EE4140 - Endterm - OFDM Simulation

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Problem

This is a simulation of OFDM System, transmitter and receiver. Bits are sent as input and bits are received at output and the Bit Error Rate (BER) is plotted for different SNR.

1. AWGN Performance of OFDM System: Plot BER Curves (BER vs E_b/N_o) without any channel impairments. Assume multi-path channel and frequency offset ABSENT. Assume perfect timing.
2. Performance with channel and estimation: Assume channel is known (multi-path channel coefficients given) and equalise the channel. No frequency offset and perfect timing.
3. Find the channel using pilots and equalise. No frequency offset and perfect timing.
4. Timing offset (estimate using preamble) and frequency offset (estimate and correct the offset).

Conditions

1. Sampling Rate: $f = 122.88MSPS$
2. Total number of Sub Carriers: 4096
3. Sub carrier spacing: $30kHz$
4. Number of useful sub carriers: 3072
5. Remaining sub carriers are to be used as guard band on either sides of the resource grid
6. Preamble: 64 with half symmetry
7. Time Domain
   - Slot: Each slot has 14 OFDM Symbols (numbered from 0 to 13) along with their Cyclic Prefix
   - Cyclic Prefix: CP length for symbol 0 is 352 and 288 for the rest of them.

8. Final Time Domain Structure: Frame = [Preamble][Slot1][Slot2]...[Slot10]
9. Pilot Structure:
    - Time Domain: Only symbol 2 and 9 have pilots
    - Frequency Domain: Every alternate sub carrier has pilot
10. All points without pilots have data which are generated randomly
11. Constallations: BPSK, QPSK, 16-QAM
12. Channel:
    - Timing offset: To be found for transmitted frame. Add random zeros before every frame
    - Multi-path channel: Coefficients given
    - Thermal noise: Added according to the theory
    - Frequency offset: Parameter epsilon

Variables

```
mQPSK = 4
kQPSK = log10(mqPSK)

Sampling Rate: f = 122.88*1e6 = 122.88MSPS
Total number of SubCarriers: nSC = 4096
FFT Size: nFFT = nSC
Number of Useful SubCarriers: nUsefulSC = 3072
SubCarrier Spacing: fSCspacing = 30kHz
Total number of symbols: nSymb = 14

CP Length Symbol 2: cpLen0 = 352
CP Length Symbol 9: cpLen1 = 288
Preable Length: nPreamble = 64
Total number of slots: nSlots = 10
Guard Band SubCarriers: nGB = (nSC - nUsefulSC)/2 on either sides
Guard Band: GB = zeros(nGB, nSymb)
endIndex = nUsefulSC + nGB
zRow0 = zeros(cpLen0, 1)
zRow1 = zeros(cpLen1, 1)
pilotSymb1 = 2
pilotSymb2 = 9

Channel Coefficients: chCoeff = [-0.014194636478986 0.022561094299837
    -0.034046661636224 0.050235872796492 -0.074564210902286
    0.116183398205243 -0.209922908839027 0.708391695270929
    0.555511290188523 -0.192634871535184 0.109629537392724
    -0.071008310551437 0.047959330035209 -0.032461758969592
    0.021413701190345 -0.013355503650246]
Channel Response: ch = fft(chCoeff)

Number of Data Carriers: nDataCarriers = nUsefulSC*nSymb - nUsefulSC
```

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Resource Grid Size: RGSize = [nUsefulSC nSymb]
Bit Size: bitSize_qpsk = [kQPSK*nDataCarriers 1]
Number of Bits: nQpskBits = kQPSK*nDataCarriers
Frame Size: frameSize_qpsk = [nQpskBits*nSlots 1]

EbNo Vector: EbNoVec = (0:12)
SNR Vector: snrVec_qpsk = EbNoVec + 10*log10(kQPSK) + 10*log10(
    nDataCarriers/(nUsefulSC*nSymb))
BER Vector: berVec_qpsk = zeros(length(EbNoVec),3)
Error Stats: errorStats_qpsk = zeros(1,3)
```

Listing 1: Variables

Steps

1. Generate random bits of required size (frame size)
2. Map it according to the constellation mapping scheme (BPSK, QPSK, QAM)
3. Convert series to Resource Grid size
4. Add pilots at designated positions
5. Add Guard Band on both sides of useful resource grid
6. Take IFFT
7. Convert to series and add cyclic prefix for different symbols
8. Transmit through channel - convolve with channel response and add appropriate noise

$$Y = H \times X + n$$

$$n = \sqrt{\frac{\overline{\text{power}} \times 10^{snr/10}}{2}} \times (randn() + j * randn())$$

9. Remove CP and convert to resource grid size
10. Take FFT
11. Remove guard band
12. Estimate channel from pilots averaging with pilots and interpolating the channel response

$$y = Hx + n$$

x at pilots are known and y is found

$$\hat{H} = \frac{y}{pilot}$$

Here, $\hat{H}_1 = y_1/pilot1$ and $\hat{H}_1 = y_1/pilot1$ and

$$\hat{H}_k = \frac{\hat{H}_1 + \hat{H}_2}{2}$$

This is for one slot. For all slots k from 1 to 14,

$$\hat{H} = \frac{(k-1) \times \hat{H} + interpolate(\hat{H}_k)}{k}$$

13. Equalise the symbols

$$\hat{x} = \frac{y}{\hat{H}}$$

14. Remove pilots
15. Demap the symbols according to the constellation
16. Compare the bits received to bits transmitted and append BER
17. Plot BER vs Eb/No

The image shown below is the rough flowchart followed in the code.

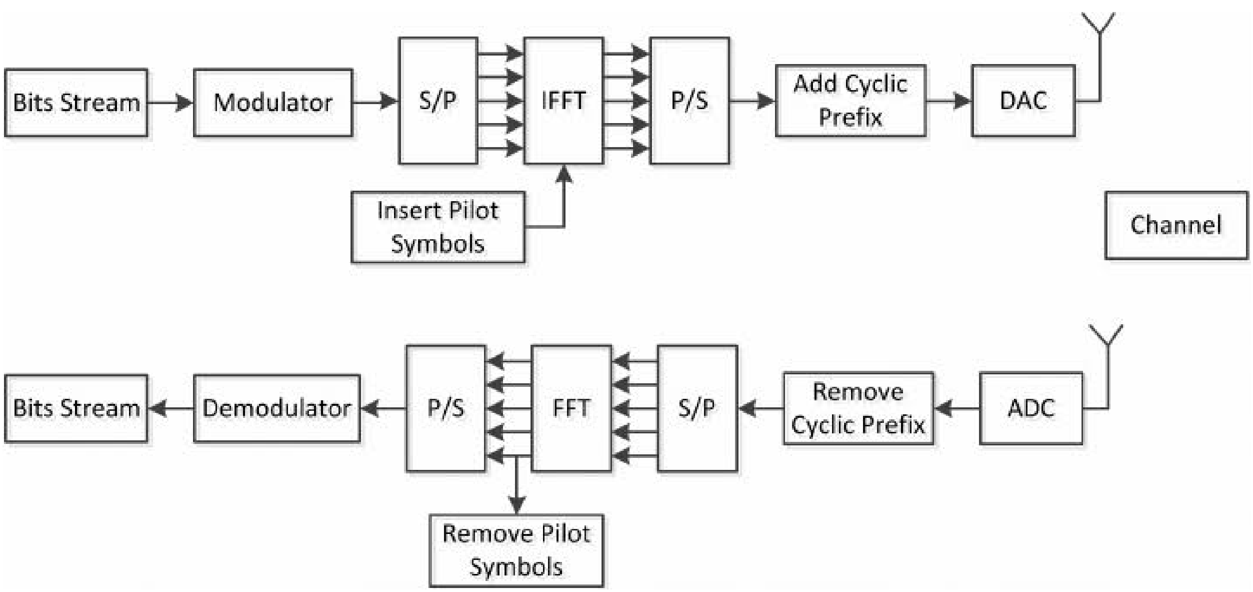


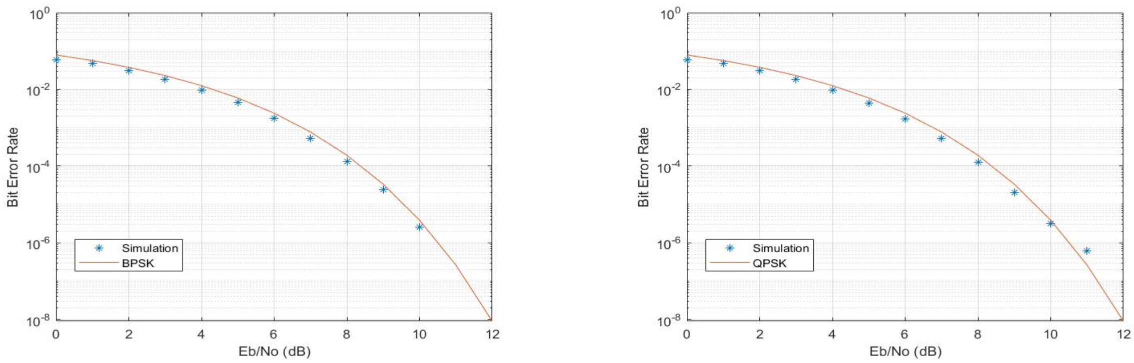
Figure 1: OFDM Block Diagram

Results

I have submitted two codes, one with no multipath channel and one with channel estimation and equalisation. I got some errors and could not get the proper plots when I used functions for some reason, so in the end I removed all of them and coded along the way. I have commented everywhere necessary. If you would like to test for BPSK, please uncomment lines 69, 75, 80, 83, 154, 166, 172 in the second file. And similarly with QAM.

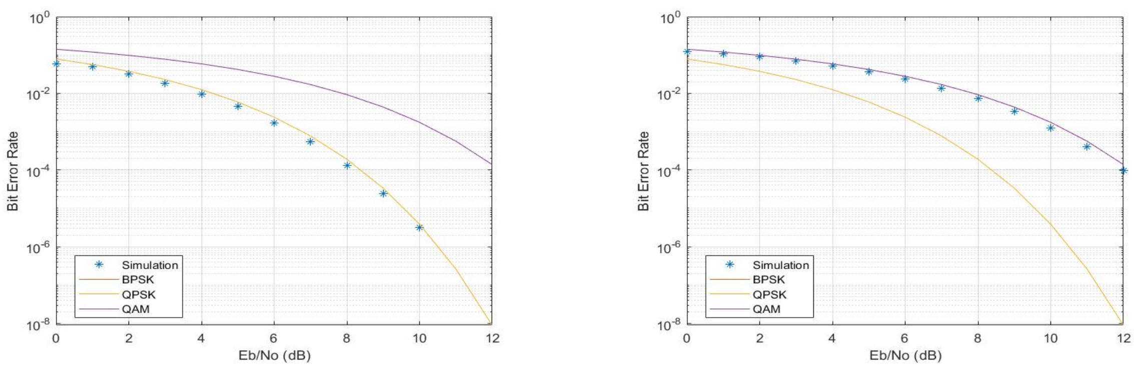
BER Curves for without multipath channel

- The BER curves for BPSK and QPSK are the same as expected.
- The BER curve for 16-QAM is above both the other curves and matches theory.
- In both simulation the simulated points are more or less on the theoretical curve.
- Here, I have shown the curves for BPSK and QPSK side by side in Figure 2
- And in Figure 3, I have shown the curves for BPSK/QPSK and QAM side by side plotting both the theoretical curves in the same plot.



(a) BPSK (b) QPSK

Figure 2: BER Curves for BPSK and QPSK



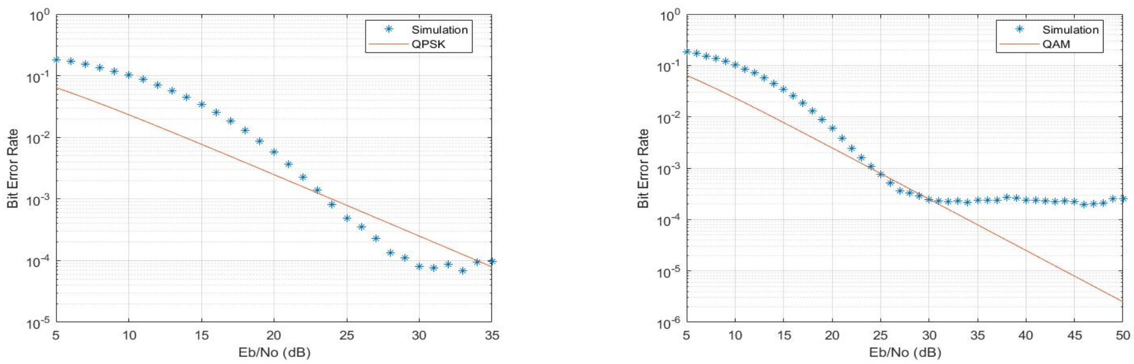
(a) BPSK/QPSK (b) 16-QAM

Figure 3: BER Curves for BPSK, QPSK, QAM

BER Curves for with channel and estimation

- The theoretical curve used for all of these are berfading function.
- Figure 4 has the BER curves for QPSK till 35dB and till 50dB.

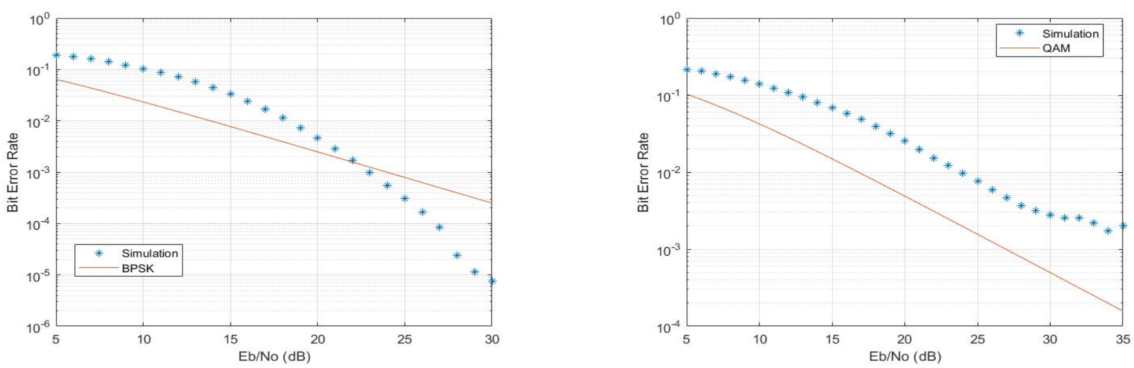
- I used the interpolation method 'pchip' and we can see that the simulation is more or less consistent with theoretical BER Curve for Rayleigh Fading.
- As the SNR increases the simulation goes to a constnt value around a little more than 10^{-4}
- In Figure 5, I have plotted the BER curves for BPSK till 30dB and 16-QAM till 35dB and we can see that the theoretical and simulated curves are more or less similar.



(a) QPSK till 35dB

(b) QPSK till 50dB

Figure 4: BER Curves for BPSK, QPSK, QAM with channel equalisation



(a) BPSK till 30dB

(b) QAM till 35dB

Figure 5: BER Curves for BPSK and QAM with channel equalisation

References

Research Gate OFDM Block Diagram
DSP Illustrations
MATLAB Communications Toolbox Documentation