EE6143 Assignment 6

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1 Setup

- Number of usable REs per OFDM symbol $numRE = 600$, FFT Size = 4096
- Assuming we keep the energy per information bit same for each code (for fair comparison of different codes). If the energy of each bit input to LDPC is E_b. Each output bit of rate matching will have energy = E_b * rate; (rate $<$ 1)
- Computing value of SNR from $\frac{E_b}{N_o}$ is done as follows.

  SNR at the input of AWGN channel

$$\begin{aligned}\text{SNR(@ AWGN channel)} &= \frac{\text{Signal Power}}{\text{Noise Power}}\\ &= \frac{\text{Average power per symbol x Number of QAM symbols}}{\text{Noise power Spectral Density x Noise Bandwidth}}\\ &= \frac{E_s \times \text{numRE}}{N_0 \times \text{FFT Size}}\\ &= \frac{\text{rate} \times E_b \times log_2(M) \times \text{numRE}}{N_0 \times \text{FFT Size}}\end{aligned}$$

  SNR at QAM demodulator

$$\begin{aligned}\text{SNR(@ Demodulator)} &= \frac{\text{Signal Power}}{\text{Noise Power}}\\ &= \frac{\text{Average power per symbol x Number of QAM symbols}}{\text{Noise power Spectral Density x Noise Bandwidth}}\\ &= \frac{E_s \times \text{numRE}}{N_0 \times \text{numRE}}\\ &= \frac{\text{rate} \times E_b \times log_2(M)}{N_0}\end{aligned}$$

  where E_s is the average energy per symbol. E_b is the average energy per information bit. E_b * rate is the energy per each output bit of rate matching. M is the modulation order. N_o is the noise power.

SNR at demodulator is higher because after FFT we are keeping only 600 out of 4096 REs and that reduces noise bandwidth.

- From the above equations

$$\text{SNR(AWGN channel) (dB)} = \frac{E_b}{N_o}(\text{dB}) + 10log_{10}(log_2(M)) - 10log_{10}(\frac{\text{FFT Size}}{numRE}) - 10log_{10}(\frac{1}{\text{rate}})$$

$$\text{SNR(QAM demodulator) (dB)} = \frac{E_b}{N_o}(\text{dB}) + 10log_{10}(log_2(M)) - 10log_{10}(\frac{1}{\text{rate}})$$

- soft bits (Log Likelihood Ratios) are computed by demodulator which are used to do soft LDPC decoding.

2 Simulation

The theoretical BER curves are obtained using *berawgn* in MATLAB.
soft bits are calculated using *qamdemod* in MATLAB.
maxIterations for LDPC decoder is set to 25.

Adaptive $\frac{E_b}{N_o}$ generation is used to get better plots when using LDPC codes.

Approximate LLRs are used for soft bits. Using exact LLR didn't give significant improvement in performance

Observations

From figures 1, 2. OFDM with LPDC codes perform slightly worse than theoretical AWGN at low $\frac{E_b}{N_o}$. But at high enough $\frac{E_b}{N_o}$ the improvement in BER is very large for even small increase in $\frac{E_b}{N_o}$ and the BER curves are almost vertical lines.

$\frac{E_b}{N_o}$ at which BER curves are almost vertical is higher for higher QAMorder, higher rate.

Modulation	code rate (rate matched)	$\frac{E_b}{N_o}$ (dB) at BER $= 10^{-3}$ LDPC OFDM	$\frac{E_b}{N_o}$ (dB) at theoretical AWGN BER $= 10^{-3}$	Coding gain $\frac{E_b}{N_o}$ (dB) gained
16 QAM	443/1024	≈ 3	≈ 10.5	≈ 7.5
16 QAM	616/1024	≈ 4	≈ 10.5	≈ 6.5
64 QAM	466/1024	≈ 5.6	≈ 14.75	≈ 9.15
64 QAM	873/1024	≈ 10.4	≈ 14.75	≈ 4.35

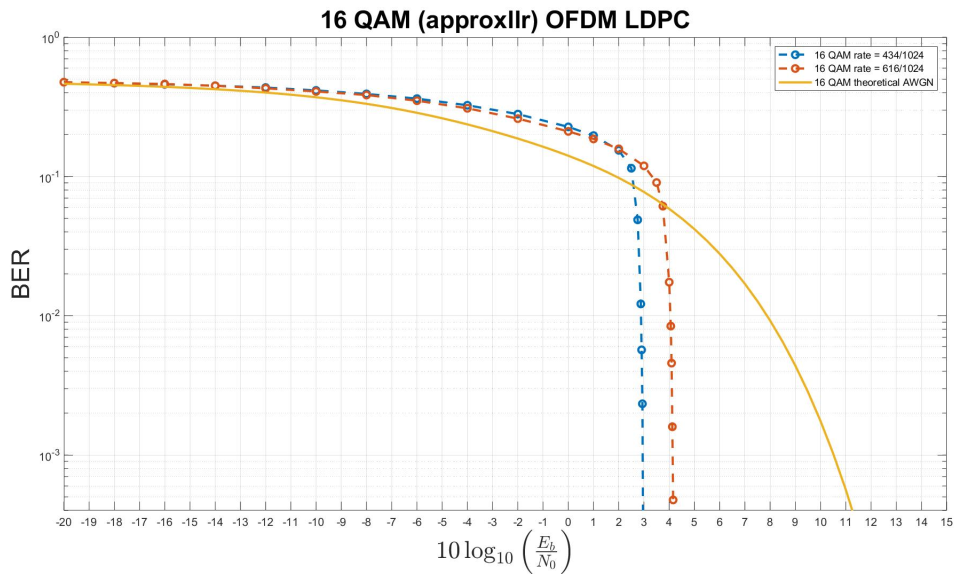

Figure 1: 16 QAM OFDM LDPC curves

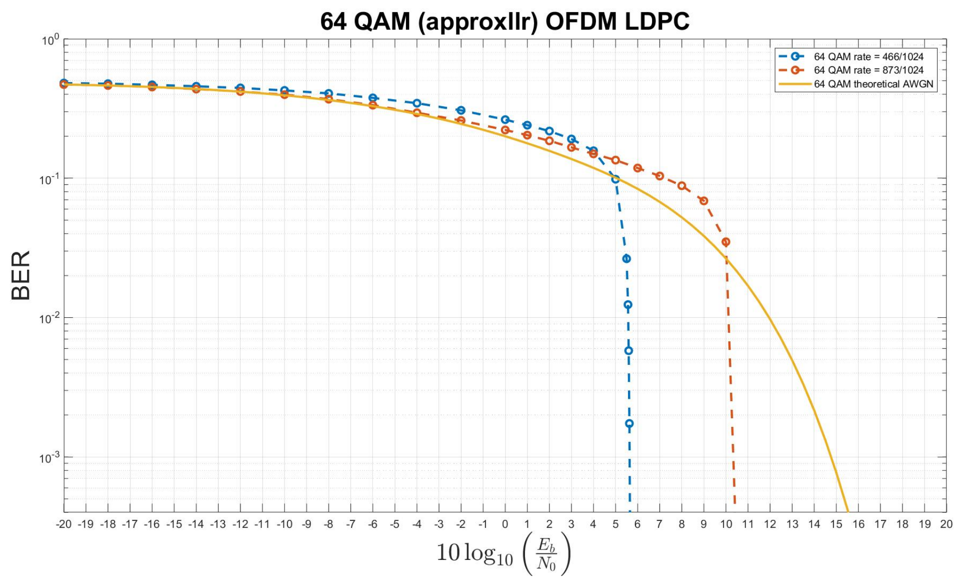

Figure 2: 64 QAM OFDM LDPC curves