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AI-generated content may be incorrect.Module Code: COMP3045

Title of the project: Path Loss at 5G Frequency Range in South Asia

Semester: Spring

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Module Convenor: Dr Kweh Yeah Lun

* **Introduction: An explanation of the problem and the motivation for solving it.**
* **Related work: A description of previous papers related to your project.**
* **Methodology/Design (storyboard, etc.): A detailed explanation of the techniques and algorithms you used to solve the problem.**
* **Implementation (must include specifics of what other components/libraries you built upon): A detailed explanations on how you implement the visualization.**
* **Results: detailed analysis and description of your visualizations**
* **Discussions: What has the audience learned from your work? What new insights or practices has your system enabled? A full user study is not expected, but informal observations of use that help evaluate your system are encouraged.**
* **Conclusions and Future Work: A recap of take-aways and detailed description of how your system could be extended or refined.**
* **Bibliography**

1. Introduction

Millimeter-wave (mm-wave) communication is an important technology for modern wireless networks, providing rapid data speeds and increased connection [1]. It is an essential part of 5G technology, which operates at very high frequencies of 30 GHz to 300 GHz [9]. However, the propagation properties of mm-wave signals are greatly impacted by atmospheric factors, making it critical to investigate their impact for optimal network design and implementation. Understanding these variances is critical for creating realistic channel models, enhancing communication protocols, and maximizing overall system effectiveness.

We will utilize a dataset created using the NYUSIM 3.0 mm-Wave channel simulator software to meet this purpose [2]. Realistic atmospheric factors including temperature, humidity, barometric pressure, and rain rate are included in this collection. Because the input data was gathered in South Asia over the course of a year, seasonal fluctuations in mm-wave channel characteristics were accurately represented. There are 2,835 records in the collection, and each one has the following parameters:

* T-R Separation Distance (m) – The distance between transmitter and receiver
* Time Delay (ns) – Time taken for signal to travel from transmitter to receiver
* Received Power (dBm) – Power level of the received signal
* Phase (rad) – Phase of the received signal, indicates position of the point in the wave at time of measure.
* Azimuth Angle of Departure (AoD) (degree) – Horizontal angle at which the signal leaves the transmitter
* Elevation Angle of Departure (AoD) (degree) – Vertical angle at which the signal leaves the transmitter
* Azimuth Angle of Arrival (AoA) (degree) – Horizontal angle at which the signal arrives at the transmitter
* Elevation Angle of Arrival (AoA) (degree) – Vertical angle at which the signal arrives at the transmitter
* Root Mean Square (RMS) Delay Spread (ns) – Measure of signal dispersion
* Season – time of the year (spring, winter, fall, summer)
* Frequency – operating frequency of the transmitted signal
* Path Loss (dB) – total signal attenuation as it travels from the transmitter to the receiver

The dataset has been cleaned and normalized, ensuring consistency and readiness for analysis. Researchers in networking can use this information to investigate the impact of weather on channel activity. It can also help evaluate communication protocols and signal processing techniques under a variety of atmospheric conditions. Although the dataset is centred around readings from South Asia, these findings could be applied to similar climatic zones. This dataset is an important resource for developing the science of mm-wave communication since it provides insights on real-world propagation characteristics in a variety of environments.

* 1. Goals & Objectives

The major purpose of this work is to examine and estimate route loss in mm-wave communication channels using a variety of environmental factors. Understanding the link between path loss and other elements such as T-R separation distance, atmospheric conditions, and multipath effects is critical for maximizing wireless network reliability and signal dependability in different environments. This study aims to:

1. Investigate the effect of environmental influences on path loss in mm-wave channels.
2. Investigate the link between path loss and spatial factors - how T-R separation distance, azimuth and elevation angles, and delay spread relate to signal attenuation.
3. To get insights about improving mm-wave communication networks, enhancing network architecture, especially in areas with high seasonal fluctuations.
4. Literature review

In applications like 5G and beyond, automotive networks, high-definition video transmission, and next-generation IoT systems, mm-waves provide ultra-fast communication due to their substantially larger bandwidth and data rates as compared to standard sub-6 GHz wireless signals [7]. However, due to the high frequencies of mm-wave propagation, these waves experience higher path loss, as they are more prone to atmospheric variables. For example, the presence of water vapor and oxygen can cause attenuation of these waves [8]. Consequently, mm-wave propagation is extremely directional, necessitating well-designed pathways to ensure reliable communication between the transmitter and receiver.

