**Introduction:**

Satellite communication is an important part of today's telecommunication, broadcasting, and navigation systems. The performance and reliability of satellite links are largely affected by several atmospheric parameters that attenuate the signal. Understanding and being able to accurately predict path loss due to environmental effects is required in order to design and optimize satellite communication networks. For Bangladesh, where the weather is diverse, it is preferable to model satellite path loss for enhancing the quality of satellite-based communication services.

Satellite communication path loss is caused by various factors such as free-space attenuation, atmospheric loss, rain attenuation, and cloud interference. Ground stations utilized to quantify attenuation by transmitting a dummy signal to the satellite and estimating its loss. This, however, takes resources and infrastructure on top of what is already needed. If a reliable predictive model can be established, it would eliminate the necessity of transmitting these dummy signals, thereby lessening operating expenses and boosting efficiency.

In this study, we take Bangladesh Satellite-1 and its ground base stations at Gazipur and Betbunia into account. Collecting historical attenuation data from Bangladesh Communication Satellite Company Limited (BCSCL) and relative weather data from Bangladesh Meteorological Department (BMD), a comprehensive dataset has been formed. The dataset integrates cloud, atmospheric, rain, and free-space attenuation data with various meteorological parameters.

In the estimation of total accumulated attenuation, two approaches are investigated: a predictive model based on machine learning and a mathematical model. Both models' accuracy and viability are compared to ascertain their efficacy in being used as substitutes for the conventional dummy signal method. This study not only helps in the enhancement of satellite communication in Bangladesh but also offers a model that can be applied in other parts of the globe that have similar climatic conditions.

By having a robust path loss model, satellite communication service providers can render their networks more stable, simplify resource planning, and enhance overall service quality. The findings of this research will give valuable insights on how to mitigate atmospheric attenuation effects and offer uninterrupted satellite communication services in Bangladesh and beyond.

**Motivation:**

The inspiration behind this research is the growing dependence on satellite communication for a number of important applications such as telecommunication, broadcasting, weather forecasting, and emergency services. It would be best to render these services more efficient, particularly in a developing nation such as Bangladesh, where satellite technology is emerging as a vital part of national infrastructure.

One of the most essential satellite communications issues is attenuation of signals caused by atmospheric conditions. Conventional attenuation monitoring methods use dummy signals, which impose cost and complexity on satellite operations. By having a good predictive model, we can make these dummy signals obsolete, promoting operational efficiency and cost savings to satellite operators.

Besides, Bangladesh has diverse and extreme climatic conditions like high monsoons and humidity, which have a pervasive impact on signal transmission. A good path loss model will help mitigate the consequences of these challenges by providing real-time attenuation predictions, thus improved signal reliability and uninterrupted communication services.

The worldwide relevance of this study cannot be ignored since atmospheric attenuation is experienced by all satellite operators around the globe. The result of this study can be used as a reference for other regions of the world with the same meteorological climate, which will add to the general body of satellite communication and path loss modeling.

In general, this study is motivated by the demand for an inexpensive, dependable, and efficient means of enhancing satellite communication in Bangladesh and elsewhere. With the use of sophisticated machine learning techniques and mathematical modeling, we seek to establish a scientifically credible method of attenuation prediction for the general goal of increasing the level of performance of satellite-based communication systems.

**Objective:**

The main goal of this research is to create an effective and precise model for predicting satellite path loss from atmospheric attenuation. Based on machine learning approaches and mathematical modeling, this research intends to establish the most appropriate method to foresee total attenuation. The main aims of this research include:

Collecting and merging BCSCL's historical attenuation data with BMD's weather data to create a comprehensive dataset.

Building a machine learning model to predict total accumulated attenuation based on meteorological data.

Creating a mathematical model for predicting attenuation and comparing the precision with the machine learning model.

Comparing the validity and accuracy of both models for determining their viability in replacement of conventional dummy signal-based attenuation monitoring.

Providing data that can be utilized for optimizing satellite communication networks, reducing operational costs, and enhancing the performance of Bangladesh Satellite-1 and other similar systems worldwide. Through these goals, this research seeks to play a role in the creation of a more efficient and resource-saving method of monitoring satellite communication signal attenuation.

**Scope of work:**

The study's importance transcends the prediction of satellite path loss—it presents a novel and globally applicable method for optimizing the performance of satellite communications. Unlike other models needing location-dependent parameters like latitude and longitude, the mathematical model proposed in this work is not geographically limited. That is, wherever a ground station is positioned or whichever country it is in, the model is still valid.

