LTE PHY layer overview

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Outline

- LTE requirement
- General overview
- LTE downlink
- LTE uplink

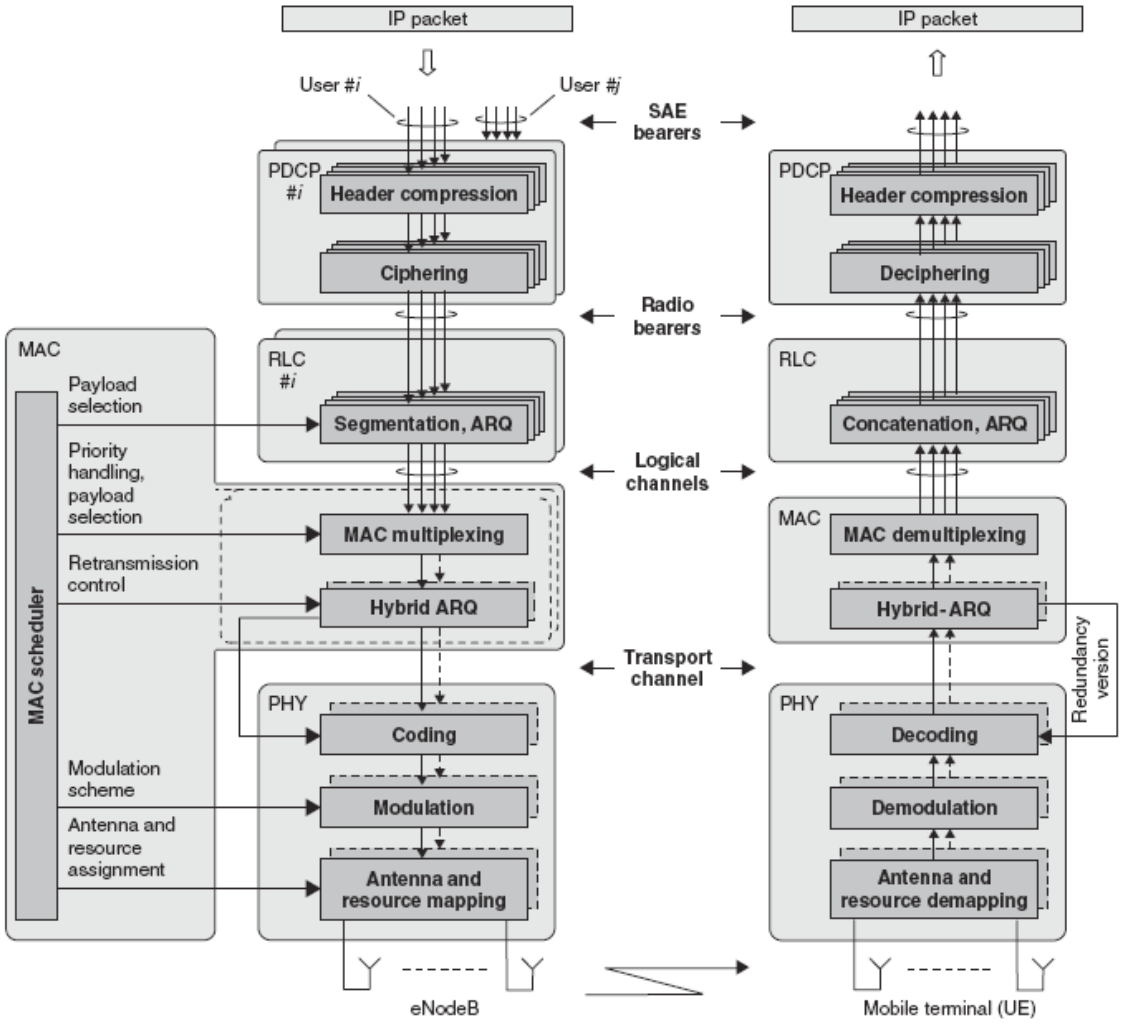
Requirement

- Peak date rate
  - DL: 100Mbps in 20MHz BW (5bps/Hz)
  - UL: 50Mbps in 20MHz BW (2.5bps/Hz)
- Throughput
  - Average
    - DL: 3~4 x of Release 6 per MHz
    - UL: 2~3 x of Release 6 per MHz
  - Cell edge
    - 2~3 x of Release 6 per MHz for both DL and UL
- Spectrum efficiency
  - DL: 3~4 x of Release 6 per MHz
  - UL: 2~3 x of Release 6 per MHz
- Latency
  - Control-plane: <100 ms for Idle to Active mode transition
  - User-plane: <5ms for 1 user with 1 data stream and small IP packet

Requirement

- Control-plane capacity
  - >200 users per cell in Active state within 5 MHz
- Spectrum flexibility
  - 1.4Mhz and 3MHz and scalable of 5, 10, 15, 20 MHz
  - Paired (FDD) or unpaired (TDD) spectrum allocation
- Mobility
  - Optimized for 0~15km/h
  - Support with high performance for 15~20 km/h
  - Maintain connection for 120~350 (even 500) km/h
- Coverage
  - All targets met for 5 km cells
  - Slight degradation for 5~30 km cells
  - Support for 30~100 km cells

LTE radio interface architure



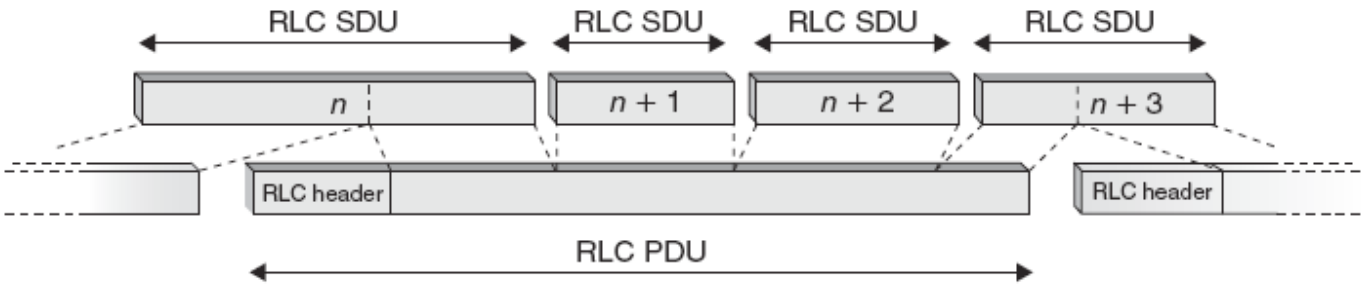
LTE protocol architure (DL)

(Ref. *3G evolution:HSPA and LTE for mobile broadband*)

Radio link control (RLC)

Responsible for

- Segmentation/concatenation of (header compressed) IP packets (RLC SDU => RLC PDU

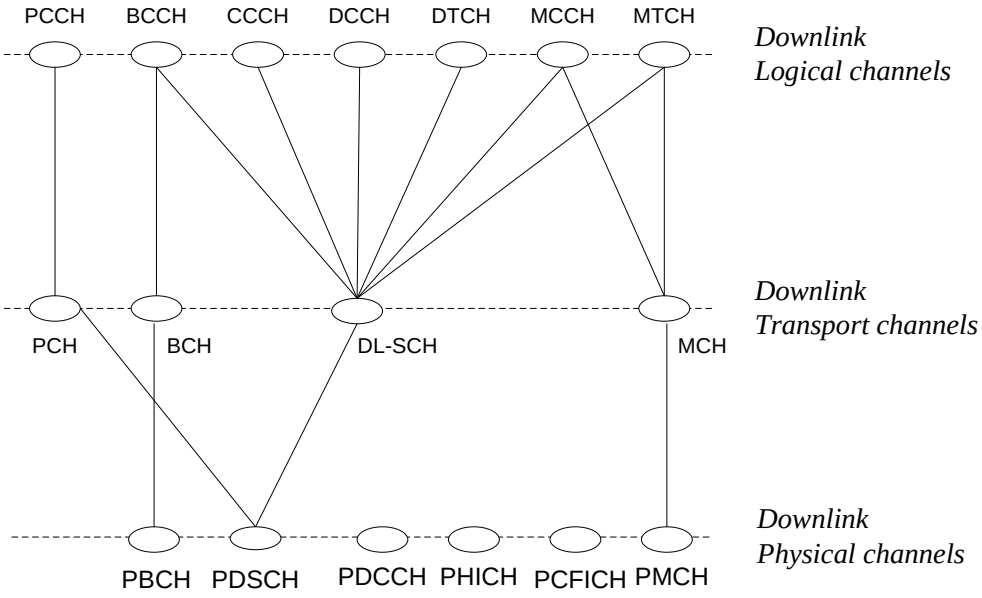


- Handle retransmission of error received PDU
- Ensure in-sequence delivery of SDUs to upper layers

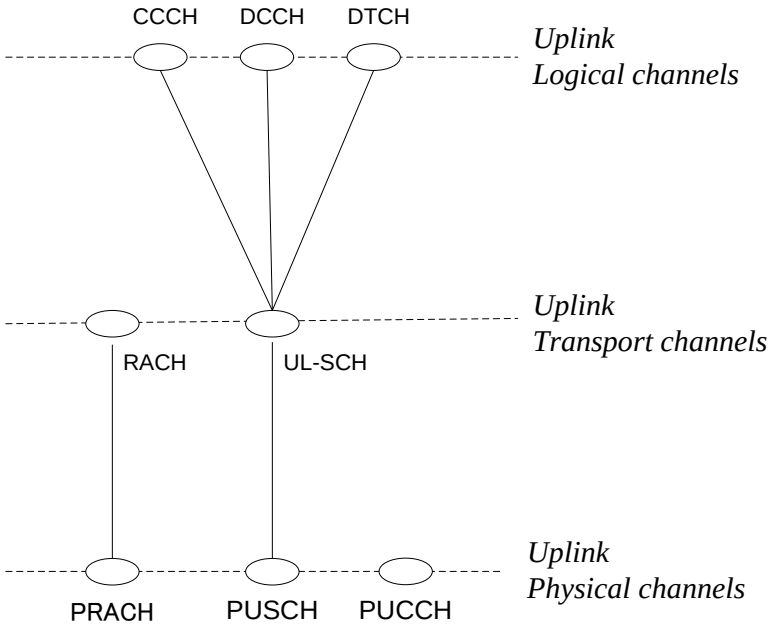
Medium access control

- Responsible
  - Logical-channel multiplexing
  - Hybrid ARQ
  - UL/DL scheduling
- Logical channels
  - Defined by the type of information it carries and include
    - Control channel: BCCH, PCCH, CCC, DCCH, MCCH
    - Traffic channel: DTCH, MTCH
- Transport channel
  - Defined by how and with what characteristics the information is transmitted over the radio interface, include
    - BCH, PCH, DL-SCH, MCH, UL-SCH, RACH
  - Data on transport channel is organized into transport blocks (TB)
  - At most 1 (for MIMO, 2) TB is transmitted in each TTI
  - Transport format (TF): size, modulation, antenna mapping

