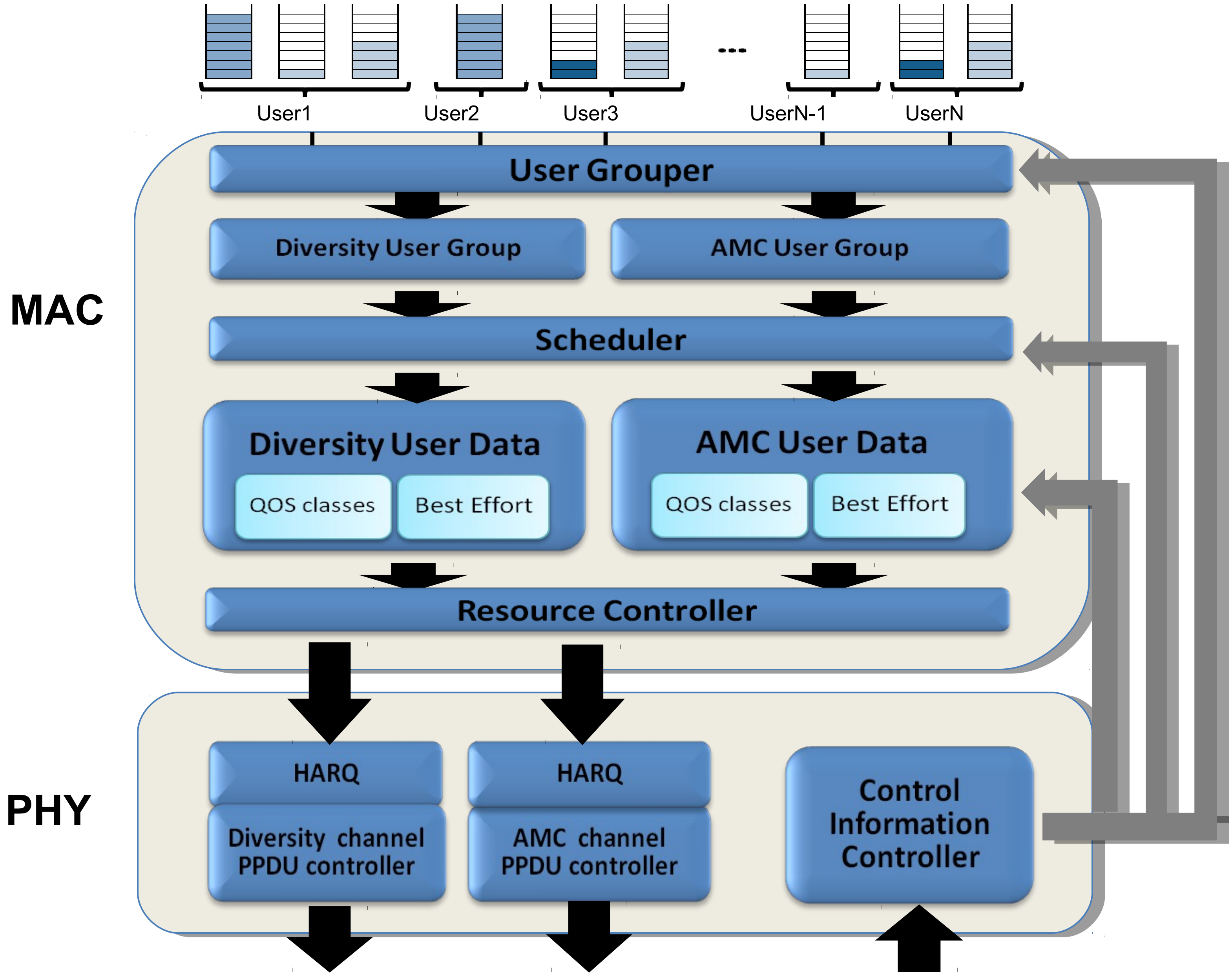
3GPP Long Term Evolution

Physical Layer

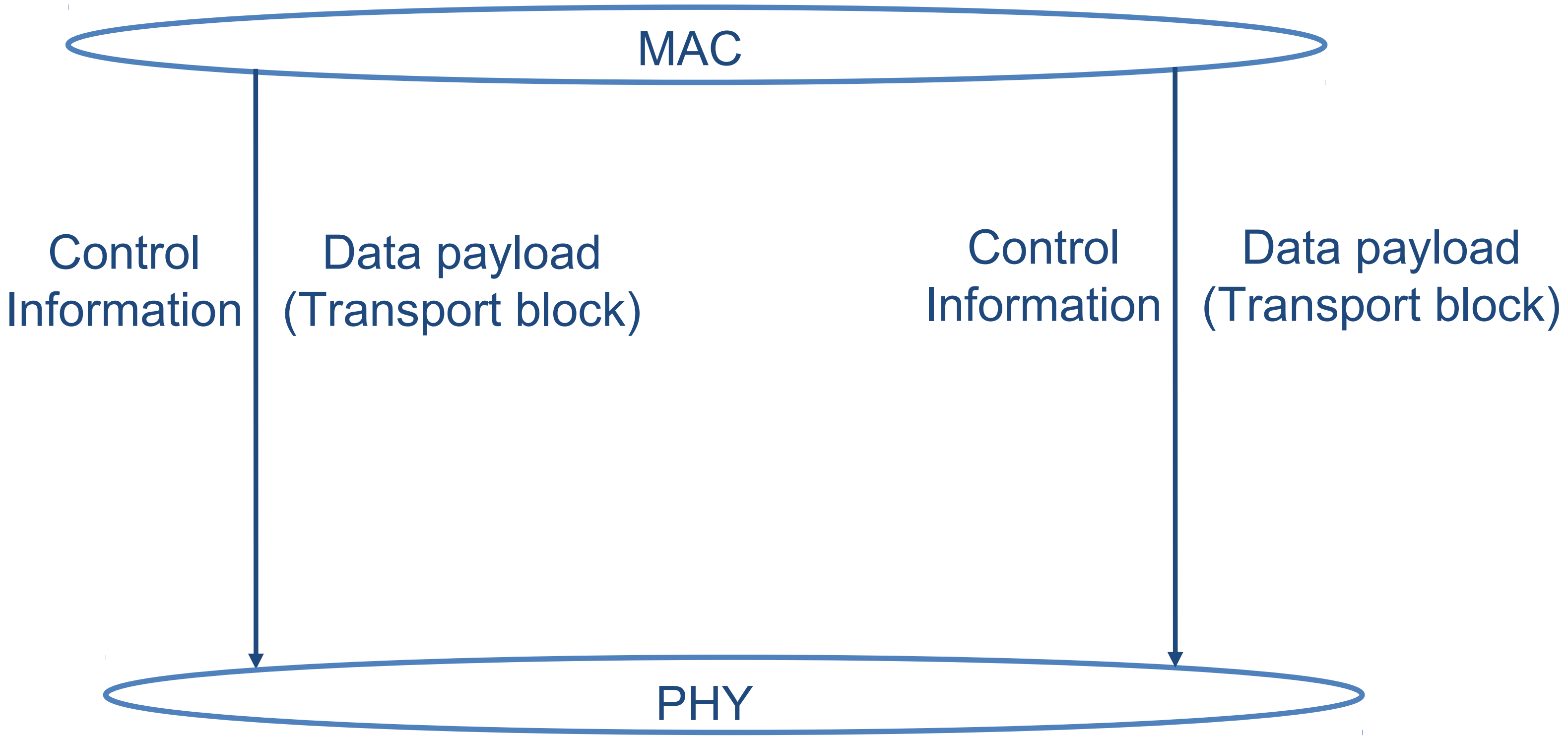
Rohit Budhiraja

Outline of the talk

- Brief overview of the eNodeB MAC-PHY interface
  - Information sent by the MAC to the PHY
    - Data and control information
- Concepts of Adaptive Modulation & Coding, BLER & CQI
- Description of Transceiver chain
  - Discussion of individual sub-blocks
- Concepts of Channel Estimation and Equalization
- Synchronization principles
  - DL Initial access
  - UL RACH
- Initial access example


User1
User2
User3
...
UserN-1
UserN
MAC
User Grouper
Diversity User Group
AMC User Group
Scheduler
Diversity User Data
QOS classes
Best Effort
AMC User Data
QOS classes
Best Effort
Resource Controller
PHY
HARQ
Diversity channel PPDU controller
HARQ
AMC channel PPDU controller
Control Information Controller

MAC-PHY Interface



Transport block (TB) sizes & Modulation order details

- TB sizes are specified in the standard using a Table
  - Table is indexed using
    - Modulation and Coding Scheme (MCS)
    - Number of PRBS
- MCS indirectly specifies the coding-rate
- MCS and number of PRBS are decided by the Scheduler
  - Based on Channel Quality Information (CQI) feedback from the UE
  - Also a function of fairness and number of active users in the system

Modulation order and TBS Index relationship

MCS Index I_{MCS}	Modulation Order Q_m	TBS Index I_{TBS}
0	2	0
1	2	1
2	2	2
3	2	3
4	2	4
5	2	5
6	2	6
7	2	7
8	2	8
9	2	9
10	4	9
11	4	10
12	4	11
13	4	12
14	4	13
15	4	14
16	4	15
17	6	15
18	6	16
19	6	17
20	6	18
21	6	19
22	6	20
23	6	21
24	6	22
25	6	23
26	6	24
27	6	25
28	6	26
29	2	reserved
30	4	
31	6	

Two MCS indices refer to same TBS indices

Reserved for UL HARQ

Ref: (Table 7.1.7.1-1 of 36.213)

Rohit Budhiraja

Transport Block Size Table

I_{TBS}	N_{PRB}									
	1	2	3	4	5	6	7	8	9	10
0	16	32	56	88	120	152	176	208	224	256
1	24	56	88	144	176	208	224	256	328	344
2	32	72	144	176	208	256	296	328	376	424
3	40	104	176	208	256	328	392	440	504	568
4	56	120	208	256	328	408	488	552	632	696
5	72	144	224	328	424	504	600	680	776	872
6	328	176	256	392	504	600	712	808	936	1032
7	104	224	328	472	584	712	840	968	1096	1224
8	120	256	392	536	680	808	968	1096	1256	1384
9	136	296	456	616	776	936	1096	1256	1416	1544
10	144	328	504	680	872	1032	1224	1384	1544	1736
11	176	376	584	776	1000	1192	1384	1608	1800	2024
12	208	440	680	904	1128	1352	1608	1800	2024	2280
13	224	488	744	1000	1256	1544	1800	2024	2280	2536
14	256	552	840	1128	1416	1736	1992	2280	2600	2856
15	280	600	904	1224	1544	1800	2152	2472	2728	3112
16	328	632	968	1288	1608	1928	2280	2600	2984	3240
17	336	696	1064	1416	1800	2152	2536	2856	3240	3624
18	376	776	1160	1544	1992	2344	2792	3112	3624	4008
19	408	840	1288	1736	2152	2600	2984	3496	3880	4264
20	440	904	1384	1864	2344	2792	3240	3752	4136	4584
21	488	1000	1480	1992	2472	2984	3496	4008	4584	4968
22	520	1064	1608	2152	2664	3240	3752	4264	4776	5352
23	552	1128	1736	2280	2856	3496	4008	4584	5160	5736
24	584	1192	1800	2408	2984	3624	4264	4968	5544	5992
25	616	1256	1864	2536	3112	3752	4392	5160	5736	6200
26	712	1480	2216	2984	3752	4392	5160	5992	6712	7480

Code – rate calculation

Ref: (Table 7.1.7.2.1-1 of 36.213)

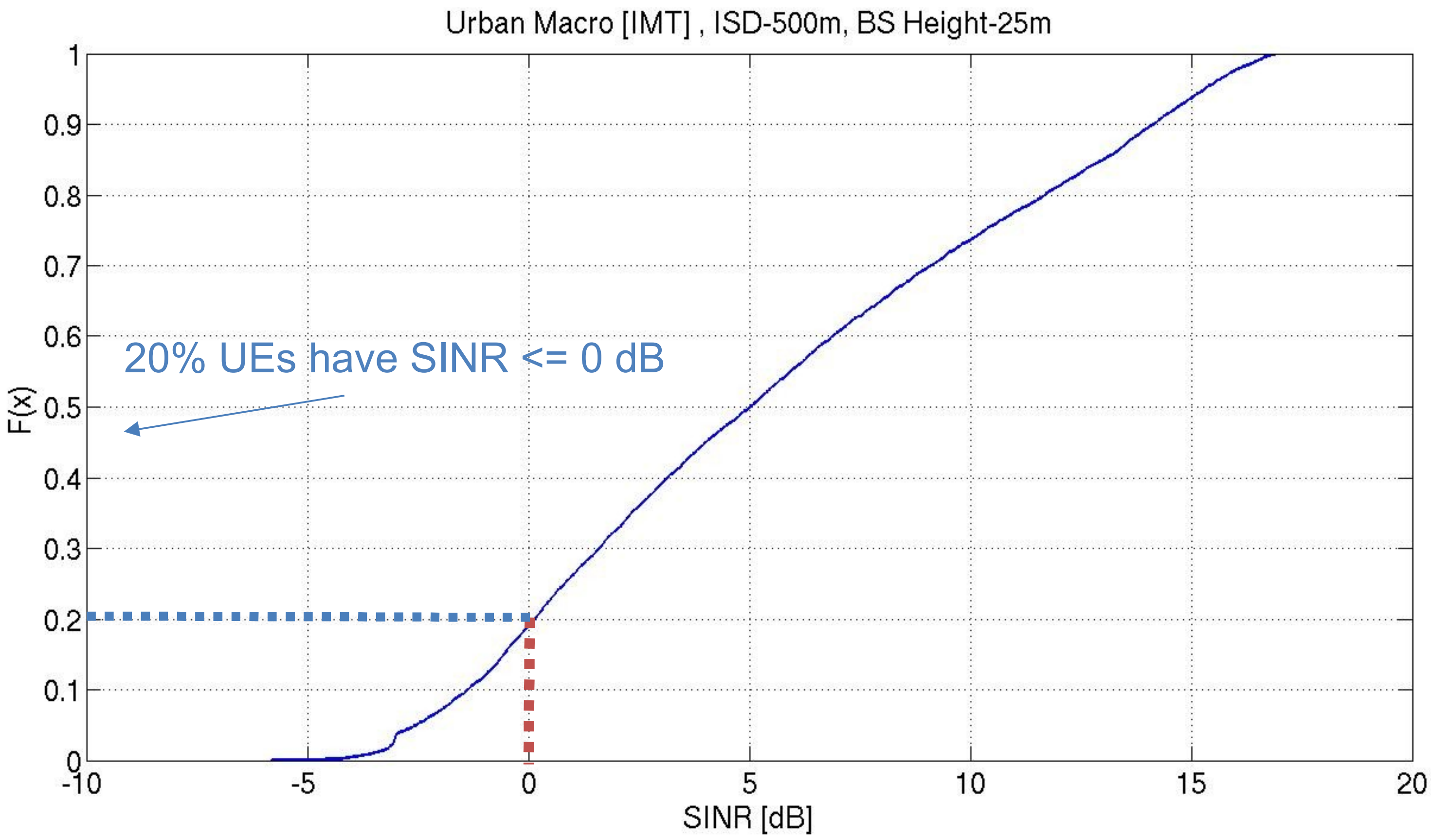
Adaptive Modulation & Coding

Fundamentals of Adaptive Modulation and Coding (AMC)

