5G NR PHY Layer Processing – Rate Matching, Modulation

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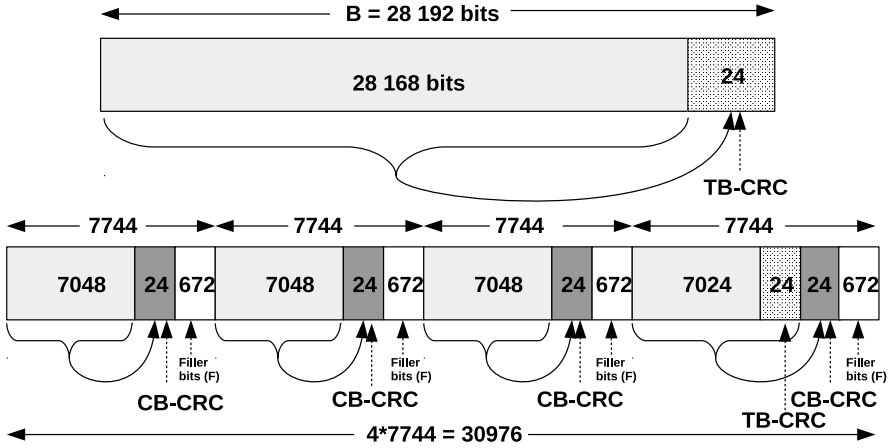
Simulation-Based Design of 5G Wireless Standards (EE698H)

Agenda for today

- Finish discussing LDPC encoding
  - Reference – Chap 4.1.7.3 of 5G NR by SassanA
- Rate matching
  - Reference – Chap 9.3 of 5G NR book by EricD
  - Section 5.4.2 of 38.212
- Modulation
  - Reference – Chap 9.5 of 5G NR book by EricD
  - Section 5.1.5 of 38.211

Example of transport block segmentation (recap)

- Our running example from last class
  - Assume a user is allocated 70 resource blocks over a slot of 14 symbols
  - MCS-16 (16-QAM), which has a code rate of $658/1024 = 0.642$

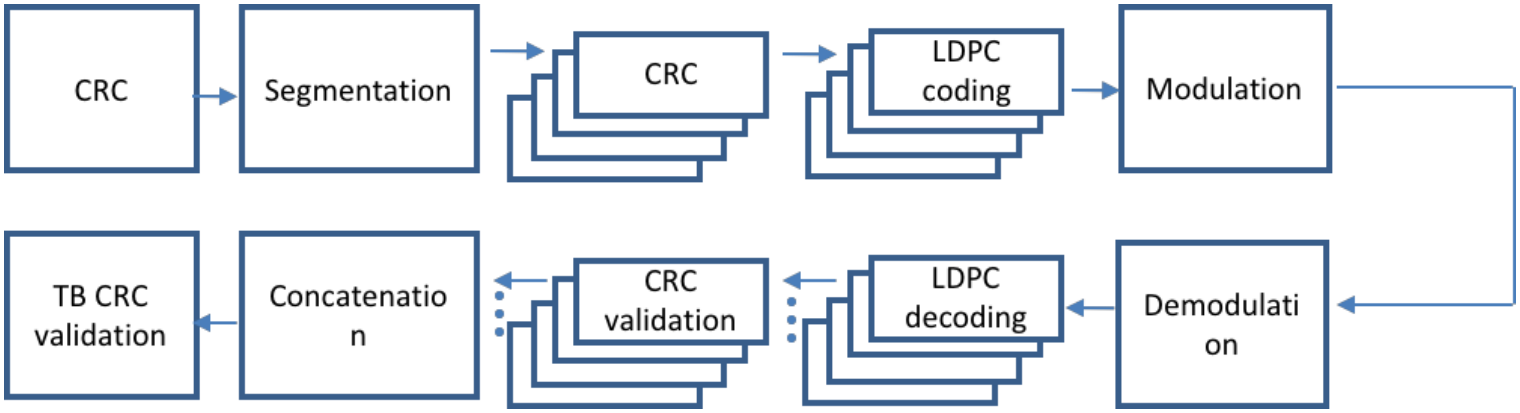


- Number of code blocks $C = 4$;
- Code block size without filler bits $K' = 7072$ bits
- Code block size with filler bits $K = 7072 + 672 = 7744$ bits
- CRC size $L = 24$ bits, lifting size $Z_c = 352$

