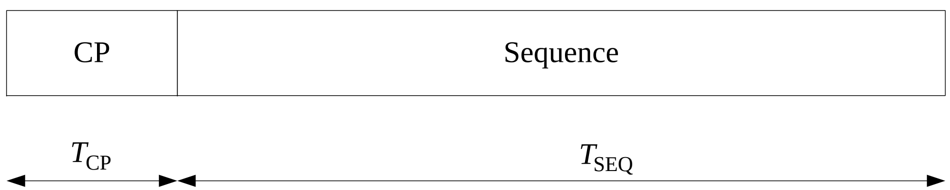
10 MHz bandwidth

Tree layer l	N_l	$n_{l,orig}$, UE#1	$n_{l,orig}$, UE#2	$n_{l,orig}$, UE#3
0	1	0	0	0
1	2	0	1	1
2	5	-	0	2



PRACH Structure

- BW of random access burst corresponds to 6RBs
- Subcarrier spacing
  - 1.25KHz for FDD
  - 7.5KHz for TDD
- RA preambles are generated from ZC sequence (ZC sequence length = 839)
- Guard bands on both sides of preamble
- For a cell which includes many power limited UEs not in good channel conditions, one repetition of preamble is supported (0.8ms + 0.8ms, preamble formats 2 and 3)



Preamble format	T_{CP}	T_{SEQ}
0	$3168 \cdot T_s$	$24576 \cdot T_s$
1	$21024 \cdot T_s$	$24576 \cdot T_s$
2	$6240 \cdot T_s$	$2 \cdot 24576 \cdot T_s$
3	$21024 \cdot T_s$	$2 \cdot 24576 \cdot T_s$
4 (frame structure type 2 only)	$448 \cdot T_s$	$4096 \cdot T_s$

PRACH Configuration

- For preamble format 0~3 , at most one RA resource per subframe for FDD
- Start of RA preamble shall be aligned with the start of the corresponding uplink subframe at the UE

PRACH configuration	System frame number	Subframe number
0	Even	1
1	Even	4
2	Even	7
3	Any	1
4	Any	4
5	Any	7
6	Any	1, 6
7	Any	2 ,7
8	Any	3, 8
9	Any	1, 4, 7
10	Any	2, 5, 8
11	Any	3, 6, 9
12	Any	0, 2, 4, 6, 8
13	Any	1, 3, 5, 7, 9
14	Any	0, 1, 2, 3, 4, 5, 6, 7, 8, 9
15	Even	9

PRACH Sequence (1)

- PRACH sequence generation
  - Network configures the set of preamble sequences the UE is allowed to use
  - The u th root ZC sequence: $x_u(n) = e^{-j\frac{\pi u n(n+1)}{N_{ZC}}}, \quad 0 \le n \le N_{ZC} - 1$

- 64 preamble sequences per cell
  - Signaling of 64 preamble sequences
    - To reduce resources of BCH consumed by signaling 64 preambles, one logical index instead of 64 sequences indices is transmitted (logical root sequence index = {0, 1, …, 837})
    - The relation between logical root sequence index and physical root sequence index (u) is specified in two tables (One for preamble formats 0~3 and the other for preamble format 4)

Table 5-7-2-4.zip

  - Finding 64 preamble sequences
    - Firstly found by all available CS (in the order of increasing CS value) of a root ZC sequence with a logical index
    - If 64 preamble sequences are not found, remaining sequences are found in the root sequences with the consecutive logical indexes until all the 64 preamble sequences are found

Preamble format	N_{ZC}
0 – 3	839
4	139

PRACH Sequence (2)

- Cyclic shifts for preamble generation
  - Cyclic shifts N_{CS} is defined for both FDD (formats 0~3) and TDD (format 4), respectively

Cyclic shifts for preamble generation (preamble formats 0~3)

N_{CS} configuration	N_{CS} value	
	Unrestricted set	Restricted set
0	0	15
1	13	18
2	15	22
3	18	26
4	22	32
5	26	38
6	32	46
7	38	55
8	46	68
9	59	82
10	76	100
11	93	128
12	119	158
13	167	202
14	279	237
15	419	-

Cyclic shifts for preamble generation (preamble format 4)

N_{CS} configuration	N_{CS} value
0	2
1	4
2	6
3	8
4	10
5	12
6	15