

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 refraction, reflection, and transmission mechanisms similar to those in outdoor areas but by making measurements indoors we avoid the risk of getting wet.

Procedure

Overview

The instructor will connect a signal generator with an unmodulated¹ output at a frequency² 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. The sampled signal is read 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 two files of 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 dis-

tance 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 walk the antenna from a distance of about $d = 3$ m from the transmitter to a distance about $d = 30$ m from the transmitter. If you average out the short-term fluctuations due to multipath, this measurement will allow you to (roughly) model the variation of signal strength with distance in an indoor environment.

This 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 pairs you should collect two sets of data so that each student has their own data to analyze.

Once you have collected the data you will compute the histogram of the short-term variations of signal amplitude and compare it to a Rayleigh distribution. You will also 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 Windows 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:

- if it’s not already installed, follow the instructions in Lab 1 to download and install Pothos SDR, Python 3.9, GNU Radio Companion and allow the initial run to download and install the necessary additional Python packages.

¹Sometimes called “CW” for continuous wave.

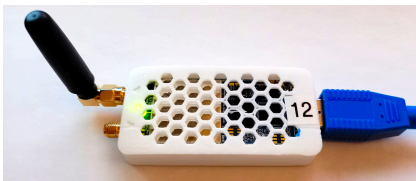
²This frequency is in an amateur radio band which your instructor is licensed to use (“call sign” VA7EX).

- if the LimeSDR device is not recognized when you plug it into your USB port you may have to 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 the connect cable to a USB (USB 3.0, if possible) port of a laptop. If the device is not recognized you may have to install the FTDI USB drivers as described above. The LED should start blinking red/green.

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



You may want to run the LimeSuite utility from the Windows Menu to verify the connection to the SDR board. Select Options/Connection Settings, select the LimeSDR Mini device, and click on connect. If you now click on the buttons Defaults and Calibrate All, the device will take a few seconds to calibrate itself and then show new DC and gain offsets. This verifies the board is connected and functional.

Run the Propagation Measurement Flow Graph

Download the `survey.grc` file from the course web site and open it. If you've installed GNU Radio, it should open with the GNU Radio Companion application.

Select Run/Execute (F6) to run the flow graph. After a few seconds this will open up a GUI that shows you the received signal as a function of time and frequency at two sampling rates (5 MHz and approximately 80 kHz) as well as a polar plot of the complex signal and the signal amplitude versus time in dB. The GUI also has controls to adjust the receive (actually, LO) frequency, the gains of various receiver stages and the name of the file being (over-)written, `C:/Windows/Temp/propdata.dat` by default.

Since the receiver filter bandwidth is only about 1 kHz, you may need to adjust the receive frequency

using the fc slider until the signal as shown in the fine frequency display is near zero. You can click and drag with the left mouse button to zoom in on a portion of the spectrum. Left-click to restore the full range.

Note that the frequency displayed is 1 MHz lower than the signal frequency³.

Normally the only other control you will need to change is the file name. You should change the default file name value by double-clicking the QT GUI Entry box in the flow graph and changing the Default Value value. *Do this before running the flow graph each time or you will lose the data you collected on the previous run.*

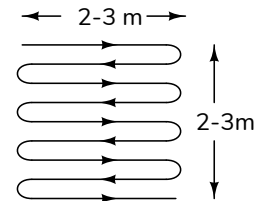
If you are in range of the transmitter you should see impulses in frequency, sine waves in time and the phasor diagram should be a point rotating around the origin and moving in and out depending on the signal amplitude. We will cover GNU Radio and signal processing in more detail later in the course.

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. `propdata-ray1.dat`) to start collecting data to a new file 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 dimension⁴.

³This will be explained in a future lecture.