Instead of being dependent on coordinates, the mathematical model only needs to be provided with typical weather parameters like rain rate, surface temperature, surface pressure, relative humidity, cloud base height, liquid water density in clouds, liquid water temperature in clouds, uplink frequency, polarization type, and path length. All these as inputs make the model deployable anywhere on the earth without any changes, which is a huge advantage when it comes to scalability and deployment ease.

By eliminating reliance on location-specific data, this model has the potential to be a globally viable solution for satellite communication path loss prediction. Even though improvements in accuracy are still possible, the groundwork for global usability is already there. This study, thus, not only has value in the enablement of satellite communication in Bangladesh but also makes a wider contribution by providing a model that can readily be incorporated into satellite networks worldwide.

**Background Work:**

### \*\*Background Work on Path Loss Modeling\*\*

To understand and predict signal attenuation in wireless communication, we studied several \*\*path loss models\*\* that describe how the strength of a transmitted signal weakens with distance. Since wireless signals are subject to varying degrees of loss due to obstructions, reflections, and environmental conditions, multiple models help estimate actual behavior.

To compare these models, we ran \*\*MATLAB simulations\*\* using a \*\*1.5 GHz\*\* carrier frequency. The simulation compares three commonly used path loss models:

1. \*\*Free-space path loss model\*\* – perfect line-of-sight (LOS) propagation.

2. \*\*Log-distance path loss model\*\* – encompasses distance-dependent attenuation in different environments.

3. \*\*Log-normal shadowing model\*\* – encompasses random variations in signal strength due to obstacles.

All the models were run with mathematical equations for the evaluation of \*\*signal attenuation over distance\*\* considering different \*\*antenna gains and path loss exponents\*\*.

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### \*\*Path Loss Models and Their Equations\*\*

#### \*\*1. Free-space Path Loss Model\*\*

The free-space model considers the signal propagating unobstructed. It is given as:

\[PL\_{\text{free}}(d) = 20\log\_{10} \left( \frac{4\pi d f\_c}{c} \right) - G\_t - G\_r\]

where:

- \( d \) = Transmitter to receiver distance (m)

- \( f\_c \) = Carrier frequency (Hz)

- \( c \) = Speed of light (\(3 \times 10^8\) m/s)

- \( G\_t \) = Transmitter antenna gain (dB)

- \( G\_r \) = Receiver antenna gain (dB)

This formula was implemented in \*\*PL\_free(fc, distance, Gt, Gr)\*\* using different antenna gains and observing their effect on path loss.

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#### \*\*2. Log-distance Path Loss Model\*\*

This is a generalization of the free-space equation using a \*\*path loss exponent\*\* (\( n \)), a factor that depends on the environment:

\[PL\_{\text{logdist}}(d) = PL(d\_0) + 10n \log\_{10} \left( \frac{d}{d\_0} \right)\]

where:

- \( PL(d\_0) \) = Reference path loss at distance \( d\_0 \)

- \( d\_0 \) = Reference distance (100m in this case)

- \( n \) = Path loss exponent (e.g. \*\*2 for free space, 3 for city, 6 for strongly obstructed conditions\*\*)

This formula was used in \*\*PL\_logdist\_or\_norm(fc, distance, d0, Exp, sigma)\*\*, using different values of \( n \) to model different environmental conditions.

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#### \*\*3. Log-normal Shadowing Model\*\*

As real-world environments cause \*\*random signal fluctuations\*\* due to obstructions, the log-normal shadowing model extends the log-distance model by adding a Gaussian random variable:

\[PL\_{\text{lognorm}}(d) = PL(d\_0) + 10n \log\_{10} \left( \frac{d}{d\_0} \right) + X\_\sigma

]

- \( X\_\\sigma \) = Gaussian random variable (dB) for \*\*shadow fading\*\*

- \( \sigma \) = Standard deviation (3 dB here)

Shadowing effect was used in \*\*PL\_logdist\_or\_norm(fc, distance, d0, Exp(1), sigma)\*\*.

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### \*\*MATLAB Implementation\*\*

- \*\*Distances\*\* were considered as \*\*squared values\*\* (1, 4, 9,., 961) to see attenuation patterns more distinctly.

- Different values of \*\*antenna gains \( G\_t, G\_r \)\*\* and path loss exponent \*\*\( n \)\*\* were used to evaluate their impact.

- \*\*Three subplots\*\* were drawn:

- \*\*Free-space model\*\* plotting different antenna gains.

- \*\*Log-distance model\*\* showing variations with different path loss exponents.

- \*\*Log-normal model\*\* showing the impacts of shadow fading.