Channel mapping

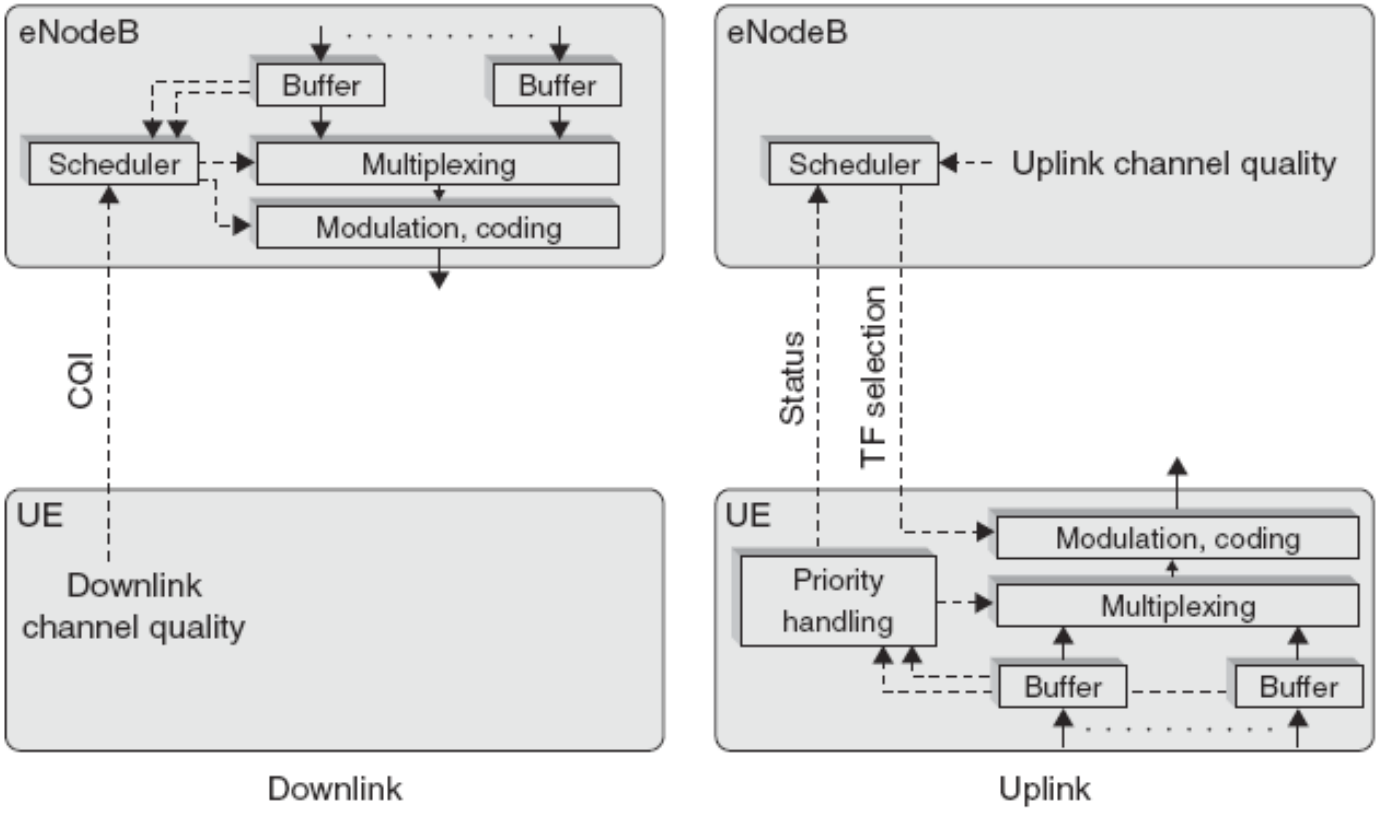


DL channel mapping



UL channel mapping

Scheduling


eNodeB
Buffer
Buffer
Scheduler
Multiplexing
Modulation, coding
CQI
UE
Downlink
channel quality
Downlink
eNodeB
Scheduler
Uplink channel quality
Status
TF selection
UE
Modulation, coding
Priority
handling
Multiplexing
Buffer
Buffer
Uplink

Scheduling

- DL scheduler: select terminals, RB used by DL-SCH, TF and logical channel multiplexing by NodeB
  - UE report channel status
- UL scheduler: select terminals, RB used by DL-SCH, TF by NodeB; the mobile terminal handles logical channel multiplexing
  - UE report buffer status
  - Channel quality estimation is based on a SRS (more overhead, optional)
- Interference coordination

Hybrid ARQ with soft combining

- Only supported for the DL-SCH and UL-SCH
- Multiple parallel stop-and wait process
- DL:
  - asynchronous protocol
  - Explicit HARQ process number
  - Retransmission need similar schedule
- UL
  - Synchronous protocol
  - Implicit HARQ process number
  - May use semi-persistent scheduling

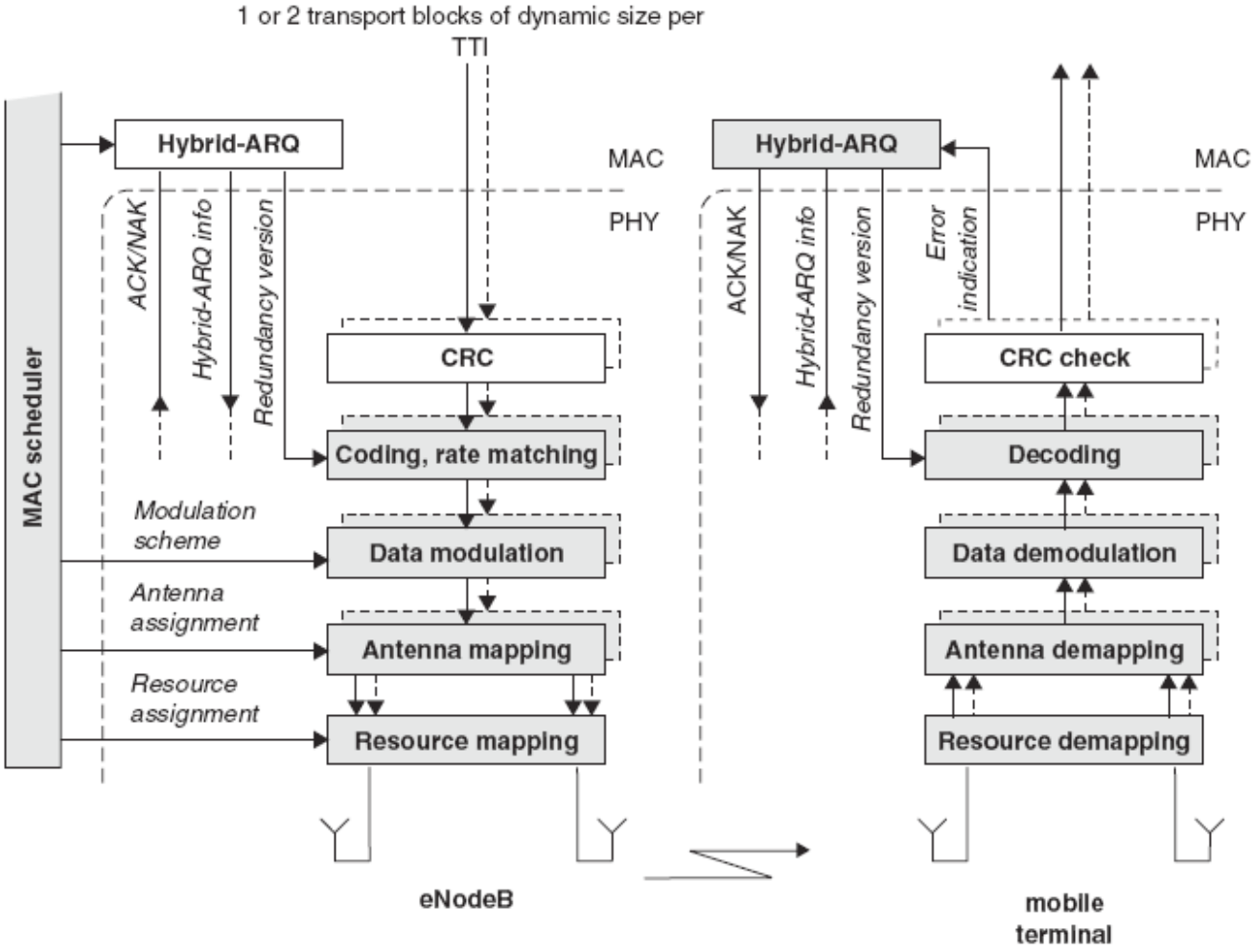
Why HARQ and ARQ

- HARQ
  - Faster retransmission
  - Due to error in feedback, residue error still high for TCP
- ARQ
  - Slower retransmission
  - Ensure error-free delivery
- HARQ and ARQ are located in the same node, tight interaction is possible

