Too Hot to Talk: A Dynamic Study of Weather and Received Signal Strength on Wireless Transmission

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Abstract

1 Introduction

Because received signal strength measurements can vary so significantly from day to night and summer to winter, it is important to fully understand the implications that weather patterns have on systems being used for research. Received signal strength measurements are gathered for many different important, practical and research applications making a dynamic understanding of data fluctuations due to weather, particularly temperature, immensely important. In particular, we will focus on the effect of a significant temperature range due to the sun's daily cycle between rooftop base stations in the POWDER advanced wireless testbed. We chose to focus on received signal strength measurements as it was the most practical tool within the environment we are working and has overarching positive implications, but it is important to remember that this can be more generally understood to be the quality of wireless communication between a transmitter and receiver. While the ultimate goal is to develop a more complete understanding of the relationship between temperature and received signal strength in the testbed environment, this simultaneously allowed for the development of many different tools for the POWDER environment that will bolster every POWDER user's experience with gathering received signal strength measurements.

The POWDER Advanced Wireless Testbed is a recently developed environment that allows for complex experimentation with wireless communication. Every part of the testbed is completely customizable allowing for precise and unique work to be done. Even more unique is the fact that no part of the environment is simulated. POWDER is a city-scale lab that allows for research to be done in a physical setting. This singular fact is fundamental to the work of understanding the natural tendencies of wireless connection due to natural phenomenon such as weather. The change in temperature, wind speed, and rainfall is not a simulated calculation, but the actual effect of a real-world environment on wireless communication.

At the moment, we are unaware of any other projects working towards an understanding of this important relationship between weather and received signal strength within the POWDER platform, but much work has been completed in this field beyond this context. This relationship is not being questioned, simply determined as a result of the years of previous research in other environments and with other equipment. Boano et al. [1] clearly illustrates the linear relationship found between temperature and received signal strength indicator values for their chosen equipment. They generalize their conclusions to all low power wireless transceivers, and we hope to realize this linear relationship within the context of the POWDER wireless testbed. Beyond temperature, Hillyard et al. [3] illustrates the effects of rainfall on received signal strength measurements within the context of their own goal. We would like to expand on the understanding of this relationship within the POWDER environment and see exactly how rainfall can effect data collection.

Ultimately, the goal is to determine and comprehend the complex correlation of various weather patterns and received signal strength measurements within the POWDER advanced wireless testbed environment to supplement the work already being done. By knowing and then applying the dependencies we hope to fully articulate, experiments, particularly those involving power loss and connection quality, may be run from day to night and summer to winter without massive discrepancies due to known environmental conditions. This paper will first lay out the general context of received signal strength measurements then apply this to the POWDER environment through practical tools and extensive data collection and analysis.

2 Related Work

Since much work has already been completed or is actively being completed with the goal of a more complete understanding of the complexities of received signal strength in mind, we chose to build upon this within the context of the POWDER advanced wireless testbed. Even more specifically, there has been much exploration within the framework of the effects of weather, particularly extreme weather, on received signal strength measurements. It is important to remember that most of this work is done due to the far reaching, practical effects of received signal strength based projects, implications within wireless connection quality as a whole, and the fact that the environment cannot always be presumed so be seventy degrees and sunny.

First, it is important to understand exactly why it is known that weather, specifically temperature, affects received signal strength measurements to such a large degree. Mentioned by Boano et al. and just about any introductory circuits professor, increased resistance in conductors and current leakages in semiconductors due to an increase in temperature is a fact of nature [1]. These physical properties illustrate a clear relationship: increases in temperature result in a reduction of current and therefore power. In a stagnant, physical world, this is where the story ends. Lucky for science, there is much more to tell. Because this initial conclusion is so easy to reach, it can be dissected and then applied in a dynamic sense as seen by the work of Lin et al. [4]. This investigation was also the exact intention of Boano et al., but with an even more general framework in mind. Through data collected in a systematic and robust manner over a year, a linear relationship was discovered between environmental temperature and both received signal strength indicator values and the wireless connection's noise floor. As temperature rises these values become more negative, illustrating the fact that the quality of wireless connections decays with temperature.

