Performance Analysis of Terrestrial-Satellite Networks

Capstone Report

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Abstract:

This research explores statistical models in mobile communication, particularly Location Management System (LMS) models, offering insights into predicting mobile station locations within cellular frameworks. Through meticulous simulations, it demonstrates the effectiveness of these models in real-world scenarios. Additionally, the study delves into broader communication performance metrics, showing how elevation angle impacts line-of-sight communication, SNR, latency, and channel capacity. It highlights the importance of optimizing elevation angles for efficient communication, paving the way for enhanced design and operation of mobile communication systems.

Contents

Preface

Satellite-terrestrial networks offer a solution to the challenge of mobile communication and internet access in rural areas, a critical issue exacerbated by distance learning and quarantine measures. Moreover, they hold promise in mitigating social disruptions and economic disparities by generating new job opportunities and curbing migration from rural to urban areas. The successful execution and ongoing deployment of this project hold the potential to diminish social and economic inequality by ensuring widespread, high-quality access to information. Motivated by these prospects, the decision was made to embark on this project.
I want to extend my sincere gratitude and heartfelt thanks to Professor Behrouz Maham. Despite his busy schedule, he dedicated his time to listen, explain, and support me, as well as other students, during our work on this capstone project under his supervision.

Nazarbayev University, April 20, 2024

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Chapter 1

Introduction

To conduct the performance analysis we need to choose the variable and then understand how it is effecting the performance metrics thus to do so we need to basically look for the variable that will connect majority of the performance metrics parameters. In this section I make a short literature review on papers that will be used in this research.

The authors of a research paper [1] looked at how to improve the performance of hybrid satellite-terrestrial networks by using a technique called non-orthogonal multiple access (NOMA). In these networks, the satellite network can use the terrestrial network to help transmit its signals. The NOMA technique helps to share the network resources fairly and efficiently by adjusting the power levels used by different users based on the current network conditions.The authors used a type of protocol called "decode-and-forward" and looked at two different types of signal interference, called "Shadowed-Rician fading" and "Nakagami-m fading", that can affect the quality of the signals being sent. They used math to figure out how likely it was that the signals would fail to transmit correctly, and how much data could be transmitted on average.They found that the NOMA technique worked better than other techniques for sharing the network resources. They also looked at how fair the resource sharing was between different users and introduced a measure called "Jain's fairness index" to evaluate it. This is one of the evaluating criteria that I can use later.

This research paper [2] suggests a new way to improve how fast data can be sent and received between low orbit satellites and Earth by using a technique called massive multiple-input multiple-output (MIMO) with full frequency reuse (FFR). This technique has been used in regular communication systems, but not with satellites before.To make this work, the researchers used information about the communication channel and made adjustments for things like delays and changes in frequency. They also created a way to group users together so they could share the same resources and avoid interference. The researchers used computer simulations to show that this new approach can significantly increase the speed of communication between satellites and Earth.This research is a valid source of data for this project work.

This research paper [3] is about using satellite constellations to improve wireless communication worldwide. The authors suggest a network architecture that combines satellite and land-based communications to provide more reliable and flexible wireless access. They propose using techniques like interference management, diversity, and cognitive radio to create seamless and high-speed wireless connections for devices with different needs. The article also discusses future research directions and three potential applications. This paper can be used in later Quantitative and Qualitative analysis.

The paper [4] suggests a new way to figure out the right timing for communication between low earth orbit (LEO) satellites and 5G networks on the ground. The current method used on the ground doesn't work with LEO satellite systems because they work differently. The new method uses measurements of the time and frequency differences when the satellite sends signals down to the ground. This helps to estimate where the satellite is located. They then use this information to solve a math problem that helps figure out the best timing for communication between the satellite and the ground. The new method works well and can make sure that multiple users can communicate effectively with the satellite at the same time. This method is suitable for data analysis that will be conducted later.

In article [5] authors focused on BER performance of OFDM-BPSK and -QPSK over Generalized Alpha-Mu Fading Distribution. This article offers an evaluation of the OFDM systems performance, incorporating the generalized fading model characterized by the alpha-mu distribution. The versatility of the alpha-mu distribution aids in producing Weibull variants, which can subsequently be employed to estimate the channel in OFDM systems. The incorporation of non-linearity in the propagation medium is vividly illustrated in the simulation outcomes, as evidenced by the notable reduction in BER when adjusting alpha from 1 to 7. Higher alpha values can potentially lead to even more pronounced decreases in BER. However, variations in BER values are not observed in other distribution curves. This article [6] suggest the methodology used to calculate composite noise temperature for satellite links, using data from the Vienna ground station within the MOST project. MOST, or Microvariability and Oscillations of Stars, is a Canadian micro satellite space telescope mission comprising a Low Earth Orbiting (LEO) Satellite and three ground stations, including one in Vienna. Thus the results will be for the Central Europe, however the data is still relevant because it is show that the atmospheric loss for the satellite in this work will be about 1 dB. [7]Utilizing NS-3 to simulate a 4-satellite trail ISL model, it offers insights into quantitative packet throughput and packet loss metrics based on the IEEE 802.11 standard. Employing transmission control protocol/internet protocol (TCP/IP) with adjusted interframe parameters, the inclusion of a four-way handshake message signaling facilitates packet re-transmission to address packet loss issues. The simulation findings demonstrate a connection between slot time, uplink data rate, and ISL throughput within the satellite topology. In the paper [8] The development of satellite Internet and advancements like phased array antenna technology have led to a diversification of traffic types and variations in traffic distribution across space and time, as well as uneven traffic demands. Consequently, the utilization of multi-beam and beam-hopping technologies has become increasingly vital in satellite communication systems. To enhance resource utilization efficiency and communication quality in the dynamic LEO satellite system, a study explores a slot allocation method for hopping beam communication systems using genetic algorithms, addressing current challenges in satellite Internet. Genetic algorithms, being parallel and adaptive search meta-heuristics, efficiently explore solution spaces and can find global optimal solutions for sequence optimization problems [9] This study aimed to aid users in selecting the most effective access method within the Integrated Satellite-Terrestrial Network (ISTN). The key findings of this research are as follows. Firstly, the study examined transmission channels through terrestrial and satellite access. Terrestrial access is susceptible to multipath effects and typically operates in the C-band, leading to significant bandwidth fluctuations per user. Conversely, satellite access is heavily influenced by transmission distance, making it challenging to meet the requirements of services with stringent delay constraints. Secondly, a time slot model and dynamic pricing mechanism are proposed within the application server to incentivize users to transmit data during periods of lower activity. Lastly, a dynamic selection mechanism for access strategies is introduced to minimize user costs. This mechanism optimizes both user energy consumption and the application server load simultaneously. The communication duration for each pass of an LEO satellite over a ground station varies due to the rapid movement of these satellites across the Earth. The visibility duration is directly influenced by the look elevation angle from the ground station. Notably, the shortest range occurs when the satellite's path achieves maximal elevation above the ground station. This variability in range introduces changes in free space loss, impacting the link budget. In this study [10], a methodology incorporating relevant formulas was employed to analyze the impact of elevation on the signal-to-spectral noise density ratio. The investigation focused on the downlink performance, with particular emphasis on the receiving system's signal-to-noise ratio. It is worth noting that the is contingent on the bandwidth of the receiving device. To maintain focus on the elevation's impact, the paper exclusively considers the influence on the signal-to-spectral noise density ratio, avoiding the confounding effects of the receiving device bandwidth. After getting the results that show to us the optimal distance from satellite to earth we can start to apply this results to satellite constellations. A satellite constellation consists of multiple orbital planes, each hosting satellites positioned at the same altitude and inclination. A pass refers to the time a satellite is within communication range of a specific ground location, typically lasting a few minutes for a Low Earth Orbit (LEO) satellite, depending on factors like elevation angle and relative positions. Satellite communication faces challenges such as latency due to long transmission distances. Interestingly, LEO satellite communication can offer lower latency compared to terrestrial networks over long distances due to faster propagation speeds in space. Both Free-Space Optical (FSO) and Radio Frequency (RF) communication technologies are considered for satellite communication. FSO offers higher data rates and lower interference but is susceptible to atmospheric effects and pointing errors. RF links, while presenting wider beams and integration with terrestrial systems, serve as fallback solutions if FSO communication is impractical. LEO satellites move rapidly, posing challenges in maintaining links due to dynamic constellations and significant Doppler shifts compared to terrestrial systems.[11] [12]The research presented in this paper proposes an analysis of the low Earth orbit (LEO) satellite downlink when the interference source moves along the satellite's trajectory with a specific elevation angle difference. To analyze the link budget more precisely in various situations, the ground station antenna radiation pattern is obtained by using geometrical optics (GO) and physical optics (PO) methods, and a regression model is applied to this radiation pattern to easily observe the tendency.

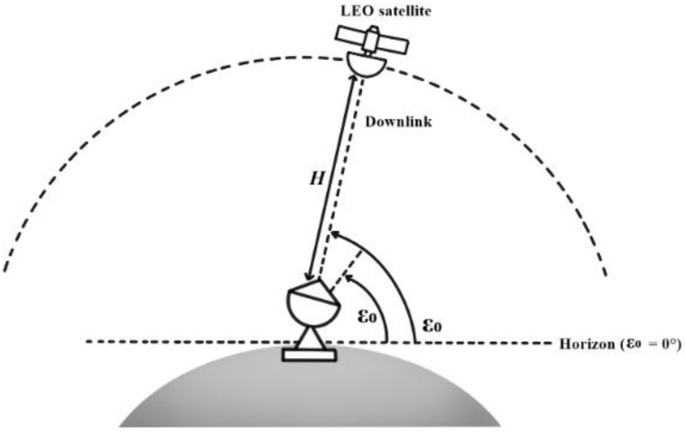

Figure 1.1: Conceptual figure of the LEO satellite downlink with interference situation

Chapter 2

Background

The constant pursuit for seamless communication has driven the evolution of various network infrastructures. As the world has become more digitally interconnected [13], two primary systems have emerged as front runners in meeting the escalating demands: terrestrial and satellite networks. Understanding the intricacies and synergies between these systems becomes paramount as we gear towards an era dominated by the Internet of Things (IoT), real-time data transfer, and global connectivity.