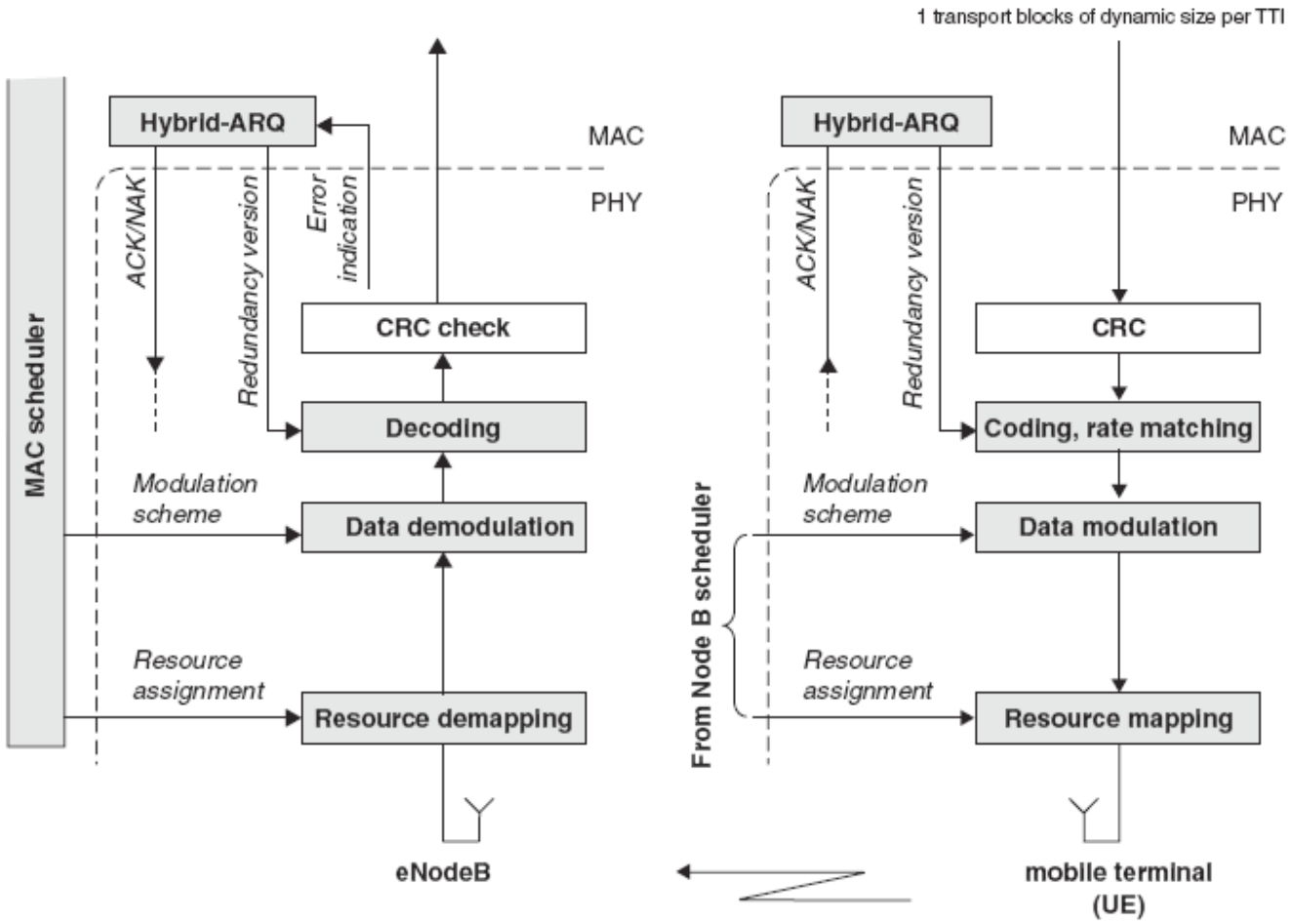
Physical layer

- Physical channel: the set of time-frequency resources either mapped to transport channel or L1/L2 control channels include
  - PSSCH, PBCH, PMCH, PDCCH, PHICH, PCFICH, PUSCH, PUCCH, PRACH

DL-SCH processing



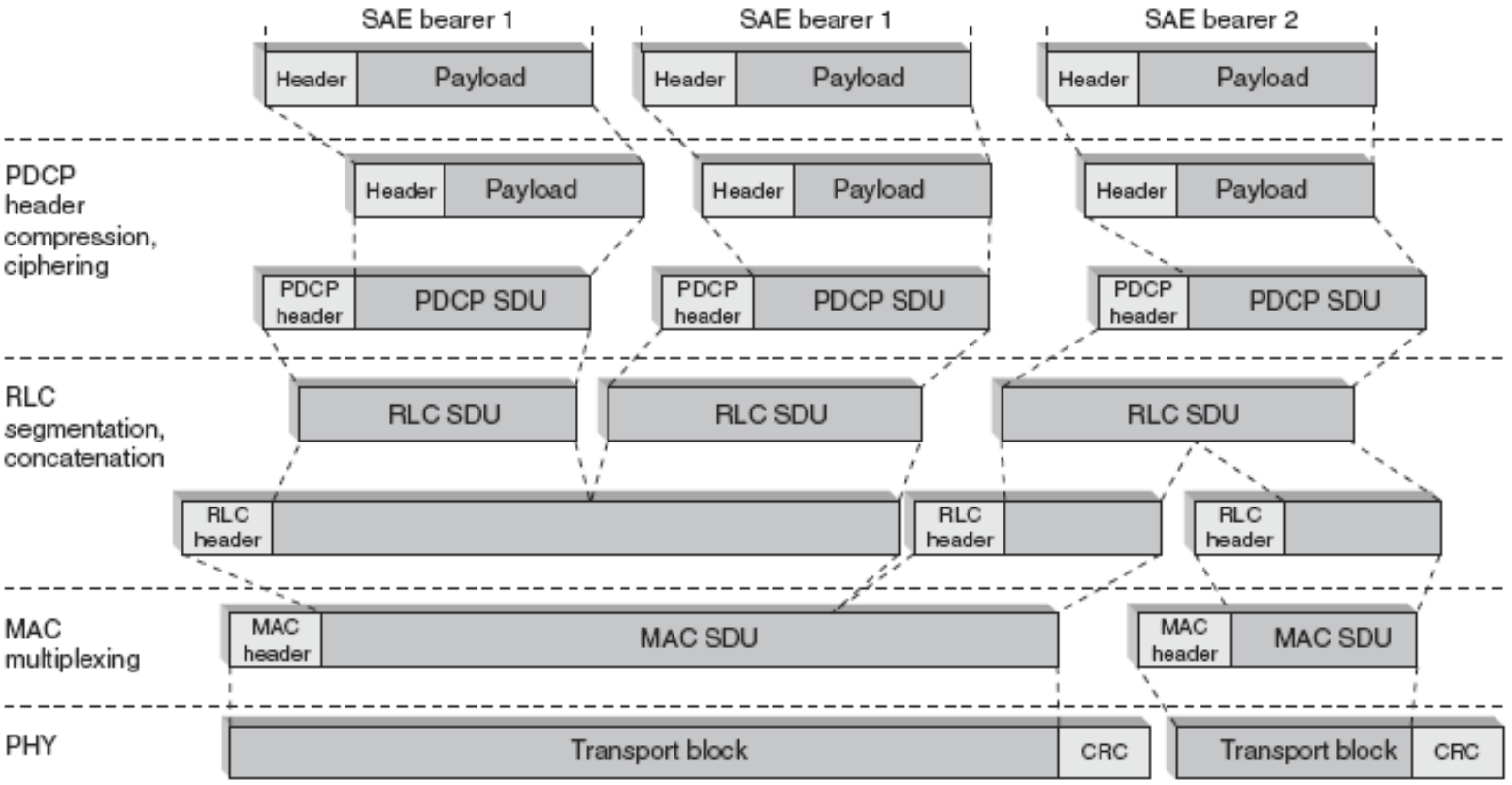
UL-SCH processing



Terminal states

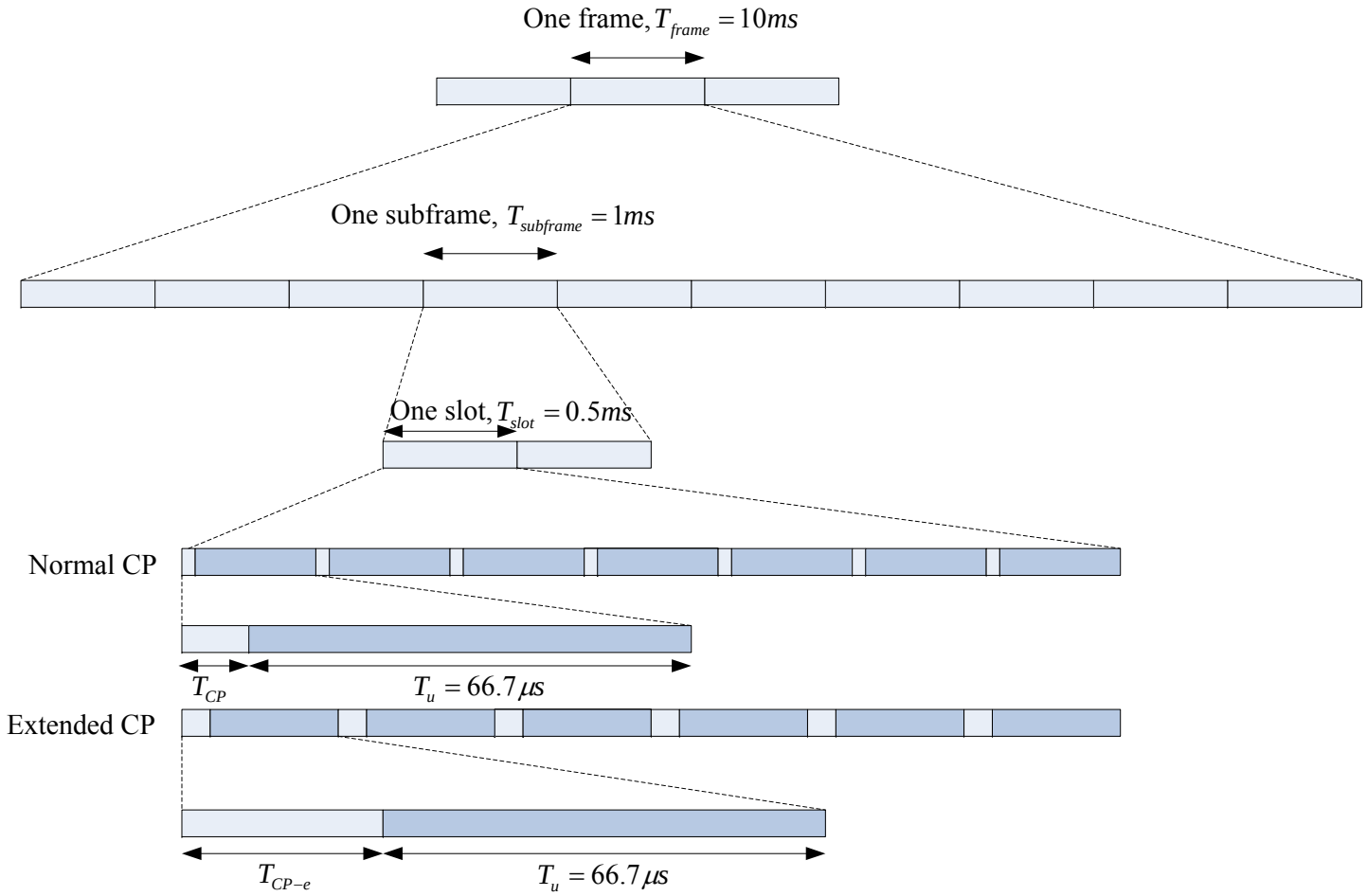
- RRC_IDLE
  - Monitors PCH according to DRX cycle
- RRC_CONNECTED
  - Connected to known cell
  - OUT_OF_SYNC
    - DL reception possible
    - No UL transmission
  - IN_SYNC
    - DL reception possible
    - UL transmission possible

