Carnegie Mellon University

18-452/750 Wireless Networks and Applications

Project 1 *Due Feb 26, 2021 by 5:00 pm*

1. Objectives

You are expected to accomplish this lab project by your own.

- To experimentally monitor the physical layer characteristics of a wireless channel between multiple devices operating on a wireless local area network (WiFi). Specifically you will perform:
  - **LOS Experiment**: An experiment observing the change in (1) signal strength and (2) data rate as distance is varied when the receiver and transmitter are in line of sight of each other
  - **NLOS Experiment**: An experiment observing the change in (1) signal strength and (2) data rate as distance is varied when the receiver and transmitter are not in line of sight of each other; and contrast these measurements with the line of sight data
  - **Your Experiment**: An experiment of your design to collect interesting data and present your findings
- To use these experimental results to gain an insight in both the physical environment's impacts on radio frequency (RF) signals and wireless challenges.

2. Overview

For each experiment there will be a number of questions associated with them. The 'pre-experiment analysis' questions are to be answered before performing the experiment to aid your design of the experiment, and the 'post-experiment data analysis' questions are to be answered after the experiment is completed to augment your findings.

1. Pre-Experiment: Modelling/Intuition

Prior to each experiment refer to the lecture material of similar nature to develop an intuition about the experimental data. You can assume the experiments are being conducted in an ideal environment, with constant noise and no environmental variability.

2. Experiments: Data Collection

For this lab, data will be collected using 2 different methods: (1) continuously varying distance while data is collected (referred to as "Continuous Data Collection") and (2) data collection at discrete distances (referred to as "Discrete Data Collection").

1. In Continuous Data Collection, data is collected as an experimental variable changes (in our experiments distance between the transmitter and receiver). This can be performed by starting the experiment with the two devices in specific locations and then slowly and continuously moving the devices apart at a 'constant' rate. This emulates what would occur when a user is moving (e.g. walking down a hallway and checking e-mail).

2. In Discrete Data Collection, a predetermined number of samples from predetermined points are collected. This can be performed by placing the transmitter and receiver at predetermined stationary locations and collecting a specific number of data points at each predetermined location. This emulates what would occur when a user is stationary (e.g. sitting at a table surfing the internet).

3. Post-Experiment: Data Analysis & Presentation

The physical layer data being collected for this lab are discrete samples (one sample per packet) of a continuous signal. This channel is constantly changing due to many factors, which can create significant variations in the sample data. This will create variability in the values collected, as the sampling rate is significantly lower than changes in the continuous signal. Thus it is important to have a number of sample data points to account for variations in the measured data. To normalize these variations, you can apply a moving average type of function to the data. Techniques for presenting the data (using both the Continuous and Discrete Data Collection methods) are illustrated below. Please also reference the recitation information for additional details.

- **Continuous Data Collection:** An example representation of the data collected continuously changing the distance while collecting sample physical layer data is shown in Figure 1. Due to the discrete sampling of a continuous signal, the data will fluctuate rapidly (as shown by the unfiltered data line in Figure 1). To aid interpretation of the data and to approximate the true value of the continuous signal, it is often beneficial to filter the data (as shown by the filtered data line on Figure 1). There are many different types of filters that can be applied to the data (e.g. moving average, Savitzky-Golay filtering, local regression, etc), filter selection should be based upon the data, noise, and collection procedures.

- **Discrete Data Collection:** An example representation of data collected at by sampling over a period of time at discrete distances is shown in Figure 2. The data will fluctuate rapidly due to the sampling of a continuous signal, to aid interpretation the data's mean and standard deviation can be plotted for each distance where samples were collected (as indicated in the figure). Alternatively, a box-and-whisker plot could be generated for each collection event.

