RUTGERS
WINLAB | Wireless Information Network Laboratory

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mmWave Channel Analysis Campaign

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Overview

Our project's primary goal was to understand mmWave channel behaviors in variable environmental conditions. We conducted several

- An **outdoors experiment**, in which a PAAM **transmitted signals** at **different distances** to a Spectrum Analyzer. The data transmitted would essentially indicate how **power was lost** as distance increases.
- An **indoor water obstruction experiment**, in which **two PAAMs** (located in SandBox 1) transmitted signals between to each other. In one situation, the signal was transmitted with **no obstructions**, and in another, the signals were transmitted with a **full water jug** placed right **infront of the transmitter.** This experimentation was then visualized and processed using different codes and programs, which ultimately led to a model that was trained to be able to identify whether or not there is an obstruction of water.

A **practical implication** of mmWave transmission is the possibility of interference with passive **weather sensing** in the **FR2 Range**. This experimentation serves as a starting point towards developing a more robust model for determining environmental obstructions in high frequency signal transmission.

Outdoor Experimentation

Measured **power of signals** sent between a PAAM and a Spectrum Analyzer over different distances.

The main goal included **modeling power** to distance relationships in order to get a baseline characterization of the **channel path loss**. The experiment consisted of transmitting a frequency at **different distances**. The diagram displays **peak magnitude vs. distance** ~ matching the theoretically expected relationship.

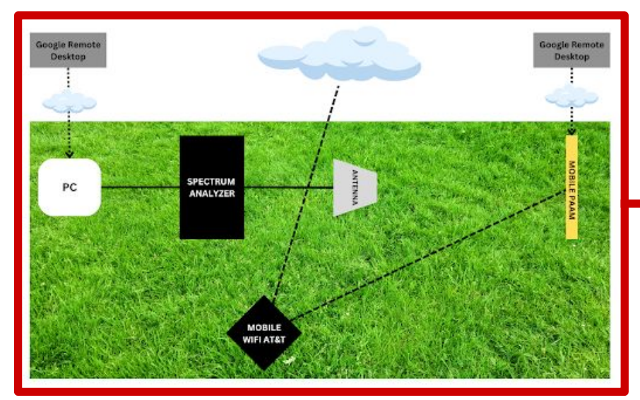


Figure 1 ~ Visualization of Outdoors Experiment

Figure 2 ~ Live Photo of Outdoors Experiment

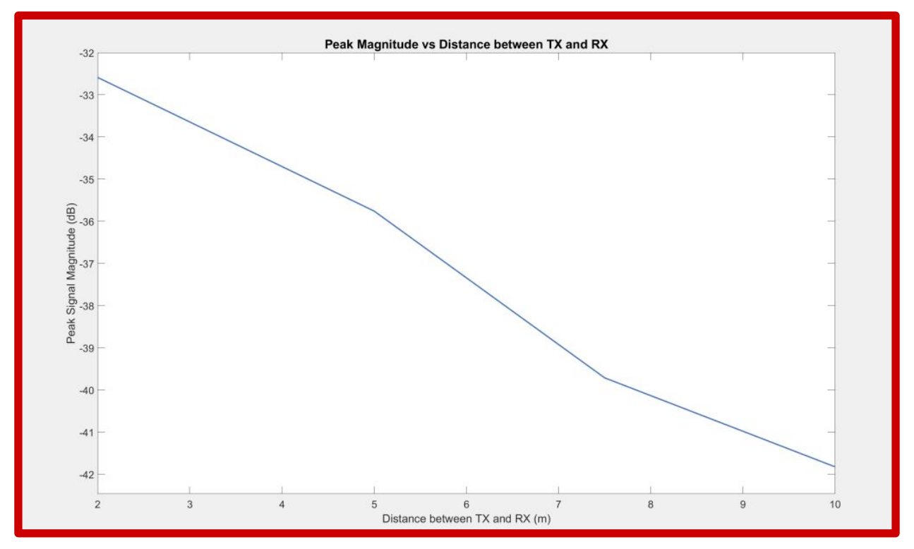


Figure 3 ~ Graph of Peak Magnitude vs Distance between TX & RX

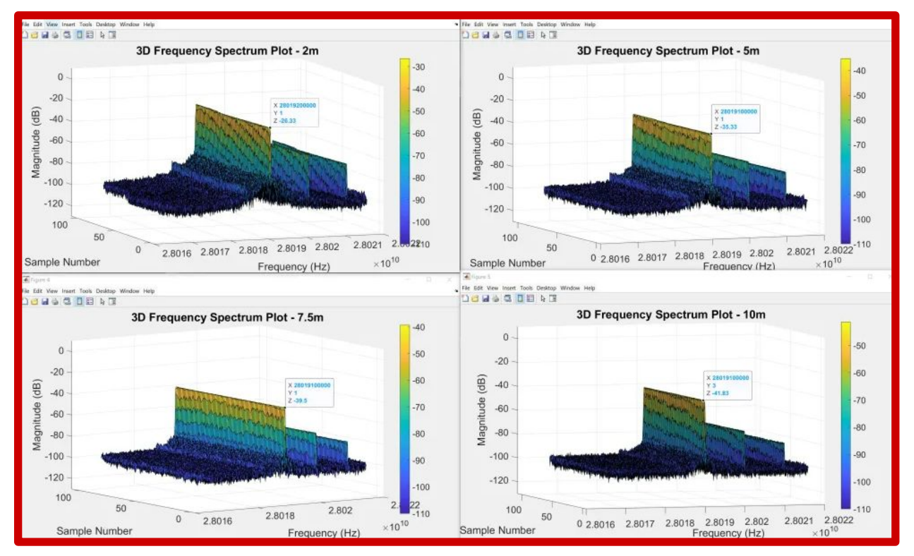
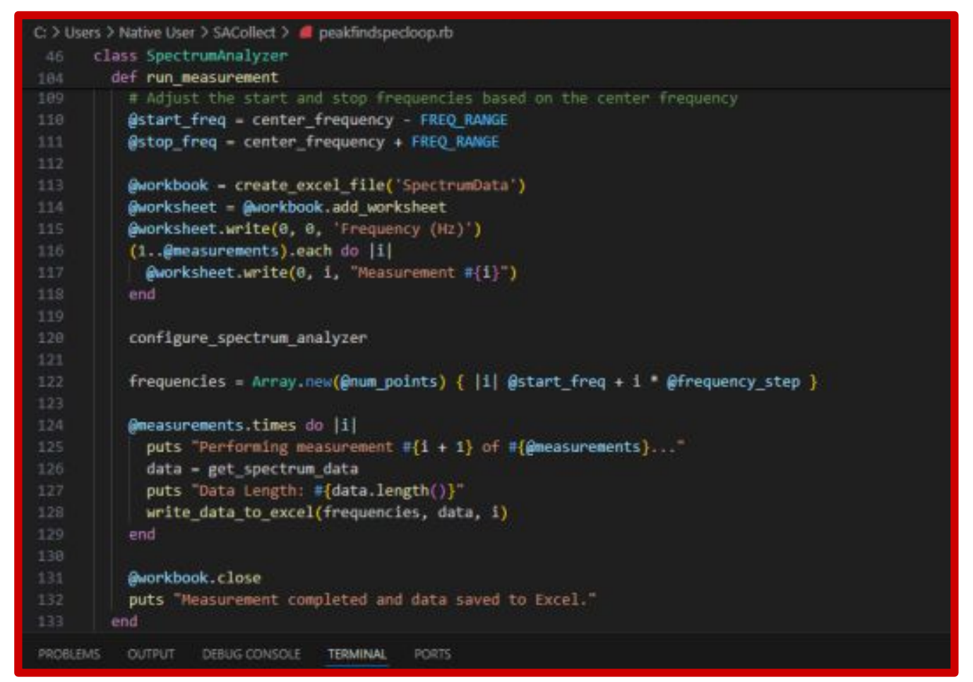


Figure 5 ~ Entire Visual of Channel Path Loss Frequency Data

Code & Processing

Getting familiar with various programming languages and environments was crucial for progressing with the project. More specifically:

- Coding in **Ruby** to use the Spectrum Analyzer to conduct the outdoor experiment.
- Using **MATLAB** to visualize the data received in experiments.
- Using Python (**SK Learn** and other libraries) to create the ML model for the water experiment and intermediate processing.



```
C: > Users > Native User > SACollect > peakfindspecloop.rb
class SpectrumAnalyzer
  def run_measurement
    # Adjust the start and stop frequencies based on the center frequency
    @start_freq = center_frequency - FREQ_RANGE
    @stop_freq = center_frequency + FREQ_RANGE

    @workbook = create_excel_file('SpectrumData')
    @worksheet = @workbook.add_worksheet
    @worksheet.write(0, 0, 'Frequency (Hz)')
    (1..@measurements).each do |i|
      @worksheet.write(0, i, "Measurement #{i}")
    end

    configure_spectrum_analyzer

    frequencies = Array.new(@num_points) { |i| @start_freq + i * @frequency_step }

    @measurements.times do |i|
      puts "Performing measurement #{i + 1} of #{@measurements}..."
      data = get_spectrum_data
      puts "Data Length: #{data.length()}"
      write_data_to_excel(frequencies, data, i)
    end

    @workbook.close
    puts "Measurement completed and data saved to Excel."
  end
```

Figure 6 ~ Entire Visual of Channel Path Loss Frequency Data

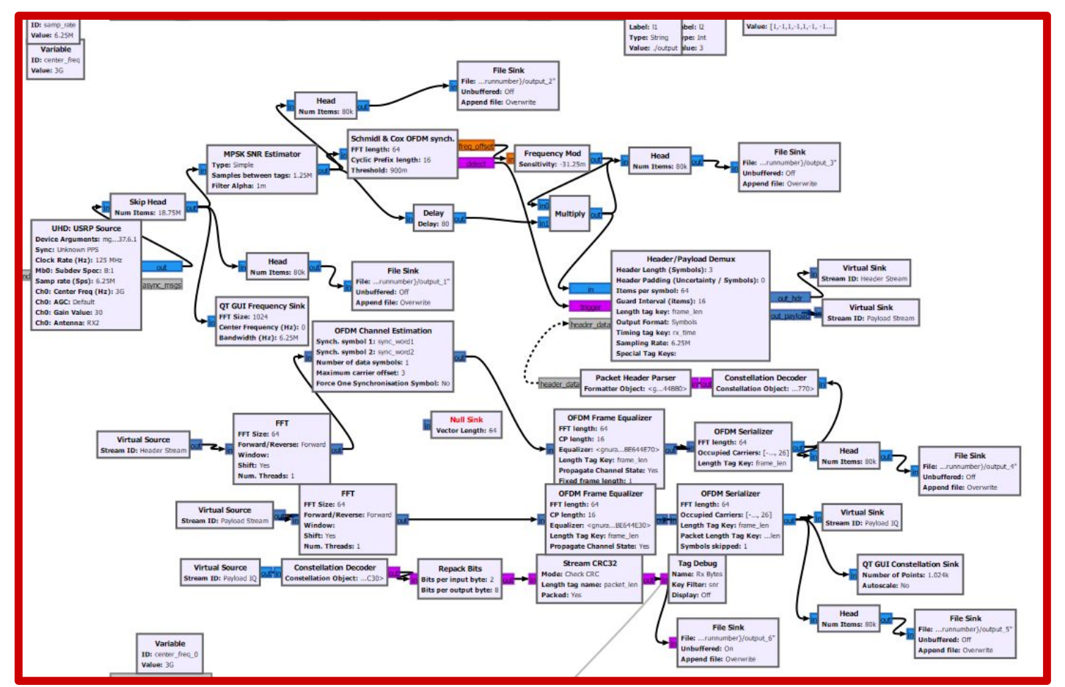


Figure 7 ~ GnuRadio RX Flowgraph

Water Experimentation

- Explored signal **interference at 28 GHz** by transmitting OFDM signals between PAAMs with/without a water jug.
- Captured **FFT data and extracted pilot carrier data and sync words** using **GNU Radio** for synchronization and demultiplexing.
- Created a metric for message error rate estimation and formed a dataset for **'air' vs. 'water' classification.**
- Achieved around **80% F1-score** in water presence detection after training simple classifier models.

Figure 8 ~ Water experiment with NO Obstruction

Figure 9 ~ Water experiment with FULL Water Jug Obstruction

OFDM

- **OFDM** (Orthogonal Frequency Division Multiplexing) divides a high-speed data stream into multiple slower substreams, on separate carrier frequencies.
- Orthogonal subcarriers in OFDM allow overlapping without interference, **improving spectral efficiency** and robustness against multipath fading.
- Widely used in Wi-Fi, 4G/5G cellular networks, and digital TV broadcasting, OFDM resists inter-symbol interference and excels in challenging environments.
- An OFDM receiver and transmitter was implemented using **GNU Radio** for the conducted experiments.

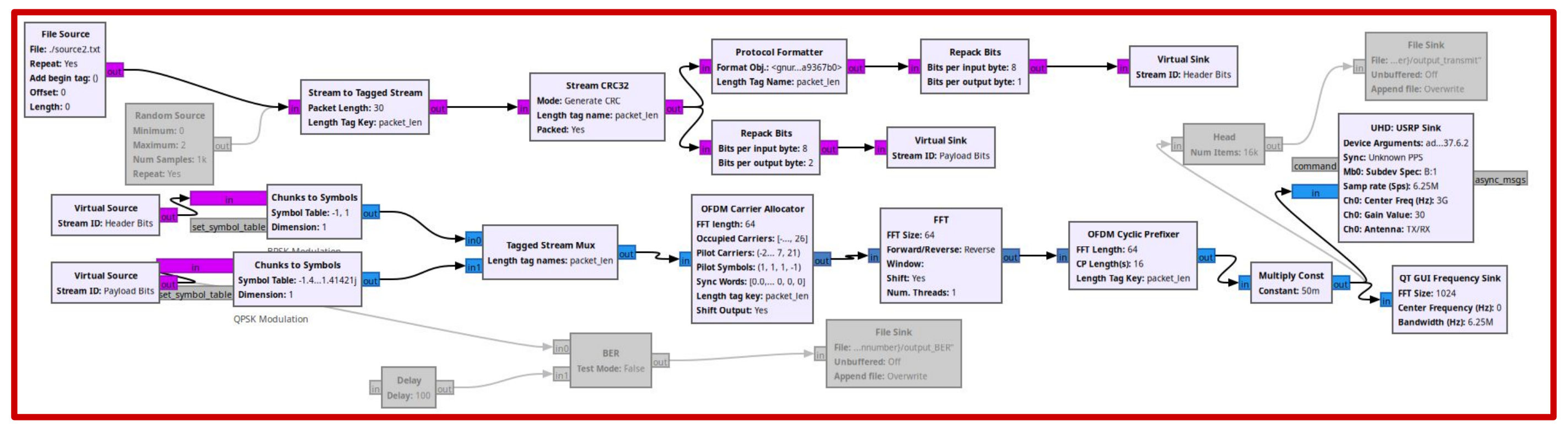


Figure 10 ~ GnuRadio OFDM TX Flowgraph

Tools & Technology

GNU Radio :

- Open Source toolkit for developing software-defined radios for signal processing applications.
- Used for signal processing and connecting with the N310 radios linked to the PAAMs.

Phased Array Antenna Module (PAAM) :

- Enables transmission and reception in ~28GHz frequencies.
- Static PAAMs are mounted on XY-tables in the Orbit lab and can change position and orientation.
- Mobile PAAMs are used for outdoor experiments.
- Beam steering allows for switching between TX directions

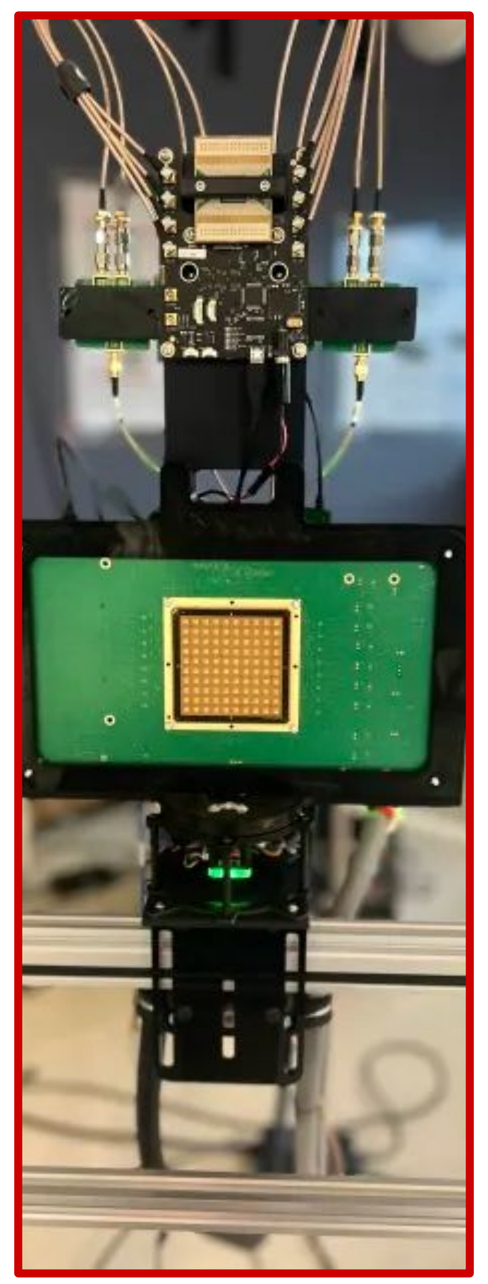


Figure 11 ~ Phased Array Antenna Module (PAAM)

Hewlett Packard 8564E Spectrum Analyzer :

- Enables frequency domain analysis from 30 Hz to 40 GHz
- Used to model power leakage between FR2 range and weather sensing frequencies

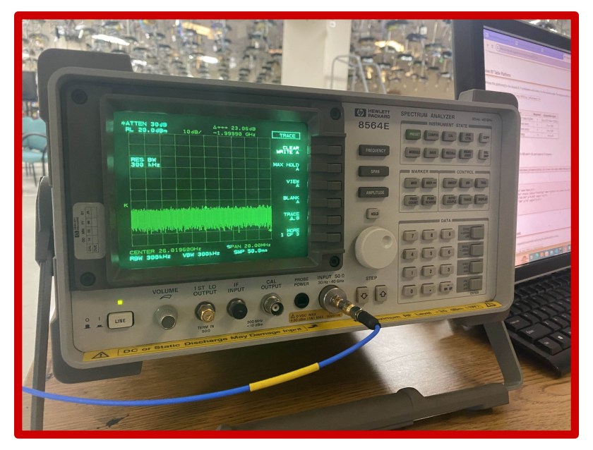


Figure 12 ~ Spectrum Analyzer

Conclusions & Future Work

Future plans for this project include continuing the outdoors experiments by **transmitting signals across various frequencies**, including 29 GHz, 30 GHz, etc. Additionally, another step forward is transmitting OFDM signals from **longer distances** to gather more data. As well as **incorporating different topologies** in the water experiment to assess the impact of Enviornmental interference at **various distances and frequencies**.

Concerning the detection of water in the channel, taking more measurements, in many different settings, and **refining the post-processing pipeline** will lead into a more **robust classification** system. Actually explaining the **reasoning of the model** is also worth working on and could yield some interesting results. Going further to practically use the **model for identification** on whether there is **water interference** or not, in actual rain conditions or simulations, is a primary goal.

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