Data flow


SAE bearer 1
SAE bearer 1
SAE bearer 2
Header
Payload
PDCP header compression, ciphering
PDCP header
PDCP SDU
RLC segmentation, concatenation
RLC SDU
RLC header
MAC multiplexing
MAC header
MAC SDU
PHY
Transport block
CRC

DL transmission scheme

- Time domain structure (FDD)



DL physical resource

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

Ref. 36.214

DL physical resource

$\Delta f = 15\text{KHz}\,(7.5\text{KHz for MBSFN})$

$T_s = 1/30720000$

$T_{\text{CP}} = 160\,T_s \approx 5.1\mu\text{s}\,(\text{first symbol}), 144\,T_s \approx 4.7\mu\text{s}\,(\text{Remaining})$

$T_{\text{CP-e}} = 512\,T_s \approx 16.7\mu\text{s for a large cell or MBSFN}$

- One RB consist 12 consective subcarriers
- DC subcarrier is not used because it may be subject to un-propotional high interference
- The basic time-domain unit in dynamical scheduling on LTE is one subframe (RB pair)

DL reference signals

- Three types of DL RS
  - Cell-specific DL RS: transmitted in every subframe and span the entire DL cell BW, used for channel estimation
  - UE-specific RS: transmitted within the RBs assigned for DL-SCH to the specific terminal, used for channel estimation of DL_SCH for which non-codebook-based beam-forming has been applied
  - MBSFN RS: used for channel estimation of signals being transmitted by MBSFN

Cell-specific DL RS

Ref. 36.211

Cell-specific DL RS

- Insert in the first and third last OFDM symbol of each slot, and 6 subcarriers spacing
- The complex values of RS vary between different positions and cells, are defined by a cell-specific 2D sequence with period of a frame and assume the maximal 110 RB
- RS in the central part of band will always be the same
- 504 RS sequences correspond to 504 physical-layer cell identities
- Six possible frequency shift in RS position can be used in neighbors cell to avoid inter-cell interference
- For MIMO, a resource element carrying a RS for a antenna port, nothing will be transmitted by other antenna ports

UE-specific RS

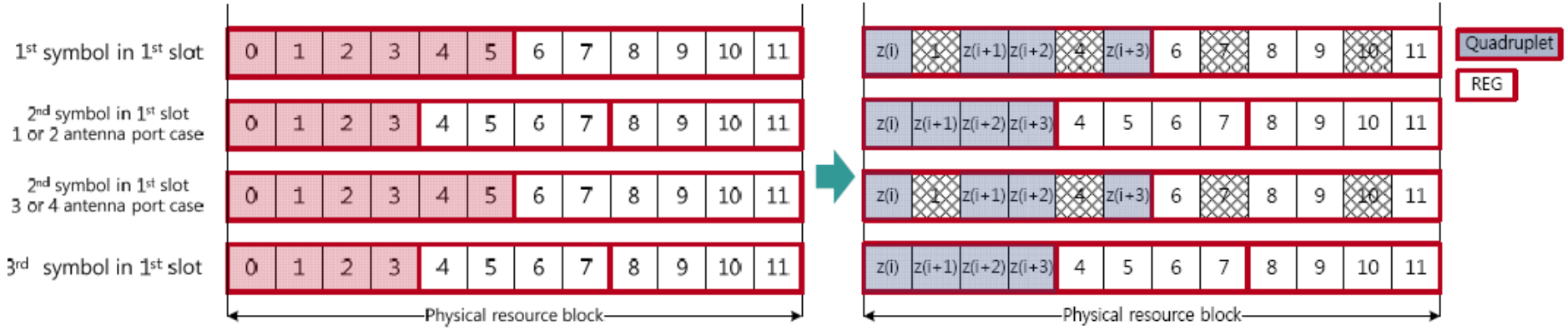
- Referred as transmission using antenna port 5
- UE-specific RSs are not inserted into symbols in which cell-specific RS are transmitted
- UE-specific RSs are transmitted on data part of assigned RB but not control part

DL L1/L2 control signaling

- Transmitted within the first part of each subframe, called control region (1~3 OFDM symbols) followed by data region
  - Allow for UE to decode DL scheduling signaling assignment as early as possible, thus reduce the delay
  - If UE not scheduled, it may power down part of receiver circuity for a part of subframe
- The size of control region can be dynamic varied on per-subframe basis, matching the instantaneous traffic
- Corresponds PCFICH, PDCCH, PHICH

Resource element groups

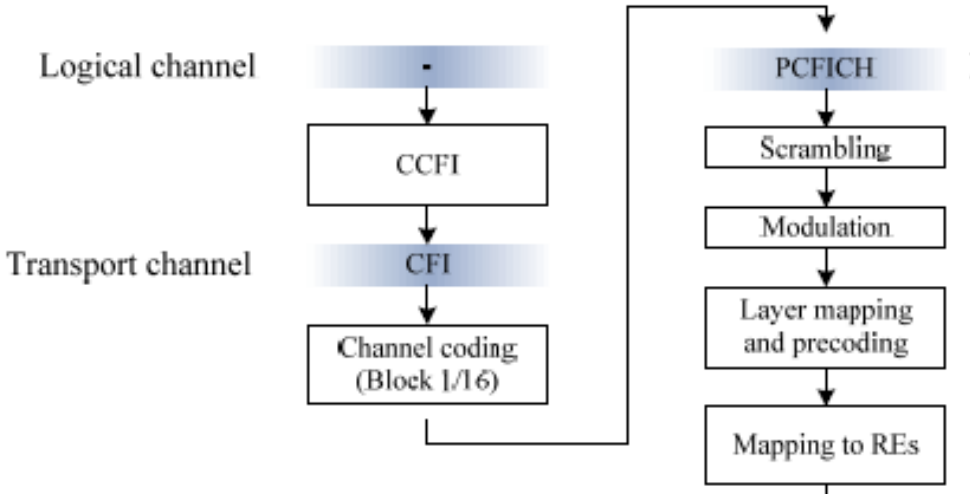
- Basic resource element mapping unit for DL control information
- 4 (quadruplet) REs (exclude RS) form a REG
- Assume 2 antenna ports in the first symbol
- Numbered in a time-first maner



PCFICH

- Indicate the size of control region, very important for later demodulation, mapped to the 1st OFDM symbol
- Transmit power is under control by eNodeB
- 2 information bits encoded to 32 bits and cell-specific scrambling prior QPSK modulation to random inter-cell interference
- Form 4 groups to map to the REG of the first OFDM symbol
  - Spread over the whole system bandwidth
  - Location of groups depends on the physical-layer cell identity

