Radio Frequency Propagation Validation

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Abstract

Recently developed technologies and frameworks at the POWDER platform accelerate learning and innovate new forms of networking research. On the other hand it is unclear how well these frameworks are performing and whether they meet their evaluation standards.

In this paper, we uncover the Shout framework. Shout is a framework developed by the POWDER team to perform a variety of measurement studies on the platform. For our purposes we will use Shout to perform radio frequency propagation measurements on the POWDER nodes. To compare these results we will use an open source radio frequency propagation modeling tool named SPLAT!. Due to the uncalibrated nature of the radios on POWDER we will use the path loss exponent as a form of assessment between the two. Furthermore, we will do a small terrain analysis of a chosen measurement frequency to bring our results to the physical world and explain why we got the results we did.

Index Terms - RF propagation, Network Measurement, SPLAT!

1 Introduction

With the creation and deployment of the Platform for Open Wireless Data-driven Experimental Research (POWDER) [5] that started in early 2018 at the University of Utah, users have been able to work on wireless networking technologies to funnel their creative nature into innovative networking research experiments. One such experiment is Shout [11]. Shout is a measurement framework developed by the POWDER team, that allows for radio frequency measurements to be conducted on the POWDER testbed. A measurement of particular interest involves the radio frequency propagation loss for each usable node on the platform. POWDER offers a wide range of wireless endpoints (i.e. rooftop nodes, static nodes at human height, nodes on campus shuttles and portable nodes) that can be used to measure radio frequency propagation.

The goal of the work described in this paper is to use the POWDER platform to perform radio frequency measurements under different conditions and to compare the results against radio frequency propagation tools. SPLAT! [9] is a radio frequency signal propagation, loss, and terrain analysis tool for the electromagnetic spectrum between 20 MHz and 20 GHz. For our purposes SPLAT! will serve as our modeling tool to predict radio frequency propagation assuming the same scenarios.

In this paper, we perform radio frequency propagation validation for the Shout framework using the modeling tool SPLAT! on the POWDER platform. For the purposes of this paper we will be using Band 7 ($\sim$2600 MHz), Band 42 ($\sim$3500 MHz), and Band 43 ($\sim$3700 MHz). We will be using the cbrssdr1 and cellsdr1 nodes as well as fixed endpoint nucs for our measurement collection.

We perform three main activities. First, using Shout we will collect experimental data on the frequencies and nodes described above. Secondly, using SPLAT! we will predict radio frequency propagation assuming the same scenarios. Lastly, we will compare and analyze any differences between the "ground truth" measurements from Shout and the predictions obtained from SPLAT!.

The contributions of this work are the following. We collect radio frequency propagation loss measurements on multiple bands for use in the POWDER platform. We create a SPLAT! research experiment profile that can be used for future radio frequency modeling within the POWDER platform. This includes the proper configuration files for every current node that is usable on the testbed. Lastly, we present our results between the "ground truth" and our simulated data.

2 Background

Depending on the environment and placement of the transmitter and receiver, the path between the two can be line-of-sight (LOS) or more complex depending on the obstacles between them. When transmitting the radio wave, losses are achieved under the influence of diffraction, reflection and scattering [4]. Multipath propagation is fairly common in every type of radio wave transmission. In fact, more commonly in non-line of sight (NLOS) but not limited to it, multipath still occurs were the received radio waves arrive with time delays from different directions, and with different amplitudes. When these waves combine at the receiver they can either usefully combine or interfere with one another and cause distortion or fade (loss).

Path Loss Models

Loss on the propagation path between the transmitter and the receiving antennas can be defined as the ratio of the transmitted to received power. This loss is called path loss and represents the ratio expressed in decibels (dB) which is expressed according to the Free space model (in dB) and can be given by the "Friis equation" as:

$$P_r(dBm) = P_t(dBm) + G_t(dB) + G_r(dB) - L_p(dB) \tag{1}$$

where,

$$L_p(dB) = 20\log_{10}(\frac{4\pi d}{\lambda}) \tag{2}$$

Here, d is the path length while the wavelength $\lambda = c/f$, where $c = 3*10^8$ meters per second is the speed of light. f is the center frequency. The path loss is L_p and is called the "free space path loss." The terms $P_r(dBm)$, $P_t(dBm)$ describe the received power and the transmit power, respectively. $G_t(dB)$ and $G_r(dB)$ are gains (when they are positive, the received power increases). And as distance increases, $L_p(dB)$ increases, which because of the negative sign, reduces the received power. Free space is useful for space communications systems, or radio astronomy. But not for cellular telephony [12].