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### \*\*Advantages and Limitations of the Models\*\*

#### \*\*Free-space Path Loss Model\*\*

\*\*Advantages:\*\*

- Provides a \*\*simple reference\*\* for calculating path loss.

- Applicable in applications where \*\*line-of-sight (LOS) propagation\*\* is dominant, e.g., satellite communication.

\*\*Limitations:\*\*

- Assumes an \*\*ideal propagation environment\*\*, which is not true for terrestrial communication.

- Does not consider \*\*reflections, diffraction, and obstructions\*\*, hence it cannot be used for urban environments.

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#### \*\*Log-distance Path Loss Model\*\*

\*\*Advantages:\*\*

- \*\*More accurate\*\* than the free-space model since it considers environmental factors through the \*\*path loss exponent \( n \)\*\*.

- Adjustable for different environments (rural, urban, and obstructed areas) by modifying \( n \).

\*\*Disadvantages:\*\*

- \*\*One path loss exponent\*\* is used, while real environments have different propagation conditions.

- Eliminates \*\*random variations\*\* due to obstacles and thus is not sufficient for modeling complex terrain.

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#### \*\*Log-normal Shadowing Model\*\*

\*\*Advantages:\*\*

- Incorporates \*\*random signal variations\*\* to accurately model actual signal behavior.

- Suitable for \*\*urban terrain and indoor environments\*\*, where signals are significantly impacted by obstacles.

\*\*Limitations:\*\*

- Requires \*\*statistical analysis\*\* to establish correct values for \( X\_\\\\sigma \).

- More intensive computationally compared to the straightforward models.

- Not yet addressing \*\*multipath fading\*\*, the outcome of reflection and interference.

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### \*\*Practical Issues\*\*

Although the models assist in describing \*\*general path loss behavior\*\*, there are more complications within actual wireless communication like:

- \*\*Multipath Effects:\*\* The signal reflects from surfaces, and there is constructive or destructive interference.

- \*\*Weather Conditions:\*\* Rain and humidity exert atmospheric influences on signal propagation.

- \*\*Dynamic Environments:\*\* Cars, individuals, and moving objects introduce further randomness.

- \*\*Antenna Characteristics:\*\* Physical antennas possess certain radiation patterns that influence reception.

Due to these, \*\*more complex models\*\* such as \*\*Hata, COST-231, ITU-R, and Rayleigh/Rician fading models\*\* are utilized for real-world wireless network design.

Hata Model:

### \*\*Overview of Hata Path Loss Model Implementation\*\*

The \*\*Hata model\*\* is an empirical path loss model that is used for the prediction of signal attenuation in \*\*macrocellular environments\*\* (150 MHz – 1500 MHz). It estimates path loss in \*\*urban, suburban, and open areas\*\* based on the heights of the transmitter and receiver from the ground. Our thesis is about \*\*satellite communication\*\*, where antennas are not on the ground, so this model is \*\*not applicable\*\* for our research.

### \*\*Hata Path Loss Model Equation\*\*

For \*\*urban\*\* situations, the formula is as follows:

\[PL\_{\text{urban}} = 69.55 + 26.16\log\_{10}(f\_c) - 13.82\log\_{10}(h\_{tx}) - C\_{Rx} + (44.9 - 6.55\log\_{10}(h\_{tx}))\log\_{10}(d/1000)\]

where:

- \( f\_c \) = Carrier frequency (MHz)

- \( h\_{tx} \) = Transmitter height (m)

- \( h\_{rx} \) = Receiver height (m)

- \( d \) = Transmitter-to-receiver distance (m)

- \( C\_{Rx} \) = Receiver correction factor (function of \( f\_c \))

Correction factors modify the path loss equation to account for \*\*suburban and open areas\*\*.

### \*\*MATLAB Implementation\*\*

The MATLAB code:

- Computes path loss for \*\*urban, suburban, and open areas\*\*.

- Takes a \*\*carrier frequency of 1.5 GHz\*\* with \*\*htx = 30m\*\*, \*\*hrx = 2m\*\*.

- Plots results against logarithmic distance values.

### \*\*Why Hata Model is Not Used in This Thesis\*\*

- Is derived from \*\*ground antenna heights\*\*, and hence cannot be used for \*\*satellite antennas\*\*.

- Is designed for use in \*\*terrestrial\*\* links, not space-based links.

- Does not take into consideration \*\*satellite path loss\*\*, where the free-space loss and atmospheric attenuation are more prominent.

Thus, alternative models like \*\*free-space path loss\*\* and \*\*satellite-specific models\*\* need to be used for our study.

ITU-R models: