A Summarization of BLE Research Over Spring 2020

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Abstract

This paper discusses my research on Bluetooth Low Energy (BLE) devices over the Spring 2020 semester. We first explain BLE devices and key components associated with them. Then we discuss some of the experiments that were conducted with these devices. Finally, we examine the results from these experiments and provide some concluding remarks on what further research can be done.

Introduction : An Overview of BLE

Bluetooth low energy devices are a subset of bluetooth devices that focus on transmitting data with small throughputs and low power consumption over small distances. These devices are primarily used in situations that require low power usage such as Indoor Positioning Systems (IPS), health monitoring, and home automation[1].

BLE devices transmit at 2.4 GHz. This is the same frequency as Wi-Fi. To reduce interference from Wi-Fi signals, BLE will transmit on channels that do not overlap with the channels that Wi-Fi uses to transmit. Since Wi-Fi uses channels 1, 6, and 11, BLE transmits on channels 37, 38, and 39.

BLE provides two different types of advertisement: scannable, and non - scannable. Scannable advertisement requires a response from the receiver whereas the non - scannable mode does not wait on a response from the receiver.

BLE also has the ability to control the strength of the signal that it sends. This is commonly referred to as txPower. Along with this variable is another measurement called RSSI. The RSSI, or the Received Signal Strength Indicator, measures the actual signal strength received by a device listening for BLE transmissions. Oftentimes, txPower has an associated RSSI. This associated value is the expected signal strength the receiver should expect if it is 1 meter away from the sender.

Experiment Setup :

Experiment #1 : Examining Changing RSSI on Different Channels

In this experiment, I made use of two different types of BLE devices. I used an Adafruit Feather nRF52840 Express as the advertiser and a Tiny Seeed BLE as the receiver (scanner). The feather transmitted a simple packet containing the name of the device in the non - scannable mode. The packet was transmitted on all three channels. The interval between the start of each transmission on each channel was 100 ms. The scanner would listen to all the packets that were being transmitted. It would spend 10 seconds on each channel and continuously rotate between the channels.

The receiver and scanner were placed 1 meter away from each other. Both devices were taped to the side of a plastic container (Fig 1) and arranged to face each other.

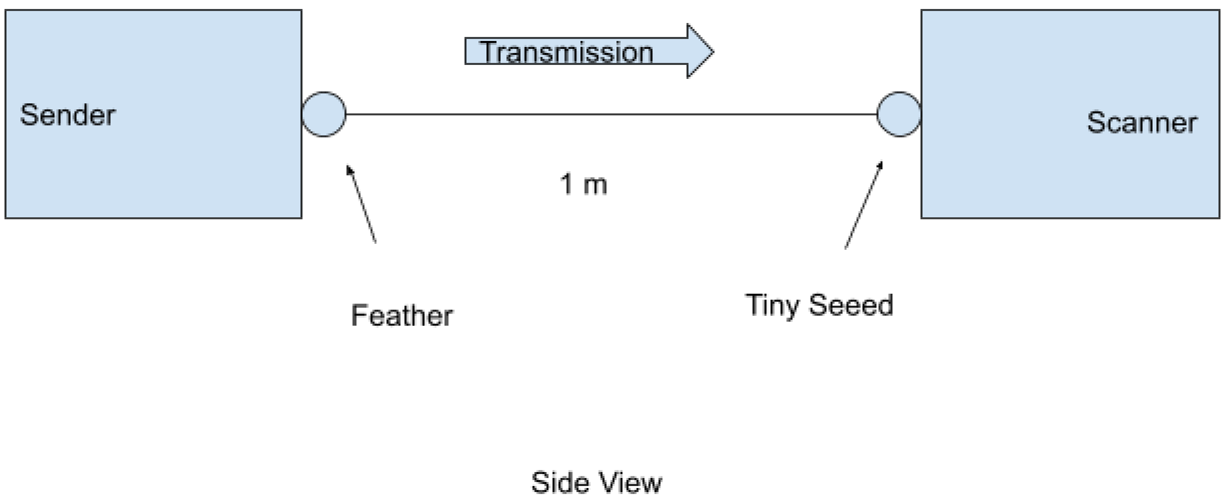

Fig 1. A side view of the layout used for experiment 1. The circles in this case represent the BLE devices and the two blue rectangles represent the plastic containers that were used to position the devices. It is also important to note that the containers were placed on a wood table.