LDPC coding in the standard

- LDPC encoder input $= K$ bits
- LDPC encoder output length
  - $N = 66Z_c$ bits for base graph 1
  - $N = 50Z_c$ bits for base graph 2
- For our example, LDPC encoder output for each segmented code block $N_r = 66 \times 352 = 23232$
- Filler bits are replaced with zeros while encoding and added back after encoding
- Rate of each code block $= 7744/23232 = 1/3$ - mother code-rate
- Bits input to LDPC encoder are denoted as $c_0, c_1, c_2, c_3, \ldots, c_{(K-1)}$
  - Subscript r is dropped while feeding data to LDPC encoder
- Bits output from LDPC encoder are denoted as $d_0, d_1, d_2, d_3, \ldots, d_{(N-1)}$

5G transceiver chain studied till now and to be studied today



- 5G NR allows 4/16/64/256-QAM modulation
- Demodulator detects bits from 4/16/64/256-QAM modulated symbols
- LDPC decoder works on the demodulated bits and not symbols
  - not practical to design decoder for different modulation schemes

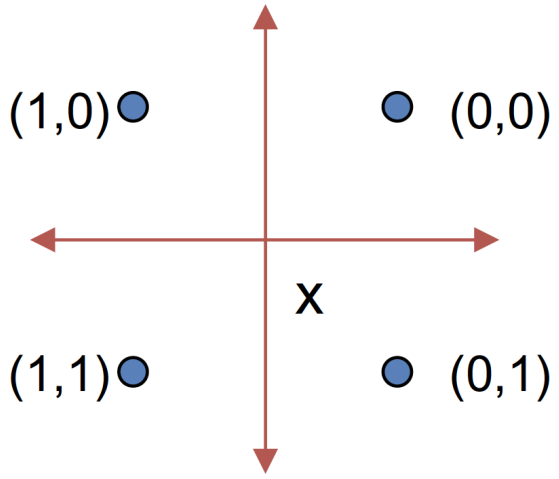
5G Modulation

- LTE allows 4/16/64/246-QAM for data. For example QPSK mapping

$b(i), b(i+1)$	**I**	**Q**
00	$1/\sqrt{2}$	$1/\sqrt{2}$
01	$1/\sqrt{2}$	$-1/\sqrt{2}$
10	$-1/\sqrt{2}$	$1/\sqrt{2}$
11	$-1/\sqrt{2}$	$-1/\sqrt{2}$

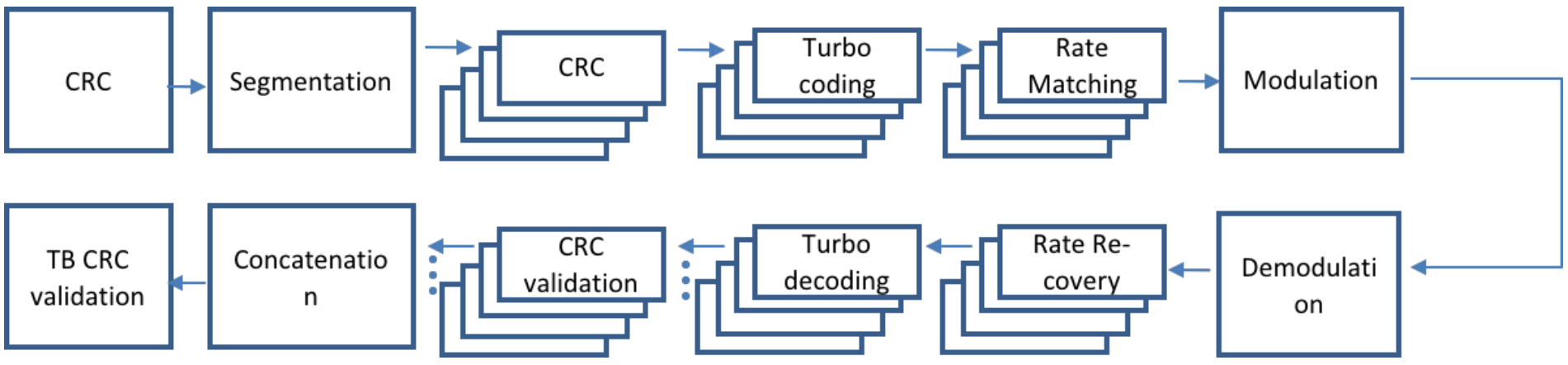
- Refer Section 5.1 of 38.211 for above mapping

QPSK demodulation



- Apply the nearest distance detection rule
- Threshold the equalized symbols to the nearest symbol
- Demap the symbols into bits

5G transceiver chain with rate matching/rate recovery



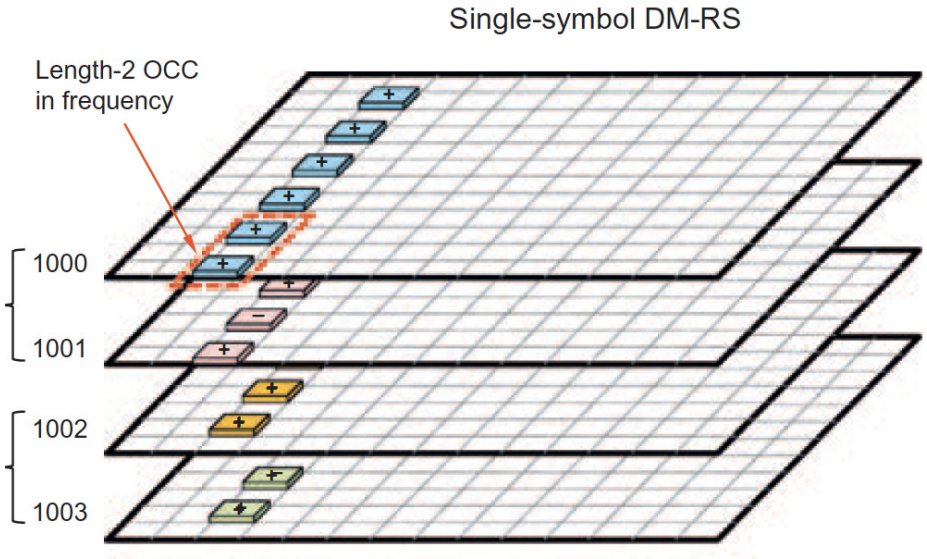
Objective of rate matching - first example

- Our running example
  - Assume a user is allocated 70 resource blocks over a slot of 14 symbols
  - MCS-16 (16-QAM), which has a code rate of $658/1024 = 0.642$
- One PRB over a slot consisting of 14 OFDM symbols will contain $12 \times 14 = 168$ subcarriers
- Out of 168 subcarriers, 6 are reserved for pilots. Subcarriers for transmitting data=162
  - Total number of bits which can be transmitted for 70 PRBS

$$G = 70(\text{NPRB}) \times 162(\text{RE}) \times 4(\text{16QAM}) = 45360$$

- Total number of segmented coded blocks $C = 4$
- Length of each rate-matched block $E = G/C = 45360/4 = 11340$
- Recall LDPC encoder output for each segmented code block $N = 66 \times 352 = 23232$

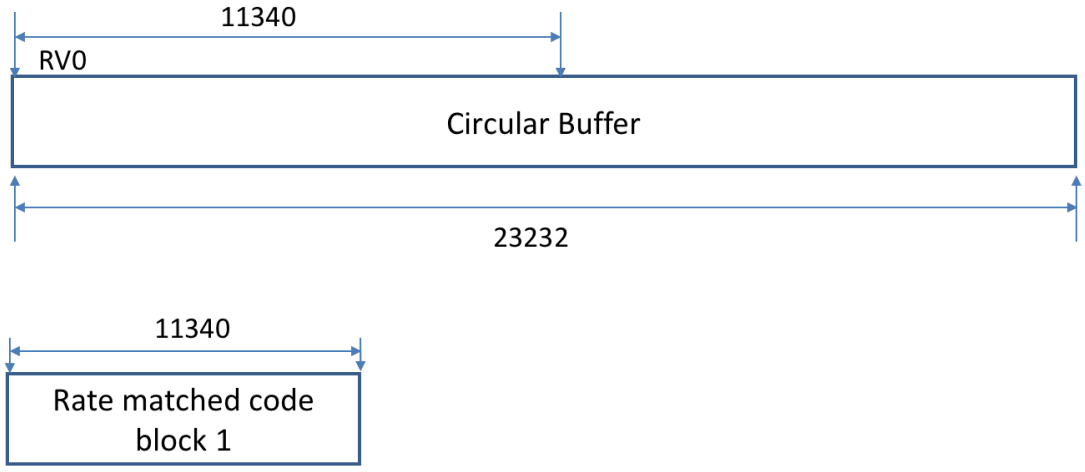
5G pilot structure



- Six subcarriers in a slot of 14 symbols are reserved for pilots
- One of the many pilots structures - will discuss in detail later

