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Enumerating and Locating Bluetooth Devices for Casualty Recovery in a First-Responder Environment

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Abstract

It is difficult for first responders to quickly locate casualties in an emergency environment such as an explosion or natural disaster. In order to provide another tool to locate individuals, this research attempts to identify and estimate the location of devices that would likely be located on or with a person. A variety of devices, such as phones, smartwatches, and Bluetooth-enabled locks, are tested in multiple environments and at various heights to determine the impact that placement and interference played in locating the devices. The hypothesis is that most Bluetooth devices can be successfully enumerated quickly, but cannot be accurately located at distances over one meter using a device-agnostic method, and that the height does not have a significant impact on signal strength while the environment does.

Five of the nine devices are enumerated correctly and the predicted distances are not accurate beyond one meter. Height played an especially important role in determining the signal strength, however, as it had a different impact than distance away from the device at the same height. In 24/27 of the experiments, the signal is stronger on average when the receive device (first responder) has additional elevation. The disaster environment has the strongest signal increase across all three environments with additional elevation, demonstrating an importance on the placement and positioning of the first responder's device when searching for victims.

This research indicates that signal strength measurements are not useful for accurately determining the location of a device, but may still be suitable for rescue efforts to locate victims. Additionally, the specific impact that elevation has on the calculated signal strength is not equivalent to simply increasing the distance between the two devices. This observation means that attempting to measure devices indoors

using Bluetooth should take into account all axes independently in order to generate the most accurate estimation of distance.

Further, the data collected indicates that the environment the devices are in also plays a significant role in the signal strength. The disaster environment had a significant number of metallic objects as sources of interference which weakened the signal strength while the office environment had stronger and more consistent results. Since any environment can become a disaster environment from a natural disaster or other significant incident, understanding the differences of signal strength in typical environments is crucial to implementing Bluetooth into a search and rescue mission.

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Acronyms

AD Advertising Data. 9

AFIT Air Force Institute of Technology. 25

BLE Bluetooth Low Energy. 8, 15, 16

dB decibels. 11, 12, 15, 67, 79

dBm decibel-milliwatts. 15

FEMA Federal Emergency Management Agency. 16

FIND Finding Inaccessible people in Natural Disasters. 86

GPS Global Positioning System. 13

INSARAG International Search and Rescue Advisory Group. 18

IoT Internet of Things. 3, 14, 21, 42, 82, 83

LE Low Energy. 10

MAC Media Access Control. 10, 14, 29, 35, 42

OCHA Office for the Coordination of Humanitarian Affairs. 18

RSSI Received Signal Strength Indicator. 4, 6, 11, 12, 13, 14, 15, 20, 27, 28, 29, 30, 31, 35, 36, 38, 39, 40, 41, 43, 44, 45, 46, 49, 53, 57, 58, 59, 61, 63, 65, 67, 70, 72, 74, 76, 79, 82, 83, 84, 85, 86

SIG Special Interest Group. 6, 7, 28, 42

ENUMERATING AND LOCATING BLUETOOTH DEVICES FOR CASUALTY RECOVERY IN A FIRST-RESPONDER ENVIRONMENT

I. Introduction

1.1 Background

In any kind of disaster scenario, one of the highest priorities is accountability: finding everyone in the area and making sure they are safe. However, disaster environments, such as fires and explosions, pose unique challenges to locating casualties by preventing typical methods of finding people such as normal sight and other types of imaging. Most modern, portable devices are Bluetooth enabled, providing a potential vector to find and locate people in such an environment. By measuring the signal strength of the Bluetooth devices that people carry, it may be possible to locate them quickly.

Unfortunately for first responders, there are a plethora of Bluetooth-enabled devices in most environments, from printers and light bulbs to locks and smartphones. In order to find an individual using Bluetooth, the first step is to identify a device that would reasonably be assumed to be on a person, such a smartphone, smartwatch, or medical device. Next, the first-responder would have to track the signal strength of that device and attempt to locate the device by converting the measurement to a distance, hopefully finding the owner of the device in the process.

1.2 Goals and Hypothesis

The goal of this research is to determine the feasibility of enumerating and locating a Bluetooth-enabled device in a variety of environments without utilizing prior information about any of the devices. Specifically, there are four objectives of this research:

1. Determine if advertising packets are reliable enough to identify the device type of a transmitting device.

2. Determine if the distance between two devices can be accurately calculated without assuming the antenna strength of either device.

3. Determine if elevation between the two devices has a disproportionate impact on the signal strength measurements.

4. Determine if the differences in environments have a significant impact on the calculated signal strength measurements.

The hypothesis is that at least 80% of Bluetooth devices can be successfully enumerated quickly, but cannot be accurately located at distances over one meter using the method applied in this research. Additionally, elevation is not expected to have a disproportionate impact on the signal strength measurements and the environments are expected to have a significant impact on the signal strength measurements.

1.3 Approach

This research uses nine transmit devices, including a mix of smartphones, smartwatches, and Internet of Things (IoT) smartlocks. The Bluetooth data the devices send is analyzed in order to identify what kind of device they are, and the signal

strength is measured at known intervals in order to estimate distance. The measurements are taken in three different environments: a home environment, an office environment, and a disaster environment.

The transmit devices are placed at a specific spot in each environment. The receive device is placed in an apparatus that allows it to adjust its height for multiple experiments. The receive device uses an Android application to collect the Bluetooth data from the transmit devices to display the Received Signal Strength Indicator (RSSI) values, device name, and manufacturer name (if those fields have a value).

1.4 Assumptions and Limitations

No attempts are made to sterilize the wireless spectrum at any environment, or to move items to minimize sources of interference. As the goal is to make the scenarios as realistic as possible, no prior information about the devices is used to estimate the distance such as signal attenuation (see Section 4.5). A single equation is used to estimate the distance between the two devices based on previous research [1], and there is a tacit assumption that such a calculation will produce usable data.

One variable examined is elevation, or a difference in height between the transmit and receive devices. In order to accomplish this task with a consistent level of interference, the receive device is placed in an apparatus during all trials. This apparatus allows the device to be set to various heights, allowing for accurate measurements. In order to minimize the apparatus as a source of interference when comparing the two elevations, it will also be holding the device when elevation is set to 0 m.

In order to get usable data from the transmit devices, they must be set to Bluetooth discoverable mode. The majority of Bluetooth devices, specifically devices that would be on an individual such as smartphones or medical devices, do not typically operate in that mode and therefore would not send any advertising packets during

normal operation. Additionally, not all Bluetooth-enabled devices have the Bluetooth functionality turned on at all times. This research assumes the devices are: Bluetooth enabled, have the Bluetooth functionality turned on, and are set to be discoverable.

1.5 Research Contributions

This research demonstrates the feasibility of identifying and categorizing a variety of devices quickly using only Bluetooth advertising packets. Additionally, this research shows the inability of estimating distance between two devices, the victim's transmit device and the first responder's receive device, using only a minimal amount of information. Further, this research shows the importance of considering each axis of distance independently in any given environment, rather than simply the total distance between two devices, as the impact of elevation may not be uniformly distributed as the impact of distance along a single axis may be. Lastly, this research highlights the importance of considering the environment in which the devices are operating and the impact that sources of interference may have, especially in the disaster environment.

1.6 Thesis Overview

Chapter II outlines how Bluetooth works with regards to this research as well as past research that has attempted distance estimation with Bluetooth. Chapter III explains the overall design for the research and how it was set up. Chapter IV describes how each experiment is conducted, the variables used and considered, and how data is gathered. Chapter V shows the results of the experiments and provides analysis on the data collected. Chapter VI summarizes the research and the results and provides avenues for further research.

II. Background and Literature Review

2.1 Overview

Section 2.2 outlines a brief history of Bluetooth as well as its uses and various versions. Section 2.3 discusses how Bluetooth devices communicate with each other and what information they share through advertising packets. Section 2.4 explains how Received Signal Strength Indicator (RSSI) measurements are calculated and used, the difficulty in using these measurements to calculate an approximate distance between devices, and the difficulty enumerating a device through advertising packets. Section 2.5 discusses prior research in distance estimation between Bluetooth devices. Section 2.6 defines a first-responder environment and Section 2.7 explores how casualties are located in these environments.

2.2 Bluetooth Basics

2.2.1 History

The Bluetooth Special Interest Group (SIG) was initially set up in 1998 as a number of tech companies at the time looked to expand wireless communications between devices [2]. The initial goal of the group was to find develop a short-link radio technology that could be used in mobile devices, such as laptops. With the combined efforts of five companies (Ericsson, Intel, Nokia, Toshiba, and IBM), the first consumer Bluetooth device was launched in 1999. The first Bluetooth mobile phone was available for consumer purchase in 2001.

2.2.2 Uses and Devices

The versatility of Bluetooth has allowed it to function in a wide variety of devices. Some examples of current Bluetooth-enabled devices are: wireless headsets, car stereo

systems, smart locks, portable speakers, fitness devices, input devices such as mice and keyboards, printers, medical equipment, barcode scanners, and even traffic control devices [3]. The flexibility of the Bluetooth standard has enabled devices in nearly every area for short-range communications purposes.

Figure 1 shows the sales of Bluetooth devices according to the Bluetooth SIG in their 2020 Bluetooth Market Update [3]. Additionally, they expect an increase of 8% annually for at least the next five years.

2.2.3 Versions

There are currently 12 versions of Bluetooth that have been certified and standardized for use: 1.0, 1.1, 1.2, 2.0, 2.1, 3.0, 4.0, 4.1, 4.2, 5.0, 5.1, and 5.2. These versions span from 1998 to 2020, and as such offer widely different capabilities. However, one important aspect of every version of Bluetooth is that it is backwards compatible, meaning that if one device is using Bluetooth 2.0 and another is using 5.0, they can still connect and communicate without issue, although there may be security considerations [4].

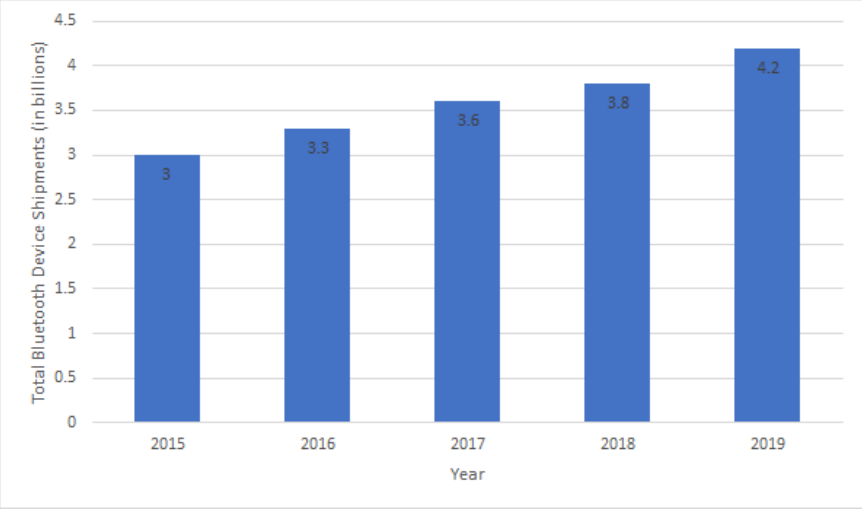

Figure 1: The Annual Total Number of Bluetooth Devices Shipped [3]

For simplicity sake, any version prior to version 4.0 is often referred to as Bluetooth Classic. Bluetooth 4.x is typically referred to as Bluetooth Low Energy (BLE) while Bluetooth 5.x is simply called Bluetooth 5. These references generally refer to the capability of the device, as shown in Table 1.

2.3 Connecting

For devices to communicate, they must first go through a sequence of tasks. First, the devices must become aware of each other, which typically means putting at least one device into Discovery mode while the other is scanning. Next, the device must initiate a request to connect to the device in Discovery mode. Third, with Bluetooth 4.2 or above, the two devices send each other passkeys to prevent unauthorized connections [5]. If the passkeys are correct, or not used for a legacy connection, then the devices are connected to each other and considered paired.

Table 1: Comparison among Bluetooth Versions [6]

Feature	**Bluetooth Classic**	**Bluetooth 4.x**	**Bluetooth 5**
Distance/Range	Up to 100m	Up to 100m	Up to 200m
Nominal Data Rate	1-3 Mbps	1 Mbps	2 Mbps
Latency	<100 ms	<6 ms	<3 ms
Network Topology	Piconet, Scatternet	Star-bus	Star-bus, Mesh
Nodes/Active Slaves	7	Unlimited	Unlimited
Message Size	Up to 358 bytes	31 bytes	255 bytes

2.3.1 Finding a Device

The Bluetooth specification includes methods for devices to let other devices know what type of device it is. According to Martin Woolley, a member of the official

Bluetooth Developer Relations team, a Bluetooth device will emit a small advertising packet, up to 31 bytes long, to tell other devices what it is [7]. Within this advertising packet, the advertising device can include a variety of Advertising Data (AD) Types, such as the class of device, the Device ID, and the transmission power level, which can be useful for determining a relative distance between two devices.

Advertising packets can contain multiple AD Types in a single packet, as shown in Figure 2. This figure shows the raw data of an advertising packet at the top, which is then split into its various data types, namely: flags (0x01), service class (0x03) and value (0x1809), and the device's local name (Thermometer Example). The full list of flags can be found at the Bluetooth specification website [8]. The data following the flag must match the flag itself as referenced in the definition of that flag, although some like "Complete Local Name" (0x09) and "Manufacturer Specific Data" (0xFF) allow for custom data to assist users that view the advertisement from another device.

In addition to advertising packets, devices can send out information in response to scan requests. A device sends a scan request packet after receiving an advertising packet in order to get more information about the advertised device. There can be many reasons for a scan request in normal operations in a Bluetooth environment,

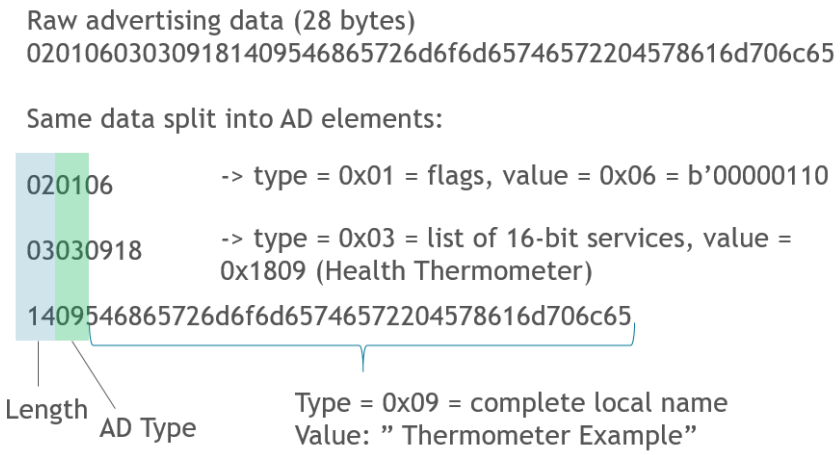

Figure 2: Example Advertising Packet [9]

such as multiple devices with the same make and model that may have identical advertising packets. The types of advertising are listed in Table 2.

In Bluetooth 4.0, a feature known as Bluetooth Low Energy (LE) Privacy was introduced that allowed devices to generate random Media Access Control (MAC) addresses when sending out advertising packets [10]. As a result, the same device remaining in the same physical location will look like a variety of different devices to any scanners in the area. In Bluetooth 4.2, directed advertising was added to allow devices to address advertising packets to known devices in order to find and reconnect with them more quickly [10].

2.3.2 Communicating

The version of Bluetooth used for the devices to communicate will also determine the method. The ways for two devices to communicate can vary significantly as more security features were introduced as the Bluetooth versions developed. Generally

Table 2: Types of Advertising Configurations

Type of Advertising	Purpose	Will Respond to Scan	Will Accept Connection
General Advertising	Generic advertising, broadcast advertisements	Potentially	Yes
Directed Advertising	Invite a specific device to connect	No	Yes (from specific device)
Non-connectable Advertising	Broadcast specific information, such as a beacon	No	No
Discoverable Advertising	Similar to Non-connectable Advertising, but will respond to scans with more information	Yes	No

speaking, any device using Bluetooth 2.0 or higher will encrypt any traffic before sending it to another device to prevent eavesdroppers from listening to clear-text traffic [11]. The devices utilize a shared long-term key that was agreed upon when the devices were initially paired.

2.4 Locating a Device

The primary method used to determine the distance to a device is by measuring the RSSI. RSSI is a measure of signal strength of the packets from the sending device by the receiving device. It is measured in decibels (dB) with a lower number indicating that a sending device is farther away from the receiving device [12]. Jung et al. noted that while RSSI is imperfect, it has a much lower cost to use for distance estimation than other methods, making it the most common in use [13]. However, given the number of variables involved in calculating the distance, such as the signal having to bounce off or pass through a variety of materials, Jung et al. concluded in 2013 that "distance estimation is impossible with the RSSI raw" and requires additional calculations or values to generate meaningful results [13].

It is important to note that while, in a best-case scenario, it may be possible to determine the distance between two devices using Bluetooth, the direction cannot be determined. In other words, knowing that two devices are 5 m apart means that the transmit device could be anywhere within a 5 m spherical radius from the receive device, including on a floor above or below in an indoor environment. In a first-responder environment, the best way to know would be walking while receiving packets and judge by the estimated distance decreasing or RSSI values increasing that the first responder is most likely going in the right direction.

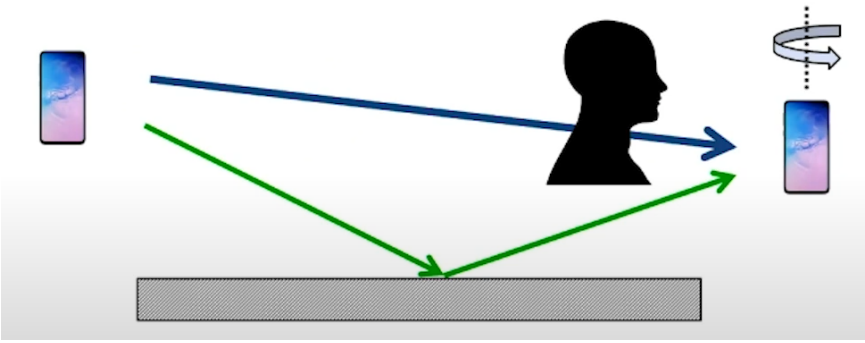

Figure 3: Bluetooth Signal Multipath and Sources of Interference [14]

2.4.1 Calculating RSSI

The RSSI value is not sent along with any of the Bluetooth packets, but rather calculated by the receiving device based on the strength of the signal of the packet at the destination [12]. Consequently, there are a number of variables that can influence the value of the RSSI. According to Swarun Kumar and displayed in Figure 3, four of the simplest and most common sources of error are [14]:

- the human body by blocking/inhibiting signals at approximately ± 15 dB as shown as the blue line running through the person
- signal multipath and environment effects at ± 10 dB as shown by the green line bouncing off the wall and taking a path longer than the distance between the two devices
- the antenna orientation and gain of the receiving device at ± 5 dB as shown by the arrow above the receiving device
- device specific behavior for the calculation at ± 15 dB

In essence, those four sources provide an error of ± 45 dB in any calculation, which is a significant error rate. Kumar noted that it "could make a 2 m device look like it is 20 m away" [14].

RSSI values are negative values, with a higher value representing a stronger signal. In this research, the range for the calculated RSSI values is -39 to -102.

Other researchers have noted the difficulty in determining accurate distance in indoor environments using Bluetooth. Some of them have achieved better results by utilizing transmit beacons at known, fixed locations to provide baseline measurements for RSSI calculations [15]. However, while such additions improved the overall accuracy of some measurements, they were still considered too inaccurate for practical use [15]. Often these systems work best when paired with other systems already in place, such as Global Positioning System (GPS) platforms [16].

2.4.2 Calculating Distance

In order to calculate a distance from the RSSI value, the following equation is used which is derived from the version used by Sheng Zhou and John K. Pollard [1]

$$P_{RX} = P_{TX} - 10n * log(d) \tag{1}$$

where d is the known or predicted distance, P_{TX} is the transmit power of the sending device, n is the attenuation factor, and P_{RX} is the measured or estimated RSSI value. When the RSSI between the two devices is known, the estimated distance can also be calculated. The transmit power used is the average RSSI calculated by the receive device when the two devices are 1 m apart. For this research, ten measurements are taken and averaged to determine the transmit power for each device. The attenuation factor is set to 2 in free space. These equations simplify much of what Zhou and Pollard used to make their calculation more accurate in order to realistically replicate the circumstances and known information that could be expected for such a system to use.

2.4.3 Problems with Enumeration

Being able to identify a device as a phone, smartwatch, or medical device would allow first responders to locate individuals faster. Additionally, knowing which devices are Internet of Things (IoT) devices such as printers or locks narrows the potential devices worth investigating. However, attempting to identify a device from just an advertising packet and a scan response can be difficult. Section 2.3.1 explains what data is contained in the packet itself. The receive device then looks at the device name and the MAC address provided by the manufacturer, which has significant freedom in how to identify the devices. Additionally, users can manually change the device name used by the device, allowing them to mislead others as to the true type of device.

Further, some devices use randomized MAC addresses even for advertising packets, which prevents the receive device from knowing who manufactured the device [10]. This information can be crucial in narrowing down devices to a specific manufacturer, as well as the information that the manufacturer may provide as to the type of device it is or the function it may serve. Knowing the manufacturer may provide additional information and assist in narrowing down the type of device, such as a company that only manufacturers one type of devices like FitBit. In these cases, it can be especially difficult to track the device from one measurement to the next as the device will randomize its address at specific intervals, interrupting and resetting previous data gathering attempts [17].

2.4.4 Problems with RSSI

The first problem in attempting to utilize RSSI values is getting them from the transmit device. If two Bluetooth devices are not connected to each other, they are not going to be communicating constantly. In order to get a device to continually transmit Bluetooth packets, namely advertising packets, it must be set in Discovery

Mode. However, this is not the default setting for most devices as there are security concerns [18]. This research addresses this problem in Section 3.7.

Another issue with RSSI measurements is that they are inherently valueless [19]. While it is common practice to assign a unit of dB or decibel-milliwatts (dBm), the notation is meaningless and RSSI cannot be directly converted from its raw form into any meaningful data through unit conversions. This point is important to note to understand part of the difficulty in generating a distance estimation from an RSSI value as there is no simple or basic equation to convert it directly into meters. RSSI is simply "a signal strength percentage-the higher the RSSI number, the stronger the signal" [20].

2.5 Past Distance Estimation Research

A number of researchers have examined the feasibility of calculating the distance between two Bluetooth connected devices. Pei et al. set up three Bluetooth access points in an office building and attempted to calculate the position of devices as they moved through the building [21]. Over a distance of approximately 40 m, the Bluetooth measurements had an average error of 5.1 m.

Pešić et al. established a BLE asset tracking system with fixed scanners to monitor known Bluetooth devices [22]. In their research, the mean error for position estimations was 0.72 m. The scanning devices were moved in each experiment and accounted for environmental aspects such as obstacles and the layout of the rooms. Additionally, the RSSI data is accumulated and then passed through a filter based on all available information in order to produce a more accurate result.

Ture and Hatipoglu used six fixed beacons with known locations to triangulate the locations of devices in a room [16]. Their research focused heavily on running their measured RSSI values through a filter algorithm that accounted for the position of

each beacon as well as considering which beacon had which measurement to correctly factor the cumulative values together.

Little research has been done attempting to locate Bluetooth devices in a first-responder environment. Yang, Schafer, and Ganz placed BLE sensors on victims after they had been rescued from a disaster [23]. These tags had information about the victim as well as be configured to send signals back to a controller to see if the victim had wondered off from the scene before being released by medical professionals. They used a maximum likelihood based movement detector and a weighted algorithm to detect if the sensor had left the designated area. Their mean localization accuracy was 11 ft, meaning that for stationary victims they could estimate the location of the sensor within 11 ft the majority of the time using off-the-shelf BLE tags.

2.6 First-Responder Environments

A disaster environment, or a first-responder environment, is any situation in which one or more persons may be injured and need to be located and evaluated for treatment. Table 3 provides a sample list of potential causes of such environments, according to the Federal Emergency Management Agency (FEMA). While some of these scenarios, like a cyber-attack, may not necessitate rescuing injured casualties, the majority of these scenarios would.

A common result of these disasters is the shifting of an environment. For example, many of the natural disasters add considerable amounts of water to areas that had none, and can use wind and other forces to move buildings and objects, trapping people in areas that are now unfamiliar to the local population and the first responders in the area, making rescue efforts particularly challenging.

2.7 Finding Casualties

It can be exceptionally difficult to find victims in a disaster environment once the environment has become difficult to navigate in and see through. The heat and smoke from fires, for example, warrant the responders to be quick but also take precautions to safeguard themselves. Paul Mastronardi notes that the initial search for victims has six components [24]:

- known life hazard versus potential life hazard
- occupant accountability/survivability
- building construction
- size and extent of the fire
- established water source
- available equipment/staffing

Table 3: Example Threats and Hazards by Category [25]

Natural	Technological	Human-Caused
Avalanche	Dam failure	Active shooter incident
Drought	Hazardous materials release	Armed assault
Earthquake	Industrial Accident	Biological attack
Epidemic	Levee failure	Chemical attack
Flood	Mine accident	Cyber-attack against data
Hurricane/Typhoon	Pipeline explosion	Cyber-attack against infrastructure
Space weather	Radiological release	Explosives attack
Tornado	Train derailment	Improvised nuclear attack
Tsunami	Transportation accident	Nuclear terrorism attack
Volcanic eruption	Urban conflagration	Radiological attack
Winter storm	Utility disruption	

Some people in disasters find themselves trapped among debris, such as from an earthquake or an explosion. While there have been individual cases of victims surviving for up to two months, the majority of people that are not rescued die from their injuries, a lack of oxygen, or a lack of water [26]. While timelines vary for each person, Dr. Shah noted that the average person can survive between three and seven days without water, which is typically the upper limit for surviving without being located in these scenarios [26].

For larger disasters, the International Search and Rescue Advisory Group (INSARAG), under the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), has detailed guidelines explaining search and rescue operations [27]. Under the INSARAG model, there are five levels of search and rescue:

1. Wide Area Assessment: preliminary survey of the affected area to identify hazards and scope of the incident; teams do not engage in rescue operations at this stage

2. Worksite Triage Assessment: identify viable rescue sites, or locations of individuals that need rescued, across the entire sector; teams do not generally engage in rescue operations at this stage

3. Rapid Search and Rescue: use quick and available means to rescue survivors, with no individual rescue attempt taking more than a couple hours

4. Full Search and Rescue: teams attempt to penetrate all survivable voids to rescue heavily trapped or entombed survivors that remain

5. Total Coverage Search and Recovery: continued search efforts generally directed at finding deceased victims that remain trapped in the area with minimal expectations that any remaining victims are alive

Not every first responder is a certified professional operating under those standards, however. In most cases, the first people to arrive on the scene are people that were in the area. Natalie Simpson notes that in any type of disaster scenario, "[e]verybody is a first-responder" [28]. Since so many first responders in these situations are untrained and uncertified, a quick app that helps locate people in such an environment could be beneficial.

III. Design

3.1 Overview

Section 3.2 explains the reasoning for conducting this research. Section 3.3 discusses device enumeration. Section 3.4 shows the devices used for this research. Section 3.5 discusses the different environments used to conduct the experiments. Section 3.6 explains how the devices are positioned in the environments and Section 3.7 describes how the data is collected.

3.2 Rationale

The goal of this research is to generalize the receiving and transmitting device. In other words, the equations and calculations utilized should be device agnostic. Previous research from Chapter II is used to determine how those values (namely device attention, n, and the transmission power, P_{TX}) should be set. As there has been considerable focus on distance estimation with Bluetooth in a variety of environments and circumstances, this research focuses on four aspects of finding a device:

1. Are advertising packets reliable enough to determine the identity of a transmitting device?

2. Can an accurate distance between two devices be calculated without assuming antenna strength of either device?

3. Does elevation between two devices have a disproportionate impact in calculating the Received Signal Strength Indicator (RSSI) values when compared to the total distance?

4. Do the differences in environments have a significant impact on the calculated RSSI values?

3.3 Device Enumeration

The only useful way to determine the make and model of a transmitting device is for that device to explicitly state in its advertising packets or scan responses. However, the vast majority of Bluetooth devices do not send out advertising packets unless they are expecting a connection (see Section 2.4.4). Therefore, for these experiments, all devices are set to Bluetooth discoverable mode in order to send and receive all the necessary Bluetooth traffic. Most devices are not in discoverable mode during normal operations as it can pose a security risk.

It is important to enumerate the device and place it into a category as described in Section 3.4 as the perspective is a first-responder environment. In order to find individuals that may be unconscious or injured, finding their phones or smart watches or medical devices can likely lead to finding the individual. However, locating light bulbs, printers, locks, and other Internet of Things (IoT) devices would only impede efforts to locate casualties.

3.4 Bluetooth Devices

The utilized devices are categorized into two groups by type: devices commonly on a person (consisting of smartphones, watches, and medical devices) and devices not commonly on a person. A variety of Bluetooth devices are used in order to determine how various devices handled broadcasting advertising packets and how manufacturers chose to identify their devices. The full list of devices is in Table 4 and displayed in Figure 4. To minimize the sources of error, the receiving device is a single Google Pixel 3 XL.

Figure 4: Transmit Devices

Table 4: Transmit Devices

Device	Manufacturer	Category	Location
Charge 2	Fitbit	Smartwatch	On person
Surge	Fitbit	Smartwatch	On person
Moto E (2nd Gen.)	Motorola Mobility	Smartphone	On person
Samsung S7	Samsung Electronics	Smartphone	On person
Samsung S8	Samsung Electronics	Smartphone	On person
Dog & Bone Lock	Dog & Bone Cases	Lock/IoT	Not on person
iBluLock	iBluLock	Lock/IoT	Not on person
Master Lock	Texas Instruments	Lock/IoT	Not on person
QuickLock	Texas Instruments	Lock/IoT	Not on person

No fixed-position beacons are used for these experiments because they would not reasonably be available in a realistic scenario. Few places have such devices as part of their infrastructure in place, and their integrity would become compromised in a disaster scenario such as a fire, explosion, or natural disaster.

3.5 Environments

This research focuses on distance estimation in a variety of indoor and disaster environments. In order to provide meaningful data, three different environments are used. One is a typical conference room; one is a room in an average household; and one is a disaster training site consisting of a partially demolished and unkempt building. These environments have various sources of interference in place, from the floors and walls to standing debris, as well as varying sources of activity on the Bluetooth spectrum from nearby devices.

The home environment uses a house in Dayton, OH. The measurements are taken in a basement that is used as a recreational room with furniture and children's toys. The chosen path is for measurements is free of any objects directly in the path, but the room is otherwise unmodified from day-to-day conditions. Like the office environment, there are a variety of devices operating on the Bluetooth spectrum

Figure 5: Household Environment

while the measurements are recorded, and may provide interference. Figure 5 shows the layout of the room.

The conference room is at the Air Force Institute of Technology (AFIT) campus at Wright Patterson Air Force Base, Dayton, OH. No items are removed from the room and only materials necessary for testing are brought in. Figure 6 shows the layout of the room. The measurements are taken throughout the course of a normal business-day, meaning that a variety of devices are present and active throughout the building and potentially causing interference.

Figure 6: Office Environment

Figure 7: Disaster Environment

The disaster environment used is the National Center for Medical Readiness at Calamityville. The site is located at 506 East Xenia Drive, Fairborn, OH. The specific environment is the abandoned meat-packing plant which has a variety of dirt and debris strewn throughout the building. Figure 7 shows the layout of the path used. Unlike the other two environments, there are no active Bluetooth devices in use during data gathering other than the devices being tested.

3.6 Device Positioning

The transmit device (victim) remains flat in a single location for each trial. The device maintains a consistent orientation, with the bottom of the device at the end of the measuring tape. The receive device (first responder) is moved along a straight line in 0.1 m increments from the transmit device while taking RSSI measurements. The height of the receive device is modified during various trials to determine the impact that it has specifically on the RSSI values. Modifying the height between the two devices should provide insight for how first responders may expect RSSI values to change as they walk or crouch as well as if the casualty is standing, sitting, or lying down. A height of 0.5 m is used as a reasonable difference in height between devices in a first-responder environment given the various positions the first responders and casualties may be in and where their devices may be located.

3.7 Data Gathering

In order to gather data, an Android application called Bluetooth Finder is used on the receiving device, shown in Figure 8. This app polls nearby devices for advertising packets and calculates an RSSI based on the signal strength. The transmitting smartphones used are opened to the Bluetooth settings screen, which automatically sets them to discoverable mode. The smartwatches are unpaired, which causes them

to default to discoverable mode. The smartlocks all function in discoverable mode but only when a physical button on them is pressed.

The app records the name of the device as contained in the advertising packets. It also captures the sequences of bytes for the manufacturer ID and references the Bluetooth Special Interest Group (SIG) list of manufacturers that have reserved a specific sequence to identify their devices.

Measurements are taken from the receiving device in increments of 0.1 m from the transmitting device. A single RSSI measurement is taken at each 0.1 m increment along the path, to a length of 6 m, resulting in 60 measurements in each trial. Each path is repeated two times and averaged to minimize the effect of outside variables. Height is set to 0 m, meaning the two devices are at the same height, and 0.5 m for the receiving device to be 0.5 m above the transmit device while still being a set distance away from the transmitting device.

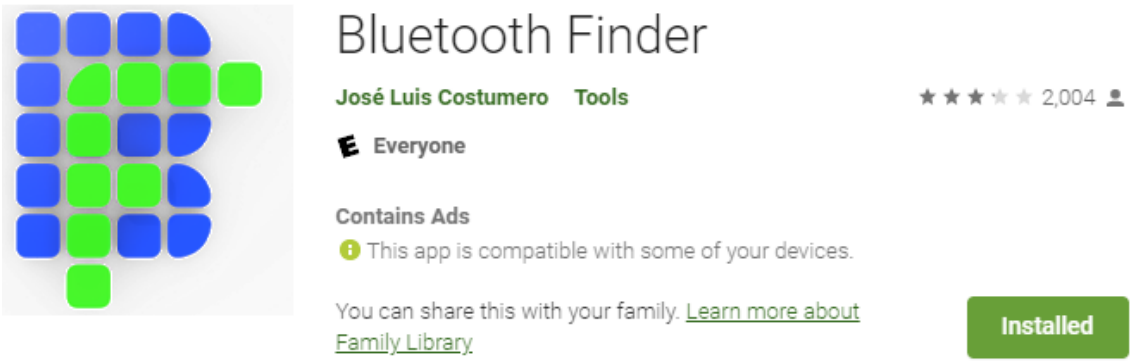

Figure 8: The Bluetooth Finder app from the Google Play Store

IV. Methodology

4.1 Overview

Section 4.2 explains the variables used in this research. Section 4.3 shows how the transmit and receive devices are positioned. Section 4.4 discusses how each Received Signal Strength Indicator (RSSI) is recorded. Section 4.5 notes what calculations are used. Section 4.6 defines enumeration in this research. Section 4.7 outlines the methods for statistical analysis used in this research.

4.2 Variables

In order to accurately determine the feasibility of enumerating a device and calculating distance using Bluetooth, the following factors are controlled:

- the distance between the two devices
- the height of the receive device
- the path which the receive device follows in each environment
- the transmit device
- the receive device
- the orientation of the two devices
- the environment
- transmit power of each device, calculated per Section 4.5
- device name and manufacturer-specific Media Access Control (MAC) address
- interference from the apparatus holding the receive device

The response variable is the estimated distance value based on the recorded RSSI value. This value is compared to the actual distance.

The uncontrolled factors include:

- physical sources of interference in each environment
- signal path from transmit to receive device
- number and impact of devices utilizing the wireless spectrum

Given the context of the experiment, these variables should remain uncontrolled to determine if it is possible to calculate an accurate distance in a non-sterile environment.

Figure 9 shows the system under test diagram. The only inputs are the advertising packets and scan responses from the transmit device. The system parameters, at the

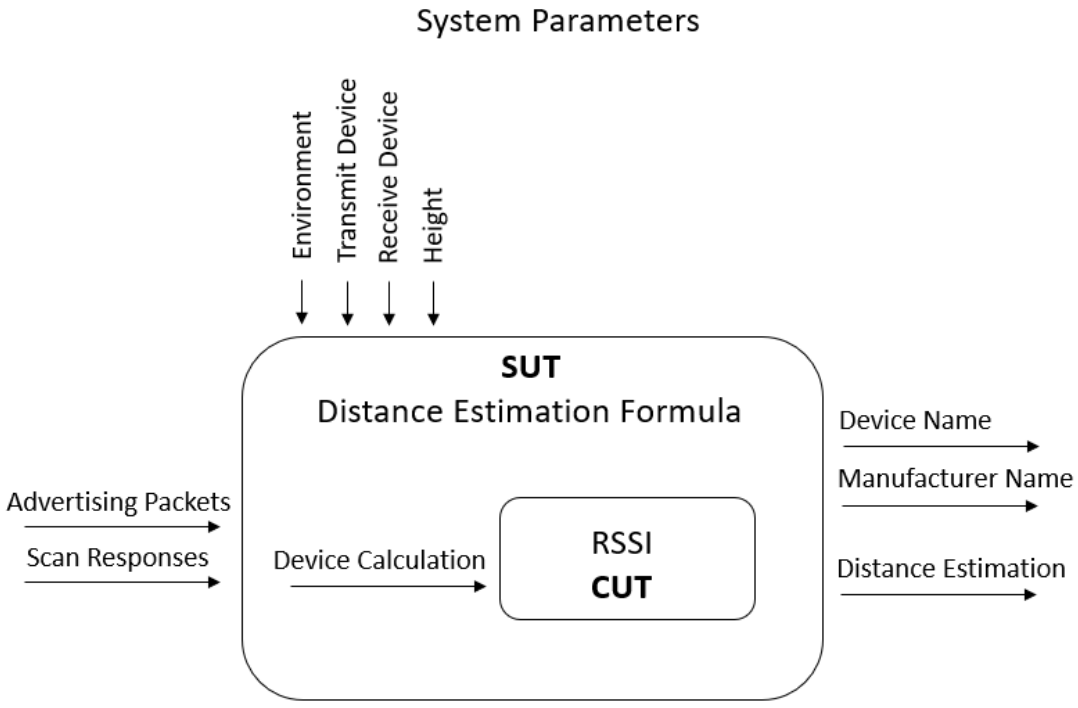

Figure 9: System Under Test Diagram

top of the diagram, are the environment, transmit and receive devices, and the height of the receive device. The receive device calculates an RSSI value based on packets from the transmit device. The data is then run through the distance estimation formula to generate a predicted distance for each device. The metrics are the device and manufacturer name for enumeration and the distance estimation.

4.3 Device Positioning

The transmit device is placed face-up and flat. The end of the measuring tape is on the bottom side of the transmit device. The Fitbit smartwatches are placed on their left sides as they could not reliably balance on the wrist strap. In the household environment, the transmit device is placed on a carpeted floor. In the office environment, the transmit device is placed on the armrest of an office chair at the head of the table to prevent the table from blocking the signal and interfering with every measurement. In the disaster environment, the transmit device is placed on a concrete floor with snow around it. Only one transmit device is measured at a time.

The receive device is placed in an apparatus to allow for adjusting the height. As shown in Figure 10, when the measurements are taken with no height difference, the receive device is placed in the apparatus and laid on the ground (or table in the office environment). When the height difference of 0.5 m is set, the apparatus is adjusted to elevate the receive device as shown in Figure 11. The receive device stays flat so it is parallel to the transmit device.

The apparatus holds the receive device at the bottom, lined up with the case to keep the measurements consistent. The receive device is a single Google Pixel 3 XL in all experiments. The receive device is moved with the measuring tape to its

left. There is a notch in the top left of the phone case that is used to line up the measurements.

Figure 10: Apparatus for Receive Device - 0 m

Figure 11: Apparatus for Receive Device - 0.5 m

In the home environment, the transmit device is placed near a wall with a couch on one side and a variety of toys to the other side. In the office environment, the transmit device is placed on the armrest of a chair at the head of the table, next to the exterior wall. This location is chosen in order to be take measurements in the middle of the room without having the table block a majority of the signals. The apparatus adjusts to a variety of heights and allowed for measurements at the appropriate height. In the disaster environment, the transmit device is placed near a variety of old metal machines and tubes. Pictures of the environments are in Section 3.5. Each environment has a wall within 1 m behind the transmit device.

4.4 Recording RSSI

Once the path is established and measured in each environment, the transmit device is placed. The receive device is placed in the apparatus that allows its height to be modified. For trials at 0 m height, the receive device is laid on the ground, but still within the grasp of the apparatus to make its level of interference consistent on all trials. The receive device is placed along the path, beginning at 0.1 m away from the transmit device and moving in increments of 0.1 m to a maximum distance of 6 m, with the Bluetooth Finder app open and running. For consistency, the receive device begins at 0.1 m from the transmit device and is moved away rather than being placed at 6 m and moving towards the transmit device.

Figure 12 shows a screenshot of the Bluetooth Finder app in use. The text in yellow is the detected device name from the respective advertising packet. The text in red is the manufacturer name based on the MAC address in the advertising packet. The number in green is calculated RSSI value of the most recent packet for that device. If the signal is not strong enough to receive an uncorrupted packet or to calculate an

RSSI value, or if the device has not been detected within one minute, the green text will reflect no value.

For the smartlocks, a physical button needs to be pressed on them to send the advertising packets. The smartphones are open to the Bluetooth settings screen with their screens remaining on to make them discoverable. The smartwatches used require no specific configurations as they continually send advertising packets when unpaired.

Within the Bluetooth Finder app, the transmit device first needs to be identified, which is done by the advertised device name (see Table 6). The RSSI value for the transmit device is then recorded by hand at each interval. Each transmit device is measured twice in each environment and height difference and averaged to minimize the sources of interference. While more trials would provide more accurate data, two trials are used to balance accuracy and time spent collecting data.

4.5 Calculations

Equation (1) is used to calculate the predicted RSSI values based on the known distance as explained in Section 2.4.2. P_{TX}, the transmit power of the tested device, is calculated individually for each device. A total of ten measurements are taken, with the receive device positioned 1 m from the transmit device. All P_{TX} measurements are recorded in the home environment. Table 5 shows the measured P_{TX} for each device. The measurements are only taken in the home environment and not the other two environments to create a generic baseline for approximating distance without assuming too much information about the individual devices, such as how they may behave differently in each environment.

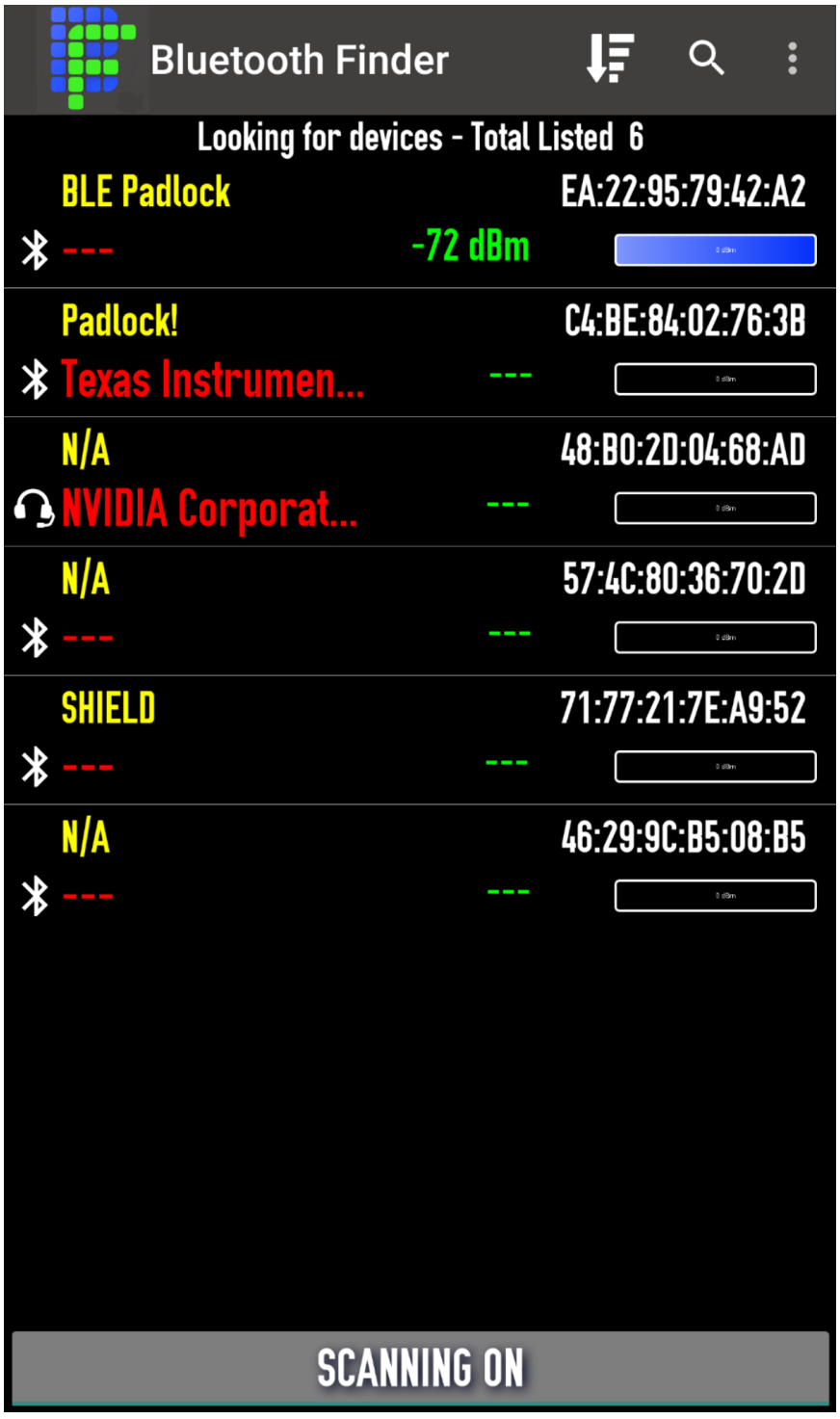

Figure 12: Screenshot of the Bluetooth Finder app

Table 5: Average Transmit Power

Device	Type	Average Tx Value (dBm)	Standard Deviation
Fitbit Charge 2	Smartwatch	-68.2	5.1
Fitbit Surge	Smartwatch	-68.0	6.5
Moto E (2nd Gen.)	Smartphone	-68.5	6.1
Samsung S7	Smartphone	-70.2	5.5
Samsung S8	Smartphone	-72.8	4.9
Dog & Bone Lock	Lock/IoT	-85.5	5.9
iBluLock	Lock/IoT	-85.7	7.8
Master Lock	Lock/IoT	-82.5	5.5
QuickLock	Lock/IoT	-71.3	6.3

4.6 Enumeration

Enumeration in the context of this research means collecting advertising packets and examining the device name and manufacturer ID in order to determine what the device is. Enumeration is tested in a binary method. The transmit device should be accurately determined, in terms of whether it is a device that is on a person, within the first three RSSI readings (excluding getting the P_{TX} value). If it is not recorded by then, or if it is recorded inaccurately, the enumeration for that trial is considered a failure.

4.7 Statistical Analysis

Two trials are conducted of each combination of variables (device, environment, height). These two trials are then averaged together in order to minimize the inherent inaccuracies of RSSI values. All statistical analysis is done using these averaged values.

In order to compare the elevations, a paired t-test is conducted between the values at 0 m and the values at 0.5 m for each device using the MatLab software across the entire data set. The p-value is examined and compared against an alpha value of 0.05 to determine significance. The null hypothesis for this test is that the increased

elevation of the receive device does not make a difference on the calculated RSSI values. This calculation produces 9 p-values, one per device.

A full comparison of the RSSI values for the trials at 0.5 m in height and the trials at 0 m in height would not produce useful results since the distances are inherently unequal. Since a right triangle is being made by the transit device, receive device, and measuring tape, the actual distance between the transmit and receive devices is greater than the measured distance by the measuring tape at any given location when the receive device is elevated. At the closest distance of 0.1 m between the transmit and receive devices, the actual distance is $\sqrt{0.1m^2 + 0.5m^2}$ or approximately 0.51 m. At the farthest measured distance of 6 m, the actual distance is $\sqrt{6m^2 + 0.5m^2}$ or approximately 6.02 m. As the distances increase, the differences between the measured distance and actual distance decrease noticeably.

In order to make some usable comparisons between the data, the first data point of the trials at 0 m elevation is removed, causing the the point at 0.2 m in distance and 0 m in height to be compared directly to the point at 0.1 m in distance and 0.5 m in distance. This skews some of the data for the measurements under 1 m in measured distance, but after the first meter the difference between the measured and actual distance is always under 0.1 m, making a simple shift of one data point line up the majority of the data fairly well. In order to account for the missing data point, the last measurement is dropped from the trials at 0.5 m elevation for these comparisons. Without this step, the data sets are too different and not directly comparable. For example, a direct comparison of the raw measurements would mean that the measurement at 0.1 m in distance and 0 m in elevation (a total distance of 0.1 between devices) is compared against the measurement at 0.1 m in distance and 0.5 m in elevation (a total distance of 0.51 m between devices). This discrepancy may make the analysis inaccurate as the t-test may be comparing the significance of the

total distances between the devices in the 0 m and 0.5 m experiments rather than the significance of the difference in elevation.

In order to compare the environments, an analysis of variance test is conducted between the three environments with the device and height constant. The p-value is examined and compared against an alpha value of 0.05 to determine significance. The null hypothesis for this test is that different environments do not significantly impact RSSI values. This calculation produces 18 p-values, one per device/height combination.

The RSSI values of the individual devices are not compared to each other because it does not provide any useful information. For the distance prediction equation, an important variable is the device's transmit power, P_{TX}. This value is different for each device and helps provide a more accurate prediction, but also means that raw RSSI comparisons between two devices do not provide any significant insight for this research.

V. Results and Analysis

5.1 Overview

Section 5.2 shows the results of the enumeration tests. Section 5.3 explains the differences in the environments on the Received Signal Strength Indicator (RSSI) measurements and Section 5.4 explains the differences in elevation on the RSSI measurements. Section 5.5 notes the feasibility of the used distance estimation equation in this research.

5.2 Enumeration Results

While there is some subjective analysis required to determine whether a device could be identified from the information in Table 6, the author took the perspective of a non-technical first responder. Consequently, the Samsung phones are considered failures as Samsung makes a variety of equipment and the device names do not make it immediately clear that they are smartphones.

Table 6: Enumeration Results

Device	Advertised Name	Advertised Manufacturer	Usably Enumerated?
Fitbit Charge 2	Charge 2	N/A	No
Fitbit Surge	Surge	N/A	No
Moto E (2nd Gen.)	MotoE2(4G-LTE)	Motorola Mobility LLC, A Lenovo Company	Yes
Samsung S7	SAMSUNG-SM-G930V	Samsung Electronics Co., Ltd.	No
Samsung S8	SAMSUNG-SM-G950U	Samsung Electronics Co., Ltd.	No
Dog & Bone Lock	BLE Padlock	N/A	Yes
iBluLock	MAPLEAF_ble_lock	N/A	Yes
Master Lock	Master Lock	Texas Instruments	Yes
QuickLock	Padlock!	Texas Instruments	Yes

The most striking result for the enumeration data is that all of the smartlocks are identifiable as locks whereas only one of the five devices on a person are identifiable. Fitbit has not yet registered a Media Access Control (MAC) address with the Bluetooth Special Interest Group (SIG), which may be because they are in the process of being acquired by another company [29].

It is worth noting that users can generally change the device name of Bluetooth devices fairly easily, which at best renders examining device names useless and at worst could cause a first responder to ignore a device that appears to be an Internet of Things (IoT) device but is actually a smartphone or other device on a person. Additionally, a number of smartphones include an option to establish a device name during its initial set up, which would make device names more useful [30].

If first responders were to use such an app and have access to this data, they would have to use a policy that every device is considered not on a person unless it is identified otherwise. Otherwise, they would be overwhelmed at offices and locations with a myriad of Bluetooth printers, locks, light bulbs, scanners, etc. Consequently, these results indicate that targeting devices in this manner would make little difference in practice: only one device on a person is usably identified. The smart locks, while correctly identified, would not be expected to be on a person and therefore would be marked to be ignored in order to focus on devices that are more likely to be with a person.

5.3 Environment Comparison

The three environments differ wildly in sources of interference that are present. In order to compare the measurements across each environment, the averages are taken of the two trials in each environment to normalize the data for an individual environment. Each set is then compared to the other environments for the same

device in order to determine how significant of an impact a change in location may have on the measured RSSI values.

In nearly every case, the office environment had the highest RSSI values, or the strongest signals. This result is expected as the measurements recorded in the office environment are taken in the middle of the room across the table shown in Figure 6 with few sources of interference in close proximity to the transmit and receive devices.

However, the results between the home and disaster environment are much less clear. The disaster environment is expected to have low values as there are a wide array of sources of interference, including large metallic objects directly beside the path as shown in Figure 7. While this expectation held true in the results, the values measured in the home environment managed to rival the values in the disaster environment, with RSSI values only slightly higher. Given the relatively few sources of interference present in the home environment as shown in Figure 5, the most likely conclusion is that the carpeting caused a significant amount of interference by preventing signals from bouncing off of the floor similar to the concrete surface in the disaster environment. Additionally, when the height is at 0 m, the signal from the transmit device travels directly through the carpeting for the shortest path, which may also degrade the signal and increase the RSSI values.

Across all the devices and environments, the most notable impact occurred in the disaster environment. Due to the signal multipathing, it is likely that elevating the receive device allowed it to receive signals much quicker as there are many objects in the disaster environment for the signal to bounce off of with minimal signal degradation. Additionally, the disaster environment had solid concrete as a surface, which also may have inhibited the signal from the transmit device. However, the home and office environment had far fewer sources of interference along the measured path. This observation likely explains why the home and office environments had less significant differences whether the receive device is elevated.

Noting that the disaster environment had the most significant impact is an important finding. If Bluetooth is used in a disaster environment to find victims, the posture of the first responder and the location of her device would impact the measured RSSI from the victim's device. Since disaster environments can take many forms as noted in Section 2.6, the first responder could be standing, crouching, or

crawling. Additionally, her device may be in her hand, on her hip, or in another location, which would impact the strength of the signal from the victim's device.

Table 7 shows the p-values that result from the analysis of variance test on the different environments with no difference in height calculated per Section 4.7. Every result is significant at the alpha = 0.05 level, indicating a rejection of the null hypothesis that the environment does not significantly impact the RSSI values between two devices without a difference in elevation.

Table 8 shows the p-values that result from the analysis of variance test on the different environments with the receive device at 0.5 m in height calculated per Section 4.7. Four results are significant at the alpha = 0.05 level. This result means the null hypothesis that the environment does not have a significant impact on the RSSI values between two devices when the receive device is raised 0.5 m is accepted for the other five devices. These results indicate that when the transmit device is on the ground and the receive device is raised by 0.5 m, the environment does not significantly impact the signal strength readings for the majority of devices. When contrasted with previous results, this finding indicates that the elevation of the receive device may have a stronger impact on the RSSI measurements than the environment the devices are in.

Table 7: Statistical Analysis of Environment, 0 m (p-values)

	Fitbit Charge 2	Dog & Bone Lock	iBluLock	Master Lock	Motorola Moto E (2nd Gen.)
p	$8.7 * 10^{-6}$	0.0020	0.0004	$3.6 * 10^{-7}$	0.0006

	Quicklock	Samsung S7	Samsung S8	Fitbit Surge
p	0.0060	$1.6 * 10^{-8}$	$2.2 * 10^{-8}$	$1.8 * 10^{-5}$

Table 8: Statistical Analysis of Environment, 0.5 m (p-values)

	Fitbit Charge 2	Dog & Bone Lock	iBluLock	Master Lock	Motorola Moto E (2nd Gen.)
p	0.5325	0.0556	0.2296	0.2481	0.2519

	Quicklock	Samsung S7	Samsung S8	Fitbit Surge
p	0.0062	0.0006	0.0160	$1.5 * 10^{-5}$

5.3.1 Individual Devices

Figure 13 shows the average measured values for the Fitbit Charge 2 in all three environments with 0 m in elevation, and Figure 14 shows the average measured values with 0.5 m in elevation. With no height difference, the office environment has the strongest measured values while the home and disaster environments averaged about the same. At 0.5 m in elevation, however, the office environment had only slightly stronger values, and the home environment had slightly lower values than the disaster environment. Comparing the two data sets, the 0.5 m measurements are slightly higher on average but also had a smaller range with a higher minimum measurement and lower maximum measurement, potentially signaling that the added elevation provided more accurate results.

Figure 15 shows the average measured values for the Dog & Bone Lock in all three environments with 0 m in elevation, and Figure 16 shows the average measured values with 0.5 m in elevation. Like the Fitbit Charge 2, the office environment had the strongest values without any height difference. The disaster and home environments are negligibly different. With the added elevation, all three environments become comparable in strength, with the office environment still having the highest average RSSI value, but only slightly. In all environments, the average RSSI value is higher in the 0.5 m elevation test than the 0 m elevation test.

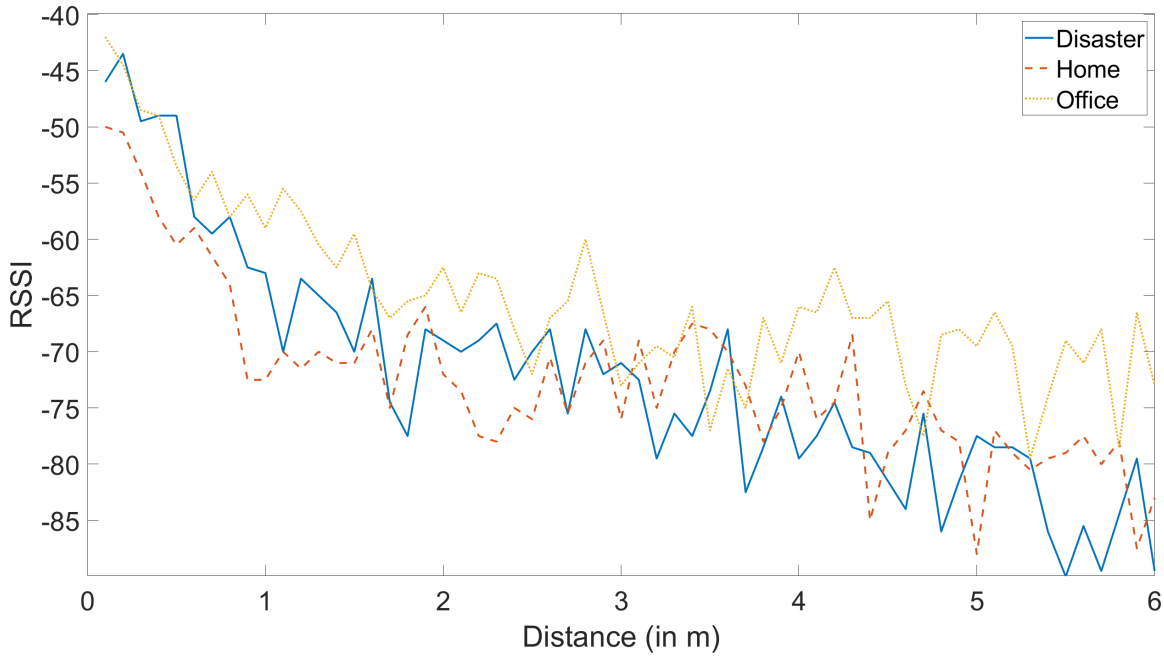

Figure 13: Fitbit Charge Environment Comparison, Height 0 m

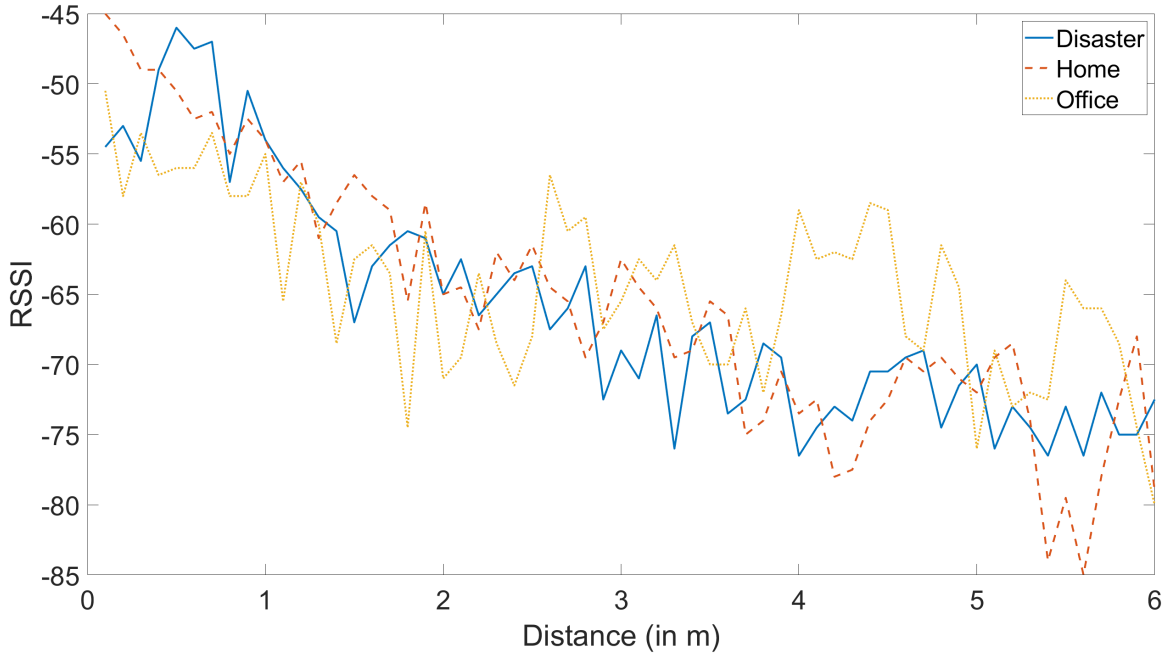

Figure 14: Fitbit Charge Environment Comparison, Height 0.5 m

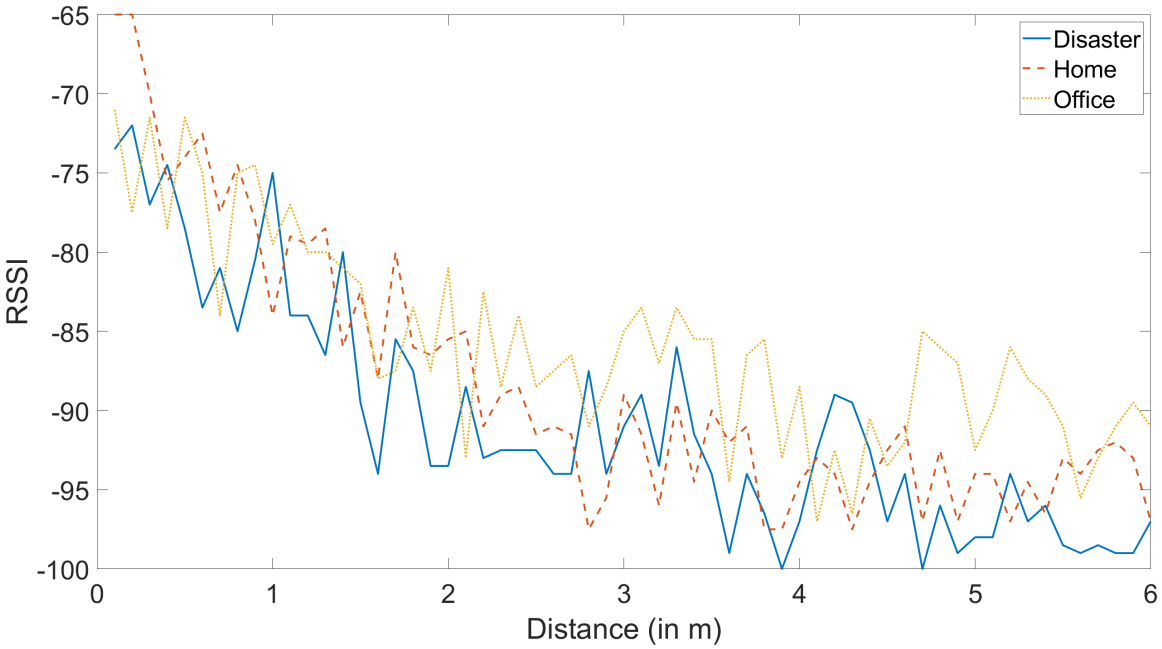

Figure 15: Dog & Bone Lock Environment Comparison, Height 0 m

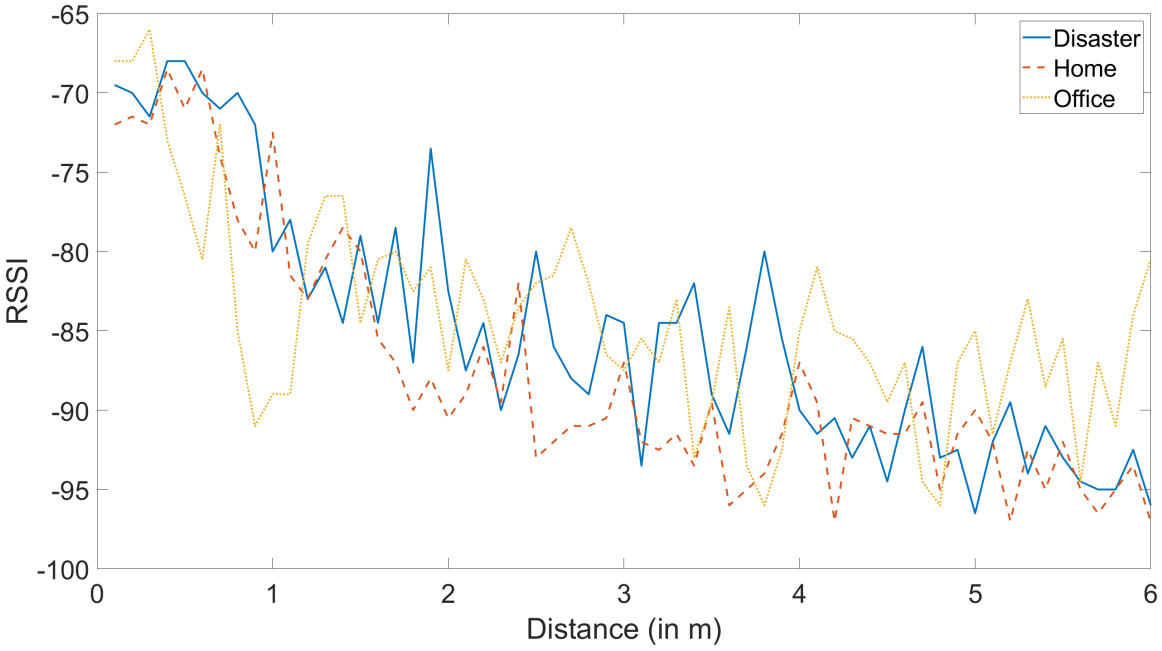

Figure 16: Dog & Bone Lock Environment Comparison, Height 0.5 m

Figure 17 shows the average measured values for the iBluLock in all three environments with 0 m in elevation, and Figure 18 shows the average measured values with 0.5 m in elevation. The iBluLock also had the strongest measurements in the office environment at a height of 0 m, only slightly higher than the office environment. At 0.5 m in elevation, the office still had the highest values but negligibly so. This device had multiple spikes in measurements in the disaster environment, particularly in the 0.5 m test. This behavior was not exhibited by the other devices and may be a result of some device-specific behavior or anomaly in the signal pathing between the two devices. In all environments, the average RSSI value is higher in the 0.5 m elevation test than the 0 m elevation test.

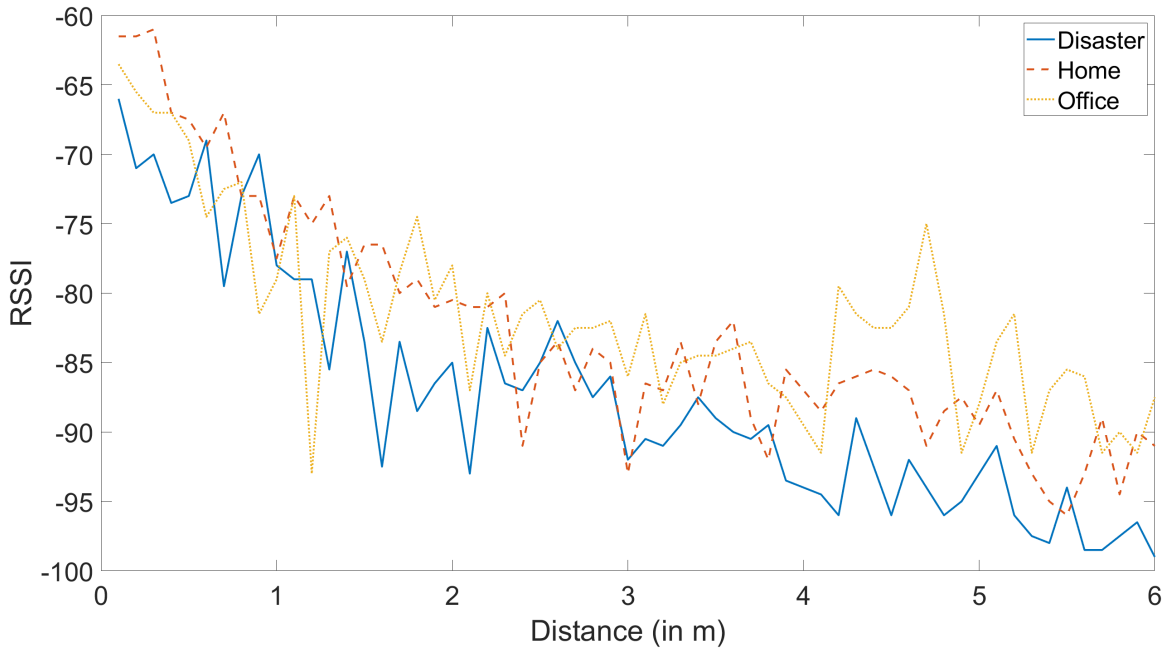

Figure 17: iBluLock Environment Comparison, Height 0 m

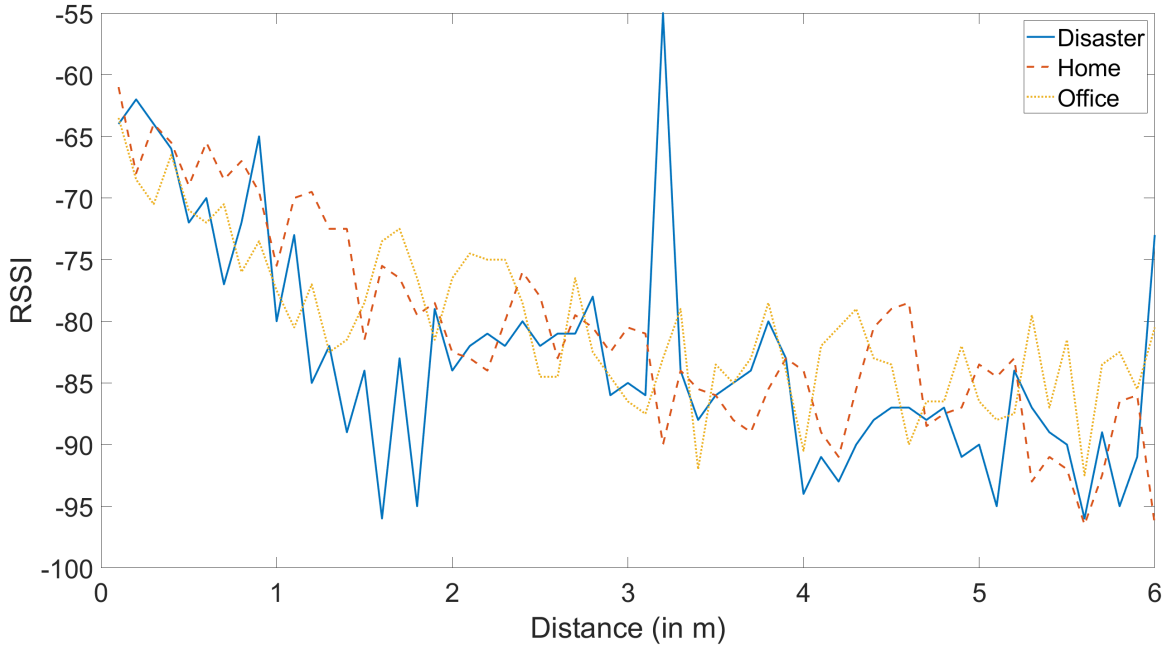

Figure 18: iBluLock Environment Comparison, Height 0.5 m

Figure 19 shows the average measured values for the Master Lock in all three environments with 0 m in elevation, and Figure 20 shows the average measured values with 0.5 m in elevation. The office environment had the highest measured values in the test without a height difference, but the home environment had the strongest values in the 0.5 m test. Additionally, the average values in the office environment decreased in the 0.5 m test while the other two environments had increased results.

Figure 21 shows the average measured values for the Motorola Moto E (2nd Gen.) in all three environments with 0 m in elevation, and Figure 22 shows the average measured values with 0.5 m in elevation. The office environment had the highest measurements in both heights, and all environments had higher values in the 0.5 m elevation test. One note with this device is the variability of the results, particularly in the 0.5 m test where there are multiple spikes that are not observed for the other devices.

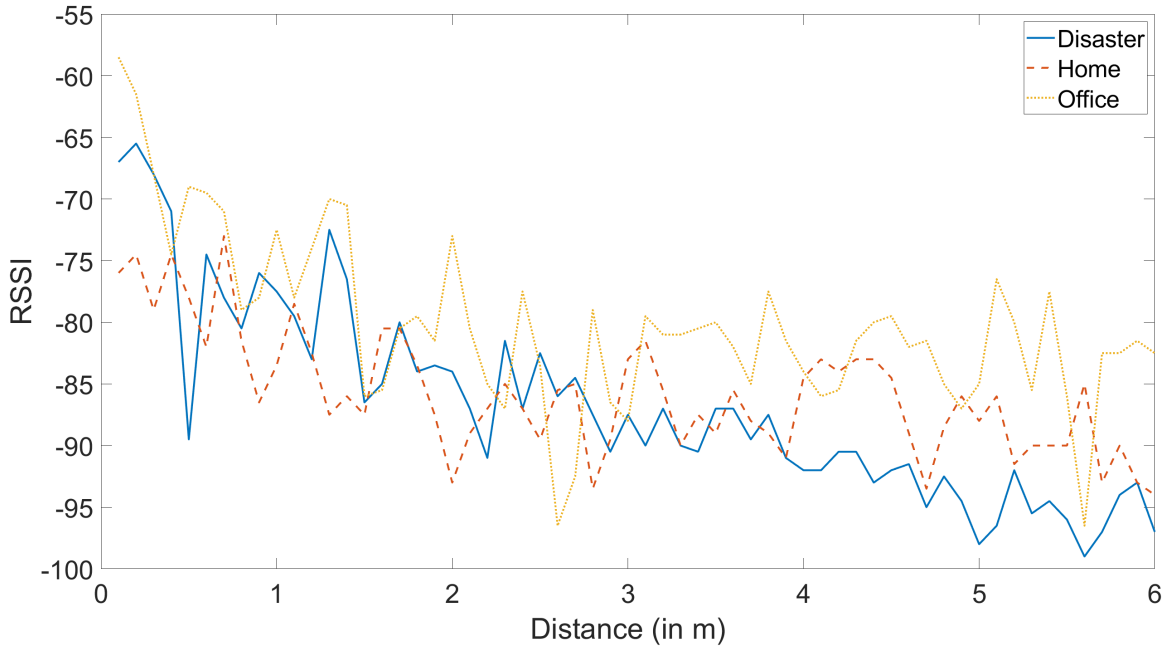

Figure 19: Master Lock Environment Comparison, Height 0 m

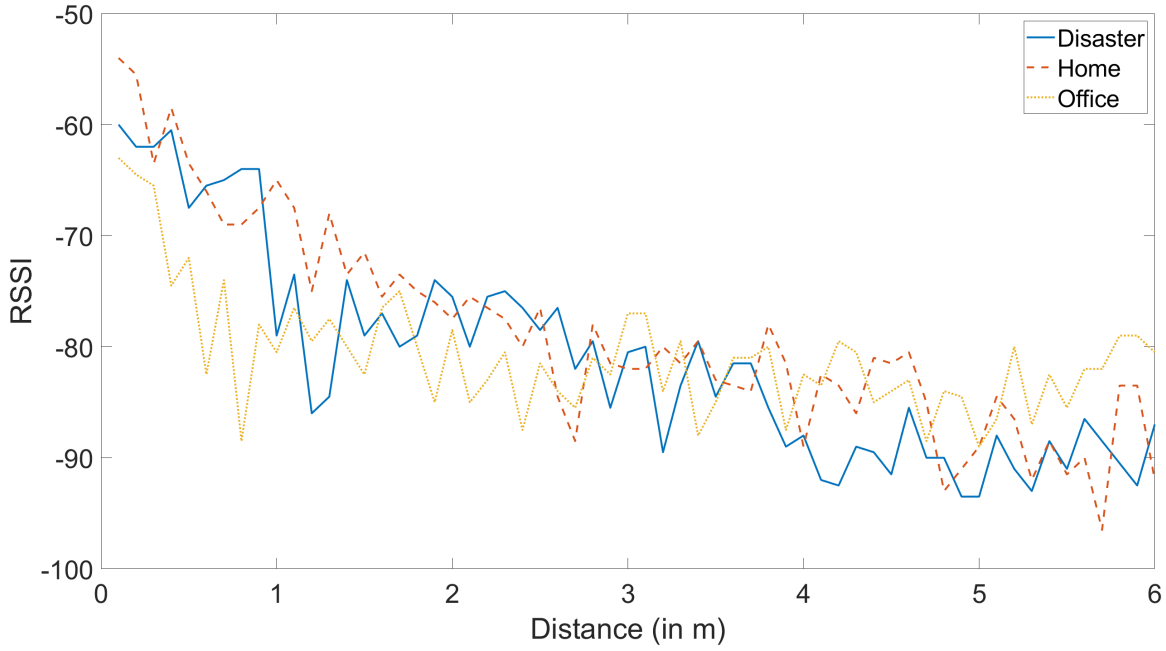

Figure 20: Master Lock Environment Comparison, Height 0.5 m

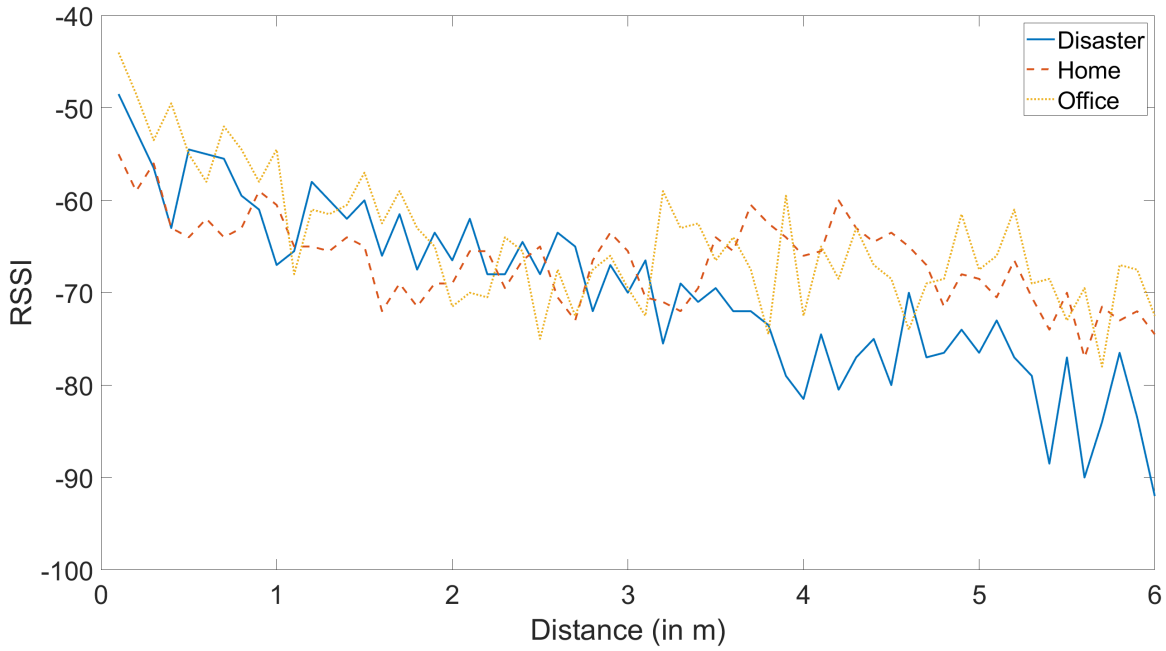

Figure 21: Motorola Moto E (2nd Gen.) Environment Comparison, Height 0 m

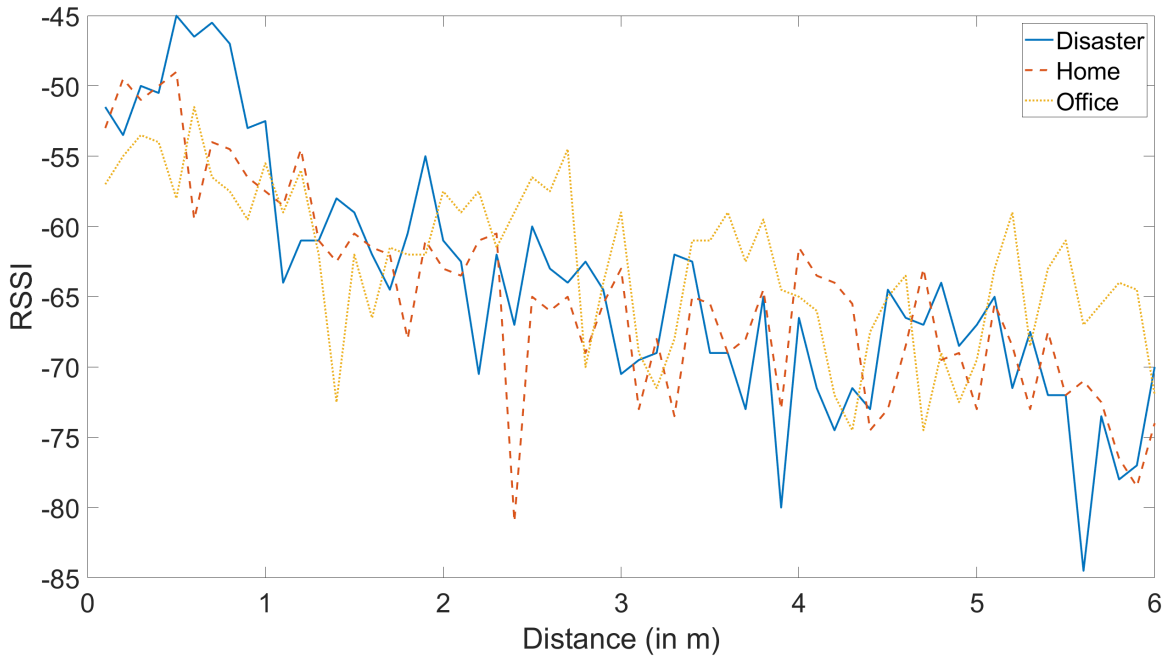

Figure 22: Motorola Moto E (2nd Gen.) Environment Comparison, Height 0.5 m

Figure 23 shows the average measured values for the Quicklock in all three environments with 0 m in elevation, and Figure 24 shows the average measured values with 0.5 m in elevation. The office environment had the highest measurements in both heights, and all environments had higher values in the 0.5 m elevation test.

Figure 25 shows the average measured values for the Samsung S7 in all three environments with 0 m in elevation, and Figure 26 shows the average measured values with 0.5 m in elevation. The office environment had the highest measurements in both heights, and the home and disaster environments had higher values in the 0.5 m elevation test. The office environment had a slight decrease in RSSI values in the test with an elevation difference.

Figure 27 shows the average measured values for the Samsung S8 in all three environments with 0 m in elevation, and Figure 28 shows the average measured values with 0.5 m in elevation. The office environment had the highest measurements in both heights, and all environments had higher values in the 0.5 m elevation test.

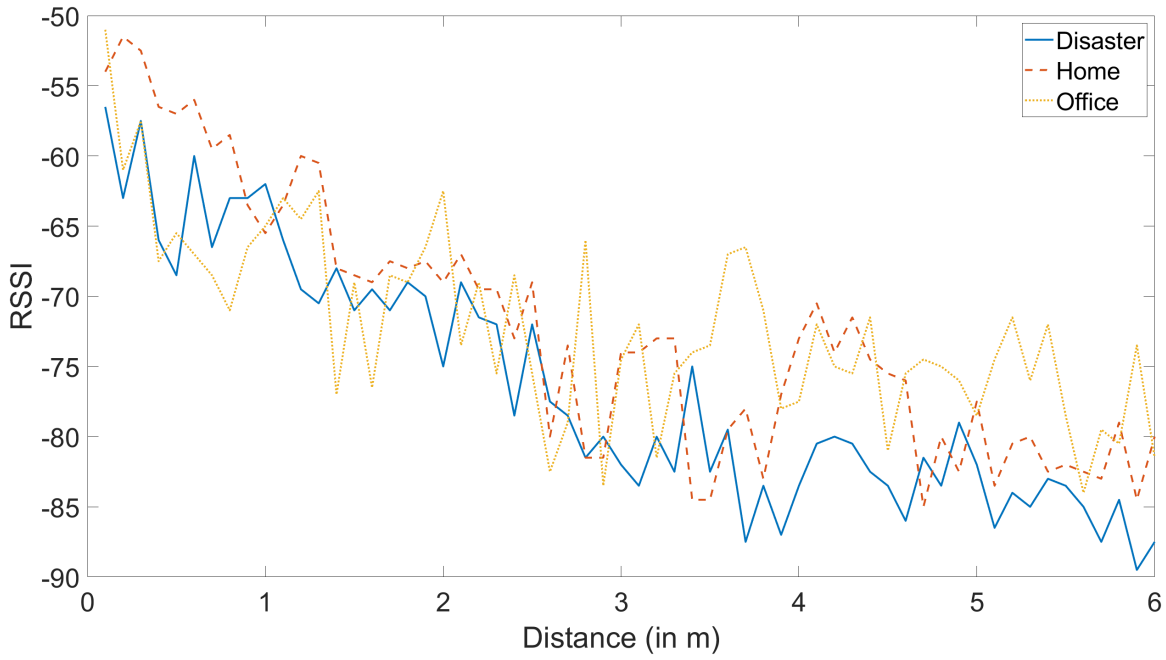

Figure 23: Quicklock Environment Comparison, Height 0 m

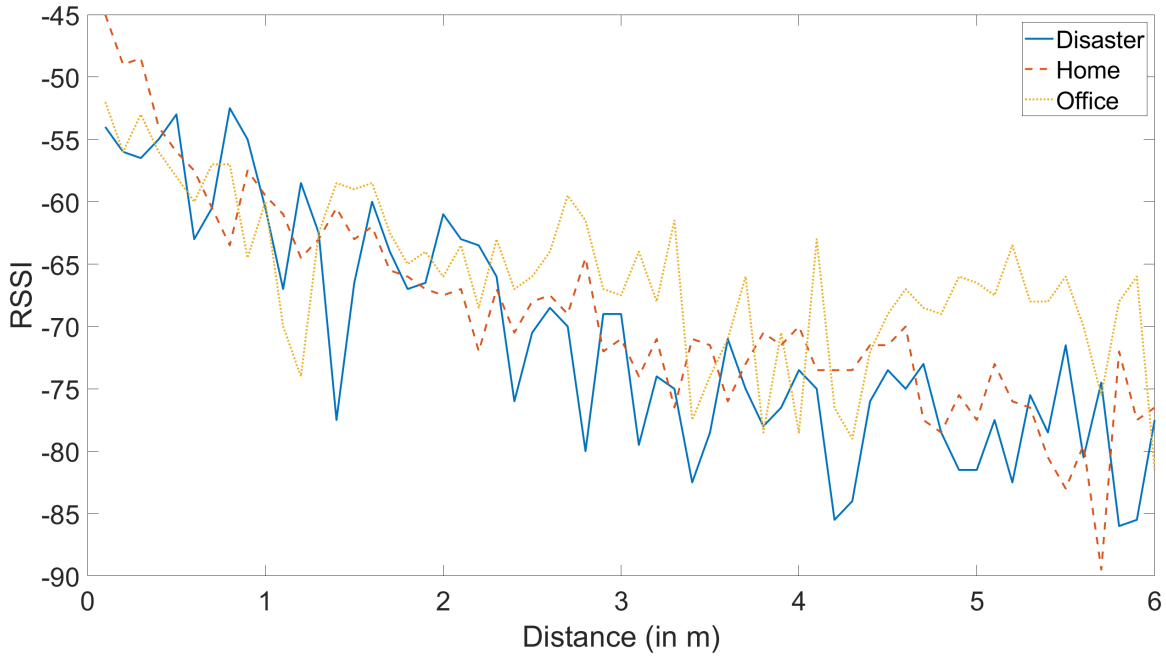

Figure 24: Quicklock Environment Comparison, Height 0.5 m

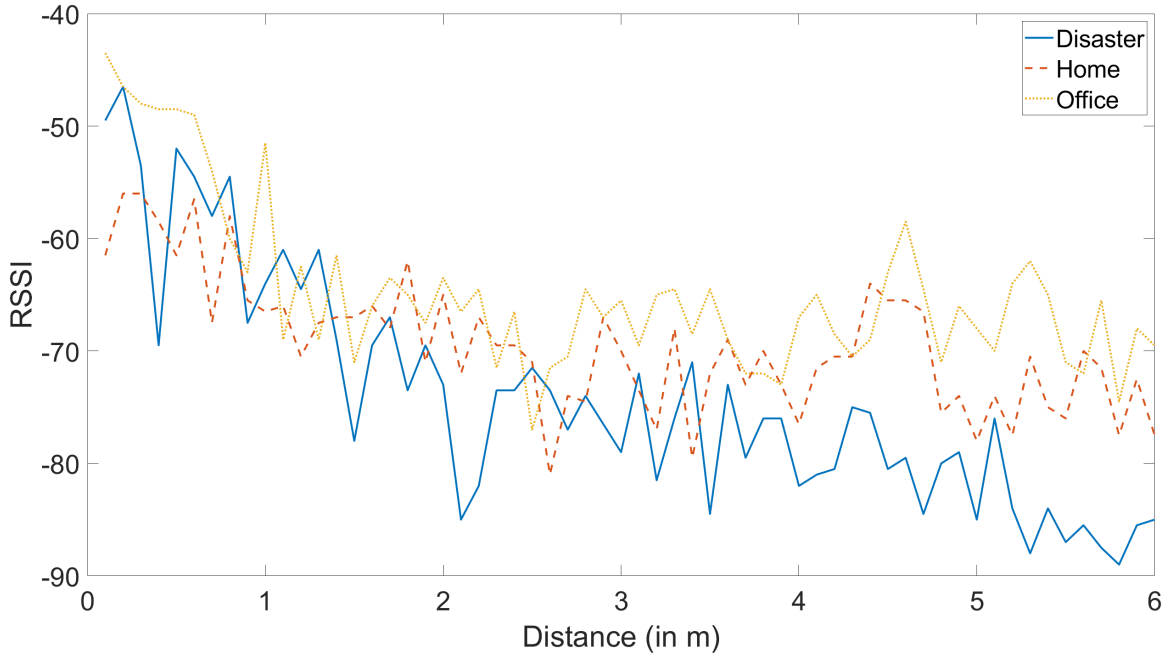

Figure 25: Samsung S7 Environment Comparison, Height 0 m

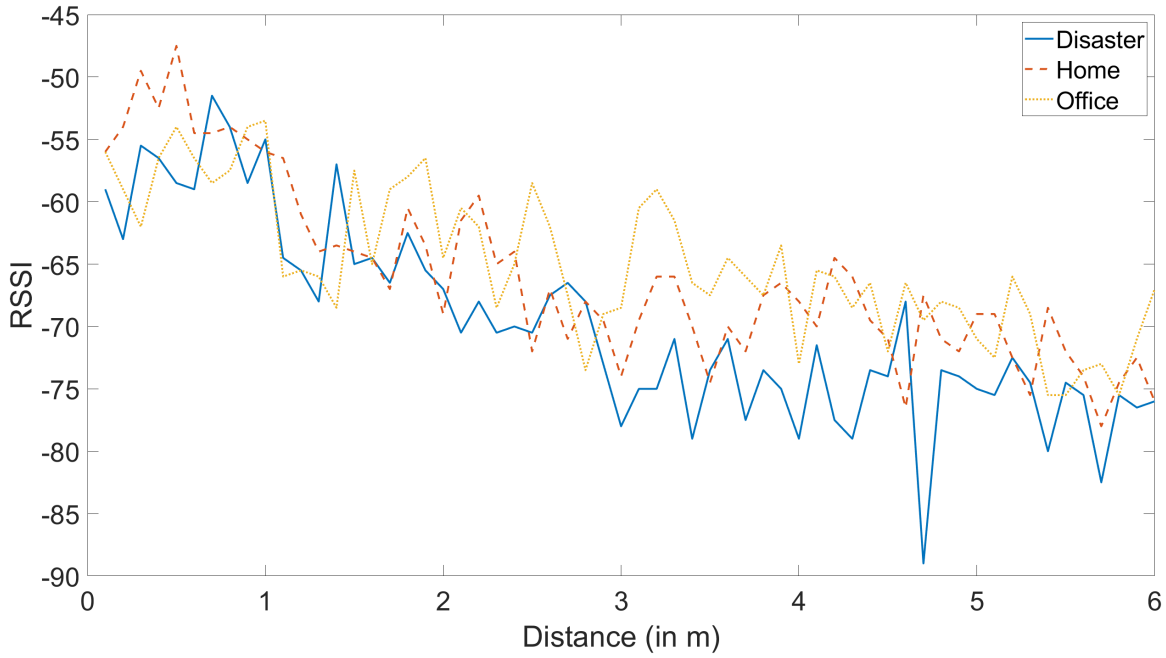

Figure 26: Samsung S7 Environment Comparison, Height 0.5 m

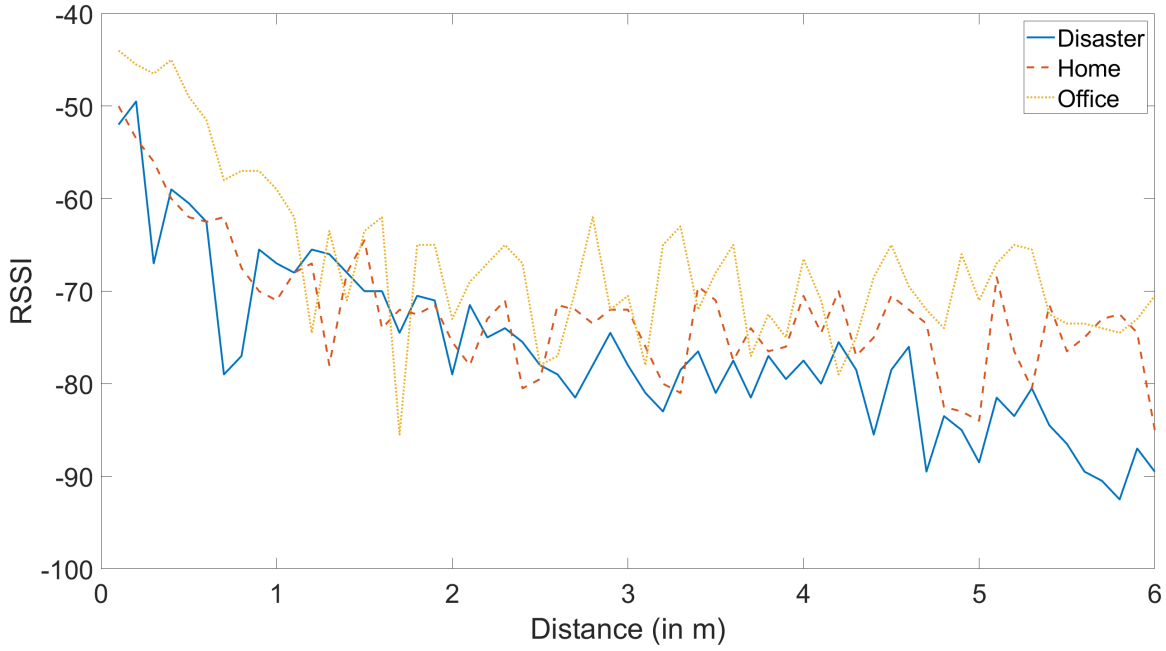

Figure 27: Samsung S8 Environment Comparison, Height 0 m

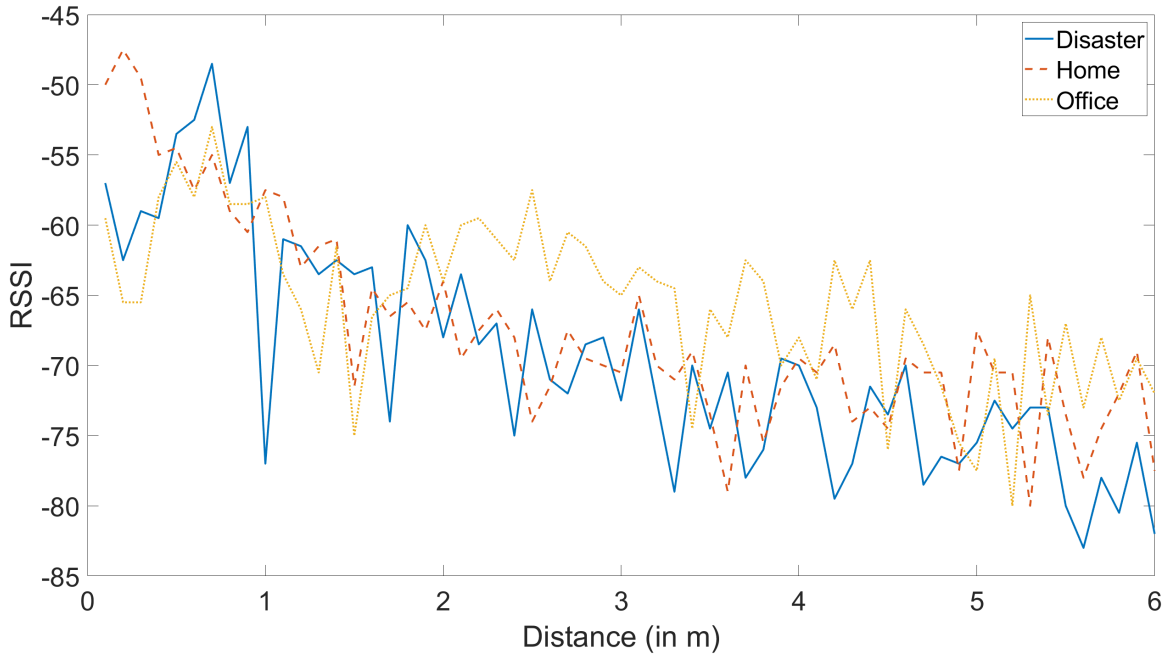

Figure 28: Samsung S8 Environment Comparison, Height 0.5 m

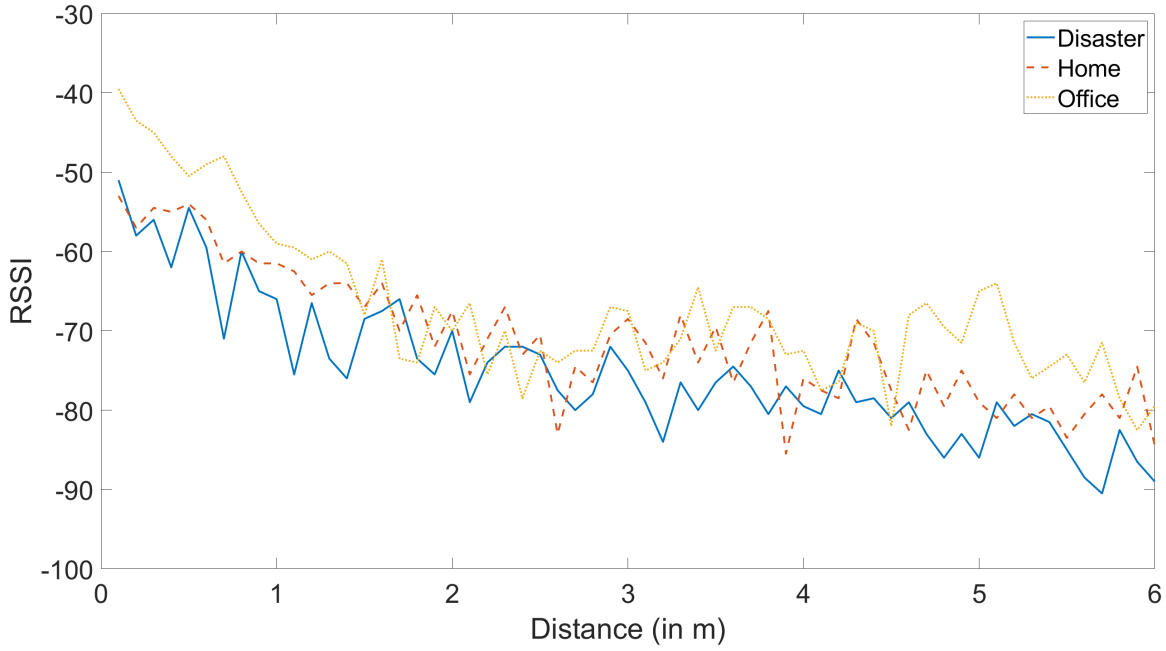

Figure 29: Fitbit Surge Environment Comparison, Height 0 m

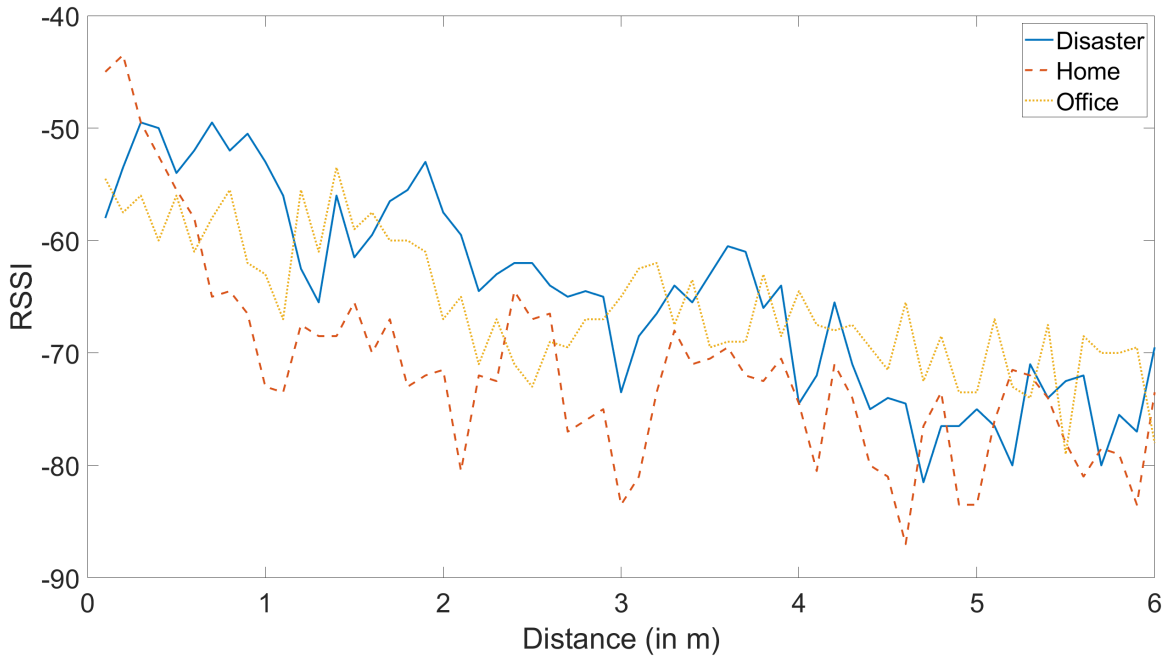

Figure 30: Fitbit Surge Environment Comparison, Height 0.5 m

Figure 29 shows the average measured values for the Fitbit Surge in all three environments with 0 m in elevation, and Figure 30 shows the average measured values with 0.5 m in elevation. The office environment had the highest measurements in the 0 m test, and the disaster environment had the highest measurements in the 0.5 m test. Additionally, the values in the home environment decreased compared to the 0.5 m test while the other two environments increased.

5.4 Elevation Comparison

The expected results are for higher RSSI values, or stronger signal strength, when the receive device is at a higher elevation. The results for all devices demonstrated this expectation is generally the case, although to varying degrees. In three of the 27 experiments, the stronger results occurred without additional height on the receive device. In many instances, such as Figure 44, the overall difference of the elevation is

negligible. Other times, such as Figure 55, the results clearly show the impact that a higher elevation has on the RSSI values.

Table 9: Statistical Analysis of Elevation (p-values)

	Fitbit Charge 2	Dog & Bone Lock	iBluLock	Master Lock	Motorola Moto E (2nd Gen.)
Disaster	$4.1 * 10^{-13}$	$1.7 * 10^{-13}$	$7.2 * 10^{-7}$	$6.8 * 10^{-11}$	$1.6 * 10^{-11}$
Home	$6.3 * 10^{-13}$	0.0087	$4.7 * 10^{-5}$	$1.7 * 10^{-10}$	0.0116
Office	0.0320	0.0356	0.0208	0.6791	0.0169

	Quicklock	Samsung S7	Samsung S8	Fitbit Surge
Disaster	$2.6 * 10^{-13}$	$8.9 * 10^{-7}$	$2.5 * 10^{-12}$	$3.6 * 10^{-22}$
Home	$8.1 * 10^{-8}$	$8.4 * 10^{-7}$	$6.5 * 10^{-10}$	0.9407
Office	$5.4 * 10^{-10}$	0.8257	0.0916	0.0266

Table 9 shows the p-values that result from the paired t-test on the heights of the devices calculated per Section 4.7. At an alpha value of 0.05, 23 of the 27 tests show that elevation of the receive device has a significant effect on the calculated RSSI values and cause a rejection of the null hypothesis. It is also worth noting that no device had a p-value greater than 0.05 in multiple environments, and that 3 of the the 4 instances occur in the office environment.

5.4.1 Individual Devices

Figure 31, Figure 32, and Figure 33 show the actual and predicted results, calculated using Equation (1), of the Fitbit Charge 2 with and without added elevation in the disaster, home, and office environments respectively. The disaster and home environment show noticeably stronger RSSI measurements on average. The office environment had lower values in the 0.5 m experiment up to approximately 2 m in distance before having stronger values afterwards, making a negligible impact overall.

Table 10 shows the average measured RSSI values at various points, as well as the means.

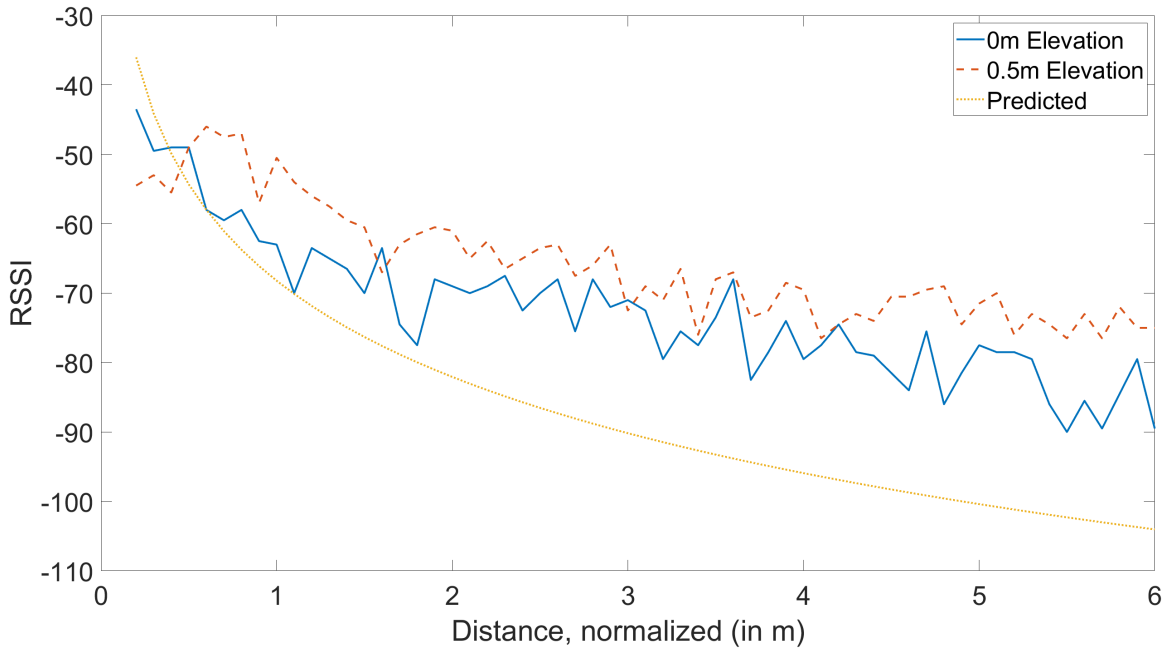

Figure 31: Fitbit Charge Elevation Comparison, Disaster Environment

Table 10: Fitbit Charge 2 Average RSSI Values

	Disaster		Home		Office	
Distance	0 m	0.5 m	0 m	0.5 m	0 m	0.5 m
0.1 m	-46	-54.5	-50	-45	-42	-50.5
1 m	-63	-54	-72.5	-54	-59	-55
2 m	-69	-65	-72	-65	-62.5	-71
3 m	-71	-69	-76	-62.5	-73	-65.5
4 m	-79.5	-76.5	-70	-73.5	-66	-59
5 m	-77.5	-70	-88	-72	-69.5	-76
6 m	-89.5	-72.5	-83	-79	-73	-80
mean	-72.6	-65.8	-72.3	-65.5	-65.2	-64.3

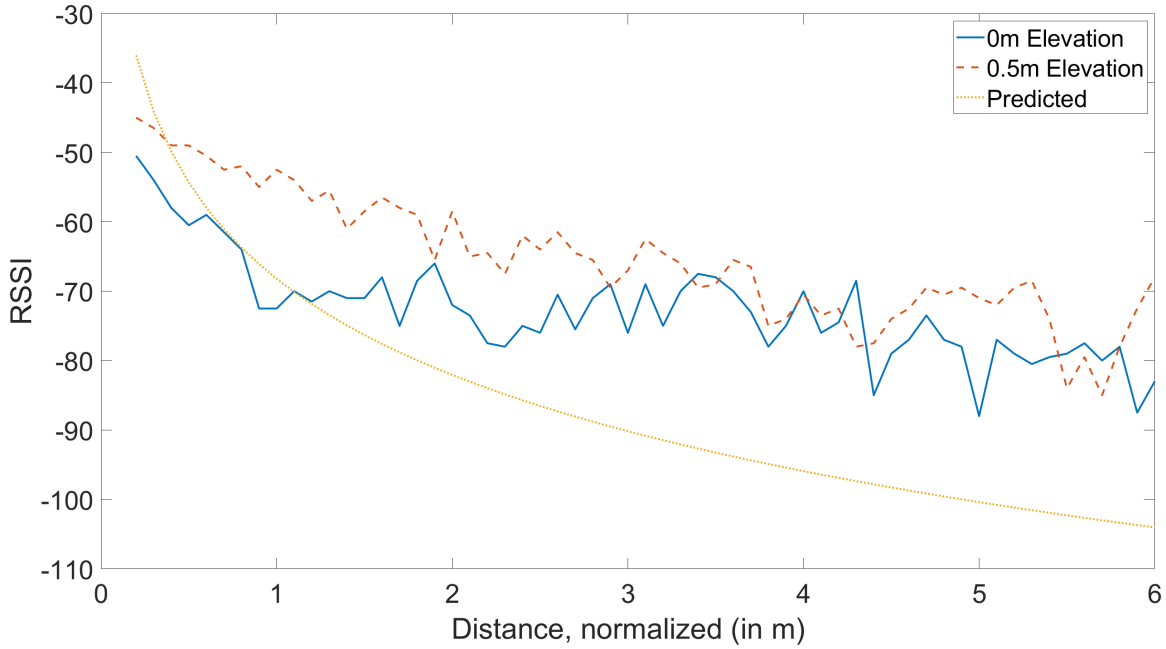

Figure 32: Fitbit Charge Elevation Comparison, Home Environment

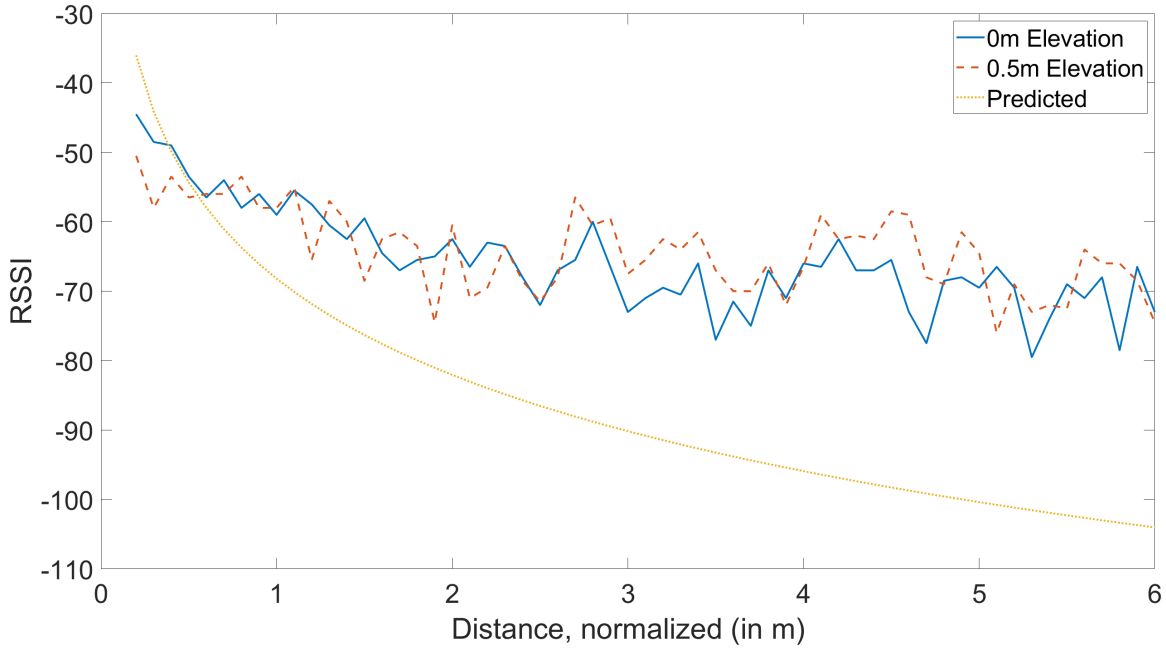

Figure 33: Fitbit Charge Elevation Comparison, Office Environment

Figure 34, Figure 35, and Figure 36 show the actual and predicted results of the Dog & Bone Lock with and without added elevation in the disaster, home, and office

environments respectively. The disaster environment had the strongest impact across the three environments with the receive device at 0.5 m in height, having stronger values at nearly every measurement. The home and office environments showed a negligible difference with and without the height difference, although the values are stronger in the 0.5 m experiment. Table 11 shows the average measured RSSI values at various points, as well as the means.

Table 11: Dog & Bone Lock Average RSSI Values

	Disaster		Home		Office	
Distance	0 m	0.5 m	0 m	0.5 m	0 m	0.5 m
0.1 m	-73.5	-69.5	-65	-72	-71	-68
1 m	-75	-80	-84	-72.5	-79.5	-89
2 m	-93.5	-82.5	-85.5	-90.5	-81	-87.5
3 m	-91	-84.5	-89	-87	-85	-87.5
4 m	-97	-90	-94.5	-87	-88.5	-85
5 m	-98	-96.5	-94	-90	-92.5	-85
6 m	-97	-96	-97	-97	-91	-80.5
mean	-90.7	-85.0	-88.3	-87.5	-85.8	-84.3

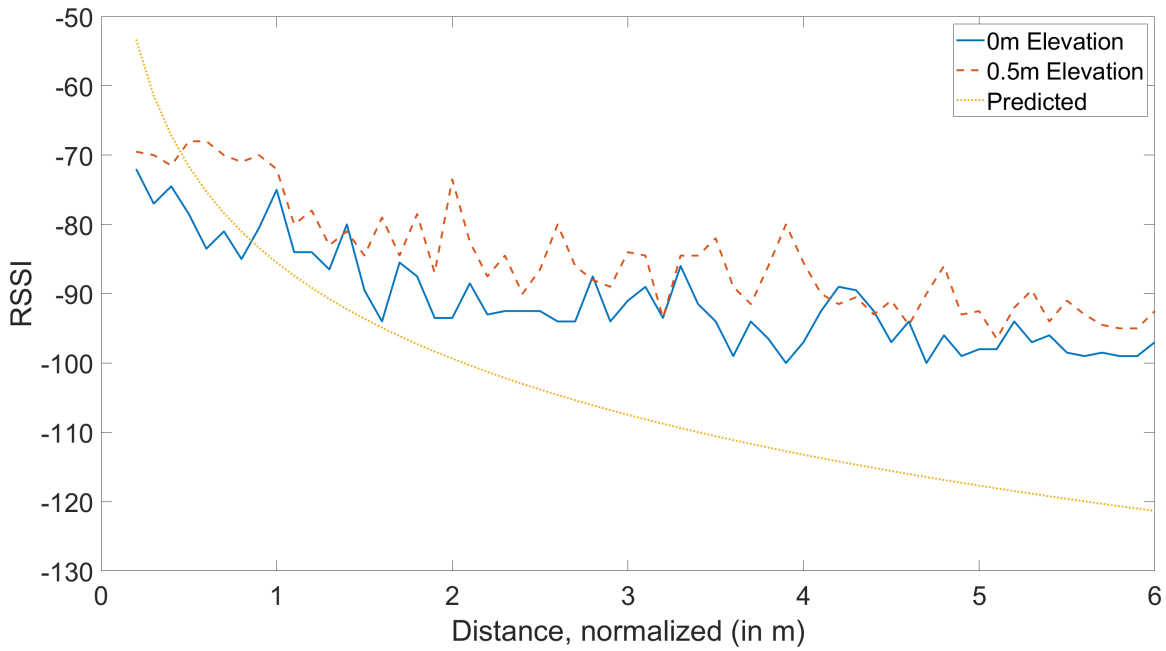

Figure 34: Dog & Bone Lock Elevation Comparison, Disaster Environment

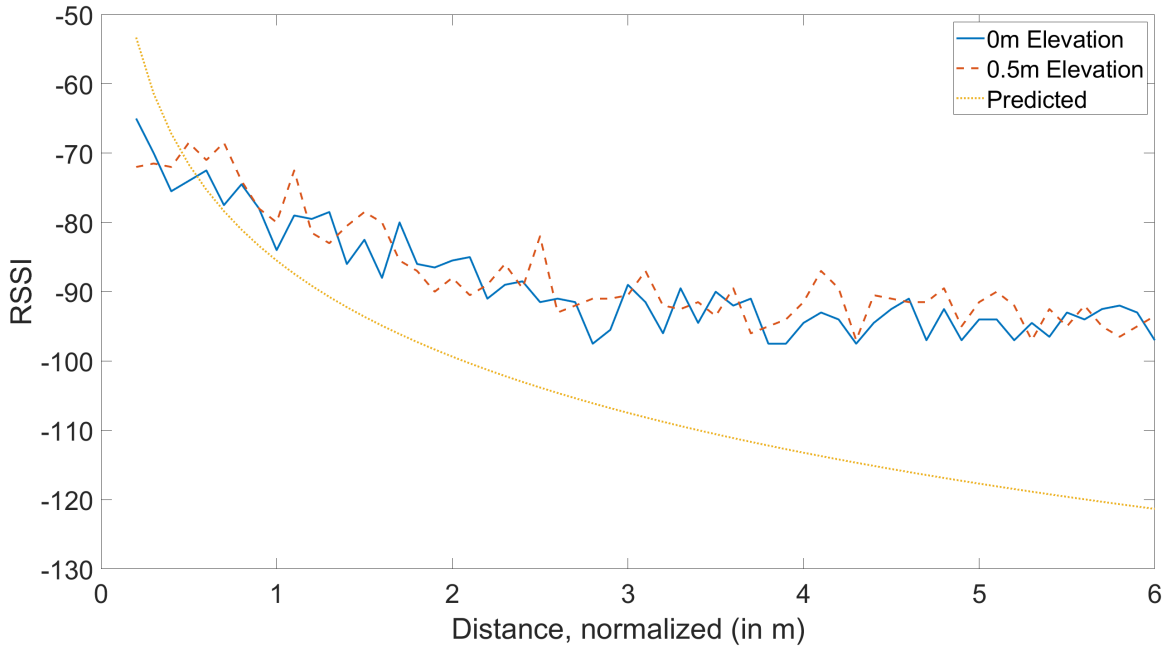

Figure 35: Dog & Bone Lock Elevation Comparison, Home Environment

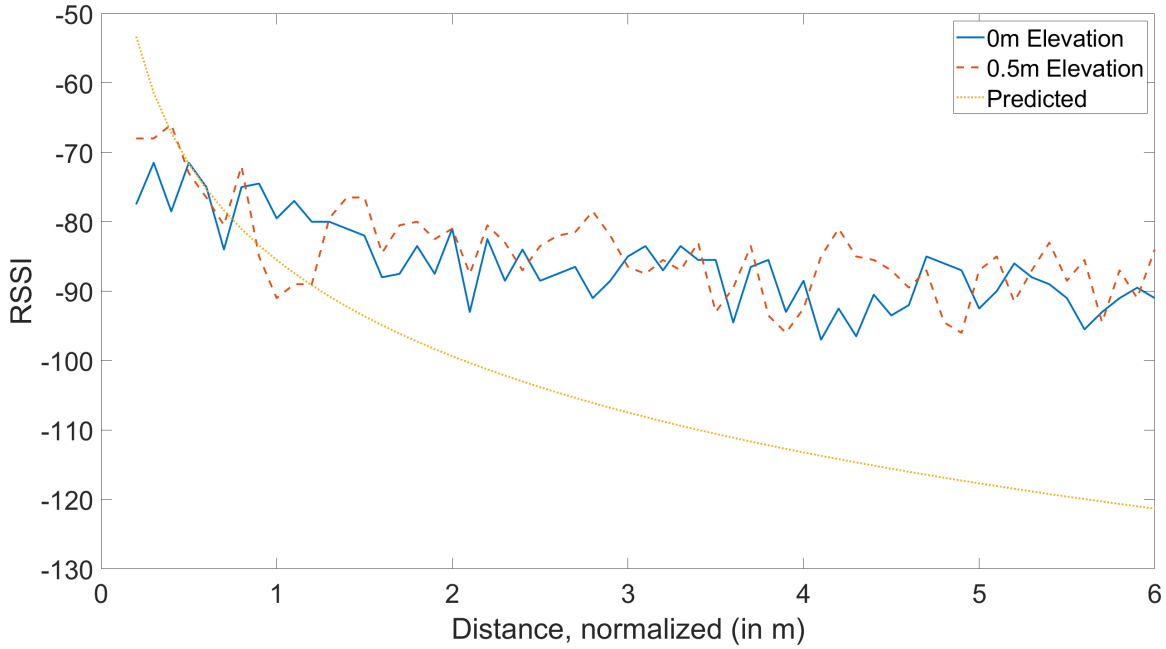

Figure 36: Dog & Bone Lock Elevation Comparison, Office Environment

Figure 37, Figure 38, and Figure 39 show the actual and predicted results of the iBluLock smartlock with and without added elevation in the disaster, home, and office environments respectively. Stronger values are recorded for all three environments in the 0.5 m experiment. The most notable difference is in the disaster environment, potentially as a result of the measurement at 3.3 m being significantly higher than expected. Table 12 shows the average measured RSSI values at various points, as well as the means.