The sender would send packets at 14 different txPower values. Each txPower would be sent for 1 second. The scanner would look at all the packets it could see and examine packets that were from the specified mac address of the Feather. From there the scanner would determine the channel that the packet was received on and also store the RSSI for that packet.

Experiment #2 : Differentiating Between Two Senders Based on RSSI

The second experiment tried to determine whether it was possible to differentiate between two senders, who were at different distances from the scanner, based on their RSSI values. In this experiment, I placed two Adafruit Feather devices at various distances from the Tiny Seeed scanner. The feathers would transmit on all three channels with the same frequency and in the same mode as the previous experiment.

The two feathers were placed at varying distances from the sender (but this distance never exceeds 1 meter). In a similar fashion to the previous experiment all the devices were taped to the side of plastic containers and arranged to face each other (Fig 2).

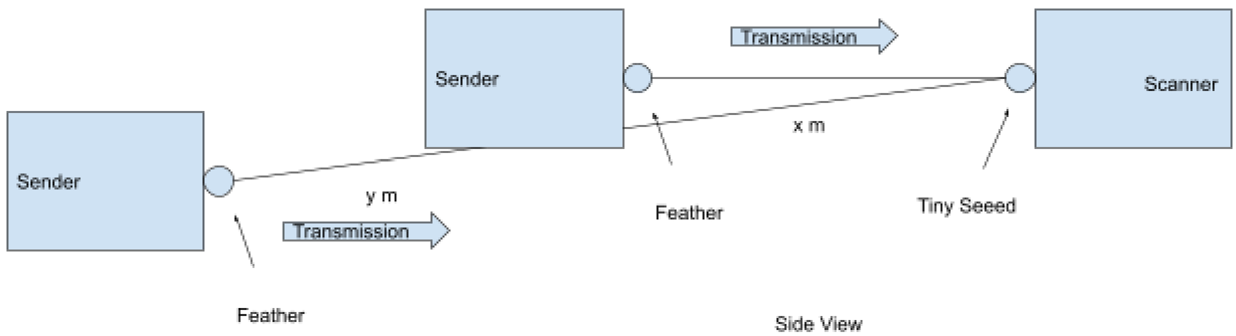

Fig 2. This figure details the layout of the devices in the second experiment. In this experiment there are two senders (both are Feathers) and one scanner (Tiny Seeed). The two senders are placed at a distance x and y meters from the scanner where x is less than y and they are both less than 1 m. Please note that although this image shows that the devices were at different heights, the devices in actuality were on the same plane (the table from the previous experiment).

In this experiment, both senders would start transmitting packets at the same time with the same txPower (-12). They would repeat the same transmission 20 times. The scanner would look for two different MAC addresses and print out the RSSI, MAC address, and channel. For simplicity's sake, one sender was designated as the device that would be further away from the scanner and one sender was designated as the device that would be closer to the scanner.

Results:

Experiment #1:

The results of this experiment were as expected. There was a clear jump in RSSI between each increase of txPower (Fig 3).