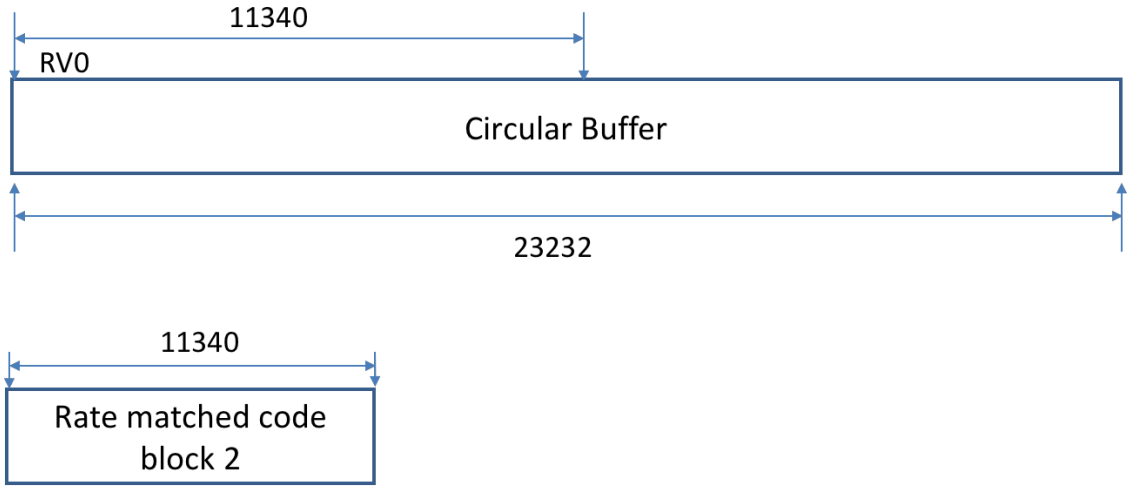
First RM example - RM for first code block

- Total number of segmented coded blocks $C = 4$
- Length of each rate-matched block $E = G/C = 45360/4 = 11340$
- Recall LDPC encoder output for each segmented code block $N = 66 \times 352 = 23232$



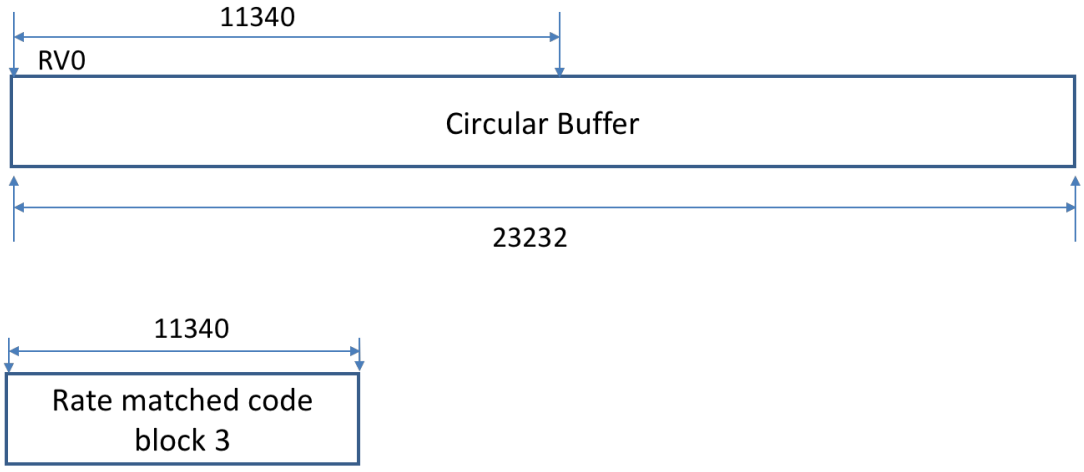
First RM example - RM for second code block

- Total number of segmented coded blocks $C = 4$
- Length of each rate-matched block $E = G/C = 45360/4 = 11340$
- Recall LDPC encoder output for each segmented code block $N = 66 \times 352 = 23232$



First RM example - RM for third code block

- Total number of segmented coded blocks $C = 4$
- Length of each rate-matched block $E = G/C = 45360/4 = 11340$
- Recall LDPC encoder output for each segmented code block $N = 66 \times 352 = 23232$



First RM example - RM for fourth code block

- Total number of segmented coded blocks $C = 4$
- Length of each rate-matched block $E = G/C = 45360/4 = 11340$
- Recall LDPC encoder output for each segmented code block $N = 66 \times 352 = 23232$