However, we must take into account that obstructions exist in our real world and thus the free space model does not take into account diffraction, and scattering losses [12]. The path loss exponent model is a simple generalization of (1) and (2) in which the exponent in the Friis model is allowed to change. We will see this in the results section where we compare linear regression slopes of our acquired data. The path loss exponent model can be shown as:

$$P_r(dBm) = P_0(dBm) - 10v\log_{10}(\frac{d}{d_0}) \tag{3}$$

where $P_0(dBm)$ is still given by the Friis equation,

$$P_0(dBm) = P_t(dBm) + G_t(dB) + G_r(dB) - 20\log_{10}(\frac{4\pi d_0}{\lambda}) \tag{4}$$

Notice, that now the path loss after d_0 has changed to include a factor of $10v$ instead of 20. This is due to the nature of the path loss exponent model where v is defined to be the path loss exponent. v is determined by empirical measurements for the area in which the receiver and transmitter reside. The value of v will be higher [12] in dense cities, in buildings with highly attenuating walls, in varying terrain, and when antennas are closer to the ground.

Propagation Models

A propagation model is a tool that is important in the process of planning, developing and analyzing of radio communication networks. There is not a one size

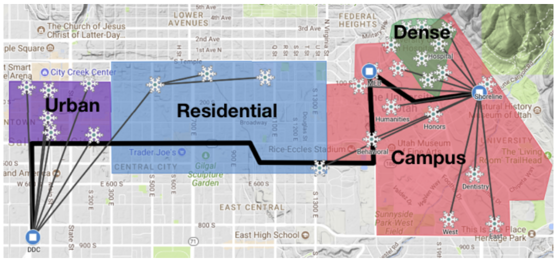

Figure 1: POWDER city-scale footprint, including a campus, residential, urban, and dense deployments [5].

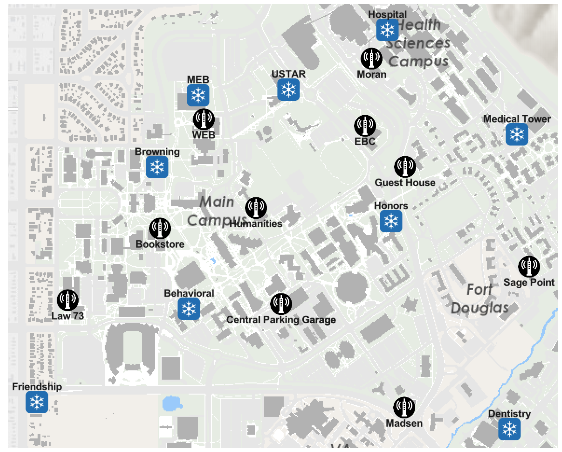

Figure 2: POWDER map. Snowflakes represent base stations. Black circles represent fixed endpoint nodes [5].

fits all type of approach when it comes to propagation models. The use of particular propagation models depends on the parameters available for the chosen area of the propagation study as well as the different parameters of the model. Propagation models can be categorized into two common groups: empirical and deterministic models. Deterministic models are based on the physical laws of wave propagation to determine the received signal power and often require a detailed map of the propagation environment. Empirical models are based on observations and measurements alone and are mainly used to predict path loss.

There is a vast array of propagation models like: Longley-Rice, Okumura-Hata, COST-231, Egli, and others. From the ones listed Longley-Rice is by far the most widely known and used. In fact, our modeling tool SPLAT! is based on the Longley-Rice model [10]. The Longley-Rice model is based on electromagnetic theory and on statistical analysis of both terrain features and radio measurements. The model can act as an area prediction model or as a point-to-point model. To use the model, one computes the additional loss to each path obstruction. These losses are summed and then added to the predicted line of sight path loss which is calculated using the Friis transmission equation in SPLAT! [8].

