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Due: July 26th, 2020

Beaverworks PiPact: Final Report

I. Abstract: For the research project PiPact, its objective of accomplishing a precise contact tracing system utilizing BLE to reduce the spread of COVID-19 faces numerous obstacles to overcome. This report will focus on determining the viability of a detection algorithm that holds a critical dependency on signal strength data. The data that will be collected will measure the level of interference that humidity and common electronic devices that produce electromagnetic radiation such as microwaves and radios can create. Data will be collected to analyze the drop in signal strength with constantly varying distance. In the end, the development of an infection susceptibility algorithm will be performed with the utilization of all the signal strength data values with predictions based on the signal strength variation over distance experiment.

II. Introduction

A. Project Description

- In this project I was provided with two Raspberry Pi 4s consisting of the newer generation of Bluetooth 5.0, which was primarily chosen due to its inclusion of the updated Bluetooth Low Energy. By utilizing the Pis' low energy beacon I will stimulate the contact tracing that will be performed among numerous smartphones of the public. I chose to focus on the various external factors that may cause difficulties when each bluetooth device communicates with each other. This includes factors such as radiation from microwaves, interference among the devices themselves as they chirp each other, and effects that humidity has on signal distribution.

B. Background Information

- Keywords:
  a) RSSI - RSSI which stands for "Received Signal Strength Indicator" is a valued signal indicating the connection strength of said device and the device that delivered the signal. The closer a RSSI is to 0 dB, the stronger the signal, whereas a RSSI of -100 dB is a very poor/unusable signal.
  b) Advertiser - During all of these experiments one pi will serve as the device delivering chirps every second to any nearby devices. These chirps that are sent in smartphones change on a daily basis to protect the users' privacy.
  c) Scanner - While one pi is serving as the advertiser that delivers these chirps, the scanner serves to receive these chirps and collects the information regarding each chirp, including its UUID (Device Identifier), time when it sent, and most importantly the RSSI.
  d) UUID - UUID which stands for "Universally Unique Identifier" is a 128-bit number serving as a unique identification for a device.

- The primary reason we depend on bluetooth is because BLE has provided a way to enable contact tracing at a much larger scale while completely respecting user privacy, it also a standard in almost all smartphones, and as implied by its name it is energy-efficient. It should be noted that any abnormalities found in the data can be caused by various factors that I am not focusing on during this experiment. I was unable to conduct all the experiments in a controlled environment, because factors like weather were affecting the experiments. Therefore, I was monitoring the humidity levels throughout my experiments.

III. Hypothesis/ Hypotheses

A. **Hypothesis 1:** Bluetooth contact tracing that depends on RSSI data alone, should not be considered viable due to electromagnetic interferences from common household/workplace electric equipment.
   - Interferences that are caused over the electromagnetic spectrum can often be overlooked, whereas most of the research conducted to develop a detection algorithm would resolve the obvious problem of physical obstructions. When in fact, it is always possible that during testing, many of the abnormalities are actually caused by the radio that's playing in the other room, or the frozen food that is being microwaved in the kitchen.

B. **Hypothesis 2:** Bluetooth contact tracing that depends on RSSI data alone, should not be considered viable due to the inconsistent data that is produced as a result of interference caused by humidity.
   - One of the most important environmental factors to study during testing is the climate. The humidity and temperature can point as a major issue during testing as it is very unpredictable. Almost all the time the conditions in which bluetooth contact tracing will be conducted in, will be very different, this is inevitable with the constantly changing climate and due to ac/heaters used in almost every building.
   - Most of this aspect of testing will be primarily focused on the impact of humidity because it will be the most varying throughout the days, serving as a more testable factor. Whereas, the temperature throughout this summer will remain relatively constant.

C. Infection Susceptibility Scorer Algorithm: This algorithm is made with the goal of determining the threat level that exposed subjects are under. This will be done by looking more into each subject’s personal behavioral attributes, the data will be collected with the full priority of respecting the subject’s privacy. Once alerted, the person will be provided with a short series of questions in order to develop a scoring of their chance of infection out of a scale of 0-100.

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IV. Experiments and Data Collection

A. Plan and Execution

- Interference of Microwave Radiation on Bluetooth Signaling:
    a) For testing the direct effect that microwave radiation has on bluetooth testing, I will conduct 4 tests (listed in order to be conducted in) at a distance of 0.91m (3ft):
        (1) One with no microwave present.
        (2) One with an unplugged microwave in between the two pis.
        (3) One with a plugged in microwave that is microwaving food in between.
        (4) One where the advertising pi is placed in the unplugged microwave after the third experiment.
            (a) Each test was conducted with a programmed timeout of 2 minutes, in which I received ~120 samples of data per test.
            (b) Measured average humidity level throughout the day (~29% humidity) and made sure to take note of the relation of the received RSSI values and the level of humidity.
- Is Interference produced as Two Devices communicate with each other:
    a) This test will be conducted by placing the two pis 0.91m (3ft) apart and initiating the advertiser and the scanner programs simultaneously on both pis. This is being done to determine if the simultaneous chirping of devices will lead to an interference between the two devices.
        (1) This test was conducted with a programmed timeout of 2 minutes, in which I received 104 samples of data.
        (2) Continued tracking average humidity level throughout the day(~72% humidity).
- RSSI Variation over a Distance with Constant Movement:
    a) For testing variation in signal strength over a varying distance I conducted two tests:
        (1) One requires the movement of two pis moving closer and further from each other alternating between a measured distance of 0.91m(3ft) and 2.74m(9ft).
        (2) One conducted with one stationary pi and an iphone simulating the advertiser using an app pacing between a distance of 1.83m(6ft) and 3.66m(12ft) away from the pi.

(a) Respectively, the two tests were conducted with programmed timeouts of 2 minutes and 1 minute, where I received 114 and 55 samples of data.
(b) Continued tracking average humidity level throughout the day(~73% humidity).

- Infection Susceptibility Scorer Algorithm Development:
    a) In order to develop this algorithm I will generate a test scenario by amassing the collected RSSI values from all of my experiments:
        (1) The roles of being the scanner and an advertiser were randomly assigned to several different UUIDs that were generated over the period of testing. I replaced the UUIDs with real names for better clarity.
        (2) The test scenario assumed that one of the UUID owners to be asymptotic for COVID-19(carrier).
        (3) Then I aggregated all the RSSI values that the carrier had with each other person in the proximity. This aggregation was calculated as a mean value. For the above man values, we created a scaled score between 0-100.
        (4) If the mean RSSI value was greater than or equal to -50dB then I assigned an infection score of 100. Otherwise, I assigned a score of 80.
        (5) Once the score was assigned I wanted to apply weights based on three personal attributes. The personal attributes are:
            (a) Wearing mask - Reduces infection score by 50.
            (b) Age as a factor - If less than 65 years old, then reduce score by 20.
            (c) Asthmatic - If not asthmatic, then reduce score by 20.
        (6) Consolidate the above weights to calculate the final score.
        (7) Display the results as a network graph for further action.

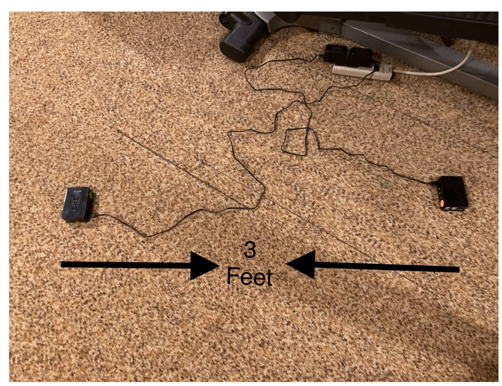
B. Data Relevance

- The experiments conducted regarding the effect of electromagnetic radiation on bluetooth signaling are done in four separate tests to give a full perspective on all the possible ways in which radiation can affect RSSI:
    a) The first test is conducted to represent the control(unaffected) data.
    b) The second test data tests if any radiation leakage from a previously used microwave can affect signaling.

c) The third test is conducted to determine the level of interference radiation leakage causes when the microwave is turned on.
d) The fourth test where the advertiser is placed inside the microwave is done in order to confirm that radiation definitely causes interference on bluetooth signaling.

- The experiment testing whether or not the chirping of two devices to each other causes interference is conducted in order to confirm that contact tracing will be effectively carried out when various devices were present in the vicinity of an infected subject. It addresses the possible problem that if the subjects in the area all accept to deliver chirps to other devices but the process is cut short due to an interference between the devices as they all try to carry out the same task.
- Throughout all these experiments I chose to constantly monitor humidity levels, because humidity constantly changes per day and it would be inefficient to focus a daily testing solely for humidity.
- The data collecting the variation in RSSI over a changing distance helps in determining an estimate of what RSSI we should use to trigger an alert for a subject in the algorithm(when disregarding any possible forms of obstructions).

C. Examples/Results

Experiment Images	 Microwave Radiation Experiment (conducted in one day).	 Fluctuating Data/Interference among 2 Devices(conducted over the course of two days).

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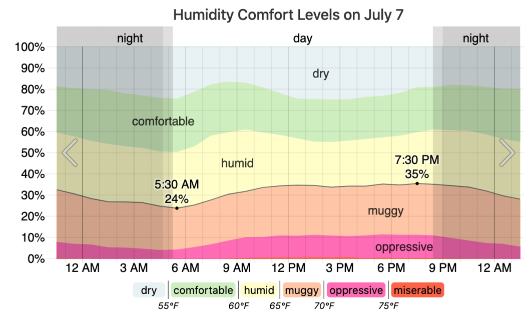
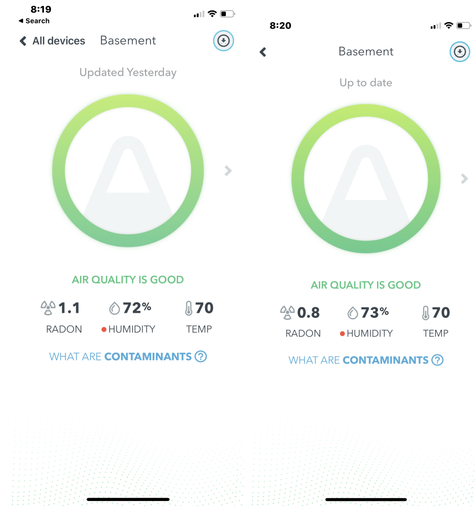
<table>
<tr>
<td>Humidity Levels</td>
<td>


Average humidity level of 29%.
</td>
<td>


Average humidity levels of 72% and 73% (collected data from dehumidifier).
</td>
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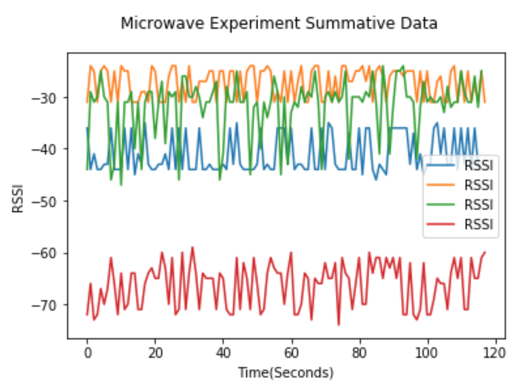
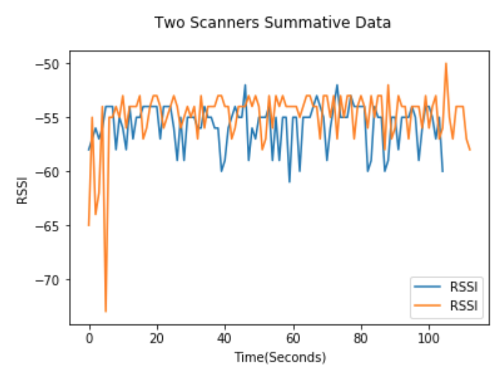
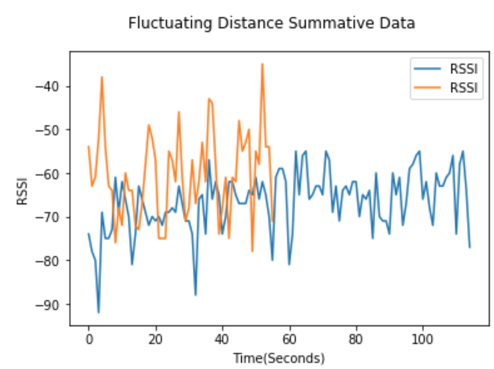
<tr>
<td>Summative Data

Note: Individual graphs that also contain the mean data are attached on the separate files.</td>
<td>


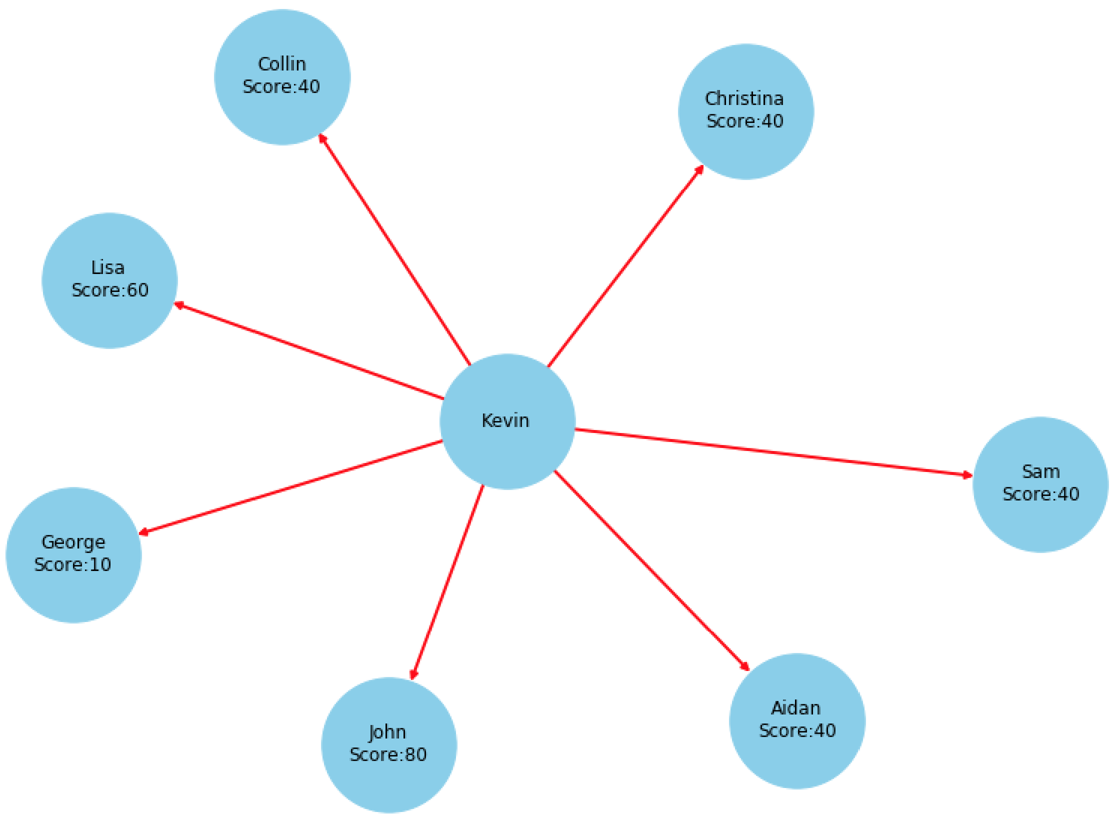
Yellow Plot = Microwave(Off)
Green Plot = Microwave(On)
Blue Plot = Control Data
Red Plot = Advertiser in Microwave
</td>
<td>


Orange Plot = Scanner One
Blue Plot = Scanner Two



Orange Plot = Human walking 6-12ft back and forth.
Blue Plot = Devices fluctuating between distance of 3-9 ft.
Note: Stronger connection in orange
</td>
</tr>
</table>

		plot despite higher distance due to iphone's better bluetooth hardware.

Infection Susceptibility Scorer Algorithm Result


V. Analysis and Algorithms

A. Final Results

- The data from the microwave experiment demonstrates that electromagnetic radiation leakage is sufficiently prevented by a microwave oven's filtering. The third test in which the oven was on and running in between the two pis caused little to no fluctuation, rather the data showed that the connection improved as the mean RSSI improved by 10dB. It is unclear as to whether or not this is due to human error or if it was due to the metal surface of the microwave enhancing the signal. This pattern continued with the second test as well, with a powered off oven in between resulting in a signal improvement of about 4dB. The final test demonstrated that RSSI can only go through significant interference if it's in direct contact with electromagnetic radiation, which in the test had a mean difference of 39dB, the lowest strength nearing almost -75dB.

- The data from the two devices that chirped to each other, led me to understand that problems may rise up in situations where areas are densely crowded up. This is due to the possibility of smartphones overwriting the data packets after getting chirped at beyond its limitations of storage.
- The data collected regarding the RSSI variation with a changing distance, led me to conclude that the RSSI value of someone who is 6ft or closer to you would range from -50dB to 0dB. I finally determined 50dB as the borderline because the testing regarding the distance was conducted during one of the most humid days of July with a 70% humidity in my basement. And I calculated that there was about a 15dB decrease in mean RSSI when I compared the control data from the day's experiment with the previous microwave experiment.
- After analyzing the data regarding the effect that humidity has on RSSI, it can be persumed that humidity holds an inverse relationship with RSSI. As mentioned before, this was very noticeable when I compared the control data from the microwave experiment and that of the RSSI variation over distance experiment.

VI. Conclusions

A. Hypothesis Evaluation

- My first hypothesis is false. Based on the data obtained from the four experiments conducted to assess the effect that microwave radiation has on bluetooth signaling, microwave oven filters do an adequate job of preventing radiation leakage. In fact, the microwave oven that was used in this experiment is over eight years old, so it is fair to postulate that newer microwave ovens would have filters that do a better job in preventing radiation leakage. In addition to this, in most real-world scenarios, a microwave/radio would not be inches away from the subject's phone to cause any major interference.
- My second hypothesis is true. Due to the significant amount of variation in collected RSSI data(~15dB decrease) with a ~40% increase in humidity, it is clear that humidity poses a serious problem which has to be taken into account by the detection algorithm.

B. Experience with Developing a Simple Algorithm

- I intended to create an algorithm with the goal of also accommodating for the personal attributes of those who are subject to exposure. *I believe this would be a good approach because this would often be an overlooked factor in determining if someone is in immediate danger through remote* *contact tracing.* A simple 0-100 scoring system actually aided in giving a much better perspective on the threat level any exposed person is under.

C. General Lessons Learned

- Throughout this experience I learned about the huge dependency this project has on a large amount of data. Without the clear view into all of the aspects of your research it is much harder to arrive at a definite conclusion about your hypotheses. I also learned that there are numerous external factors that must be considered, while developing a proximity detection algorithm. When I first started this project I thought it was possible to produce a semi-viable detection algorithm. As I realized the limitations, I decided to consider other influencing factors. This whole experience proved to be a great exposure to real-world programming using Python and also hardware to software interactions.

VII. Next Steps

A. In the future, I plan to attempt developing a machine-learning based predictive model. I still need to learn a lot more skills to get into developing code that's needed to get to this level. I also hope to conduct more experiments much like these but with a lot more trials. I believe I am heading in the right path and look forward to learning more about solving real-world problems like COVID-19 using science and technology.

VIII. References

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