- Wireless channel has statistical variations
  - A mobile user channel will vary with its location & speed
- Channel variations can be estimated and fed-back
  - For a slow moving user:
    - (Nearly) exact channel can be fed-back to eNodeB
    - Done by quantizing the channel
      - Done by feeding back the MCS, PMI and RI (Will revisit later)
  - For a fast moving user
    - First (mean) and second order (variance) statistics can be fed
- AMC
  - Achieves capacity
  - Binary (but not practical) way to state:
    - Transmit only when channel is good and don't when channel is bad
  - Non binary way:
    - Match the code-rate to the channel conditions

Channel Conditions

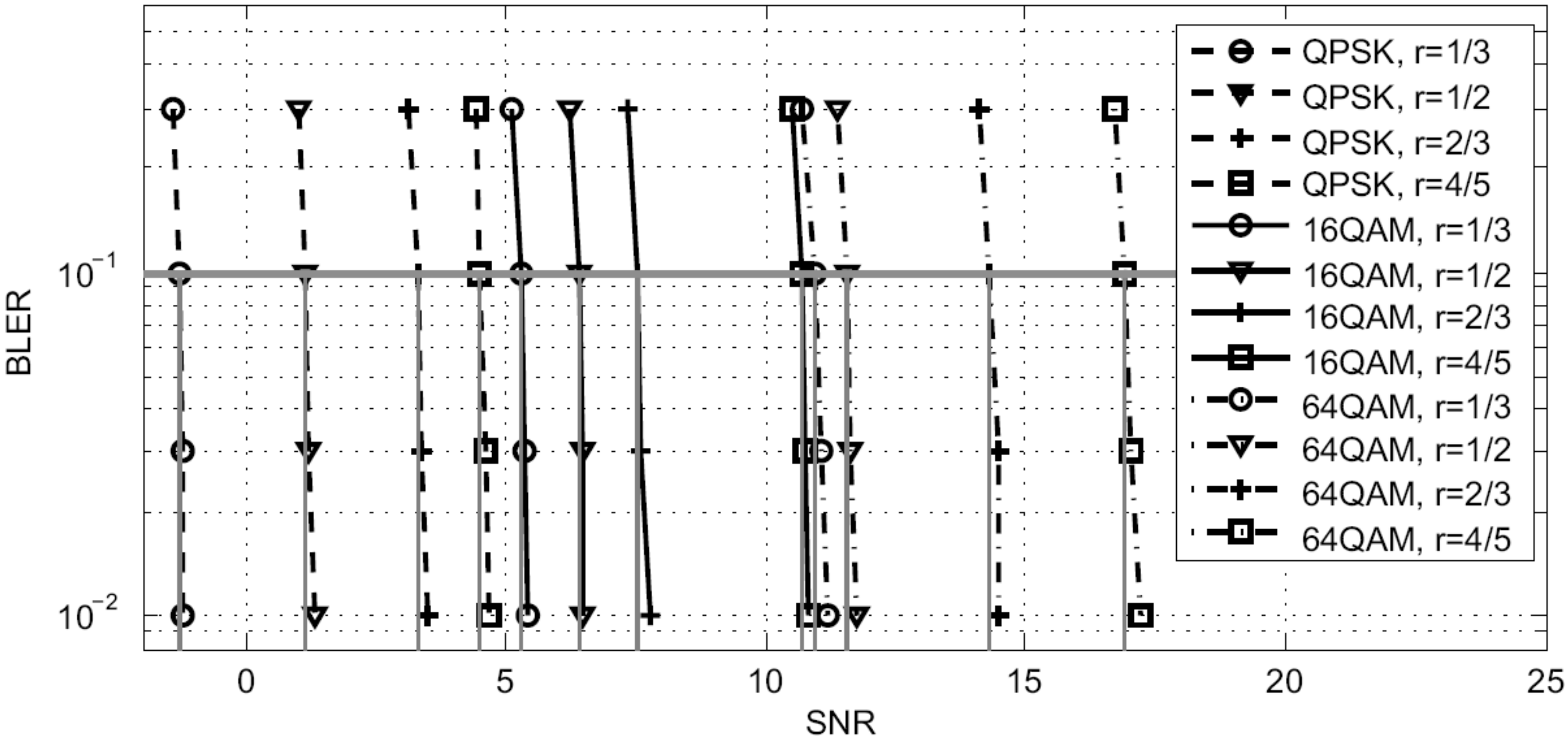
- Channel condition = SINR seen by a particular user



SINR CDF plot

BLER concept

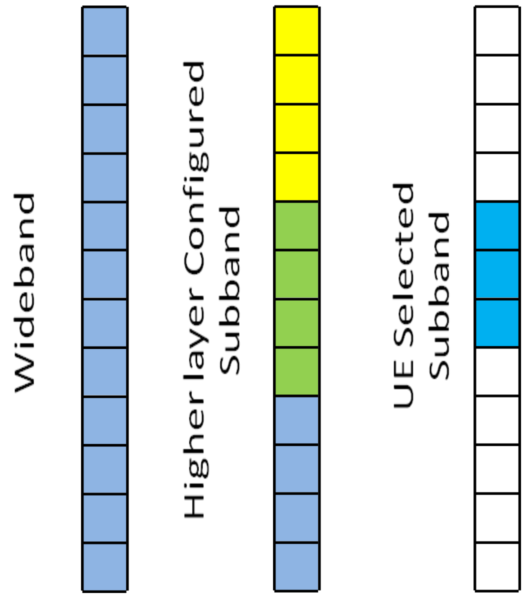
- Turbo codes are capacity achieving
  - Does-not follow water-fall behavior like Convolutional code
  - BER/BLER drops to zero after a particular SNR



Ref: (Figure 10.1 **Stefania Sesia et. al,** LTE – The UMTS Long Term Evolution)

CQI concept

- UE calculates the post-processing SNR
  - Post-processing SNR – Depends on the capability of UE (UE category)
  - A particular category UE has 2 antennas
    - 3 dB extra gain
    - Category indirectly refers to the UE price
- UE maps the post-processing SNR to the MCS
- Different kinds of CQI



Aperiodic CQI reporting (1/2)

- Wideband
  - CQI for the entire system bandwidth
- Higher layer configured sub-band
  - UE reports a wideband CQI value for the whole system bandwidth
  - In addition, the UE reports a CQI value for each subband, calculated assuming transmission only in the relevant sub-band
  - Sub-band CQI reports are encoded differentially with respect to the wideband CQI using 2-bits as follows

Sub-band differential CQI offset = Sub-band CQI index −Wideband CQI index

  - Possible sub-band differential CQI offsets are {<-1,0,+1,>+2}

Ref: (Table 7.2.1-3 of 36.213)

Aperiodic CQI reporting (2/2)

- UE selected sub-bands
  - UE selects a set of *M* preferred sub-bands of size *k* within the whole system bandwidth
  - UE reports one wideband CQI value and one CQI value reflecting the average quality of the *M* selected sub-bands
  - UE also reports the positions of the *M* selected sub-bands
  - Sub-band CQI reports are encoded differentially with respect to the wideband CQI using 2-bits as follows

Differential CQI = Index for average of *M* preferred sub-bands − Wideband CQI index

  - Possible sub-band differential CQI offsets are {<+1,+2,+3,

System Bandwidth $N_{\mathrm{RB}}^{\mathrm{DL}}$	Subband Size k (RBs)	*M*
6 – 7	NA	NA
8 – 10	2	1
11 – 26	2	3
27 – 63	3	5
64 – 110	4	6

Ref: (Table 7.2.1-5 of 36.213)

Periodic reporting

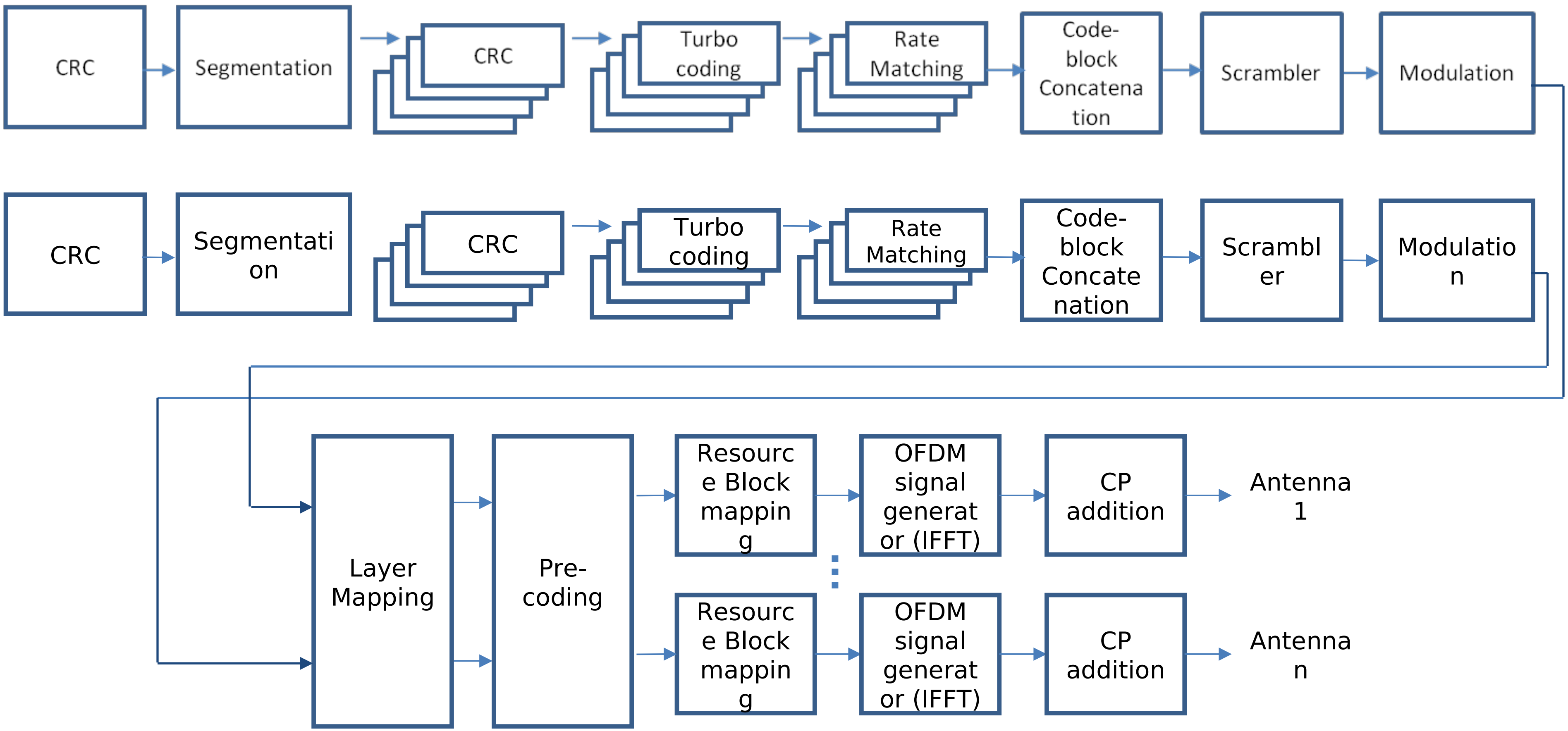
- RRC connection reconfiguration message configures the reporting modes
  - Only wideband and UE-selected sub-band feedback is possible for periodic CQI reporting
  - Sent using the PUCCH
  - Period = {2, 5, 10, 16, 20, 32, 40, 64, 80, 160} ms or Off
  - The UE selected subband reports are based on bandwidth parts and not on subbands as in the aperiodic case

System Bandwidth N_{RB}^{DL}	Subband Size k (RBs)	Bandwidth Parts (J)
6 – 7	NA	NA
8 – 10	4	1
11 – 26	4	2
27 – 63	6	3
64 – 110	8	4

Ref: (Table 7.2.2-2 of 36.213)

LTE Transceiver chain

eNodeB PHY Transmit chain



CRC

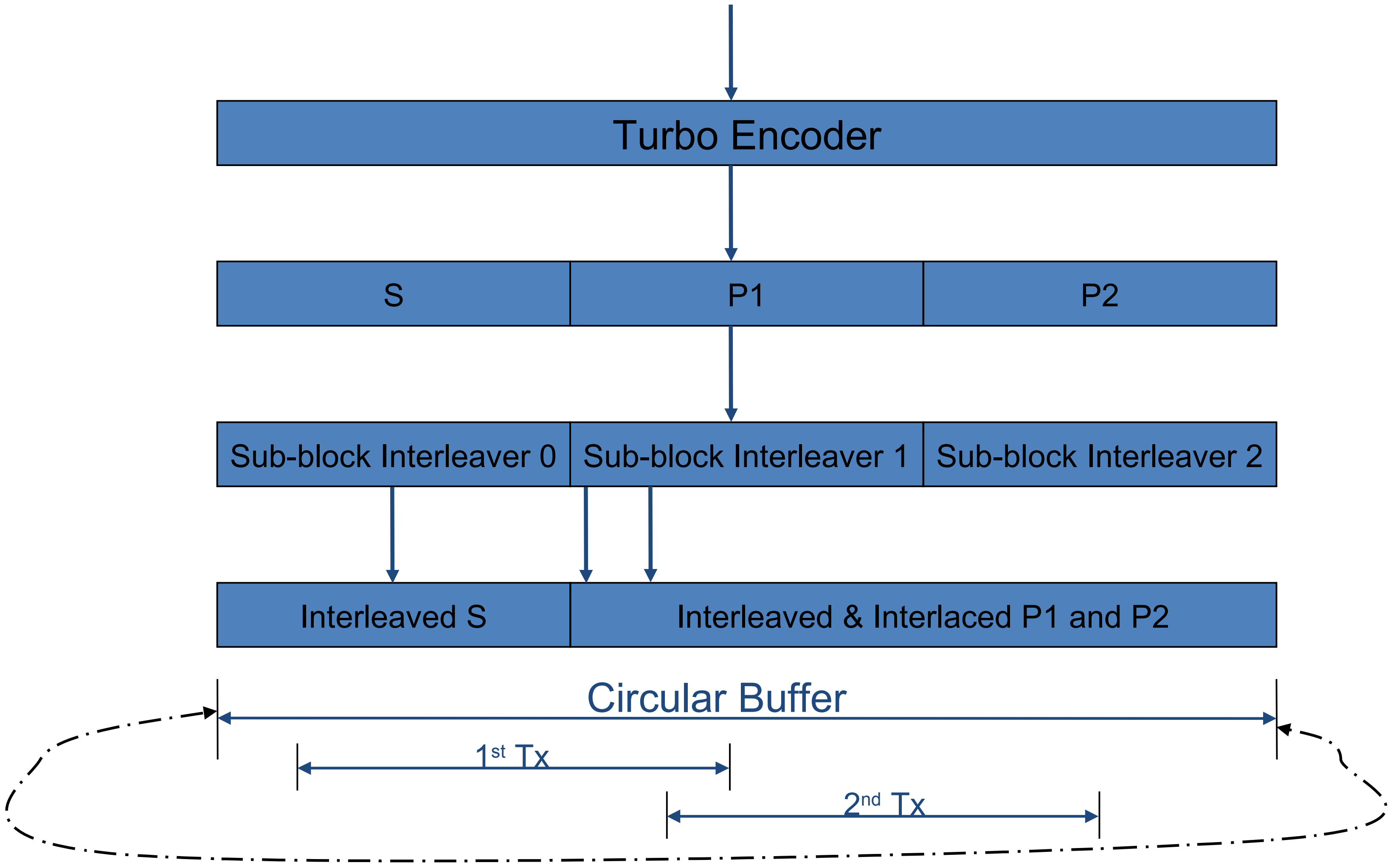
- Performs error detection
  - Does not correct
- Essential for HARQ implementation
- Different CRC for data and control
- 24-bit for data
  - Transport block can be segmented into multiple code blocks
  - CRC is computed for the Transport Block and each segmented code block
    - Allows error detection at code-block level
    - If a code-block is in error, no need to process remaining code blocks
  - CRC for TB and each code-block
    - Duplication of efforts?
    - Different polynomials for TB-CRC and code-block CRC
      - Allows detection of any residual errors
- 16-bit for DL control
- 8-bit for UL control (when multiplexed with data)