Unknown Reference

In the POWDER platform we have uncalibrated radios. This means that when we take power measurements, we will have power values with respect to an unknown reference [12]. The receiver still provides a dB measurement of power, however, there is no known reference. This proves to be extremely frustrating when comparing data from other places as you simply cannot compare point-to-point values. A few possible solutions exist to solve this problem. You can calibrate the receiver and transmitter or simply find other ways of legitimately comparing your data. The latter is used in our results section.

3 Measurement Methodology

Our measurement is conducted on the POWDER platform (Figure 1). Most of our experiments focused on a campus environment with a variety of terrain. Part of the area includes a typical spread out university campus, while other parts include a more densely populated urban-like environment. POWDER offers 9 general purpose rooftop base stations (Figure 3) that include networked software-defined-radios (X310s), a radio frequency front-end (time division duplex and frequency division duplex), and signal amplification. Furthermore, POWDER offers 10 fixed endpoints (Figure 4). Similar to the general purpose rooftop base stations, the components include software-defined-radios, radio frequency front-end and antenna elements. Figure 2 provides an overview of the current nodes available to us on the POWDER platform.

Figure 3: General purpose base station [5].

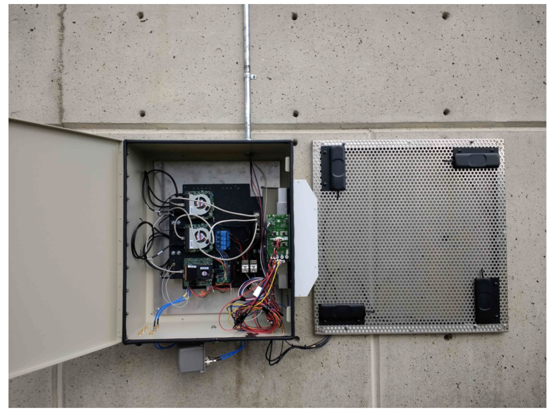

Figure 4: Fixed endpoint [5].

Measurement Tool: Shout

Shout [11] is a measurements framework developed by the POWDER team. Using Shout you are able to collect radio frequency measurements for the nodes within the testbed. The framework was developed on python and offers a rich set of measurement collections. Shout follows a client server architecture in which we have an orchestrator node running at all times. On each client (radio node) we connect to the orchestrator via IP address. The orchestrator prints out commands telling us what nodes have connected. Once all chosen nodes have connect we can then begin the measurement process.

For our purposes we used Shout to collect radio frequency propagation among the nodes on the platform. Shout uses JSON files as command files to tell the orchestrator how it should direct the other nodes. We used a configuration file which directed the framework to treat each node as a receiver and transmitter in a round-robin fashion. Figure 5 shows the JSON file used to produce our results. Notice, that the JSON file used follows this approach:

$$PL_M = CF + \frac{1}{2}SR \tag{5}$$

Where CF is the center frequency (tuned frequency) and SR is the sample rate. PL_M describes the upper bound for collection, with a frequency step size dictated by the JSON file. In other words for the given CF we collect measurements up to PL_M with a given frequency step. Shout then averages these results to produce an average received power for the given frequency between two nodes. This is the approach we follow when calculating radio frequency propagation using the Shout framework.

Measurement Tool: SPLAT!

SPLAT! [9] will be our modeling tool to compare with Shout's results. SPLAT! can be used to produce terrain analysis maps of the designated area, but for our purposes we will use SPLAT! as a point-to-point analysis model to calculate radio frequency propagation. For radio frequency propagation, SPLAT! requires two primary files: QTH, and LRP. QTH files are site location files that contain the site's name, the site's latitude, the site's longitude and the site's antenna height above ground level. LRP files are the irregular terrain model parameter files that are used to determine radio frequency path loss, field strength, or received signal power level. Figure 6 shows an example of the QTH and LRP files used on SPLAT!. Each node used on the POWDER platform was created QTH and LRP files.

