Evaluating the Effectiveness of BLE RSSI Measurements in Determining “Too Close for Too Long”

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***Abstract*—It is known that the RSSI measurement of a Bluetooth signal alone cannot be used to determine the distance between two devices. However, it is possible that RSSI can predict whether two devices are in a relative position that, if carried by people, would qualify as too close for too long (less than six feet for more than 15 minutes). The goal of this project was to determine if Bluetooth RSSI measurements can be used to accurately predict “too close for too long” at least 80 percent of the time, assuming that the devices are being held in front of a person’s body by measuring RSSI in a variety of likely every-day scenarios.**

Keywords—PACT, obstructions, advertiser, receiver, RSSI, BLE.

I. Introduction

A. Project Description

The Coronavirus Disease (COVID-19) has proven to be a problem on an international scale. Having infected more than ten million people and killed hundreds of thousands, it can be seen that the virus is both contagious and virulent. However, the effects of the disease are not limited to infections and deaths. COVID-19 has caused worldwide economies to plummet, people to lose jobs, and widespread fear.

One promising weapon against the spread of the virus is contact tracing. Unfortunately, traditional (manual) contact tracing is not scalable and it relies too heavily on the limited ability of humans to recall exactly whom they have been in contact with recently. This is where private automated contact tracing (PACT) comes in. PACT relies on computers to do the work of contact tracing and cellular devices to determine proximity, which is clearly more scalable than manual contact tracing.

This project addresses the ability to use a Bluetooth device on the body of a person in order to determine whether that person has been “too close for too long” to another person with a Bluetooth device. This was done by setting up two BLE (Bluetooth Low Energy) devices in a variety of scenarios. Some of the scenarios represented people being “too close for too long,” others did not. The exact procedure will be explained in more detail in an upcoming section.

B. Background Information

The devices used to emit (advertise) and collect (scan) BLE signals were Raspberry Pi (Model 4B). The Raspberry Pi is a miniature computer that can connect to the Internet, other devices via Bluetooth and USB, and serve as a fully functional computing device. BLE is a subset of classic Bluetooth that allows a wide variety of different devices to be able to connect with each other using only limited energy [1]. As two devices exchanging BLE signals increase in distance from each other, the received signal strength indicator (RSSI) decreases. A multitude of other things can cause RSSI values to vary, including but not limited to temperature and humidity [2], reflection off of nearby surfaces, device orientation, and direct path obstruction by objects or bodies.

II. Hypothesis/Hypotheses

Null hypothesis: an RSSI measurement can be used to predict whether or not two people were too close for too long less than 80 percent of the time.

Alternative hypothesis: an RSSI measurement can be used to predict whether or not two people were too close for too long more than 80 percent of the time.

This hypothesis relates to PACT because it sets up an experiment that attempts to determine if BLE signal strength can be used to determine if people have been “too close for too long” (typically, the definition is closer than six feet for at least fifteen minutes, however, for the purposes of this project, it is considered closer than six feet for at least one minute). If it is found that the alternative hypothesis is supported by the data, it could contribute to the possibility that Bluetooth-based PACT is indeed feasible. Additionally, this data could be contributed to the ever-growing dataset for PACT.

The aspect of the hypothesis that requires the most investigation is determining the exact RSSI measurement that serves as the divider between safe and “too close for too long.” Several different methods for finding this RSSI value will be described in further detail below.

III. Experiments and Data Collections

TABLE I. Experiment Overview

Exp. #	Hypothesis	Reason	Repetitions
1: RSSI values at distances of 2, 4, 6, 8, 10, and 12 feet with no obstructions	Effect of increased linear distance on RSSI	Adding another scenario to the overall dataset	18
2: RSSI values at distances of 2, 4, 6, 8, 10, and 12 feet with an obstruction of one person	Effect of a person obstructing device path on RSSI	Adding another scenario to the overall dataset	18
3: RSSI values at distances of 2, 4, 6, 8, 10, and 12 feet with an obstruction of two people	Effect of two people obstructing device path on RSSI	Adding another scenario to the overall dataset	18
4: RSSI values at distances of 2, 4, 6, 8, 10, and 12 feet with an obstruction of a 4.5-inch plaster wall with a nearby gap	Effect of a plaster wall obstructing device path on RSSI	Adding another scenario to the overall dataset	18
5: RSSI values at distances of 2, 4, 6, 8, 10, and 12 feet with an obstruction of a 4.5-inch plaster wall without a nearby gap	Effect of a plaster wall obstructing device path on RSSI	Adding another scenario to the overall dataset	18

A. *Plan and Execution*

Two Raspberry Pi 4Bs (one acting as a beacon, another as a receiver) were set up in the following way: the Raspberry Pi computers were placed at distances of two, four, six, eight, 10, and 12 feet apart. At each distance, there were three scenarios tested: no obstruction (representing two people facing each other), an obstruction of one human body (representing two people facing in the same direction, one with back turned to another), an obstruction of two human bodies (representing two people facing away from each other), a plaster wall with thickness four and a half inches and a nearby gap (representing people in different rooms but with an open connecting door), and a plaster wall with thickness four and a half inches but no nearby gap. All of the scenarios that involve an obstruction of two human bodies or a plaster wall, no matter the distance, are considered not too close for too long, as if people were really in scenarios like these, it would be extremely unlikely that a virus could be spread between people through the air. For the scenarios with other forms of obstruction (no obstruction or one body), the definition of six feet apart will serve as the decision boundary of too close for too long. RSSI measurements between the Raspberry Pi devices were taken every second for a total of one minute. Three trials were performed at every combination of distance and obstruction.

Several factors were controlled during the collection of data. The temperature was kept at a constant 72°F, all experiments were conducted indoors, the Raspberry Pi computers were placed in a consistent orientation (facing directly upwards and USB ports facing in the same direction), and all experiments were conducted in rooms with carpeted floors.

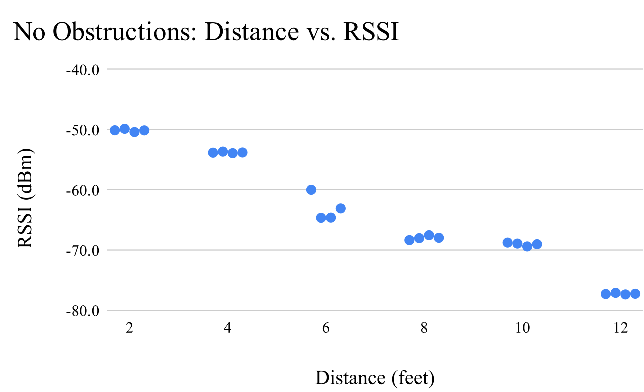
Despite the care taken to eliminate possible confounding variables, there were some factors that could not be controlled. These included: family members occasionally walking near or through the experimental setup and multiple sources of signal interference, including but not limited to Wi-Fi signals, a nearby microwave, other Bluetooth devices being used near the experimental setup, and changing presence of various furniture items as the experiments were conducted in several different rooms.

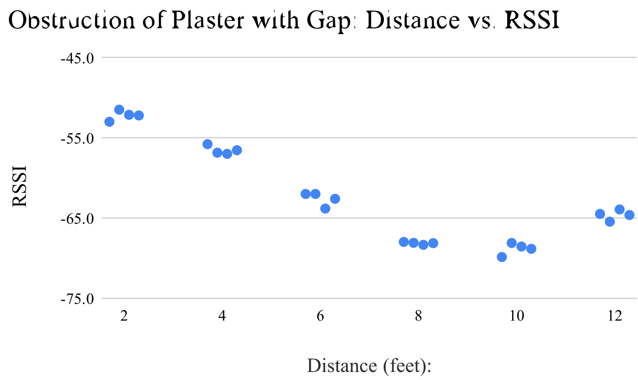
B. *Data Relevance*

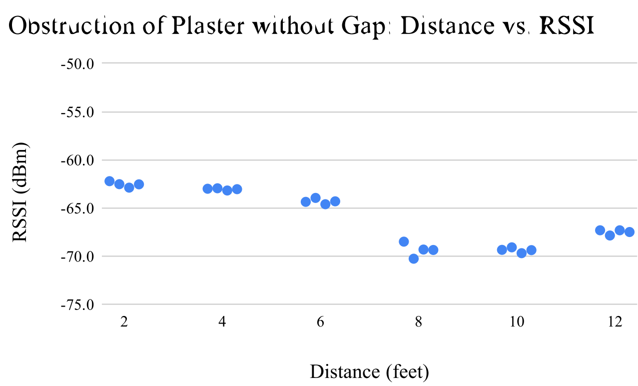
The goal of the described experimental setup was to create a wide variety of feasible real-world scenarios in a controlled environment. For example, it is very likely that the situation represented by Experiment 1 of Table I (two people facing each other holding Bluetooth devices in front of them) would occur in an interaction between two people in a public arena. The data collected from these scenarios was used to train an algorithm that would hopefully be able to determine "too close for too long" at least 80 percent of the time. Setting up scenarios that could happen in real life better allows a model to be created that predicts "too close for too long" in a practical application of PACT.

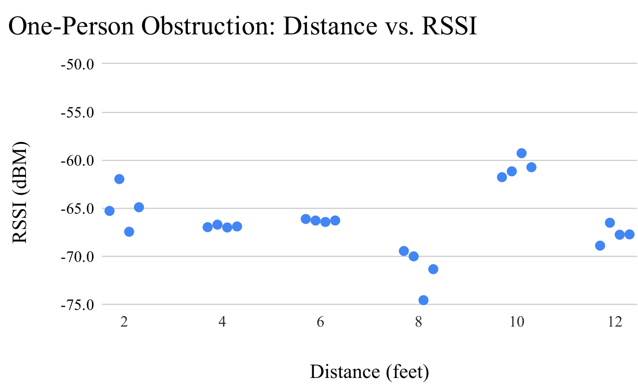
C. *Examples*

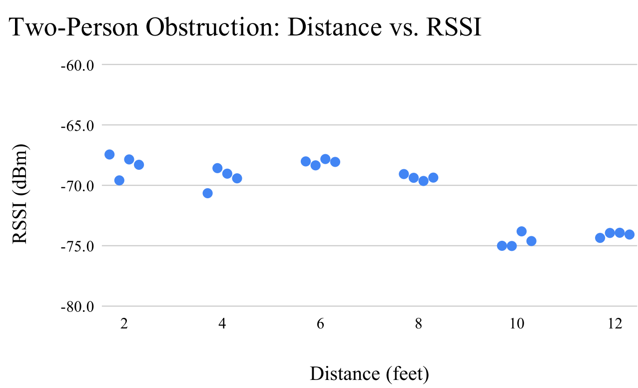
For the complete datasets, please visit https://github.com/aidmelvin/piPACT_data.git for more information. Below are the graphs for every scenario. In each graph, jitter was applied so that all points for each distance could be seen clearly.











IV. Analysis and Algorithms

A. Description

In order to try to predict "too close for too long," two different methods were used: logistic regression and a neural network. In order to calculate the logistic regression, an online tool(http://stats.blue/Stats_Suite/logistic_regression_calculator.html) was used. In order to create the neural network, TensorFlow and Keras were implemented in Python.

B. Results and Examples

The equation for logistic regression on the datasets was:

$$P = \frac{1}{1 + e^{-(8.5076 + 0.1541x_1)}} \text{ [1]},$$

where x_1 is the RSSI value, and P is the probability that the scenario represented "too close for too long." Below is a graph of the regression line through the given points.

The model had a p-value of 0.0000.

The neural network had an accuracy of 50.09%

V. Conclusions

A. Hypothesis Evaluation

The null hypothesis was not rejected. The neural network model was able to successfully predict "too close for too long" only about 50 percent of the time, which is essentially just as good as a random guess.

B. Noteworthy Conclusions

It was concluded that a RSSI values cannot be used to successfully determine "too close for too long" at least 80 percent of the time, at least using the methods implemented in this study. The null hypothesis was not rejected.

C. General Lessons Learned

Multiple lessons were learned during the completion of this project. These were:

- Planning out all of the steps of an experiment beforehand prevents problems further on (e.g. having to teach oneself how to implement a neural network last minute without much prior knowledge).
- Data collection and evaluation is not perfect and might give completely unexpected results.

- Despite my null hypothesis not being rejected, I still believe that Bluetooth-based PACT can work, it just needs to look at different parameters than what was analyzed here.

VI. Next Steps

If there were more resources and time, several more things would have been done. These are:

1. Many more scenarios would have been tested, with more ranges of temperatures and device orientations.
2. Different sensors (possibly Wi-Fi, sonic, or others) would have been tested on the Raspberry Pi devices.

This experiment greatly augmented my experience, including data collection, analysis, and programming. After this, I will definitely look into this topic more and run some more experiments myself, changing different parameters and variables. I will also try different methods of data analysis.

Thank you for this opportunity.

References

[1] Townsend, K. (n.d.). Introduction to Bluetooth Low Energy. Retrieved July 5, 2020, from https://learn.adafruit.com/introduction-to-bluetooth-low-energy/gap

[2] Luomala, J., & Hakala, I. (2015). Effects of Temperature and Humidity on Radio Signal Strength in Outdoor Wireless Sensor Networks. Proceedings of the 2015 Federated Conference on Computer Science and Information Systems. doi:10.15439/2015f241