Ref: (5.1.1 of 36.212)

Segmentation

- Transport block size can be greater than Turbo code block size
  - Maximum Turbo code block size – 6144
  - Maximum Transport block size (for MCS-26 and 110 RBs)-73376
    - TB should be segmented if TB size > 6144
- BLER performance is limited by the smallest TB size
  - Coding gain is less
- Segmentation block ensures that a TB is divided into equal size code-blocks
  - E.g., TB size of 6224 is segmented into two code block of sizes 3136
- Maximum Turbo code block size in UMTS – 5114
  - Size increased in LTE such that 1500-byte TCP/IP packet is segmented into two code blocks instead of three
    - Increase the coding gain

Forward Error Correction Block



Forward Error Correction Block

- Turbo block input = K bits
  - Turbo block output - 3 streams of K bits +12 tail bits
    - K Systematic bits, K Parity1 bits, K Parity2 bits
    - 12 tail bits are shared across three stream
- Three streams are rearranged with their own sub-block Interleavers
  - Interleaver handles the block errors by spreading them across the code-block
- Single buffer is formed by placing the rearranged systematic bits
- Systematic bits are followed by interlacing of the two rearranged parity streams
  - Interlacing allows equal protection for each constituent code

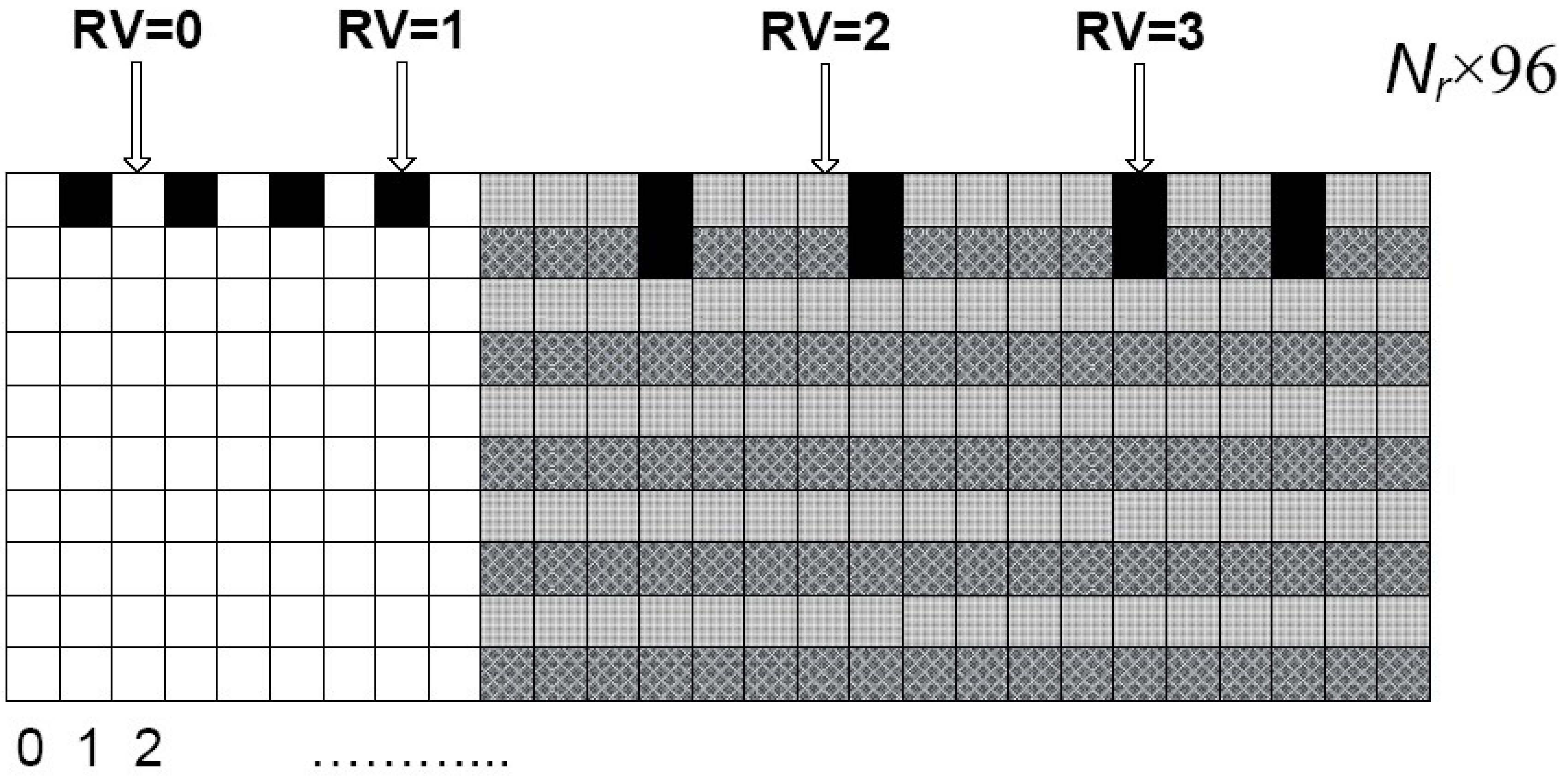
Sub-block Interleaver is based on row-column interleaver.

Rate Matching Principles

- Mother code-rate is 1/3
- Coded bits should be pruned to match the allocated resources
- Pruning implies repetition/puncturing
  - E.g., TB size is 256 for MCS-0 (QPSK) and NPRB-10
    - Total number of bits which can be transmitted
      - 10(NPRB) * 120(RE) * 2(QPSK) = 2400
    - Turbo encoder output length – 256*3 = 768
    - Bits should be repeated as encoded data is less than the resources available
      - code-rate is lower than 1/3rd
  - E.g., TB size is 1544 for MCS-9 (QPSK) and NPRB-10
    - Total number of bits which can be transmitted
      - 10(NPRB) * 120(RE) * 2(QPSK) = 2400
    - Turbo encoder output length – 1544*3 = 4632
    - Bits should be punctured as encoded data is more than the resources available
      - code-rate is higher than 1/3rd

Rate Matcher in LTE

- Circular buffer based rate-matcher



2-D view of the circular buffer

Rate Matcher in LTE

- Redundancy version specifies a starting point in the circular buffer
- Different RVs are specified by defining different starting points
- Usually RV-0 is selected for initial transmission to send as many systematic bits as possible
- Scheduler can choose different RVs to support Chase and IR HARQ
- Systematic bits are also punctured
  - ◊ Leads to enhanced performance at high-code rates [1]

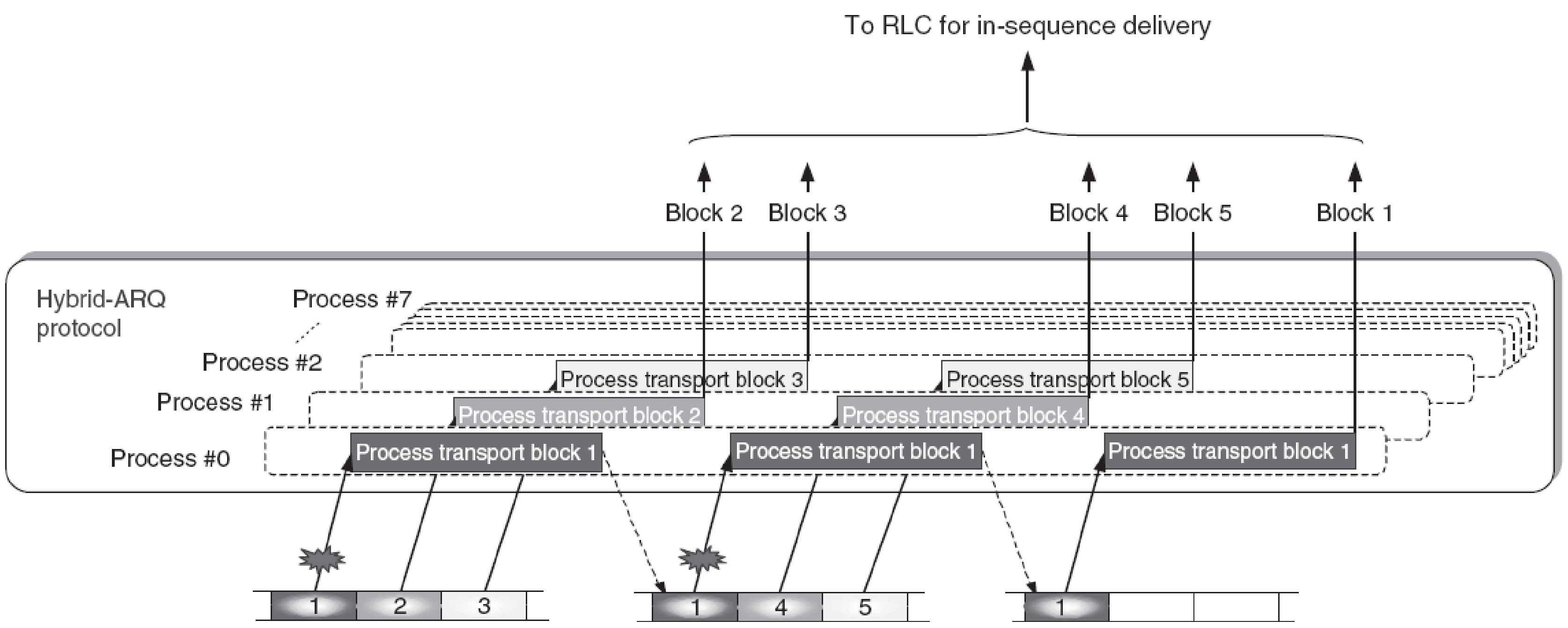
[1] *S. ten Brink, "Code Doping for Triggering Iterative Decoding Convergence"*

HARQ Principles

- Code-rate is decided by eNodeB after getting the CQI feed-back from UE
- In spite of this, a received TB could be in error
  - Fast moving user
    - CQI reported may be outdated
  - Slow moving user
    - Erroneous reporting of CQI in interference limited scenario
  - Standard specifies that the UE should specify the MCS
    - such that BLER= 10^{-1}
- HARQ is employed to utilize the time diversity
  - Chase – Same bits are transmitted
    - Allows Maximal ratio combining
  - Incremental redundancy – different RVs are transmitted
    - Coding gain

HARQ details

- Multiple parallel Stop and Wait processes in parallel

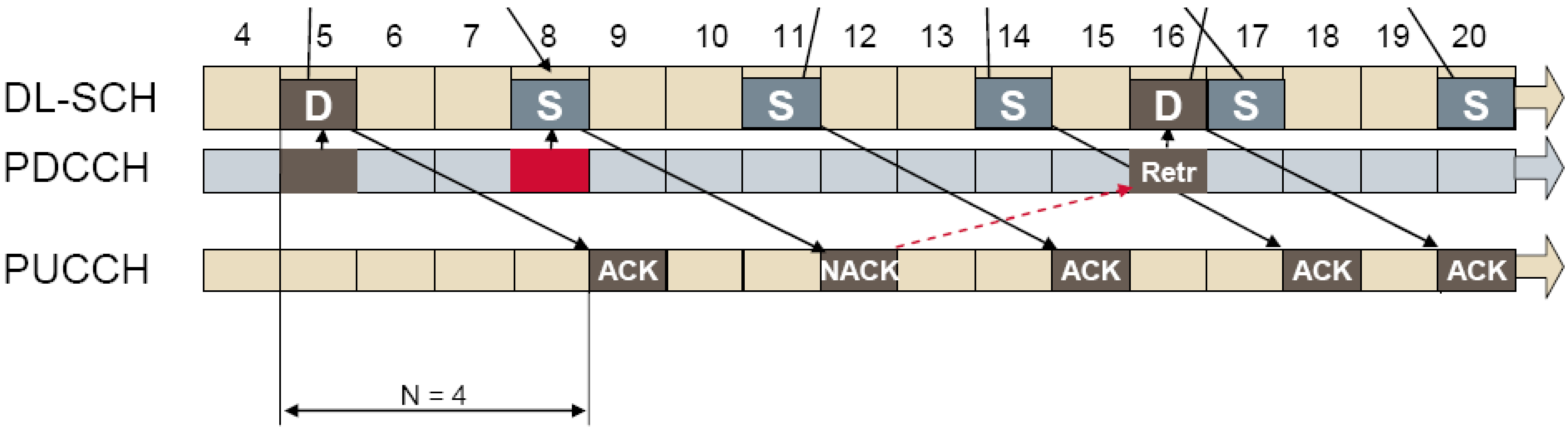


- Eight processes in parallel

Ref: (Figure 19.1, Dehlman et. al. 3G EVOLUTION : HSPA AND LTE FOR MOBILE BROADBAND)

HARQ flow-diagram in DL

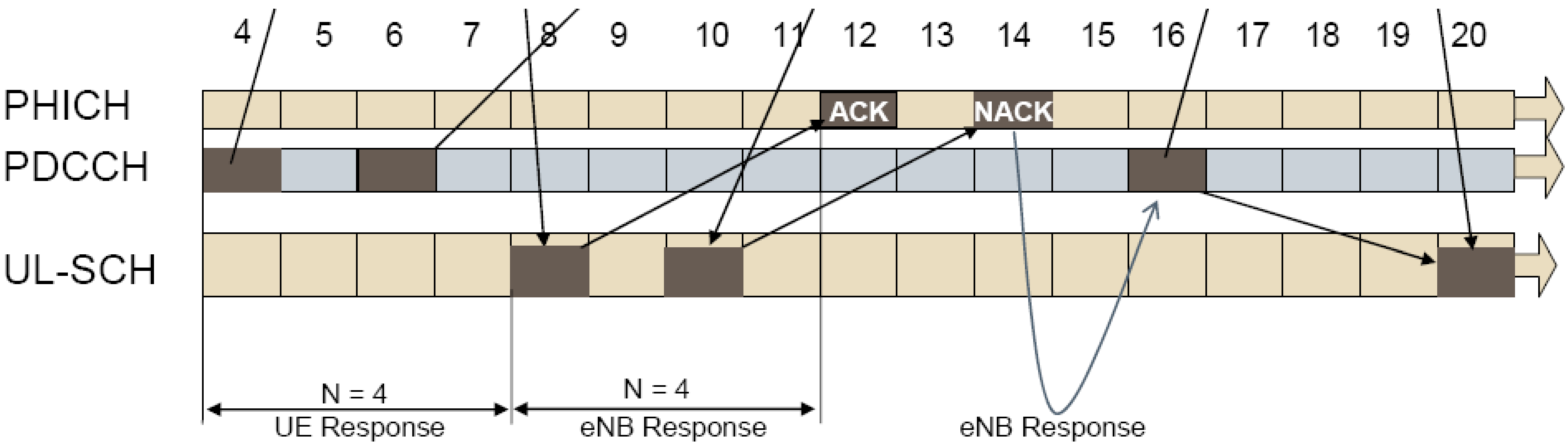
- ACK/NACK for data packets transmitted in the downlink: UE requests retransmission of incorrectly received data packets
  - ◊ ACK/NACK is transmitted in UL, either on PUCCH or mux with PUSCH
  - ◊ ACK/NACK transmission refers to the data packet received four sub-frames (= 4 ms) before,