To produce and compare accurate results between Shout and SPLAT!, we followed the same approach as in formula (5). Using the proper QTH and LRP files for each node we were able to create a python script that easily mediates the process of collecting the data for a given frequency. SPLAT! is a command-

```
3         "cmd": "measure_paths",
4         "get_samples": true,
5         "nsamps": 1024,
6         "freq": 2.45e9,
7         "txgain": 30,
8         "rxgain": 30,
9         "rate": 1e6,
10        "wampl": 0.8,
11        "freq_step": 5e4,
12        "time_step": 3,
13        "timeout": 60,
14        "client_list": ["all"]
```

Figure 5: Example JSON file that tells the orchestrator how to treat the nodes. Line 3 dictates the measurement study. While line 6 and 14 states the center frequency and which nodes to use respectively.

```
Honors.lrp Below

5.000       ; Earth Dielectric Constant (Relative permittivity)
0.001       ; Earth Conductivity (Siemens per meter)
301.000     ; Atmospheric Bending Constant (N-Units)
2100.000    ; Frequency in MHz (20 MHz to 20 GHz)
5           ; Radio Climate
0           ; Polarization (0 = Horizontal, 1 = Vertical)
0.50        ; Fraction of Situations
0.50        ; Fraction of Time
0.01        ; Transmitter Effective Radiated Power in Watts or dBm (optional)

Honors.qth Below

Honors
40.7644037
111.8369526
100
```

Figure 6: LRP and QTH SPLAT! files for Honors.

line driven application that reads in the data from the QTH and LRP files and produces a results file that can be parsed for the necessary data.

Measurements

Following the above methodology we perform extensive measurements on the POWDER platform using Shout and SPLAT! via multiple frequencies and nodes. For this project we conducted 4 measurement runs with each run being done 3 times. These 4 measurement runs span over 3 different frequency bands. To summaries:

- Run 1 took place in early October. The measurement conducted used the 3561 MHz frequency, and used the: Behavioral Science, Browning, Friendship Manor, Sagepoint, MEB, and South Medical Tower nodes. This run was conducted at mid-day.
- Run 2 took place in early November. The measurement conducted used the 2620 MHz frequency, and used the: Behavioral Science, Browning, Friendship Manor, Honors, Sagepoint, Ustar as transmitters nodes. And used Bookstore, EBC, Garage, Guesthouse, Humanities, Law73, Madsen, Moran, and WEB as receiver fixed endpoint nodes. This run does not follow the typical round-robin approach among all the nodes where each one acts as a receiver and transmitter because only the transmitter nodes listed where able to transmit at the listed frequency. We still followed the approach discussed in equation (5). This run was conducted early morning.
- Run 3 took place in late November. The measurement conducted used the 3550 MHz frequency, and used the: Behavioral Science, Browning, Honors, Sagepoint, South Medical Tower, Ustar, and Friendship Manor nodes. This run was conduct early morning.
- Run 4 took place in late November. The measurement conducted used the 3690 MHz frequency, and used the: Behavioral Science, Browning, Honors, Sagepoint, South Medical Tower, Ustar, and Friendship Manor nodes. This run was conducted early morning.

4 Results and Discussion

After the 4 measurement runs completed on Shout, we perform an analysis with the SPLAT! tool using the same frequencies, radio locations and following the same method discussed in section 3. We convert the acquired data to Excel spreadsheets that are later

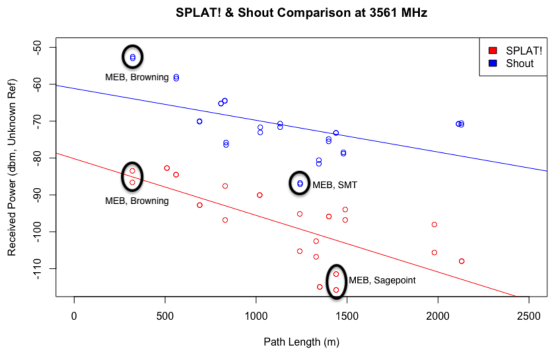

Figure 7: Run 1. Used 3561 MHz frequency

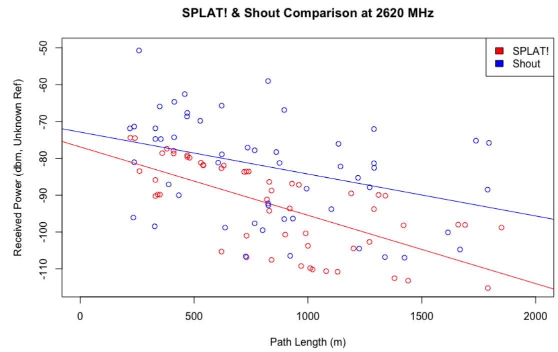

Figure 8: Run 2. Used 2620 MHz frequency

imported into RStudio to create our plots. Each dot on the plot is a pairwise connection between the transmitter and receiver at the given frequency. Due to the multitude of dots we neglect from naming each dot as it overwhelms the plot for further analysis. Due to the unknown reference for either Shout or SPLAT! we are unable to directly compare the two. However, we will compare the two using the path loss exponent which happens to be the slope of the linear regression line. Following the path loss exponent analysis we will do a brief terrain analysis of the results to verify if what we got appears to be accurate.

Run #	Frequency	Shout	SPLAT!
Run 1	3561 MHz	-0.0086	-0.0154
Run 2	2620 MHz	-0.0114	-0.0186
Run 3	3550 MHz	-0.0132	-0.0113
Run 4	3690 MHz	-0.0163	-0.0103

Table 1: Path Loss Exponents for each run.

Path Loss Exponent

Due to the POWDER platforms uncalibrated radios there is not a single reference point for the Shout data. This is the reason why all of our plots for each run define the Y-axis as the received power in dBm with an unknown reference. Notice that SPLAT!'s data is represented by the red color while Shout's data is represented by the blue color. Table 1 summarizes the path loss exponents for each run.

Run 1 (Figure 7), was conducted on the 3561 MHz frequency in early October at around 11AM. This run followed the typical round-robin fashion, where each circle on the plot represents a pairwise connection between the transmitter and receiver. The slope for Shout in run 1 was -0.00862, this tells us that the power decays proportionally to $d^{-0.00862}$ where d is the path length. Similarly, we determined the measurements fit of SPLAT!. The path loss exponent is -0.0154 that is the power decays proportionally to $d^{-0.0154}$. We can see SPLAT!'s path loss exponent has a steeper slope. That is for the 3561 MHz frequency, SPLAT! has over-predicted the path loss when compared to Shout's ground truth measurements.

We now conduct a similar procedure to the remaining runs. Run 2 (Figure 8) was conducted in early November at around 9AM and used the largest amount of nodes within our experiments. Shout's path loss exponent was -0.0114 with a power decay proportional to $d^{-0.0114}$. While SPLAT!'s path loss exponent was -0.0186 with a power decay proportional to $d^{-0.0186}$. These are fairly close but once again SPLAT! is over-predicting the POWDER platform's radio path loss at the 2620 MHz frequency.

Run 3 (Figure 9) and run 4 (Figure 10) were conducted in late November. Specifically, run 3 was conducted at around 2AM while run 4 occurred around 6AM. For run 3, Shout's path loss exponent is -0.0132 while SPLAT!'s is -0.0113. Run 3 offers the closest in comparing the path loss exponent values for the data collected. However, this time SPLAT! is under-predicting the POWDER platforms path loss

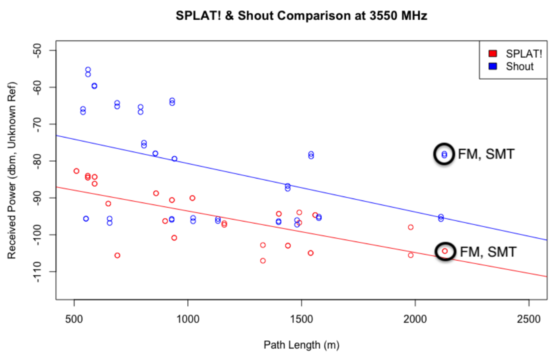

Figure 9: Run 3. Used 3550 MHz frequency

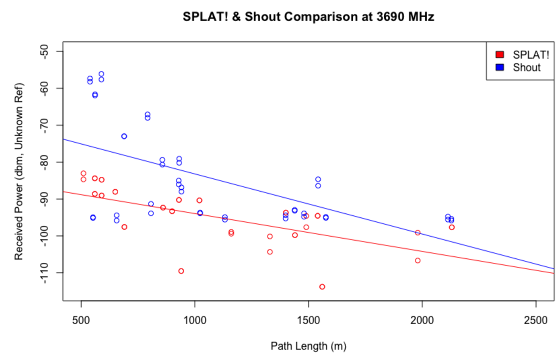

Figure 10: Run 4. Used 3690 MHz frequency

for the 3550 MHz frequency. Similarly, in run 4 we see SPLAT! under-predicting the path loss on the 3690 MHz frequency. In run 4 we see that Shout's path loss exponent is -0.0163, while SPLAT!'s path loss exponent is -0.0103.

Terrain Analysis

The purpose of this section is to bring SPLAT! to real life and compare the model to physical locations. We will be utilizing Google Maps to take a closer view of the environment in run 1. Notice that in figure 7, we label the best and worst path loss nodes for each data set. We will focus on the two nodes with the best path loss, and the two nodes with the worst path loss and compare Shout and SPLAT! when differences arise.

Best Path Loss

We first look at the two nodes in run 1 with the best path loss. Table 2 lists the best path loss nodes for both Shout and SPLAT!, at the 3561 MHz frequency. We can see that for both data sets, MEB and Browning hold the best propagation values. Figure 11 shows the Google Maps image of the two nodes. Both nodes are rooftop base stations with an open Line of Sight. We believe that these two nodes received the best propagation simply due to the distance between them and the fact that there is nothing directly blocking them.

Set	Nodes	Received Power
Shout	MEB, Browning	-52 dBm
SPLAT!	MEB, Browning	-83 dBm

Table 2: Run 1, best path loss for Shout and SPLAT!.

Set	Nodes	Received Power
Shout	MEB, SMT	-87 dBm
SPLAT!	MEB, Sagepoint	-115 dBm

Table 3: Run 1, worst path loss for Shout and SPLAT!.

Worst Path Loss

We now look at the two worst nodes with regards to propagation loss. Table 3 lists the worst path loss nodes for both Shout and SPLAT! at the 3561 MHz frequency. For SPLAT! these two nodes are MEB and Sagepoint. We note that Sagepoint is the only fixed endpoint node for run 1 and is 1.5 meters above the ground, while MEB is a rooftop base station. From figure 12 we notice that the environment between MEB and Sagepoint is not a clear line of sight. In fact, three sports fields, the student life center, a traffic induced road, and multiple housing units lie in-between these two nodes. Furthermore, since Sagepoint is a fixed endpoint node it is placed behind a wall that is not facing the MEB.

However, Shout thinks differently. It believes that the two worst nodes are MEB, and South Medical Tower (SMT). The environment between these two include the Biotechnology Building, a traffic induced

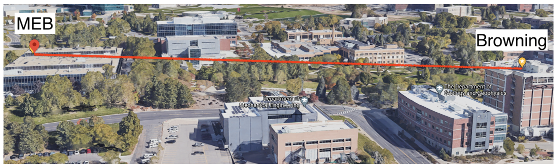

Figure 11: MEB left and Browning right

Figure 12: MEB left with the red line leading to Sagepoint, while the blue leads to SMT.

road, parking structures, and the College of Pharmacy. However, both MEB and SMT are rooftop base stations with MEB being the shorter one.

Discussion

We now offer a few insights as to why we got the results we did. We can see how early hours affected Shout's data in run 3. In figure 9 where we can see that at a striking distance of about 2128 meters we appear to be getting -78 dBm in received power compared to SPLAT!'s -104 dBm, for the Friendship Manor and SMT nodes. Again we can't compare point-to-point due to unknown reference, but it is a bit of an astonishment when compared to the rest of Shout's data where about half the points are underneath -78 dBm given their respective smaller path length.

As expected for all case in every run we saw multipath powers with exponentially decreasing magnitude as a function of distance. Meaning that in all cases we saw propagation loss increase with distance. As discussed in section 2, there exists multiple path loss models that can be used depending on the parameters available to us. For example, SPLAT! follows the Longley-Rice path loss model, it just could so happen that this model is simply not intended for the Utah environment on a campus with a dense city-like section.

Differences between the ground truth and modeling tools will always occur. Again this is due to time, weather, un-updated map data for the modeling tool, or simply the wrong model is being used. During this 8 week project we saw the seasons transform from summer to fall. That is measurements taken at different time periods will have an affect on our data. A good exercise would be to continue this work using different frequency bands, POWDER nodes, and path loss models.

