EGH443 - Advanced Telecommunications
Assignment 2 (30%)

May 20, 2024

In this assessment, you will model large-scale fading of the wireless channel and design and test multi-carrier wireless communication system to provide wireless broadband services. Data collected from an extensive measurement campaign can be used to place access points at strategic locations to maximise reliability and coverage. The channel measurement campaign has found that the wireless channel in the intended coverage area has multi-path characteristics, with a number of delayed paths and a set of measured data is available to estimate the path loss exponent.

Following the instructions in Part 1, you can extract the path loss data and the measured channel delay profile parameters. Each group will have a unique set of data based on your Team number. The Part 2 simulation model can be modified to get the results required for Part 3 and Part 4.

Preliminary Instructions

Download **A2GenData.p** from Canvas and save the file into your working directory.

Workspace Preparation

Run the command 'A2GenData' on the MATLAB command prompt to generate the data for your Team. Enter your team number when prompted.

```
>> A2GenData

>> Enter your Team's number to generate the data:
```

The Assessment data unique to your team will be stored in MATLAB data file called ‘channel.mat’. Use the MATLAB command ‘load’ to get the assessment data onto the MATLAB workspace.

```
>>load('Channel.mat')
```

Part 1 – Estimate Path Loss Exponent of the Channel

Large-scale fading can be modelled as a combination of path loss and log-normal shadowing. The path loss L_{dB} in dB as a function of distance d is calculated by:

$$L_{dB} = L_{0,dB} + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma,$$

where $L_{0,dB}$ is the path loss in dB obtained at the reference distance of d_0 away from the transmitter, n the path loss exponent and X_σ the shadowing component. The shadowing component is normally distributed when the path loss is specified in dB, and has zero mean with a standard deviation of σ also specified in dB.

An extensive measurement campaign was conducted to model the large-scale fading in an urban environment. The received power was measured at 30 different distances from the transmitter, and 100 measurements were recorded at each distance. In this part, you will be estimating the value of the path loss exponent (n) and standard deviation of the shadow fading (σ). Load the '`channel.mat`' data file to get the following data for your group.

- `d`: This vector corresponds to the distance between the transmitter and the receiver at which a measurement was taken. The units are in meters [m].
- `Prx_dBm`: This matrix stores the received power captured in the measurement campaign. Each row of the matrix corresponds to a new measurement trial at different distances and each column corresponds to 100 received power measurements at a given distance. The units are in [dBm].
- `PTxmW`: Transmit power in milliwatts [mW].
- `TxG`: Transmitter antenna gain [dB]
- `RxG`: Receiver antenna gain [dB]
- `Txfreq`: Transmitter frequency [Hz]
- `Rx_Sensitivity`: Receiver Sensitivity [dBm]

1.1 Calculate and present the path loss data at different distances in a scatter plot. Select a distance and plot the histogram of the path loss. Find the mean and the standard deviation of the path loss at that distance. Comment on your observations.

1.2 For each of the distances inside `d`, calculate the average path loss and plot the distance [dB] vs average path loss [dB] in a separate figure. Comment on the linearity of the plot.

1.3 Fit a linear model for the above plot and estimate the path loss exponent (`n`). The `fitlm` function may be a helpful MATLAB function for this step.

1.4 With the given receiver sensitivity, estimate the minimum transmitted power required if the receiver is 100 m away from the transmitter. In this calculation, you must allow for a 5 dB fade margin.

1.5 For each of the distances inside `d`, calculate the standard deviation and find an estimate for the mean standard deviation of X_σ. Calculate the receiver outage probability for the case presented in [1.4].

Part 2 – Design an OFDM System

You are asked to design an Orthogonal Frequency Division Multiplexing (OFDM) system to provide broadband fixed wireless access (FWA). Your system should be capable of offering over 2 Gb/sec download speed using a 400 MHz band centred around the 26 GHz spectrum. The modulation order can be up to 256-QAM.

2.1 Load the channel `channel.mat` file and extract the variables `pvec` and `tvec`, where `pvec` and `tvec` are channel time delay vector in nanoseconds and the delayed relative power vector of the channel in dB respectively. Plot and label the multipath impulse response of the channel.

2.2 Estimate the RMS delay spread and the coherence bandwidth of the channel.

2.3 Design your OFDM system using the above information and the following system parameters.

   - $K = 4096$ - FFT/IFFT size .
   - $N = 3300$ - Number of data carrying sub-carriers.
   - $\Delta f = 120\text{kHz}$ - Subcarrier spacing
   - $T_g = 10\%$ of OFDM symbol duration without the Guard interval

   Estimate the following parameters of your system.

   - T - OFDM Symbol duration
   - T_g - Guard interval
   - Ts - OFDM Symbol duration including the guard interval
   - B - Total occupied bandwidth. Check if this is within the allocated bandwidth and comment on the observation.

   Tabulate the data rate of the system for modulations 16-QAM, 64-QAM and 256 QAM. The system needs 6% of the resources for overhead (control and other signalling). Does your system satisfy the requirements? Justify your answer. NOTE: The guard interval should satisfy $T_g \approx 10 \times \sigma_\tau$.

   Compare above data rates with that of a equivalent single carrier system and comment on whether the single carrier system would be appropriate for the given fading channel (Hint: compare bit duration with the delay spread of the channel).

2.4 Write a MATLAB code to simulate the performance of the OFDM system with the chosen modulation scheme in an AWGN channel. Simulate and plot the bit-error-rate performance within the bit-error-rate (BER) range from 0.5 to 10^{-5} and compare it with the theoretical bit-error-rate performance.

   You can use built-in MATLAB functions in this step. Some of the useful MATLAB functions would be, `fft`, `ifft`, `qammod`, `awgn` and `biterr`. However, do not use built-in MATLAB functions to implement the OFDM system.

2.5 Comment on the observed bit-error-rate performances and describe in detail **two** methods that a practical communication system can use to improve the bit error rate at the receiver.

2.5 Describe in detail **two** methods that can be used to improve the data rate of the system.

2.6 Compare this system's maximum data rate with current Australian NBN data rates.

Part 3 – Performance in Fading Channels

You are able to meet the required data rate for the AWGN channel. Now you need to simulate the performance of above OFDM system in a Rayleigh fading channel with the impulse response given by `pvec` and `tvec`.

The impulse response of the fading channel follows a Raleigh distribution. Let's define a complex Gaussian random variable as $h = X + i \times Y$, where both X and Y are Gaussian random variables with zero mean and the same variance. The envelope (square root) of this complex Gaussian random variable has a Rayleigh distribution.

3.1 Simulate a complex Gaussian random variable, **h** with variance 1 using the `randn` command and plot a normalised histogram of its envelope. Compare the normalised histogram against the theoretical Rayleigh distribution, given by:

$$f_A(a) = \frac{a}{\sigma^2} \exp\left\{-\frac{a^2}{2\sigma^2}\right\}$$

If $X_n (n = 1, 2, \dots N)$ is a vector of modulated symbols, the OFDM signal can be generated by:

$$x_k = \texttt{ifft}(X_n), \quad k = 1, 2, \dots N$$

Assuming the fading channel is stationery during the OFDM symbol duration, we can find the frequency response of the channel using:

$$H_n = \texttt{fft}(h) \quad n = 1, \dots N$$

The **FFT** output at the receiver can be expressed as:

$$Y_n = H_n X_n + n_n$$

Therefore, the received signal can be recovered using a single tap equalisation:

$$\tilde{X}_n = \frac{Y_n}{H_n} = X_n + \frac{n_n}{H_n} = X_n + \tilde{n}_n$$

Now, $\tilde{X}_n$ can be demodulated to extract the transmitted data. You can assume that full channel information is available at the receiver for the following simulation. In practice, channel needs to be estimated using pilot symbols.

3.2 Write MATLAB code to simulate the performance of OFDM system in flat (single path) Rayleigh fading channel within the E_b/N_0 range from 0 dB to 30 dB. Simulate and plot the bit error rate performance and compare with the theoretical bit-error rate performance in fading and AWGN channels.

The power delay profile of the multipath fading channel is given as:

$$h(\tau) = p(\tau_i)\delta(t - \tau_i) \;\; i = 1 \dots L,$$

where L is the number of paths. For the simulation we need to normalise the power. The normalisation factor α can be estimated as:

$$\alpha = \frac{1}{\sum_i^L p(\tau_i)}$$

Then the variance of each path can be estimated as:

$$\sigma(\tau_i) = \alpha p(\tau_i)$$

Finally, each path can be generated as below:

$$h(\tau_i) = \sqrt{\frac{\sigma(\tau_i)}{2}} \times (\texttt{randn(1,K)} + 1i * \texttt{randn(1,K)})$$

where K is the number of channel samples.

3.3 Simulate and plot the performance of the OFDM system in a multipath Rayleigh fading channel. Compare bit error rate performances in AWGN channel, flat fading channel and multi-path fading channel and comment on the observations.

You can load the `channel.mat` file to get the multipath power delay profile of the channel.

Part 4 – Error Detection and Correction

4.1 The uncoded OFDM system implemented in Part 3 does not provide sufficient reliability.

Implement a forward error correction code to improve the reliability of the received data. You can choose any forward error correction method for this section. You can also use built-in MATLAB functions to implement the chosen error control coding method.

Simulate and plot the bit-error rate of the coded OFDM system in the above multi-path fading channel and compare with the bit error rate performance of the uncoded OFDM system in the multipath-fading channel.

4.2 Discuss the effects that a multipath fading channel has on bit errors in the system compared with an AWGN channel. Does your forward error correction code address these effects?

4.3 What is the data rate (information rate) of this system after taking into account the new forward error correction encoding system?

4.4 The designed proposed wireless system to be used for mobile banking and other financial activities. You have been instructed to update the system with an appropriate cyclic-redundancy check code (CRC) to ensure bit errors can be detected.

This CRC should be implemented to detect whether the decoded data after the forward error correction code contains any errors.

Use a block diagram to demonstrate how CRC can implemented in your system.

Update the code to include a CRC-16 in your system. You can use the built-in MATLAB function '`nrCRCEncode`' for this part.

4.5 Estimate the rate at which a user can transmit data when the system is upgraded with the chosen error control coding and CRC scheme.