In this literature review, we will look at existing studies on how environmental factors affect route loss in mm-Wave communications systems.

Several research have been conducted to explore mm-wave communication and how it responds to changing atmospheric conditions. Numerous studies have demonstrated how atmospheric conditions like as rain, humidity, and temperature may influence mm-wave propagation. For example, Rappaport et al. [3] discovered that high-frequency transmissions (especially mm-wave) are attenuated owing to rain and human blocking, stressing the significance of constructing trustworthy communication channel models. Marcus and Pattan [4] have investigated the influence of ambient gases and humidity on mm-wave propagation loss by modifying molecular absorption and scattering effects via diffraction and reflection.

The NYUSIM simulator, which was used to create the dataset, has been thoroughly verified in academic research as an excellent tool for simulating real-world mm-wave communication. Sun et al.’s paper in 2017 [13] unveiled NYUSIM, which can predict channel properties under a variety of environmental circumstances. In the same year, Rappaport et al. found that the NYUSIM provides more realistic simulations of urban mm-wave channels than the 3GPP TR 38.900 Release 14 model.

* 1. Atmospheric Absorption

A study by Rappaport et. al. in 2019 [10] discovered that at mm-wave frequencies (30 GHz – 300 GHz), water (H₂O) and oxygen (O₂) molecules generate large amounts of attenuation due to higher absorption, especially at 60 GHz where oxygen absorption peaks and 183 GHz. In the same study, the atmospheric attenuation at 28 GHz is around 0.1dB/km, but increases to around 0.5dB/km at 73 GHz.

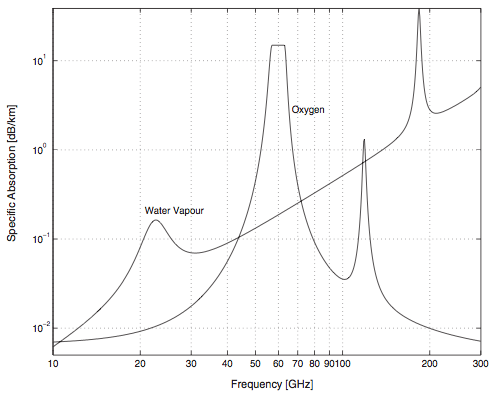


Figure 1. Specific attenuation of water vapor and oxygen. [ITU-P676-9, 11]

* 1. Vegetation & Foliage, Building Materials and Human Blockage

Besides atmospheric absorption, the presence of physical obstructions, such as vegetation and foliage, buildings and human bodies would also introduce a lot of complexity in mm-wave propagation as they can also cause attenuation:

* **Vegetation & Foliage**: Highly dense foliage can cause signal dispersion and absorption. Zhang et al. (2019) [12] measured foliage loss at 28 GHz and reported that there was signal degradation compared to empty space. The attenuation effects vary according to density of leaves, amount of moisture and the existence of branches, which makes mm-wave propagation very dependent on vegetation and seasonal vegetation changes.
* **Building Materials & Urban Structures**: Building penetration loss, which occurs when mm-wave signals are attenuated as they pass through walls, windows, and other buildings, poses a serious challenge for mm-wave propagation in urban environments. It is shown that different building materials, such as glass, concrete, metal can contribute to variable amounts of signal attenuation [6], decreasing the stability of mm-wave communication in densely populated urban cities.
* **Human Blockage:** Human bodies can result in temporary signal shadowing and reflection as they behave like movable obstacles. For example, Chen et al. (2016) conducted measurements on a 28 GHz signal indoors and suggested the basic human body shadowing model that emphasized the influence of human blockage on signal attenuation.

