AMC and OFDM in 5G-NR

Rohit Budhiraja

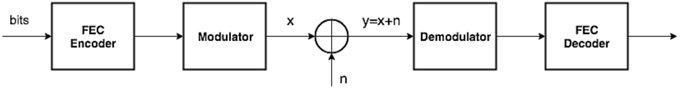
Simulation-Based Design of 5G Wireless Standards (EE698H)

Agenda for today

- Finish discussion on AMC and discuss OFDM in context of 5G-NR
- Reference – Chap3 of the 5G-NR book for spectrum discussion
- Reference – Chap10.1 and 10.2 of LTE Baker book for adaptive modulation and coding
- Reference – Chap3 of the 4G LTE/LTE-A book for OFDM

Adaptive modulation and coding (recap)

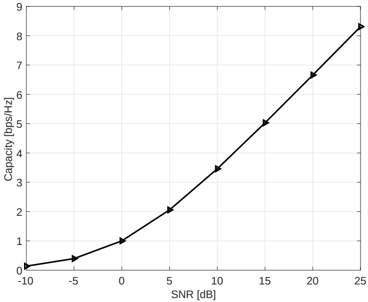
- 5G systems achieve capacity using adaptive modulation and coding
- Block diagram of capacity achieving transceiver



- FEC encoder adds parity bits to input message bits to guarantee a low BLER
- FEC encoder should use large code-block lengths to guarantee a low BLER
- FEC encoder code rate $r = \frac{\text{Number of FEC input bits}}{\text{Number of FEC output bits}}$
- FEC encoder code rate r is always ≤ 1
- If SNR is 2.5 dB, capacity is 1.5 bps/Hz, we will use 4-QAM with a code rate of $3/4$

Capacity achieving codes (recap)

- 5G NR uses capacity achieving LDPC codes



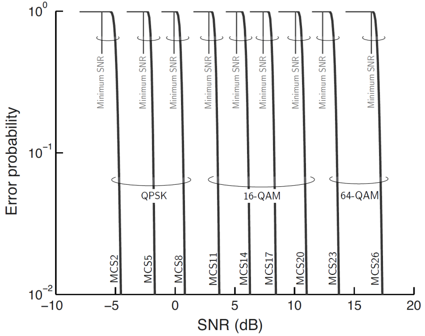
- Capacity achieving – Provide low BLER with reasonable code block length at reasonable SNR offset from the capacity curve

Adaptive modulation and coding in 5G NR (1)

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

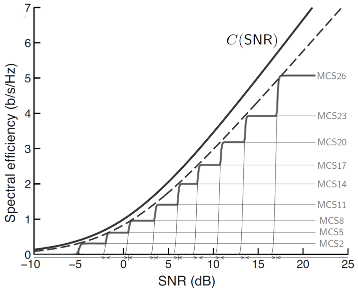
- UEs report MCS (modulation and coding scheme) to the BS instead of SNR

Adaptive modulation and coding in 5G NR (2)



- Above plots show BLER for LDPC with code block length of $N = 6000$

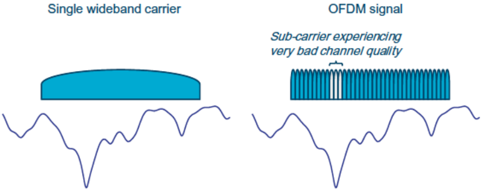
Adaptive modulation and coding in 5G NR(3)



- Cellular systems are designed to achieve capacity and use capacity-achieving FEC codes (uncoded cellular system do not exist)
- AMC achieves capacity by switching modulation and code rate

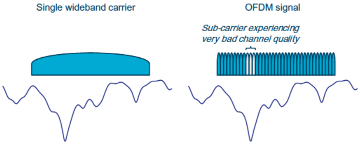
Key reasons why OFDM in 5G (1)

- Peak data rate = system bandwidth × peak spectral efficiency
- For a given spectral efficiency, peak data rate is scaled by increasing bandwidth
- For increased bandwidth, channel estimation and equalization is extremely complicated



- OFDM simplifies the channel estimation and equalization problem

Key reasons why OFDM in 5G (2)



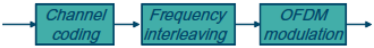
- UE calculates SNR for each subcarrier $\gamma_i = \frac{|h_i|^2 P}{N_0}$. Enables AMC implementation
  - UE averages SNR over a bunch of subcarriers to calculate a single SNR (MCS)
  - One popular way is Effective Exponential SNR (EESM)

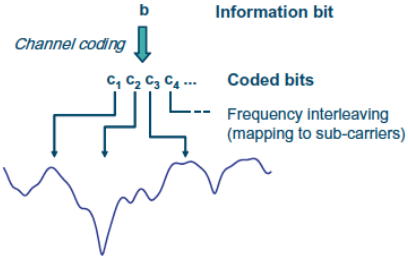
$$\gamma_{eff} = -\lambda \ln \left(\frac{1}{N_c} \sum_{i=1}^{N_c} e^{-\frac{\gamma_i}{\lambda}} \right)$$

  - λ is calibration parameter and N_c is the number of subcarriers

Key reasons why OFDM in 5G (2)

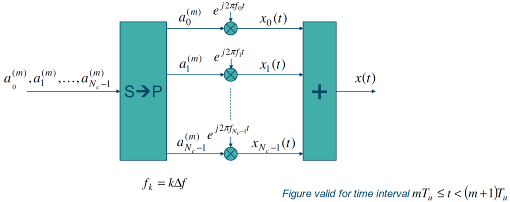
- Help in exploiting frequency diversity with channel coding





OFDM Transmitter

- Consider a system with T_u OFDM symbol duration and N_c subcarriers



- Subcarrier spacing should be $\Delta f = 1/T_u$ for orthogonal subcarriers
- For two subcarriers $f_{k1} = k_1 \Delta f$ and $f_{k2} = k_2 \Delta f$, orthogonality implies

$$\int_{mT_u}^{(m+1)T_u} e^{j2\pi k_1 \Delta f t} e^{-j2\pi k_2 \Delta f t} dt = 0 \qquad \text{for } k_1 \neq k_2$$

OFDM receiver

- OFDM receive signal is $r(t) = x(t) + n(t)$