5G Spectrum and Key 5G Technologies

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

Agenda for today

- Spectrum for 5G
- Discuss one of the key technologies used in 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

3GPP documents

- 3GPP documents are divided into releases
  - Each release has a set of features added compared to the previous release
- LTE is defined from Release 8 and onwards
- Release 15 is New Radio (NR)
  - first set of the specifications was published in December 2017
  - full specifications were due in mid-2018
- 3GPP Technical Specifications (TS) are organized in multiple series
- Following series of specifications are of interest to us:
  - 38-series: Transceiver design aspects for NR.

Spectrum for mobile systems

- Frequency bands – operating frequency range
- Frequency band for 1G and 2G – around 800 to 900 MHz, but also in a few lower and higher bands
- When 3G (IMT-2000) was rolled out, focus was on the 2 GHz band
- With 3G and 4G, new bands were added at both lower and higher frequencies, presently spanning from 450 MHz to around 6 GHz
- Bands at different frequencies have different characteristics
- Bands at lower frequencies have good propgation properties
  - Good for wide-area coverage deployments, in urban, suburban, and rural environments
- Propagation properties of higher frequencies make them difficult to use for wide-area coverage
  - Used for boosting bit-rate in dense indoor deployments

Spectrum for 5G/NR

- With 5G, the eMBB usage scenario even higher data rates and high capacity in dense deployments
  - Frequency range 1 (FR1) includes all existing and new bands below 6 GHz
  - Frequency range 2 (FR2) includes new bands in the range 24.25 to 52.6 GHz
- Frequency bands where NR will operate are in both paired (FDD) and unpaired (TDD) spectra
- Operating bands have a number, where NR bands are numbered n1, n2, n3
- 3GPP Release 15 for NR specifies 26 operating bands in FR1, and 3 in FR2

Example NR frequency bands

- For frequency range 1 (FR1)

NR Band	Uplink Range (MHz)	Downlink Range (MHz)	Duplex Mode	Main Region(s)
n41	2496–2690	2496–2690	TDD	US, China
n50	1432–1517	1432–1517	TDD	
n51	1427–1432	1427–1432	TDD	
n66	1710–1780	2110–2200	FDD	Americas
n70	1695–1710	1995–2020	FDD	
n71	663–698	617–652	FDD	Americas
n74	1427–1470	1475–1518	FDD	Japan
n75	N/A	1432–1517	SDL	Europe
n76	N/A	1427–1432	SDL	Europe
n77	3300–4200	3300–4200	TDD	Europe, Asia
n78	3300–3800	3300–3800	TDD	Europe, Asia

- For frequency range 2 (FR2)

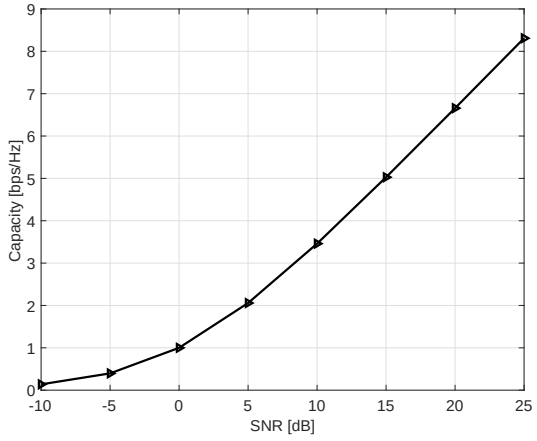
NR Band	Uplink and Downlink Range (MHz)	Duplex Mode	Main Region(s)
n257	26,500–29,500	TDD	Asia, Americas (global)
n258	24,250–27,500	TDD	Europe, Asia (global)
n259	37,000–40,000	TDD	US (global)

Key technologies of 4G/5G systems

- Adaptive modulation and coding
- OFDM
- MIMO
- Scheduling and Hybrid ARQ

Adaptive modulation and coding (AMC) (1)

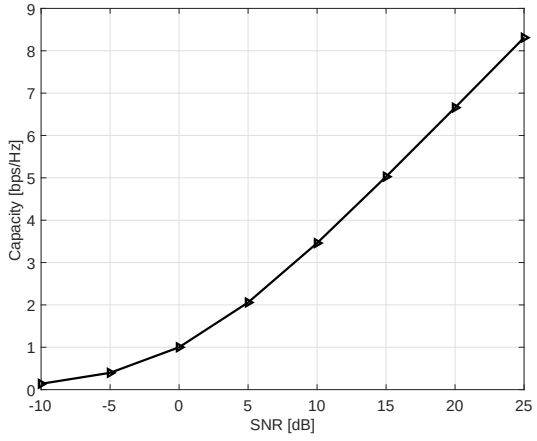
- Capacity of AWGN single-antenna channel $y = x + n$ is $\log(1 + \text{SNR})$ bps/Hz when x is Gaussian



- AMC helps us achieve capacity using discrete constellations e.g., M-QAM with $M = 2/4/16/64/256$
- If SNR is 5 dB, capacity is 2 bps/Hz, using 4-QAM achieves capacity, BLER ≈ 0 is achieved

Adaptive modulation and coding (AMC) (2)

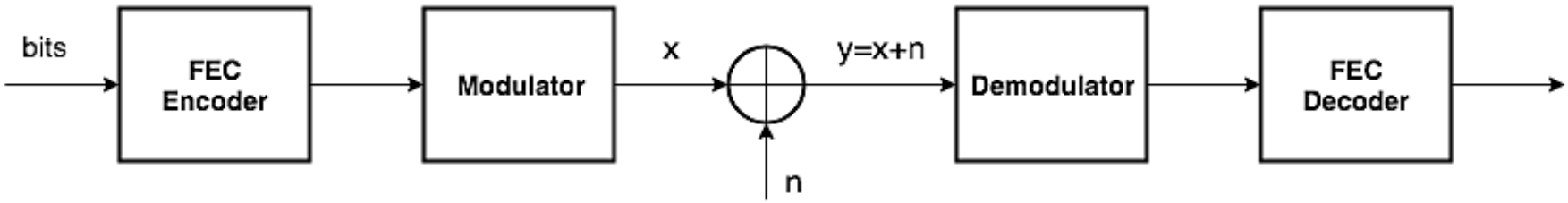
- Capacity of AWGN single-antenna channel $y = x + n$ is $\log(1 + \text{SNR})$ bps/Hz when x is Gaussian



- If SNR is ≈ 12 dB, capacity is 4 bps/Hz, using 16-QAM achieves capacity, BLER ≈ 0 is achieved
- Idea of switching modulation, according to SNR is called adaptive modulation
- Achieve other points on capacity curve? For example, when SNR is 2.5 dB, capacity is 1.5 bps/Hz

Adaptive modulation and coding (AMC) (3)

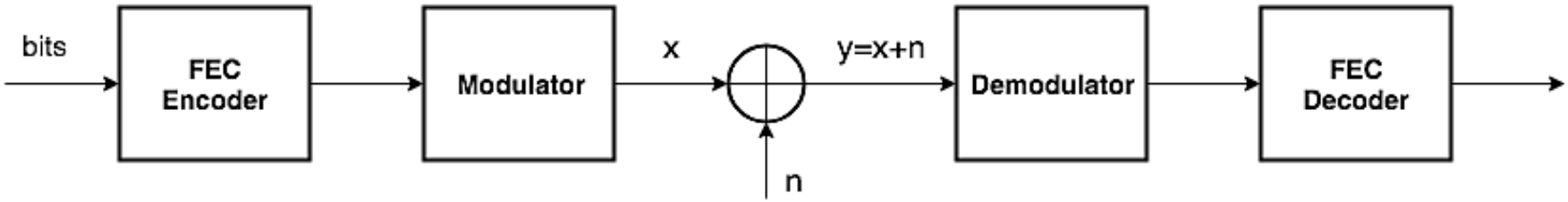
- All the points on capacity curve are achieved using adaptive modulation and (error control) coding
- Block diagram of capacity achieving transceiver



- 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

Adaptive modulation and coding (AMC) (4)

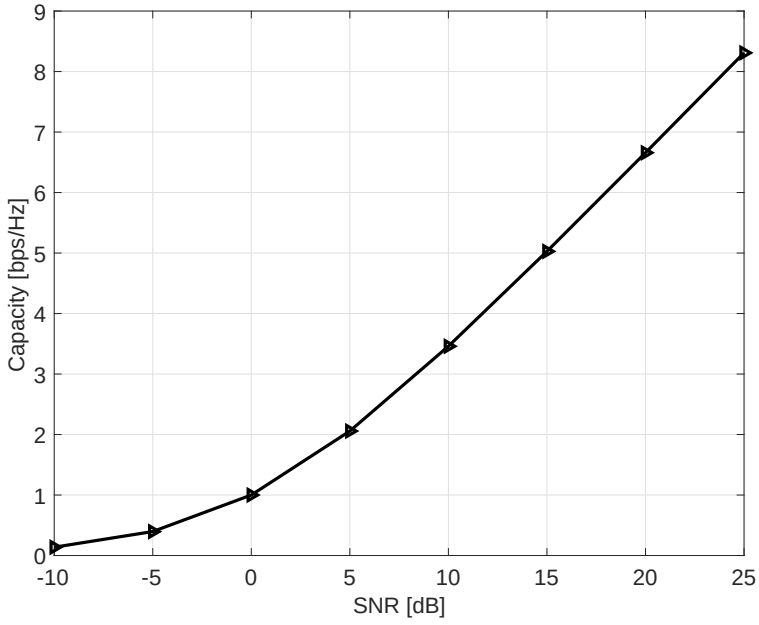
- All the points on capacity curve are achieved using adaptive modulation and (error control) coding
- Block diagram of capacity achieving transceiver



- 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
- 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

- 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