Wireless Communication Systems Laboratory

Lab #3: Digital modulation techniques

Objective

The objective of this experiment is to understand the various digital modulation techniques and observe the related modulation quality measurements. The students will be familiar with the following items:

- Various modulation types.
- Constant envelope versus higher order modulations.
- Understanding power, spectral efficiency, and data rate trade-offs.
- Comparisons of various modulation types in terms of time envelope, spectral efficiency, EVM performance, constellation, and eye diagrams.
- The tradeoff between higher data rates and higher susceptibility to noise at higher orders of modulation (*e.g.,* 64QAM). Investigation of overall capacity change (increase or decrease) at higher modulations.
- Understanding CCDF (Complementary Cumulative Distribution Function).
- Controlling SDR devices using MATLAB.

Procedure

PART I

1. Initialize two objects for transmitter and receiver with the following parameters:
   - Tx:
     1. Gain: -10dB
     2. CenterFrequency: 2.4GHz
     3. BasebandSampleRate: 1e6 Samples/s
     4. RadioID: (for this one select the serial number using findPlutoRadio command)
   - Rx:
     1. CenterFrequency: 2.4GHz
     2. BasebandSampleRate: 1e6 Samples/s
     3. SamplesPerFrame: 40e3 Samples
     4. GainSource: 'Manual'
     5. Gain: 20dB
     6. OutputDataType: 'double'
     7. RadioID: (for this one select the serial number using findPlutoRadio command)

2. Build a frame for transmission with the following setup. It has two parts; data part, where data symbols are loaded, and a preamble consisting of two cascaded identical m-sequences. The frame parameters are as follows:
   - Preamble: two m-sequences each with (2^7-1) BPSK symbols.
   - Data: 512 QPSK symbols.

   Use the provided `mseq()` function to generate the sequence.

3. Use the provided `fltr()` function to filter the generated sequence of symbols by a root raised cosine filter with 0.5 roll-off factor.

4. Send the generated frame repeatedly using the initialized transmitter object, and use the provided `receive()` function to capture the transmitted frame. Finally, release both device objects.

5. Plot the power spectrum of the received signal and use it to calculate the received signal power.

6. Calculate the RMS value of EVM (you will use it in step 10).

7. With the transmitter turned off, use a receiver object to capture a noise signal. Plot the spectrum of the received signal and calculate the received signal power.

8. Using the results in (5) and (7), calculate the signal to noise power ratio.

9. Repeat steps (1-6) with a higher transmitter gain. Compare the calculated SNRs at different gains.

10. Using the calculated RMS value of EVM in (6), find SNR and compare it with the results obtained in (8).

PART II

1. Using the same setup and procedure in part I send and receive frames with the following modulations: 4-QAM, 16-QAM, and 64-QAM. Make sure you use proper gains for the devices to capture the frames successfully.

2. Compare the power spectral densities of the received signals.

3. Plot constellation and eye diagrams for the received signals and comment on the results. How do you explain the number of levels in the eye diagram?

4. Calculate EVM for each of the received signals. Does EVM increase with the modulation order? Why?

5. Plot the spectrum of each received signal and calculate the 99% occupied bandwidth. Does it increase with the modulation order? Why?

PART III

In this part, use Keysight VSG and VSA. At the generator side, use an arbitrary signal with a rate of 500Ksymbols/s. At the analyzer side, two measurement types are used: (*Check the videos for the detailed setup*)

Digital modulation analysis mode: After adjusting the demodulation properties to match those at the transmitter side, pick a screen layout of 2x2 and observe the following plots in each window:

a- Polar diagram (*includes the constellation*)
b- Spectrum
c- I-Eye diagram
d- Q-Eye diagram

Time-Frequency analysis mode: Use a 2x2 layout and see the following plots in each window:

a- Spectrum (Avg.)
b- CCDF
c- Main Time
d- Inst. Spectrum.

1. Send and receive signals with the following modulations: QPSK, OQPSK, and Pi/4-QPSK. Compare the digital modulation and time-frequency analysis results for the different signals.
    - Explain the constellation diagrams and spectrums. Are they different?
    - Which signal has better polar diagram and why?
    - Which signal has the lowest PAPR and why?

2. Send and receive signals with the following modulations: QPSK, MSK.
    - Compare the polar diagram and CCDF of the signals.
    - Compare the power spectrum of both signals.

PART IV (Optional)

For an AWGN channel:

1. Numerically, compare the spectral efficiency of BPSK, QPSK, 16-QAM and 64-QAM, by plotting the mutual information, as a function of SNR, for the channel of each case.
2. Plot the capacity of the AWGN channel along with the efficiencies plots above. Comment on the obtained results.
3. Using SDRs (Adalm Pluto), set the devices gains to get a fixed SNR value. Based on the results you got in (1), find a proper transmission rate that ensures exceeding the spectral efficiency of 16-QAM. Start transmitting a 16-QAM signal at this rate and show that the bit error rate is very high; hence, no reliable transmission is possible.
4. Repeat (3) but with a lower transmission rate that meets the spectral efficiency of the modulation scheme (keep some guard). By investigating the bit error rate, show that a reliable transmission is possible.