Ref: (Figure 4.4, Freescale white paper, Long Term Evolution Protocol Overview)

HARQ flow-diagram in UL

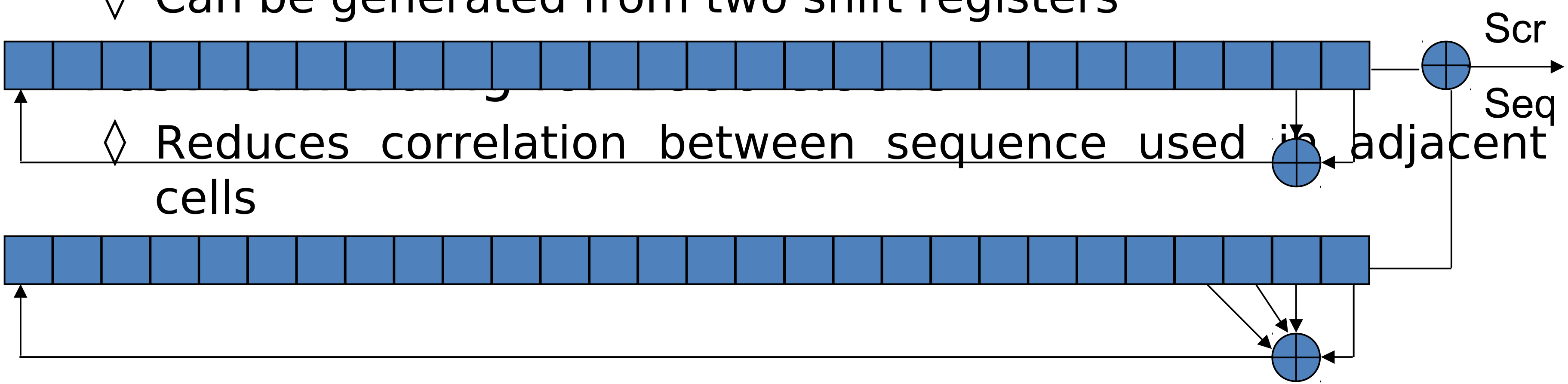
- eNodeB requests retransmission of incorrectly received data packets
  - ACK/NACK is transmitted in PHICH
  - ACK/NACK transmission refers to the data packet received four sub-frames (= 4 ms) before,



Ref: (Figure 4.6, Freescale white paper, Long Term Evolution Protocol Overview)

Scrambler

- Scrambling is applied to all downlink physical channels
- Initialized using cell-id
  - Serves the purpose of interference randomization
- Order-31 Gold code
  - 2^{31} sequences
- Can be generated with very low implementation complexity
  - Modulo-2 addition of two sequences
  - Can be generated from two shift registers



  - Reduces correlation between sequence used in adjacent cells

Modulation – Downlink Alphabet

Channels	Modulation scheme
PBCH	QPSK
PDCCH	QPSK
PDSCH	QPSK, 16-QAM, 64-QAM
PMCH	QPSK, 16-QAM, 64-QAM
PCFICH	QPSK
PHICH	BPSK modulated on I and Q with the spreading factor 2 or 4 Walsh codes

Signals	Modulation scheme
RS	Complex I+jQ pseudo random sequence (length-31 Gold sequence) derived from cell ID
P-SCH	One of three Zadoff-Chu sequences
S-SCH	Two 31-bit BPSK PN-sequence

Modulation – Uplink Alphabet

Channels	Modulation scheme
PUCCH	BPSK, QPSK
PUSCH	QPSK, 16-QAM, 64-QAM
PRACH	Zadoff-Chu

Signals	Modulation scheme
Demodulation RS	Zadoff-chu
Sounding RS	Based on Zadoff-Chu

Code-word to Layer Mapping (1/3)

- Mapping of symbols on-to the antenna ports
- Layer mapping depends on the MIMO scheme employed
- Number of layers is equal to the antenna ports used
  - Concept of Antenna Port
- Layer Mapping fo… n on single antenna port

$$x^{(0)}(i) = d^{(0)}(i)$$

(Ref:6.3.3.2 of 36.211)

Code-word to Layer Mapping (2/3)

- Layer Mapping for transmit diversity

Number of layers	Number of code words	Codeword-to-layer mapping $i = 0,1,\ldots,M_{\text{symb}}^{\text{layer}} - 1$	
2	1	$x^{(0)}(i) = d^{(0)}(2i)$ $x^{(1)}(i) = d^{(0)}(2i+1)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/2$
4	1	$x^{(0)}(i) = d^{(0)}(4i)$ $x^{(1)}(i) = d^{(0)}(4i+1)$ $x^{(2)}(i) = d^{(0)}(4i+2)$ $x^{(3)}(i) = d^{(0)}(4i+3)$	$M_{\text{symb}}^{\text{layer}} = \begin{cases} M_{\text{symb}}^{(0)}/4 & \text{if } M_{\text{symb}}^{(0)} \bmod 4 = 0 \\ \left(M_{\text{symb}}^{(0)}+2\right)/4 & \text{if } M_{\text{symb}}^{(0)} \bmod 4 \neq 0 \end{cases}$ If $M_{\text{symb}}^{(0)} \bmod 4 \neq 0$ two null symbols shall be appended to $d^{(0)}(M_{\text{symb}}^{(0)} - 1)$

(Ref:6.3.3.2 of 36.211)

Code-word to Layer Mapping (3/3)

- Layer Mapping for spatial multiplexing

Number of layers	Number of code words	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	2	$x^{(0)}(i) = d^{(0)}(i)$ $x^{(1)}(i) = d^{(1)}(i)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)} = M_{\text{symb}}^{(1)}$
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	2	$x^{(0)}(i) = d^{(0)}(i)$ $x^{(1)}(i) = d^{(1)}(2i)$ $x^{(2)}(i) = d^{(1)}(2i+1)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)} = M_{\text{symb}}^{(1)}/2$
4	2	$x^{(0)}(i) = d^{(0)}(2i)$ $x^{(1)}(i) = d^{(0)}(2i+1)$ $x^{(2)}(i) = d^{(1)}(2i)$ $x^{(3)}(i) = d^{(1)}(2i+1)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}/2 = M_{\text{symb}}^{(1)}/2$

(Ref:6.3.3.2 of 36.211)

Rank Indicator (RI)

- A 2 x 2 MIMO system is represented as a set of linear equations

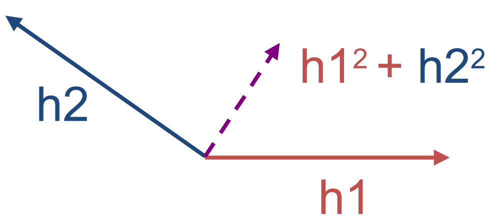
$$h_{11}x + h_{12}\,y = c_1$$

$$h_{21}x + h_{22}\,y = c_2$$

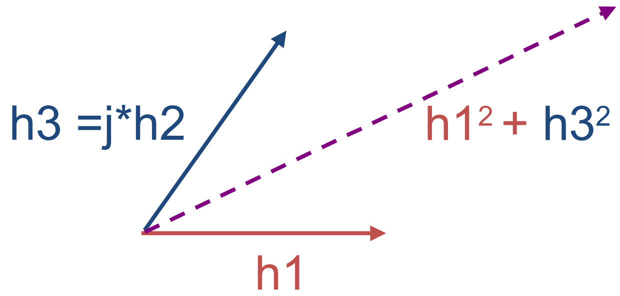
- RI definition in the LTE framework
  - Borrowed from Linear Algebra and is defined as the number of independent columns
    - Number of independent columns = Number of streams
    - For a 2 x 2 MIMO system,
      - Number of independent columns = 1, 2
- UE can decide the Rank using different performance criterion
  - Throughput maximization
    - Calculate the throughput using Rank - 1 and Rank – 2
    - Feedback the rank which gives the maximum throughput

Precoder

- Open loop precoding
  - No feedback from UE
    - Transmit diversity
- Closed loop precoding
  - Requires feedback from the UE
    - UE calculates the post-processing SNR for different precoding matrices
    - Reports the matrix which results in best SNR (PMI)
- Post-processing SNR for single stream transmission



Without PMI



With PMI = 3

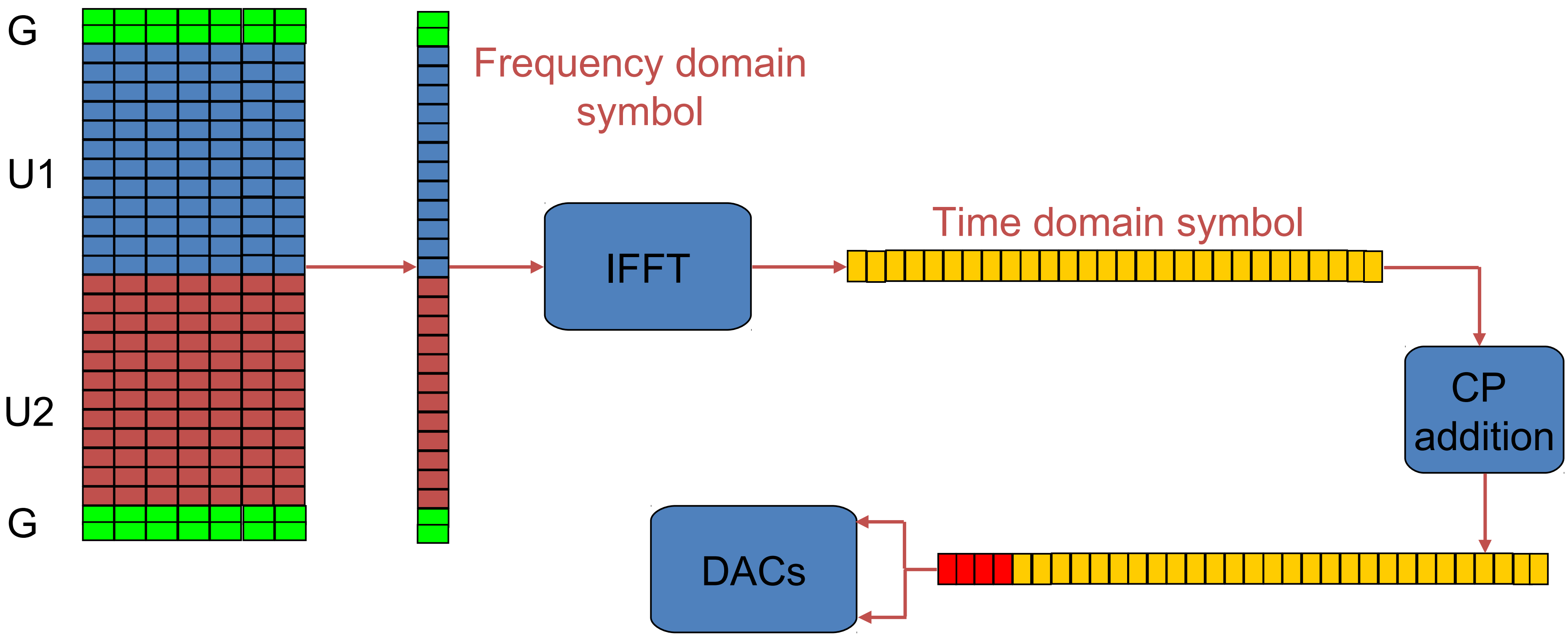
Precoding Matrix Indicator

- Applicable for transmission modes 4, 5 and 6
- Indicates the precoder weights used for precoding
  - usual objective function is post-SINR maximization
- Feedback bits depends on the number of tx antenna ports
  - {0, 1} in case with 2 antenna port
  - {0, 1, … , 15} with 4 antenna ports
- PMI sent on either PUSCH or PUCCH

	Single stream	Dual stream
Two transmit antennas	[1 1]	[[1 1], [1 -1]]
	[1 -1]	[[1 j], [1 -j]]
	[1 j]	
	[1 -j]	

Resource Block Mapping and Baseband Signal Generation

- Symbols are mapped on-to the 2-D Resource Blocks
- Location of Resource blocks allocated to a user depends on the CQI feedback from the user
  - Decided by the scheduler in the MAC layer

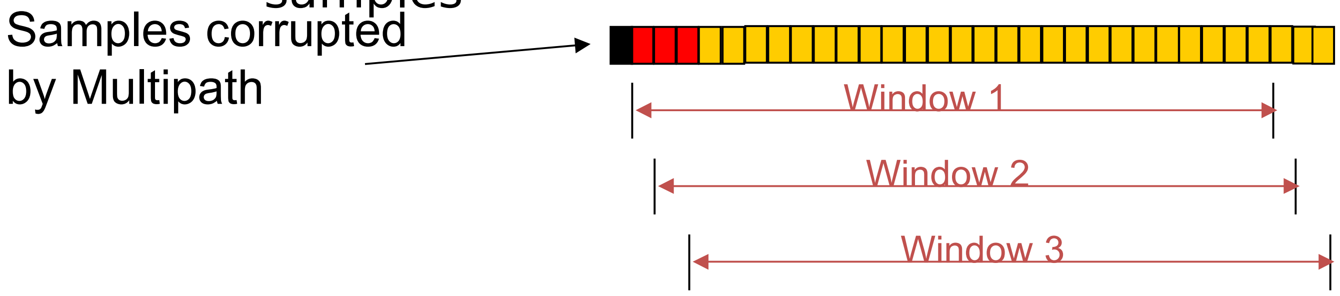


OFDM basics (1/2)

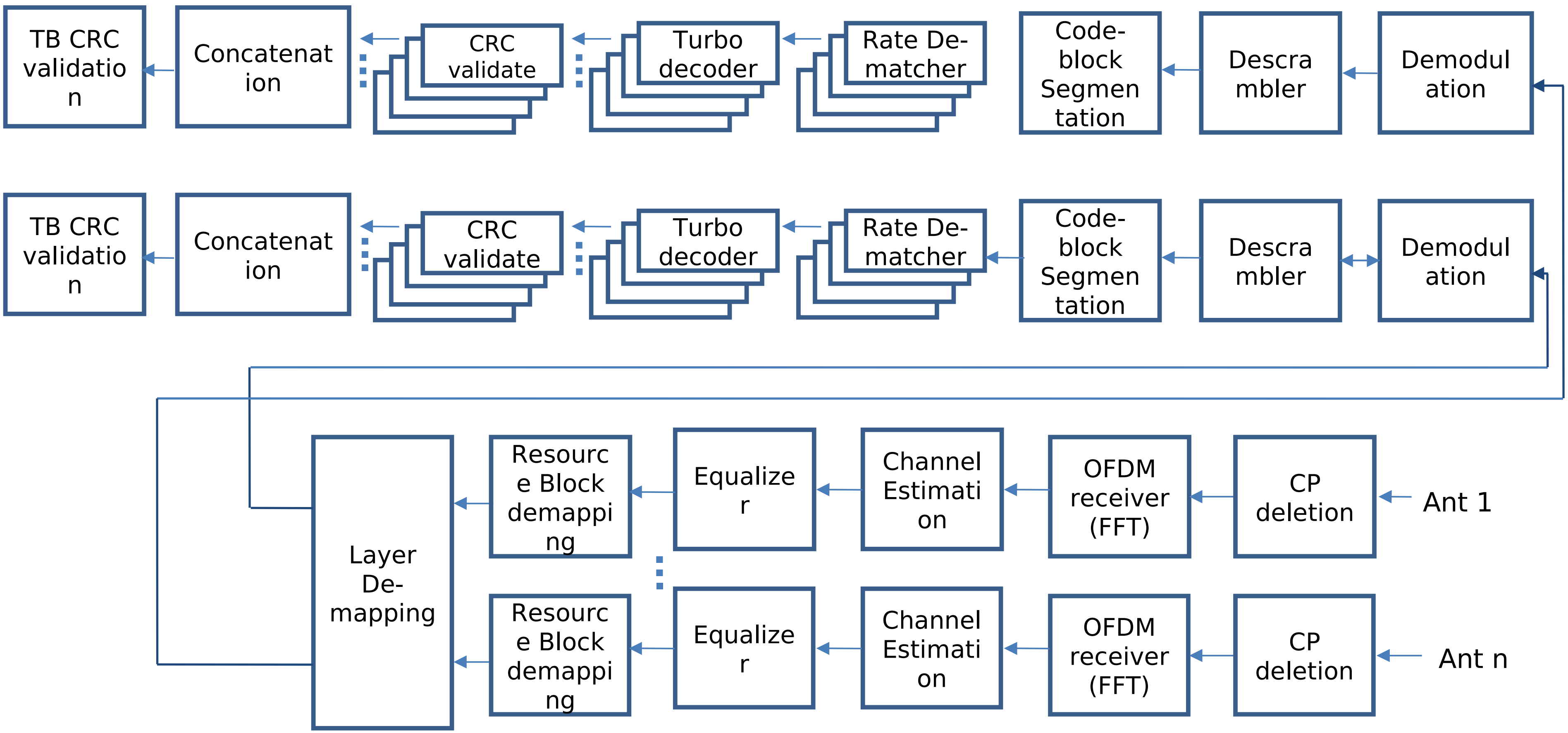
- OFDM is sum of sinusoids on in-phase and quadrature arms
  - $I = \sum_i sin(2*\pi*f_i t) + j*\sum_i cos(2*\pi*f_i t)$
  - Sinusoids are orthogonal over one period of lowest frequency sinusoid
  - Sinusoids are separated by $\Delta f = 1/Ts$
  - Can be easily separated at the receiver by observing one period of lowest frequency sinusoid
- From '*Signal and Systems fundamentals*'
  - Sinusoids are Eigen functions of an LTI systems
    - In case of wireless systems, multipath channel is the LTI system
  - O/P is only a scaled version of the I/P
    - Individual rx subcarriers are scaled version of tx subcarriers
    - Scaling factor (Channel coefficients) can be easily determined using well established signal processing techniques like Least Squares etc

OFDM basics (2/2)

- CP – Few samples of the sum of sinusoids are taken from the end are appended in the beginning
  - Extends the symbol duration and also phase continuity is maintained
    - Helps in tackling multipath
    - Ensures that timing estimation can have tolerance of few samples

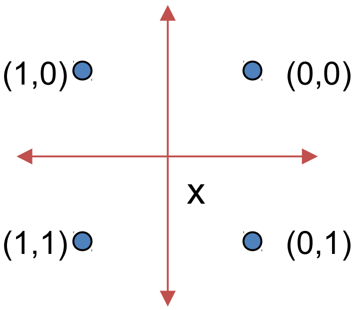


PHY Receive Chain



Demodulation (1/2)

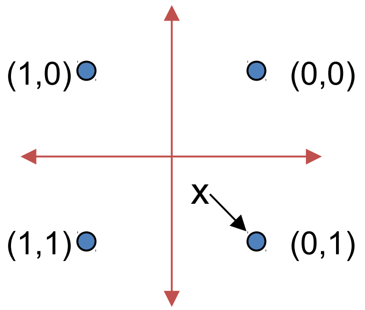
- Equalizer output can be processed in two ways
  - Sub-optimum



- Apply the nearest distance detection rule
  - Threshold the equalized symbols to the nearest transmitted symbol
  - Demap the symbols into bits
- Results in a penalty of 2-3 dB

Demodulation (2/2)

- Optimum



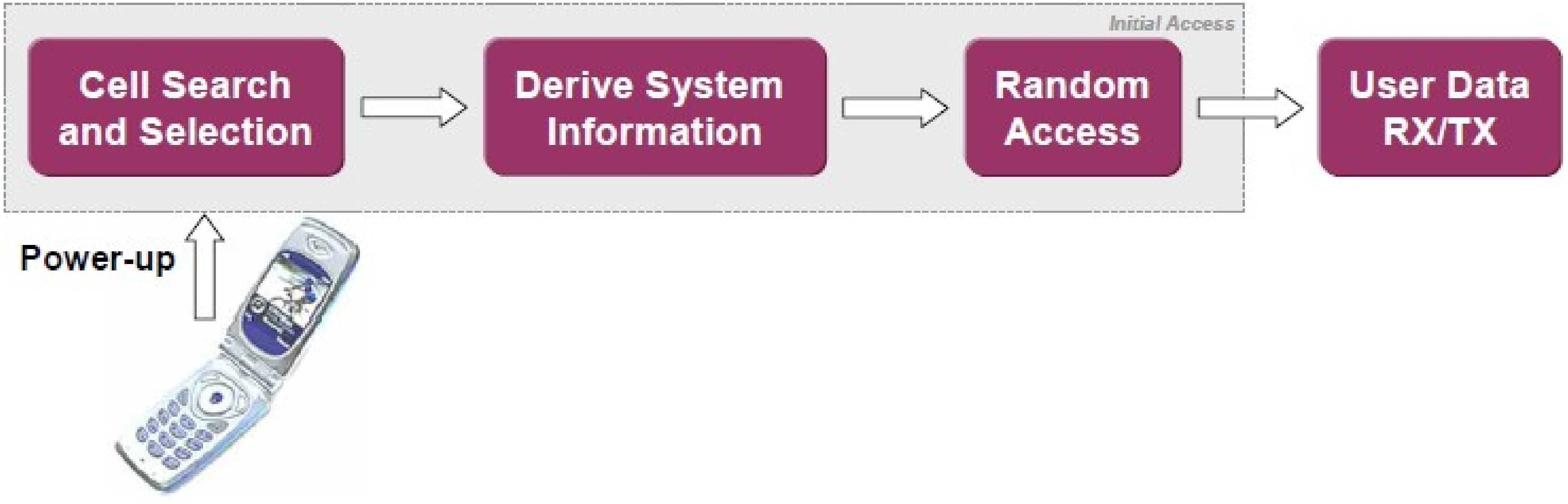
- Apply the nearest distance detection rule
  - Calculate LLR = $\log(b_0/b_1)$
  - E.g., if x = 0.1 – j0.1,
    - LLR_bit0 ≈ 0.1 & LLR_bit1 ≈ - 0.1

De-rate Matching Principles

- Recall
  - Turbo mother code-rate is 1/3
  - Coded bits were pruned to match the allocated resources
    - Pruning implies repetition/puncturing
      - Repetition implies that code-rate is lower than 1/3rd
      - Puncturing implies that code-rate is higher than 1/3rd
- Turbo decoder is designed for code-rate = 1/3
  - Code rate should be made = 1/3
    - LLRs of repeated bits are added
    - Zeros are inserted in place of LLRs of punctured bits

Synchronisation

LTE Initial access



Cell search (1/3)

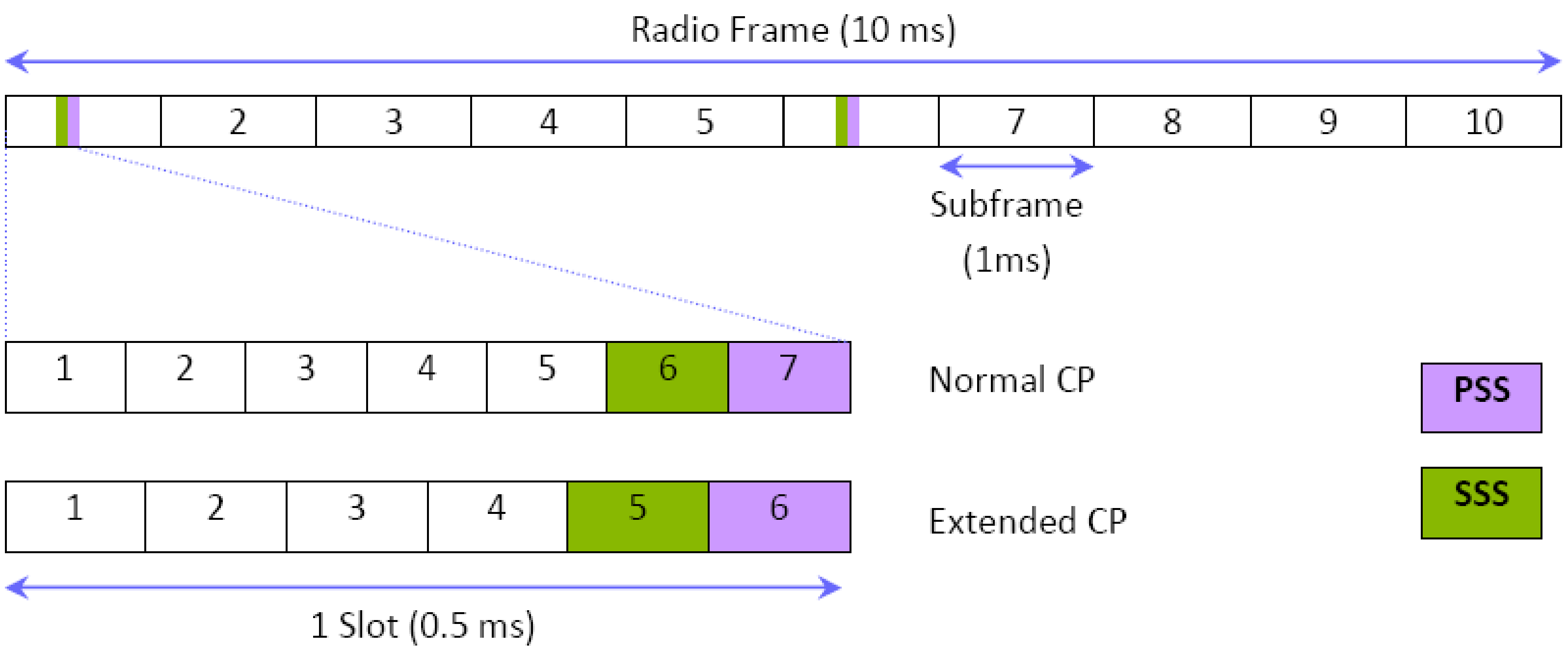
- Cell search: Mobile terminal or user equipment (UE) acquires time and frequency synchronization with a cell and detects the cell ID of that cell
  - Based on BCH (Broadcast Channel) signal and hierarchical SCH (Synchronization Channel) signals
- Cell search procedure:

  Step 1: Find Primary SCH sequence
    - Obtain 5ms timing
    - Get cell identity within the cell-identity group (3 nos)

  Step 2: Find Secondary SCH sequence
    - Sequence pair to obtain exact frame timing
    - Obtain cell identity group (168 nos)
    - Know also the reference signal sequence

  Step 3: Read BCH
    - Obtain basic data as bandwidth, number of antennas etc.

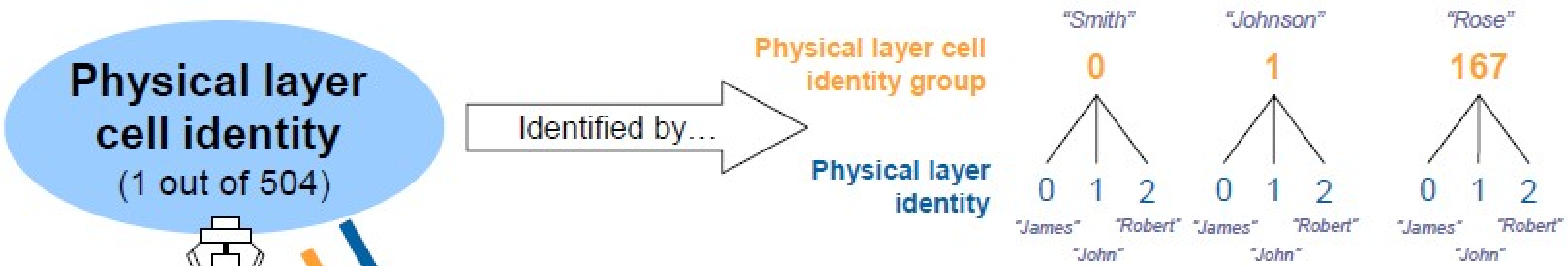
Cell search (2/3)

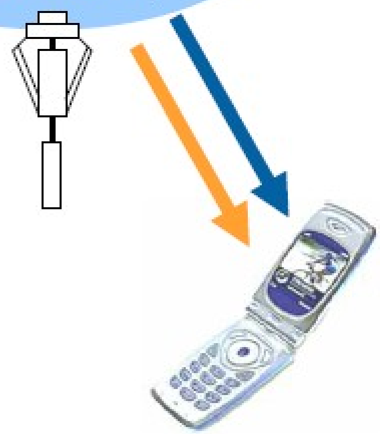


Synchronization signals in the time domain

[Src: Telesystem Innov.]