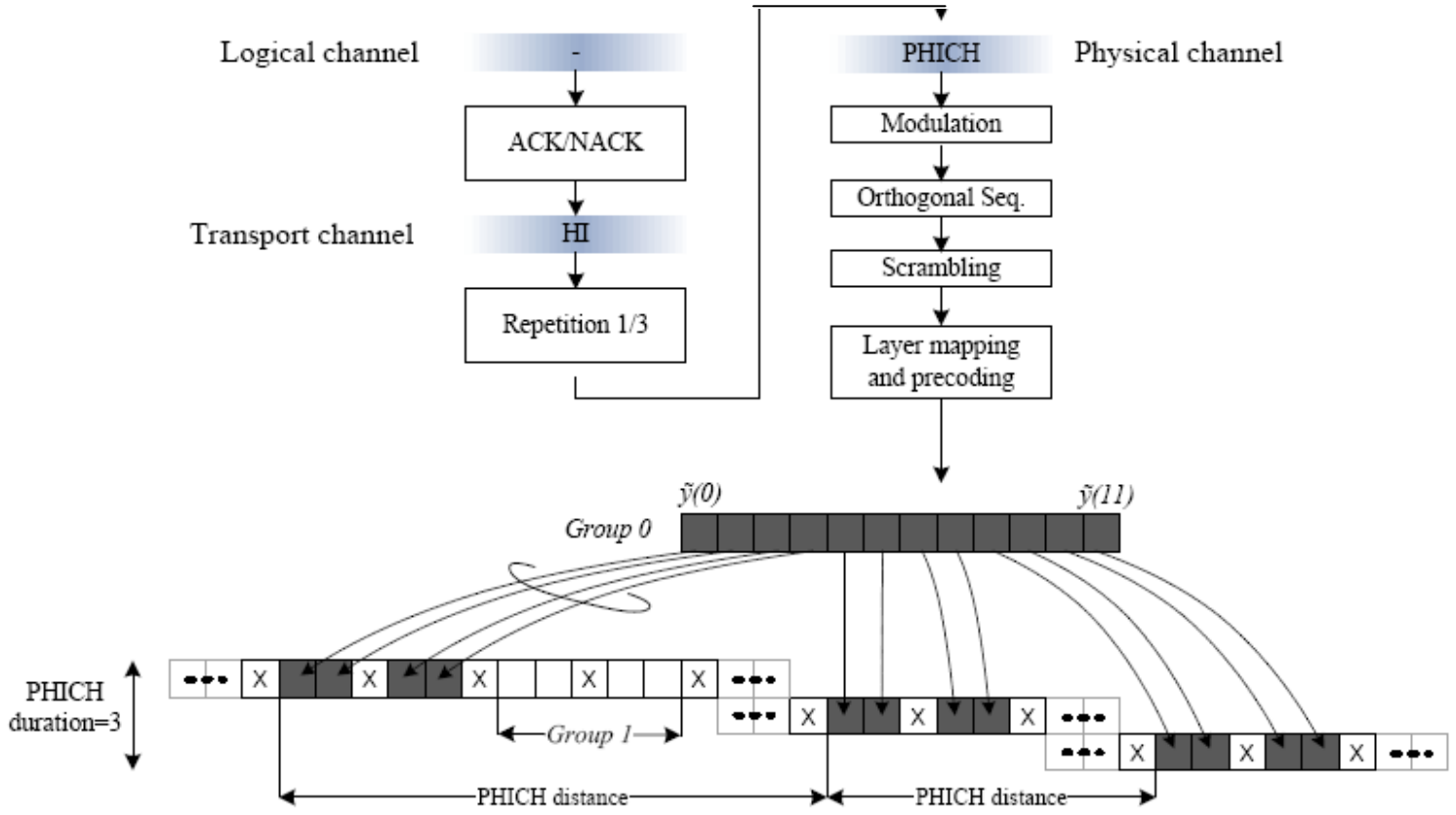
PCFICH processing



PHICH

- Carries DL HARQ ACK/NACK
- PHICH group
  - 1 PHICH group = 8 PHICHs (normal CP) use length 4 orthogonal sequence
  - 1 PHICH group = 4 PHICHs (extend CP) use length 2 orthogonal sequence
- Typically transmitted on the 1st OFDM symbol but also can be 3 OFDM symbols durarion
- PHICH configuration is part of system information transmitted on PBCH
  - 1 bit to indicate 1 or 3 OFDM symbols
  - 2 bits indicate
- The PHICH which the terminal will expect the HARQ acknowledgement upon (PHICH group #, orthogonal Seq., and the I/Q branch) is given by the number of the 1st RB upon which the current UL PUSCH transmission occurred and RS phase rotation signaled as part of UL grant

PHICH processing



PDCCH

- Used to carry DL control information includes
  - DL scheduling assignment: PDSCH resource indication, TF HARQ information, control information related spatial multiplexing and command for power control of PUCCH UL physical channel
  - UL scheduling grants: PUSCH resource indication, TF, HARQ information, phase rotation of UL RS, channel status request flag, command for power control of PUSCH UL physical channel
  - Power control commands for a set of terminals
- Different type have different DCI formats
- Multiple simultaneous PDCCH transmission with each cell
- Link adaption to match channel condition is used

PDCCH

- DCI format [Ref TS36.212]
  - DCI format 0 is used for the transmission of UL-SCH grant
  - DCI format 1 is used for the transmission of DL-SCH assignments for SIMO operation, support non-contiguous RB allocation
  - DCI format 1A is used for a compact transmission of DL-SCH assignments for SIMO operation, frequency-contiguous RB allocation only
  - 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 1D is used for the compact scheduling of one PDSCH codeword with precoding and power offset information.
  - DCI format 2 is used for the transmission of DL-SCH assignments for MIMO operation, similar to DCI format 1 with extension of SM support
  - DCI format 2A is used for scheduling PDSCH to UEs configured in open–loop spatial multiplexing mode.
  - DCI format 3 is used for the transmission of power-control commands for PUCCH and PUSCH with 2-bit power adjustments
  - DCI format 3A is used for the transmission of power-control commands for PUCCH and PUSCH with single bit power adjustments

DL scheduling assignment

- Are valid for the same subframe in which they are transmitted
- Use one of DCI formats: 1, 1A, 1B, 1C, 1D, 2, 2A with different size and different capabilities
- Signaling of RB allocation
  - Type 0: indicate group of RB using bitmap, group size may be as large as 4 RBs with largest cell BW, granularity is reduced
  - Type 1: indicate subset of RB with fine granularity
  - Type 2: support frequency-contiguous only

DL scheduling assignment

- Signaling of transport-block size
  - Provided by a 5-bit field in the DCI
  - Out of 32 combinations, 29 are used to signaling modulation-and-coding scheme
  - modulation-and-coding scheme together with the number of RS to form a 29x110 table to indicate transport block size
  - With the overlap, only 27 unique rows of transport block size
  - Three reserved combinations at the beginning are used for retransmission only, where transport block size is unchanged and not need to signal this piece of information assuming initial transmission properly received. Thus is used to represent modulation scheme, QPSK, 16QAM and 64QAM

UL scheduling grants

- Use DCI format 0
- Resource allocation type 2 is used
- Three reserved combinations at the beginning are used to explicitly indicate redundancy version and use the same modulation-and-coding scheme as previous transmission
- The time between reception of an uplink grant and transmission on the UL-SCH if fixed, for FDD is *n* subframe for uplink grant and *n*+4 subframe for UL-SCH transmission

PDCCH processing

- RNTI is included in CRC calculation but not explicit transmitted, different RNTIs are used for different DCI message
- PDCCH is transmitted on an aggregation of one or several control channel elements (CCE) where a CCE corresponds a set of RE
  - 1 PDCCH = 1, 2, 4, 8 CCEs depending on DCI payload and channel coding rate
  - 1 CCE = 9 REGs
- PDCCH is mapped to REG following the map of PCFICH and PHICH

Blind decoding of PDCCHs

- The number of CCEs is not signaled and has to be blindly decoded
- To reduced decoding complexity, use 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, ...)

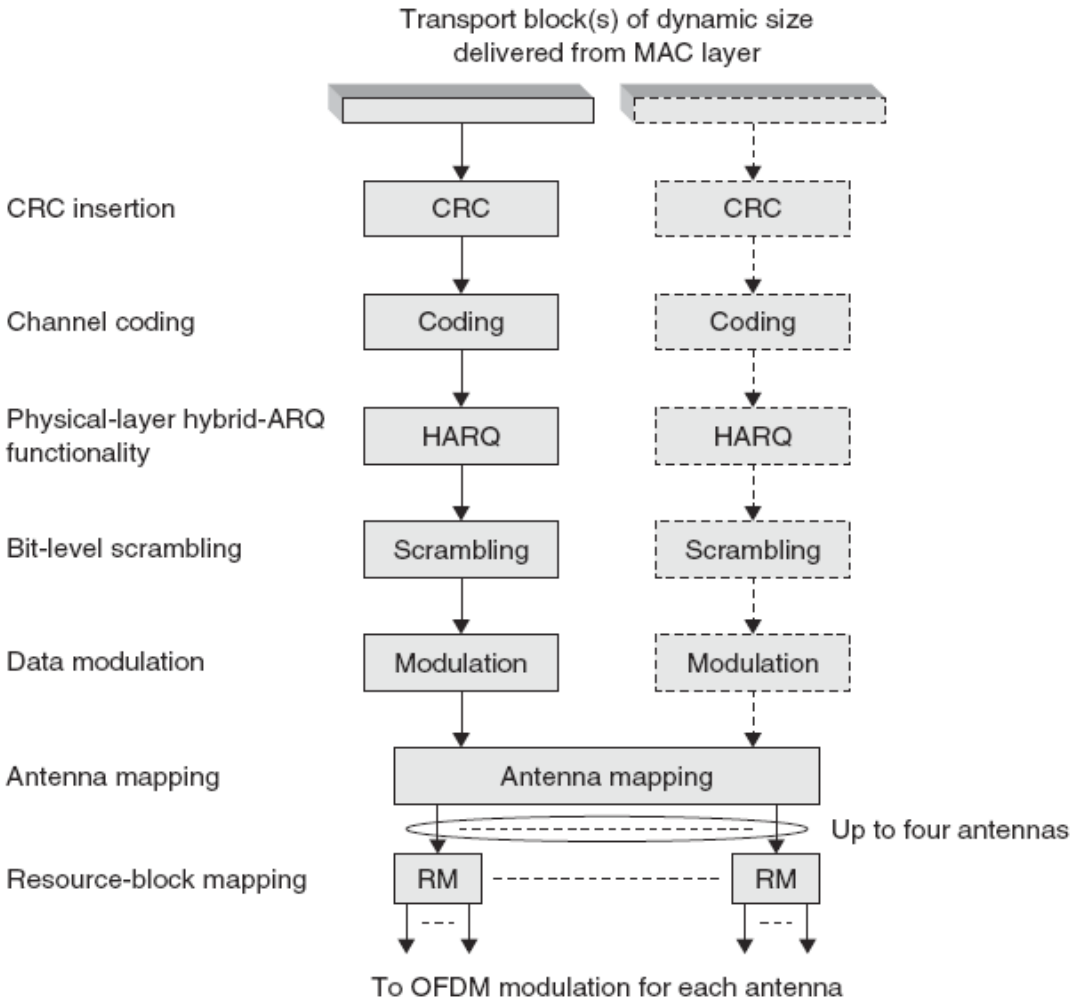
Blind decoding of PDCCHs

- 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 signaling (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

Blind decoding of PDCCHs

- UE-specific search space
  - 32 blind decoding attempts
  - Aggregation levels 1, 2, 4, 8
  - Decoding attempts per payload size
  - defined through a function of the terminal identity and subframe number, thus time varying (help resolving blocking)

DL transport-channel processing



DL transport-channel processing

- CRC appended per transport block: 24 bit
- Code-block segmentation
  - transport block segment into smaller code blocks (<=6144 bits) to match code size of turbo coder
  - Filler bits inserted at the head of the first code blocks
  - CRC is appended in each code block
- Turbo coding
  - 8 states, 1/3 code rate
  - QPP interleaver: maximum contention free, allow parallel processing