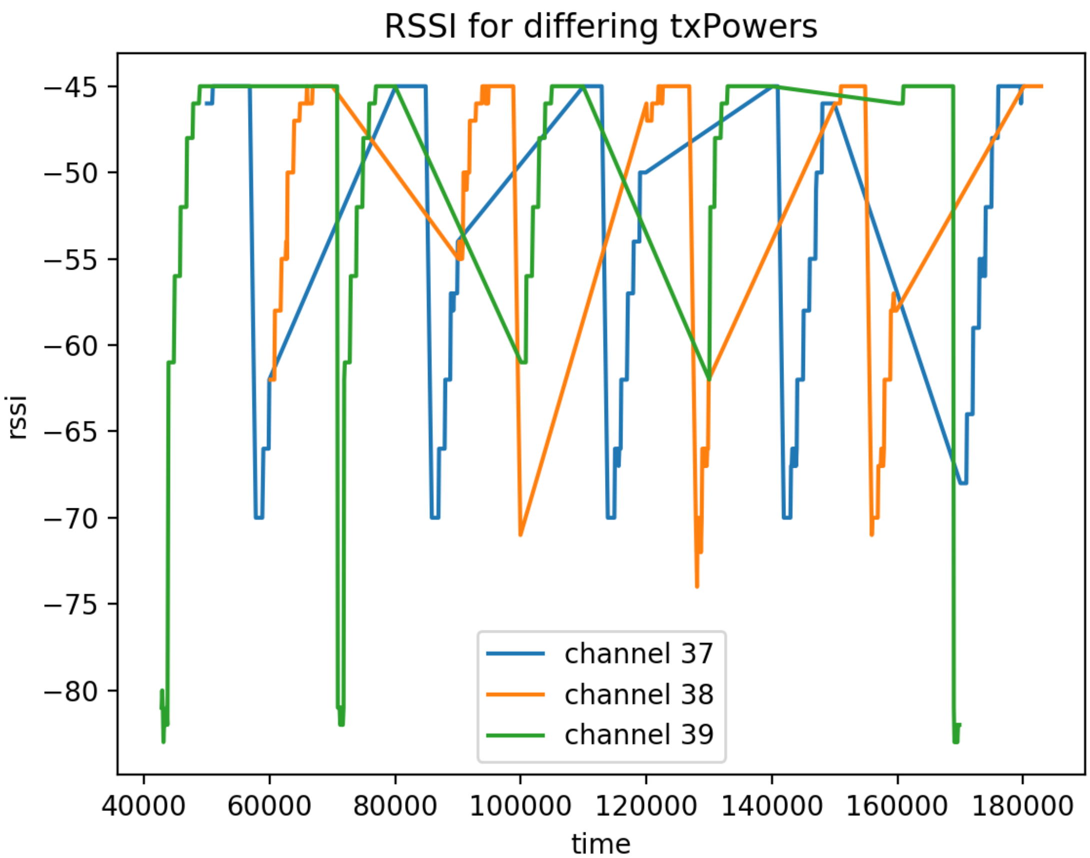

Fig 3. This graph shows the RSSI values at 1 meter for the three different channels

An interesting detail that can be observed is channel 39 was able to get the full range of txPowers whereas the other channels were only getting data points after the RSSI reached a value of around -70 dBm. The data provides clear indication that the scanner is able to detect different channels and that the txPower was clearly impacting the RSSI at 1 meter. However, many jagged lines like the jump from time 60000 to 80000 on channel 37 indicate that there are missing data points.

Experiment #2:

In this experiment, I looked at a variety of distances to determine whether the scanner would be able to differentiate between the two transmitters just based on their RSSI. The first distances I looked at was the closest sender being at 50 cm and the further sender being at 90 cm (Fig 4). The second distances I examined were 60 cm and 90 cm (Fig 5), followed by 70 cm and 90 cm (Fig 6). Finally, I brought both devices much closer to the scanner setting one at a distance of 20 cm and the other sender at 25 cm (Fig 7)[1].

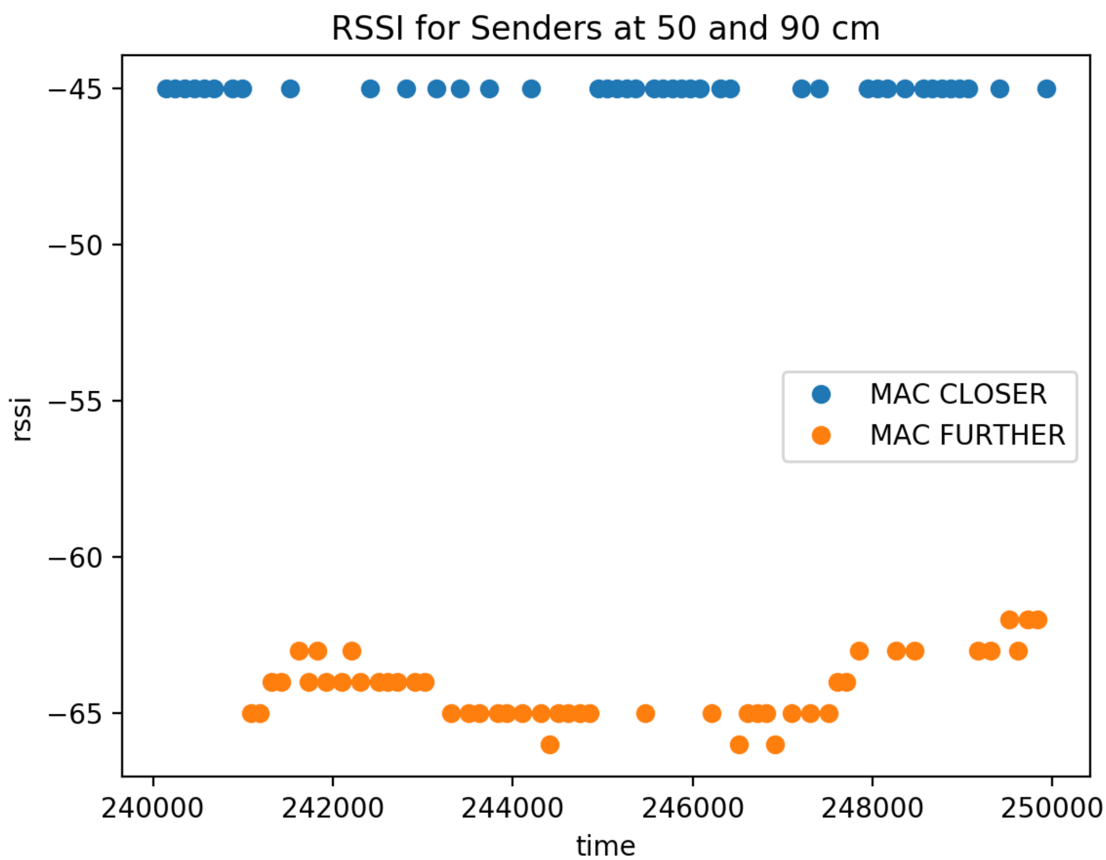

Fig 4. This graph shows the RSSI values for the transmitter at 50 cm (in blue) and the transmitter at 90 cm (in orange)

[1] *Please note that in Fig 4 - 7 all of the data points are obtained on channel 38 as that was the only channel with enough data values.*

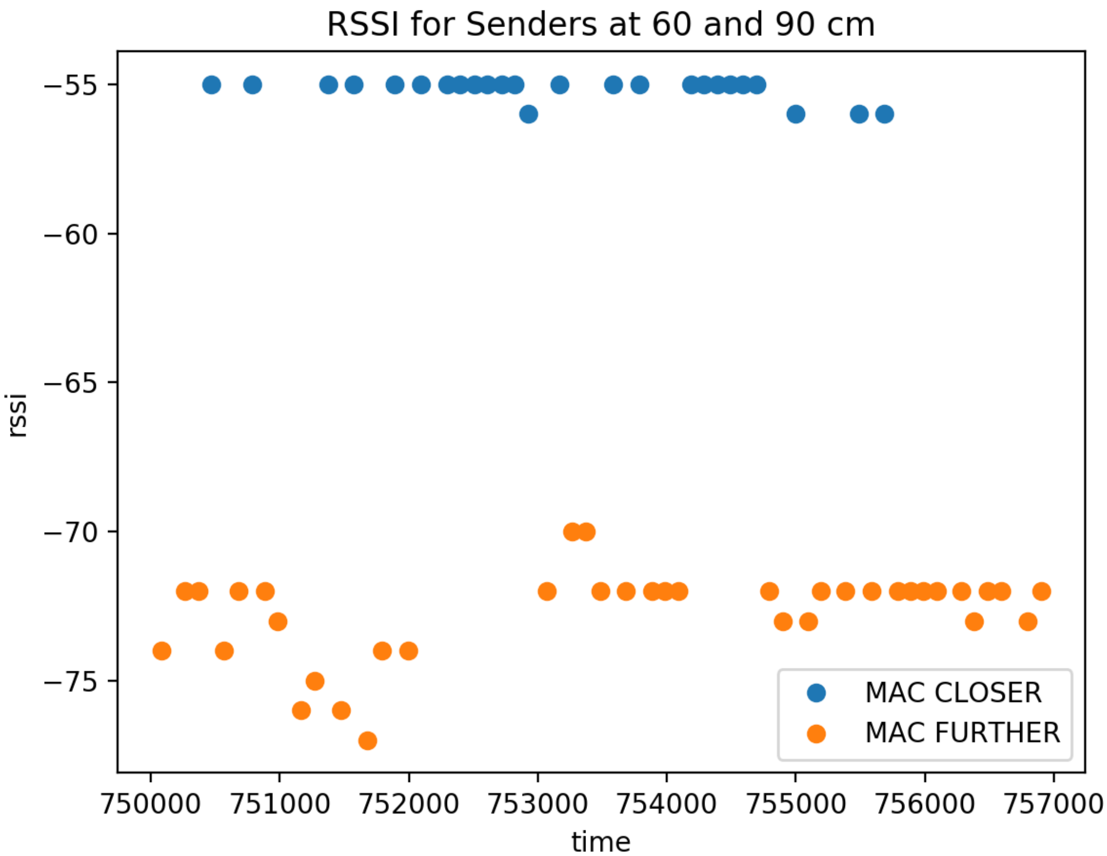

Fig 5. This graph shows the RSSI values for the transmitter at 60 cm (in blue) and the transmitter at 90 cm (in orange)

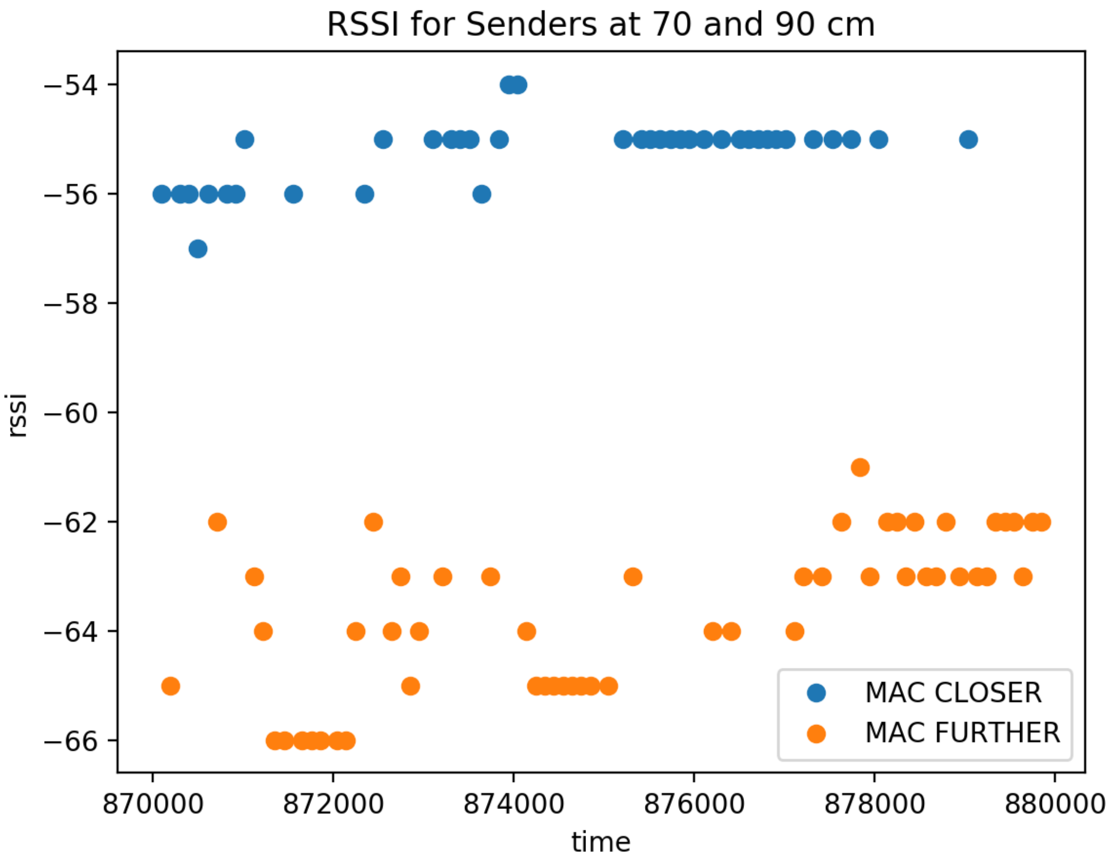

Fig 6. This graph shows the RSSI values for the transmitter at 70 cm (in blue) and the transmitter at 90 cm (in orange)

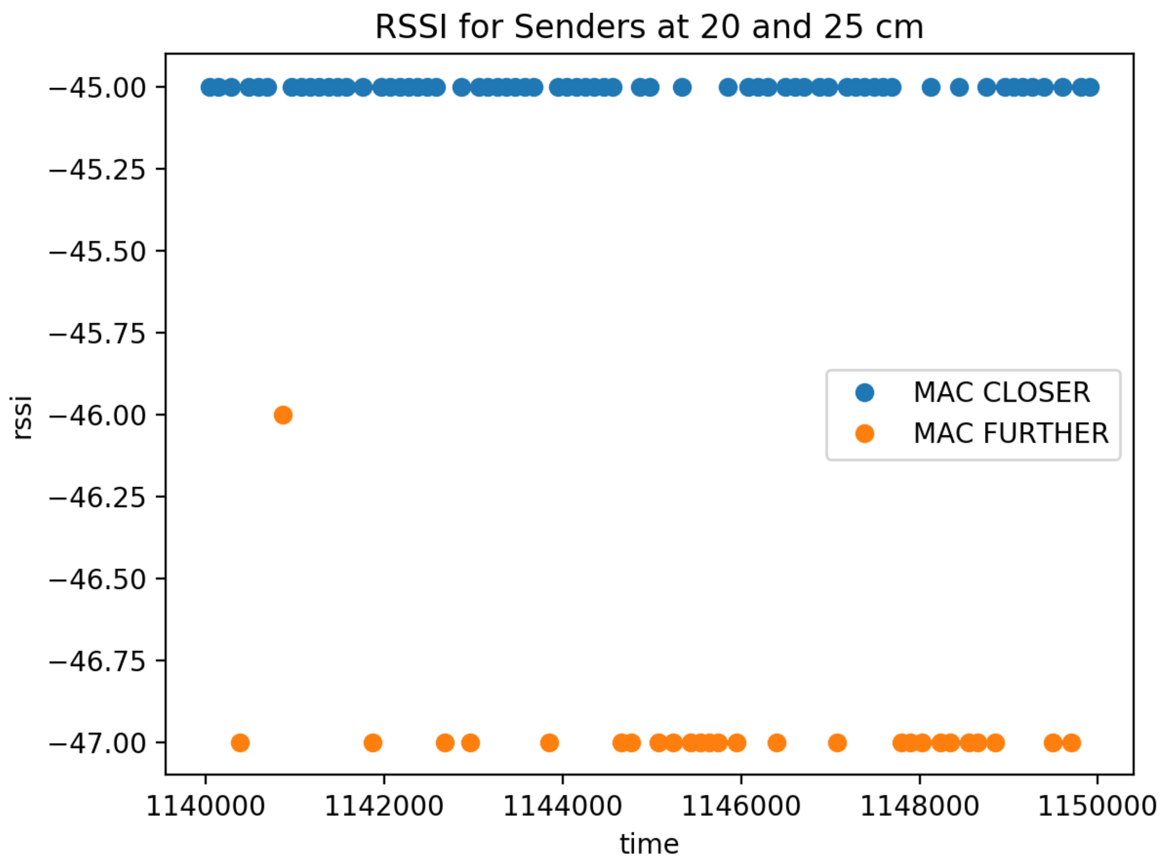

Fig 7. This graph shows the RSSI values for the transmitter at 20 cm (in blue) and the transmitter at 25 cm (in orange)

In general, the devices are easily identifiable based on their RSSI value. Something of importance is that as the distances between the transmitter and scanner were increased, a lot more variation could be observed between the RSSI values for the same device. This is very evident in figure 6, where the device at 70 cm has RSSI values ranging from -54 dBm to - 57 dBm and the device at 90 cm has values ranging from -61 dBm to -66 dBm. Another key takeaway from these experiments was that even when the devices were not that far apart, it was very easy to identify them. This was especially true when the devices were brought closer to the scanner (Fig 7) -- observe the reduction in the variation of the RSSI values[2].

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[2] *It would be very interesting to see how much closer the devices can be placed before they are not differentiable*.

Concluding Remarks:

Overall, both experiments highlighted some key components of BLE. In experiment 1, I explored how changing txPower impacts RSSI at a fixed distance of 1 meter. In experiment 2, I examined the relation between distance and RSSI. Both of these experiments taught me a great deal about BLE and its potential usages in the world. If there was more time to continue researching, I would have continued to work on furthering knowledge I gained from experiment 2. It would be very interesting to see how many potential devices can be differentiated. I would have also liked to examine how different surfaces impact the RSSI of a packet. BLE has been continually on the rise as more and more use cases have been identified. It will be interesting to see how BLE is used in the future.

References

[1] Yang, Jian, et al. "Beyond Beaconing: Emerging Applications and Challenges of BLE." *Ad Hoc Networks*, vol. 97, 25 Sept. 2019, p. 102015., doi:10.1016/j.adhoc.2019.102015.