Terrestrial Networks: Rooted in the earth's landscape, terrestrial networks have historically been the backbone of urban communication. Initially characterized by wired systems like telegrams and landlines, the progression of technology witnessed the onset of fiber-optic cables, DSL lines, and more recently, the wireless technologies of 4G and 5G networks [14].These ground-based systems primarily bank on physical infrastructure, such as transmission towers, cables, and routers, to facilitate data transfer. Major cities and towns across the world are intricately woven together with these networks, ensuring high-speed, low-latency communication.

Satellite Networks: Reaching where terrestrial networks often falter, satellite communication emerged as a solution to the globe's remote corners. By leveraging satellites in space, these networks overcome terrestrial barriers, enabling connectivity in areas as diverse as isolated islands, vast deserts, and the high seas. Depending on their orbits—geostationary (GEO), medium earth orbit (MEO), or low earth orbit (LEO)—satellites can cover expansive regions, albeit often at the cost of higher latency compared to their terrestrial counterparts.

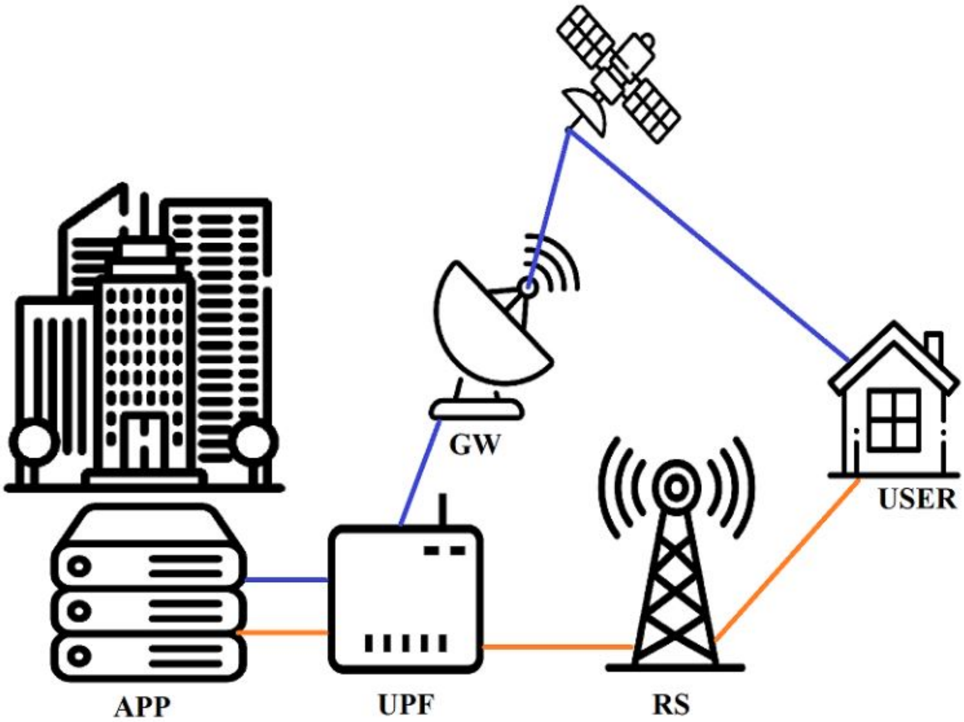

Figure 2.1: Schematically depicted terrestrial-satellite network

Hybrid Satellite-Terrestrial Network Utilizing Software-Defined Networking (SDN) facilitates centralized management of a Hybrid Satellite-Terrestrial Network (HSTN). SDN enables dynamic resource allocation based on global network state information, allowing efficient collaboration between terrestrial communication network (TCN) and satellite communication network (SCN) entities. In this network setup, SDN-enabled ground stations, satellite gateways, base stations (BS), and switches facilitate traffic classification and flow management. SDN controllers, strategically deployed, orchestrate dynamic resource allocation strategies for efficient link aggregation within the HSTN. A Hardware-in-the-Loop (HIL) simulation platform is employed for experiments, combining physical components with simulation models. The platform consists of servers A, B, and C connected by cables. Servers A and B represent physical terminals, while server C hosts the simulation part. Time synchronization ensures alignment between simulation time and system time, with packet interception and filtering facilitated by Winpcap. Real-time packet translation and transmission are managed through the System In The Loop (SITL) module. The simulation platform comprises six main components: SDN controller for dynamic path selection, SITL modules for packet filtering and translation, GS-equipped eNodeB nodes for packet transmission control, satellite and router nodes for forwarding, and SITL modules for packet reordering and unpacking. Overall, SDN enhances link aggregation and resource allocation in the HSTN, while the HIL simulation platform enables realistic experiments combining physical and simulated components.[15]

Chapter 3

Methodology

3.1 Hypotheses

The realm of communications has been perennially marked by the duality of terrestrial and satellite systems. While they converge on the common goal of data transmission, their distinct operational methodologies have always piqued interest. This research intends to pierce through the veil of generalized understanding to dissect the intrinsic performance dynamics of these systems. Presented below are the primary hypotheses driving this study, complemented by their theoretical underpinnings.

1. **Hypothesis**: Increasing the elevation angle in satellite communication systems will lead to improvements in communication performance metrics
   Theoretical Rationale: Elevating the angle reduces the path through the Earth's atmosphere, which tends to attenuate signals and introduce noise. By minimizing atmospheric interference, higher elevation angles can result in stronger and clearer signals reaching the receiver. Additionally, a higher elevation angle typically corresponds to a shorter path length, reducing the propagation delay and thus improving the overall speed and efficiency of communication. Moreover, with a greater elevation angle, the satellite appears higher in the sky, reducing the likelihood of obstructions such as buildings or terrain, further enhancing signal quality and reliability. Consequently, elevating the angle offers a multifaceted approach to optimizing communication performance in satellite systems.

2. **Hypothesis**: Satellite communications face heightened vulnerability to environmental and atmospheric factors compared to their terrestrial counterparts.
   Theoretical Rationale: The trajectory of satellite signals, which encompasses transmission through the Earth's atmospheric layers, exposes them to an array of external interferences. Phenomena like rain fade and solar interjections

can compromise signal quality. In contrast, terrestrial networks, anchored and often insulated, present a robust front to such challenges. However, the narrative is shifting with the advent of contemporary satellite technologies. Modern satellite systems leverage adaptive [16] modulation and refined error correction mechanisms, aiming to diminish the adversarial impacts of atmospheric disturbances. rain attenuation can disrupt satellite-ground communication, this study presents a method to evaluate service availability in Low Earth Orbit (LEO) satellite communication systems, accounting for rain attenuation. Through a case study, the impact of rainfall on user link availability and overall system service availability was analyzed. The findings indicate that rain attenuation, particularly in rainy coastal areas, can significantly degrade user links, thereby affecting system availability due to increased noise levels. Consequently, addressing rain attenuation is crucial to maintaining communication quality. Potential strategies include adjusting polarization methods and increasing antenna aperture size to mitigate its impact and ensure reliable communication.[17]

3.2 Research Design

3.2.1 Selection of Variables

- Dependent Variables:
    1. Latency
    2. Bandwidth or throughput
    3. Signal-to-noise ratio (SNR)
    4. Outage Probability
    5. Free Space Loss
    6. Elevation Angle
- Independent Variables:
    1. Type of network
    2. Atmospheric condition

3.2.2 Data Collection

- Primary Data:
    1. Literature review of past research studies and articles related to terrestrial and satellite communication performance.

- Choose the variable:
    1. We need to build relationship with some the performance metrics and illustrate how some dependent variables changes with chosen variable.
- Analyze the results using Matlab:
    1. Matlab plots are essential for this work because to understand the change in performance metrics we need to build plots and see the how variable effect the plot and how it effect any of the performance metrics.

3.3 Data Analysis

3.3.1 Quantitative Analysis

- Use Matlab software to make whole Quantitative analysis

3.3.2 Qualitative Analysis

- Correlate findings with the literature to understand any discrepancies.

3.4 Limitations

There are inherent restrictions to take into account in the complex analysis of the performance dynamics between terrestrial and satellite communication networks. Some of our conclusions may only be relevant for the present due to the fast changing nature of communication technology [18], such as the introduction of 5G and low-earth orbit (LEO) satellites. Environmental factors [19] [20] provide an element of uncertainty, especially those that affect satellite communications such solar flares [21] and rain fade [22]. Our study's geographical breadth might not fully encompass the many terrains and habitats found around the world, which could cause results to deviate from an accurate global representation. Furthermore, the complexity of various terrestrial infrastructures, such as fiber, cable, and wireless networks, as well as the variations in satellite orbits (GEO, MEO, LEO), add levels of complexity that our generalized method may not be able to handle [23].Because Low Earth Orbit (LEO) satellites move regularly and swiftly in orbit, they repeatedly follow the same patterns, such as rising and setting. These movements create varying correlations over time in elevation angles and relative positions. Leveraging these temporal correlations, we have developed a scheme for predicting Channel State Information (CSI) in satellite-terrestrial networks, without requiring knowledge of the terrestrial device's position or the LEO satellite ephemeris data. Our simulation results demonstrate that our scheme achieves low prediction errors across a range of factors including LEO altitude and orbit, terrestrial device location and mobility, ground conditions, weather variations, and elevation angles during handover events.[24]

Chapter 4

Results and Discussions

Table of estimations

Parameters	Values
Carrier Frequency $f(GHz)$	2
EIRP (dBW)	30
$G/T_s(dB/K)$	15
Channel bandwidth W (MHz)	50
Pocket size $(MBits)$	1
Antenna Efficiency	60
$\gamma(dB)$	8.5

At this part I am going to show the relationship of the angle of elevation and signal to spectral in noise density ratio. I am going to research the Elevation impact on signal to spectral noise density ratio for Low Earth Orbiting satellite ground stations at S-band and take data from it.

Using Figure 4.3 we can derive formulas

$$\epsilon_0 + \alpha_0 + \beta_0 = 90$$

$$d \cos \epsilon_0 = r \sin \beta_0$$

$$d \sin \alpha_0 = R_e \sin \beta_0$$

Then we can derive main formula of $d(\epsilon_0)$

$$d(\epsilon_0) = R_e\left(\sqrt{\left(\frac{H+R_e}{R_e}\right)^2 - \cos^2 \epsilon_0} - \sin \epsilon_0\right)$$

Here Re is an Earth radius. Here I made a matlab simulation for different H from 800 to 1200 and different 0 from 0 to 90 degrees.

In the depicted figure, the relationship between the angle of elevation (ϵ_0) and the distance (d) to a satellite is illustrated. The angle of elevation is represented as the angle between the observer's line of sight and the horizontal plane, denoted as ϵ_0. As this angle varies, it is evident in the figure that the distance to the satellite

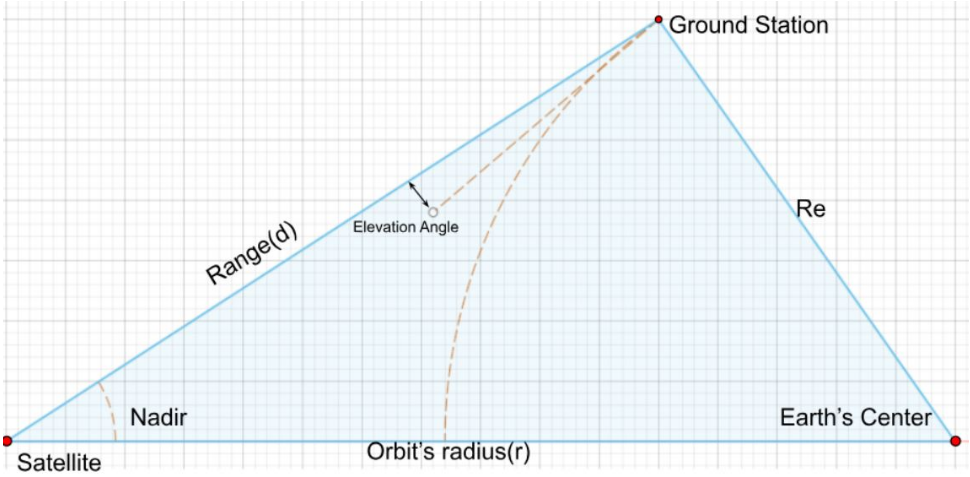

Figure 4.1: Ground station geometry

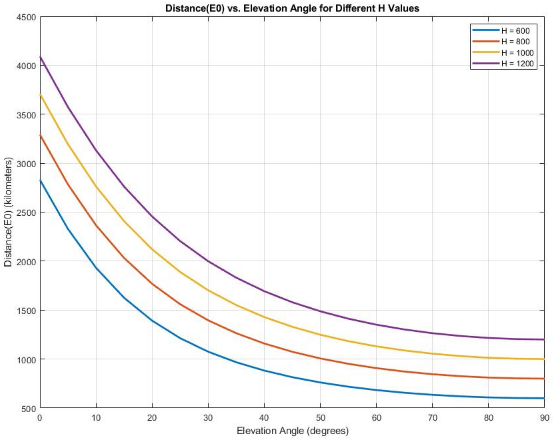

Figure 4.2: Different values of Distance(d) for different angles and distances H

(d) also undergoes changes.

When the satellite is positioned directly overhead, corresponding to a higher angle of elevation (ϵ_0), the distance (d) is comparatively shorter. This configuration is visually depicted by a steeper line or curve in the figure. Conversely, as the satellite moves towards the horizon, resulting in a lower angle of elevation (ϵ_0), the distance (d) increases. This relationship is represented by a shallower line or curve in the figure.

The graphical representation provides a clear visual understanding of how changes in the angle of elevation impact the distance to the satellite. It highlights the dynamic nature of these two parameters, offering valuable insights into the satellite's position relative to the observer on Earth.

Now we need to calculate the free space loss. I will use formulas from the paper. Where c is a speed of light and f is equal to 2 GHz because this is common frequency for LEO satellites.

$$L_s = (\frac{4\pi f}{c})^2 * d^2(\epsilon_0)$$

We need to turn this formula in decibels

$$L_s = 98.45 + 20logd(\epsilon_0)$$

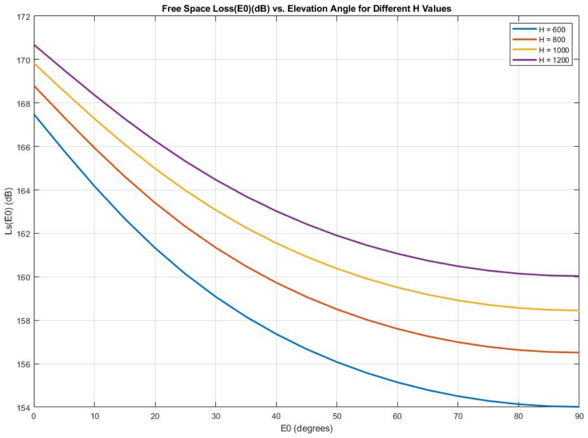

Figure 4.3: Free space loss graph

The Free Space Loss (FSL) graph illustrates the relationship between the angle of elevation (E_0) and Free Space Loss (L_0 in dB) for satellite communication. The x-axis represents the angle of elevation (E_0) in degrees, while the y-axis represents the Free Space Loss (L_0) in decibels (dB). The graph comprises four distinct lines corresponding to different distances: 600 km, 800 km, 1000 km, and 1200 km.

As the angle of elevation (E_0) increases along the x-axis, moving from left to right, the Free Space Loss (L_0) decreases. Each line on the graph represents a specific distance, with the lines diverging from the higher distance (1200 km) at the top to the lower distance (600 km) at the bottom. This signifies that, for a given distance, a higher angle of elevation results in a lower Free Space Loss.

The graph visually demonstrates a fundamental characteristic of satellite communication: a higher angle of elevation leads to a more direct path between the transmitter and the satellite, resulting in reduced Free Space Loss. The inclusion of distinct lines for different distances provides a clear visual representation of how Free Space Loss varies with both the angle of elevation and distance in a free space propagation environment, with all distances measured in kilometers.

Now we can calculate SNR using range equation

$$\frac{S}{N_0} = \frac{EIRP(\frac{G}{T_s})}{kL_sL_0}$$

We need to simplify it and turn it into dB. Using values from the papers [6] we know that atmospheric loss is about 1dB, so to better represent the effect of the elevation angle on SNR other noises are neglected. Now we can replace L_s with values decibel values and get rid of losses and get

$$\frac{S}{N_0} = EIRP - L_0 - 20logd(\epsilon_0) + (\frac{G}{T_s}) + 130.15$$

Other losses denoted as L_0 and we can repalce EIRP on estimated value so we can modify previous formula ones again

$$\frac{S}{N_0} = 175.15 - 20logd(\epsilon_0)$$

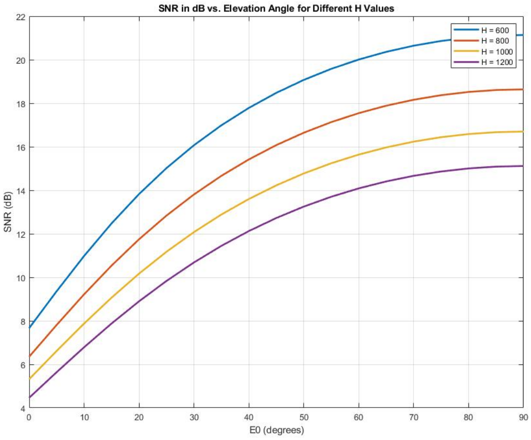

Figure 4.4: Signal to spectral noise density ratio

The graph illustrates the relationship between the angle of elevation (E_0) on the x-axis and the Signal-to-Noise Ratio (SNR) in dB on the y-axis. The angle of elevation represents the highest point of the Low Earth Orbit (LEO) satellite's path above the ground station. The varying distance between the ground station and the LEO satellite leads to fluctuations in free space loss along the satellite's path, dependent on the viewing angle from the ground station.

In terms of downlink performance, the SNR is crucial at the receiver. As the orbital altitude of the LEO satellite increases, the maximum difference in SNR decreases. The graph indicates that the maximum difference in SNR for different orbital altitudes is approximately 12 dB. This information highlights the impact of viewing angles on signal quality and emphasizes the importance of considering orbital altitudes for optimizing communication performance in satellite systems.

Now using Shannon-Hartley theorem and estimated bandwidth we can see the relation between angle of elevation and distance $d(\epsilon_0)$

Using previously gain data we can calculate transmission delay for different distances $d(\epsilon_0)$ and elevation angles ϵ_0 Figure 4.6.

The elevation angle influence the delay, potentially causing variations based on the path the signal takes through the atmosphere. When considering both distance and elevation angle, intriguing patterns may emerge, revealing optimal conditions

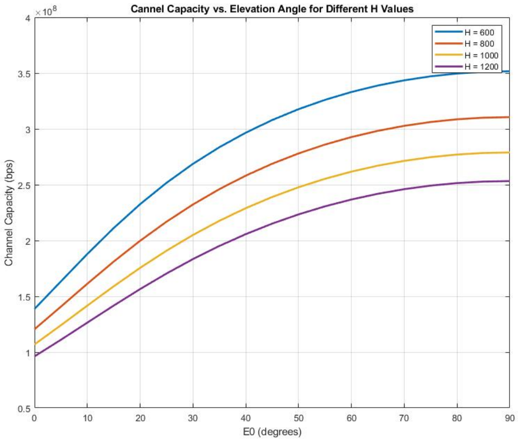

Figure 4.5: Channel capacity relation

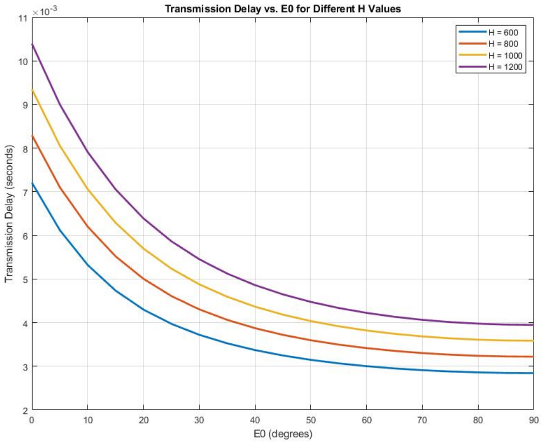

Figure 4.6: Transmission Delay

for shorter delays. At very long distances, you might observe a saturation effect in transmission delay due to system or medium limitations.
Using SNR we can plot SNR vs BER graphs Figure 4.7 for BPSK and QPSK modulations for every value of H to illustrate dependence between Bit Error Rate and Height of the satellite above the Earth's surface and elevation angle. BER is one of the most important performance metrics in satellite communications.
One of the key performance metrics is Outage Probability, knowing SNR we can also plot a graph that will illustrate the relationship between Height of the Satellite above the Earth's surface and elevation angle with Outage probability Figure 4.8.

Latency is also one of the performance metrics in satellite communications. Latency consists of Transmission, Propagation and Processing delays. We already

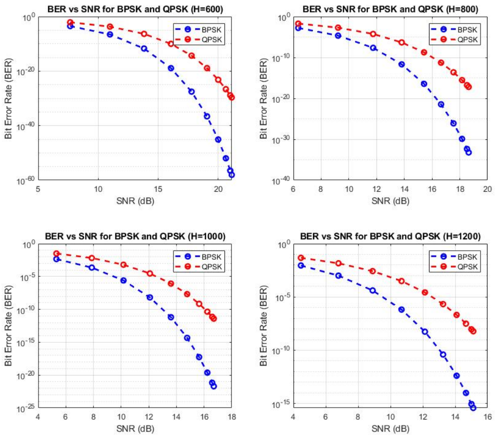

Figure 4.7: BER vs SNR graphs for all values of H

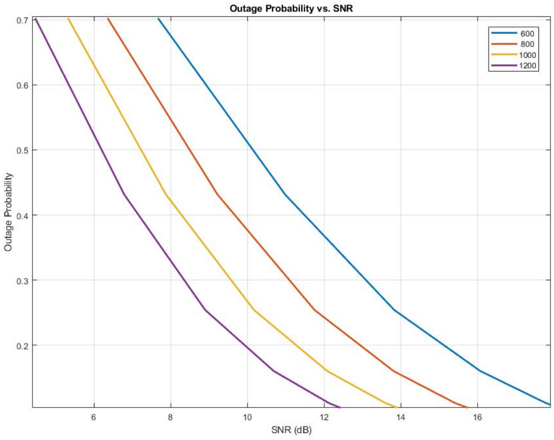

Figure 4.8: Outage Probability vs SNR graphs for all values of H

calculate Transmission delay 4.6, knowing distance from the ground station and satellite we can calculate the Propagation delay using formula. In our case with the different elevation angle and height we can see the relationship between this variables and propagation delay that you can see in Figure 4.9.

$$Propagationdelay = \frac{Distance}{SpeedofLigth}$$

According to the article [25] we can come to conclusion that Queuing Delay for the satellite in our case will be 0.341ms. Using inforation from Figure 4.6 and Figure 4.9 and Queuing Delay of that we can calculate Latency for every Elevation angle and show the relationship between elevation angle and latency on Figure 4.10.

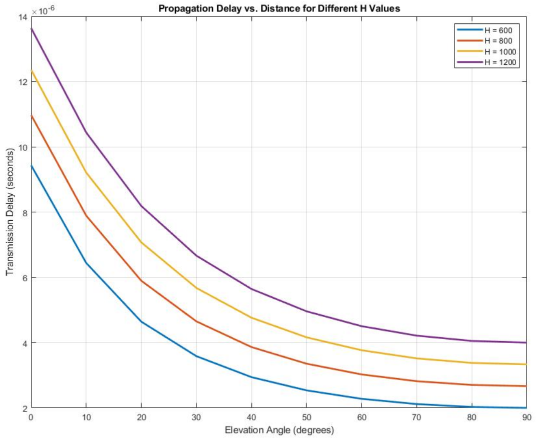

Figure 4.9: Propagation Delay vs Elevation Angle for all values of H

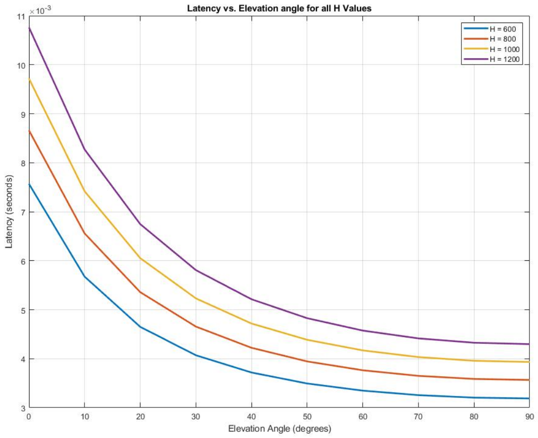

Figure 4.10: Latency vs. Elevation angle for Every all values of H

4.1 Discussions

The endeavor to recreate several types of LMS as outlined in the article [26] presents a significant step in the progression of mobile communication research. This work's essence revolves around the mathematical model commonly associated with mobile communications, especially in predicting mobile station locations within cellular frameworks.

One of the notable revelations from this exercise is evident in Figure 4.3. This visual representation underscores the effectiveness of the recreated LMS models. The meticulous approach of conducting simulations within a precise interval, a strategic decision aimed at nullifying potential errors, especially those stemming from software platforms like Matlab, showcases an understanding of the intricate balance between theory and real-world application.

However, it's worth noting that the recreated LMS models represent just a segment of the diverse spectrum of statistical models available. Drawing from the acquired knowledge and hands-on experience from these simulations, it is plausible to consider the recreation of other statistical models for the LMS channel. Diverse models could cater to various mobile communication scenarios, offering tailored solutions to specific challenges. Good example of such solution is given in article [27].

The transition delay experiences a decrease with the expansion of the distance and elevation angle. You can see it at Figure 4.6 . This phenomenon can be attributed to the increased propagation path length, resulting in a longer time for signals to traverse the communication channel. As a consequence, the transition delay diminishes due to the extended propagation distance.

The channel capacity exhibits an augmentation with the growth of both distance and elevation angle Figure 4.5. This effect can be elucidated by considering the expanded spatial diversity resulting from a higher elevation angle, leading to improved multipath propagation. The increased channel capacity implies a greater ability to transmit information without loss or degradation, emphasizing the positive impact of distance and elevation angle on the overall communication performance.

The signal-to-noise ratio (SNR) undergoes an increase as distance and elevation angle escalate Figure 4.4. The elevation angle, in particular, plays a crucial role in enhancing the line-of-sight communication and reducing signal attenuation, contributing to a higher SNR. Additionally, the increased distance can lead to a reduction in atmospheric and environmental interference, further boosting the SNR.

With the increase in SNR we can see the decrease in BER in Figure 4.7, where as the SNR rises, the BER diminishes. A higher SNR implies that the signal power is stronger compared to the noise power, making it easier for the receiver to distinguish between transmitted symbols. As a result, fewer errors occur in decoding the received signal, leading to a lower BER. Also increase in SNR means increase in channel capacity which is also means that it is closely dependent on the elevation angle and height as we can see in Figure 4.5.

The situation is opposite with latency, free space loss and outage probability they are decreasing with the increase of elevation angle. Increase in the elevation angle improves the line-of-sight and shortens the path between satellite and ground station whe can see they effect on signal on Figures 4.10, 4.8 and 4.3

Chapter 5

Conclusion

In conclusion, the exploration of various statistical models, particularly in the context of mobile communication research, marks a significant advancement in the field. The recreation and analysis of different Location Management System (LMS) models, as highlighted in the referenced article [27], provide valuable insights into predicting mobile station locations within cellular frameworks. The meticulous simulation approach, as demonstrated in Figure 4.3, underscores the effectiveness of these models in real-world scenarios, showcasing a delicate balance between theoretical understanding and practical application.

Moreover, the discussion extends beyond LMS models to encompass broader aspects of communication performance, such as transition delay, channel capacity, signal-to-noise ratio (SNR), and latency. Figures 4.4, 4.5, 4.6, and 4.7 illustrate how distance and elevation angle impact these performance metrics. Specifically, an increase in elevation angle correlates with improvements in line-of-sight communication, reduced signal attenuation, and higher SNR, ultimately leading to decreased Bit Error Rate (BER) and increased channel capacity.

Furthermore, the inverse relationship between elevation angle and latency, free space loss, and outage probability highlights the importance of clear line-of-sight paths in mitigating communication impairments. Figures 4.8, 4.10, and 4.3 illustrate the effects of elevation angle on these parameters, emphasizing the significance of optimizing elevation angles for efficient communication.

Overall, the findings underscore the critical role of elevation angle in shaping communication performance, with implications for both theoretical modeling and practical implementation. By understanding and leveraging the effects of elevation angle on communication metrics, researchers and practitioners can enhance the design and operation of mobile communication systems, paving the way for more reliable and efficient terrestrial-satellite networks.

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Appendix A

Appendix A name