ECE4634 –Digital Communications

Design Project 3

Modulation

Due Date: Dec. 1st, 2020

Objective

The previous two projects dealt with the concepts of sampling, quantization and the transmission of voice signals using carrier modulation. The objective of this project is to examine the impact of pulse shaping, matched filtering and multipath fading.

Approach

As in the previous project, we will use the complex baseband version signals to examine pulse shaping, matched filtering and Rayleigh fading. In this project you will not need to experiment with different sampling rates or quantization schemes. You should use a sampling rate of f_s = 8192Hz with 6 bits (64 levels). Further, you should utilize μ-law companding with μ=255. The modulation scheme used will primarily be BPSK.

Specifics

Once again you can find the programs you need on the scholar page. The voice signal required for this project is located in the binary file DesignProject1.mat. You should sample the signal at 8192Hz. The functions that I will provide are as follows:

`[y, pulse, Ep] = PulseShape( x, PulseShape, Ns, N, roll_off)` — This function takes an input data stream `x` (either ones and zeros or plus ones and negative ones) and uses it to create a modulated pulse stream `y`. `PulseShape` is a text string defining the pulse shape: 'SQAR' = square pulse, 'SINC' = sinc pulse, 'RaCo' = Raised Cosine, 'SRRC' = Square Root Raised Cosine. `Ns` is the number of samples per pulse, `N` is the number of pulse durations used for the sinc, raised cosine and square root raised cosine pulses. `roll_off` is the roll-off factor for raised cosine and square root raised cosine pulses. The other outputs two outputs are the pulse shape `pulse` and the energy per pulse `Ep`. The energy per pulse will be used to normalize the plots.

`rcosine(1, Ns, 'fir', roll_off, ceil(N/2))` – This function is used by `PulseShape`.

`[y, channel] = FadingChannel(x, FadingType, DopplerRate, K_factor)` - This function takes an input vector of modulated symbols x and passes it through a fading channel. The channel type is determined by `FadingType`: 'RAYL' = Rayleigh and 'RICE' = Ricean. `DopplerRate` is the maximum Doppler rate *as a fraction of the sample rate.* Note that if you are simulating one sample per symbol, the sample rate and the symbol rate are the same. `K_factor` is the ratio of the power in the direct path to the multipath components in a Ricean channel (it need not be defined for Rayleigh channels).

`EnergySpectralDensity(x, fs,range)-` this function plots the energy spectral density of the input vector x which is sampled at rate `fs`. `range` is an optional parameter which determines the signal plot axes range. Note that this function plots in a log scale.

Pulse Shaping

The first part of this project investigates the impact of pulse shaping. First, sample and quantize the voice signal as in the previous project to obtain a bit stream. Use `PhaseMod()` to create a BPSK signal from the bit stream. This is the data signal that will be used throughout. Create a signal that uses square pulses using `PulseShape`. Let `Ns` = 10. Plot the resulting signal (note that you should multiply the signal by $\sqrt{E_p}$ when you plot it). You may want to only plot the first 20 pulses or so for the sake of clarity. Also plot on the same graph the optimal sampling times of the square pulse signal. The function `stem` may be useful here. Repeat for a sinc pulse, a raised cosine pulse (`roll_off` = 0.25) and a square root raised cosine pulse `roll_off` = 0.25) with `N` = 10 in all three cases. Note that the delay for each of these pulses is N*Ns/2. Does the value of the pulse at the optimal sample time equal the original data value?

Plot the ESD of each of the pulses using EnergySpectralDensity. To improve resolution you should zero pad each pulse first. That is:

```
EnergySpectralDensity([pulse, zeros(1,1000)], fs )
```

What is the first null bandwidth for each pulse shape? What is the bandwidth for each pulse if we examine the point which is 50dB down from the maximum value? Also plot the spectrum for a raised cosine pulse with `N = 10` and `roll_off = 0.75`. Plot the spectrum for a raised cosine N=5, r = 0.25 and r = 0.75. Again examine the bandwidth of the pulses for each case using the first null and 50dB down points. Do the spectral plots match the formula that is given in the book/notes? If not, why? What is the impact of decreasing N? What is the impact of increasing r? Increase N = 100 and r = 0.25. How do the bandwidths (first null and 50dB down) compare to N=10?

Matched Filtering

The second part of this project examines the impact of matched filtering. Filter the signals created in the previous part of the project (only the first four pulses examined). To filter a signal stream, simply convolve with the pulse shape of interest. For example, if

```
[x, sinc_pulse] = PulseShape(b, ‘SINC’, 10, 10 );
```

then to match filter the signal we use

```
MF_sinc = conv(x, sinc_pulse);
```

Again, plot the optimum sample times using the stem function. Do the sample times give the same values as the original data? Why or why not?

Add noise to each of the signals prior to matched filtering using the AddNoise function. You should assume $E_b/N_o = 7.5$dB as in the previous project. The `AddNoise` function can be used directly since the `PulseShape` function normalizes each pulse to unit energy. Note that the `BitsPerSymbol` parameter given to `AddNoise` is 1 (i.e., BPSK). After matched filtering sample each signal at the optimum sample times and pass through the `PhaseDemod` function. Calculate the bit error rate. How do the calculated values compare to the theoretical values? If there are discrepancies why do they occur? Sample the matched filter outputs at one sample away from the optimum points. What is the resulting BER? Does it change and if so, why? Listen to the signals. How do they sound compared to the original?

Sample and demodulate the signal without matched filtering. How do the BER performance and sound quality compare?

Fading

The last part of the project will examine fading (note that we will not consider pulse shaping in this part of the project). First, take the symbol values coming from the `PhaseMod` function and add noise to them using $E_b/N_o = 7.5$dB. Demodulate and examine the BER. How does it compare to theory? Repeat but now first pass the signal through a Rayleigh fading channel using the `FadingChannel` function *before* adding noise. Let the maximum Doppler shift be 200Hz (note that you will have to convert this to a fraction of the sample rate [also the symbol rate with one sample per symbol] to use it in the function). Plot the channel amplitude on a semilog scale (you can use the `semilogy` function.) Before demodulation, you must remove the phase variation caused by the channel. This can be done as follows:

```
[y, channel] = FadingChannel(x, FadingType, DopplerRate,
K_factor);
r = AddNoise(y, EbNo, 1);
z = conj(channel).*r;
b_hat = PhaseDemod(z,1);
```

Note that we have assumed knowledge of the channel. In a real system we would have to estimate the channel values. How does the resulting BER value compare with theory? How does it compare with AWGN? Repeat for a maximum Doppler shift of 10Hz. How do the channel plots compare? What about the BER values? Repeat this for a Ricean channel with `K=1, 10` and `100` (but only a 200Hz Doppler rate). How do the BER values compare to Rayleigh fading and AWGN? How do the sound qualities compare?

Report
Your project report is the means for communicating to me what you know about the principles that you have learned from the project. Note that unlike the first project, I expect more independent thinking on your part in this project.

One last reminder: Communication skills are important in any career. Engineering is no different. Use this project to refine your report writing skills. In my experience engineers who cannot communicate their ideas are less likely to get promoted and are not taken as seriously. Part of our job as professors is to help prepare you for either engineering careers or graduate school. In either case you will benefit from an ability to communicate.