These variables must be considered while developing reliable mm-wave networks, as they can present new signal-blocking barriers that can affect path loss and overall connectivity.

1. METHODOLOGY

The goal of this project is to investigate, visualize, and forecast Path Loss in 5G communication settings across South Asia by combining interactive data exploration approaches with machine learning-based regression modeling.

* 1. Data Acquisition and Preprocessing

The initial step was to obtain the dataset '5g-South Asia.csv', which provides signal transmission characteristics and its associated season. The raw dataset has the following fundamental features:

* **Transmission-reception distance** (T-R Separation Distance (m))
* **Received signal power** (Received Power (dBm))
* **Directional characteristics** (Azimuth and elevation angles at both the Angle of Departure and Angle of Arrival, demonstrated in Figure 2)

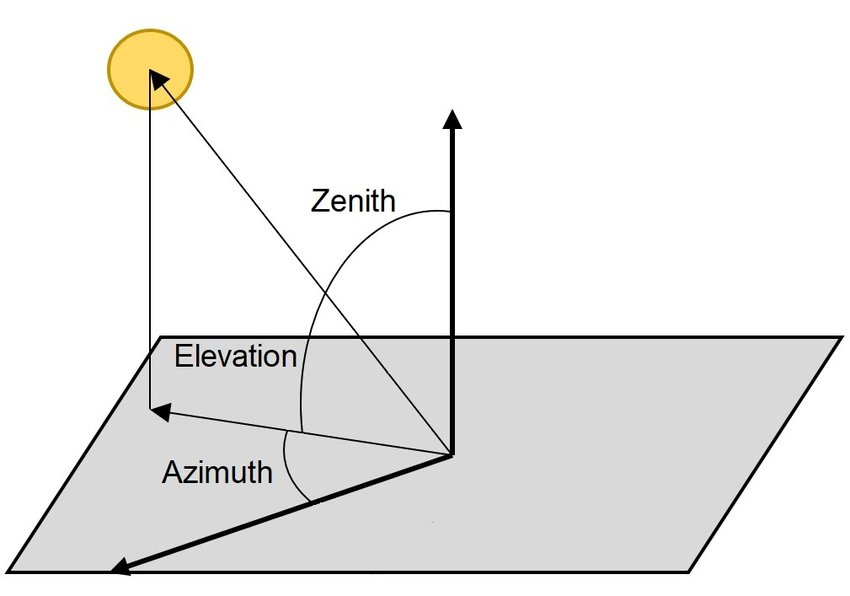


Figure 2. Local coordinates of the sun: elevation, zenith and azimuth angles.

* **RMS Delay Spread (ns)** (How long it takes for different signal paths to arrive at the receiver)
* **Frequency of transmission**
* **Seasonal Variation**
* **Target Variable:** Path Loss (dB)

To prepare the data for analysis and modelling, the following preparation processes were used:

* **Seasonal Normalization:** The “Seasonal Variation” column has inconsistencies in its format. Using pandas string operations, a new column called “Normalized Season” can be extracted and normalized, which is in lowercase and separates the values into the 4 different seasons (summer, autumn, spring and winter).
* **Data Cleaning:** Using pandas, the dataset is checked for missing values and removed if found. There were no missing values in the dataset.
  1. Interactive Dashboard (Built using Streamlit)

The interactive dashboard for this project was created with Streamlit and encased in a structured Python script. To improve modularity, custom component functions were moved to a separate “components” module and the code used to train and test the model is moved into a separate “ml” module, encouraging code reusability and readability.

This dashboard allows users to visually explore the dataset, filter it by key factors, and study feature correlations using a variety of interactive visualizations. It also allows for real-time display of model performance based on machine learning experiment outcomes.

Key functionalities of the dashboard:

* **Sidebar Filters:** The seasonal filter allows users to filter data by choosing between the four seasons: fall, spring, summer, and winter. A distance range slider is also included to allow users to modify the T-R Separation distance.
* **Interactive Scatter Plot:** The scatter plot allows users to choose independent variables to compare against path loss. Users can also choose between different types of trendlines to determine relationships between the variables.
* **Seasonal Box Plot:** Shows how path loss varies across different seasons
* **Correlation Heatmap:** Shows the correlations between different variables in numerical figures.
* **Toggle-based Visualization Control:** The checkboxes on the sidebar allow users to show and hide each of the visualizations as they please.
  1. Machine Learning Pipeline

The machine learning component was implemented in a separate **ml.py** module, allowing for reusability and helps to abstract the machine learning pipeline logic from the Streamlit dashboard logic.

* + 1. Data Processing for Machine Learning pipeline

The initial stage of the pipeline was to preprocess the data to make it possible to train the models. The key features used for training were:

* T-R Separation Distance
* Received Power
* Azimuth and Elevation angles of departure and arrival
* RMS Delay Spread
* Frequency

The seasonal data was also encoded with one-hot encoding through the get\_dummies function of the pandas library, to produce binary columns like Normalised\_Season\_fall, Normalised\_Season\_summer and so on. This would ensure that the data could be used to train the machine learning models.

After selecting the features to train the machine learning models, the dataset was split into training and testing groups with an 80/20 ratio. To improve the performance of scale-sensitive models such as SVR, KNN and MLP neural networks, StandardScaler was used to normalize the numerical values of the dataset. K-Fold cross-validation was also used to improve the accuracy of the model. Using K-Fold guarantees that model performance measures, such Mean Absolute Error (MAE) and R² Score, are not influenced by a single train-test split and accurately reflect the model's capabilities.

Tables are “float elements” which should be inserted after their first text reference and have specific styles for identification. Do not use images to present tables, or they will be inaccessible to readers using assistive technologies.

Authors can insert tables by using the MS Word option (INSERT ->Table) and providing the required row and column size. Every table must have a caption (title) above it, which must have the **“TableCaption**” style applied. Please note that tables **should not** be supplied as image files, but if they are images they must have the “Image” style applied. As an example, Table 1 shows all the styles available in this template, to be applied to the respective element of your text.

Table 1: Styles available in the Word template

| Style Tag | Definition | Style Tag | Definition |
| --- | --- | --- | --- |
| Title\_document | main title of article | ListParagraph | list items |
| Subtitle | subtitle of article | Statements | math statements |
| Authors | author name | Extract | block quotations |
| Affiliation | author affiliation information | Algorithm Caption | caption for algorithm |
| AuthNotes | footnote to author(s) | AckHead | heading for acknowledgements |
| Abstract | abstract text | AckPara | acknowledgements text |
| CCSHead | heading for CSS Concepts | GrantSponsor | sponsor of grant |
| CCSDescription | CSS terms | GrantNumber | number for the grant |
| KeyWordHead | heading for keywords | ReferenceHead | heading for references |
| Keywords | keywords text | Bib\_entry | references |
| ORCID | author's ORCHID # | AppendixH1 | appendix heading level 1 |
| Head1 | heading level 1 | AppendixH2 | appendix heading level 2 |
| Head2 | heading level 2 | AppendixH3 | appendix heading level 3 |
| Head3 | heading level 3 | TableCaption | title of table |
| PostHeadPara | first paragraph after a heading | TableHead  TableFootnote | column head of table  footnote to table |
| Para | Subsequent paragraphs of general text | Image | figures |
| ParaContinue  DisplayFormula | flush left text after display items like math equations, lists etc.  numbered math equation | DOI | Digital object identifier |
| DisplayFormulaUnnum | unnumbered equations | Label | labela |
| ComputerCode | Display Computer codes | In-text code | intext computer code |
| Short Title | Short title of article | History | Dates of article |

a This is example of table footnote.

Tables can be very difficult for people using screen reader technology to understand unless they include markup that explicitly defines the relationships between all the parts (i.e.: headers and data cells). *A key to making data tables accessible to screen reader users is to clearly identify column and row headers.* In Word, authors should identify which row or rows contain column headers. Below are the steps to do this:

1. Select that table’s row, then right-click the row and select “Table Properties”;
2. In the *Table Properties* window, click the *Row* tab and select the box that says “Repeat as header row at the top of each page.”