The motivation behind exploring the relationship between rainfall and received signal strength is much less clear, but does have a basis which is important to understand before moving forward. Due to the fact that the direct relationship between active rainfall and received signal strength measurements is much less clear, there is not a significant amount of completed research with this in mind. It can be reasonably concluded that the act of water droplets falling through the air is not the cause of any reduction in wireless connection quality, and therefore must be a result of water droplets on the physical nodes. Supported by the work of Hillyard et al., rainfall causes a decline in wireless communication quality illustrated by received signal strength measurements [3]. When looking at both received signal strength measurements and collected rainfall, a clear decrease in power measurements and therefore connection quality is seen during rainfall. Because this effect is seen both during and after rain showers, any interference must not be caused by the actual act of rain, but by the result of water droplets found on the physical transmitter and receiver. While this cause of interference can often be mitigated, it is not always the case, especially within the POWDER environment. While water landing on equipment during a rainstorm can be an easy fix, the interesting implications of this is one of the topics we hope to investigate further.

When looking at the both of these relationships, the common disadvantage of all previous research is that it has not occurred within the POWDER testbed. The relationships between both temperature and received signal strength and rainfall and received signal strength will have slightly different characteristics due to the unique environment in which testing is being done. This can be said for any and all testing environ-

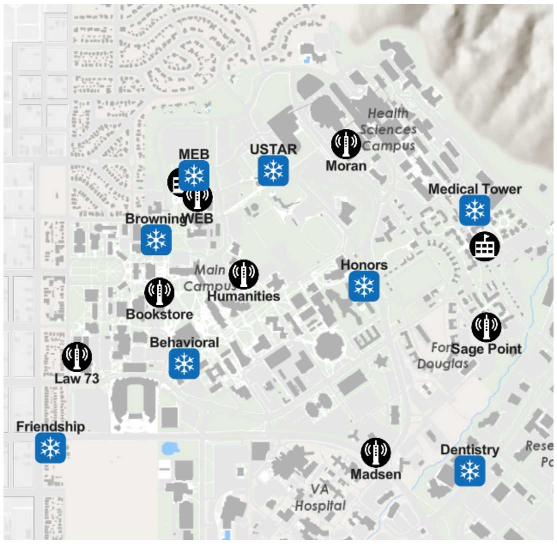

Figure 1: Map of currently deployed rooftop base stations used for data collection

ments, but it does not minimize the importance of the work being explored here.

3 Background

The entire experimental setup is built on POWDER's rooftop base stations designated by the blue squares in Figure 1. As seen in Figure 1, the POWDER environment is built within the University of Utah's campus, and this plays an important role in understanding causes of excess interference. Parking lots, roads, and buildings are not factors that can be controlled, only monitored. Transmission and reception is implemented through the usage of the USRP Hardware Driver (UHD) library. All tools and experiments use the Citizens Broadband Radio service, specifically transmitting and receiving at 3.555 GHz.

The received signal strength measurements being used in both the tools and experiments we implemented are relative gain measurements given in decibels. Ultimately, this means that the exact numbers collected should not be expanded beyond this context as they have no concrete meaning, but their relation to other values and trends is incredibly important. In the tools we created within the POWDER environment, the baseline received signal strength measurement with no transmission is approximately -86. Anything greater than this value shows that a transmitted signal has been received and is significant. Since received signal strength measurements are collected as negative values, the closer a value is to zero, the better the connection between transmitter and receiver. Other factors can cause interference and as a result a decreased received signal strength measurement, but a better wireless connection is usually attributed to physical distance between devices and will be seen in any received power measurements.

Weather is collected through the use of the Open Weather Map API. From this, we are currently collecting temperature, rainfall, wind speed, and humidity. Internal temperature reading are also being collected for each transmitter and receiver being used. Beyond environmental temperature, specific device temperature relates even more closely to the functionality and power capabilities of transmitters and receivers. An interesting aspect that Boano et al. mentioned is that temperature variations and differences between the transmitter and receiver can have even more specific effects to their functionality [1]. Boano et al. states that temperature variations within the transmitter affect received signal strength to a greater degree than temperature variations within the receiver. Because of this, collection of internal temperature for each device became important to collect. The collection of humidity data also became important following our first few rounds of experimentation. Due to the initial conclusion that water droplets from rainfall causes decreased quality of connection, water droplets from nighttime humidity and dew could equally cause a compromised connection.

4 Method

The first job that needed to be tackled was the building and refining of tools to be used for both weather and received signal strength data collection. Creating the tools involved significant updating to the UHD commands on the rooftop base stations' SDRs. For obvious reasons, it is very important that transmission and reception can occur simultaneously. This involved the use of Python's multiprocessing capabilities and the rewriting of UHD's transmission commands to function for a specified amount of time. These updates allow for a variety of different applications for received signal strength collection. The process of data collection is executed entirely by Python scripts. Each node being used in the current experiment is sshed into using Python's Fabric API. Once connected, the UHD tools developed above are used to transmit, receive, and then saved into the appropriate form. Basic tools were first created for a variety of different transmission and reception combinations and then built upon for more in depth data collection. The most complete and considered tool that was implemented involves the collection of received signal strength measurements between every combination of transmitter and receivers. In this application, each of the eight rooftop base stations within the POWDER environment are cycled through as transmitters. For each transmission, all other base stations collect a received signal strength measurement. Once all eight of the base stations have transmitted, the process stops and all data is complied into a table as seen in Table 1.

The collection of weather and power data is completed in a similar matter as described above. A Python script was created that first collected the received signal strength data between the specified rooftop base stations and then gathered the appropriate weather data from the Open Weather Map API. This power and weather collection process occurs every minute for as long as desired. For a complete picture of the relationship to be realized, the data collection script needs to be run for sixteen to thirty-six hours as it is important to collect data during the high temperatures of the day and low temperatures of the night. The specific internal temperature of individual devices is gathered from data collected by the POWDER platform for other applications. Currently, data is being graphed and analyzed in both Python and MatLab. The most important relationships that we are actively investigating at the moment are received signal strength values over time compared to the different weather values over time and received signal strength as a function of temperature.

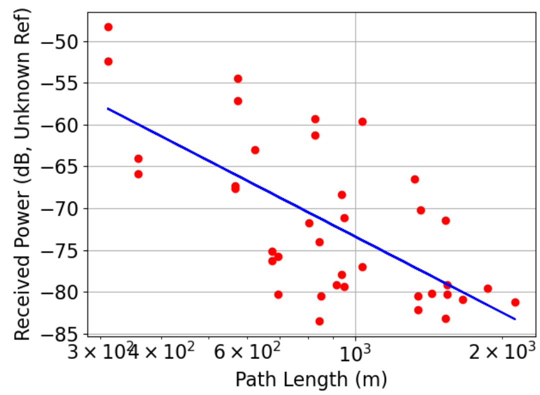

Figure 2: Relationship between received signal strength and distance using data collected with streamlined tool.

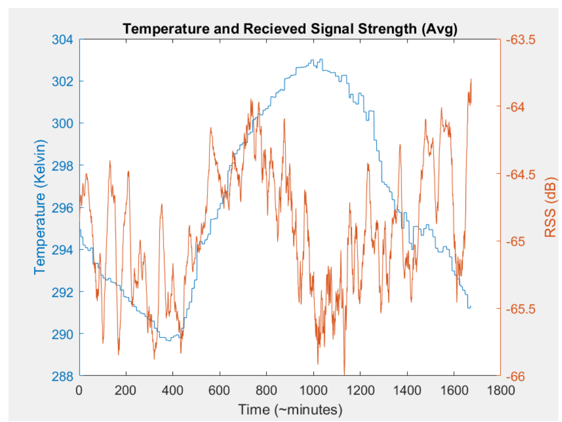

Figure 3: Received signal strength, temperature, rainfall, and wind speed values collected over 28 hours