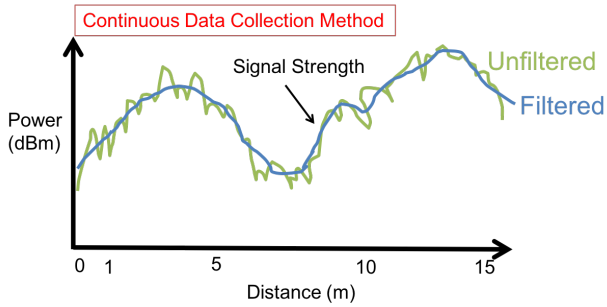

Figure 1: Continuous Data Collection with Filtering

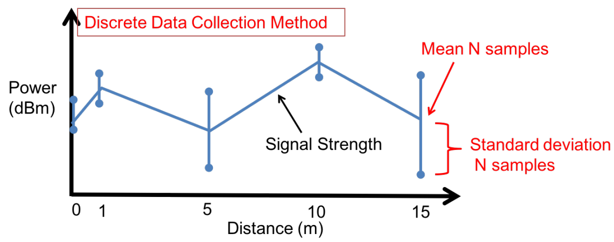

Figure 2: Discrete Data Collection plotting the Mean and Standard Deviation

Additionally, keep in mind that when observing experimental data, it can be beneficial to analyze the data from different perspectives. For example, when observing changes in the physical layer data rate, it might be beneficial to look at how the received signal strength is also changing. While a different insight might be gained by observing the data rate with the SNR. Other times, it is beneficial to compare two different experiments when observing the impact of changing a common variable.

3. Experiments

There are two prescribed experiments and one that is developed by you.

The experiments that you will be conducting as a portion of this lab are:

1. **Line of Sight (LOS) Experiment.** With the 2 devices in line of sight (LOS) of each other collect WiFi packets at varying distances, starting with the devices a few centimeters apart until a few meters (e.g. 5 meters, higher is better).
   Pre-Experiment Analysis
   - LOS signal strength can be modeled using the Friis transmission equation (Free Space Path Loss in the lecture slides). Create a model of your experiment showing how the signal strength will vary with distance, and generate a plot from this model.

Collect Experiment Data
The key data being collected is (1) signal strength and (2) data rate over distance. Collect this data using the following methods:

- Continuous data collection method
- Discrete data collection method

Post-Experiment Analysis

- Write 1-2 sentences describing your experimental setup
- Generate a plot of your experimental data with both (1) signal strength and (2) data rate over distance from both the continuous and discrete collection methods (one plot for each method).
- Write 2-3 sentences noting trends or abnormalities in the plots and describing how you processed the data.
- Write 1-2 sentences describing any differences between data collected using the continuous and the discrete data collection methods.

2. **Non Line of Sight (NLOS) Experiment.** With the 2 devices *NOT* in line of sight (NLOS) of each other collect WiFi packets at varying distances, starting with the devices a few centimeters apart until a few meters (like 5 meters, or higher if possible). A simple way to ensure the devices are not in line of sight is to place one device behind a wall or place a cardboard in front of one device.
Pre-Experiment Analysis

- Write 1-2 sentences describing your intuition about how the (1) signal strength and (2) data rate over distance will be different from the LOS experiment.

Collect Experiment Data
The key data being collected is (1) signal strength and (2) data rate over distance. Collect this data using the method continuous data collection method.
Post-Experiment Analysis

- Write 1-2 sentences describing your experimental setup
- Generate a plot of your experimental data with both (1) signal strength and (2) data rate over distance.
- Write 2-3 sentences noting trends or abnormalities in the plots and describing how you processed the data.
- Generate a plot comparing the LOS and NLOS data (1) signal strength and (2) data rate over distance from both the continuous collection method.
- Write 1-2 sentences noting how NLOS data compares to LOS data. Did the results match your intuition?

- Based upon the data from the LOS and NLOS experiments, does the data rate change with signal strength? Was this expected?

3. **Your experiment.** Create your own experiment or choose among these:

   - For a fixed distance, experiment in different scenarios such as when they are obstructed by different materials (and/or combinations of materials) such as a metal, a person, a thin wall, a concrete wall.
   - Run the LOS experiment in a different space (e.g., outdoor/indoor, hallway/apartment, bedroom/bathroom/living room, etc.) and compare your results.

   Pre-Experiment Analysis

   - Write 1-2 sentences describing your intuition about your experiment.

   Collect Experiment Data
   Determine the key data needed to be collected, and collect using the the method you determine to be best for your experiment.

   Post-Experiment Analysis

   - Write 1-2 sentences describing your experimental setup.
   - Generate a plot of your experimental data.
   - Write 2-3 sentences noting trends or abnormalities in the plots and describing how you processed the data.
   - Write 1-2 sentences describing any conclusions you can draw from your results.

4. Submission

Your lab submission should include the following items for each experiment.

1. **Line of Sight (LOS) Experiment.**

   (a) Plot of your model signal strength and your experimental data signal strength collected using both continuous and discrete techniques compared to distance.

   (b) Plot of your experimental data (1) signal strength and (2) data rate compared to distance collected using both the continuous and discrete techniques. These can all be plotted on the same figure where the left y-axis is one unit (e.g. dBm) and the right y-axis is another unit (e.g. Mb/s). This can be performed in MATLAB using the the 'yyaxis' command.

   (c) Answers to the following questions:

      i. Write 1-2 sentences describing your experimental setup.

      ii. Write 1-2 sentences noting trends or abnormalities in the plot.

iii. Write 1-2 sentences describing any differences between your data collected using the continuous method and the data collected using the discrete method.

2. **Non Line of Sight (NLOS) Experiment.**

   (a) Plot of your experimental data (1) signal strength and (2) data rate compared to distance collected using the continuous technique, using similar filtering techniques to those used for the LOS data.

   (b) Plot a comparison of the LOS and NLOS (1) signal strength and (2) data rate compared to distance using the data collected with the continuous technique.

   (c) Answers to the following questions:

      i. Write 1-2 sentences describing your experimental setup.

      ii. Write 1-2 sentences describing your intuition about how the (1) signal strength and (2) noise level over distance will be different from the LOS experiment (from before performing the experiment).

      iii. Write 1-2 sentences noting trends or abnormalities in the plot.

      iv. Write 1-2 sentences noting how NLOS data compares to the LOS data. Did the results match your predictions?

      v. Based upon the data from Experiment 1 and Experiment 2, does the data rate change with signal strength? Is this expected?

3. **Your experiment.**

   (a) Plot your findings.

   (b) Answers to the following questions:

      i. Write 1-2 sentences describing your experimental setup.

      ii. Write 1-2 sentences describing your intuition about the data you will collect.

      iii. Write 1-2 sentences on reasoning about any trends or abnormalities in the plot.

      iv. Write 1-2 sentences describing any conclusions you can draw from your results.

Appendix

A. Experiment Setup

Big Picture: Monitor two devices communicating over WiFi using Wireshark (installed on device A).

Figure 3: Overview Diagram of Experiment Setup: Device A is running Wireshark, Device B can be any device communicating with Device A.

Instructions

1. **Preparation:** (1) You need one laptop (Device A in Figure. 3) running Wireshark (Installation: `https://www.wireshark.org/download.html`). We highly recommend you using a MacOS laptop to run this tutorial. (2) You need another device (Device B in Figure. 3) to communicate with your Device A. Device B can be another laptop, a Wi-Fi router, etc. In the following steps, we assume you are using your Wi-Fi router as Device B.

2. **Establish a wireless connection** between the two devices by simply connecting them on the same Wi-Fi network.

3. **Wireshark in Monitor Mode**.

   (a) Open Wireshark on Device A. In the drop down menu for "Capture" ensure that 'Wireless' is selected. It should display 'Wi-Fi' below with a graphical display of the number of messages received over time next to it.

   (b) Click on the 'Capture' drop down menu, and select 'Options ...'. In the new window that opens, ensure that for the Wi-Fi Interface, 'Monitor' box is checked. With the 'Wi-Fi' Interface highlighted, click the 'Start' button.

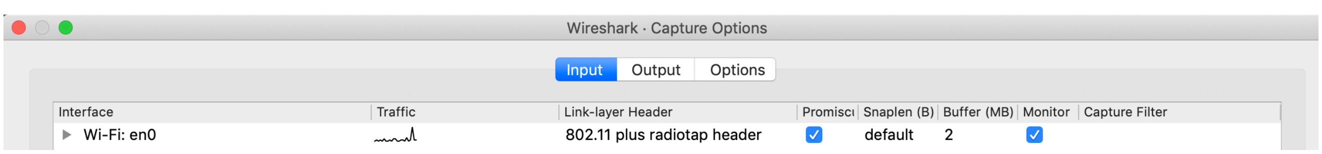

Figure 4: Setting Monitor Mode on Wireshark

- Note: there are OS and wireless hardware eccentricities, and not all combinations of hardware and OSes support Wireshark in Monitor Mode. Please refer to this website for additional troubleshooting assistance for specific OSes and wireless hardware: `https://wiki.wireshark.org/CaptureSetup/WLAN#Turning_on_monitor_mode`.

4. **Check for Physical Layer Data**. If Wireshark is operating in Monitor Mode and the wireless hardware, when a packet is selected (i.e. clicked on) a packet dissection will be shown below. In the packet dissection, there should be a category titled '802.11 radio information'. Select this to view the values obtained.

   - If there is not an '802.11 radio information' category, Wireshark is not operating in Monitor Mode. Go back to the previous step to ensure Wireshark is operating in Monitor Mode.

   The '802.11 radio information' category should include data for: 'PHY type', 'Data rate', 'Frequency', 'Signal strength (dBm)', 'Noise level (dBm)', 'Bandwidth', and 'TSF timestamp'. Observe the value of 'Signal strength (dBm)'.

5. **Sanity Check** that the measurements are acting as expected. Create a larger separation between the devices, the value of the 'Signal strength (dBm)' should decrease.

6. **Apply a Wireshark Display Filter**. For easier analysis, Wireshark allows filtering the display so that only packets with specific properties are displayed. To apply a filter for only viewing packets with a source MAC address of Device B, in the 'Apply a display filter ...' window you can type:

```
wlan.sa == 20:c0:47:20:c:7f
```

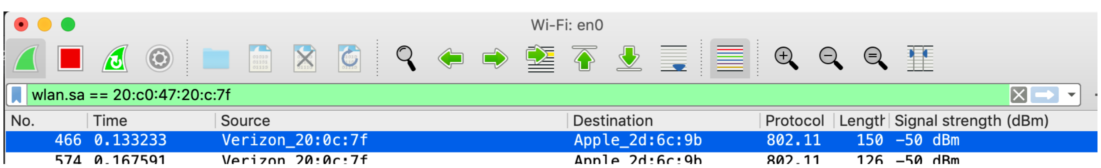

Figure 5: Apply the filter

   If you are using your Wi-Fi router as the Device B, you can use the following way to check the MAC address of that, type in the following command in your terminal:

```
arp -a
```

   More info about displaying filters: `https://wiki.wireshark.org/DisplayFilters`

7. **Save packets to a file**. To process and to display the data collected during experiments, save the data to a file. To save the data collected from a Wireshark capture, select the 'File' drop down menu > 'Export Packet Dissections' > select data format. The data formats listed in Table 1 are available.

Figure 6: Check the mac address of your connected Wi-Fi router

Table 1: Data Formats Available in Wireshark

Format	**Notes**
Plain Text	Able to save all the data in the packet dissection
CSV	Only saves the data in the display window (above packet dissection information)
"C" Array	
PSML/PDML XML	
JSON	

8. **Adding Data Headers to Display Window**. Wireshark allows for data in the packet dissections to be added to the display window. This can be beneficial for quick analysis and for post-processing the data using one of the many available file formats. To add a data value from the packet dissections to the display window, right-click on the data item > select 'Apply as Column'. This will add the value to the display window, and cause those values to be saved to the CSV, "C" Array, PSML/PDML XML, and JSON output files.

B. Data to be Collected

Information being Collected:

For each experiment, collect the data variables shown in Table 2.

Table 2: Data Categories & Example Values

Data Category	**Example Value**
PHY type	802.11a/n
Data rate	6.0 Mb/s
Signal strength (dBm)	-50 dBm
Noise level (dBm)	-80 dBm
Frequency	2412 MHz
Bandwidth	20 MHz
TSF Timestamp	2634373546

Note: the TSF timestamp is the measure of clock ticks were 1 tick is equivalent to 1 microsecond. The difference between two packets TSF timestamps is the time difference between the reception of the two packets in microseconds. The Wireshark time value is within ±5 microseconds of the difference between TSF timestamps.

C. Alternative Approach

If you are using another laptop as Device B, you need to actively send packets from B to A. The simplest way to perform this is using the 'ping' command from the command prompt/terminal. Determine each device's IP address by running the 'ifconfig' command (in MacOS/Linux). For example, if the laptop running wireshark has an IP address of 192.168.1.1, the following command would be sent from the other laptop to send a ping to the laptop running wireshark:

```
$ ping 192.168.1.1
```

It is recommended to send a flood of ping requests to your Device A. A flood of ping requests can be sent on the device B using the following command:

```
sudo ping -f 192.168.1.25
```