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

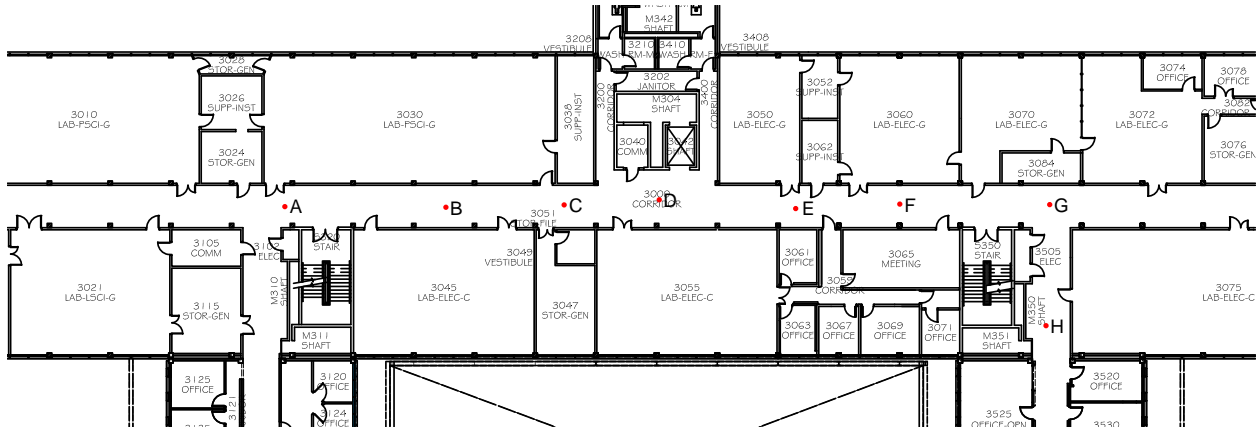


Figure 1: Floor plan, third floor of SW1 (by BCIT Facilities).

Collect data for about a minute. At the sampling rate of $5 \times 10^6 / 2^{12} \approx 1.221$ kHz this will give you about 60k samples, and a file of approximately 240 kBytes. Close the GUI window to stop the flow graph and stop collecting data.

Path Loss

Figure 1 shows labelled points at various distances to the transmitter which is located in SW1-3061. The distances are given in the following table⁵:

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.

Change the file name (e.g. `propdata-loss2.dat`). Start collecting data and simultaneously start a timer. As you reach each measurement point record the time at which you arrive. At each measurement point move the

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

antenna back and forth at an approximately constant distance from the transmitter for a few (e.g. 10) seconds. Then record the time at which you move away from that point.

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 Matlab (or Octave) 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 Octave commands read the values into the vector `s` and plot them⁶ as a sanity check:

```
f=fopen('c:/Windows/Temp/propdata.dat','r');
s=fread(f,Inf,'float');
fclose(f);
plot(20*log10(s(2:end)));
```

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`.

⁶Skipping the first sample – it seems to be zero.

Probability Distribution

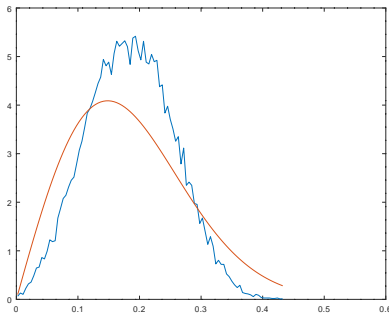
You can use `hist()` to compute the bin counts and bin centers of the histogram and `raylpdf()` to compute the theoretical pdf:

```
[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 good⁷) 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. Since the sample rate is 1.221 kHz, you can calculate the range of sample indices by multiplying the elapsed time by 1221. For example, if the samples for point D were recorded between 20 to 25 seconds past the start of the measurement, the then corresponding samples will be `s(1221*20:1221*24)`.

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 in this may not be the case over this particular path.

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:

$$P_{R(\text{dB})} = -n10 \log(d/d_0) + k_{\text{dB}}$$

This is a straight line with a slope $-10n$. By fitting a straight line to a plot of the received power in dB versus $10 \log(d/d_0)$ you can estimate n .

Note that the values saved to the file are the magnitudes of the received signal in linear units (voltages), not powers in dB.

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 versus distance (or suitable functions thereof) along with the best fit to a power law
- the exponent that results in the best fit

You do not need to include any additional material.

⁷This data looks a better fit to a [Ricean](#) distribution.