DL transport-channel processing

- Rate-matching and HARQ
- Bit-level scrambling
  - Applied to all transport channels
  - Cell specific scrambling to ensure interference randomization
  - MBSFN use cell-common scrambling
- Modulation
  - QPSK, 16QAM, 64QAM
  - BCH use QPSK only

DL transport-channel processing

- Multi-antenna transmission
  - Transmit diversity
    - SFBC for 2 antenna ports
    - SFBC/FSTD for 4 antenna ports
    - Can be applied to BCH(must), PCH, PCFICH, PCHICH and PDSCH
  - Spatial multiplexing
    - Layer mapping
    - Close loop
      - UE report recommended number of layers (rank, RI) and pre-coder matrix (PMI) depending channel estimation
      - Network may or may not follow the recommedation. If not, will inform UE what precoder is used

	Codeword 1	Codeword2
Rank 1	Layer 1	
Rank 2	Layer 1	Layer 2
Rank 3	Layer 1	Layer 2 and Layer 3
Rank 4	Layer 1 and Layer 2	Layer 3 and Layer 4

Codeword-to-layer mapper for spatial multiplexing

DL transport-channel processing

- Open loop (large delay CDD)
  - Applicable for 2 or more layers
  - Suitable for high-mobility scenarios
  - Is a combination matrix P and W
  - W is fixed for 2 antenna ports and cycling through 4 of the defined 4XNL precoder matrix and is different for consecutive Res. But no information is needed to provide to terminal
  - P=UD, D is equivalent to CDD in the layer domain, P is used to average out any difference in channel conditions as seen by the different layers
- SM is only supported by DL-SCH

– General beam-forming
  - Non-codebook based, means the network can apply an arbitrary beam-forming at the transmitter side and does not need to inform the terminal
  - Base station transmit UE-specific RS to which has been applied the same BF
  - UE perform channel estimation on UE-specific RS to know what BF has been used
  - Only supported by DL-SCH

DL transport-channel processing

- RB mapping
  - Maps symbols to be transmitted to assigned RB pairs exclude
    - DL RS
    - DL L1/L2 control signaling
    - REs used for BCH ans synchronization signals
  - RB allocation usually based on channel condition, but in some case, channel dependent scheduling is not suitable or even practically possible
    - Low rate service, extensive overhead
    - High mobility, difficult to track the channel
  - In those cases, better utilize frequency diversity by using resource allocation type 0 or 1, but with some drawbacks
    - Minimal size of RB can be as large as 4 RB pairs, not suitable for limit size resource allocation
    - Resource allocation type 0 or 1 are associated with relatively large PDCCH payload

DL transport-channel processing

- Virtual RB (VRB)
  - provide distribute RB allocation in case of resource allocation type 2 and also distributing a single RB pair in frequency domain
- Mapping of VRB to physical RB (PRB)
  - Localized VRBs: direct mapping
  - Distributed VRBs
    - Step1: use block interleaver such that consecutive VRB pairs are not mapped to frequency-consecutive PRB pairs
    - Step2: use a certain frequency gap to split each RB pair

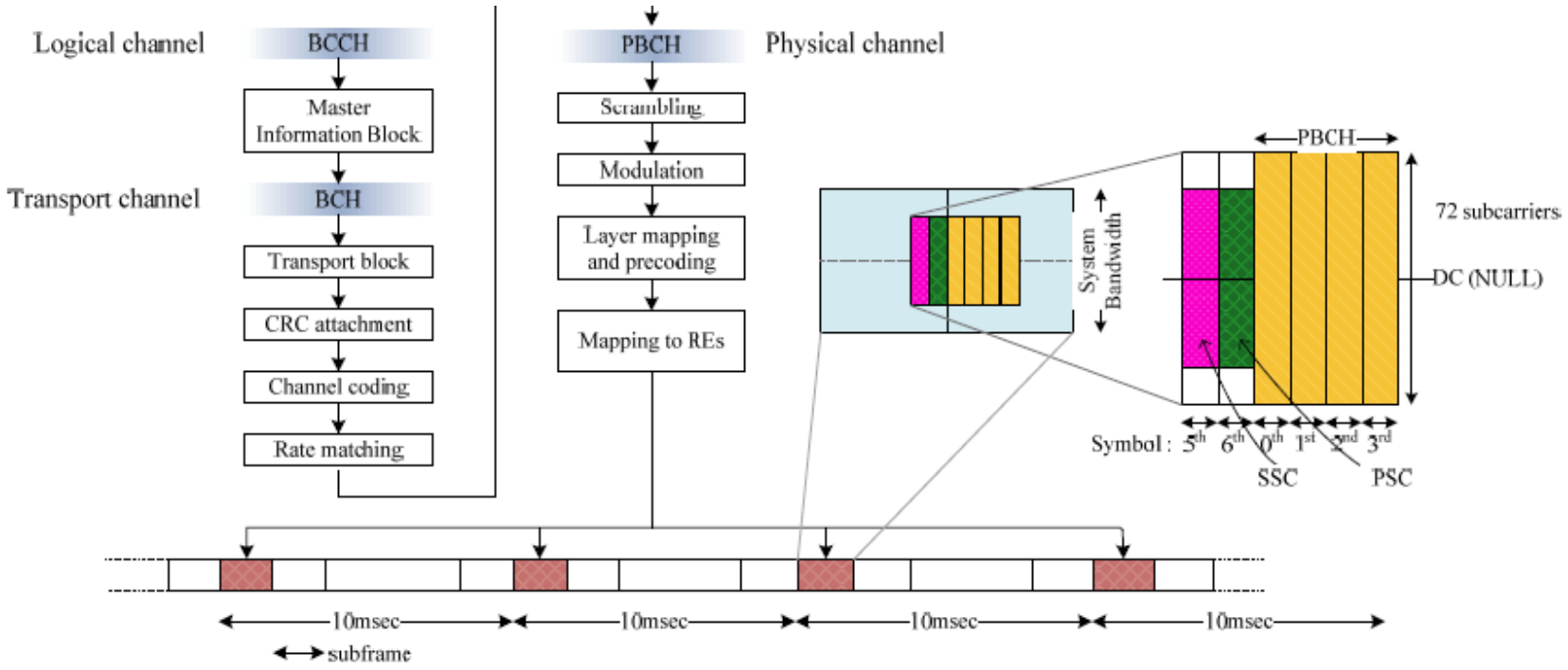
System Information PBCH

- 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

- Cell-specific scrambled prior to modulation
- Modulation: QPSK
- Mapping to resource elements
  - Within the first four OFDM symbols of the second slot of the first subframe of each frame in four consecutive frames with 40ms interval
  - Over 72 center subcarriers
- 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…
- TX diversity is used

PBCH

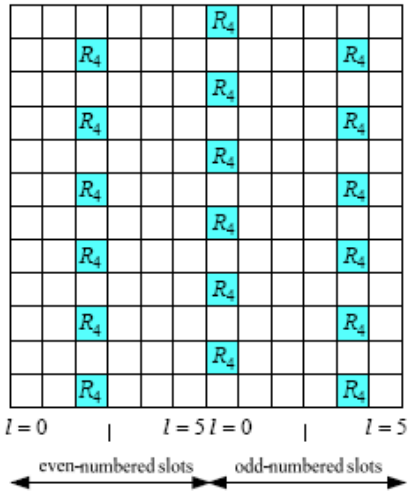

Logical channel
BCCH
Master Information Block
Transport channel
BCH
Transport block
CRC attachment
Channel coding
Rate matching
PBCH
Physical channel
Scrambling
Modulation
Layer mapping and precoding
Mapping to REs
System Bandwidth
PBCH
72 subcarriers
DC (NULL)
Symbol : 5th 6th 0th 1st 2nd 3rd
SSC
PSC
10msec
10msec
10msec
10msec
subframe

MBSFN transmission and MCH

- Benefits
  - Increase received signal strength, especially at the cell borders
  - Reduced interference, especially at the cell borders
  - Additional diversity gain
- MBSFN transmitted on MCH and mapped to MBSFN subframe, consist of
  - A unicast part (may or may not be available)
    - Use the same CP length as Non-MBSFN subframe
    - Sever as the same purpose as the control region of Non-MBSFN subframe
    - Consist UL scheduling grant, HARQ ACK/NACK, power control for UL but no DL scheduling assignment
    - Maximal 2 OFDM symbols, must be same for all cells involve in the MBSFN and can not dynamically adjusted

MBSFN transmission and MCH

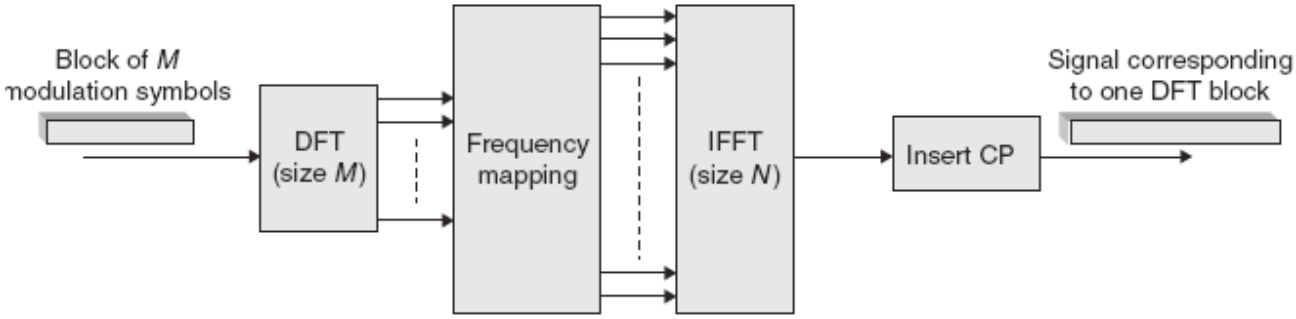
  - An MBSFN part
    - Use extend-CP, there is hole between unicast part and MBSFN part
- MBSFN is referred as transmission using antenna port 4
  - Use MBSFN RS to do channel estimation, those RSs have the same values from each cell
  - MBSFN RS has higher density because of higher frequency selectivity



RS structure in MBSFN

UL transmission scheme

- DFTS-OFDM (SC-FDMA) is used in UL
- Output of DFT is always mapped to consecutive inputs of OFDM modulator
- Consider DFT implementation and resource allocation flexibility tradeoff, DFT size is limited to the produce of 2, 3, 5
- Time-frequency structure is similar to DL but no unused DC



The basic principle of DFTS-OFDM

UL transmission scheme

- MIMO is not supported because only one MBSFN RS, MBSFN has provided substantial diversity
- All UEs need to know which is MBSFN subframe. This information is provided as part cell system information.
- The same data transmitted with same TF using the same physical resources from multiple cells. Resource allocation can not be dynamically adjusted
- HARQ is not directly supported
- Scrambling must be MBSFN-area specific.

UL RS

- UL demodulation RS (DRS)
  - Used for coherent demodulation of the PUSCH and PUCCH
  - Transmitted together with and covering the same frequency band as the corresponding physical channel
- UL sounding RS (SRS)
  - Allow network to estimate the channel quality at different frequency
  - Cover a larger frequency span

UL DRS

- Transmitted in the 4th symbol of each slot for PUSCH
- The number of symbols used for DRS and the exact position differs between different PUCCH formats
- Use a frequency-domain reference sequence as a consecutive inputs of OFDM modulator plus a time-domain CP
  - The length of sequence is a multiple of 12
  - Limited power variations in the frequency domain to allow for similar channel-estimation quality of all frequencies
  - Limited power variations in the time domain to allow for high power-amplifier efficiency

UL DRS

- In LTE, for sequence length larger than or equal to 36, cyclic extensions of Zadoff-Chu sequences is used
- For sequence length equal to 12 and 24, special QPSK-based sequences have been found through computer search
- At least 30 sequences available for each length
- Those sequences are used as basic RS sequences
- Additional RS sequences are derived by applying different linear phase rotation to the same basic RS sequences

UL DRS

- Orthogonality of RS sequences
  - RSs defined from different RS sequences have relatively low but non-zero orthogonality
  - RSs defined from the same basic RS sequences with phase rotation of $m\pi/6$ where m = 1 to 11 are orthogonal
  - At the receiver side, to a subset of phase rotation values should be used to keep orthogonality when channel is frequency selective over the span of 1 RB
  - The RSs defined from the same basic RS sequences with different phase rotation should be received relatively time aligned
- Orthogonal RS sequences can be used
  - For different terminals within the same cell using the same UL frequency resource (eg, UL virtual MIMO)
  - For different terminals in neighbor cells belonging to the same eNodeB

UL DRS

- RS assignment to cells
  - First grouped into 30 sequence groups, each group consist of:
    - One RS sequence for each length less than or equal to 60
    - Two RS sequences for each length larger than or equal to 72
  - In a given time slot, UL RS sequence to be used within a cell is taken from one specific group
    - Fix assignment: use the same group for the all the slots;
      - For PUCCH, the group to use is indicated by physical layer cell identity (0~503) modulus 30
      - For PUSCH, the group to use is signaled as part of cell system information
    - Group hopping: the group to use is given by the group-hopping pattern (given by the cell identity) plus cell identity modulus 30
  - for each length larger than or equal to 72
    - Fixed: always use the first sequence
    - Sequence hopping: varying between slots, only group hopping is not enabled

UL SRS

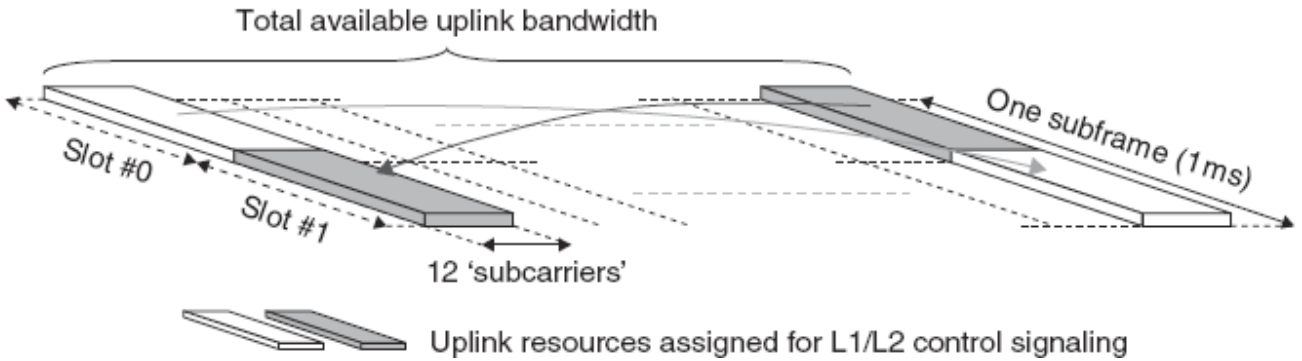
- Transmitted at regular interval (2ms ~160 ms), occupies the last symbol of the subframe
- Cover the frequency band of interest for frequency domain scheduling
  - Sufficient wide band, but suffer from low received power density at bad channel
  - Narrow band with frequency hopping
  - Be a multiple of 4 RBs
- To avoid collision
  - all terminals within a cell should aware what set of subframes used by SRS and not used
  - Use similar SRS as DRS, and different phase rotation
  - Mapped to different frequency shift in comb-type spectrum

UL L1/L2 control signaling

- Consist of
  - HARQ ACK/NACK for received DL-SCH transport block
  - Terminal reports related to the DL channel conditions
  - Scheduling request for UL-SCH
- UL L1/L2 control signaling need to be transmitted on the UL regardless of mobile terminal has UL-SCH or not
  - No simultaneous transmission of UL-SCH, use PUCCH
  - simultaneous transmission of UL-SCH, time multiplexed with the coded UL-SCH

UL L1/L2 control signaling on PUCCH

- PUCCH resources are located at the edge of total available BW and different slots of the same subframe
  - Maximize frequency diversity
  - Avoid fragmented UL spectrum
- Multiple terminals can share the same RB for PUCCH by assigning different orthogonal phase rotation of a cell-specific frequency sequence similar to RS sequence



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)

Normal CP

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

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

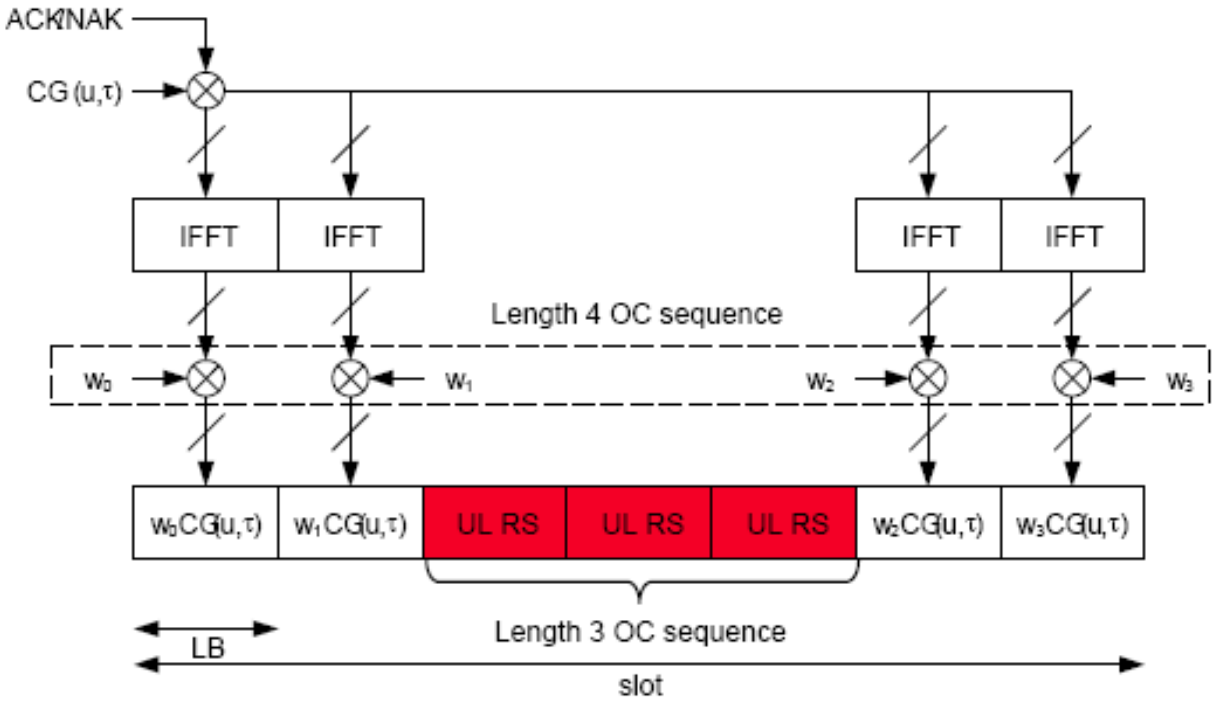
Demodulation reference signal location for different PUCCH formats

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/1b

- UE ACK/NACK signals are distinguished by both frequency sequences with different phase rotation 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 signaled once when the persistent scheduling information for data is sent to the UE
- The use of phase rotation together with orthogonal cover (OC) provides orthogonality between different terminals in the same cell transmitting PUCCH on the same set of RBs
- To randomize inter-cell interference
  - Phase rotation varies on a symbol-base according to cell-specific hopping pattern
  - Slot level hopping is applied to OC and phase rotation
- In case of PUCCH and sounding in the same subframe, use length 3 sequence for BPSK/QPSK symbol to leave one symbol for souding