5 Related Work

The idea of measuring [14, 16] radio frequency propagation as well as using propagation models to simulate [4] radio frequency propagation loss [13] is not a new idea. As we will see, there are multiple related works associated with this work, however, the overall idea is to compare Shout [11] using a radio frequency tool, such as SPLAT! [9]. SPLAT! is one of few open source radio frequency propagation modeling analysis tools. CloudRF [3] is another familiar radio propagation modeling tool that offers more in terms of cellular propagation models for mobile networks, as well as faster results due to its proprietary propagation engine.

SPLAT!

SPLAT! allows for propagation loss and terrain analysis for the electromagnetic spectrum between 20 MHz and 20 GHz. Our first example of SPLAT! is used in an architecture [15] that can be used for simulation and in-situ learning of the attenuation of RF signals in the environment. SPLAT! is used to generate a prediction mean field for CU Mountain Research Station to determine radio frequency propagation loss in the rocky terrain.

Another study [10], that similarly resembles ours, aims to compare accurate measurements taken by Rohde & Schwarz portable spectrum analyzer and precision antennas for digital TV, with simulated results from multiple coverage prediction models like SPLAT!. However, SPLAT! in this study produces big differences compared with the real measurement results. This is due to SPLAT!'s inability to work properly in the line-of-sight mode as well as a lack of detailed terrain information.

Digital Terrestrial Television (DTT) is degraded [6] due to the coexistence between LTE operating in the adjacent frequency band. To study these results the authors of the paper used SPLAT! to produce a DTT system model. To produce such a model they took into account earth conductivity, atmospheric bending constant, antenna polarization, relative permittivity, and antenna height above the ground.

CloudRF

Long Range (LoRa) is a low-power wide-area networking protocol that is designed to connect Internet of Things (IoT) devices to the internet in regional, national or global networks. Deployment of LoRa access points requires taking into consideration the spatial distribution of clients, and radio signal propagation. A heuristic algorithm [7] was designed for gateway location selection for LoRa networks. CloudRF was used to estimate the coverage of LoRa gateways on the map allowing the algorithm to decide if the placement of access nodes are at the best place they could be.

Similarly, a simulation [2] was done to replace the Peruvian Navy's Supervisory Control and Data Acquisition (SCADA) system with an IoT-based solution using LoRaWAN. SCADA is a system to monitor and control remote meteorological and luminous stations. Path loss calculations between stations were made using the Okumura-Hata radio propagation model. The results were then validated using CloudRF. Results conclude that the LoRaWAN system is superior to the currently used SCADA system.

Propagation Models

Propagation models are designed in order to give acceptable accuracy level and computational complexity. Ray tracing [16] is one example of deterministic models. Ray tracing is a method for calculating wave propagation through the use of repeatedly advanced narrow beams through a medium by discrete amounts. Through the use of Maxwell's equations ray tracing provides valid wave propagation measurements.

A comparison [1] of three path loss models for fixed wireless access systems was done. The comparison measurements were taken at 3.5 GHz in Cambridge, UK and their applicability was validated in three environments: rural, suburban, and urban environments. Specifically, three empirical models the Stanford University Interim (SUI), the COST-231 Hata, and the ECC-33 models were chosen for this comparison. The results show that ECC-33 model shows the best results, especially in urban environments. While for the general case the COST-231 Hata and SUI models highly over predict the path loss in all the environments.

6 Conclusion

In this paper we discussed radio frequency propagation. Specifically, we covered radio frequency propagation models, ran a few measurements on the POWDER platform, discussed our results, and compared the data between our propagation model and the ground truth. SPLAT! was our radio frequency propagation model of choice and its measurement results were compared with the Shout framework. Shout was developed by the POWDER team to conduct measurement studies on the POWDER platform.

Our results showed that SPLAT! on the 3561 MHz and 2620 MHz frequencies overpredicted the path loss, however on the 3550 MHz and 3690 MHz SPLAT! under-predicted the path loss with respect to the Shout framework. Furthermore, on the 3561 MHz frequency, Shout and SPLAT! both picked the same two nodes with the best radio frequency propagation, but failed to choose the same two nodes when it came to picking nodes with the worst radio frequency propagation. There is no definitive answer as to whether or not Shout has been validated with respect to SPLAT!. Radio frequency propagation models take into account multiple parameters to calculate path loss, it could just so be that SPLAT! is not the ideal model for the POWDER platform.

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