5 Evaluation

Table 1 shows the results of the tools that automates the process of determining received signal strength values for all possible combinations of transmission and reception. This collected data can be very insightful when it comes to understanding the connections between the various rooftop base stations within the POWDER environment. In this setup, received signal strength measurements of approximately −85 or above correspond to a receiver that cannot measure the transmitted value. For example, Table 1 illustrates that the Dentistry receiver does not collect a signal from any of the rooftop transmitters. This could have

	BES	Browning	Dentistry	FM	Honors	MEB	SMT	USTAR
BES	x	-67.3514	-86.4585	-80.2778	-74.0295	-61.2219	-85.1051	-84.6483
Browning	-67.6533	x	-86.3395	-59.5711	-71.0958	-48.2258	-85.2628	-54.4489
Dentistry	-66.4940	-80.9542	x	-79.5305	-71.7398	-84.9279	-84.9796	-84.5641
FM	-75.7798	-76.9733	-86.2353	x	-71.4222	-82.1361	-85.4893	-80.3030
Honors	-83.5304	-79.4031	-86.3222	-83.1574	x	-77.9564	-85.4169	-75.1284
MEB	-59.3037	-52.3776	-86.3914	-80.4751	-68.3280	x	-84.2640	-63.9794
SMT	-80.1833	-70.2205	-86.3907	-81.2329	-62.9959	-85.0724	x	-80.5034
USTAR	-79.1834	-57.1572	-86.3121	-79.1866	-76.2495	-65.8648	-85.0646	x

Table 1: Table of results using received signal strength data collection tool. Rows correspond to the transmitter and columns correspond to the receiver.

many different consequences in experiments involving the Dentistry rooftop base station.

Another important application of this data is the increased understanding of the relationship between received signal strength and geographical distance. As geographical distance increases, RSS measurements become more negative: the connection quality decreases. Not only is this a result of the length of travel of the signal, but also due to outside interference including cars, buildings, trees etc. which are often unpredictable, but consistently decrease connection quality. Using the data we collected and a Python script that relates RSS measurements and distance Figure 2 was created to illustrate this relationship [2]. Certain data points were removed when they were obviously a result of no transmitted signal received as they hold no pertinent information when it comes to the relationship between transmitter and receiver. The negative slope of the line of best fit shows our data supports the conclusion that increased distance between a rx/tx pair results in a decreased connection quality. The data collected is accurate and a useful tool in many different applications.

Figure 3 shows the graphical results of data collected over an extended period of time, approximately twenty-eight hours. The relationship between temperature and received signal strength is clearly seen from this. A more negative RSS measurement corresponds to a weaker connection between the end points. The data clearly shows that as the environmental temperature increases during the day time hours, the RSS measurements fall significantly. This supports the relationship between temperature measurements and received signal strength as laid out previously.

The sharp spikes in received signal strength measurements as seen in Figure 3 can be attributed to many other outside factors. While the rooftop base stations being used in this experiment are geographically close to each other, there is a parking lot and road between them. Interference due to cars both moving and stationary could play a part in these spikes. Another factor could be humidity levels during the evening, nighttime, and early morning. As mentioned when discussing rainfall, water located on rooftop base stations are a likely cause for reduced connection quality and any dew or moisture on these devices could effect the RSS measurements. The final alternative factor we plan to explore is the fluctuating temperature of the physical rooftop base station either transmitting or receiving. Preliminary measurements show that the temperature of these devices rarely stay constant for more than a few minutes, often spiking by multiple degrees Fahrenheit within five minutes. Because we know that the temperature of the transmitter and receiver play such a large role in connection strength and quality, it seems very likely that these drastic temperature spikes within the individual devices play a part in the drastic received signal strength measurements over time.

Due to the high level of interference and fluctuation found during our first few experiments, the data found in Figure 4 was compiled and analyzed with a refreshed intention. While initially an interesting topic, it became obvious that it did not rain

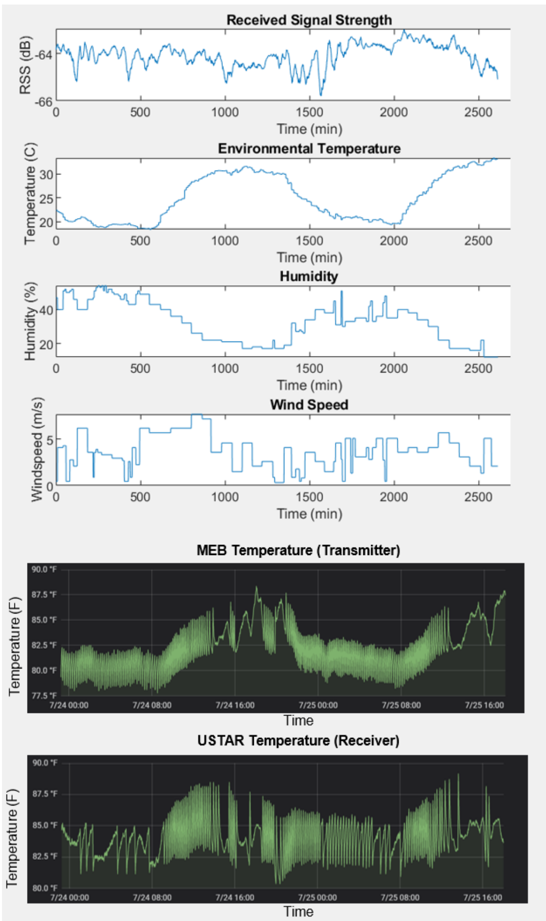

Figure 4: Received signal strength, environmental temperature, humidity, wind speed, transmitter temperature, and receiver temperature values collected over 36 hours

frequently enough in Salt Lake City to gather useful data about its relationship with received signal strength and would no longer be a focus of research. Replacing this is the idea of humidity affecting the functionality of the device transmission and reception similarly to rainfall. As seen in Figure 4 humidity clearly increases at night and is significantly lower during the day. Humidity is moisture in the air and can also be thought of as slight moisture on the physical devices compromising their ability to transmit and receive. Figure 4 shows that RSS measurements do not respond to temperature changes as quickly as expected or in the smoothest way and the additional humidity in nighttime air most likely plays a part in this. Specifically, the first night of data collection did not increase the received signal strength values significantly, especially when compared to the second night of data collection. The main difference as seen in the data is that the first night was significantly more humid than the second. The smaller increase in signal strength is likely a result of the increased humidity and therefore moisture in the experimental environment. Similarly to rainfall, a clear relationship between wind speed and received signal strength is difficult to determine. While we are unable to clearly isolate a direct relationship between the two, it is impossible to completely disregard the effect fluctuating wind gusts could have on power measurements and should be kept in mind for future analysis.

Ultimately, the factor that most obviously affects received signal strength measurements is temperature, both environmental and within individual devices. The analysis of environmental temperature and power measurements from above is supported by this data: increasing temperature causes a decrease in received signal strength and decreasing temperature causes a increase in received signal strength. But, by collected the internal device temperatures of the transmitter and receiver, we are hoping to at least partially answer the question of why the received signal strength measurements fluctuate so severely and constantly. We believe the data manages to answer just that. In this experimental setup, the MEB rooftop base station is transmitting and the USTAR rooftop base station is receiving, and their respective temperatures during data collection is seen in Figure 4. Both graphs include relatively consistent, large fluctuations in temperature throughout the day. As Boano et al. clearly states, the temperature of wireless transmitters and receivers directly affects their respective received signal strength measurements [1]. The spikes in the received signal strength measurements begin to make a lot more sense when looked at in conjunction with the $2 to 4^{\circ} F$ spikes in the temperature of the devices.

6 Conclusion

Acknowledgments

We performed our experiments in the POWDER advanced wireless testbed [5].

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