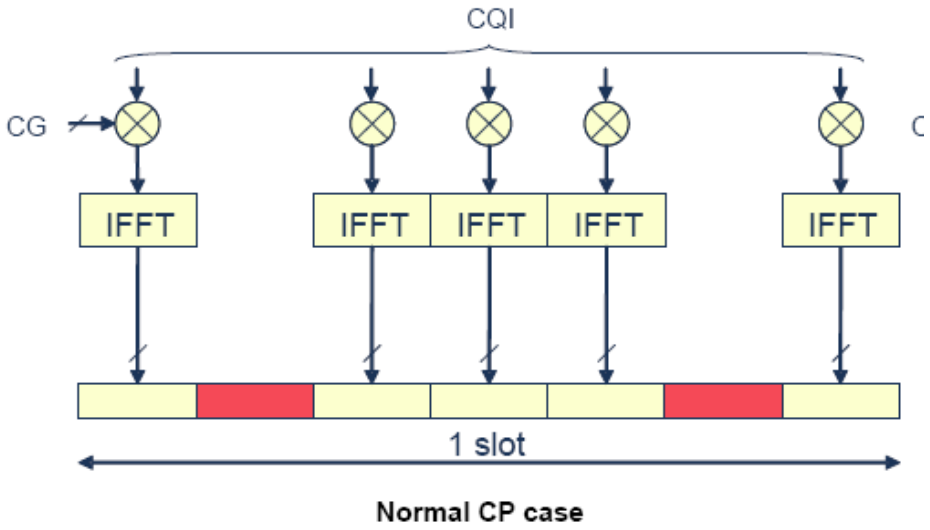
PUCCH format 1a/1b



Normal CP case

PUCCH Format 2

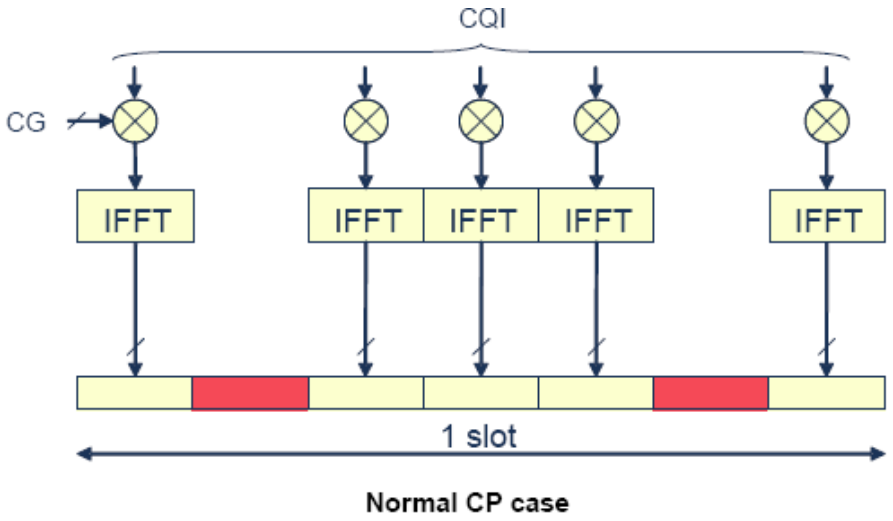
- Cases
  - CQI only
  - CQI+ACK/NACK with expended CP
- Bit scrambled by UE specific scrambling sequence
- QPSK, (20, A) simplex code
- Phase rotation based orthogonality of CG sequence
- Phase rotation hopping on symbol basis



Normal CP case

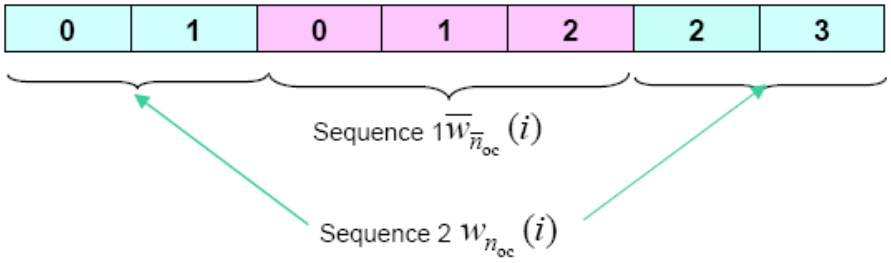
PUCCH Format 2a and 2b

- 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 2nd RS symbol in each slot
- Format 2a: QPSK CQI + BPSK ACK/NACK
- Format 2b: QPSK CQI + QPSK ACK/NACK



PUCCH Format 1

- 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
  - Sequence 2: Length 4
- 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



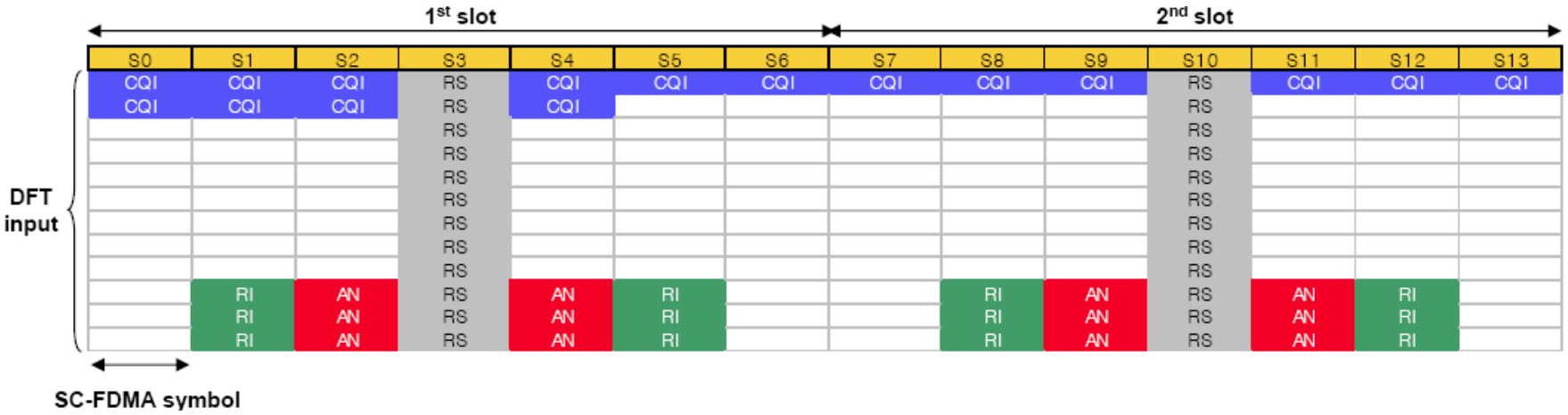
Mapping PUCCH to Physical Resources

- 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

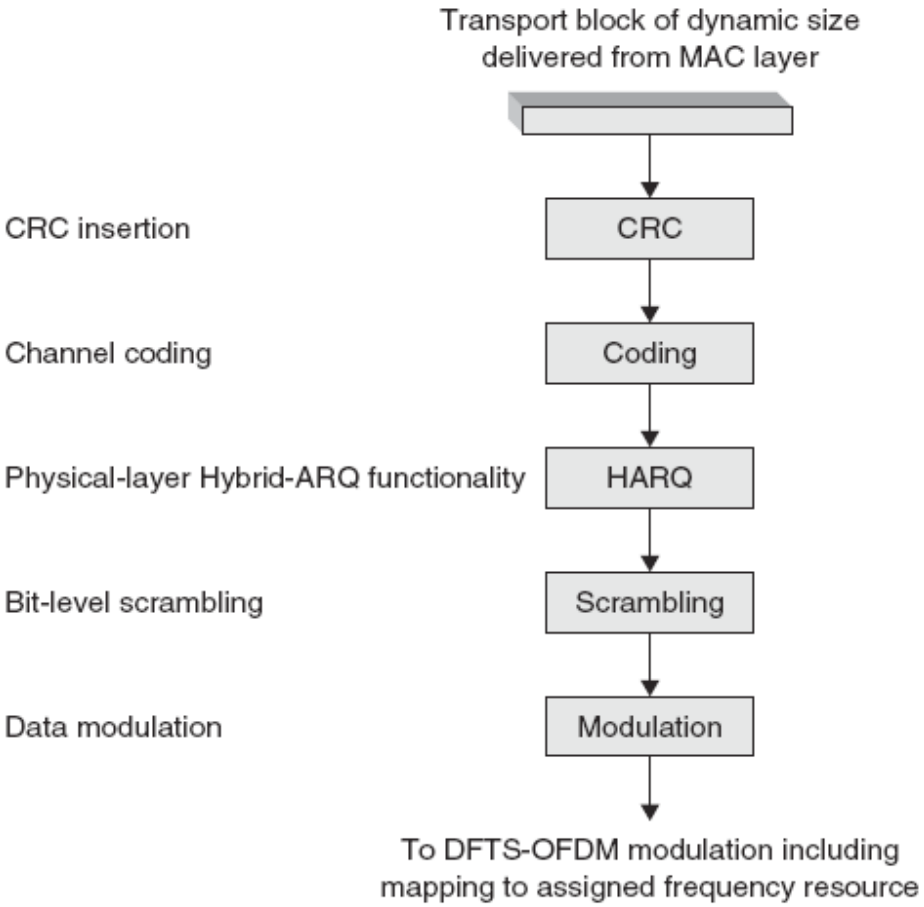
UL L1/L2 control signaling on PUSCH

- Only HARQ and channel status report are transmitted on PUSCH
- HARQ ACK/NACK use QPSK are punctured into the coded UL-SCH bit stream
- Channel status report on PUSCH is aperiodic report and requested by eNodeB
- If a period report is configure on PUCCH in a subframe where PUSCH scheduled, period report is rerouted on PUSCH
- The channel coding of channel status report can be block coding for small size or tail-biting CC for CQI/PMI, RI use (3, 2) block code
- The code rate for L1/L2 control signaling is varied according to scheduling decision for data of data part P412

UL L1/L2 control signaling on PUSCH



UL transport channel processing



PUSCH frequency hopping

- RB pairs in different slots need frequency separation
- Two types of hopping
  - Subband hopping according to cell-specific hopping/mirroring patterns
    - First, a set of consecutive subbands of a certain size is defined, edges excluded
    - In scheduling grant, virtual resource (a set of VRBs) is given
    - PRB shift according to predefined cell-specific hopping or mirror pattern
  - Hopping based on explicit hopping information in the scheduling grant include:
    - Information about the resource to use in the first slot
    - Additional information, about the offset of the resource to use

PRACH

- BW of random access burst corresponds to 6RBs
- Subcarrier spacing
  - 1.25KHz for FDD
  - 7.5KHz for TDD
- Consiste preamble sequence and CP
- 64 PA in a cell with two contention-based subsets and one contention-free subset
- 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

Thank you !