Or

Apply the “table head” style by highlighting the respective row and applying the “**TableHead**” style found in the “Body Element” section of the ACM Master Article Template.

* 1. Figures

Figures are “float elements” which should be inserted after their first text reference, and have specific styles for identification. Insert a figure and apply the “**Image**” paragraph style to it. For the figure caption, apply the style “**FigureCaption.**”

To accommodate readers with color vision differences, figures should still be usable when printed in grayscale. Refer to elements of the figure with non-color terms, for example “indicated as squares” instead of “indicated in blue”. Use different patterns in bar charts, different line patterns in graphs, and different shapes in plots to distinguish groups of elements and reinforce color differences.

* + 1. Half Width Figures.

Figure 1 is an example of a figure and caption spanning the half-page width (one column in a two column format) with the styles applied. If your figure contains third-party material, you must clearly identify it as such, as shown in the example below.



Figure 1: 1907 Franklin Model D roadster. Photograph by Harris & Ewing, Inc. [Public domain], via Wikimedia Commons. (https://goo.gl/VLCRBB)

* + 1. Full Width Figures.

Figure 2 is an example of a figure and caption spanning the full-page width with the styles applied. If your figure contains third-party material, you must clearly identify it as such, as shown in the examples.



Figure 2: Mockup of a bombe machine at Bletchley Part. Photograph by Sarah Hartwell. [Public domain], via Wikimedia Commons. (<https://commons.wikimedia.org/wiki/File:TuringBombeBletchleyPark.jpg>)

* + 1. Multi-part figure.

Authors can also insert a multi-part figure above a single caption. Every inserted figure must have the “Image” style applied. Below are instructions regarding how to insert a multi-part figure in your paper.

* If the author wants to insert two multi-part images, they must draw a one row and one column table and insert the images one-by-one in the cells.
* If the author wants to insert three multi-part images, they must draw a one-row and three-column table and insert the images one by one in all three cells.
* If the author wants to insert four multi-part images, they must draw a two-row and two-column table and insert the images one-by-one in all four cells. (see the following example):

| Figure 2: The layout of multipart images should be as per the above example within the table in image 1. | Figure 2: The layout of multipart images should be as per the above example within the table in image 2. |
| --- | --- |
| Figure 2: The layout of multipart images should be as per the above example within the table in image 3. | Figure 2: The layout of multipart images should be as per the above example within the table in image 4. |

Figure 3: The layout of multipart images should be as per the above example within the table. All images must have the “Image” style applied.

* 1. Algorithms

Algorithms use the styles “AlgorithmCaption” and “Algorithm”.

ALGORITHM 1: Iterative Algorithm

current\_position center

current\_direction up

current\_position is inside circle

while current\_position is inside circle, do

neighborhood all grid hexes within two hexes from current\_position

for each hex in neighborhood, do

for each neuron in hex do

convert neuron\_orientation to vector

scale vector by neuron\_excitation

vector\_sum vector\_sum + vector

end

end

normalize vector\_sum

end

1. COMPUTER CODE

Display Computer codes can be inserted using “ComputerCode” style.

CHAT Start

SAY Welcome to my world

WAIT 1.2

SAY Thanks for Visiting

ASK Do you want to play a game?

OPT Sure

OPT No Thanks

Similary, this is an example of intext code text.

Similary, this is an example of intext code text.

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A  APPENDICES

In the appendix section, three levels of Appendix headings are available.

A.1 General Guidelines

1. Save as you go and backup your file regularly.

A.1.1 Preparing Graphics

1. Accepted image file formats: TIFF (.tif), JPEG (.jpg).
2. Scalable vector formats (i.e., SVG, EPS and PS) are greatly preferred.
3. Application files (e.g., Corel Draw, MS Word, MS Excel, PPT, etc.) are NOT recommended.
4. Images created in Microsoft Word using text-box, shapes, clip-art are NOT recommended.
5. IMPORTANT: All fonts must be embedded in your figure files.
6. Set the correct orientation for each graphics file.

A.2 Placeholder Text

Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua.