NLOS Propagation

Introduction

In this lab we will measure the amplitude of a signal propagating over an indoor NLOS path. You will compare the probability distribution of the amplitude of the received signal to the Rayleigh distribution. You will also plot the average signal strength as a function of distance and fit a power law model.

Indoor propagation involves difraction, reflection, and transmission mechanisms similar to those outdoors. By making measurements indoors we avoid getting wet.

Procedure

Overview

The instructor will connect a signal generator with an unmodulated[1] output at a frequency[2] of 222.28 MHz ($\lambda = 1.35$ m) to an "antenna" consisting of clip leads.

You will use a LimeSDR Mini board that uses a Lime Microsystems LMS7002M IC to downconvert and sample an RF signal to a digitized complex baseband signal. This signal is transferred to your PC over a USB 3.0 interface.

GNU Radio is a software package that can be used to prototype the signal processing required to implement a software-defined radio (SDR). The instructor will supply a GNU Radio flow graph, `survey.grc`, that selects the desired signal, computes the amplitudes of the complex samples and saves them to a file.

You will collect several files containing samples of the received signal amplitude versus time. You will move the antenna during the measurements so that the samples will also correspond to signal amplitude versus position.

Probability Distribution of Signal Amplitude First you will look for a location where the signal level has large variations over short distances indicating multipath propagation. For this measurement the distance to the transmitter (d) will not change significantly. If there are multiple propagation paths to the location where you are taking your measurements, the interference between the paths will cause constructive and destructive interference (fading). These measurements will allow you to verify models for the probability distribution of signal amplitude due to multipath fading.

Signal Amplitude versus Distance Then you will move to various positions at distances from about $d = 3$ m from the transmitter to a distance about $d = 30$ m from the transmitter. If you average out the signal level fluctuations due to multipath, this measurement will allow you to measure the variation of signal strength with distance in this environment.

The data collection portion of the lab should not take very long so if you do not have a laptop with GNU Radio installed you may use someone else's laptop to collect the data and then post-process it yourself on the lab computers. If you work in a group, each student should collect and analyze their own data.

Once you have collected the data you will use the first set of data to compute the histogram of the short-term variations of signal amplitude and compare it to a Rayleigh distribution. You will use the other measurements to fit a curve to the the amplitude vs distance data.

It's a good idea to plot your data before leaving the lab as it's common for things to go wrong.

Install the Software

If you have a laptop with about 500 Mb of free disk space you can install GNU Radio and the drivers for the LimeSDR board.

The process is as follows:

- Download and install `radioconda`. This includes GNU Radio, a compatible version of Python and the necessary libraries.

[1] Sometimes called "CW" for continuous wave.

[2] This frequency is in an amateur radio band which your instructor is licensed to use.

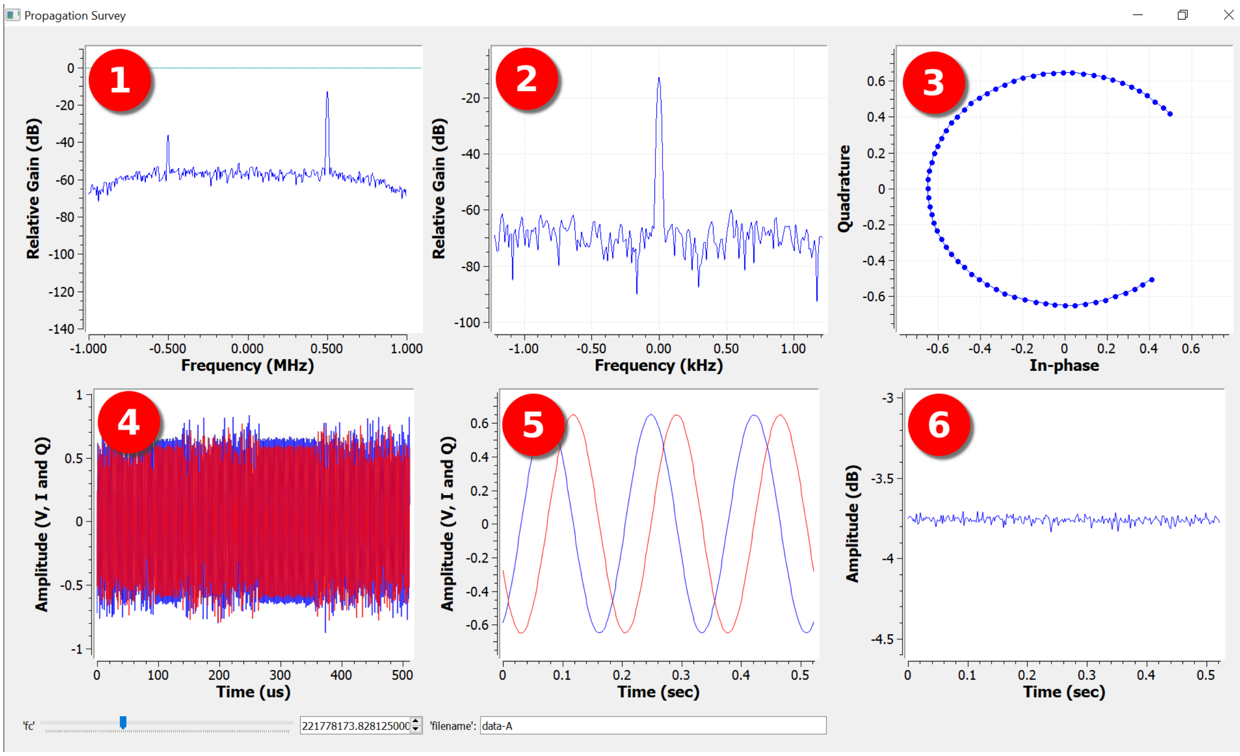
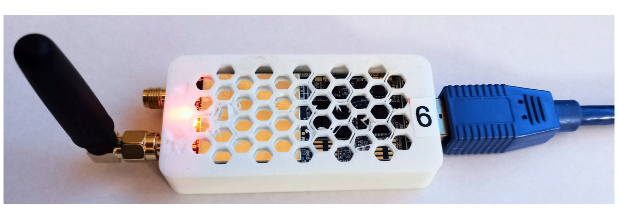


Figure 1: **survey.grc** GUI showing: (1) spectrum with the received signal at 500 kHz; (2) spectrum centered at 0, (3) I/Q plot of signal samples; (4) I and Q signals at a sampling rate of 2 MHz; (5) and at approximately 500 Hz; and (6) the signal amplitude in dB. The fc slider allows fine adjustment of the receive frequency and the filename field shows the file to which samples are being saved.

- if the LimeSDR device is not recognized when you plug it into your USB port, download and install FTDI drivers from: `http://www.ftdichip.com/Drivers/D3XX.htm`

Connect the SDR Module

Connect a Software Defined Radio (SDR) module to a USB 3.0 cable and connect the cable to a USB (USB 3.0, if possible) port of your laptop. If the device is not recognized you may have to install the FTDI USB drivers described above. The LED should start blinking red/yellow.



Use the supplied antenna. The module will have a case; the receive port is indicated by a triangle pointing inwards.

The radioconda distribution includes the `LimeSuiteGUI.exe` utility in the **Library/bin** subdirectory. To test the connection to the SDR board select Options/Connection Settings, select the LimeSDR Mini device, and click on Connect. If you then click on the Default button the LED will start flashing green. Click on Calibrate All and the device will take a few seconds to calibrate itself and then show new I/Q gains and DC offsets. This verifies the board is connected and functional.

Run the Propagation Measurement Flow Graph

Run GNU Radio Companion and open the **survey.grc** file available on the course web site.

Before you run the flow-graph you should double-click the filename field and change the name of the file being written, `data-A` by default, as described below.

Change the file name before running the flow graph each time or you will lose the data you collected on the previous run.

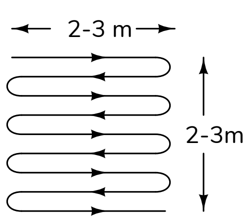
Select Run/Execute (F6) to run the flow graph. After a few seconds this will open up the GUI shown in Figure 1. If you are in range of the transmitter you should see a signal at 500 kHz in sub-window 1. Since the receiver filter bandwidth is only about 300 Hz you'll need to use the slider to center the received signal at frequency 0 in sub-window 2. You should then see I/Q samples arranged in a circle in sub-window 3 due to the remaining frequency difference.

Collect Data

Rayleigh Fading

Move to a location where the signal is likely to be received over multiple paths (e.g. another room with a door that opens up to the same hallway as the lab) and where the signal is significantly stronger than the noise. There should be strong variation of signal level with antenna position (e.g. you might find nulls a quarter-wavelength away from a reflecting object). This confirms the existence of multipath propagation.

Change the file name (e.g. `data-1`) to start collecting data to a new file[3] and systematically move the antenna in a regular pattern left-to-right, up-and-down, and forward-and-back:



to uniformly sample the signal strength within a volume of a few wavelengths (a few metres) in each dimension[4].

[3] By default it will be saved in the same folder as the `.grc` file.

[4] Don't just move the antenna back and forth along the same path; you'll simply be sampling the same locations repeatedly.

Collect data for about a minute. At the sampling rate of $2 \times 10^6/2^{12} \approx 488$ Hz this will give you about 30k samples, and a file of approximately 120 kBytes. Close the GUI window to stop the flow graph and stop collecting data.

Path Loss

Figure 2 shows labelled points at various distances to the transmitter which is located in room SW1-3061. The distances are given in the following table[5]:

location	distance (m)
A	40
B	28
C	19
D	12
E	4
F	8
G	18.5
H	18

For the second measurement you will repeat the collection process above but at various locations in the hallway to measure the average received signal level at various distances from the transmitter.

At each measurement point change the file name to match the collection location (e.g. `data-A1`). Then start collecting data and move the antenna to uniformly sample a volume of several wavelengths (2-3 meters) for 10 or 20 seconds.

Data Analysis

The final step is to check whether the collected data fits theoretical predictions for multipath fading and path loss versus distance. You should plot your data before leaving the lab to make sure it looks reasonable. The multipath fading data should contain fades and the path loss data should vary with distance. More detailed analysis can be done later.

The examples below use Octave (or Matlab) but you may use other numerical analysis software if you prefer.

The data files contain sequences of 4-byte ("single precision") floating point values. The following Oc-

[5] You can use additional points; the scale is 500:1 (e.g. 1 cm on the plan corresponds to a distance of 5 m).

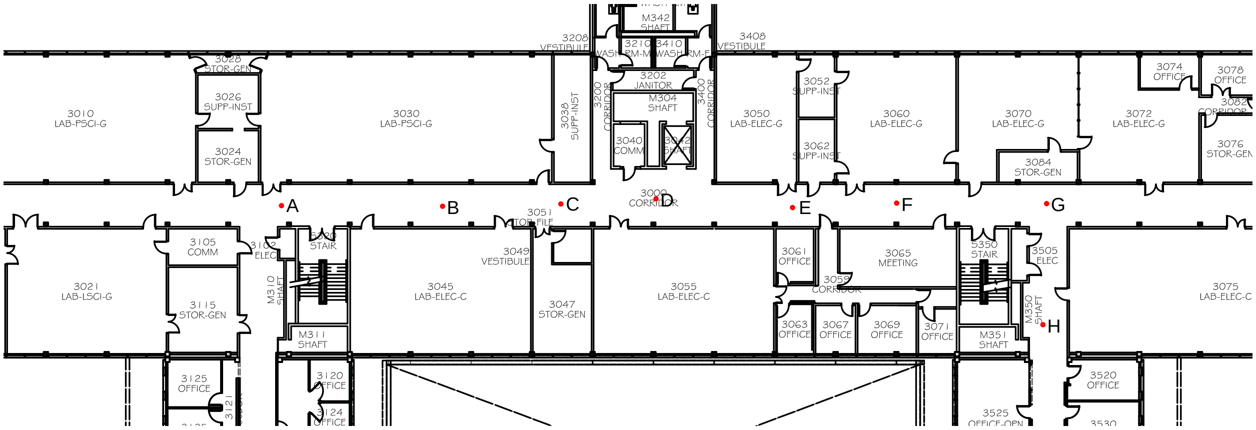


Figure 2: Floor plan, third floor of SW1 (by BCIT Facilities).

tave commands read the values into the vector **s** and plots them[6] as a sanity check:

```
f=fopen('data-1')
s=fread(f,Inf,'float') ;
fclose(f)
plot(20*log10(s))
```

If your data includes points that you do not want to include in your analysis (e.g. because you were not moving) you can use different starting and ending indices of the vector **s**.

Probability Distribution

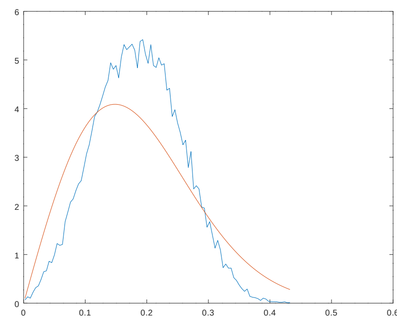
You can use **hist()** to compute the bin counts and bin centers of the histogram and **raylpdf()** to compute the theoretical pdf:

```
[n,x]=hist(s,100);
dx=x(2)-x(1);
h=n/sum(n)/dx;
plot(x,h);

sigma=mean(s)/1.25

plot(x,[h;raylpdf(x,sigma)])
```

Which might result in something like the following (not very good[7]) fit:



If your data is not a good fit to a Rayleigh distribution you can compute the mean and variance and plot the corresponding Ricean distribution to see if it's a better fit.

Path Loss Exponent

The mean signal level at each distance can be obtained by averaging the sample values recorded at each location.

A common model for distance-dependent path loss is that the received signal power drops off as a power of the distance. In free space, as given by the Friis equation, the path loss exponent is -2. For NLOS propagation the signal typically drops off with distance more quickly, although there are exceptions.

If we express the received signal power as a function of distance:

$$P_R = P_R(d_0)\left(\frac{d}{d_0}\right)^{-n}$$

then the received power in dB will be a linear function of the log of distance:

$$P_{R(\mathrm{dB})} = -n10\log(d) + k_{\mathrm{dB}}\,.$$

[6] Skipping the first sample – it seems to be zero.
[7] This data looks a better fit to a Ricean distribution.

This is a straight line with a slope $-10n$. By fitting a straight line to a plot of the received power in dB versus $10\log(d)$ you can estimate n.

Note that the values saved to the file are the magnitudes of the received signal voltage in linear units, not the received power, and not in dB. Do the averaging in linear power units. Convert each average power to dB correctly or your exponent will be off by a factor of 2.

Lab Report

Submit a lab report to the appropriate Assignments dropbox in the file format described in the course information document. In addition to the required identification information, include the following your report:

- a plot of the first few seconds of data from your multipath measurements to look at the trend of the data
- the histogram of your multipath data and a superimposed Rayleigh pdf that has the same σ
- a plot of the path loss in dB versus log of distance along with the best fit to a power law. You can do the fit graphically or numerically (e.g. using `polyfit`).
- the best-fit value of the path loss exponent

You do not need to include any additional material.