Cell search (3/3)



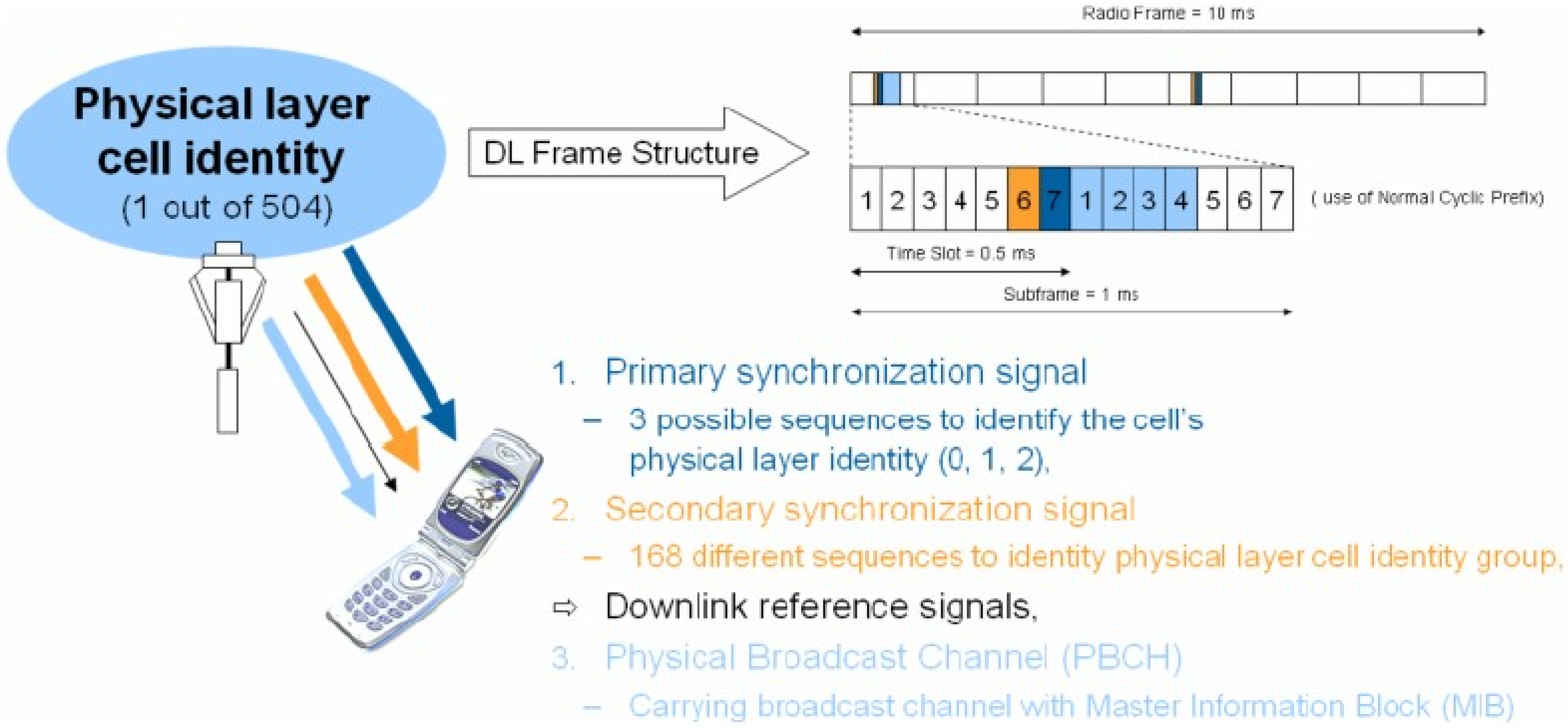


1. ***Primary synchronization signal (PSS)***
   - 3 possible sequences to identify the cells physical layer identity (0, 1, 2)
1. ***Secondary synchronization signal (SSS)***
   - 168 different sequences to identify physical layer cell identity group

- Hierarchical cell search as in 3G; providing PSS and SSS for assistance,
  - PSS is carrying physical layer identity $N_{ID}^{(2)}$,
  - SSS is carrying physical layer cell identity group $N_{ID}^{(1)}$,
  - Cell Identity is computed as $N_{ID}^{cell} = 3N_{ID}^{(1)} + N_{ID}^{(2)}$, where $N_{ID}^{(1)} = 0,1,\ldots,167$ and $N_{ID}^{(2)} = 0, 1, 2$

[Src: Rohde Schwarz]

Summary of Cell-search Stages



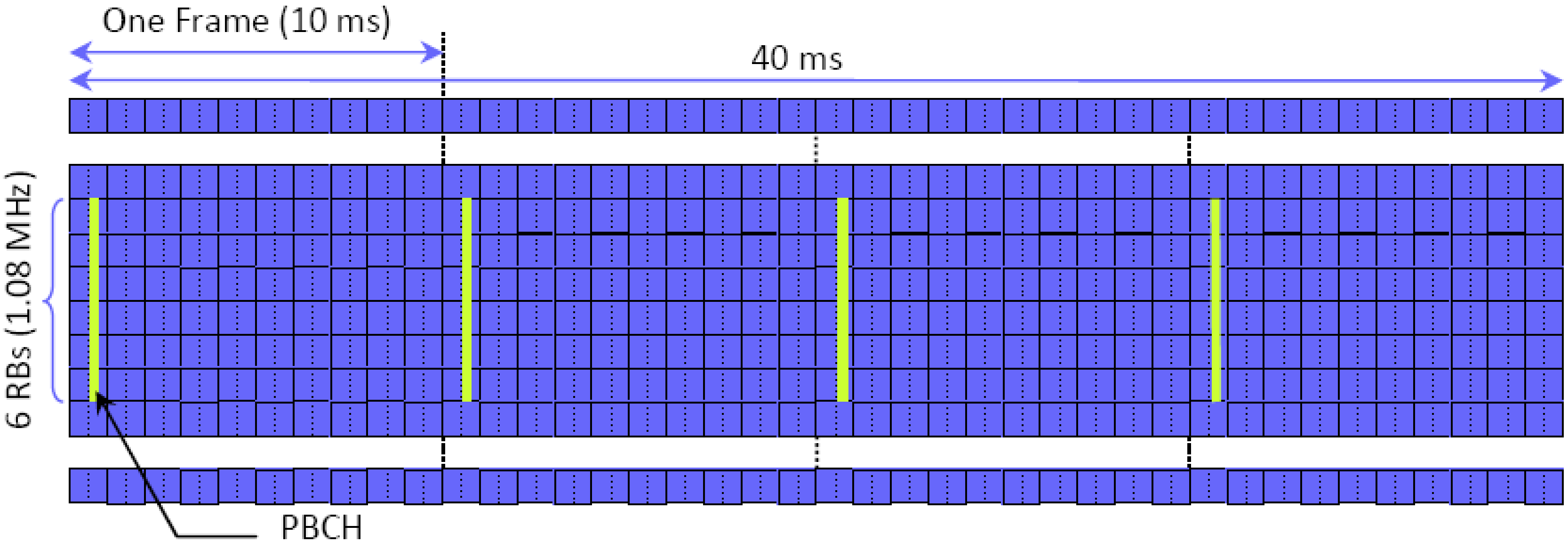
[Src: Rohde Schwarz]

PBCH

- Physical Broadcast Channel (PBCH)
  - Carrying broadcast channel (BCH) with Master Information Block (MIB) System bandwidth [4 bit], PHICH configuration [Duration: 1 bit, Resource: 2 bit], System Frame Number [SFN, 8 bit] and indirect about the used Tx antennas,
  - QPSK modulated, cell-specific scrambling
  - Transmitted on 72 subcarriers around the carrier frequency

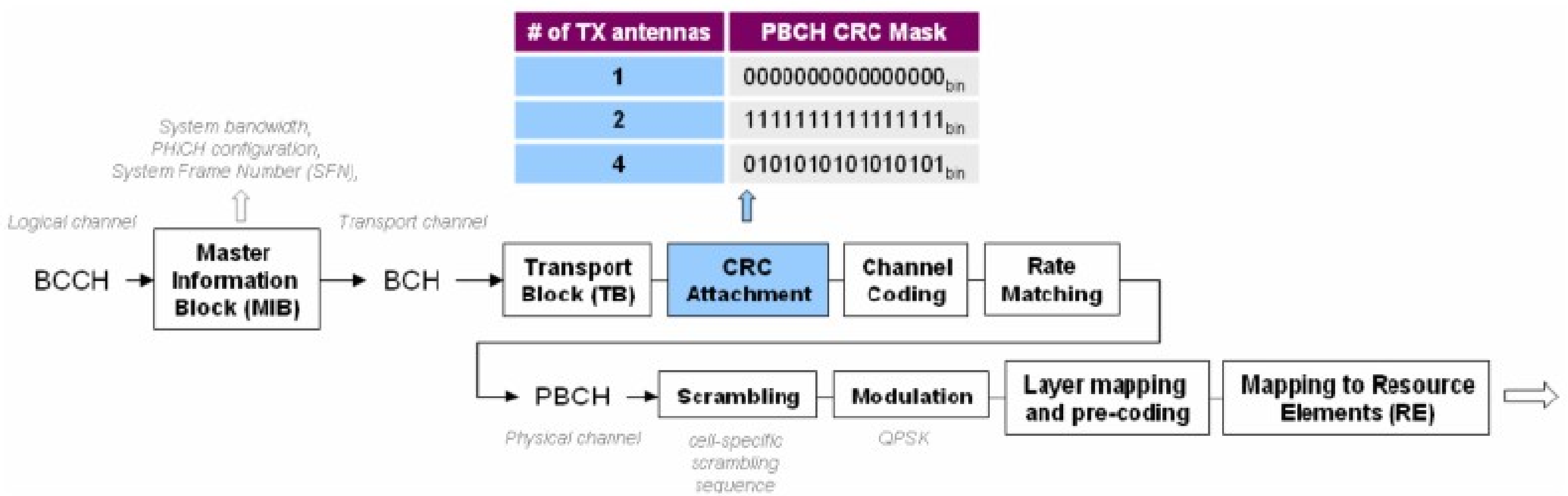
PBCH

- PBCH structure



[Src: Telesystem Innov.]

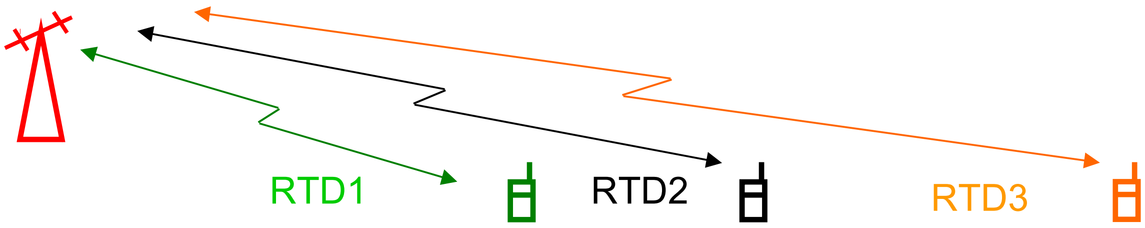
PBCH Generation



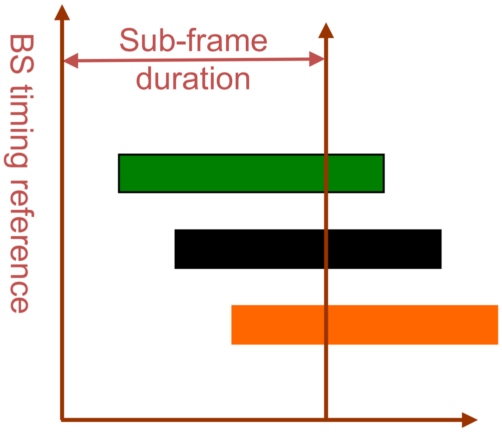
[Src: Rohde Schwarz]

Uplink Synchronisation (1/2)

- Three users in a system
- Three of them located at differential distances from the eNodeB



- Different RTDs will lead to interference at the eNodeB

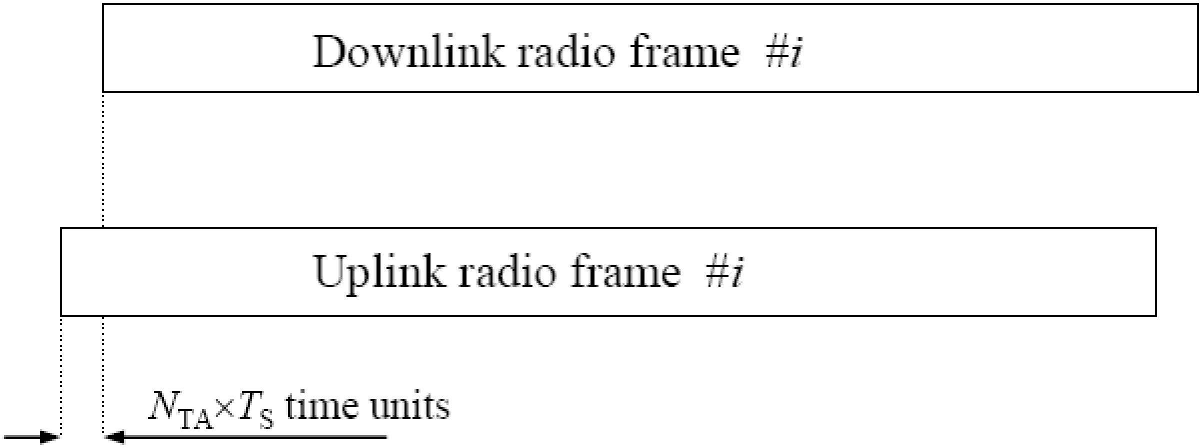


Rohit Budhiraja

Uplink Synchronisation (2/2)

- Uplink transmission orthogonality between users is maintained by timing advance
  - Set initially during Random Access Procedure
  - Updated as necessary subsequently
- Supports at least 100 km cell range
  - Greater ranges are upto implementation

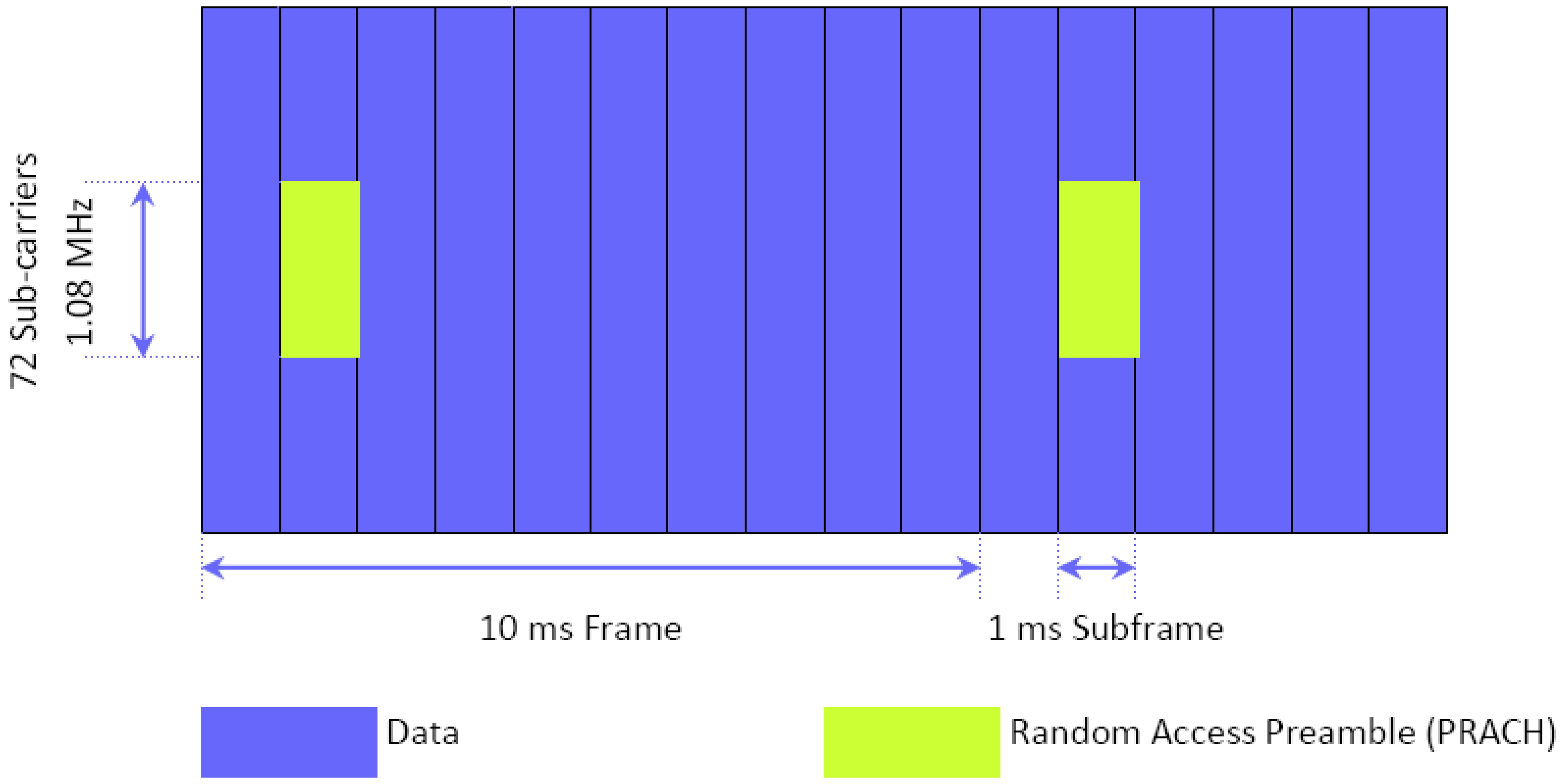
TS 36.211



N_{TA} can range from 0 to 20512, Ts = 1/30.72 μsec

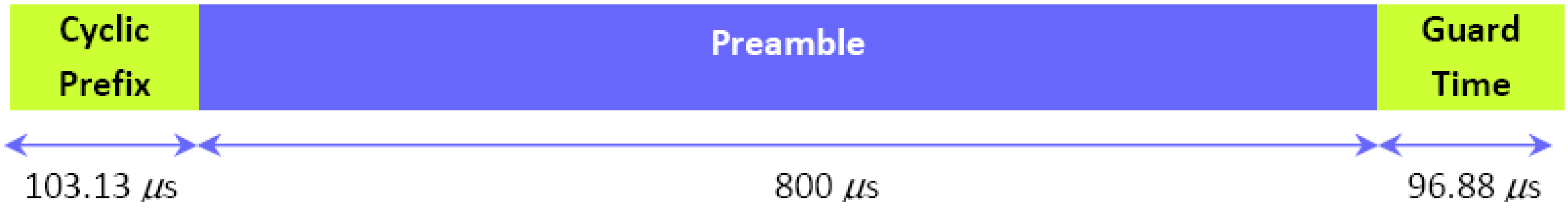
PRACH (1/2)

- Carries the RACH preamble a UE sends to access the network in non-synchronized mode and used to allow the UE to synchronize timing with the eNodeB

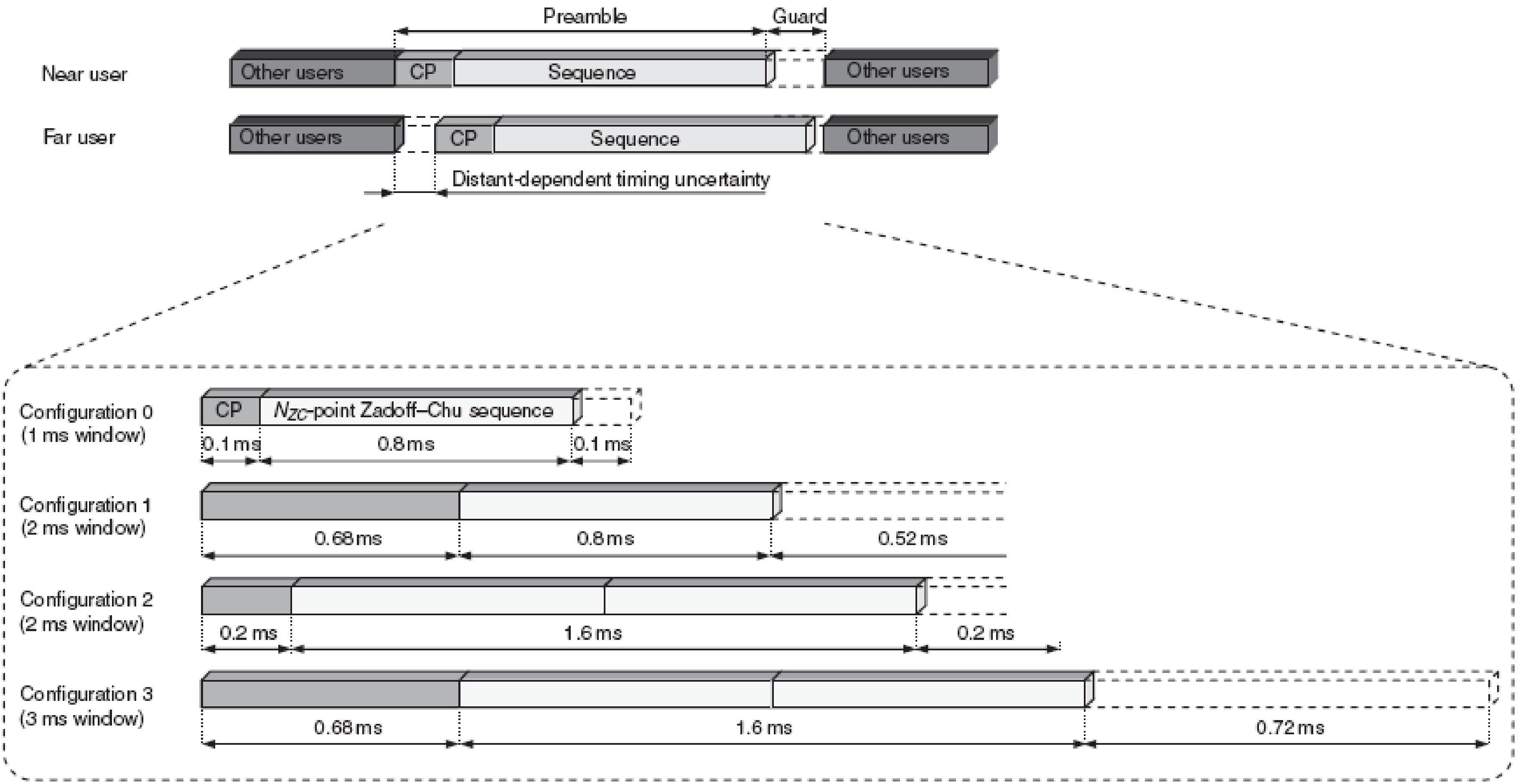


PRACH (2/2)

- Subcarrier spacing of 1.25 KHz
- Consists of 839 subcarriers = 1.05 MHz
  - 15 KHz guard, either side
- FDD LTE -> 4 formats
  - Format 0, good upto 14 Km
    - 1 msec subframe
- Position fixed by SIB2



Preamble Formats

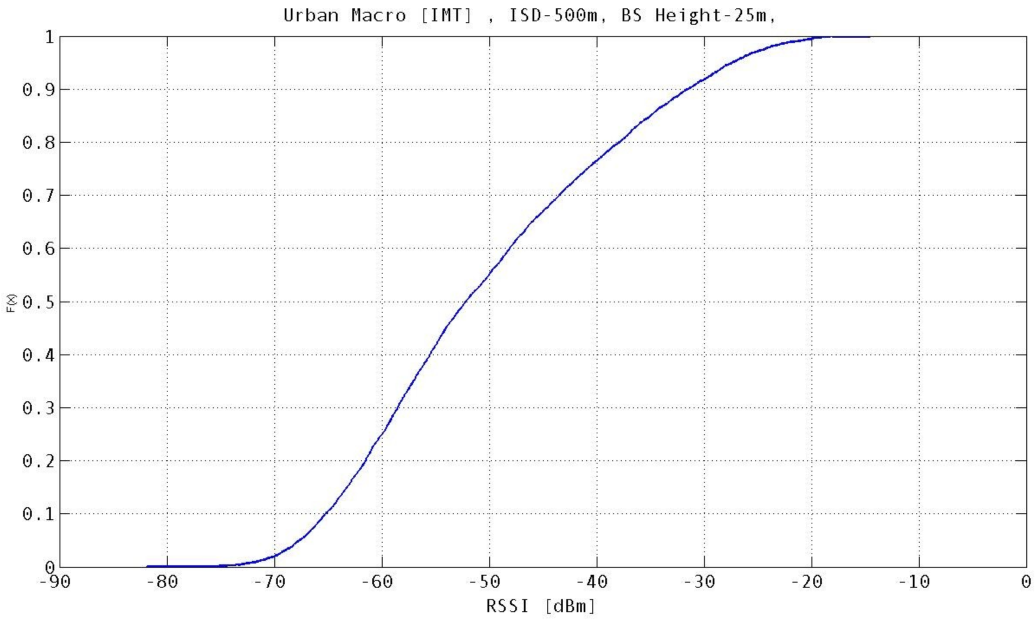


UL Power Control

- Controls uplink power spectral density
  - Total uplink transmit power scales linearly with transmitted bandwidth
- Fractional power control can compensate for all or part of path loss
  - Allows trade-off between intra-cell fairness and inter-cell interference
- MCS-specific offsets may be applied
- Closed-loop power control commands can fine-tune the power setting
  - Carried on PDCCH
    - Individual commands in UL resource grants
    - Group commands for groups of UEs
- Separate power control for PUCCH and PUSCH

Reference Signal Received Power (RSRP)

- RSRP is defined as the linear average over the power contributions (in [W]) of the resource elements that carry cell-specific reference signals within the considered measurement frequency bandwidth
- Reference point for the RSRP shall be the antenna connector of the UE



Reference Signal Received Quality (RSRQ)

RSRQ = N x RSRP /Carrier RSSI

- *N* is the number of RBs of the carrier RSSI measurement bandwidth.
- Carrier RSSI is the linear average of the
  - Total received power (in [W]) observed only in
    - Reference symbols for antenna port 0 in *N* RBs
- Measurements in the numerator and denominator shall be made over the same set of resource blocks

References

- 3GPP Documents
  - 36.101 Overview
  - 36.211 Physical channels and modulation
  - 36.212 Multiplexing and channel coding
  - 36.213 Physical layer procedures
  - 36.214 Physical layer measurements
  - 36.133 Radio resource management


3GPP TS 36.211 V1.0.0 (2007-03)

Technical Specification

3rd Generation Partnership Project;
Technical Specification Group Radio Access Network;
Physical Channels and Modulation
(Release 8)

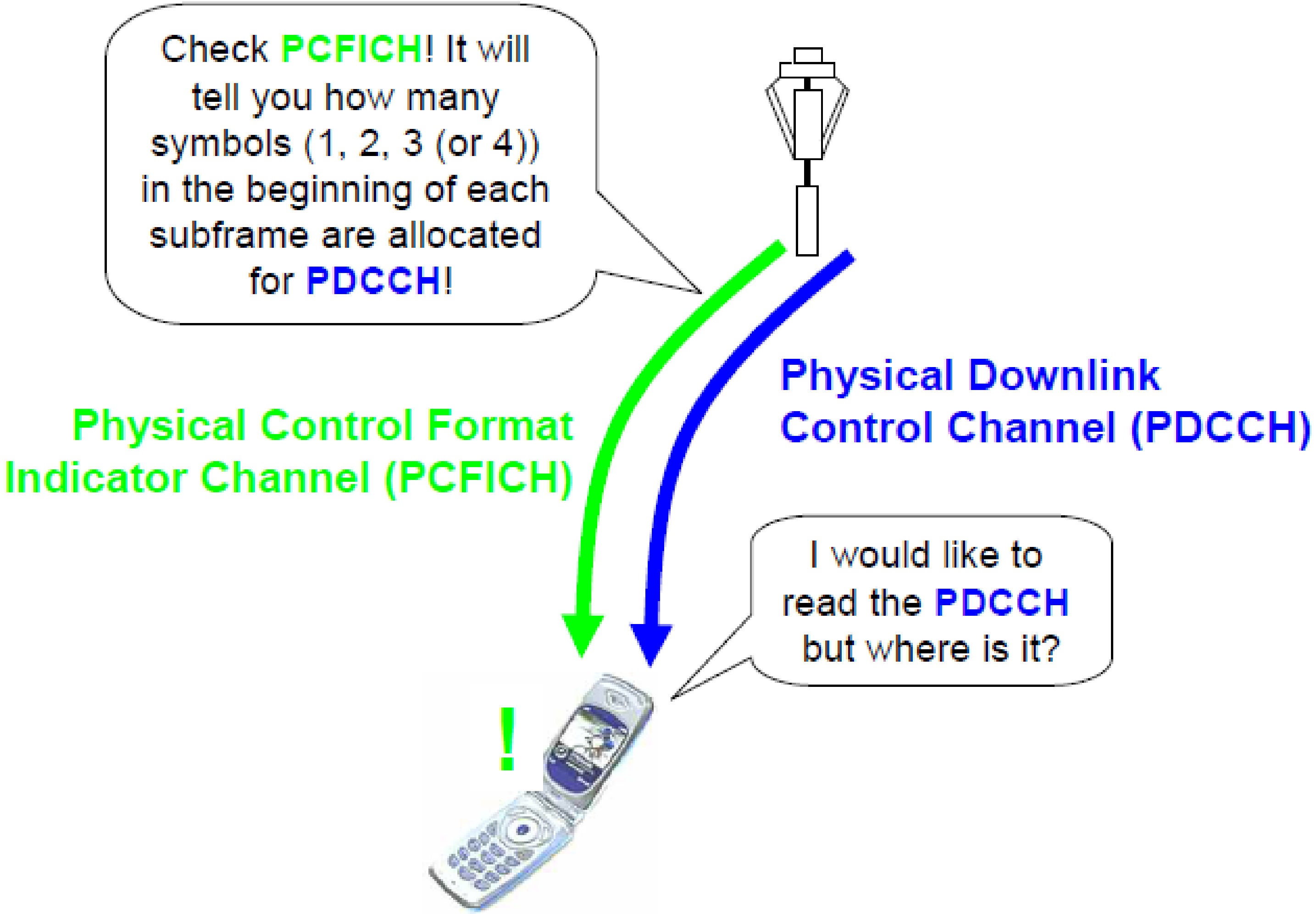
- Books
  - LTE, The UMTS Long Term Evolution: From Theory to Practice (Matthew Baker et. al., Philips)
  - 3G EVOLUTION: HSPA and LTE for Mobile Broadband (Erik Dahlman et. al., Ericsson)
  - LTE for UMTS - OFDMA and SC-FDMA Based Radio Access (Anti Toskala et. al., Nokia / NSN)
- Whitepapers and tutorials from Rohde Schwarz, Agilent, …

Thanks

Back-up Slides

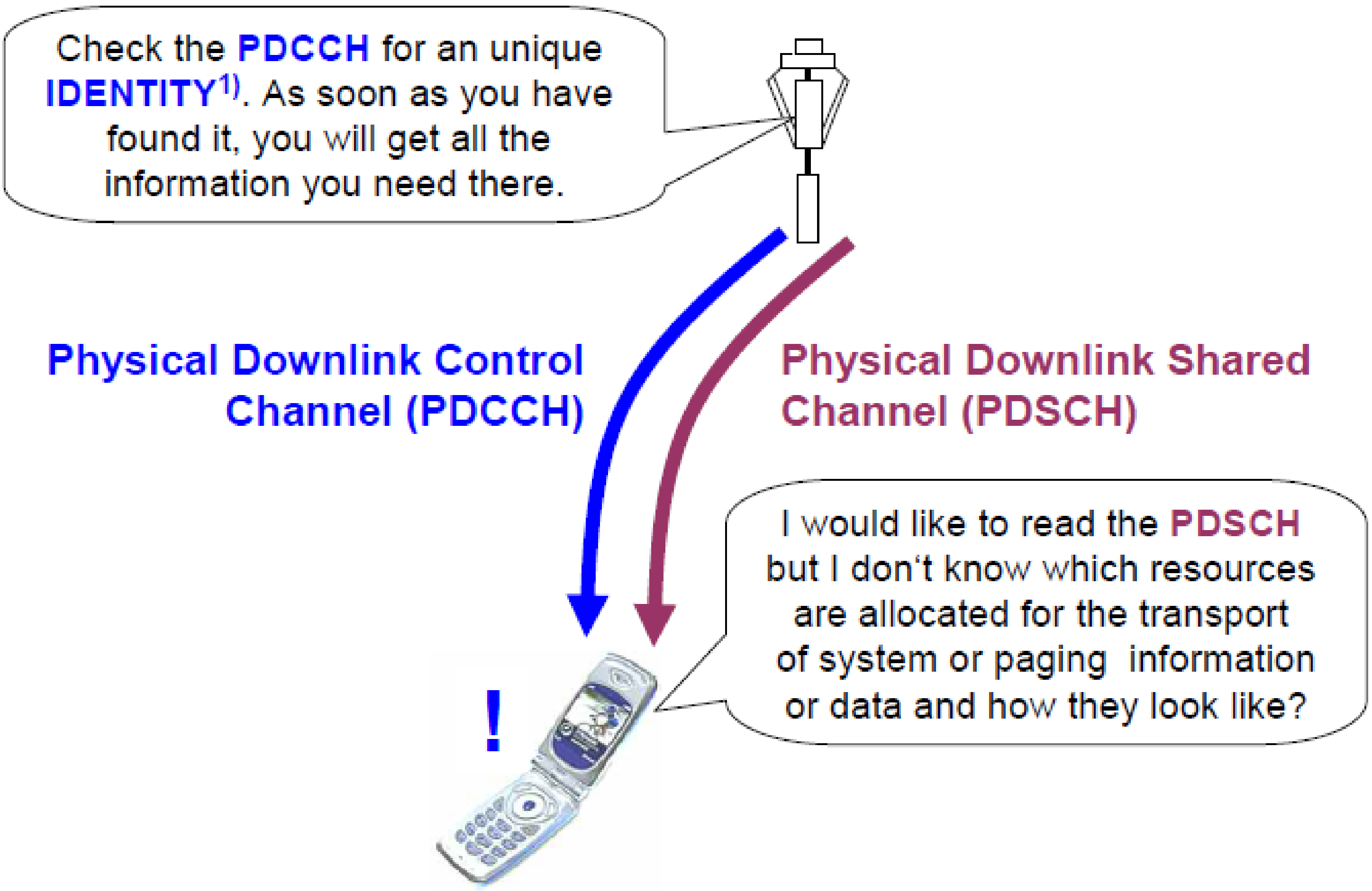
Example procedures

Example: Indicating PDCCH format



[Src: Rohde Schwarz]

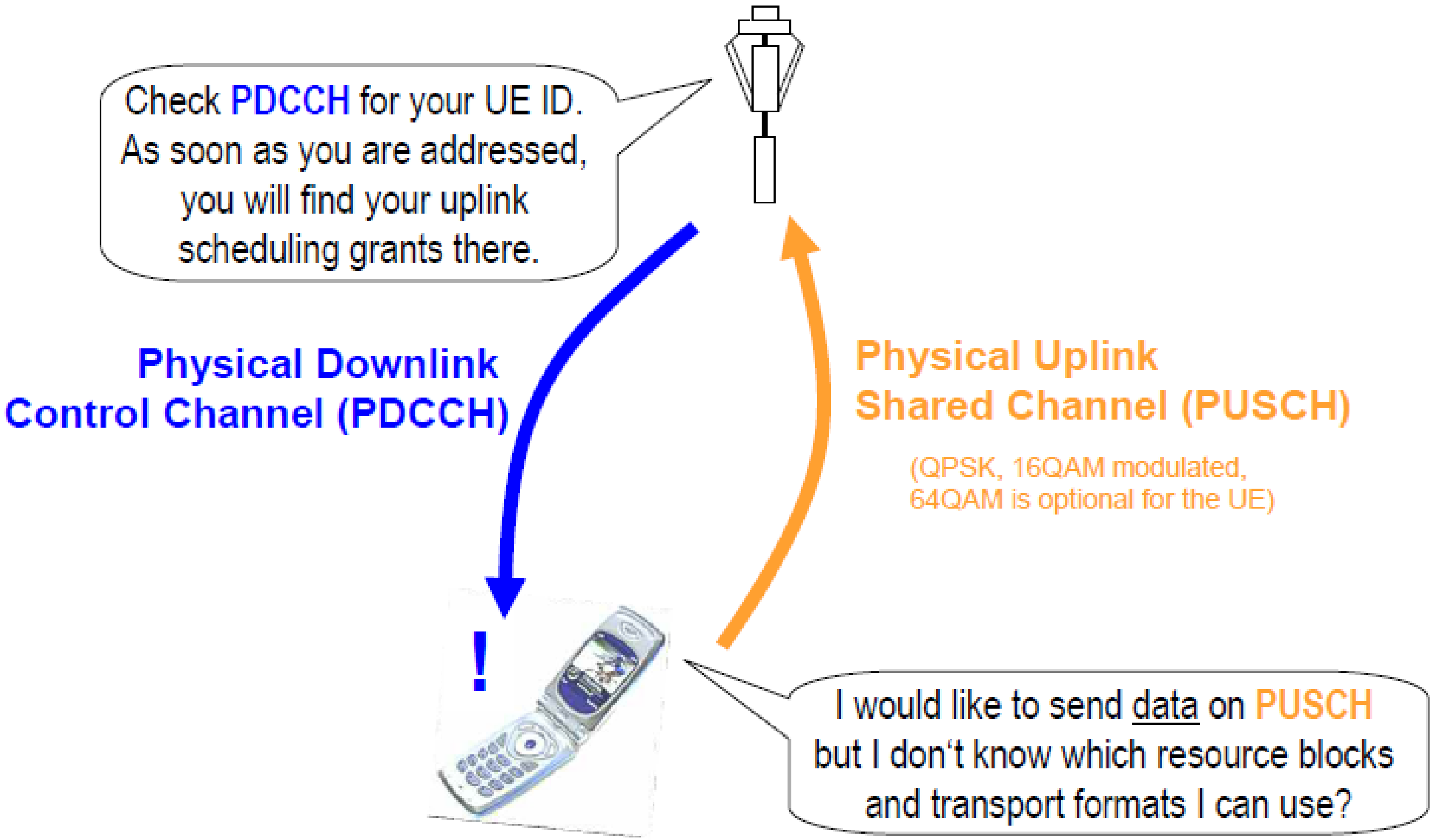
Example: Deriving information in LTE



1) Several identities are used in LTE to identify UE's (e.g. C-RNTI), System Information (SI-RNTI), Paging Information (P-RNTI) or during Random Access Procedure (RA-RNTI), for details see 3GPP TS36.321 V8.5.0 MAC Protocol Specification

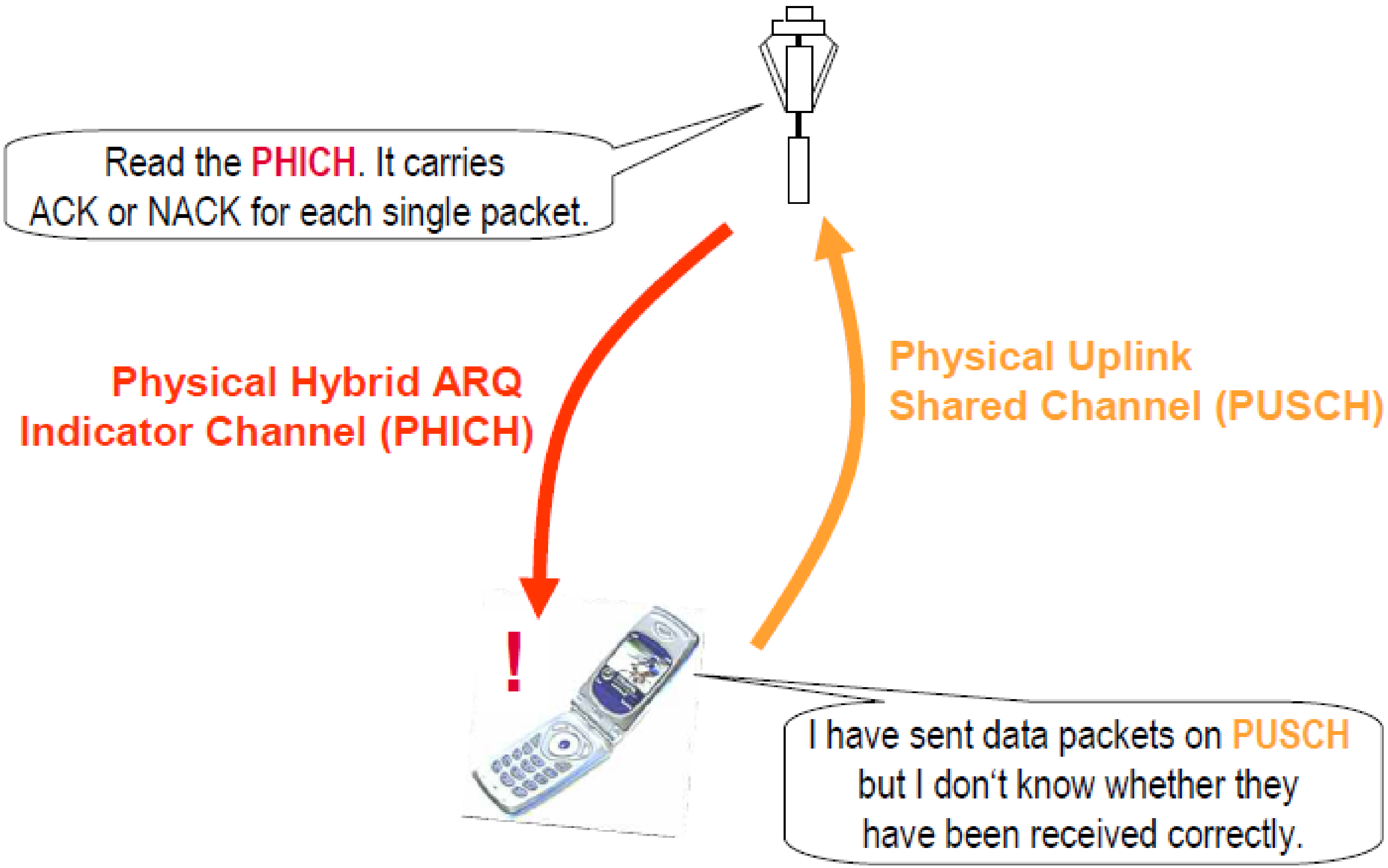
[Src: Rohde Schwarz]

Example: Scheduling for uplink data



[Src: Rohde Schwarz]

Example: Ack. UL data packets on PHICH



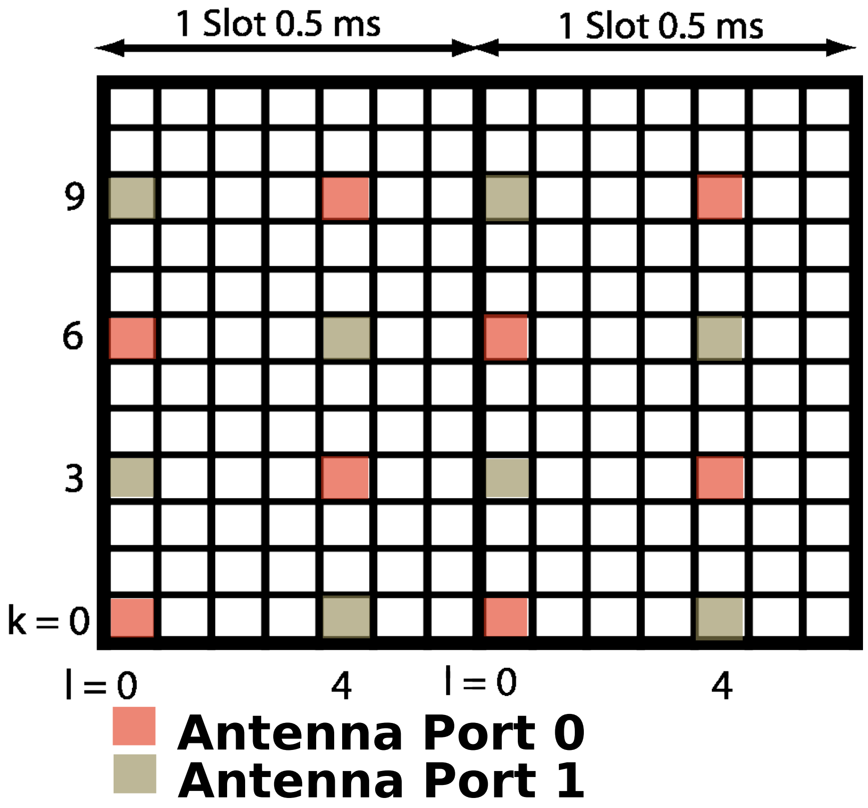
[Src: Rohde Schwarz]

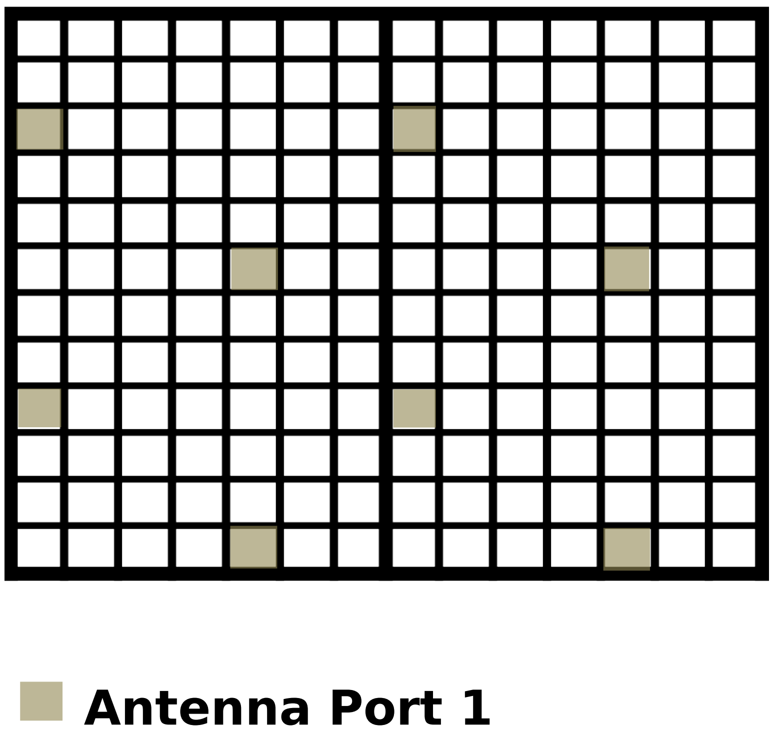
Thanks

Thanks

Concept of Antenna port (1/2)

- RS structure for 1, 2 and 4 antennas in normal CP





Concept of Antenna port (2/2)

- UE specific RS for normal CP
  - Supports non-code book based beam forming

Code-rate calculation

- Code – rate = k/n
  - k = Number of information bits
  - n = Total number of bits transmitted
- TBS – 0 & NPRBS = 10
  - k = 256
  - n = modulation-order * Number of resource elements

    = 2 * (NPRBS * 120)

    = 2 * (10 * 120)

    = 2400
  - Code – rate = 256 / 2400 = .1066