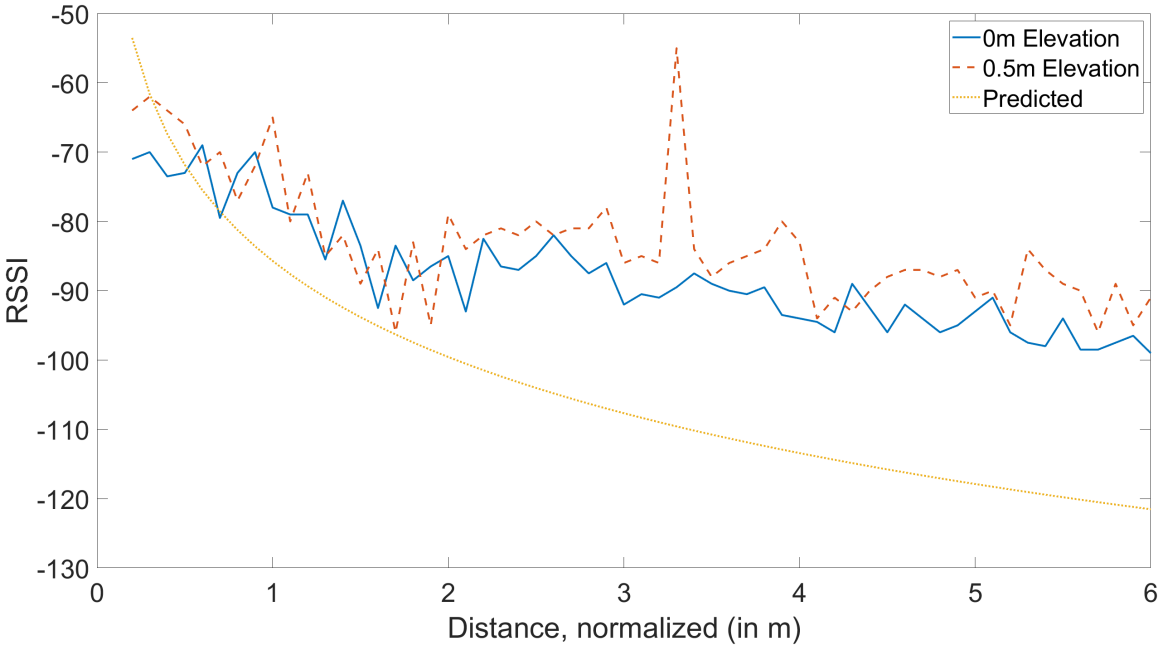

Figure 37: iBluLock Elevation Comparison, Disaster Environment

Table 12: iBluLock Average RSSI Values

	Disaster		Home		Office	
Distance	0 m	0.5 m	0 m	0.5 m	0 m	0.5 m
0.1 m	-66	-64	-61.5	-61	-63.5	-63.5
1 m	-78	-80	-77.5	-75.5	-79	-77.5
2 m	-85	-84	-80.5	-82.5	-78	-76.5
3 m	-92	-85	-93	-80.5	-86	-86.5
4 m	-94	-94	-87	-84	-89.5	-90.5
5 m	-93	-90	-89.5	-83.5	-88	-86.5
6 m	-99	-73	-91	-96.5	-87.5	-80.5
mean	-87.3	-82.8	-82.7	-80.8	-81.7	-80.4

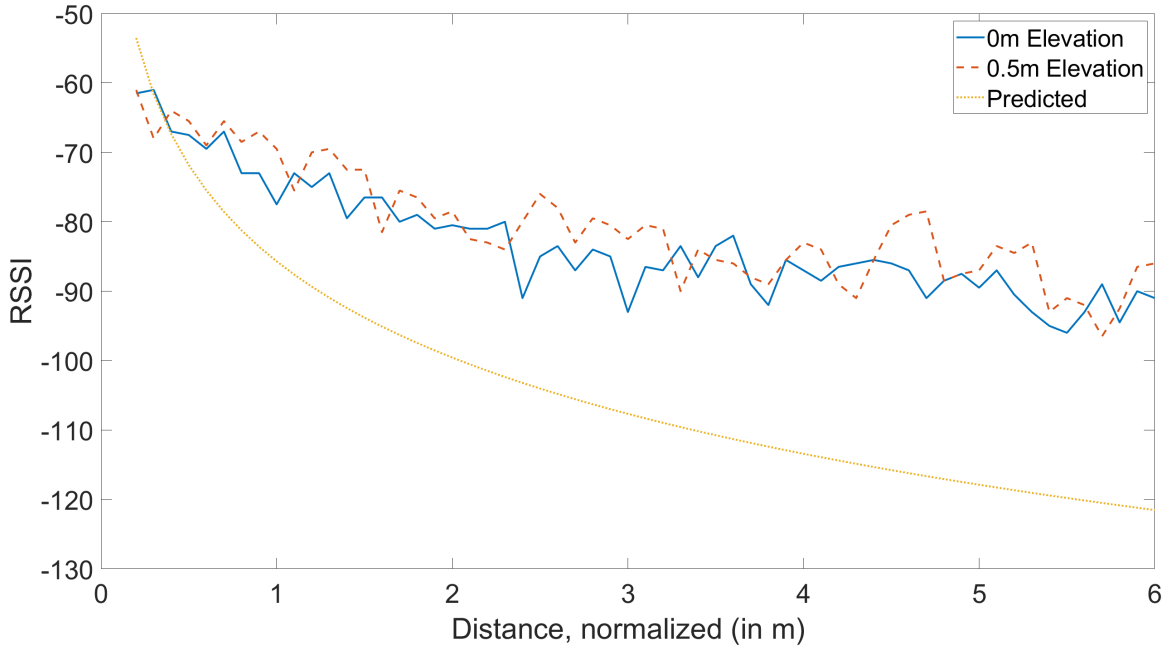

Figure 38: iBluLock Elevation Comparison, Home Environment

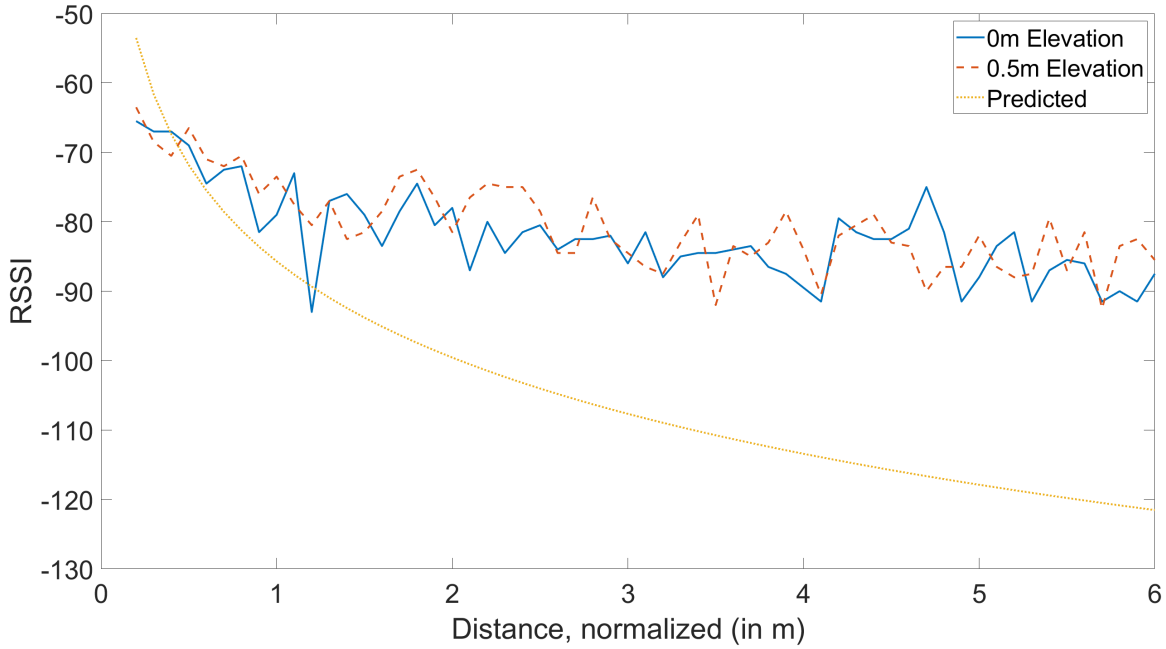

Figure 39: iBluLock Elevation Comparison, Office Environment

Figure 40, Figure 41, and Figure 42 show the actual and predicted results of the Master Lock with and without added elevation in the disaster, home, and office environments respectively. In the disaster and home environments, nearly every measurement is stronger in the 0.5 m experiment. However, unlike nearly every other result, the values in the office environment are weaker in the 0.5 m experiment, albeit negligibly so. Table 13 shows the average measured RSSI values at various points, as well as the means.

Table 13: Master Lock Average RSSI Values

	Disaster		Home		Office	
Distance	0 m	0.5 m	0 m	0.5 m	0 m	0.5 m
0.1 m	-67	-60	-76	-54	-58.5	-63
1 m	-77.5	-79	-83.5	-65	-72.5	-80.5
2 m	-84	-75.5	-93	-77.5	-73	-78.5
3 m	-87.5	-80.5	-83	-82	-88	-77
4 m	-92	-88	-84.5	-89	-84	-82.5
5 m	-98	-93.5	-88	-89	-85	-89
6 m	-97	-87	-94	-92	-82.5	-80.5
mean	-86.7	-81.1	-85.8	-78.8	-80.2	-80.9

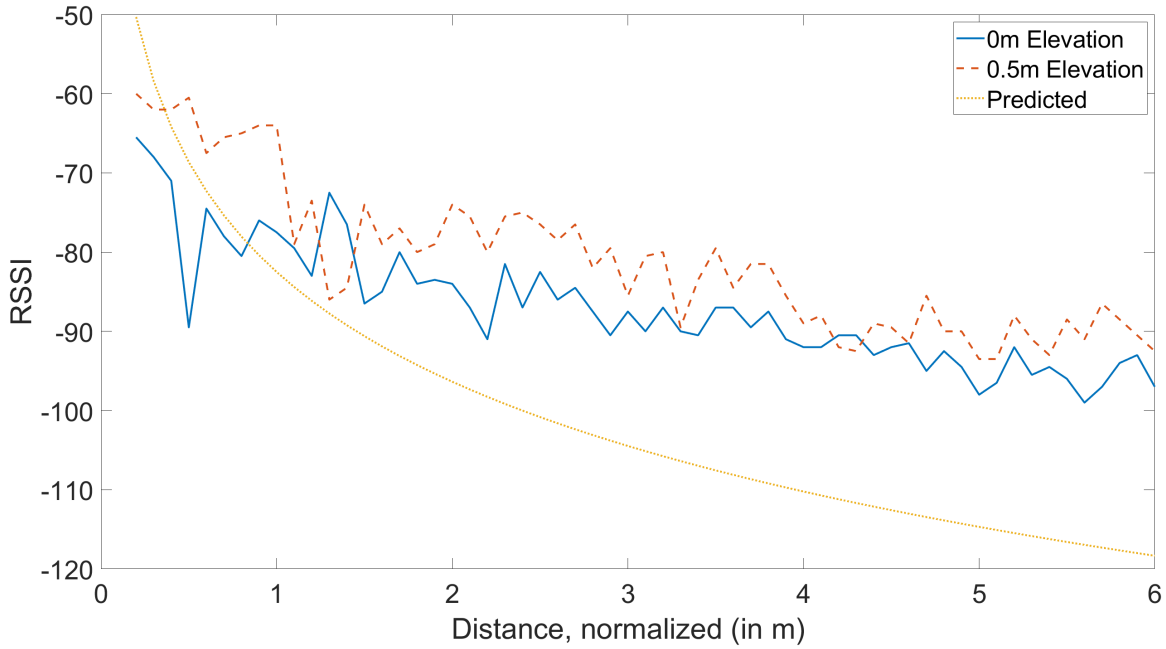

Figure 40: Master Lock Elevation Comparison, Disaster Environment

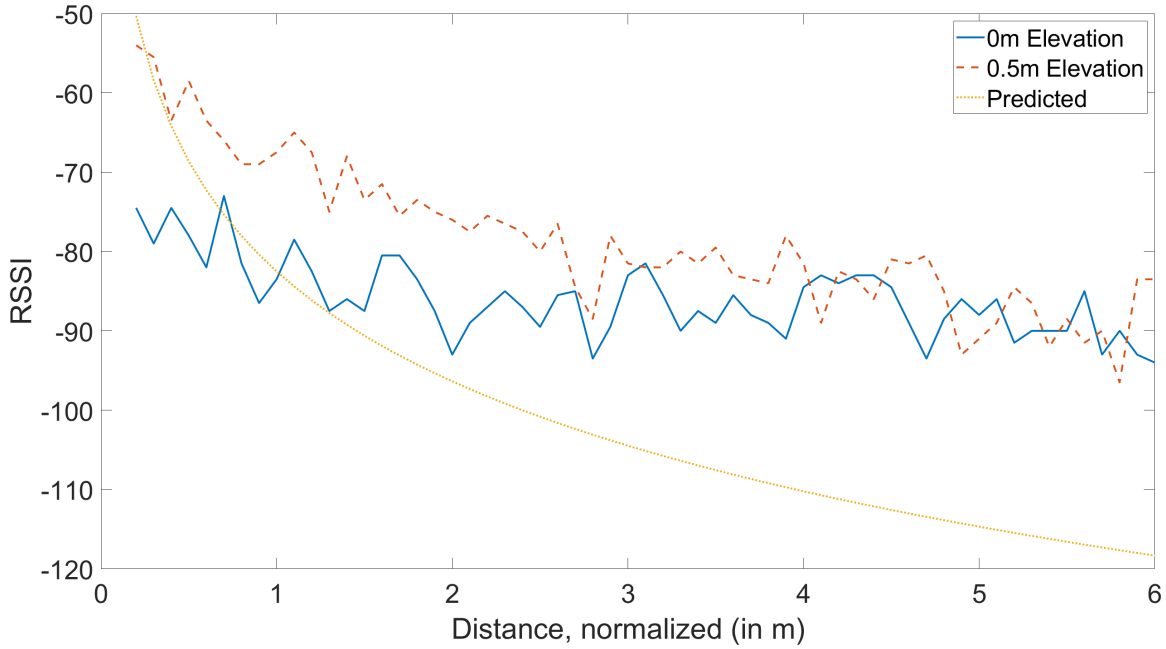

Figure 41: Master Lock Elevation Comparison, Home Environment

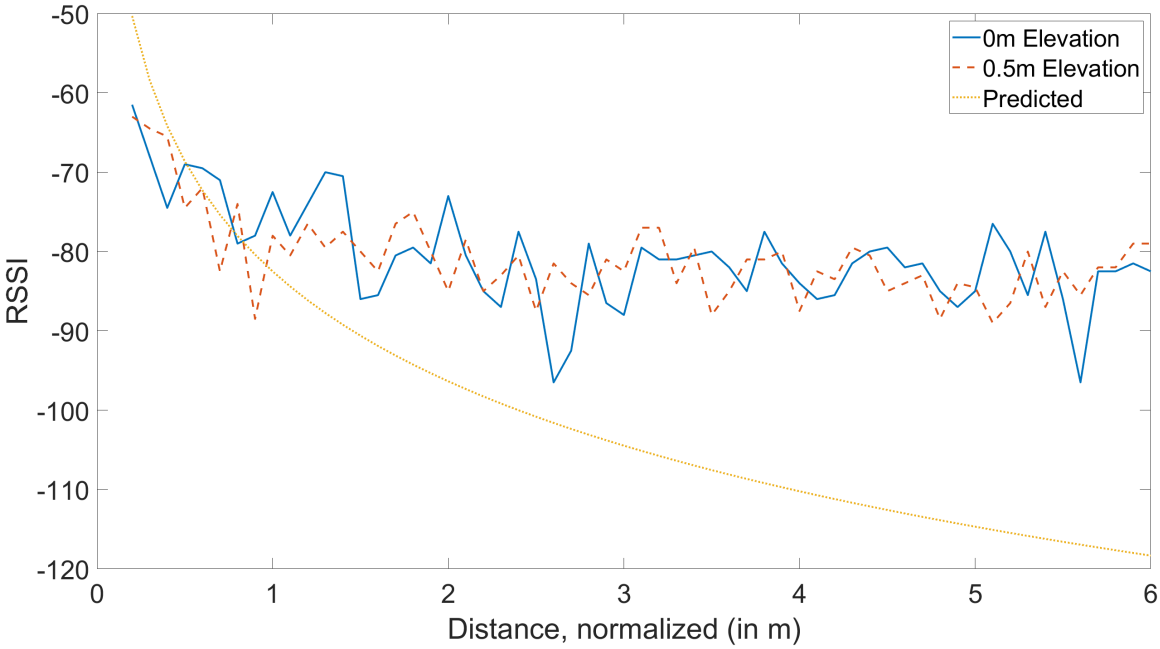

Figure 42: Master Lock Elevation Comparison, Office Environment

Figure 43, Figure 44, and Figure 45 show the actual and predicted results of the Motorola Moto E (2nd Gen.) with and without added elevation in the disaster, home, and office environments respectively. The biggest difference is measured in the disaster environment, with nearly every individual measurement being stronger in the 0.5 m experiment. The home and office environments are more mixed throughout the measurements, but the 0.5 m experiment is stronger by about 2 decibels (dB) in both environments. Table 14 shows the average measured RSSI values at various points, as well as the means.

Table 14: Motorola Moto E. (2nd Gen.) Average RSSI Values

	Disaster		Home		Office	
Distance	0 m	0.5 m	0 m	0.5 m	0 m	0.5 m
0.1 m	-48.5	-51.5	-55	-53	-44	-57
1 m	-67	-52.5	-60.5	-57.5	-54.5	-55.5
2 m	-66.5	-61	-69	-63	-71.5	-57.5
3 m	-70	-70.5	-65.5	-63	-69.5	-59
4 m	-81.5	-66.5	-66	-61.5	-72.5	-65
5 m	-76.5	-67	-68.5	-73	-67.5	-69.5
6 m	-92	-70	-74.5	-74	-72.5	-72
mean	-69.7	-64.2	-66.5	-64.8	-64.5	-62.7

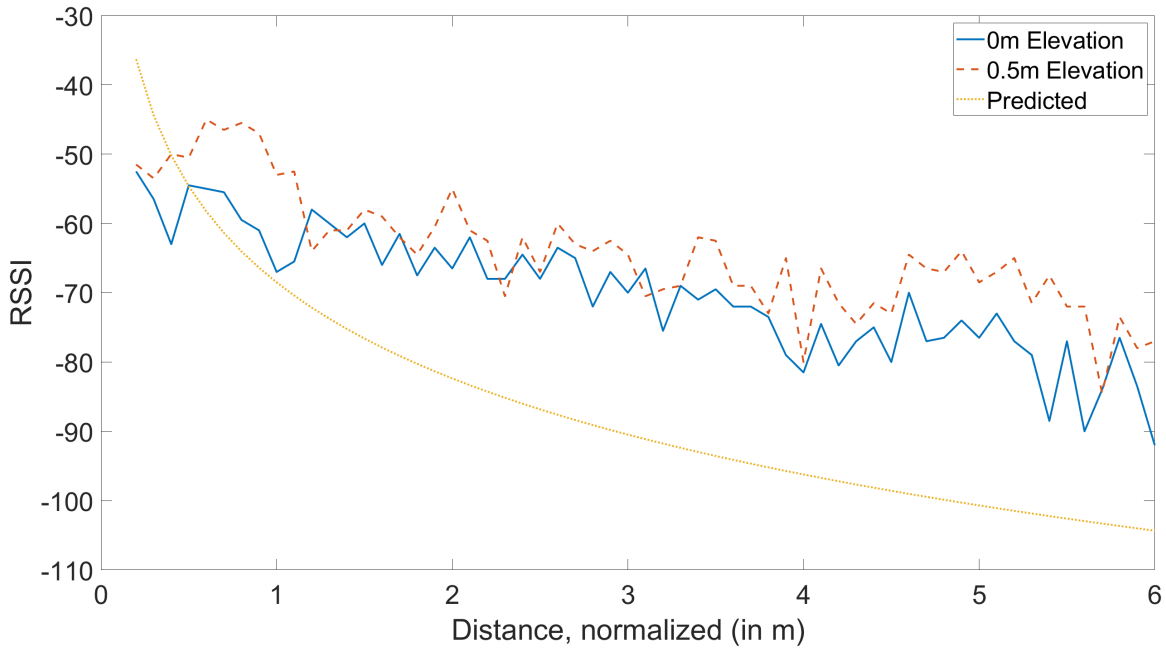

Figure 43: Motorola Moto E (2nd Gen.) Elevation Comparison, Disaster Environment

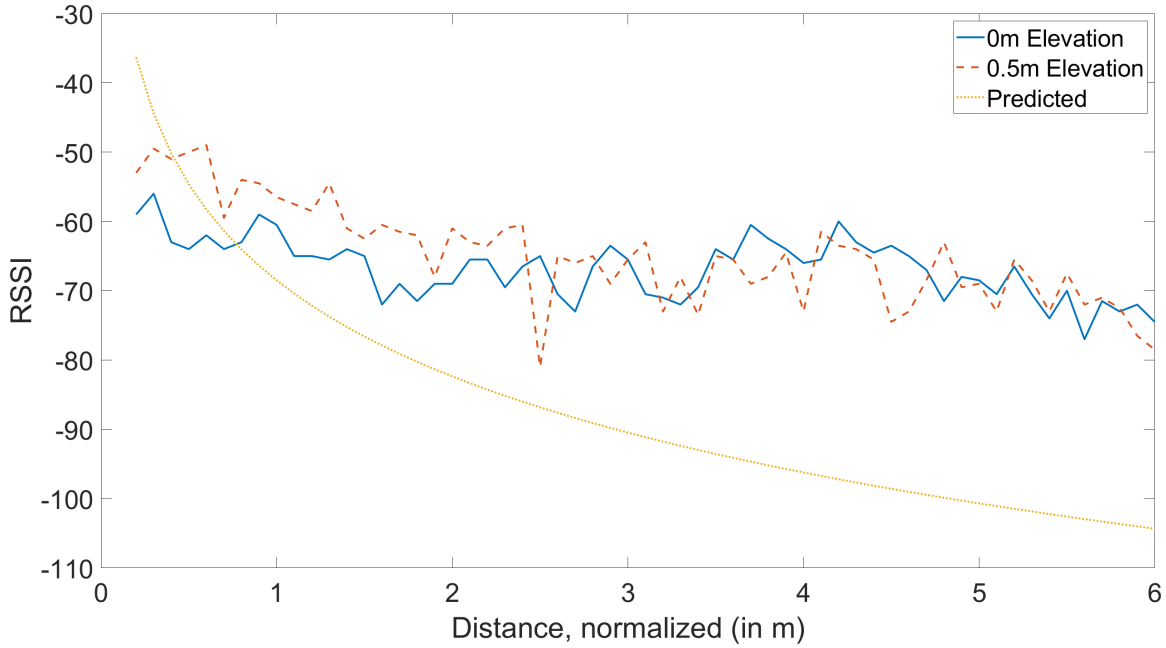

Figure 44: Motorola Moto E (2nd Gen.) Elevation Comparison, Home Environment

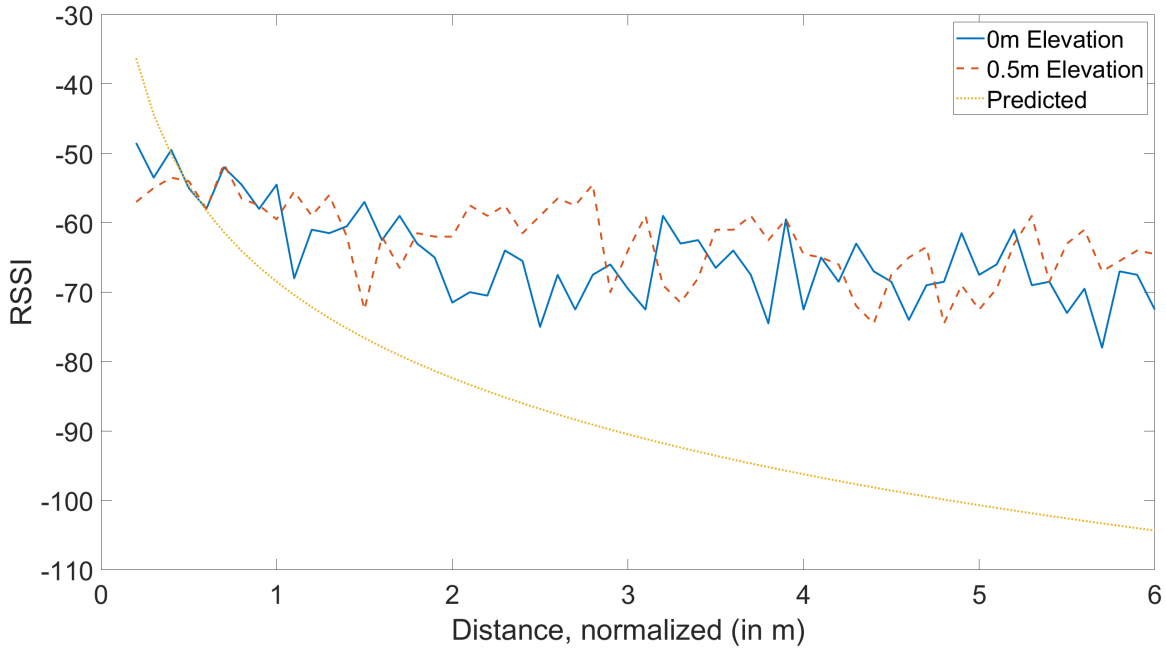

Figure 45: Motorola Moto E (2nd Gen.) Elevation Comparison, Office Environment

Figure 46, Figure 47, and Figure 48 show the actual and predicted results of the Quicklock smartlock with and without added elevation in the disaster, home, and office environments respectively. In all three environments, the 0.5 m measurements are stronger at nearly every point, especially in the disaster environment. Table 15 shows the average measured RSSI values at various points, as well as the means.

Table 15: Quicklock Average RSSI Values

	Disaster		Home		Office	
Distance	0 m	0.5 m	0 m	0.5 m	0 m	0.5 m
0.1 m	-56.5	-54	-54	-45	-51	-52
1 m	-62	-60.5	-65.5	-59.5	-65	-60
2 m	-75	-61	-69	-67.5	-62.5	-66
3 m	-82	-69	-74	-71	-74.5	-67.5
4 m	-83.5	-73.5	-73	-70	-77.5	-78.5
5 m	-82	-81.5	-77.5	-77.5	-78.5	-66.5
6 m	-87.5	-77.5	-80	-76.5	-81.5	-81.5
mean	-76.5	-70.8	-72.3	-68.8	-72.2	-66.0

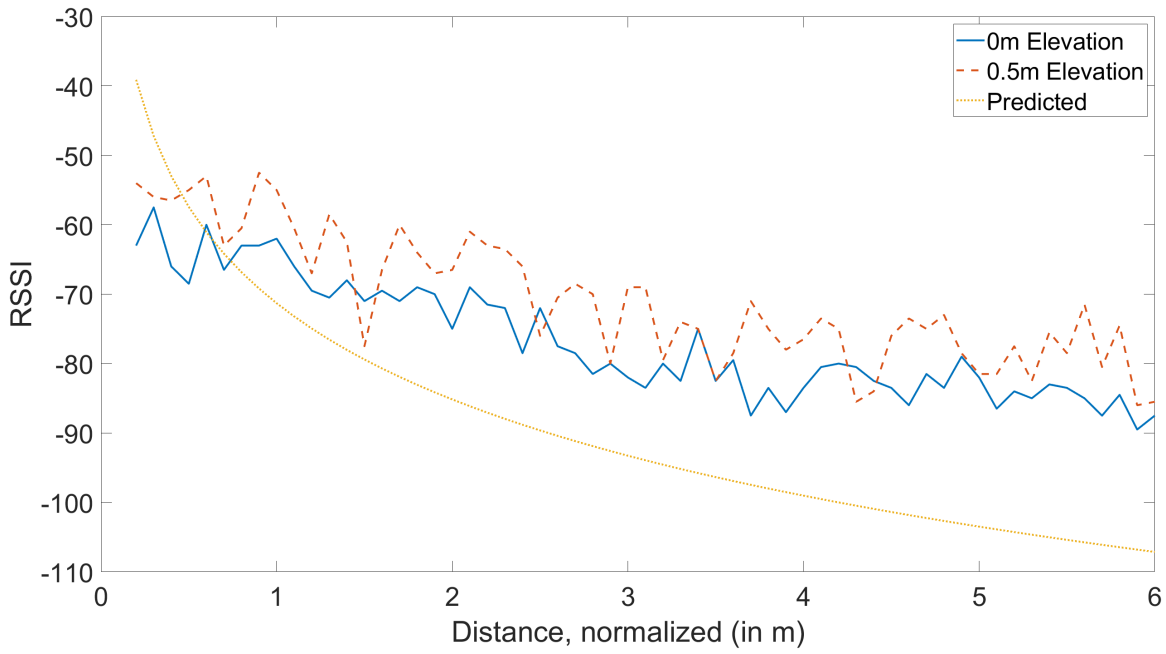

Figure 46: Quicklock Elevation Comparison, Disaster Environment

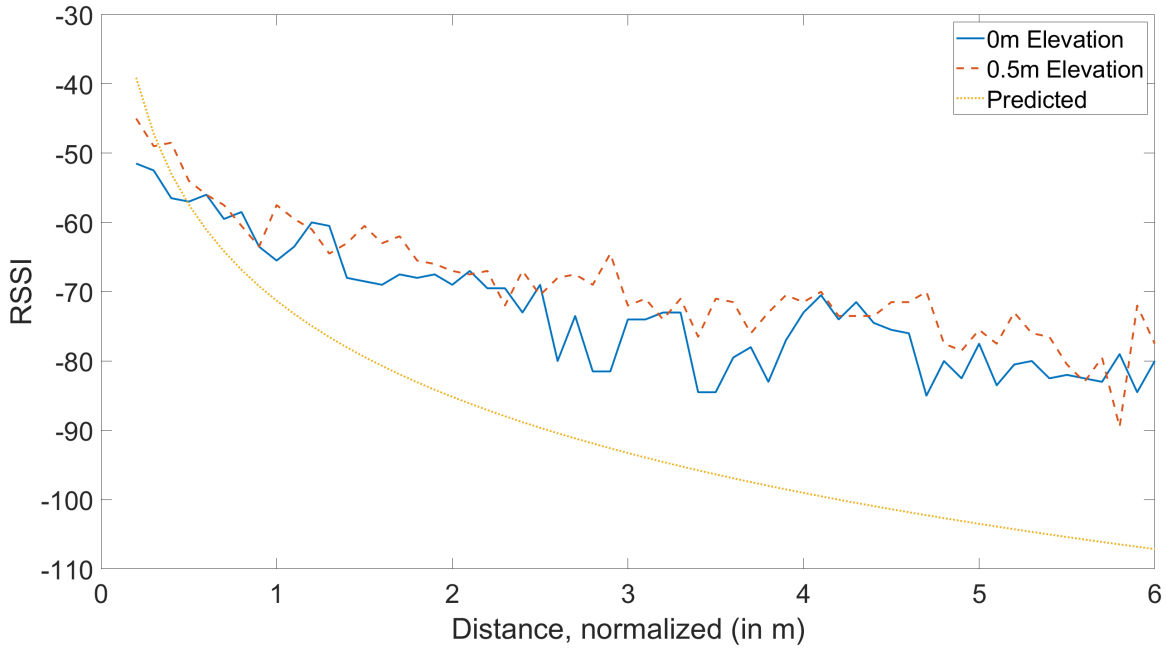

Figure 47: Quicklock Elevation Comparison, Home Environment

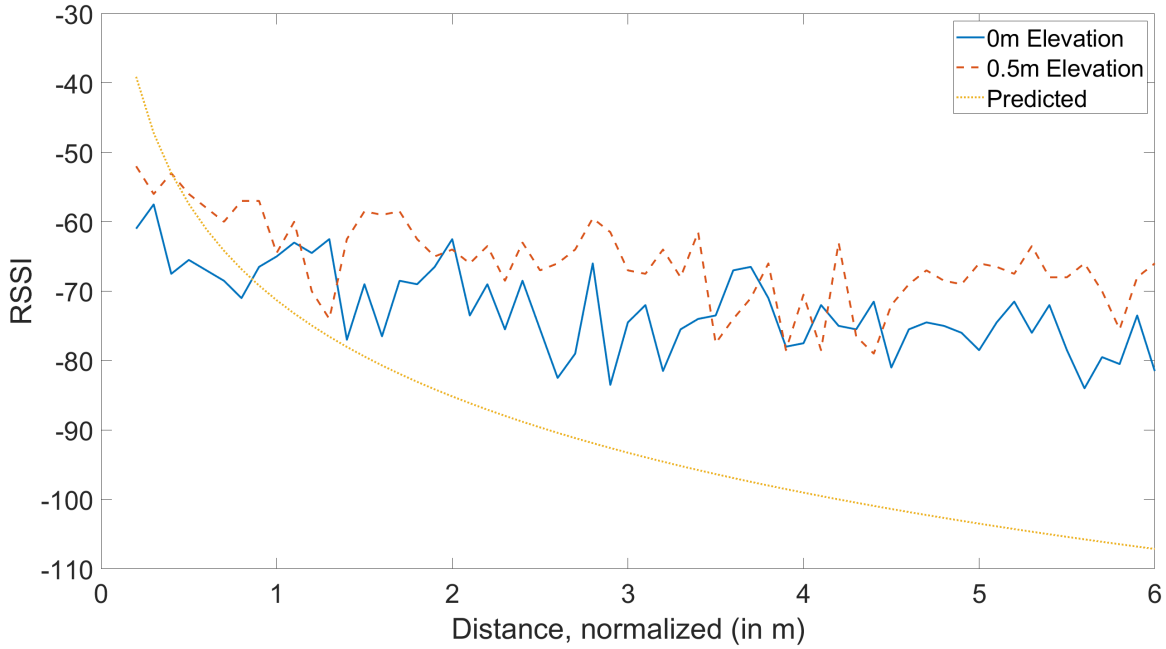

Figure 48: Quicklock Elevation Comparison, Office Environment

Figure 49, Figure 50, and Figure 51 show the actual and predicted results of the Samsung S7 with and without added elevation in the disaster, home, and office environments respectively. The results are similar to the Master Lock in that the disaster and home environments showed marked stronger measurements in the 0.5 m experiment, but the office environment is slightly weaker on average. The disaster and home environments showed stronger measurements at nearly every point, while the office environment had stronger measurements with elevation until 3.4 m in distance, at which point they become weaker on average. Table 16 shows the average measured RSSI values at various points, as well as the means.

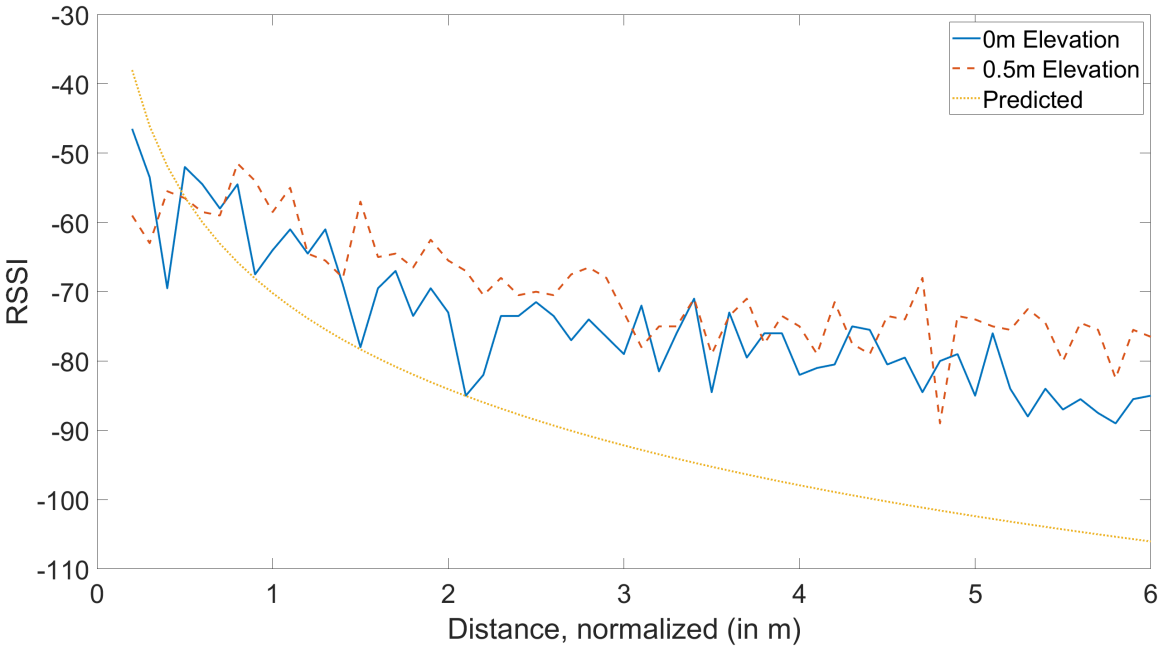

Figure 49: Samsung S7 Elevation Comparison, Disaster Environment

Table 16: Samsung S7 Average RSSI Values

	Disaster		Home		Office	
Distance	0 m	0.5 m	0 m	0.5 m	0 m	0.5 m
0.1 m	-49.5	-59	-61.5	-56	-43.5	-56
1 m	-64	-55	-66.5	-56	-51.5	-53.5
2 m	-73	-67	-65	-69	-63.5	-64.5
3 m	-79	-78	-70	-74	-65.5	-68.5
4 m	-82	-79	-76.5	-68	-67	-73
5 m	-85	-75	-78	-69	-68	-71
6 m	-85	-76	-77.5	-76	-69.5	-67
mean	-74.0	-69.8	-69.5	-66.0	-64.8	-65.0

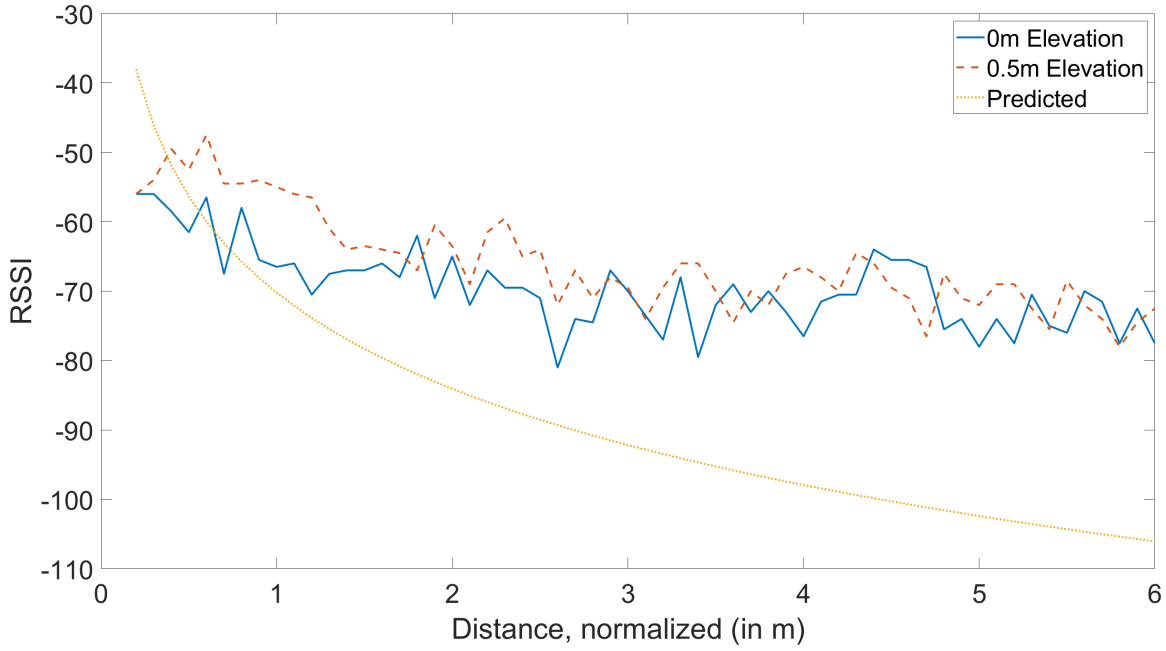

Figure 50: Samsung S7 Elevation Comparison, Home Environment

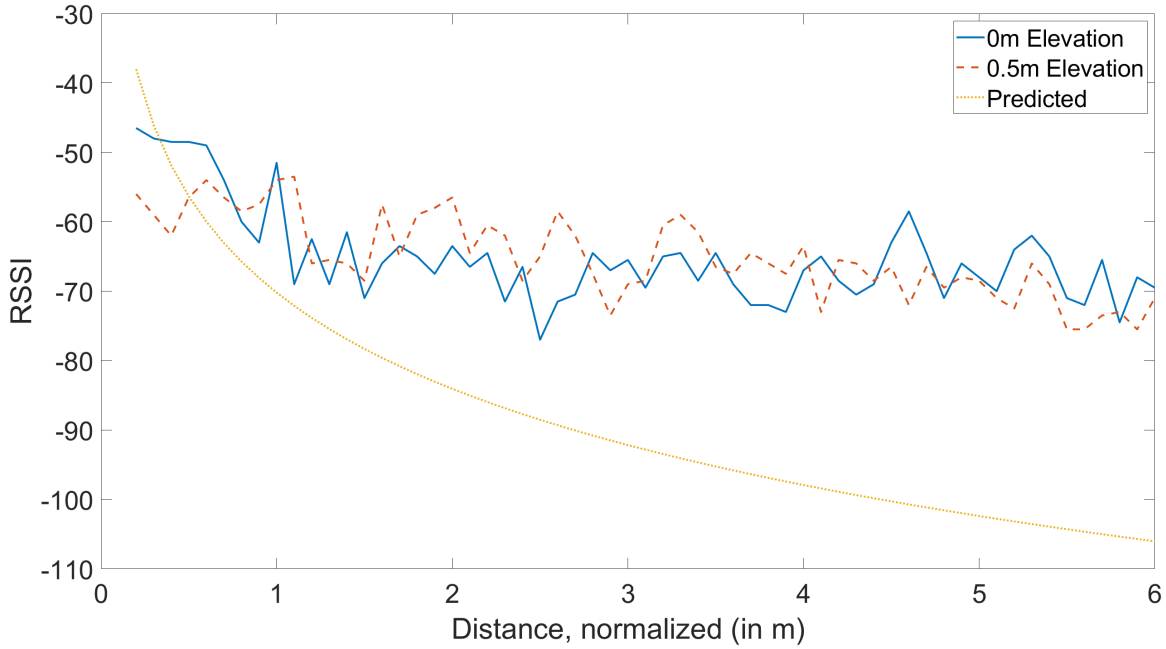

Figure 51: Samsung S7 Elevation Comparison, Office Environment

Figure 52, Figure 53, and Figure 54 show the actual and predicted results of the Samsung S8 with and without added elevation in the disaster, home, and office environments respectively. The results are stronger in all environments in the 0.5 m experiment, with the strongest improvement occurring in the disaster environment. In the disaster environment, nearly every measurement is stronger in the 0.5 m experiment. Table 17 shows the average measured RSSI values at various points, as well as the means.

Table 17: Samsung S8 Average RSSI Values

	Disaster		Home		Office	
Distance	0 m	0.5 m	0 m	0.5 m	0 m	0.5 m
0.1 m	-52	-57	-50	-50	-44	-59.5
1 m	-67	-77	-71	-57.5	-59	-58
2 m	-79	-68	-75.5	-64	-73	-64
3 m	-78	-72.5	-72	-70.5	-70.5	-65
4 m	-77.5	-70	-70.5	-69.5	-66.5	-68
5 m	-88.5	-75.5	-84	-67.5	-71	-77.5
6 m	-89.5	-82	-85	-77.5	-70.5	-72
mean	-76.4	-69.4	-72.3	-67.4	-67.0	-65.6

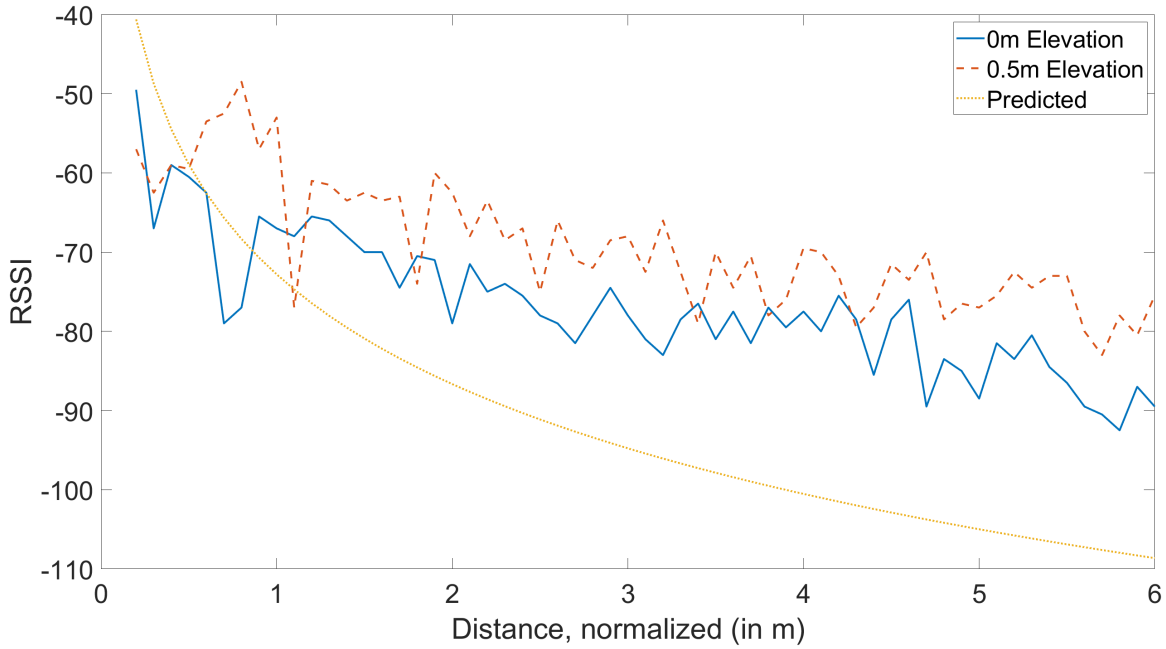

Figure 52: Samsung S8 Elevation Comparison, Disaster Environment

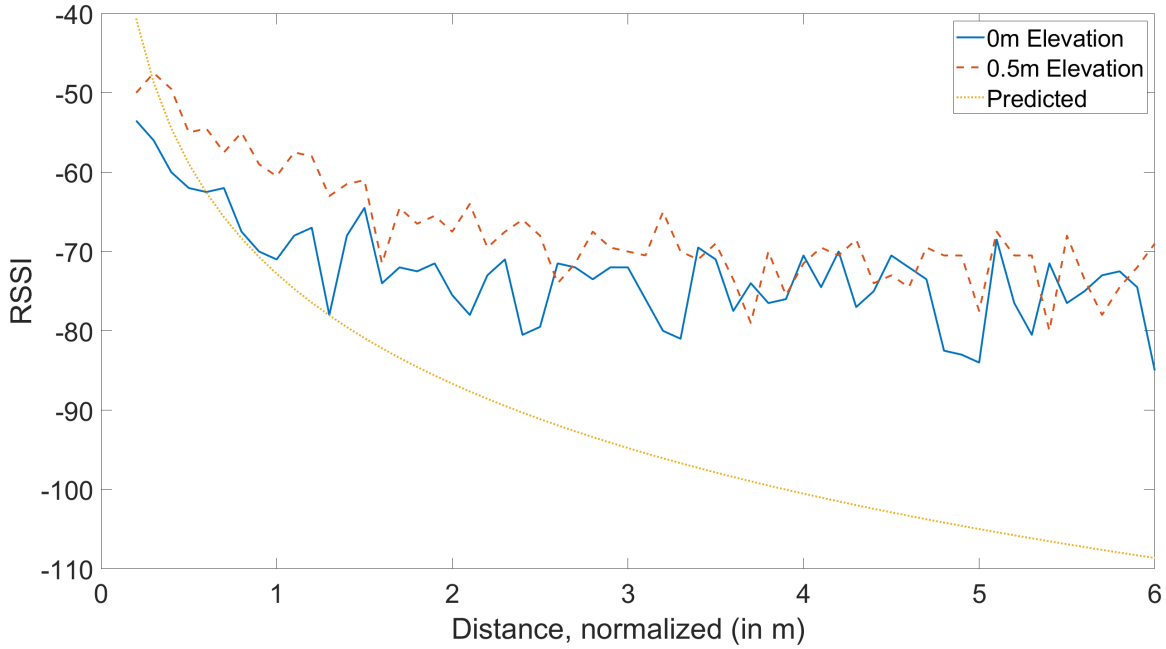

Figure 53: Samsung S8 Elevation Comparison, Home Environment

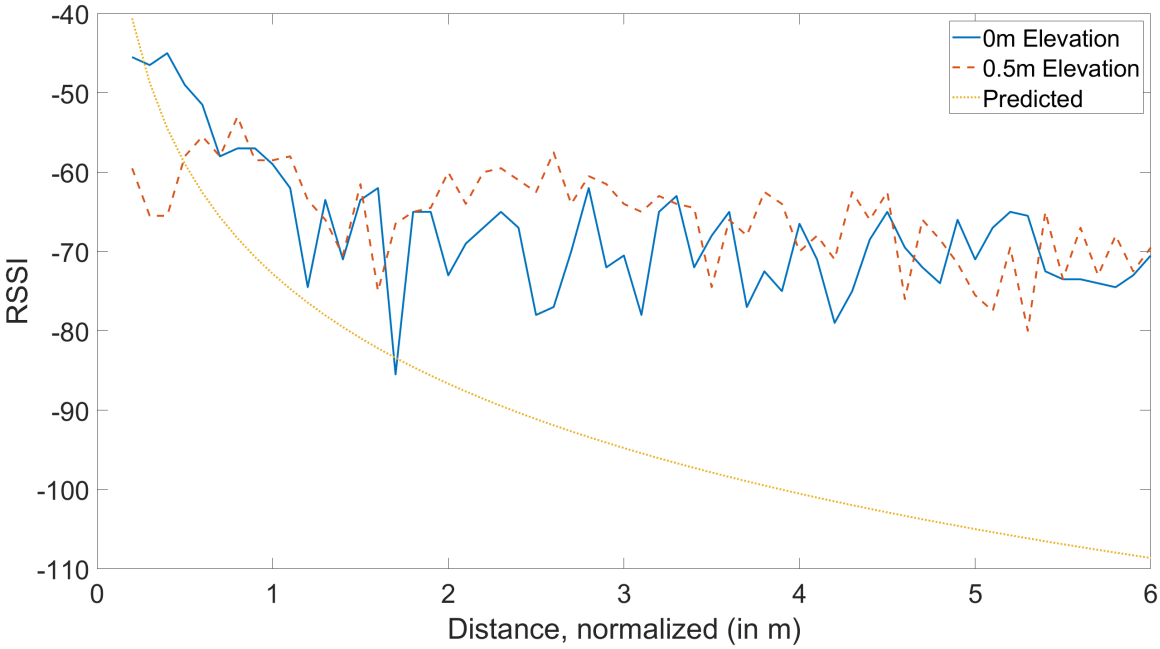

Figure 54: Samsung S8 Elevation Comparison, Office Environment

Figure 55, Figure 56, and Figure 57 show the actual and predicted results of the Fitbit Surge with and without added elevation in the disaster, home, and office environments respectively. The RSSI measurements are stronger in the office and disaster environments, with no individual average measurement in the 0.5 m experiment being weaker than in the experiment without additional elevation. This device is also the only one with a weaker average measurement in the home environment in the 0.5 m experiment, although marginally so. Table 18 shows the average measured RSSI values at various points, as well as the means.

Table 18: Fitbit Surge Average RSSI Values

	Disaster		Home		Office	
Distance	0 m	0.5 m	0 m	0.5 m	0 m	0.5 m
0.1 m	-51	-58	-53	-45	-39.5	-54.5
1 m	-66	-53	-61.5	-73	-59	-63
2 m	-70	-57.5	-67.5	-71.5	-70	-67
3 m	-75	-73.5	-68.5	-83.5	-67.5	-65
4 m	-79.5	-74.5	-76	-74.5	-72.5	-64.5
5 m	-86	-75	-79	-83.5	-65	-73.5
6 m	-89	-69.5	-84.5	-73.5	-79.5	-78
mean	-75.1	-64.9	-71.1	-71.4	-67.2	-65.7

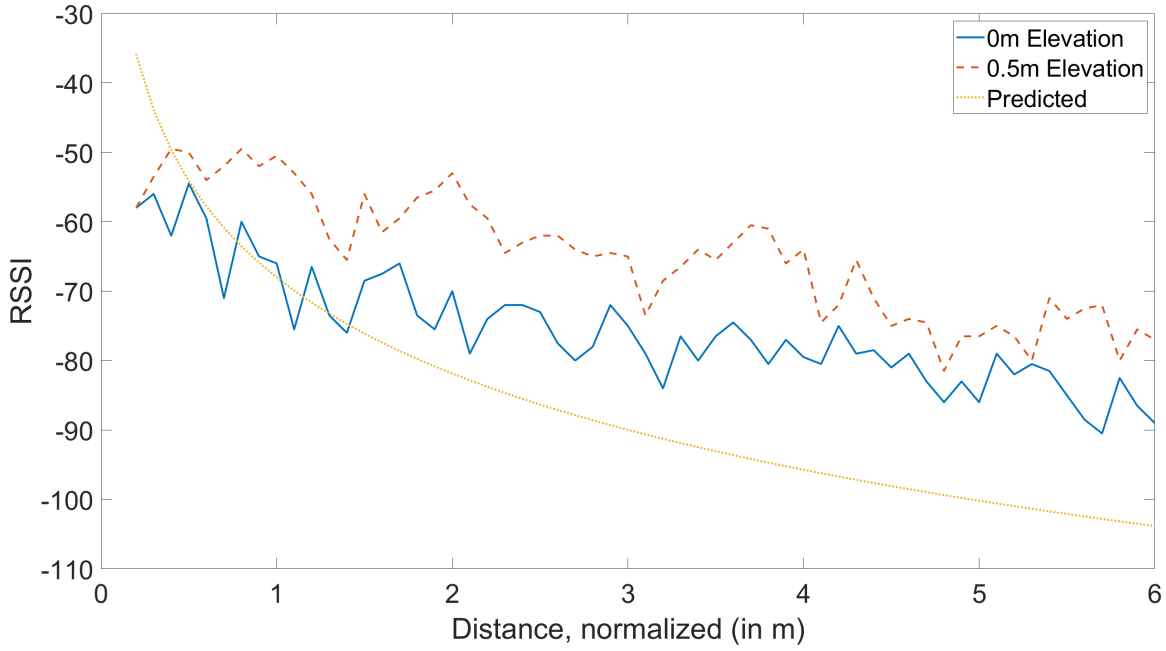

Figure 55: Fitbit Surge Elevation Comparison, Disaster Environment

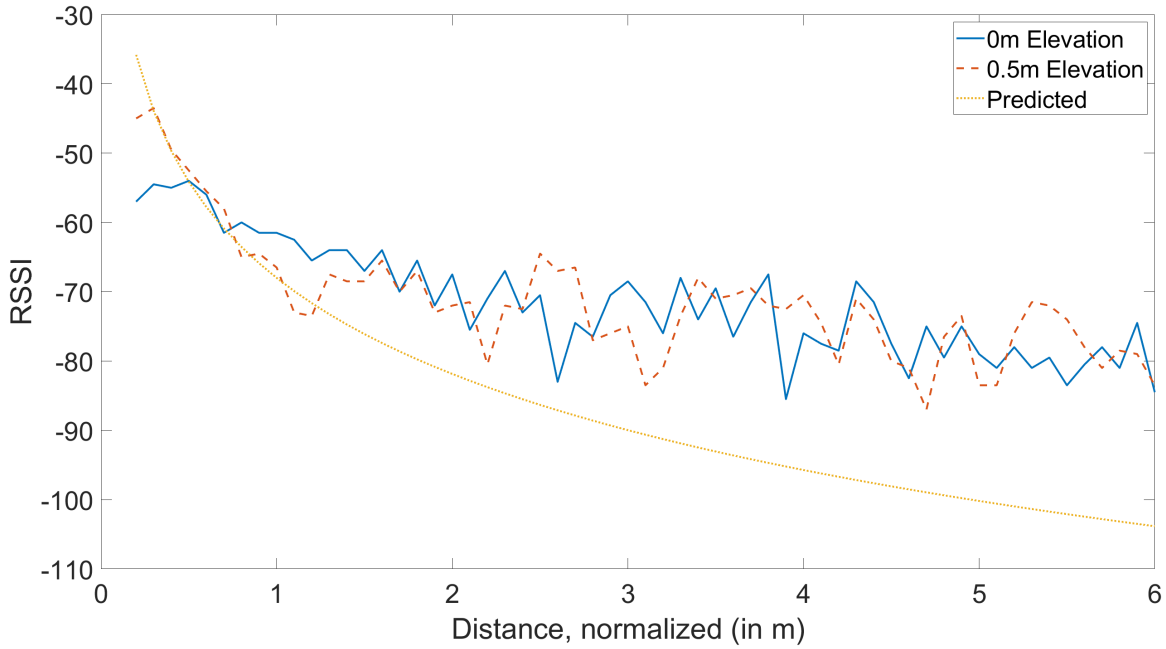

Figure 56: Fitbit Surge Elevation Comparison, Home Environment

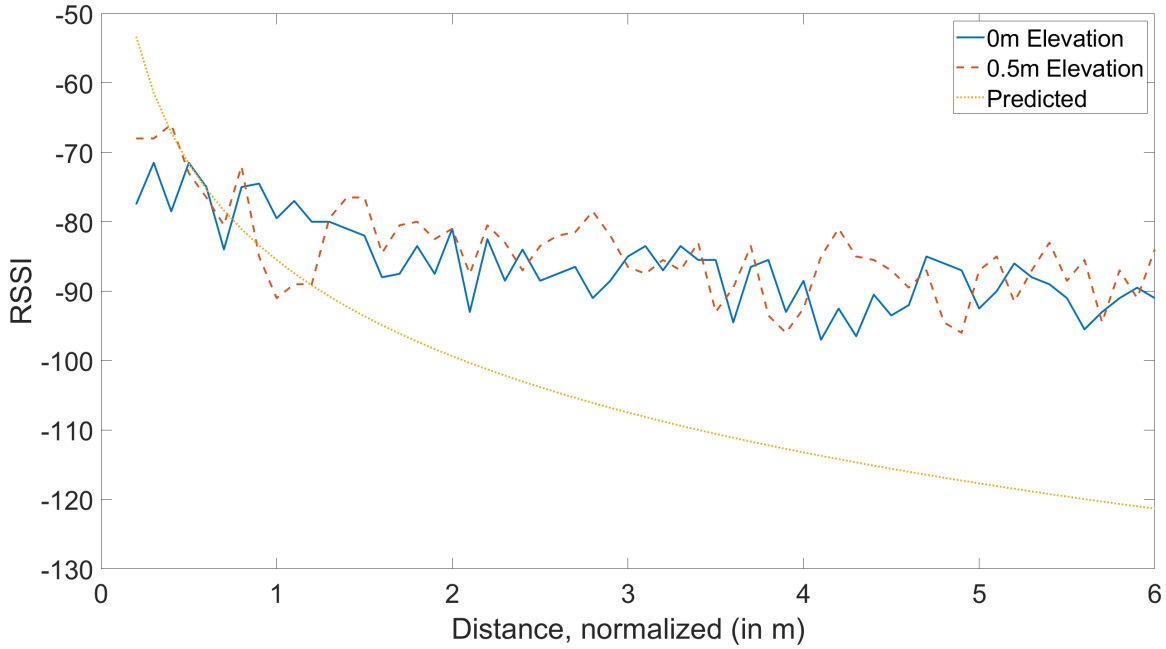

Figure 57: Fitbit Surge Elevation Comparison, Office Environment

5.5 Distance Estimation

A key intention of this research is to convert the RSSI values to distances without knowing anything about the device. However, as other research proved that to be impossible already, a minimum amount of information is utilized, specifically the transmit power of each device as noted in Section 4.5. As expected, the measurements are unreliable for most practical uses. The figures in Section 5.4 show the measured and predicted RSSI values of each device in each environment. Since the distance estimation equation has only a couple static values, the total value becomes more influenced by the values that can change, namely the RSSI values and the distance values, depending on which direction the equation is going. Consequently, the distance prediction decreases too quickly, causing significant discrepancies as the distance increases.

As can be seen in every prediction, the predicted values stray away from the data by 2 m in distance and continue decreasing sharply while the measured RSSI values decrease gradually, causing the predicted value at 6 m to be off by between 20-30 dB from the measured values. This result is especially significant in any attempts to use Bluetooth distance estimation at large distances. For example, by examining Figure 54, attempting to predict the location of a transmit device with a signal strength of -65 RSSI should be just under 1 m away, according to the distance estimation formula. However, measured results indicate that the device could equally likely be anywhere from half a meter to over 5.5 m away. This result means that without a strong and reliable filter or formula, it is unlikely for Bluetooth RSSI measurements to be accurately usable for distance estimation, especially in a device-agnostic manner with no prior information about the transmit device.

5.6 Raw Data

The entirety of the raw data is available in Appendix A.

VI. Conclusions

6.1 Overview

Section 6.2 restates the current state of casualty recovery in a first-responder environment used to frame this research. section 6.3 highlights the conclusions and significance of this research. Section 6.4 notes the limitations and assumptions in this research. Section 6.5 outlines future work that could further expand on Bluetooth distance estimation and device enumeration for use in a first-responder environment.

6.2 Current State

When first responders need to locate casualties in a disaster environment, time is crucial. The faster first responders can locate a casualty, the higher the likelihood of the victim getting medical attention and surviving the incident with minimal lasting injuries. However, some scenarios inhibit the use of sight or other sources of imaging to locate casualties. By making use of the Bluetooth spectrum and devices that people already have on their bodies, first responders may be able to locate some victims much faster.

6.3 Research Conclusions and Significance

This research examined four questions:

1. Are advertising packets reliable enough to determine the identity of a transmitting device?

2. Can an accurate distance between two devices be calculated without assuming antenna strength of either device?

3. Does elevation between two devices have a disproportionate impact in calculating the Received Signal Strength Indicator (RSSI) values when compared to the total distance?

4. Do the differences in environments have a significant impact on the calculated RSSI values?

The hypothesis is that at least 80% of Bluetooth devices can be successfully enumerated quickly, but cannot be accurately located at distances over one meter using the method applied in this research. Additionally, elevation is not expected to have a disproportionate impact on the signal strength measurements and the environments are expected to have a significant impact on the signal strength measurements.

Advertising packets can be reliable enough to determine the identity of a transmitting device. However, not uniformly so. The data indicates that while the Internet of Things (IoT) devices are all sufficiently enumerated, only one of the smartphones is, and neither of the Fitbit watches. The set of devices used in this research may not be indicative of all Bluetooth-enabled devices in use, but as the goal is to specifically locate devices that would be on a person, advertising packets are not descriptive enough in this research to be used for those devices. The hypothesis is rejected for this aspect of the research.

RSSI is not considered an accurate measurement for distance between Bluetooth devices, as indicated by previous research. However, this research removed a variable from the equation and attempted to simplify the distance predictions using only the transmit power of the devices. In the context of this research, the prediction is accurate if a first responder could take an RSSI measurement, insert it into the distance calculation for that device, and be no more than 0.5 m away. The measurements in this research indicates that the prediction is not accurate after 1 m in nearly all

instances, with no device being accurate after 2 m. The hypothesis is accepted for this aspect of the research.

The elevation between the devices creates a disproportionate impact to the signal strength measurements compared to the overall distance. Raising the receive device to 0.5 m created stronger signals consistently in nearly every scenario when compared to the measurements from the total distance. This effect is likely created by allowing signals to reach the receive device from more directions. Consequently, this impact may be nullified if the receive device is in the hand of a first responder as their body may create measurements more inline with experiments without additional height. The hypothesis is rejected for this aspect of the research.

The environments have a significant impact on the RSSI values, as well. The office environment had the strongest signals between the three environments, likely due to a lack of interference from nearby objects. However, the disaster environment had the most improvement when the receive device was raised to 0.5 m. Both of these results are significant as an office environment could become a disaster environment if, for example, an explosive device is detonated in the room. Additionally, the height difference between the first responder's device and victim's device could vary based on the position of both individuals, the extent of which also depends on the environment. The hypothesis is accepted for this aspect of the research.

There are a number of significant problems in an attempt to use such a system for first responders to identify and locate casualties. First, most devices are not in Bluetooth discoverable mode by default which renders the idea unusable in nearly every situation (see Section 6.4). Second, this research indicates that it is not likely feasible for first responders to discern which Bluetooth devices would be likely to be on a person versus other IoT devices. However, even if a system were developed for paired devices to estimate distances between them using only Bluetooth information,

these results indicate that the distance estimations would vary wildly to the point of being unusable in all but the shortest distances, at which point it is not necessary.

This research highlights some important factors concerning RSSI measurements and the height differential between two devices. The data indicates that in most cases, an elevated device would have higher signal strength readings, the degree of which depends on the actual environment the devices are in. Further, the exact environment makes a significant difference for what the RSSI measurements are. Specifically, areas with multiple sources of observable interference, such as the disaster environment used, may actually serve to strengthen the signal compared to less cluttered environments like the home environment used.

However, this data collected does indicate that RSSI values continue to decrease as the distance between the devices increases. The goal of this research is not precise accuracy, but rather a general range for where a device, and therefore a victim, may be. The best use of this data may simply be for first responders to passively collect data in disasters and, coupled with enumeration to determine the appropriate devices, simply record whether the signal is getting stronger or weaker during a search. This method would not impede practices already utilized and may lead to locating individuals that are trapped behind or under debris of various sources over the course of a rescue effort.

6.4 Limitations of this Research

The most obvious limitations are the number and variety of devices used for testing. It is possible that a wider array of devices could reveal some bias for certain types of transmitters or devices in certain environments that is not noticeable here. Additionally, the height differential stopped at 0.5 m but would provide more insights around 1 m as that is closer to a person carry a device in their pocket or hand

compared to a person on the ground. Further, an intentional limitation is not using a full distance estimation formula and prior knowledge about the devices to more accurately estimate the distances.

In order to make use of such a system, the Bluetooth devices must be transmitting advertising packets at a minimum in order to be detected usefully as other data may be encrypted. Most Bluetooth devices are not set to be discoverable as it also poses an inherent security risk of enabling malicious actors the potential to connect to one's device over Bluetooth.

This research also examined the relatively accuracy of RSSI measurements in the given environments, but did not carry out a real-world test of first responders using the data to attempt to locate the devices. It is possible that a first responder knowing that a device, and therefore a person, is likely within 3-5 m could quickly stop and locate the individual during the course of a search without any more precise accuracy.

6.5 Future Work

A potential method to discern accurate distances may be to create a mesh network of Bluetooth devices in order to locate a transmit device. If multiple first responders were each scanning an indoor area and communicating between themselves to triangulate the location of a device, the measurements may become more reliable. However, past research indicates that the sources and strengths of interference would likely cause even more significant problems for such a system.

One workaround may be to develop a database of transmit strengths for various sets of common hardware, such as smartphones with the highest market share in a given region. Additionally, testing devices in a room with no interference to adapt to determine signal attenuation for that hardware set and adding that to the database could allow for a system to measure devices much more accurately in first response

scenarios. Further, categorizing default Bluetooth device names and manufacturer ID combinations could also create a potential solution to the enumeration problem.

Another study could examine inverting the measurement system used here and instead increment along elevation at set distances away from the transmit device with the receive device a set distance away along the x-axis. This study could isolate and more strongly examine the impact that elevation has on RSSI measurements as few studies have examined that axis thoroughly. Additionally, such a study could ensure the total distance between two devices is constant across each data set to appropriately isolate the impact that elevation has.

Additionally, a similar program was developed in 2014 named Finding Inaccessible people in Natural Disasters (FIND) [31]. This program, however, specifically uses Wi-Fi as opposed to Bluetooth, and attempts to create a mesh network between the devices. This program could be furthered by adding Bluetooth as an option, enabling it to connect to a variety of devices on a person without Wi-Fi enabled such as watches, headphones, and medical devices.

One notable issue with the system described in this thesis is the inability to determine the direction to a device. If a first responder knew that a smartphone was likely within 5 m as well as the general direction of the device, she could quickly examine the area to look for a casualty in a disaster. However, checking the full 5 m radius in all directions, which may involve physically moving debris, could slow down the search given the number of variables that may impact the RSSI measurements. Future research using a small, directional antenna may provide insight into this issue and enhance its usability in the field.

A staged environment in which first responders attempt to use the data to locate the devices could also provide valuable insight. By placing the transmit (victim) devices throughout an area and allowing the first responders to collect RSSI mea-

surements to get a general idea of where a victim may be and executing a more thorough search in that area, the necessary level of accuracy for such a system could be determined.

Appendix A. Raw Data

Table 19: Fitbit Charge, Disaster Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-46	3.1 m	-74
0.2 m	-43	3.2 m	-79
0.3 m	-49	3.3 m	-83
0.4 m	-50	3.4 m	-82
0.5 m	-47	3.5 m	-75
0.6 m	-59	3.6 m	-67
0.7 m	-61	3.7 m	-69
0.8 m	-53	3.8 m	-73
0.9 m	-63	3.9 m	-74
1.0 m	-61	4.0 m	-76
1.1 m	-72	4.1 m	-78
1.2 m	-65	4.2 m	-77
1.3 m	-66	4.3 m	-80
1.4 m	-65	4.4 m	-80
1.5 m	-71	4.5 m	-75
1.6 m	-63	4.6 m	-80
1.7 m	-68	4.7 m	-76
1.8 m	-67	4.8 m	-88
1.9 m	-71	4.9 m	-80
2.0 m	-68	5.0 m	-77
2.1 m	-68	5.1 m	-75
2.2 m	-71	5.2 m	-80
2.3 m	-66	5.3 m	-82
2.4 m	-71	5.4 m	-83
2.5 m	-72	5.5 m	-86
2.6 m	-69	5.6 m	-80
2.7 m	-71	5.7 m	-85
2.8 m	-69	5.8 m	-85
2.9 m	-72	5.9 m	-80
3.0 m	-71	6.0 m	-92

Table 20: Fitbit Charge, Disaster Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-46	3.1 m	-71
0.2 m	-44	3.2 m	-80
0.3 m	-50	3.3 m	-68
0.4 m	-48	3.4 m	-73
0.5 m	-51	3.5 m	-72
0.6 m	-57	3.6 m	-69
0.7 m	-58	3.7 m	-96
0.8 m	-63	3.8 m	-84
0.9 m	-62	3.9 m	-74
1.0 m	-65	4.0 m	-83
1.1 m	-68	4.1 m	-77
1.2 m	-62	4.2 m	-72
1.3 m	-64	4.3 m	-77
1.4 m	-68	4.4 m	-78
1.5 m	-69	4.5 m	-88
1.6 m	-64	4.6 m	-88
1.7 m	-81	4.7 m	-75
1.8 m	-88	4.8 m	-84
1.9 m	-65	4.9 m	-83
2.0 m	-70	5.0 m	-78
2.1 m	-72	5.1 m	-82
2.2 m	-67	5.2 m	-77
2.3 m	-69	5.3 m	-77
2.4 m	-74	5.4 m	-89
2.5 m	-68	5.5 m	-94
2.6 m	-67	5.6 m	-91
2.7 m	-80	5.7 m	-94
2.8 m	-67	5.8 m	-84
2.9 m	-72	5.9 m	-79
3.0 m	-71	6.0 m	-87

Table 21: Fitbit Charge, Disaster Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-52	3.1 m	-66
0.2 m	-52	3.2 m	-68
0.3 m	-55	3.3 m	-71
0.4 m	-46	3.4 m	-73
0.5 m	-45	3.5 m	-68
0.6 m	-47	3.6 m	-74
0.7 m	-48	3.7 m	-74
0.8 m	-48	3.8 m	-69
0.9 m	-45	3.9 m	-73
1.0 m	-47	4.0 m	-85
1.1 m	-56	4.1 m	-84
1.2 m	-58	4.2 m	-76
1.3 m	-60	4.3 m	-75
1.4 m	-65	4.4 m	-71
1.5 m	-68	4.5 m	-70
1.6 m	-64	4.6 m	-73
1.7 m	-56	4.7 m	-70
1.8 m	-58	4.8 m	-76
1.9 m	-63	4.9 m	-71
2.0 m	-70	5.0 m	-68
2.1 m	-59	5.1 m	-78
2.2 m	-66	5.2 m	-69
2.3 m	-64	5.3 m	-73
2.4 m	-66	5.4 m	-74
2.5 m	-66	5.5 m	-72
2.6 m	-64	5.6 m	-81
2.7 m	-66	5.7 m	-71
2.8 m	-61	5.8 m	-73
2.9 m	-74	5.9 m	-76
3.0 m	-71	6.0 m	-73

Table 22: Fitbit Charge, Disaster Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-57	3.1 m	-76
0.2 m	-54	3.2 m	-65
0.3 m	-56	3.3 m	-81
0.4 m	-52	3.4 m	-63
0.5 m	-47	3.5 m	-66
0.6 m	-48	3.6 m	-73
0.7 m	-46	3.7 m	-71
0.8 m	-66	3.8 m	-68
0.9 m	-56	3.9 m	-66
1.0 m	-61	4.0 m	-68
1.1 m	-56	4.1 m	-65
1.2 m	-57	4.2 m	-70
1.3 m	-59	4.3 m	-73
1.4 m	-56	4.4 m	-70
1.5 m	-66	4.5 m	-71
1.6 m	-62	4.6 m	-66
1.7 m	-67	4.7 m	-68
1.8 m	-63	4.8 m	-73
1.9 m	-59	4.9 m	-72
2.0 m	-60	5.0 m	-72
2.1 m	-66	5.1 m	-74
2.2 m	-67	5.2 m	-77
2.3 m	-66	5.3 m	-76
2.4 m	-61	5.4 m	-79
2.5 m	-60	5.5 m	-74
2.6 m	-71	5.6 m	-72
2.7 m	-66	5.7 m	-73
2.8 m	-65	5.8 m	-77
2.9 m	-71	5.9 m	-74
3.0 m	-67	6.0 m	-72

Table 23: Fitbit Charge, Home Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-48	3.1 m	-70
0.2 m	-50	3.2 m	-78
0.3 m	-54	3.3 m	-70
0.4 m	-58	3.4 m	-67
0.5 m	-61	3.5 m	-67
0.6 m	-57	3.6 m	-70
0.7 m	-61	3.7 m	-73
0.8 m	-65	3.8 m	-80
0.9 m	-62	3.9 m	-75
1.0 m	-78	4.0 m	-70
1.1 m	-67	4.1 m	-82
1.2 m	-72	4.2 m	-74
1.3 m	-72	4.3 m	-68
1.4 m	-70	4.4 m	-88
1.5 m	-72	4.5 m	-77
1.6 m	-69	4.6 m	-72
1.7 m	-83	4.7 m	-74
1.8 m	-72	4.8 m	-76
1.9 m	-67	4.9 m	-78
2.0 m	-74	5.0 m	-91
2.1 m	-71	5.1 m	-76
2.2 m	-80	5.2 m	-78
2.3 m	-81	5.3 m	-87
2.4 m	-76	5.4 m	-82
2.5 m	-67	5.5 m	-80
2.6 m	-71	5.6 m	-80
2.7 m	-75	5.7 m	-77
2.8 m	-71	5.8 m	-73
2.9 m	-70	5.9 m	-90
3.0 m	-68	6.0 m	-86

Table 24: Fitbit Charge, Home Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-52	3.1 m	-68
0.2 m	-51	3.2 m	-72
0.3 m	-54	3.3 m	-70
0.4 m	-58	3.4 m	-68
0.5 m	-60	3.5 m	-69
0.6 m	-61	3.6 m	-70
0.7 m	-62	3.7 m	-73
0.8 m	-63	3.8 m	-76
0.9 m	-83	3.9 m	-75
1.0 m	-67	4.0 m	-70
1.1 m	-73	4.1 m	-70
1.2 m	-71	4.2 m	-75
1.3 m	-68	4.3 m	-69
1.4 m	-72	4.4 m	-82
1.5 m	-70	4.5 m	-81
1.6 m	-67	4.6 m	-82
1.7 m	-67	4.7 m	-73
1.8 m	-65	4.8 m	-78
1.9 m	-65	4.9 m	-78
2.0 m	-70	5.0 m	-85
2.1 m	-76	5.1 m	-78
2.2 m	-75	5.2 m	-80
2.3 m	-75	5.3 m	-74
2.4 m	-74	5.4 m	-77
2.5 m	-85	5.5 m	-78
2.6 m	-70	5.6 m	-75
2.7 m	-76	5.7 m	-83
2.8 m	-71	5.8 m	-83
2.9 m	-68	5.9 m	-85
3.0 m	-84	6.0 m	-80

Table 25: Fitbit Charge, Home Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-45	3.1 m	-61
0.2 m	-45	3.2 m	-67
0.3 m	-48	3.3 m	-68
0.4 m	-50	3.4 m	-71
0.5 m	-49	3.5 m	-66
0.6 m	-54	3.6 m	-67
0.7 m	-49	3.7 m	-78
0.8 m	-56	3.8 m	-82
0.9 m	-52	3.9 m	-69
1.0 m	-54	4.0 m	-79
1.1 m	-55	4.1 m	-73
1.2 m	-54	4.2 m	-75
1.3 m	-59	4.3 m	-77
1.4 m	-61	4.4 m	-74
1.5 m	-56	4.5 m	-73
1.6 m	-57	4.6 m	-72
1.7 m	-60	4.7 m	-71
1.8 m	-61	4.8 m	-68
1.9 m	-58	4.9 m	-70
2.0 m	-65	5.0 m	-70
2.1 m	-65	5.1 m	-71
2.2 m	-69	5.2 m	-69
2.3 m	-63	5.3 m	-70
2.4 m	-60	5.4 m	-83
2.5 m	-61	5.5 m	-79
2.6 m	-67	5.6 m	-89
2.7 m	-64	5.7 m	-74
2.8 m	-75	5.8 m	-71
2.9 m	-64	5.9 m	-68
3.0 m	-62	6.0 m	-81

Table 26: Fitbit Charge, Home Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-45	3.1 m	-68
0.2 m	-48	3.2 m	-65
0.3 m	-50	3.3 m	-71
0.4 m	-48	3.4 m	-67
0.5 m	-52	3.5 m	-65
0.6 m	-51	3.6 m	-66
0.7 m	-55	3.7 m	-72
0.8 m	-54	3.8 m	-66
0.9 m	-53	3.9 m	-72
1.0 m	-54	4.0 m	-68
1.1 m	-59	4.1 m	-72
1.2 m	-57	4.2 m	-81
1.3 m	-63	4.3 m	-78
1.4 m	-56	4.4 m	-74
1.5 m	-57	4.5 m	-72
1.6 m	-59	4.6 m	-67
1.7 m	-58	4.7 m	-70
1.8 m	-70	4.8 m	-71
1.9 m	-59	4.9 m	-72
2.0 m	-65	5.0 m	-74
2.1 m	-64	5.1 m	-68
2.2 m	-66	5.2 m	-68
2.3 m	-61	5.3 m	-78
2.4 m	-68	5.4 m	-85
2.5 m	-62	5.5 m	-80
2.6 m	-62	5.6 m	-81
2.7 m	-67	5.7 m	-82
2.8 m	-64	5.8 m	-74
2.9 m	-70	5.9 m	-68
3.0 m	-63	6.0 m	-77

Table 27: Fitbit Charge, Office Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-43	3.1 m	-73
0.2 m	-44	3.2 m	-70
0.3 m	-50	3.3 m	-74
0.4 m	-52	3.4 m	-66
0.5 m	-53	3.5 m	-78
0.6 m	-57	3.6 m	-72
0.7 m	-53	3.7 m	-82
0.8 m	-58	3.8 m	-64
0.9 m	-56	3.9 m	-73
1.0 m	-62	4.0 m	-69
1.1 m	-56	4.1 m	-61
1.2 m	-57	4.2 m	-61
1.3 m	-64	4.3 m	-71
1.4 m	-61	4.4 m	-67
1.5 m	-61	4.5 m	-62
1.6 m	-66	4.6 m	-71
1.7 m	-71	4.7 m	-76
1.8 m	-62	4.8 m	-71
1.9 m	-64	4.9 m	-69
2.0 m	-59	5.0 m	-69
2.1 m	-64	5.1 m	-68
2.2 m	-62	5.2 m	-66
2.3 m	-62	5.3 m	-76
2.4 m	-69	5.4 m	-77
2.5 m	-73	5.5 m	-68
2.6 m	-65	5.6 m	-74
2.7 m	-69	5.7 m	-70
2.8 m	-60	5.8 m	-71
2.9 m	-71	5.9 m	-68
3.0 m	-71	6.0 m	-72

Table 28: Fitbit Charge, Office Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-41	3.1 m	-69
0.2 m	-45	3.2 m	-69
0.3 m	-47	3.3 m	-67
0.4 m	-46	3.4 m	-66
0.5 m	-54	3.5 m	-76
0.6 m	-56	3.6 m	-71
0.7 m	-55	3.7 m	-68
0.8 m	-58	3.8 m	-70
0.9 m	-56	3.9 m	-69
1.0 m	-56	4.0 m	-63
1.1 m	-55	4.1 m	-72
1.2 m	-58	4.2 m	-64
1.3 m	-57	4.3 m	-63
1.4 m	-64	4.4 m	-67
1.5 m	-58	4.5 m	-69
1.6 m	-63	4.6 m	-75
1.7 m	-63	4.7 m	-79
1.8 m	-69	4.8 m	-66
1.9 m	-66	4.9 m	-67
2.0 m	-66	5.0 m	-70
2.1 m	-69	5.1 m	-65
2.2 m	-64	5.2 m	-73
2.3 m	-65	5.3 m	-83
2.4 m	-67	5.4 m	-71
2.5 m	-71	5.5 m	-70
2.6 m	-69	5.6 m	-68
2.7 m	-62	5.7 m	-66
2.8 m	-60	5.8 m	-86
2.9 m	-62	5.9 m	-65
3.0 m	-75	6.0 m	-74

Table 29: Fitbit Charge, Office Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-49	3.1 m	-63
0.2 m	-56	3.2 m	-62
0.3 m	-55	3.3 m	-61
0.4 m	-62	3.4 m	-62
0.5 m	-56	3.5 m	-71
0.6 m	-57	3.6 m	-69
0.7 m	-53	3.7 m	-72
0.8 m	-56	3.8 m	-77
0.9 m	-61	3.9 m	-70
1.0 m	-58	4.0 m	-58
1.1 m	-74	4.1 m	-62
1.2 m	-60	4.2 m	-62
1.3 m	-60	4.3 m	-64
1.4 m	-69	4.4 m	-59
1.5 m	-59	4.5 m	-62
1.6 m	-64	4.6 m	-71
1.7 m	-65	4.7 m	-64
1.8 m	-76	4.8 m	-63
1.9 m	-60	4.9 m	-68
2.0 m	-69	5.0 m	-78
2.1 m	-67	5.1 m	-68
2.2 m	-70	5.2 m	-74
2.3 m	-68	5.3 m	-69
2.4 m	-67	5.4 m	-76
2.5 m	-63	5.5 m	-61
2.6 m	-57	5.6 m	-70
2.7 m	-64	5.7 m	-69
2.8 m	-61	5.8 m	-65
2.9 m	-70	5.9 m	-73
3.0 m	-65	6.0 m	-78

Table 30: Fitbit Charge, Office Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-52	3.1 m	-62
0.2 m	-60	3.2 m	-66
0.3 m	-52	3.3 m	-62
0.4 m	-51	3.4 m	-72
0.5 m	-56	3.5 m	-69
0.6 m	-55	3.6 m	-71
0.7 m	-54	3.7 m	-60
0.8 m	-60	3.8 m	-67
0.9 m	-55	3.9 m	-63
1.0 m	-52	4.0 m	-60
1.1 m	-57	4.1 m	-63
1.2 m	-54	4.2 m	-62
1.3 m	-60	4.3 m	-61
1.4 m	-68	4.4 m	-58
1.5 m	-66	4.5 m	-56
1.6 m	-59	4.6 m	-65
1.7 m	-62	4.7 m	-74
1.8 m	-73	4.8 m	-60
1.9 m	-61	4.9 m	-61
2.0 m	-73	5.0 m	-74
2.1 m	-72	5.1 m	-70
2.2 m	-57	5.2 m	-72
2.3 m	-69	5.3 m	-75
2.4 m	-76	5.4 m	-69
2.5 m	-73	5.5 m	-67
2.6 m	-56	5.6 m	-62
2.7 m	-57	5.7 m	-63
2.8 m	-58	5.8 m	-72
2.9 m	-65	5.9 m	-76
3.0 m	-66	6.0 m	-82

Table 31: Dog & Bone Lock, Disaster Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-78	3.1 m	-92
0.2 m	-73	3.2 m	-93
0.3 m	-78	3.3 m	-76
0.4 m	-79	3.4 m	-88
0.5 m	-81	3.5 m	-100
0.6 m	-84	3.6 m	-101
0.7 m	-84	3.7 m	-94
0.8 m	-86	3.8 m	-96
0.9 m	-81	3.9 m	-100
1.0 m	-77	4.0 m	-97
1.1 m	-86	4.1 m	-92
1.2 m	-84	4.2 m	-90
1.3 m	-78	4.3 m	-88
1.4 m	-76	4.4 m	-89
1.5 m	-92	4.5 m	-100
1.6 m	-90	4.6 m	-96
1.7 m	-86	4.7 m	-100
1.8 m	-88	4.8 m	-95
1.9 m	-96	4.9 m	-99
2.0 m	-97	5.0 m	-100
2.1 m	-92	5.1 m	-96
2.2 m	-94	5.2 m	-91
2.3 m	-93	5.3 m	-98
2.4 m	-89	5.4 m	-93
2.5 m	-95	5.5 m	-98
2.6 m	-98	5.6 m	-100
2.7 m	-96	5.7 m	-100
2.8 m	-82	5.8 m	-100
2.9 m	-94	5.9 m	-99
3.0 m	-91	6.0 m	-100

Table 32: Dog & Bone Lock, Disaster Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-69	3.1 m	-86
0.2 m	-71	3.2 m	-94
0.3 m	-76	3.3 m	-96
0.4 m	-70	3.4 m	-95
0.5 m	-76	3.5 m	-88
0.6 m	-83	3.6 m	-97
0.7 m	-78	3.7 m	-94
0.8 m	-84	3.8 m	-97
0.9 m	-80	3.9 m	-100
1.0 m	-73	4.0 m	-97
1.1 m	-82	4.1 m	-93
1.2 m	-84	4.2 m	-88
1.3 m	-95	4.3 m	-91
1.4 m	-84	4.4 m	-96
1.5 m	-87	4.5 m	-94
1.6 m	-98	4.6 m	-92
1.7 m	-85	4.7 m	-100
1.8 m	-87	4.8 m	-97
1.9 m	-91	4.9 m	-99
2.0 m	-90	5.0 m	-96
2.1 m	-85	5.1 m	-100
2.2 m	-92	5.2 m	-97
2.3 m	-92	5.3 m	-96
2.4 m	-96	5.4 m	-99
2.5 m	-90	5.5 m	-99
2.6 m	-90	5.6 m	-98
2.7 m	-92	5.7 m	-97
2.8 m	-93	5.8 m	-98
2.9 m	-94	5.9 m	-99
3.0 m	-91	6.0 m	-94

Table 33: Dog & Bone Lock, Disaster Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-64	3.1 m	-87
0.2 m	-67	3.2 m	-82
0.3 m	-74	3.3 m	-80
0.4 m	-70	3.4 m	-82
0.5 m	-68	3.5 m	-86
0.6 m	-72	3.6 m	-84
0.7 m	-71	3.7 m	-86
0.8 m	-72	3.8 m	-78
0.9 m	-68	3.9 m	-87
1.0 m	-80	4.0 m	-94
1.1 m	-78	4.1 m	-90
1.2 m	-83	4.2 m	-91
1.3 m	-80	4.3 m	-95
1.4 m	-84	4.4 m	-91
1.5 m	-81	4.5 m	-93
1.6 m	-85	4.6 m	-92
1.7 m	-79	4.7 m	-89
1.8 m	-97	4.8 m	-94
1.9 m	-77	4.9 m	-93
2.0 m	-80	5.0 m	-96
2.1 m	-82	5.1 m	-91
2.2 m	-85	5.2 m	-88
2.3 m	-91	5.3 m	-94
2.4 m	-83	5.4 m	-95
2.5 m	-81	5.5 m	-91
2.6 m	-87	5.6 m	-93
2.7 m	-94	5.7 m	-98
2.8 m	-90	5.8 m	-96
2.9 m	-80	5.9 m	-97
3.0 m	-84	6.0 m	-98

Table 34: Dog & Bone Lock, Disaster Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-75	3.1 m	-100
0.2 m	-73	3.2 m	-87
0.3 m	-69	3.3 m	-89
0.4 m	-66	3.4 m	-82
0.5 m	-68	3.5 m	-92
0.6 m	-68	3.6 m	-99
0.7 m	-71	3.7 m	-86
0.8 m	-68	3.8 m	-82
0.9 m	-76	3.9 m	-84
1.0 m	-80	4.0 m	-86
1.1 m	-78	4.1 m	-93
1.2 m	-83	4.2 m	-90
1.3 m	-82	4.3 m	-91
1.4 m	-85	4.4 m	-91
1.5 m	-77	4.5 m	-96
1.6 m	-84	4.6 m	-88
1.7 m	-78	4.7 m	-83
1.8 m	-77	4.8 m	-92
1.9 m	-70	4.9 m	-92
2.0 m	-85	5.0 m	-97
2.1 m	-93	5.1 m	-93
2.2 m	-84	5.2 m	-91
2.3 m	-89	5.3 m	-94
2.4 m	-90	5.4 m	-87
2.5 m	-79	5.5 m	-95
2.6 m	-85	5.6 m	-96
2.7 m	-82	5.7 m	-92
2.8 m	-88	5.8 m	-94
2.9 m	-88	5.9 m	-88
3.0 m	-85	6.0 m	-94

Table 35: Dog & Bone Lock, Home Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-62	3.1 m	-90
0.2 m	-65	3.2 m	-98
0.3 m	-69	3.3 m	-94
0.4 m	-71	3.4 m	-93
0.5 m	-69	3.5 m	-88
0.6 m	-71	3.6 m	-90
0.7 m	-75	3.7 m	-93
0.8 m	-74	3.8 m	-97
0.9 m	-80	3.9 m	-99
1.0 m	-81	4.0 m	-99
1.1 m	-83	4.1 m	-90
1.2 m	-76	4.2 m	-98
1.3 m	-80	4.3 m	-96
1.4 m	-90	4.4 m	-95
1.5 m	-83	4.5 m	-92
1.6 m	-90	4.6 m	-90
1.7 m	-82	4.7 m	-98
1.8 m	-92	4.8 m	-97
1.9 m	-88	4.9 m	-94
2.0 m	-83	5.0 m	-94
2.1 m	-84	5.1 m	-96
2.2 m	-94	5.2 m	-98
2.3 m	-93	5.3 m	-95
2.4 m	-87	5.4 m	-97
2.5 m	-84	5.5 m	-92
2.6 m	-92	5.6 m	-98
2.7 m	-89	5.7 m	-93
2.8 m	-99	5.8 m	-97
2.9 m	-96	5.9 m	-92
3.0 m	-92	6.0 m	-98

Table 36: Dog & Bone Lock, Home Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-68	3.1 m	-93
0.2 m	-65	3.2 m	-94
0.3 m	-71	3.3 m	-85
0.4 m	-80	3.4 m	-96
0.5 m	-79	3.5 m	-92
0.6 m	-74	3.6 m	-94
0.7 m	-80	3.7 m	-89
0.8 m	-75	3.8 m	-98
0.9 m	-76	3.9 m	-96
1.0 m	-87	4.0 m	-90
1.1 m	-75	4.1 m	-96
1.2 m	-83	4.2 m	-90
1.3 m	-77	4.3 m	-99
1.4 m	-82	4.4 m	-94
1.5 m	-82	4.5 m	-93
1.6 m	-86	4.6 m	-92
1.7 m	-78	4.7 m	-96
1.8 m	-80	4.8 m	-88
1.9 m	-85	4.9 m	-100
2.0 m	-88	5.0 m	-94
2.1 m	-86	5.1 m	-92
2.2 m	-88	5.2 m	-96
2.3 m	-85	5.3 m	-94
2.4 m	-90	5.4 m	-96
2.5 m	-99	5.5 m	-94
2.6 m	-90	5.6 m	-90
2.7 m	-94	5.7 m	-92
2.8 m	-96	5.8 m	-87
2.9 m	-95	5.9 m	-94
3.0 m	-86	6.0 m	-96

Table 37: Dog & Bone Lock, Home Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-70	3.1 m	-93
0.2 m	-70	3.2 m	-91
0.3 m	-79	3.3 m	-94
0.4 m	-70	3.4 m	-94
0.5 m	-76	3.5 m	-90
0.6 m	-70	3.6 m	-96
0.7 m	-78	3.7 m	-90
0.8 m	-81	3.8 m	-91
0.9 m	-88	3.9 m	-85
1.0 m	-74	4.0 m	-83
1.1 m	-85	4.1 m	-90
1.2 m	-82	4.2 m	-98
1.3 m	-80	4.3 m	-90
1.4 m	-81	4.4 m	-92
1.5 m	-80	4.5 m	-91
1.6 m	-86	4.6 m	-89
1.7 m	-84	4.7 m	-88
1.8 m	-86	4.8 m	-98
1.9 m	-82	4.9 m	-89
2.0 m	-92	5.0 m	-97
2.1 m	-88	5.1 m	-92
2.2 m	-88	5.2 m	-96
2.3 m	-87	5.3 m	-95
2.4 m	-80	5.4 m	-94
2.5 m	-90	5.5 m	-90
2.6 m	-92	5.6 m	-92
2.7 m	-94	5.7 m	-97
2.8 m	-88	5.8 m	-94
2.9 m	-90	5.9 m	-92
3.0 m	-88	6.0 m	-98

Table 38: Dog & Bone Lock, Home Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-74	3.1 m	-91
0.2 m	-73	3.2 m	-94
0.3 m	-65	3.3 m	-89
0.4 m	-67	3.4 m	-93
0.5 m	-66	3.5 m	-89
0.6 m	-67	3.6 m	-96
0.7 m	-70	3.7 m	-100
0.8 m	-75	3.8 m	-97
0.9 m	-72	3.9 m	-98
1.0 m	-71	4.0 m	-91
1.1 m	-78	4.1 m	-89
1.2 m	-84	4.2 m	-96
1.3 m	-81	4.3 m	-91
1.4 m	-76	4.4 m	-90
1.5 m	-80	4.5 m	-92
1.6 m	-85	4.6 m	-94
1.7 m	-90	4.7 m	-91
1.8 m	-94	4.8 m	-92
1.9 m	-94	4.9 m	-94
2.0 m	-89	5.0 m	-83
2.1 m	-90	5.1 m	-92
2.2 m	-84	5.2 m	-98
2.3 m	-92	5.3 m	-90
2.4 m	-84	5.4 m	-96
2.5 m	-96	5.5 m	-94
2.6 m	-92	5.6 m	-98
2.7 m	-88	5.7 m	-96
2.8 m	-94	5.8 m	-96
2.9 m	-91	5.9 m	-95
3.0 m	-86	6.0 m	-96

Table 39: Dog & Bone Lock, Office Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-69	3.1 m	-79
0.2 m	-75	3.2 m	-85
0.3 m	-71	3.3 m	-85
0.4 m	-80	3.4 m	-86
0.5 m	-68	3.5 m	-82
0.6 m	-74	3.6 m	-96
0.7 m	-86	3.7 m	-85
0.8 m	-74	3.8 m	-87
0.9 m	-77	3.9 m	-93
1.0 m	-76	4.0 m	-96
1.1 m	-76	4.1 m	-100
1.2 m	-87	4.2 m	-97
1.3 m	-83	4.3 m	-100
1.4 m	-80	4.4 m	-94
1.5 m	-84	4.5 m	-92
1.6 m	-82	4.6 m	-92
1.7 m	-83	4.7 m	-84
1.8 m	-85	4.8 m	-87
1.9 m	-91	4.9 m	-87
2.0 m	-80	5.0 m	-92
2.1 m	-84	5.1 m	-88
2.2 m	-83	5.2 m	-86
2.3 m	-90	5.3 m	-88
2.4 m	-82	5.4 m	-87
2.5 m	-89	5.5 m	-94
2.6 m	-90	5.6 m	-95
2.7 m	-86	5.7 m	-97
2.8 m	-93	5.8 m	-96
2.9 m	-85	5.9 m	-92
3.0 m	-90	6.0 m	-91

Table 40: Dog & Bone Lock, Office Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-73	3.1 m	-88
0.2 m	-80	3.2 m	-89
0.3 m	-72	3.3 m	-82
0.4 m	-77	3.4 m	-85
0.5 m	-75	3.5 m	-89
0.6 m	-76	3.6 m	-93
0.7 m	-82	3.7 m	-88
0.8 m	-76	3.8 m	-84
0.9 m	-72	3.9 m	-93
1.0 m	-83	4.0 m	-81
1.1 m	-78	4.1 m	-94
1.2 m	-73	4.2 m	-88
1.3 m	-77	4.3 m	-93
1.4 m	-82	4.4 m	-87
1.5 m	-80	4.5 m	-95
1.6 m	-94	4.6 m	-92
1.7 m	-92	4.7 m	-86
1.8 m	-82	4.8 m	-85
1.9 m	-84	4.9 m	-87
2.0 m	-82	5.0 m	-93
2.1 m	-102	5.1 m	-92
2.2 m	-82	5.2 m	-86
2.3 m	-87	5.3 m	-88
2.4 m	-86	5.4 m	-91
2.5 m	-88	5.5 m	-88
2.6 m	-85	5.6 m	-96
2.7 m	-87	5.7 m	-89
2.8 m	-89	5.8 m	-86
2.9 m	-92	5.9 m	-87
3.0 m	-80	6.0 m	-91

Table 41: Dog & Bone Lock, Office Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-67	3.1 m	-89
0.2 m	-71	3.2 m	-86
0.3 m	-63	3.3 m	-82
0.4 m	-70	3.4 m	-93
0.5 m	-72	3.5 m	-86
0.6 m	-78	3.6 m	-82
0.7 m	-70	3.7 m	-92
0.8 m	-92	3.8 m	-92
0.9 m	-87	3.9 m	-91
1.0 m	-94	4.0 m	-83
1.1 m	-91	4.1 m	-78
1.2 m	-80	4.2 m	-84
1.3 m	-81	4.3 m	-86
1.4 m	-81	4.4 m	-81
1.5 m	-88	4.5 m	-90
1.6 m	-79	4.6 m	-86
1.7 m	-78	4.7 m	-98
1.8 m	-84	4.8 m	-92
1.9 m	-86	4.9 m	-83
2.0 m	-84	5.0 m	-82
2.1 m	-82	5.1 m	-88
2.2 m	-80	5.2 m	-90
2.3 m	-84	5.3 m	-85
2.4 m	-84	5.4 m	-89
2.5 m	-80	5.5 m	-91
2.6 m	-79	5.6 m	-93
2.7 m	-76	5.7 m	-89
2.8 m	-80	5.8 m	-94
2.9 m	-93	5.9 m	-85
3.0 m	-88	6.0 m	-78

Table 42: Dog & Bone Lock, Office Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-69	3.1 m	-82
0.2 m	-65	3.2 m	-88
0.3 m	-69	3.3 m	-84
0.4 m	-76	3.4 m	-93
0.5 m	-81	3.5 m	-93
0.6 m	-83	3.6 m	-85
0.7 m	-74	3.7 m	-95
0.8 m	-78	3.8 m	-100
0.9 m	-95	3.9 m	-94
1.0 m	-84	4.0 m	-87
1.1 m	-87	4.1 m	-84
1.2 m	-79	4.2 m	-86
1.3 m	-72	4.3 m	-85
1.4 m	-72	4.4 m	-93
1.5 m	-81	4.5 m	-89
1.6 m	-82	4.6 m	-88
1.7 m	-82	4.7 m	-91
1.8 m	-81	4.8 m	-100
1.9 m	-76	4.9 m	-91
2.0 m	-91	5.0 m	-88
2.1 m	-79	5.1 m	-95
2.2 m	-86	5.2 m	-84
2.3 m	-90	5.3 m	-81
2.4 m	-83	5.4 m	-88
2.5 m	-84	5.5 m	-80
2.6 m	-84	5.6 m	-96
2.7 m	-81	5.7 m	-85
2.8 m	-84	5.8 m	-88
2.9 m	-80	5.9 m	-83
3.0 m	-87	6.0 m	-83

Table 43: iBluLock, Disaster Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-61	3.1 m	-89
0.2 m	-64	3.2 m	-91
0.3 m	-60	3.3 m	-91
0.4 m	-67	3.4 m	-88
0.5 m	-68	3.5 m	-91
0.6 m	-70	3.6 m	-84
0.7 m	-70	3.7 m	-88
0.8 m	-64	3.8 m	-88
0.9 m	-62	3.9 m	-94
1.0 m	-80	4.0 m	-96
1.1 m	-78	4.1 m	-92
1.2 m	-82	4.2 m	-94
1.3 m	-76	4.3 m	-91
1.4 m	-76	4.4 m	-91
1.5 m	-83	4.5 m	-96
1.6 m	-99	4.6 m	-93
1.7 m	-93	4.7 m	-91
1.8 m	-93	4.8 m	-93
1.9 m	-88	4.9 m	-97
2.0 m	-82	5.0 m	-90
2.1 m	-89	5.1 m	-89
2.2 m	-87	5.2 m	-96
2.3 m	-94	5.3 m	-97
2.4 m	-87	5.4 m	-98
2.5 m	-90	5.5 m	-92
2.6 m	-86	5.6 m	-98
2.7 m	-86	5.7 m	-97
2.8 m	-90	5.8 m	-98
2.9 m	-91	5.9 m	-101
3.0 m	-93	6.0 m	-99

Table 44: iBluLock, Disaster Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-71	3.1 m	-92
0.2 m	-78	3.2 m	-91
0.3 m	-80	3.3 m	-88
0.4 m	-80	3.4 m	-87
0.5 m	-78	3.5 m	-87
0.6 m	-68	3.6 m	-96
0.7 m	-89	3.7 m	-93
0.8 m	-82	3.8 m	-91
0.9 m	-78	3.9 m	-93
1.0 m	-76	4.0 m	-92
1.1 m	-80	4.1 m	-97
1.2 m	-76	4.2 m	-98
1.3 m	-95	4.3 m	-87
1.4 m	-78	4.4 m	-94
1.5 m	-84	4.5 m	-96
1.6 m	-86	4.6 m	-91
1.7 m	-74	4.7 m	-97
1.8 m	-84	4.8 m	-99
1.9 m	-85	4.9 m	-93
2.0 m	-88	5.0 m	-96
2.1 m	-97	5.1 m	-93
2.2 m	-78	5.2 m	-96
2.3 m	-79	5.3 m	-98
2.4 m	-87	5.4 m	-98
2.5 m	-80	5.5 m	-96
2.6 m	-78	5.6 m	-99
2.7 m	-84	5.7 m	-100
2.8 m	-85	5.8 m	-97
2.9 m	-81	5.9 m	-92
3.0 m	-91	6.0 m	-99

Table 45: iBluLock, Disaster Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-64	3.1 m	-86
0.2 m	-62	3.2 m	-55
0.3 m	-64	3.3 m	-84
0.4 m	-66	3.4 m	-88
0.5 m	-72	3.5 m	-86
0.6 m	-70	3.6 m	-85
0.7 m	-77	3.7 m	-84
0.8 m	-72	3.8 m	-80
0.9 m	-65	3.9 m	-83
1.0 m	-80	4.0 m	-94
1.1 m	-73	4.1 m	-91
1.2 m	-85	4.2 m	-93
1.3 m	-82	4.3 m	-90
1.4 m	-89	4.4 m	-88
1.5 m	-84	4.5 m	-87
1.6 m	-96	4.6 m	-87
1.7 m	-83	4.7 m	-88
1.8 m	-95	4.8 m	-87
1.9 m	-79	4.9 m	-91
2.0 m	-84	5.0 m	-90
2.1 m	-82	5.1 m	-95
2.2 m	-81	5.2 m	-84
2.3 m	-82	5.3 m	-87
2.4 m	-80	5.4 m	-89
2.5 m	-82	5.5 m	-90
2.6 m	-81	5.6 m	-96
2.7 m	-81	5.7 m	-89
2.8 m	-78	5.8 m	-95
2.9 m	-86	5.9 m	-91
3.0 m	-85	6.0 m	-73

Table 46: iBluLock, Disaster Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-65	3.1 m	-86
0.2 m	-66	3.2 m	-88
0.3 m	-67	3.3 m	-82
0.4 m	-71	3.4 m	-84
0.5 m	-69	3.5 m	-87
0.6 m	-70	3.6 m	-88
0.7 m	-72	3.7 m	-88
0.8 m	-71	3.8 m	-86
0.9 m	-88	3.9 m	-95
1.0 m	-72	4.0 m	-100
1.1 m	-78	4.1 m	-93
1.2 m	-73	4.2 m	-95
1.3 m	-80	4.3 m	-88
1.4 m	-91	4.4 m	-83
1.5 m	-80	4.5 m	-84
1.6 m	-90	4.6 m	-98
1.7 m	-83	4.7 m	-90
1.8 m	-90	4.8 m	-95
1.9 m	-79	4.9 m	-93
2.0 m	-81	5.0 m	-88
2.1 m	-83	5.1 m	-91
2.2 m	-81	5.2 m	-93
2.3 m	-82	5.3 m	-93
2.4 m	-83	5.4 m	-90
2.5 m	-85	5.5 m	-86
2.6 m	-81	5.6 m	-91
2.7 m	-86	5.7 m	-92
2.8 m	-87	5.8 m	-90
2.9 m	-82	5.9 m	-88
3.0 m	-89	6.0 m	-86

Table 47: iBluLock, Home Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-63	3.1 m	-88
0.2 m	-61	3.2 m	-88
0.3 m	-64	3.3 m	-85
0.4 m	-63	3.4 m	-88
0.5 m	-69	3.5 m	-82
0.6 m	-71	3.6 m	-82
0.7 m	-68	3.7 m	-89
0.8 m	-74	3.8 m	-96
0.9 m	-74	3.9 m	-87
1.0 m	-80	4.0 m	-89
1.1 m	-74	4.1 m	-94
1.2 m	-73	4.2 m	-81
1.3 m	-72	4.3 m	-84
1.4 m	-82	4.4 m	-88
1.5 m	-79	4.5 m	-86
1.6 m	-78	4.6 m	-86
1.7 m	-82	4.7 m	-92
1.8 m	-79	4.8 m	-89
1.9 m	-85	4.9 m	-90
2.0 m	-80	5.0 m	-94
2.1 m	-84	5.1 m	-82
2.2 m	-86	5.2 m	-90
2.3 m	-80	5.3 m	-94
2.4 m	-94	5.4 m	-92
2.5 m	-90	5.5 m	-94
2.6 m	-85	5.6 m	-92
2.7 m	-97	5.7 m	-92
2.8 m	-84	5.8 m	-91
2.9 m	-87	5.9 m	-94
3.0 m	-90	6.0 m	-98

Table 48: iBluLock, Home Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-60	3.1 m	-85
0.2 m	-62	3.2 m	-86
0.3 m	-58	3.3 m	-82
0.4 m	-71	3.4 m	-88
0.5 m	-66	3.5 m	-85
0.6 m	-68	3.6 m	-82
0.7 m	-66	3.7 m	-89
0.8 m	-72	3.8 m	-88
0.9 m	-72	3.9 m	-84
1.0 m	-75	4.0 m	-85
1.1 m	-72	4.1 m	-83
1.2 m	-77	4.2 m	-92
1.3 m	-74	4.3 m	-88
1.4 m	-77	4.4 m	-83
1.5 m	-74	4.5 m	-86
1.6 m	-75	4.6 m	-88
1.7 m	-78	4.7 m	-90
1.8 m	-79	4.8 m	-88
1.9 m	-77	4.9 m	-85
2.0 m	-81	5.0 m	-85
2.1 m	-78	5.1 m	-92
2.2 m	-76	5.2 m	-91
2.3 m	-80	5.3 m	-92
2.4 m	-88	5.4 m	-98
2.5 m	-80	5.5 m	-98
2.6 m	-82	5.6 m	-94
2.7 m	-77	5.7 m	-86
2.8 m	-84	5.8 m	-98
2.9 m	-83	5.9 m	-86
3.0 m	-96	6.0 m	-84

Table 49: iBluLock, Home Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-65	3.1 m	-81
0.2 m	-78	3.2 m	-93
0.3 m	-66	3.3 m	-84
0.4 m	-68	3.4 m	-88
0.5 m	-75	3.5 m	-84
0.6 m	-68	3.6 m	-92
0.7 m	-71	3.7 m	-96
0.8 m	-66	3.8 m	-87
0.9 m	-73	3.9 m	-81
1.0 m	-81	4.0 m	-84
1.1 m	-72	4.1 m	-87
1.2 m	-70	4.2 m	-92
1.3 m	-73	4.3 m	-85
1.4 m	-71	4.4 m	-80
1.5 m	-76	4.5 m	-80
1.6 m	-73	4.6 m	-78
1.7 m	-74	4.7 m	-88
1.8 m	-77	4.8 m	-82
1.9 m	-78	4.9 m	-86
2.0 m	-81	5.0 m	-82
2.1 m	-80	5.1 m	-83
2.2 m	-89	5.2 m	-82
2.3 m	-78	5.3 m	-94
2.4 m	-75	5.4 m	-95
2.5 m	-78	5.5 m	-94
2.6 m	-83	5.6 m	-98
2.7 m	-80	5.7 m	-88
2.8 m	-81	5.8 m	-86
2.9 m	-80	5.9 m	-87
3.0 m	-81	6.0 m	-99

Table 50: iBluLock, Home Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-57	3.1 m	-81
0.2 m	-58	3.2 m	-87
0.3 m	-62	3.3 m	-84
0.4 m	-63	3.4 m	-83
0.5 m	-63	3.5 m	-88
0.6 m	-63	3.6 m	-84
0.7 m	-66	3.7 m	-82
0.8 m	-68	3.8 m	-84
0.9 m	-66	3.9 m	-85
1.0 m	-70	4.0 m	-84
1.1 m	-68	4.1 m	-91
1.2 m	-69	4.2 m	-90
1.3 m	-72	4.3 m	-86
1.4 m	-74	4.4 m	-81
1.5 m	-87	4.5 m	-78
1.6 m	-78	4.6 m	-79
1.7 m	-79	4.7 m	-89
1.8 m	-82	4.8 m	-93
1.9 m	-79	4.9 m	-88
2.0 m	-84	5.0 m	-85
2.1 m	-86	5.1 m	-86
2.2 m	-79	5.2 m	-84
2.3 m	-82	5.3 m	-92
2.4 m	-77	5.4 m	-87
2.5 m	-78	5.5 m	-90
2.6 m	-83	5.6 m	-95
2.7 m	-79	5.7 m	-97
2.8 m	-80	5.8 m	-87
2.9 m	-85	5.9 m	-85
3.0 m	-80	6.0 m	-94

Table 51: iBluLock, Office Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-65	3.1 m	-80
0.2 m	-62	3.2 m	-83
0.3 m	-71	3.3 m	-86
0.4 m	-68	3.4 m	-87
0.5 m	-70	3.5 m	-87
0.6 m	-75	3.6 m	-78
0.7 m	-74	3.7 m	-82
0.8 m	-74	3.8 m	-88
0.9 m	-79	3.9 m	-86
1.0 m	-80	4.0 m	-84
1.1 m	-72	4.1 m	-85
1.2 m	-95	4.2 m	-80
1.3 m	-80	4.3 m	-78
1.4 m	-80	4.4 m	-84
1.5 m	-82	4.5 m	-83
1.6 m	-86	4.6 m	-81
1.7 m	-81	4.7 m	-75
1.8 m	-73	4.8 m	-85
1.9 m	-78	4.9 m	-89
2.0 m	-80	5.0 m	-83
2.1 m	-93	5.1 m	-89
2.2 m	-82	5.2 m	-82
2.3 m	-82	5.3 m	-91
2.4 m	-83	5.4 m	-86
2.5 m	-79	5.5 m	-84
2.6 m	-82	5.6 m	-89
2.7 m	-83	5.7 m	-93
2.8 m	-80	5.8 m	-91
2.9 m	-82	5.9 m	-92
3.0 m	-80	6.0 m	-88

Table 52: iBluLock, Office Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-62	3.1 m	-83
0.2 m	-69	3.2 m	-93
0.3 m	-63	3.3 m	-84
0.4 m	-66	3.4 m	-82
0.5 m	-68	3.5 m	-82
0.6 m	-74	3.6 m	-90
0.7 m	-71	3.7 m	-85
0.8 m	-70	3.8 m	-85
0.9 m	-84	3.9 m	-89
1.0 m	-78	4.0 m	-95
1.1 m	-74	4.1 m	-98
1.2 m	-91	4.2 m	-79
1.3 m	-74	4.3 m	-85
1.4 m	-72	4.4 m	-81
1.5 m	-76	4.5 m	-82
1.6 m	-81	4.6 m	-81
1.7 m	-76	4.7 m	-75
1.8 m	-76	4.8 m	-78
1.9 m	-83	4.9 m	-94
2.0 m	-76	5.0 m	-93
2.1 m	-81	5.1 m	-78
2.2 m	-78	5.2 m	-81
2.3 m	-87	5.3 m	-92
2.4 m	-80	5.4 m	-88
2.5 m	-82	5.5 m	-87
2.6 m	-86	5.6 m	-83
2.7 m	-82	5.7 m	-90
2.8 m	-85	5.8 m	-89
2.9 m	-82	5.9 m	-91
3.0 m	-92	6.0 m	-87

Table 53: iBluLock, Office Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-60	3.1 m	-92
0.2 m	-68	3.2 m	-79
0.3 m	-70	3.3 m	-82
0.4 m	-69	3.4 m	-99
0.5 m	-72	3.5 m	-85
0.6 m	-71	3.6 m	-84
0.7 m	-72	3.7 m	-77
0.8 m	-81	3.8 m	-81
0.9 m	-73	3.9 m	-86
1.0 m	-80	4.0 m	-100
1.1 m	-88	4.1 m	-77
1.2 m	-81	4.2 m	-77
1.3 m	-80	4.3 m	-83
1.4 m	-81	4.4 m	-86
1.5 m	-81	4.5 m	-85
1.6 m	-77	4.6 m	-94
1.7 m	-73	4.7 m	-91
1.8 m	-80	4.8 m	-82
1.9 m	-76	4.9 m	-82
2.0 m	-74	5.0 m	-91
2.1 m	-76	5.1 m	-90
2.2 m	-76	5.2 m	-90
2.3 m	-78	5.3 m	-82
2.4 m	-77	5.4 m	-85
2.5 m	-75	5.5 m	-81
2.6 m	-76	5.6 m	-97
2.7 m	-75	5.7 m	-84
2.8 m	-89	5.8 m	-88
2.9 m	-79	5.9 m	-84
3.0 m	-96	6.0 m	-83

Table 54: iBluLock, Office Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-67	3.1 m	-83
0.2 m	-69	3.2 m	-87
0.3 m	-71	3.3 m	-76
0.4 m	-64	3.4 m	-85
0.5 m	-70	3.5 m	-82
0.6 m	-73	3.6 m	-86
0.7 m	-69	3.7 m	-89
0.8 m	-71	3.8 m	-76
0.9 m	-74	3.9 m	-82
1.0 m	-75	4.0 m	-81
1.1 m	-73	4.1 m	-87
1.2 m	-73	4.2 m	-84
1.3 m	-85	4.3 m	-75
1.4 m	-82	4.4 m	-80
1.5 m	-76	4.5 m	-82
1.6 m	-70	4.6 m	-86
1.7 m	-72	4.7 m	-82
1.8 m	-73	4.8 m	-91
1.9 m	-87	4.9 m	-82
2.0 m	-79	5.0 m	-82
2.1 m	-73	5.1 m	-86
2.2 m	-74	5.2 m	-85
2.3 m	-72	5.3 m	-77
2.4 m	-80	5.4 m	-89
2.5 m	-94	5.5 m	-82
2.6 m	-93	5.6 m	-88
2.7 m	-78	5.7 m	-83
2.8 m	-76	5.8 m	-77
2.9 m	-90	5.9 m	-87
3.0 m	-77	6.0 m	-78

Table 55: Masterlock, Disaster Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-63	3.1 m	-89
0.2 m	-62	3.2 m	-86
0.3 m	-65	3.3 m	-83
0.4 m	-75	3.4 m	-89
0.5 m	-82	3.5 m	-85
0.6 m	-70	3.6 m	-90
0.7 m	-68	3.7 m	-88
0.8 m	-78	3.8 m	-86
0.9 m	-72	3.9 m	-91
1.0 m	-77	4.0 m	-87
1.1 m	-74	4.1 m	-87
1.2 m	-86	4.2 m	-88
1.3 m	-74	4.3 m	-92
1.4 m	-75	4.4 m	-97
1.5 m	-88	4.5 m	-92
1.6 m	-90	4.6 m	-87
1.7 m	-82	4.7 m	-94
1.8 m	-81	4.8 m	-91
1.9 m	-79	4.9 m	-94
2.0 m	-82	5.0 m	-96
2.1 m	-93	5.1 m	-100
2.2 m	-97	5.2 m	-93
2.3 m	-83	5.3 m	-95
2.4 m	-82	5.4 m	-92
2.5 m	-85	5.5 m	-96
2.6 m	-88	5.6 m	-100
2.7 m	-80	5.7 m	-97
2.8 m	-87	5.8 m	-96
2.9 m	-96	5.9 m	-98
3.0 m	-87	6.0 m	-96

Table 56: Masterlock, Disaster Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-71	3.1 m	-91
0.2 m	-69	3.2 m	-88
0.3 m	-71	3.3 m	-97
0.4 m	-67	3.4 m	-92
0.5 m	-97	3.5 m	-89
0.6 m	-79	3.6 m	-84
0.7 m	-88	3.7 m	-91
0.8 m	-83	3.8 m	-89
0.9 m	-80	3.9 m	-91
1.0 m	-78	4.0 m	-97
1.1 m	-85	4.1 m	-97
1.2 m	-80	4.2 m	-93
1.3 m	-71	4.3 m	-89
1.4 m	-78	4.4 m	-89
1.5 m	-85	4.5 m	-92
1.6 m	-80	4.6 m	-96
1.7 m	-78	4.7 m	-96
1.8 m	-87	4.8 m	-94
1.9 m	-88	4.9 m	-95
2.0 m	-86	5.0 m	-100
2.1 m	-81	5.1 m	-93
2.2 m	-85	5.2 m	-91
2.3 m	-80	5.3 m	-96
2.4 m	-92	5.4 m	-97
2.5 m	-80	5.5 m	-96
2.6 m	-84	5.6 m	-98
2.7 m	-89	5.7 m	-97
2.8 m	-88	5.8 m	-92
2.9 m	-85	5.9 m	-88
3.0 m	-88	6.0 m	-98

Table 57: Masterlock, Disaster Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-58	3.1 m	-78
0.2 m	-62	3.2 m	-91
0.3 m	-65	3.3 m	-87
0.4 m	-60	3.4 m	-81
0.5 m	-73	3.5 m	-85
0.6 m	-68	3.6 m	-82
0.7 m	-68	3.7 m	-81
0.8 m	-67	3.8 m	-74
0.9 m	-63	3.9 m	-78
1.0 m	-85	4.0 m	-88
1.1 m	-73	4.1 m	-94
1.2 m	-82	4.2 m	-92
1.3 m	-85	4.3 m	-87
1.4 m	-74	4.4 m	-89
1.5 m	-76	4.5 m	-91
1.6 m	-74	4.6 m	-82
1.7 m	-78	4.7 m	-86
1.8 m	-80	4.8 m	-87
1.9 m	-74	4.9 m	-89
2.0 m	-78	5.0 m	-93
2.1 m	-84	5.1 m	-89
2.2 m	-77	5.2 m	-88
2.3 m	-76	5.3 m	-90
2.4 m	-77	5.4 m	-88
2.5 m	-84	5.5 m	-90
2.6 m	-77	5.6 m	-84
2.7 m	-82	5.7 m	-90
2.8 m	-76	5.8 m	-91
2.9 m	-87	5.9 m	-98
3.0 m	-84	6.0 m	-89

Table 58: Masterlock, Disaster Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-62	3.1 m	-82
0.2 m	-62	3.2 m	-88
0.3 m	-59	3.3 m	-80
0.4 m	-61	3.4 m	-78
0.5 m	-62	3.5 m	-84
0.6 m	-63	3.6 m	-81
0.7 m	-62	3.7 m	-82
0.8 m	-61	3.8 m	-97
0.9 m	-65	3.9 m	-100
1.0 m	-73	4.0 m	-88
1.1 m	-74	4.1 m	-90
1.2 m	-90	4.2 m	-93
1.3 m	-84	4.3 m	-91
1.4 m	-74	4.4 m	-90
1.5 m	-82	4.5 m	-92
1.6 m	-80	4.6 m	-89
1.7 m	-82	4.7 m	-94
1.8 m	-78	4.8 m	-93
1.9 m	-74	4.9 m	-98
2.0 m	-73	5.0 m	-94
2.1 m	-76	5.1 m	-87
2.2 m	-74	5.2 m	-94
2.3 m	-74	5.3 m	-96
2.4 m	-76	5.4 m	-89
2.5 m	-73	5.5 m	-92
2.6 m	-76	5.6 m	-89
2.7 m	-82	5.7 m	-87
2.8 m	-83	5.8 m	-90
2.9 m	-84	5.9 m	-87
3.0 m	-77	6.0 m	-85

Table 59: Masterlock, Home Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-68	3.1 m	-78
0.2 m	-74	3.2 m	-85
0.3 m	-73	3.3 m	-88
0.4 m	-77	3.4 m	-86
0.5 m	-80	3.5 m	-85
0.6 m	-78	3.6 m	-84
0.7 m	-72	3.7 m	-93
0.8 m	-80	3.8 m	-93
0.9 m	-83	3.9 m	-90
1.0 m	-89	4.0 m	-88
1.1 m	-80	4.1 m	-82
1.2 m	-82	4.2 m	-81
1.3 m	-83	4.3 m	-81
1.4 m	-81	4.4 m	-83
1.5 m	-86	4.5 m	-85
1.6 m	-83	4.6 m	-92
1.7 m	-80	4.7 m	-95
1.8 m	-81	4.8 m	-87
1.9 m	-90	4.9 m	-87
2.0 m	-91	5.0 m	-89
2.1 m	-94	5.1 m	-84
2.2 m	-88	5.2 m	-88
2.3 m	-90	5.3 m	-90
2.4 m	-86	5.4 m	-93
2.5 m	-96	5.5 m	-92
2.6 m	-89	5.6 m	-84
2.7 m	-83	5.7 m	-88
2.8 m	-89	5.8 m	-86
2.9 m	-91	5.9 m	-90
3.0 m	-81	6.0 m	-96

Table 60: Masterlock, Home Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-84	3.1 m	-85
0.2 m	-75	3.2 m	-86
0.3 m	-85	3.3 m	-92
0.4 m	-72	3.4 m	-89
0.5 m	-76	3.5 m	-93
0.6 m	-86	3.6 m	-87
0.7 m	-74	3.7 m	-83
0.8 m	-83	3.8 m	-85
0.9 m	-90	3.9 m	-92
1.0 m	-78	4.0 m	-81
1.1 m	-77	4.1 m	-84
1.2 m	-83	4.2 m	-87
1.3 m	-92	4.3 m	-85
1.4 m	-91	4.4 m	-83
1.5 m	-89	4.5 m	-84
1.6 m	-78	4.6 m	-86
1.7 m	-81	4.7 m	-92
1.8 m	-86	4.8 m	-90
1.9 m	-85	4.9 m	-85
2.0 m	-95	5.0 m	-87
2.1 m	-84	5.1 m	-88
2.2 m	-86	5.2 m	-95
2.3 m	-80	5.3 m	-90
2.4 m	-88	5.4 m	-87
2.5 m	-83	5.5 m	-88
2.6 m	-82	5.6 m	-86
2.7 m	-87	5.7 m	-98
2.8 m	-98	5.8 m	-94
2.9 m	-88	5.9 m	-96
3.0 m	-85	6.0 m	-92

Table 61: Masterlock, Home Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-54	3.1 m	-77
0.2 m	-56	3.2 m	-82
0.3 m	-68	3.3 m	-80
0.4 m	-59	3.4 m	-79
0.5 m	-67	3.5 m	-78
0.6 m	-60	3.6 m	-84
0.7 m	-74	3.7 m	-89
0.8 m	-62	3.8 m	-78
0.9 m	-68	3.9 m	-80
1.0 m	-65	4.0 m	-92
1.1 m	-68	4.1 m	-83
1.2 m	-67	4.2 m	-84
1.3 m	-68	4.3 m	-83
1.4 m	-74	4.4 m	-81
1.5 m	-72	4.5 m	-81
1.6 m	-70	4.6 m	-80
1.7 m	-69	4.7 m	-82
1.8 m	-73	4.8 m	-95
1.9 m	-72	4.9 m	-98
2.0 m	-77	5.0 m	-86
2.1 m	-75	5.1 m	-82
2.2 m	-74	5.2 m	-85
2.3 m	-79	5.3 m	-95
2.4 m	-80	5.4 m	-83
2.5 m	-76	5.5 m	-91
2.6 m	-81	5.6 m	-88
2.7 m	-81	5.7 m	-97
2.8 m	-76	5.8 m	-83
2.9 m	-79	5.9 m	-85
3.0 m	-78	6.0 m	-92

Table 62: Masterlock, Home Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-54	3.1 m	-87
0.2 m	-55	3.2 m	-78
0.3 m	-59	3.3 m	-83
0.4 m	-58	3.4 m	-80
0.5 m	-60	3.5 m	-88
0.6 m	-72	3.6 m	-83
0.7 m	-64	3.7 m	-79
0.8 m	-76	3.8 m	-78
0.9 m	-67	3.9 m	-83
1.0 m	-65	4.0 m	-86
1.1 m	-67	4.1 m	-82
1.2 m	-83	4.2 m	-83
1.3 m	-68	4.3 m	-89
1.4 m	-73	4.4 m	-81
1.5 m	-71	4.5 m	-82
1.6 m	-81	4.6 m	-81
1.7 m	-78	4.7 m	-88
1.8 m	-77	4.8 m	-91
1.9 m	-80	4.9 m	-84
2.0 m	-78	5.0 m	-92
2.1 m	-76	5.1 m	-87
2.2 m	-79	5.2 m	-88
2.3 m	-76	5.3 m	-89
2.4 m	-80	5.4 m	-94
2.5 m	-77	5.5 m	-92
2.6 m	-88	5.6 m	-92
2.7 m	-96	5.7 m	-96
2.8 m	-80	5.8 m	-84
2.9 m	-84	5.9 m	-82
3.0 m	-86	6.0 m	-92

Table 63: Masterlock, Office Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-56	3.1 m	-80
0.2 m	-61	3.2 m	-88
0.3 m	-65	3.3 m	-79
0.4 m	-76	3.4 m	-82
0.5 m	-72	3.5 m	-80
0.6 m	-66	3.6 m	-77
0.7 m	-72	3.7 m	-88
0.8 m	-82	3.8 m	-80
0.9 m	-76	3.9 m	-85
1.0 m	-73	4.0 m	-82
1.1 m	-79	4.1 m	-91
1.2 m	-73	4.2 m	-88
1.3 m	-67	4.3 m	-82
1.4 m	-70	4.4 m	-82
1.5 m	-89	4.5 m	-78
1.6 m	-82	4.6 m	-80
1.7 m	-80	4.7 m	-84
1.8 m	-77	4.8 m	-88
1.9 m	-81	4.9 m	-86
2.0 m	-74	5.0 m	-87
2.1 m	-82	5.1 m	-76
2.2 m	-86	5.2 m	-82
2.3 m	-91	5.3 m	-84
2.4 m	-78	5.4 m	-76
2.5 m	-82	5.5 m	-79
2.6 m	-95	5.6 m	-95
2.7 m	-91	5.7 m	-84
2.8 m	-77	5.8 m	-80
2.9 m	-84	5.9 m	-86
3.0 m	-92	6.0 m	-82

Table 64: Masterlock, Office Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-61	3.1 m	-79
0.2 m	-62	3.2 m	-74
0.3 m	-71	3.3 m	-83
0.4 m	-73	3.4 m	-79
0.5 m	-66	3.5 m	-80
0.6 m	-73	3.6 m	-87
0.7 m	-70	3.7 m	-82
0.8 m	-76	3.8 m	-75
0.9 m	-80	3.9 m	-78
1.0 m	-72	4.0 m	-86
1.1 m	-77	4.1 m	-81
1.2 m	-75	4.2 m	-83
1.3 m	-73	4.3 m	-81
1.4 m	-71	4.4 m	-78
1.5 m	-83	4.5 m	-81
1.6 m	-89	4.6 m	-84
1.7 m	-81	4.7 m	-79
1.8 m	-82	4.8 m	-82
1.9 m	-82	4.9 m	-88
2.0 m	-72	5.0 m	-83
2.1 m	-79	5.1 m	-77
2.2 m	-84	5.2 m	-78
2.3 m	-83	5.3 m	-87
2.4 m	-77	5.4 m	-79
2.5 m	-85	5.5 m	-93
2.6 m	-98	5.6 m	-98
2.7 m	-94	5.7 m	-81
2.8 m	-81	5.8 m	-85
2.9 m	-89	5.9 m	-77
3.0 m	-84	6.0 m	-83

Table 65: Masterlock, Office Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-66	3.1 m	-76
0.2 m	-63	3.2 m	-86
0.3 m	-66	3.3 m	-79
0.4 m	-81	3.4 m	-89
0.5 m	-80	3.5 m	-83
0.6 m	-95	3.6 m	-80
0.7 m	-74	3.7 m	-82
0.8 m	-93	3.8 m	-77
0.9 m	-78	3.9 m	-84
1.0 m	-87	4.0 m	-86
1.1 m	-81	4.1 m	-84
1.2 m	-85	4.2 m	-77
1.3 m	-80	4.3 m	-86
1.4 m	-84	4.4 m	-85
1.5 m	-87	4.5 m	-88
1.6 m	-77	4.6 m	-84
1.7 m	-73	4.7 m	-85
1.8 m	-84	4.8 m	-80
1.9 m	-84	4.9 m	-81
2.0 m	-82	5.0 m	-92
2.1 m	-88	5.1 m	-91
2.2 m	-89	5.2 m	-77
2.3 m	-87	5.3 m	-81
2.4 m	-93	5.4 m	-82
2.5 m	-80	5.5 m	-87
2.6 m	-84	5.6 m	-78
2.7 m	-92	5.7 m	-82
2.8 m	-84	5.8 m	-81
2.9 m	-80	5.9 m	-81
3.0 m	-79	6.0 m	-83

Table 66: Masterlock, Office Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-60	3.1 m	-78
0.2 m	-66	3.2 m	-82
0.3 m	-65	3.3 m	-80
0.4 m	-68	3.4 m	-87
0.5 m	-64	3.5 m	-87
0.6 m	-70	3.6 m	-82
0.7 m	-74	3.7 m	-80
0.8 m	-84	3.8 m	-83
0.9 m	-78	3.9 m	-91
1.0 m	-74	4.0 m	-79
1.1 m	-72	4.1 m	-83
1.2 m	-74	4.2 m	-82
1.3 m	-75	4.3 m	-75
1.4 m	-76	4.4 m	-85
1.5 m	-78	4.5 m	-80
1.6 m	-76	4.6 m	-82
1.7 m	-77	4.7 m	-92
1.8 m	-76	4.8 m	-88
1.9 m	-86	4.9 m	-88
2.0 m	-75	5.0 m	-86
2.1 m	-82	5.1 m	-82
2.2 m	-77	5.2 m	-83
2.3 m	-74	5.3 m	-93
2.4 m	-82	5.4 m	-83
2.5 m	-83	5.5 m	-84
2.6 m	-84	5.6 m	-86
2.7 m	-79	5.7 m	-82
2.8 m	-78	5.8 m	-77
2.9 m	-85	5.9 m	-77
3.0 m	-75	6.0 m	-78

Table 67: Motorola Moto E2, Disaster Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-50	3.1 m	-69
0.2 m	-56	3.2 m	-82
0.3 m	-54	3.3 m	-69
0.4 m	-66	3.4 m	-70
0.5 m	-55	3.5 m	-69
0.6 m	-54	3.6 m	-72
0.7 m	-56	3.7 m	-74
0.8 m	-52	3.8 m	-76
0.9 m	-56	3.9 m	-82
1.0 m	-67	4.0 m	-92
1.1 m	-59	4.1 m	-74
1.2 m	-57	4.2 m	-83
1.3 m	-62	4.3 m	-81
1.4 m	-63	4.4 m	-69
1.5 m	-58	4.5 m	-84
1.6 m	-65	4.6 m	-68
1.7 m	-59	4.7 m	-84
1.8 m	-70	4.8 m	-74
1.9 m	-64	4.9 m	-74
2.0 m	-67	5.0 m	-76
2.1 m	-63	5.1 m	-72
2.2 m	-68	5.2 m	-76
2.3 m	-66	5.3 m	-76
2.4 m	-67	5.4 m	-97
2.5 m	-67	5.5 m	-74
2.6 m	-63	5.6 m	-92
2.7 m	-63	5.7 m	-80
2.8 m	-80	5.8 m	-76
2.9 m	-65	5.9 m	-80
3.0 m	-72	6.0 m	-96

Table 68: Motorola Moto E2, Disaster Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-47	3.1 m	-64
0.2 m	-49	3.2 m	-69
0.3 m	-59	3.3 m	-69
0.4 m	-60	3.4 m	-72
0.5 m	-54	3.5 m	-70
0.6 m	-56	3.6 m	-72
0.7 m	-55	3.7 m	-70
0.8 m	-67	3.8 m	-71
0.9 m	-66	3.9 m	-76
1.0 m	-67	4.0 m	-71
1.1 m	-72	4.1 m	-75
1.2 m	-59	4.2 m	-78
1.3 m	-58	4.3 m	-73
1.4 m	-61	4.4 m	-81
1.5 m	-62	4.5 m	-76
1.6 m	-67	4.6 m	-72
1.7 m	-64	4.7 m	-70
1.8 m	-65	4.8 m	-79
1.9 m	-63	4.9 m	-74
2.0 m	-66	5.0 m	-77
2.1 m	-61	5.1 m	-74
2.2 m	-68	5.2 m	-78
2.3 m	-70	5.3 m	-82
2.4 m	-62	5.4 m	-80
2.5 m	-69	5.5 m	-80
2.6 m	-64	5.6 m	-88
2.7 m	-67	5.7 m	-88
2.8 m	-64	5.8 m	-77
2.9 m	-69	5.9 m	-87
3.0 m	-68	6.0 m	-88

Table 69: Motorola Moto E2, Disaster Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-51	3.1 m	-71
0.2 m	-53	3.2 m	-61
0.3 m	-48	3.3 m	-64
0.4 m	-52	3.4 m	-60
0.5 m	-46	3.5 m	-65
0.6 m	-48	3.6 m	-71
0.7 m	-44	3.7 m	-73
0.8 m	-44	3.8 m	-62
0.9 m	-48	3.9 m	-76
1.0 m	-52	4.0 m	-64
1.1 m	-62	4.1 m	-73
1.2 m	-60	4.2 m	-78
1.3 m	-60	4.3 m	-71
1.4 m	-55	4.4 m	-75
1.5 m	-56	4.5 m	-65
1.6 m	-60	4.6 m	-70
1.7 m	-64	4.7 m	-68
1.8 m	-61	4.8 m	-66
1.9 m	-55	4.9 m	-65
2.0 m	-60	5.0 m	-67
2.1 m	-65	5.1 m	-65
2.2 m	-72	5.2 m	-66
2.3 m	-61	5.3 m	-67
2.4 m	-62	5.4 m	-74
2.5 m	-62	5.5 m	-79
2.6 m	-63	5.6 m	-86
2.7 m	-65	5.7 m	-77
2.8 m	-61	5.8 m	-74
2.9 m	-62	5.9 m	-76
3.0 m	-63	6.0 m	-63

Table 70: Motorola Moto E2, Disaster Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-52	3.1 m	-68
0.2 m	-54	3.2 m	-77
0.3 m	-52	3.3 m	-60
0.4 m	-49	3.4 m	-65
0.5 m	-44	3.5 m	-73
0.6 m	-45	3.6 m	-67
0.7 m	-47	3.7 m	-73
0.8 m	-50	3.8 m	-68
0.9 m	-58	3.9 m	-84
1.0 m	-53	4.0 m	-69
1.1 m	-66	4.1 m	-70
1.2 m	-62	4.2 m	-71
1.3 m	-62	4.3 m	-72
1.4 m	-61	4.4 m	-71
1.5 m	-62	4.5 m	-64
1.6 m	-64	4.6 m	-63
1.7 m	-65	4.7 m	-66
1.8 m	-60	4.8 m	-62
1.9 m	-55	4.9 m	-72
2.0 m	-62	5.0 m	-67
2.1 m	-60	5.1 m	-65
2.2 m	-69	5.2 m	-77
2.3 m	-63	5.3 m	-68
2.4 m	-72	5.4 m	-70
2.5 m	-58	5.5 m	-65
2.6 m	-63	5.6 m	-83
2.7 m	-63	5.7 m	-70
2.8 m	-64	5.8 m	-82
2.9 m	-67	5.9 m	-78
3.0 m	-78	6.0 m	-77

Table 71: Motorola Moto E2, Home Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-59	3.1 m	-73
0.2 m	-56	3.2 m	-67
0.3 m	-55	3.3 m	-70
0.4 m	-70	3.4 m	-73
0.5 m	-66	3.5 m	-66
0.6 m	-71	3.6 m	-62
0.7 m	-63	3.7 m	-61
0.8 m	-65	3.8 m	-67
0.9 m	-60	3.9 m	-63
1.0 m	-62	4.0 m	-68
1.1 m	-72	4.1 m	-62
1.2 m	-65	4.2 m	-60
1.3 m	-63	4.3 m	-62
1.4 m	-66	4.4 m	-62
1.5 m	-65	4.5 m	-63
1.6 m	-79	4.6 m	-67
1.7 m	-66	4.7 m	-66
1.8 m	-70	4.8 m	-67
1.9 m	-70	4.9 m	-69
2.0 m	-72	5.0 m	-66
2.1 m	-67	5.1 m	-68
2.2 m	-65	5.2 m	-66
2.3 m	-68	5.3 m	-70
2.4 m	-64	5.4 m	-74
2.5 m	-63	5.5 m	-70
2.6 m	-69	5.6 m	-80
2.7 m	-74	5.7 m	-76
2.8 m	-66	5.8 m	-76
2.9 m	-58	5.9 m	-72
3.0 m	-68	6.0 m	-74

Table 72: Motorola Moto E2, Home Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-51	3.1 m	-68
0.2 m	-62	3.2 m	-75
0.3 m	-57	3.3 m	-74
0.4 m	-56	3.4 m	-66
0.5 m	-62	3.5 m	-62
0.6 m	-53	3.6 m	-69
0.7 m	-65	3.7 m	-60
0.8 m	-61	3.8 m	-58
0.9 m	-58	3.9 m	-65
1.0 m	-59	4.0 m	-64
1.1 m	-58	4.1 m	-69
1.2 m	-65	4.2 m	-60
1.3 m	-68	4.3 m	-64
1.4 m	-62	4.4 m	-67
1.5 m	-65	4.5 m	-64
1.6 m	-65	4.6 m	-63
1.7 m	-72	4.7 m	-68
1.8 m	-73	4.8 m	-76
1.9 m	-68	4.9 m	-67
2.0 m	-66	5.0 m	-71
2.1 m	-64	5.1 m	-73
2.2 m	-66	5.2 m	-67
2.3 m	-71	5.3 m	-71
2.4 m	-69	5.4 m	-74
2.5 m	-67	5.5 m	-70
2.6 m	-72	5.6 m	-74
2.7 m	-72	5.7 m	-67
2.8 m	-67	5.8 m	-70
2.9 m	-69	5.9 m	-72
3.0 m	-63	6.0 m	-75

Table 73: Motorola Moto E2, Home Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-56	3.1 m	-71
0.2 m	-52	3.2 m	-70
0.3 m	-56	3.3 m	-76
0.4 m	-55	3.4 m	-70
0.5 m	-53	3.5 m	-68
0.6 m	-71	3.6 m	-65
0.7 m	-61	3.7 m	-68
0.8 m	-59	3.8 m	-63
0.9 m	-60	3.9 m	-75
1.0 m	-61	4.0 m	-59
1.1 m	-67	4.1 m	-64
1.2 m	-59	4.2 m	-63
1.3 m	-66	4.3 m	-63
1.4 m	-69	4.4 m	-79
1.5 m	-70	4.5 m	-82
1.6 m	-70	4.6 m	-69
1.7 m	-62	4.7 m	-64
1.8 m	-80	4.8 m	-70
1.9 m	-67	4.9 m	-73
2.0 m	-68	5.0 m	-79
2.1 m	-66	5.1 m	-62
2.2 m	-64	5.2 m	-68
2.3 m	-63	5.3 m	-70
2.4 m	-74	5.4 m	-68
2.5 m	-63	5.5 m	-66
2.6 m	-70	5.6 m	-72
2.7 m	-66	5.7 m	-72
2.8 m	-76	5.8 m	-73
2.9 m	-64	5.9 m	-82
3.0 m	-65	6.0 m	-70

Table 74: Motorola Moto E2, Home Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-50	3.1 m	-75
0.2 m	-47	3.2 m	-66
0.3 m	-46	3.3 m	-71
0.4 m	-45	3.4 m	-60
0.5 m	-45	3.5 m	-63
0.6 m	-48	3.6 m	-73
0.7 m	-47	3.7 m	-68
0.8 m	-50	3.8 m	-66
0.9 m	-53	3.9 m	-71
1.0 m	-54	4.0 m	-64
1.1 m	-50	4.1 m	-63
1.2 m	-50	4.2 m	-65
1.3 m	-56	4.3 m	-68
1.4 m	-56	4.4 m	-70
1.5 m	-51	4.5 m	-64
1.6 m	-53	4.6 m	-68
1.7 m	-62	4.7 m	-62
1.8 m	-56	4.8 m	-69
1.9 m	-55	4.9 m	-65
2.0 m	-58	5.0 m	-67
2.1 m	-61	5.1 m	-69
2.2 m	-58	5.2 m	-69
2.3 m	-58	5.3 m	-76
2.4 m	-88	5.4 m	-67
2.5 m	-67	5.5 m	-78
2.6 m	-62	5.6 m	-70
2.7 m	-64	5.7 m	-73
2.8 m	-62	5.8 m	-80
2.9 m	-67	5.9 m	-75
3.0 m	-61	6.0 m	-78

Table 75: Motorola Moto E2, Office Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-44	3.1 m	-59
0.2 m	-49	3.2 m	-60
0.3 m	-57	3.3 m	-64
0.4 m	-52	3.4 m	-64
0.5 m	-56	3.5 m	-67
0.6 m	-60	3.6 m	-59
0.7 m	-52	3.7 m	-71
0.8 m	-55	3.8 m	-75
0.9 m	-57	3.9 m	-61
1.0 m	-53	4.0 m	-73
1.1 m	-71	4.1 m	-71
1.2 m	-62	4.2 m	-69
1.3 m	-60	4.3 m	-60
1.4 m	-61	4.4 m	-65
1.5 m	-58	4.5 m	-68
1.6 m	-62	4.6 m	-77
1.7 m	-62	4.7 m	-70
1.8 m	-64	4.8 m	-72
1.9 m	-65	4.9 m	-61
2.0 m	-76	5.0 m	-71
2.1 m	-67	5.1 m	-62
2.2 m	-74	5.2 m	-62
2.3 m	-66	5.3 m	-67
2.4 m	-69	5.4 m	-68
2.5 m	-80	5.5 m	-72
2.6 m	-70	5.6 m	-73
2.7 m	-83	5.7 m	-71
2.8 m	-64	5.8 m	-70
2.9 m	-68	5.9 m	-69
3.0 m	-69	6.0 m	-78

Table 76: Motorola Moto E2, Office Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-44	3.1 m	-86
0.2 m	-48	3.2 m	-58
0.3 m	-50	3.3 m	-62
0.4 m	-47	3.4 m	-61
0.5 m	-54	3.5 m	-66
0.6 m	-56	3.6 m	-69
0.7 m	-52	3.7 m	-64
0.8 m	-54	3.8 m	-74
0.9 m	-59	3.9 m	-58
1.0 m	-56	4.0 m	-72
1.1 m	-65	4.1 m	-59
1.2 m	-60	4.2 m	-68
1.3 m	-63	4.3 m	-66
1.4 m	-60	4.4 m	-69
1.5 m	-56	4.5 m	-69
1.6 m	-63	4.6 m	-71
1.7 m	-56	4.7 m	-68
1.8 m	-62	4.8 m	-65
1.9 m	-65	4.9 m	-62
2.0 m	-67	5.0 m	-64
2.1 m	-73	5.1 m	-70
2.2 m	-67	5.2 m	-60
2.3 m	-62	5.3 m	-71
2.4 m	-62	5.4 m	-69
2.5 m	-70	5.5 m	-74
2.6 m	-65	5.6 m	-66
2.7 m	-62	5.7 m	-85
2.8 m	-71	5.8 m	-64
2.9 m	-64	5.9 m	-66
3.0 m	-70	6.0 m	-67

Table 77: Motorola Moto E2, Office Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-63	3.1 m	-67
0.2 m	-54	3.2 m	-63
0.3 m	-49	3.3 m	-67
0.4 m	-52	3.4 m	-62
0.5 m	-61	3.5 m	-66
0.6 m	-51	3.6 m	-61
0.7 m	-59	3.7 m	-62
0.8 m	-62	3.8 m	-61
0.9 m	-55	3.9 m	-67
1.0 m	-55	4.0 m	-68
1.1 m	-63	4.1 m	-67
1.2 m	-56	4.2 m	-74
1.3 m	-71	4.3 m	-68
1.4 m	-64	4.4 m	-70
1.5 m	-62	4.5 m	-69
1.6 m	-72	4.6 m	-66
1.7 m	-65	4.7 m	-75
1.8 m	-57	4.8 m	-69
1.9 m	-58	4.9 m	-68
2.0 m	-57	5.0 m	-70
2.1 m	-54	5.1 m	-63
2.2 m	-57	5.2 m	-60
2.3 m	-62	5.3 m	-74
2.4 m	-61	5.4 m	-62
2.5 m	-58	5.5 m	-64
2.6 m	-55	5.6 m	-68
2.7 m	-56	5.7 m	-67
2.8 m	-76	5.8 m	-67
2.9 m	-70	5.9 m	-69
3.0 m	-62	6.0 m	-71

Table 78: Motorola Moto E2, Office Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-51	3.1 m	-71
0.2 m	-56	3.2 m	-80
0.3 m	-58	3.3 m	-69
0.4 m	-56	3.4 m	-60
0.5 m	-55	3.5 m	-56
0.6 m	-52	3.6 m	-57
0.7 m	-54	3.7 m	-63
0.8 m	-53	3.8 m	-58
0.9 m	-64	3.9 m	-62
1.0 m	-56	4.0 m	-62
1.1 m	-55	4.1 m	-65
1.2 m	-56	4.2 m	-70
1.3 m	-53	4.3 m	-81
1.4 m	-81	4.4 m	-65
1.5 m	-62	4.5 m	-61
1.6 m	-61	4.6 m	-61
1.7 m	-58	4.7 m	-74
1.8 m	-67	4.8 m	-69
1.9 m	-66	4.9 m	-77
2.0 m	-58	5.0 m	-69
2.1 m	-64	5.1 m	-63
2.2 m	-58	5.2 m	-58
2.3 m	-61	5.3 m	-63
2.4 m	-57	5.4 m	-64
2.5 m	-55	5.5 m	-58
2.6 m	-60	5.6 m	-66
2.7 m	-53	5.7 m	-64
2.8 m	-64	5.8 m	-61
2.9 m	-58	5.9 m	-60
3.0 m	-56	6.0 m	-73

Table 79: Quicklock, Disaster Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-58	3.1 m	-81
0.2 m	-65	3.2 m	-76
0.3 m	-59	3.3 m	-89
0.4 m	-62	3.4 m	-76
0.5 m	-67	3.5 m	-77
0.6 m	-63	3.6 m	-74
0.7 m	-74	3.7 m	-81
0.8 m	-62	3.8 m	-83
0.9 m	-66	3.9 m	-94
1.0 m	-66	4.0 m	-87
1.1 m	-65	4.1 m	-80
1.2 m	-64	4.2 m	-76
1.3 m	-71	4.3 m	-80
1.4 m	-71	4.4 m	-82
1.5 m	-76	4.5 m	-86
1.6 m	-74	4.6 m	-80
1.7 m	-72	4.7 m	-82
1.8 m	-72	4.8 m	-87
1.9 m	-71	4.9 m	-80
2.0 m	-74	5.0 m	-77
2.1 m	-64	5.1 m	-88
2.2 m	-67	5.2 m	-88
2.3 m	-68	5.3 m	-84
2.4 m	-76	5.4 m	-82
2.5 m	-74	5.5 m	-81
2.6 m	-78	5.6 m	-86
2.7 m	-78	5.7 m	-92
2.8 m	-87	5.8 m	-81
2.9 m	-82	5.9 m	-92
3.0 m	-80	6.0 m	-90

Table 80: Quicklock, Disaster Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-55	3.1 m	-86
0.2 m	-61	3.2 m	-84
0.3 m	-56	3.3 m	-76
0.4 m	-70	3.4 m	-74
0.5 m	-70	3.5 m	-88
0.6 m	-57	3.6 m	-85
0.7 m	-59	3.7 m	-94
0.8 m	-64	3.8 m	-84
0.9 m	-60	3.9 m	-80
1.0 m	-58	4.0 m	-80
1.1 m	-67	4.1 m	-81
1.2 m	-75	4.2 m	-84
1.3 m	-70	4.3 m	-81
1.4 m	-65	4.4 m	-83
1.5 m	-66	4.5 m	-81
1.6 m	-65	4.6 m	-92
1.7 m	-70	4.7 m	-81
1.8 m	-66	4.8 m	-80
1.9 m	-69	4.9 m	-78
2.0 m	-76	5.0 m	-87
2.1 m	-74	5.1 m	-85
2.2 m	-76	5.2 m	-80
2.3 m	-76	5.3 m	-86
2.4 m	-81	5.4 m	-84
2.5 m	-70	5.5 m	-86
2.6 m	-77	5.6 m	-84
2.7 m	-79	5.7 m	-83
2.8 m	-76	5.8 m	-88
2.9 m	-78	5.9 m	-87
3.0 m	-84	6.0 m	-85

Table 81: Quicklock, Disaster Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-53	3.1 m	-86
0.2 m	-56	3.2 m	-80
0.3 m	-58	3.3 m	-82
0.4 m	-56	3.4 m	-88
0.5 m	-54	3.5 m	-82
0.6 m	-70	3.6 m	-72
0.7 m	-68	3.7 m	-78
0.8 m	-55	3.8 m	-81
0.9 m	-58	3.9 m	-77
1.0 m	-56	4.0 m	-75
1.1 m	-62	4.1 m	-78
1.2 m	-56	4.2 m	-89
1.3 m	-67	4.3 m	-84
1.4 m	-78	4.4 m	-76
1.5 m	-70	4.5 m	-75
1.6 m	-60	4.6 m	-77
1.7 m	-68	4.7 m	-77
1.8 m	-67	4.8 m	-81
1.9 m	-71	4.9 m	-82
2.0 m	-63	5.0 m	-81
2.1 m	-60	5.1 m	-80
2.2 m	-64	5.2 m	-81
2.3 m	-65	5.3 m	-79
2.4 m	-74	5.4 m	-76
2.5 m	-71	5.5 m	-73
2.6 m	-69	5.6 m	-79
2.7 m	-65	5.7 m	-73
2.8 m	-73	5.8 m	-95
2.9 m	-65	5.9 m	-92
3.0 m	-68	6.0 m	-75

Table 82: Quicklock, Disaster Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-55	3.1 m	-73
0.2 m	-56	3.2 m	-68
0.3 m	-55	3.3 m	-68
0.4 m	-54	3.4 m	-77
0.5 m	-52	3.5 m	-75
0.6 m	-56	3.6 m	-70
0.7 m	-53	3.7 m	-72
0.8 m	-50	3.8 m	-75
0.9 m	-52	3.9 m	-76
1.0 m	-65	4.0 m	-72
1.1 m	-72	4.1 m	-72
1.2 m	-61	4.2 m	-82
1.3 m	-58	4.3 m	-84
1.4 m	-77	4.4 m	-76
1.5 m	-63	4.5 m	-72
1.6 m	-60	4.6 m	-73
1.7 m	-60	4.7 m	-69
1.8 m	-67	4.8 m	-76
1.9 m	-62	4.9 m	-81
2.0 m	-59	5.0 m	-82
2.1 m	-66	5.1 m	-75
2.2 m	-63	5.2 m	-84
2.3 m	-67	5.3 m	-72
2.4 m	-78	5.4 m	-81
2.5 m	-70	5.5 m	-70
2.6 m	-68	5.6 m	-82
2.7 m	-75	5.7 m	-76
2.8 m	-87	5.8 m	-77
2.9 m	-73	5.9 m	-79
3.0 m	-70	6.0 m	-80

Table 83: Quicklock, Home Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-56	3.1 m	-72
0.2 m	-53	3.2 m	-76
0.3 m	-51	3.3 m	-74
0.4 m	-56	3.4 m	-96
0.5 m	-52	3.5 m	-90
0.6 m	-56	3.6 m	-72
0.7 m	-58	3.7 m	-78
0.8 m	-59	3.8 m	-82
0.9 m	-62	3.9 m	-73
1.0 m	-66	4.0 m	-76
1.1 m	-68	4.1 m	-68
1.2 m	-58	4.2 m	-74
1.3 m	-61	4.3 m	-72
1.4 m	-73	4.4 m	-70
1.5 m	-70	4.5 m	-74
1.6 m	-71	4.6 m	-80
1.7 m	-72	4.7 m	-78
1.8 m	-74	4.8 m	-82
1.9 m	-70	4.9 m	-81
2.0 m	-71	5.0 m	-75
2.1 m	-68	5.1 m	-83
2.2 m	-70	5.2 m	-80
2.3 m	-72	5.3 m	-77
2.4 m	-72	5.4 m	-81
2.5 m	-68	5.5 m	-78
2.6 m	-82	5.6 m	-80
2.7 m	-75	5.7 m	-78
2.8 m	-78	5.8 m	-76
2.9 m	-87	5.9 m	-85
3.0 m	-79	6.0 m	-80

Table 84: Quicklock, Home Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-52	3.1 m	-76
0.2 m	-50	3.2 m	-70
0.3 m	-54	3.3 m	-72
0.4 m	-57	3.4 m	-73
0.5 m	-62	3.5 m	-79
0.6 m	-56	3.6 m	-87
0.7 m	-61	3.7 m	-78
0.8 m	-58	3.8 m	-84
0.9 m	-65	3.9 m	-81
1.0 m	-65	4.0 m	-70
1.1 m	-59	4.1 m	-73
1.2 m	-62	4.2 m	-74
1.3 m	-60	4.3 m	-71
1.4 m	-63	4.4 m	-79
1.5 m	-67	4.5 m	-77
1.6 m	-67	4.6 m	-72
1.7 m	-63	4.7 m	-92
1.8 m	-62	4.8 m	-78
1.9 m	-65	4.9 m	-84
2.0 m	-67	5.0 m	-80
2.1 m	-66	5.1 m	-84
2.2 m	-69	5.2 m	-81
2.3 m	-67	5.3 m	-83
2.4 m	-74	5.4 m	-84
2.5 m	-70	5.5 m	-86
2.6 m	-78	5.6 m	-85
2.7 m	-72	5.7 m	-88
2.8 m	-85	5.8 m	-82
2.9 m	-76	5.9 m	-84
3.0 m	-69	6.0 m	-80

Table 85: Quicklock, Home Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-45	3.1 m	-72
0.2 m	-47	3.2 m	-71
0.3 m	-49	3.3 m	-80
0.4 m	-50	3.4 m	-72
0.5 m	-58	3.5 m	-76
0.6 m	-58	3.6 m	-79
0.7 m	-62	3.7 m	-74
0.8 m	-66	3.8 m	-69
0.9 m	-54	3.9 m	-68
1.0 m	-63	4.0 m	-67
1.1 m	-60	4.1 m	-80
1.2 m	-64	4.2 m	-71
1.3 m	-62	4.3 m	-77
1.4 m	-58	4.4 m	-69
1.5 m	-65	4.5 m	-71
1.6 m	-60	4.6 m	-70
1.7 m	-71	4.7 m	-77
1.8 m	-71	4.8 m	-81
1.9 m	-65	4.9 m	-74
2.0 m	-69	5.0 m	-73
2.1 m	-71	5.1 m	-71
2.2 m	-76	5.2 m	-77
2.3 m	-68	5.3 m	-76
2.4 m	-70	5.4 m	-80
2.5 m	-67	5.5 m	-84
2.6 m	-68	5.6 m	-80
2.7 m	-66	5.7 m	-85
2.8 m	-65	5.8 m	-72
2.9 m	-69	5.9 m	-76
3.0 m	-74	6.0 m	-80

Table 86: Quicklock, Home Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-45	3.1 m	-76
0.2 m	-51	3.2 m	-71
0.3 m	-48	3.3 m	-73
0.4 m	-58	3.4 m	-70
0.5 m	-54	3.5 m	-67
0.6 m	-57	3.6 m	-73
0.7 m	-59	3.7 m	-72
0.8 m	-61	3.8 m	-72
0.9 m	-61	3.9 m	-75
1.0 m	-56	4.0 m	-73
1.1 m	-62	4.1 m	-67
1.2 m	-65	4.2 m	-76
1.3 m	-64	4.3 m	-70
1.4 m	-63	4.4 m	-74
1.5 m	-61	4.5 m	-72
1.6 m	-64	4.6 m	-70
1.7 m	-60	4.7 m	-78
1.8 m	-61	4.8 m	-76
1.9 m	-69	4.9 m	-77
2.0 m	-66	5.0 m	-82
2.1 m	-63	5.1 m	-75
2.2 m	-68	5.2 m	-75
2.3 m	-66	5.3 m	-77
2.4 m	-71	5.4 m	-81
2.5 m	-69	5.5 m	-82
2.6 m	-67	5.6 m	-79
2.7 m	-72	5.7 m	-94
2.8 m	-64	5.8 m	-72
2.9 m	-75	5.9 m	-79
3.0 m	-68	6.0 m	-73

Table 87: Quicklock, Office Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-51	3.1 m	-72
0.2 m	-51	3.2 m	-74
0.3 m	-57	3.3 m	-73
0.4 m	-70	3.4 m	-72
0.5 m	-68	3.5 m	-76
0.6 m	-74	3.6 m	-68
0.7 m	-72	3.7 m	-65
0.8 m	-70	3.8 m	-69
0.9 m	-67	3.9 m	-76
1.0 m	-58	4.0 m	-71
1.1 m	-66	4.1 m	-73
1.2 m	-56	4.2 m	-74
1.3 m	-55	4.3 m	-77
1.4 m	-70	4.4 m	-70
1.5 m	-69	4.5 m	-84
1.6 m	-76	4.6 m	-77
1.7 m	-68	4.7 m	-80
1.8 m	-72	4.8 m	-76
1.9 m	-66	4.9 m	-83
2.0 m	-66	5.0 m	-74
2.1 m	-69	5.1 m	-79
2.2 m	-70	5.2 m	-73
2.3 m	-81	5.3 m	-72
2.4 m	-69	5.4 m	-74
2.5 m	-75	5.5 m	-81
2.6 m	-81	5.6 m	-91
2.7 m	-87	5.7 m	-84
2.8 m	-67	5.8 m	-90
2.9 m	-76	5.9 m	-74
3.0 m	-76	6.0 m	-83

Table 88: Quicklock, Office Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-51	3.1 m	-72
0.2 m	-71	3.2 m	-89
0.3 m	-58	3.3 m	-78
0.4 m	-65	3.4 m	-76
0.5 m	-63	3.5 m	-71
0.6 m	-60	3.6 m	-66
0.7 m	-65	3.7 m	-68
0.8 m	-72	3.8 m	-73
0.9 m	-66	3.9 m	-80
1.0 m	-72	4.0 m	-84
1.1 m	-60	4.1 m	-71
1.2 m	-73	4.2 m	-76
1.3 m	-70	4.3 m	-74
1.4 m	-84	4.4 m	-73
1.5 m	-69	4.5 m	-78
1.6 m	-77	4.6 m	-74
1.7 m	-69	4.7 m	-69
1.8 m	-66	4.8 m	-74
1.9 m	-67	4.9 m	-69
2.0 m	-59	5.0 m	-83
2.1 m	-78	5.1 m	-70
2.2 m	-68	5.2 m	-70
2.3 m	-70	5.3 m	-80
2.4 m	-68	5.4 m	-70
2.5 m	-76	5.5 m	-76
2.6 m	-84	5.6 m	-77
2.7 m	-71	5.7 m	-75
2.8 m	-65	5.8 m	-71
2.9 m	-91	5.9 m	-73
3.0 m	-73	6.0 m	-80

Table 89: Quicklock, Office Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-50	3.1 m	-63
0.2 m	-57	3.2 m	-62
0.3 m	-50	3.3 m	-65
0.4 m	-53	3.4 m	-82
0.5 m	-57	3.5 m	-74
0.6 m	-62	3.6 m	-78
0.7 m	-56	3.7 m	-72
0.8 m	-57	3.8 m	-82
0.9 m	-60	3.9 m	-80
1.0 m	-60	4.0 m	-80
1.1 m	-59	4.1 m	-62
1.2 m	-83	4.2 m	-65
1.3 m	-65	4.3 m	-70
1.4 m	-61	4.4 m	-73
1.5 m	-61	4.5 m	-69
1.6 m	-60	4.6 m	-66
1.7 m	-58	4.7 m	-65
1.8 m	-60	4.8 m	-70
1.9 m	-68	4.9 m	-65
2.0 m	-65	5.0 m	-66
2.1 m	-65	5.1 m	-65
2.2 m	-70	5.2 m	-63
2.3 m	-65	5.3 m	-68
2.4 m	-70	5.4 m	-70
2.5 m	-64	5.5 m	-70
2.6 m	-62	5.6 m	-75
2.7 m	-60	5.7 m	-82
2.8 m	-64	5.8 m	-66
2.9 m	-61	5.9 m	-65
3.0 m	-69	6.0 m	-87

Table 90: Quicklock, Office Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-54	3.1 m	-65
0.2 m	-55	3.2 m	-74
0.3 m	-56	3.3 m	-58
0.4 m	-59	3.4 m	-73
0.5 m	-59	3.5 m	-74
0.6 m	-58	3.6 m	-64
0.7 m	-58	3.7 m	-60
0.8 m	-57	3.8 m	-75
0.9 m	-69	3.9 m	-61
1.0 m	-60	4.0 m	-77
1.1 m	-81	4.1 m	-64
1.2 m	-65	4.2 m	-88
1.3 m	-60	4.3 m	-88
1.4 m	-56	4.4 m	-71
1.5 m	-57	4.5 m	-69
1.6 m	-57	4.6 m	-68
1.7 m	-67	4.7 m	-72
1.8 m	-70	4.8 m	-68
1.9 m	-60	4.9 m	-67
2.0 m	-67	5.0 m	-67
2.1 m	-62	5.1 m	-70
2.2 m	-67	5.2 m	-64
2.3 m	-61	5.3 m	-68
2.4 m	-64	5.4 m	-66
2.5 m	-68	5.5 m	-62
2.6 m	-66	5.6 m	-65
2.7 m	-59	5.7 m	-69
2.8 m	-59	5.8 m	-70
2.9 m	-73	5.9 m	-67
3.0 m	-66	6.0 m	-76

Table 91: Samsung S7, Disaster Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-51	3.1 m	-72
0.2 m	-48	3.2 m	-87
0.3 m	-54	3.3 m	-77
0.4 m	-63	3.4 m	-71
0.5 m	-54	3.5 m	-80
0.6 m	-58	3.6 m	-71
0.7 m	-61	3.7 m	-77
0.8 m	-57	3.8 m	-75
0.9 m	-63	3.9 m	-78
1.0 m	-58	4.0 m	-89
1.1 m	-62	4.1 m	-90
1.2 m	-64	4.2 m	-82
1.3 m	-60	4.3 m	-74
1.4 m	-76	4.4 m	-78
1.5 m	-80	4.5 m	-77
1.6 m	-71	4.6 m	-85
1.7 m	-63	4.7 m	-84
1.8 m	-73	4.8 m	-82
1.9 m	-73	4.9 m	-82
2.0 m	-81	5.0 m	-88
2.1 m	-78	5.1 m	-78
2.2 m	-72	5.2 m	-90
2.3 m	-71	5.3 m	-87
2.4 m	-69	5.4 m	-81
2.5 m	-73	5.5 m	-86
2.6 m	-72	5.6 m	-83
2.7 m	-82	5.7 m	-84
2.8 m	-82	5.8 m	-96
2.9 m	-82	5.9 m	-87
3.0 m	-76	6.0 m	-83

Table 92: Samsung S7, Disaster Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-48	3.1 m	-72
0.2 m	-45	3.2 m	-76
0.3 m	-53	3.3 m	-75
0.4 m	-76	3.4 m	-71
0.5 m	-50	3.5 m	-89
0.6 m	-51	3.6 m	-75
0.7 m	-55	3.7 m	-82
0.8 m	-52	3.8 m	-77
0.9 m	-72	3.9 m	-74
1.0 m	-70	4.0 m	-75
1.1 m	-60	4.1 m	-72
1.2 m	-65	4.2 m	-79
1.3 m	-62	4.3 m	-76
1.4 m	-62	4.4 m	-73
1.5 m	-76	4.5 m	-84
1.6 m	-68	4.6 m	-74
1.7 m	-71	4.7 m	-85
1.8 m	-74	4.8 m	-78
1.9 m	-66	4.9 m	-76
2.0 m	-65	5.0 m	-82
2.1 m	-92	5.1 m	-74
2.2 m	-92	5.2 m	-78
2.3 m	-76	5.3 m	-89
2.4 m	-78	5.4 m	-87
2.5 m	-70	5.5 m	-88
2.6 m	-75	5.6 m	-88
2.7 m	-72	5.7 m	-91
2.8 m	-66	5.8 m	-82
2.9 m	-71	5.9 m	-84
3.0 m	-82	6.0 m	-87

Table 93: Samsung S7, Disaster Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-56	3.1 m	-69
0.2 m	-66	3.2 m	-72
0.3 m	-57	3.3 m	-76
0.4 m	-63	3.4 m	-88
0.5 m	-65	3.5 m	-75
0.6 m	-63	3.6 m	-69
0.7 m	-52	3.7 m	-82
0.8 m	-53	3.8 m	-73
0.9 m	-54	3.9 m	-77
1.0 m	-54	4.0 m	-84
1.1 m	-62	4.1 m	-65
1.2 m	-65	4.2 m	-78
1.3 m	-63	4.3 m	-78
1.4 m	-58	4.4 m	-76
1.5 m	-64	4.5 m	-72
1.6 m	-66	4.6 m	-65
1.7 m	-68	4.7 m	-88
1.8 m	-60	4.8 m	-72
1.9 m	-64	4.9 m	-71
2.0 m	-72	5.0 m	-84
2.1 m	-73	5.1 m	-78
2.2 m	-68	5.2 m	-72
2.3 m	-65	5.3 m	-72
2.4 m	-66	5.4 m	-80
2.5 m	-72	5.5 m	-74
2.6 m	-70	5.6 m	-79
2.7 m	-67	5.7 m	-76
2.8 m	-72	5.8 m	-70
2.9 m	-73	5.9 m	-75
3.0 m	-72	6.0 m	-75

Table 94: Samsung S7, Disaster Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-62	3.1 m	-81
0.2 m	-60	3.2 m	-78
0.3 m	-54	3.3 m	-66
0.4 m	-50	3.4 m	-70
0.5 m	-52	3.5 m	-72
0.6 m	-55	3.6 m	-73
0.7 m	-51	3.7 m	-73
0.8 m	-55	3.8 m	-74
0.9 m	-63	3.9 m	-73
1.0 m	-56	4.0 m	-74
1.1 m	-67	4.1 m	-78
1.2 m	-66	4.2 m	-77
1.3 m	-73	4.3 m	-80
1.4 m	-56	4.4 m	-71
1.5 m	-66	4.5 m	-76
1.6 m	-63	4.6 m	-71
1.7 m	-65	4.7 m	-90
1.8 m	-65	4.8 m	-75
1.9 m	-67	4.9 m	-77
2.0 m	-62	5.0 m	-66
2.1 m	-68	5.1 m	-73
2.2 m	-68	5.2 m	-73
2.3 m	-76	5.3 m	-77
2.4 m	-74	5.4 m	-80
2.5 m	-69	5.5 m	-75
2.6 m	-65	5.6 m	-72
2.7 m	-66	5.7 m	-89
2.8 m	-64	5.8 m	-81
2.9 m	-73	5.9 m	-78
3.0 m	-84	6.0 m	-77

Table 95: Samsung S7, Home Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-61	3.1 m	-68
0.2 m	-59	3.2 m	-81
0.3 m	-57	3.3 m	-70
0.4 m	-53	3.4 m	-84
0.5 m	-54	3.5 m	-70
0.6 m	-58	3.6 m	-69
0.7 m	-66	3.7 m	-80
0.8 m	-59	3.8 m	-72
0.9 m	-66	3.9 m	-74
1.0 m	-60	4.0 m	-75
1.1 m	-64	4.1 m	-71
1.2 m	-66	4.2 m	-76
1.3 m	-66	4.3 m	-65
1.4 m	-74	4.4 m	-64
1.5 m	-68	4.5 m	-66
1.6 m	-69	4.6 m	-65
1.7 m	-64	4.7 m	-64
1.8 m	-62	4.8 m	-79
1.9 m	-76	4.9 m	-76
2.0 m	-70	5.0 m	-80
2.1 m	-73	5.1 m	-70
2.2 m	-64	5.2 m	-84
2.3 m	-65	5.3 m	-68
2.4 m	-71	5.4 m	-75
2.5 m	-70	5.5 m	-73
2.6 m	-85	5.6 m	-69
2.7 m	-69	5.7 m	-74
2.8 m	-76	5.8 m	-85
2.9 m	-66	5.9 m	-71
3.0 m	-67	6.0 m	-77

Table 96: Samsung S7, Home Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-62	3.1 m	-79
0.2 m	-53	3.2 m	-73
0.3 m	-55	3.3 m	-66
0.4 m	-64	3.4 m	-75
0.5 m	-69	3.5 m	-74
0.6 m	-55	3.6 m	-69
0.7 m	-69	3.7 m	-66
0.8 m	-57	3.8 m	-68
0.9 m	-65	3.9 m	-72
1.0 m	-73	4.0 m	-78
1.1 m	-68	4.1 m	-72
1.2 m	-75	4.2 m	-65
1.3 m	-69	4.3 m	-76
1.4 m	-60	4.4 m	-64
1.5 m	-66	4.5 m	-65
1.6 m	-63	4.6 m	-66
1.7 m	-72	4.7 m	-69
1.8 m	-62	4.8 m	-72
1.9 m	-66	4.9 m	-72
2.0 m	-60	5.0 m	-76
2.1 m	-71	5.1 m	-78
2.2 m	-70	5.2 m	-71
2.3 m	-74	5.3 m	-73
2.4 m	-68	5.4 m	-75
2.5 m	-72	5.5 m	-79
2.6 m	-77	5.6 m	-71
2.7 m	-79	5.7 m	-69
2.8 m	-73	5.8 m	-70
2.9 m	-68	5.9 m	-74
3.0 m	-73	6.0 m	-78

Table 97: Samsung S7, Home Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-69	3.1 m	-74
0.2 m	-68	3.2 m	-68
0.3 m	-58	3.3 m	-69
0.4 m	-59	3.4 m	-74
0.5 m	-51	3.5 m	-79
0.6 m	-59	3.6 m	-73
0.7 m	-62	3.7 m	-74
0.8 m	-58	3.8 m	-68
0.9 m	-58	3.9 m	-70
1.0 m	-60	4.0 m	-70
1.1 m	-60	4.1 m	-62
1.2 m	-65	4.2 m	-65
1.3 m	-75	4.3 m	-67
1.4 m	-73	4.4 m	-69
1.5 m	-72	4.5 m	-68
1.6 m	-72	4.6 m	-71
1.7 m	-78	4.7 m	-68
1.8 m	-66	4.8 m	-68
1.9 m	-68	4.9 m	-75
2.0 m	-75	5.0 m	-68
2.1 m	-63	5.1 m	-66
2.2 m	-62	5.2 m	-69
2.3 m	-68	5.3 m	-72
2.4 m	-63	5.4 m	-66
2.5 m	-70	5.5 m	-72
2.6 m	-69	5.6 m	-68
2.7 m	-82	5.7 m	-75
2.8 m	-73	5.8 m	-78
2.9 m	-75	5.9 m	-75
3.0 m	-72	6.0 m	-76

Table 98: Samsung S7, Home Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-43	3.1 m	-65
0.2 m	-40	3.2 m	-64
0.3 m	-41	3.3 m	-63
0.4 m	-46	3.4 m	-66
0.5 m	-44	3.5 m	-70
0.6 m	-50	3.6 m	-67
0.7 m	-47	3.7 m	-70
0.8 m	-50	3.8 m	-67
0.9 m	-52	3.9 m	-63
1.0 m	-52	4.0 m	-66
1.1 m	-53	4.1 m	-78
1.2 m	-57	4.2 m	-64
1.3 m	-53	4.3 m	-65
1.4 m	-54	4.4 m	-70
1.5 m	-56	4.5 m	-74
1.6 m	-57	4.6 m	-82
1.7 m	-56	4.7 m	-67
1.8 m	-55	4.8 m	-74
1.9 m	-59	4.9 m	-69
2.0 m	-63	5.0 m	-70
2.1 m	-60	5.1 m	-72
2.2 m	-57	5.2 m	-76
2.3 m	-62	5.3 m	-79
2.4 m	-65	5.4 m	-71
2.5 m	-74	5.5 m	-72
2.6 m	-65	5.6 m	-80
2.7 m	-60	5.7 m	-81
2.8 m	-63	5.8 m	-71
2.9 m	-64	5.9 m	-70
3.0 m	-76	6.0 m	-76

Table 99: Samsung S7, Office Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-41	3.1 m	-64
0.2 m	-46	3.2 m	-70
0.3 m	-52	3.3 m	-65
0.4 m	-46	3.4 m	-72
0.5 m	-50	3.5 m	-63
0.6 m	-48	3.6 m	-62
0.7 m	-54	3.7 m	-72
0.8 m	-58	3.8 m	-74
0.9 m	-62	3.9 m	-74
1.0 m	-52	4.0 m	-67
1.1 m	-61	4.1 m	-62
1.2 m	-58	4.2 m	-73
1.3 m	-69	4.3 m	-70
1.4 m	-60	4.4 m	-72
1.5 m	-69	4.5 m	-67
1.6 m	-66	4.6 m	-59
1.7 m	-62	4.7 m	-64
1.8 m	-63	4.8 m	-67
1.9 m	-66	4.9 m	-68
2.0 m	-62	5.0 m	-74
2.1 m	-65	5.1 m	-73
2.2 m	-63	5.2 m	-66
2.3 m	-70	5.3 m	-64
2.4 m	-71	5.4 m	-68
2.5 m	-81	5.5 m	-73
2.6 m	-76	5.6 m	-72
2.7 m	-64	5.7 m	-65
2.8 m	-67	5.8 m	-73
2.9 m	-62	5.9 m	-65
3.0 m	-65	6.0 m	-67

Table 100: Samsung S7, Office Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-46	3.1 m	-75
0.2 m	-47	3.2 m	-60
0.3 m	-44	3.3 m	-64
0.4 m	-51	3.4 m	-65
0.5 m	-47	3.5 m	-66
0.6 m	-50	3.6 m	-76
0.7 m	-54	3.7 m	-72
0.8 m	-62	3.8 m	-70
0.9 m	-64	3.9 m	-72
1.0 m	-51	4.0 m	-67
1.1 m	-77	4.1 m	-68
1.2 m	-67	4.2 m	-64
1.3 m	-69	4.3 m	-71
1.4 m	-63	4.4 m	-66
1.5 m	-73	4.5 m	-59
1.6 m	-66	4.6 m	-58
1.7 m	-65	4.7 m	-65
1.8 m	-67	4.8 m	-75
1.9 m	-69	4.9 m	-64
2.0 m	-65	5.0 m	-62
2.1 m	-68	5.1 m	-67
2.2 m	-66	5.2 m	-62
2.3 m	-73	5.3 m	-60
2.4 m	-62	5.4 m	-62
2.5 m	-73	5.5 m	-69
2.6 m	-67	5.6 m	-72
2.7 m	-77	5.7 m	-66
2.8 m	-62	5.8 m	-76
2.9 m	-72	5.9 m	-71
3.0 m	-66	6.0 m	-72

Table 101: Samsung S7, Office Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-60	3.1 m	-61
0.2 m	-56	3.2 m	-60
0.3 m	-64	3.3 m	-60
0.4 m	-53	3.4 m	-70
0.5 m	-57	3.5 m	-71
0.6 m	-52	3.6 m	-67
0.7 m	-58	3.7 m	-72
0.8 m	-61	3.8 m	-65
0.9 m	-53	3.9 m	-62
1.0 m	-51	4.0 m	-72
1.1 m	-60	4.1 m	-64
1.2 m	-65	4.2 m	-68
1.3 m	-60	4.3 m	-70
1.4 m	-62	4.4 m	-68
1.5 m	-58	4.5 m	-68
1.6 m	-67	4.6 m	-73
1.7 m	-58	4.7 m	-59
1.8 m	-52	4.8 m	-67
1.9 m	-55	4.9 m	-70
2.0 m	-60	5.0 m	-66
2.1 m	-62	5.1 m	-70
2.2 m	-62	5.2 m	-68
2.3 m	-63	5.3 m	-70
2.4 m	-72	5.4 m	-65
2.5 m	-60	5.5 m	-74
2.6 m	-61	5.6 m	-67
2.7 m	-62	5.7 m	-76
2.8 m	-76	5.8 m	-71
2.9 m	-72	5.9 m	-68
3.0 m	-67	6.0 m	-69

Table 102: Samsung S7, Office Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-52	3.1 m	-60
0.2 m	-62	3.2 m	-58
0.3 m	-60	3.3 m	-63
0.4 m	-60	3.4 m	-63
0.5 m	-51	3.5 m	-64
0.6 m	-61	3.6 m	-62
0.7 m	-59	3.7 m	-60
0.8 m	-54	3.8 m	-70
0.9 m	-55	3.9 m	-65
1.0 m	-56	4.0 m	-74
1.1 m	-72	4.1 m	-67
1.2 m	-66	4.2 m	-64
1.3 m	-72	4.3 m	-67
1.4 m	-75	4.4 m	-65
1.5 m	-57	4.5 m	-76
1.6 m	-63	4.6 m	-60
1.7 m	-60	4.7 m	-80
1.8 m	-64	4.8 m	-69
1.9 m	-58	4.9 m	-67
2.0 m	-69	5.0 m	-76
2.1 m	-59	5.1 m	-75
2.2 m	-62	5.2 m	-64
2.3 m	-74	5.3 m	-68
2.4 m	-58	5.4 m	-86
2.5 m	-57	5.5 m	-77
2.6 m	-63	5.6 m	-80
2.7 m	-73	5.7 m	-70
2.8 m	-71	5.8 m	-80
2.9 m	-66	5.9 m	-74
3.0 m	-70	6.0 m	-65

Table 103: Samsung S8, Disaster Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-51	3.1 m	-80
0.2 m	-51	3.2 m	-76
0.3 m	-66	3.3 m	-83
0.4 m	-54	3.4 m	-75
0.5 m	-55	3.5 m	-83
0.6 m	-58	3.6 m	-73
0.7 m	-87	3.7 m	-83
0.8 m	-84	3.8 m	-82
0.9 m	-60	3.9 m	-79
1.0 m	-64	4.0 m	-78
1.1 m	-63	4.1 m	-80
1.2 m	-64	4.2 m	-77
1.3 m	-69	4.3 m	-80
1.4 m	-67	4.4 m	-84
1.5 m	-76	4.5 m	-81
1.6 m	-72	4.6 m	-80
1.7 m	-71	4.7 m	-91
1.8 m	-70	4.8 m	-88
1.9 m	-69	4.9 m	-88
2.0 m	-83	5.0 m	-89
2.1 m	-78	5.1 m	-87
2.2 m	-72	5.2 m	-77
2.3 m	-74	5.3 m	-79
2.4 m	-83	5.4 m	-78
2.5 m	-76	5.5 m	-84
2.6 m	-80	5.6 m	-93
2.7 m	-81	5.7 m	-93
2.8 m	-82	5.8 m	-97
2.9 m	-76	5.9 m	-85
3.0 m	-75	6.0 m	-89

Table 104: Samsung S8, Disaster Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-53	3.1 m	-82
0.2 m	-48	3.2 m	-90
0.3 m	-68	3.3 m	-74
0.4 m	-64	3.4 m	-78
0.5 m	-66	3.5 m	-79
0.6 m	-67	3.6 m	-82
0.7 m	-71	3.7 m	-80
0.8 m	-70	3.8 m	-72
0.9 m	-71	3.9 m	-80
1.0 m	-70	4.0 m	-77
1.1 m	-73	4.1 m	-80
1.2 m	-67	4.2 m	-74
1.3 m	-63	4.3 m	-77
1.4 m	-69	4.4 m	-87
1.5 m	-64	4.5 m	-76
1.6 m	-68	4.6 m	-72
1.7 m	-78	4.7 m	-88
1.8 m	-71	4.8 m	-79
1.9 m	-73	4.9 m	-82
2.0 m	-75	5.0 m	-88
2.1 m	-65	5.1 m	-76
2.2 m	-78	5.2 m	-90
2.3 m	-74	5.3 m	-82
2.4 m	-68	5.4 m	-91
2.5 m	-80	5.5 m	-89
2.6 m	-78	5.6 m	-86
2.7 m	-82	5.7 m	-88
2.8 m	-74	5.8 m	-88
2.9 m	-73	5.9 m	-89
3.0 m	-81	6.0 m	-90

Table 105: Samsung S8, Disaster Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-61	3.1 m	-65
0.2 m	-56	3.2 m	-70
0.3 m	-62	3.3 m	-74
0.4 m	-64	3.4 m	-73
0.5 m	-55	3.5 m	-75
0.6 m	-59	3.6 m	-72
0.7 m	-50	3.7 m	-72
0.8 m	-51	3.8 m	-74
0.9 m	-50	3.9 m	-65
1.0 m	-68	4.0 m	-68
1.1 m	-63	4.1 m	-69
1.2 m	-64	4.2 m	-76
1.3 m	-66	4.3 m	-76
1.4 m	-65	4.4 m	-71
1.5 m	-58	4.5 m	-75
1.6 m	-68	4.6 m	-71
1.7 m	-76	4.7 m	-81
1.8 m	-59	4.8 m	-75
1.9 m	-57	4.9 m	-73
2.0 m	-70	5.0 m	-71
2.1 m	-62	5.1 m	-71
2.2 m	-67	5.2 m	-66
2.3 m	-68	5.3 m	-67
2.4 m	-80	5.4 m	-70
2.5 m	-64	5.5 m	-73
2.6 m	-66	5.6 m	-76
2.7 m	-70	5.7 m	-70
2.8 m	-71	5.8 m	-78
2.9 m	-70	5.9 m	-82
3.0 m	-71	6.0 m	-81

Table 106: Samsung S8, Disaster Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-53	3.1 m	-67
0.2 m	-69	3.2 m	-75
0.3 m	-56	3.3 m	-84
0.4 m	-55	3.4 m	-67
0.5 m	-52	3.5 m	-74
0.6 m	-46	3.6 m	-69
0.7 m	-47	3.7 m	-84
0.8 m	-63	3.8 m	-78
0.9 m	-56	3.9 m	-74
1.0 m	-86	4.0 m	-72
1.1 m	-59	4.1 m	-77
1.2 m	-59	4.2 m	-83
1.3 m	-61	4.3 m	-78
1.4 m	-60	4.4 m	-72
1.5 m	-69	4.5 m	-72
1.6 m	-58	4.6 m	-69
1.7 m	-72	4.7 m	-76
1.8 m	-61	4.8 m	-78
1.9 m	-68	4.9 m	-81
2.0 m	-66	5.0 m	-80
2.1 m	-65	5.1 m	-74
2.2 m	-70	5.2 m	-83
2.3 m	-66	5.3 m	-79
2.4 m	-70	5.4 m	-76
2.5 m	-68	5.5 m	-87
2.6 m	-76	5.6 m	-90
2.7 m	-74	5.7 m	-86
2.8 m	-66	5.8 m	-83
2.9 m	-66	5.9 m	-69
3.0 m	-74	6.0 m	-83

Table 107: Samsung S8, Home Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-48	3.1 m	-72
0.2 m	-50	3.2 m	-78
0.3 m	-50	3.3 m	-81
0.4 m	-61	3.4 m	-69
0.5 m	-64	3.5 m	-66
0.6 m	-65	3.6 m	-75
0.7 m	-63	3.7 m	-75
0.8 m	-67	3.8 m	-79
0.9 m	-74	3.9 m	-76
1.0 m	-69	4.0 m	-74
1.1 m	-68	4.1 m	-77
1.2 m	-66	4.2 m	-70
1.3 m	-91	4.3 m	-81
1.4 m	-66	4.4 m	-74
1.5 m	-63	4.5 m	-69
1.6 m	-81	4.6 m	-74
1.7 m	-74	4.7 m	-66
1.8 m	-71	4.8 m	-86
1.9 m	-70	4.9 m	-75
2.0 m	-81	5.0 m	-81
2.1 m	-86	5.1 m	-69
2.2 m	-68	5.2 m	-74
2.3 m	-74	5.3 m	-81
2.4 m	-80	5.4 m	-67
2.5 m	-81	5.5 m	-71
2.6 m	-68	5.6 m	-80
2.7 m	-71	5.7 m	-73
2.8 m	-67	5.8 m	-68
2.9 m	-70	5.9 m	-73
3.0 m	-74	6.0 m	-84

Table 108: Samsung S8, Home Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-52	3.1 m	-80
0.2 m	-57	3.2 m	-82
0.3 m	-62	3.3 m	-81
0.4 m	-59	3.4 m	-70
0.5 m	-60	3.5 m	-76
0.6 m	-60	3.6 m	-80
0.7 m	-61	3.7 m	-73
0.8 m	-68	3.8 m	-74
0.9 m	-66	3.9 m	-76
1.0 m	-73	4.0 m	-67
1.1 m	-68	4.1 m	-72
1.2 m	-68	4.2 m	-70
1.3 m	-65	4.3 m	-73
1.4 m	-70	4.4 m	-76
1.5 m	-66	4.5 m	-72
1.6 m	-67	4.6 m	-70
1.7 m	-70	4.7 m	-81
1.8 m	-74	4.8 m	-79
1.9 m	-73	4.9 m	-91
2.0 m	-70	5.0 m	-87
2.1 m	-70	5.1 m	-68
2.2 m	-78	5.2 m	-79
2.3 m	-68	5.3 m	-80
2.4 m	-81	5.4 m	-76
2.5 m	-78	5.5 m	-82
2.6 m	-75	5.6 m	-70
2.7 m	-73	5.7 m	-73
2.8 m	-80	5.8 m	-77
2.9 m	-74	5.9 m	-76
3.0 m	-70	6.0 m	-86

Table 109: Samsung S8, Home Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-53	3.1 m	-67
0.2 m	-49	3.2 m	-73
0.3 m	-54	3.3 m	-84
0.4 m	-64	3.4 m	-74
0.5 m	-61	3.5 m	-72
0.6 m	-66	3.6 m	-86
0.7 m	-61	3.7 m	-72
0.8 m	-66	3.8 m	-84
0.9 m	-70	3.9 m	-72
1.0 m	-62	4.0 m	-67
1.1 m	-60	4.1 m	-68
1.2 m	-72	4.2 m	-69
1.3 m	-70	4.3 m	-68
1.4 m	-68	4.4 m	-73
1.5 m	-88	4.5 m	-80
1.6 m	-69	4.6 m	-65
1.7 m	-76	4.7 m	-75
1.8 m	-73	4.8 m	-68
1.9 m	-76	4.9 m	-77
2.0 m	-70	5.0 m	-71
2.1 m	-81	5.1 m	-70
2.2 m	-74	5.2 m	-68
2.3 m	-72	5.3 m	-71
2.4 m	-74	5.4 m	-69
2.5 m	-83	5.5 m	-75
2.6 m	-74	5.6 m	-79
2.7 m	-71	5.7 m	-75
2.8 m	-78	5.8 m	-74
2.9 m	-70	5.9 m	-70
3.0 m	-66	6.0 m	-79

Table 110: Samsung S8, Home Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-53	3.1 m	-67
0.2 m	-49	3.2 m	-73
0.3 m	-54	3.3 m	-84
0.4 m	-64	3.4 m	-74
0.5 m	-61	3.5 m	-72
0.6 m	-66	3.6 m	-86
0.7 m	-61	3.7 m	-72
0.8 m	-66	3.8 m	-84
0.9 m	-70	3.9 m	-72
1.0 m	-62	4.0 m	-67
1.1 m	-60	4.1 m	-68
1.2 m	-72	4.2 m	-69
1.3 m	-70	4.3 m	-68
1.4 m	-68	4.4 m	-73
1.5 m	-88	4.5 m	-80
1.6 m	-69	4.6 m	-65
1.7 m	-76	4.7 m	-75
1.8 m	-73	4.8 m	-68
1.9 m	-76	4.9 m	-77
2.0 m	-70	5.0 m	-71
2.1 m	-81	5.1 m	-70
2.2 m	-74	5.2 m	-68
2.3 m	-72	5.3 m	-71
2.4 m	-74	5.4 m	-69
2.5 m	-83	5.5 m	-75
2.6 m	-74	5.6 m	-79
2.7 m	-71	5.7 m	-75
2.8 m	-78	5.8 m	-74
2.9 m	-70	5.9 m	-70
3.0 m	-66	6.0 m	-79

Table 111: Samsung S8, Office Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-45	3.1 m	-88
0.2 m	-44	3.2 m	-62
0.3 m	-44	3.3 m	-62
0.4 m	-46	3.4 m	-63
0.5 m	-51	3.5 m	-70
0.6 m	-47	3.6 m	-66
0.7 m	-55	3.7 m	-88
0.8 m	-56	3.8 m	-72
0.9 m	-60	3.9 m	-67
1.0 m	-58	4.0 m	-66
1.1 m	-57	4.1 m	-73
1.2 m	-68	4.2 m	-82
1.3 m	-64	4.3 m	-81
1.4 m	-74	4.4 m	-71
1.5 m	-65	4.5 m	-65
1.6 m	-62	4.6 m	-76
1.7 m	-79	4.7 m	-72
1.8 m	-64	4.8 m	-75
1.9 m	-68	4.9 m	-65
2.0 m	-70	5.0 m	-72
2.1 m	-72	5.1 m	-65
2.2 m	-67	5.2 m	-69
2.3 m	-64	5.3 m	-65
2.4 m	-69	5.4 m	-72
2.5 m	-77	5.5 m	-73
2.6 m	-80	5.6 m	-79
2.7 m	-65	5.7 m	-71
2.8 m	-64	5.8 m	-74
2.9 m	-72	5.9 m	-72
3.0 m	-74	6.0 m	-73

Table 112: Samsung S8, Office Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-43	3.1 m	-68
0.2 m	-47	3.2 m	-68
0.3 m	-49	3.3 m	-64
0.4 m	-44	3.4 m	-81
0.5 m	-47	3.5 m	-66
0.6 m	-56	3.6 m	-64
0.7 m	-61	3.7 m	-66
0.8 m	-58	3.8 m	-73
0.9 m	-54	3.9 m	-83
1.0 m	-60	4.0 m	-67
1.1 m	-67	4.1 m	-69
1.2 m	-81	4.2 m	-76
1.3 m	-63	4.3 m	-69
1.4 m	-68	4.4 m	-66
1.5 m	-62	4.5 m	-65
1.6 m	-62	4.6 m	-63
1.7 m	-92	4.7 m	-72
1.8 m	-66	4.8 m	-73
1.9 m	-62	4.9 m	-67
2.0 m	-76	5.0 m	-70
2.1 m	-66	5.1 m	-69
2.2 m	-67	5.2 m	-61
2.3 m	-66	5.3 m	-66
2.4 m	-65	5.4 m	-73
2.5 m	-79	5.5 m	-74
2.6 m	-74	5.6 m	-68
2.7 m	-75	5.7 m	-77
2.8 m	-60	5.8 m	-75
2.9 m	-72	5.9 m	-74
3.0 m	-67	6.0 m	-68

Table 113: Samsung S8, Office Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-61	3.1 m	-66
0.2 m	-69	3.2 m	-65
0.3 m	-63	3.3 m	-67
0.4 m	-57	3.4 m	-71
0.5 m	-52	3.5 m	-70
0.6 m	-56	3.6 m	-71
0.7 m	-52	3.7 m	-62
0.8 m	-64	3.8 m	-61
0.9 m	-57	3.9 m	-70
1.0 m	-60	4.0 m	-74
1.1 m	-65	4.1 m	-68
1.2 m	-64	4.2 m	-62
1.3 m	-64	4.3 m	-68
1.4 m	-63	4.4 m	-62
1.5 m	-83	4.5 m	-80
1.6 m	-61	4.6 m	-70
1.7 m	-60	4.7 m	-71
1.8 m	-71	4.8 m	-76
1.9 m	-61	4.9 m	-68
2.0 m	-62	5.0 m	-79
2.1 m	-63	5.1 m	-75
2.2 m	-62	5.2 m	-73
2.3 m	-60	5.3 m	-66
2.4 m	-63	5.4 m	-70
2.5 m	-58	5.5 m	-69
2.6 m	-62	5.6 m	-76
2.7 m	-60	5.7 m	-72
2.8 m	-67	5.8 m	-71
2.9 m	-66	5.9 m	-66
3.0 m	-61	6.0 m	-68

Table 114: Samsung S8, Office Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-58	3.1 m	-60
0.2 m	-62	3.2 m	-63
0.3 m	-68	3.3 m	-62
0.4 m	-59	3.4 m	-78
0.5 m	-59	3.5 m	-62
0.6 m	-60	3.6 m	-65
0.7 m	-54	3.7 m	-63
0.8 m	-53	3.8 m	-67
0.9 m	-60	3.9 m	-70
1.0 m	-56	4.0 m	-62
1.1 m	-62	4.1 m	-74
1.2 m	-68	4.2 m	-63
1.3 m	-77	4.3 m	-64
1.4 m	-60	4.4 m	-63
1.5 m	-67	4.5 m	-72
1.6 m	-72	4.6 m	-62
1.7 m	-70	4.7 m	-66
1.8 m	-58	4.8 m	-67
1.9 m	-59	4.9 m	-83
2.0 m	-66	5.0 m	-76
2.1 m	-57	5.1 m	-64
2.2 m	-57	5.2 m	-87
2.3 m	-62	5.3 m	-64
2.4 m	-62	5.4 m	-77
2.5 m	-57	5.5 m	-65
2.6 m	-66	5.6 m	-70
2.7 m	-61	5.7 m	-64
2.8 m	-56	5.8 m	-74
2.9 m	-62	5.9 m	-73
3.0 m	-69	6.0 m	-76

Table 115: Fitbit Surge, Disaster Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-51	3.1 m	-79
0.2 m	-59	3.2 m	-78
0.3 m	-56	3.3 m	-82
0.4 m	-65	3.4 m	-76
0.5 m	-52	3.5 m	-80
0.6 m	-52	3.6 m	-73
0.7 m	-72	3.7 m	-77
0.8 m	-61	3.8 m	-80
0.9 m	-70	3.9 m	-82
1.0 m	-63	4.0 m	-82
1.1 m	-80	4.1 m	-80
1.2 m	-71	4.2 m	-77
1.3 m	-63	4.3 m	-78
1.4 m	-75	4.4 m	-76
1.5 m	-63	4.5 m	-81
1.6 m	-66	4.6 m	-80
1.7 m	-67	4.7 m	-82
1.8 m	-78	4.8 m	-89
1.9 m	-78	4.9 m	-75
2.0 m	-71	5.0 m	-87
2.1 m	-79	5.1 m	-82
2.2 m	-68	5.2 m	-86
2.3 m	-71	5.3 m	-78
2.4 m	-73	5.4 m	-79
2.5 m	-74	5.5 m	-88
2.6 m	-75	5.6 m	-83
2.7 m	-78	5.7 m	-87
2.8 m	-82	5.8 m	-89
2.9 m	-69	5.9 m	-89
3.0 m	-72	6.0 m	-92

Table 116: Fitbit Surge, Disaster Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-51	3.1 m	-79
0.2 m	-57	3.2 m	-90
0.3 m	-56	3.3 m	-71
0.4 m	-59	3.4 m	-84
0.5 m	-57	3.5 m	-73
0.6 m	-67	3.6 m	-76
0.7 m	-70	3.7 m	-77
0.8 m	-59	3.8 m	-81
0.9 m	-60	3.9 m	-72
1.0 m	-69	4.0 m	-77
1.1 m	-71	4.1 m	-81
1.2 m	-62	4.2 m	-73
1.3 m	-84	4.3 m	-80
1.4 m	-77	4.4 m	-81
1.5 m	-74	4.5 m	-81
1.6 m	-69	4.6 m	-78
1.7 m	-65	4.7 m	-84
1.8 m	-69	4.8 m	-83
1.9 m	-73	4.9 m	-91
2.0 m	-69	5.0 m	-85
2.1 m	-79	5.1 m	-76
2.2 m	-80	5.2 m	-78
2.3 m	-73	5.3 m	-83
2.4 m	-71	5.4 m	-84
2.5 m	-72	5.5 m	-82
2.6 m	-80	5.6 m	-94
2.7 m	-82	5.7 m	-94
2.8 m	-74	5.8 m	-76
2.9 m	-75	5.9 m	-84
3.0 m	-78	6.0 m	-86

Table 117: Fitbit Surge, Disaster Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-61	3.1 m	-67
0.2 m	-56	3.2 m	-62
0.3 m	-50	3.3 m	-63
0.4 m	-52	3.4 m	-70
0.5 m	-56	3.5 m	-62
0.6 m	-54	3.6 m	-62
0.7 m	-47	3.7 m	-59
0.8 m	-50	3.8 m	-66
0.9 m	-50	3.9 m	-63
1.0 m	-51	4.0 m	-72
1.1 m	-56	4.1 m	-75
1.2 m	-68	4.2 m	-66
1.3 m	-65	4.3 m	-70
1.4 m	-56	4.4 m	-77
1.5 m	-56	4.5 m	-76
1.6 m	-60	4.6 m	-76
1.7 m	-59	4.7 m	-75
1.8 m	-56	4.8 m	-78
1.9 m	-52	4.9 m	-80
2.0 m	-56	5.0 m	-74
2.1 m	-60	5.1 m	-81
2.2 m	-63	5.2 m	-85
2.3 m	-65	5.3 m	-71
2.4 m	-64	5.4 m	-73
2.5 m	-62	5.5 m	-71
2.6 m	-68	5.6 m	-70
2.7 m	-65	5.7 m	-81
2.8 m	-63	5.8 m	-73
2.9 m	-68	5.9 m	-78
3.0 m	-67	6.0 m	-67

Table 118: Fitbit Surge, Disaster Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-55	3.1 m	-70
0.2 m	-51	3.2 m	-71
0.3 m	-49	3.3 m	-65
0.4 m	-48	3.4 m	-61
0.5 m	-52	3.5 m	-64
0.6 m	-50	3.6 m	-59
0.7 m	-52	3.7 m	-63
0.8 m	-54	3.8 m	-66
0.9 m	-51	3.9 m	-65
1.0 m	-55	4.0 m	-77
1.1 m	-56	4.1 m	-69
1.2 m	-57	4.2 m	-65
1.3 m	-66	4.3 m	-72
1.4 m	-56	4.4 m	-73
1.5 m	-67	4.5 m	-72
1.6 m	-59	4.6 m	-73
1.7 m	-54	4.7 m	-88
1.8 m	-55	4.8 m	-75
1.9 m	-54	4.9 m	-73
2.0 m	-59	5.0 m	-76
2.1 m	-59	5.1 m	-72
2.2 m	-66	5.2 m	-75
2.3 m	-61	5.3 m	-71
2.4 m	-60	5.4 m	-75
2.5 m	-62	5.5 m	-74
2.6 m	-60	5.6 m	-74
2.7 m	-65	5.7 m	-79
2.8 m	-66	5.8 m	-78
2.9 m	-62	5.9 m	-76
3.0 m	-80	6.0 m	-72

Table 119: Fitbit Surge, Home Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-50	3.1 m	-74
0.2 m	-56	3.2 m	-72
0.3 m	-55	3.3 m	-65
0.4 m	-54	3.4 m	-76
0.5 m	-54	3.5 m	-69
0.6 m	-56	3.6 m	-71
0.7 m	-57	3.7 m	-72
0.8 m	-58	3.8 m	-66
0.9 m	-59	3.9 m	-91
1.0 m	-63	4.0 m	-76
1.1 m	-62	4.1 m	-78
1.2 m	-62	4.2 m	-81
1.3 m	-64	4.3 m	-68
1.4 m	-65	4.4 m	-72
1.5 m	-63	4.5 m	-73
1.6 m	-66	4.6 m	-79
1.7 m	-67	4.7 m	-76
1.8 m	-65	4.8 m	-80
1.9 m	-66	4.9 m	-73
2.0 m	-68	5.0 m	-78
2.1 m	-76	5.1 m	-80
2.2 m	-72	5.2 m	-72
2.3 m	-69	5.3 m	-84
2.4 m	-73	5.4 m	-79
2.5 m	-67	5.5 m	-81
2.6 m	-78	5.6 m	-79
2.7 m	-79	5.7 m	-82
2.8 m	-78	5.8 m	-82
2.9 m	-69	5.9 m	-74
3.0 m	-69	6.0 m	-79

Table 120: Fitbit Surge, Home Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-56	3.1 m	-69
0.2 m	-58	3.2 m	-80
0.3 m	-54	3.3 m	-71
0.4 m	-56	3.4 m	-72
0.5 m	-54	3.5 m	-70
0.6 m	-56	3.6 m	-82
0.7 m	-66	3.7 m	-71
0.8 m	-62	3.8 m	-69
0.9 m	-64	3.9 m	-80
1.0 m	-60	4.0 m	-76
1.1 m	-63	4.1 m	-77
1.2 m	-69	4.2 m	-76
1.3 m	-64	4.3 m	-69
1.4 m	-63	4.4 m	-71
1.5 m	-71	4.5 m	-82
1.6 m	-62	4.6 m	-86
1.7 m	-73	4.7 m	-74
1.8 m	-66	4.8 m	-79
1.9 m	-78	4.9 m	-77
2.0 m	-67	5.0 m	-80
2.1 m	-75	5.1 m	-82
2.2 m	-70	5.2 m	-84
2.3 m	-65	5.3 m	-78
2.4 m	-73	5.4 m	-80
2.5 m	-74	5.5 m	-86
2.6 m	-88	5.6 m	-82
2.7 m	-70	5.7 m	-74
2.8 m	-75	5.8 m	-80
2.9 m	-72	5.9 m	-75
3.0 m	-68	6.0 m	-90

Table 121: Fitbit Surge, Home Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-45	3.1 m	-89
0.2 m	-43	3.2 m	-73
0.3 m	-50	3.3 m	-67
0.4 m	-51	3.4 m	-70
0.5 m	-54	3.5 m	-70
0.6 m	-58	3.6 m	-69
0.7 m	-60	3.7 m	-73
0.8 m	-61	3.8 m	-70
0.9 m	-66	3.9 m	-74
1.0 m	-68	4.0 m	-74
1.1 m	-76	4.1 m	-77
1.2 m	-69	4.2 m	-71
1.3 m	-70	4.3 m	-72
1.4 m	-63	4.4 m	-80
1.5 m	-67	4.5 m	-84
1.6 m	-74	4.6 m	-86
1.7 m	-65	4.7 m	-75
1.8 m	-68	4.8 m	-73
1.9 m	-73	4.9 m	-84
2.0 m	-71	5.0 m	-86
2.1 m	-78	5.1 m	-78
2.2 m	-75	5.2 m	-73
2.3 m	-74	5.3 m	-72
2.4 m	-61	5.4 m	-74
2.5 m	-67	5.5 m	-79
2.6 m	-65	5.6 m	-81
2.7 m	-70	5.7 m	-77
2.8 m	-75	5.8 m	-78
2.9 m	-71	5.9 m	-80
3.0 m	-89	6.0 m	-71

Table 122: Fitbit Surge, Home Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-45	3.1 m	-73
0.2 m	-44	3.2 m	-74
0.3 m	-49	3.3 m	-69
0.4 m	-54	3.4 m	-72
0.5 m	-57	3.5 m	-71
0.6 m	-58	3.6 m	-70
0.7 m	-70	3.7 m	-71
0.8 m	-68	3.8 m	-75
0.9 m	-67	3.9 m	-67
1.0 m	-78	4.0 m	-75
1.1 m	-71	4.1 m	-84
1.2 m	-66	4.2 m	-71
1.3 m	-67	4.3 m	-76
1.4 m	-74	4.4 m	-80
1.5 m	-64	4.5 m	-78
1.6 m	-66	4.6 m	-88
1.7 m	-69	4.7 m	-78
1.8 m	-78	4.8 m	-74
1.9 m	-71	4.9 m	-83
2.0 m	-72	5.0 m	-81
2.1 m	-83	5.1 m	-74
2.2 m	-69	5.2 m	-70
2.3 m	-71	5.3 m	-72
2.4 m	-68	5.4 m	-74
2.5 m	-67	5.5 m	-77
2.6 m	-68	5.6 m	-81
2.7 m	-84	5.7 m	-80
2.8 m	-77	5.8 m	-80
2.9 m	-79	5.9 m	-87
3.0 m	-78	6.0 m	-76

Table 123: Fitbit Surge, Office Environment, 0 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-39	3.1 m	-78
0.2 m	-42	3.2 m	-80
0.3 m	-46	3.3 m	-66
0.4 m	-47	3.4 m	-64
0.5 m	-50	3.5 m	-77
0.6 m	-49	3.6 m	-68
0.7 m	-48	3.7 m	-65
0.8 m	-52	3.8 m	-69
0.9 m	-56	3.9 m	-75
1.0 m	-61	4.0 m	-72
1.1 m	-57	4.1 m	-84
1.2 m	-57	4.2 m	-83
1.3 m	-58	4.3 m	-67
1.4 m	-60	4.4 m	-71
1.5 m	-68	4.5 m	-84
1.6 m	-60	4.6 m	-62
1.7 m	-76	4.7 m	-67
1.8 m	-79	4.8 m	-69
1.9 m	-66	4.9 m	-72
2.0 m	-68	5.0 m	-64
2.1 m	-66	5.1 m	-63
2.2 m	-67	5.2 m	-73
2.3 m	-69	5.3 m	-77
2.4 m	-78	5.4 m	-80
2.5 m	-69	5.5 m	-73
2.6 m	-76	5.6 m	-77
2.7 m	-70	5.7 m	-73
2.8 m	-71	5.8 m	-72
2.9 m	-69	5.9 m	-82
3.0 m	-62	6.0 m	-75

Table 124: Fitbit Surge, Office Environment, 0 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-43	3.1 m	-68
0.2 m	-47	3.2 m	-68
0.3 m	-49	3.3 m	-64
0.4 m	-44	3.4 m	-81
0.5 m	-47	3.5 m	-66
0.6 m	-56	3.6 m	-64
0.7 m	-61	3.7 m	-66
0.8 m	-58	3.8 m	-73
0.9 m	-54	3.9 m	-83
1.0 m	-60	4.0 m	-67
1.1 m	-67	4.1 m	-69
1.2 m	-81	4.2 m	-76
1.3 m	-63	4.3 m	-69
1.4 m	-68	4.4 m	-66
1.5 m	-62	4.5 m	-65
1.6 m	-62	4.6 m	-63
1.7 m	-92	4.7 m	-72
1.8 m	-66	4.8 m	-73
1.9 m	-62	4.9 m	-67
2.0 m	-76	5.0 m	-70
2.1 m	-66	5.1 m	-69
2.2 m	-67	5.2 m	-61
2.3 m	-66	5.3 m	-66
2.4 m	-65	5.4 m	-73
2.5 m	-79	5.5 m	-74
2.6 m	-74	5.6 m	-68
2.7 m	-75	5.7 m	-77
2.8 m	-60	5.8 m	-75
2.9 m	-72	5.9 m	-74
3.0 m	-67	6.0 m	-68

Table 125: Fitbit Surge, Office Environment, 0.5 m Elevation, First Run

Distance	RSSI	Distance	RSSI
0.1 m	-54	3.1 m	-61
0.2 m	-57	3.2 m	-63
0.3 m	-55	3.3 m	-73
0.4 m	-55	3.4 m	-64
0.5 m	-56	3.5 m	-74
0.6 m	-58	3.6 m	-68
0.7 m	-57	3.7 m	-71
0.8 m	-55	3.8 m	-64
0.9 m	-64	3.9 m	-71
1.0 m	-55	4.0 m	-64
1.1 m	-67	4.1 m	-69
1.2 m	-56	4.2 m	-65
1.3 m	-58	4.3 m	-68
1.4 m	-54	4.4 m	-71
1.5 m	-54	4.5 m	-73
1.6 m	-57	4.6 m	-66
1.7 m	-58	4.7 m	-69
1.8 m	-57	4.8 m	-70
1.9 m	-62	4.9 m	-79
2.0 m	-66	5.0 m	-67
2.1 m	-71	5.1 m	-70
2.2 m	-73	5.2 m	-78
2.3 m	-64	5.3 m	-82
2.4 m	-71	5.4 m	-67
2.5 m	-76	5.5 m	-70
2.6 m	-69	5.6 m	-70
2.7 m	-64	5.7 m	-69
2.8 m	-67	5.8 m	-71
2.9 m	-66	5.9 m	-66
3.0 m	-63	6.0 m	-84

Table 126: Fitbit Surge, Office Environment, 0.5 m Elevation, Second Run

Distance	RSSI	Distance	RSSI
0.1 m	-55	3.1 m	-64
0.2 m	-58	3.2 m	-61
0.3 m	-57	3.3 m	-62
0.4 m	-65	3.4 m	-63
0.5 m	-56	3.5 m	-65
0.6 m	-64	3.6 m	-70
0.7 m	-59	3.7 m	-67
0.8 m	-56	3.8 m	-62
0.9 m	-60	3.9 m	-66
1.0 m	-71	4.0 m	-65
1.1 m	-67	4.1 m	-66
1.2 m	-55	4.2 m	-71
1.3 m	-64	4.3 m	-67
1.4 m	-53	4.4 m	-68
1.5 m	-64	4.5 m	-70
1.6 m	-58	4.6 m	-65
1.7 m	-62	4.7 m	-76
1.8 m	-63	4.8 m	-67
1.9 m	-60	4.9 m	-68
2.0 m	-68	5.0 m	-80
2.1 m	-59	5.1 m	-64
2.2 m	-69	5.2 m	-68
2.3 m	-70	5.3 m	-66
2.4 m	-71	5.4 m	-68
2.5 m	-70	5.5 m	-88
2.6 m	-69	5.6 m	-67
2.7 m	-75	5.7 m	-71
2.8 m	-67	5.8 m	-69
2.9 m	-68	5.9 m	-73
3.0 m	-67	6.0 m	-72

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14. ABSTRACT

It is difficult for first-responders to quickly locate casualties in an emergency environment such as an explosion or natural disaster. In order to provide another tool to locate individuals, this research attempts to identify and estimate the location of devices that would likely be located on or with a person. A variety of devices, such as phones, smartwatches, and Bluetooth-enabled locks, are tested in multiple environments and at various heights to determine the impact that placement and interference played in locating the devices. The hypothesis is that most Bluetooth devices can be successfully enumerated quickly, but cannot be accurately located at distances over one meter using a device-agnostic method, and that the height does not have a significant impact on signal strength while the environment does.

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