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Impact of Environmental Factors on Optical Fiber Communication in North East India: A Study on Weather, Terrain and Infrastructure

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***Abstract*: This paper describes the study of the effect of environmental factors—weather, terrain, and overhead versus underground deployment—on optical fiber communication performance of telecom network of Power Grid Corporation of India Limited across several cities in Northeast India. Using appropriate data collected from field testing, including Optical Time Domain Reflectometry (OTDR) analysis, we present a comprehensive comparison of network performance under varied environmental conditions. Results reveal significant differences in attenuation and downtime due to these factors, emphasizing the importance of customized infrastructure deployment in the region.**

***Keywords*: Attenuation, Fiber Optics, Environment, Northeast India, Signal Reliability, Terrain.**

1. Introduction

The extremely rapid expansion of telecommunication networks necessitates robust infrastructure, especially in regions with challenging environmental conditions like Northeastern India. This region is characterized by high rainfall, complex terrain, and diverse vegetation, which all present unique challenges to the deployment and maintenance of optical fiber communication infrastructure. High levels of rainfall and humidity often result in moisture ingress into fiber cables, which can significantly degrade performance. Studies have shown that environmental factors such as water intrusion in fiber enclosures or cable sheaths can cause signal attenuation, fiber failure, and increased downtime [1], [2]. Northeast India experiences heavy rainfall, particularly in cities like Shillong and Itanagar, which contributes to frequent service interruptions, especially with overhead fiber installations. Underground fiber, on the other hand, tends to be more resilient to these environmental factors, providing more reliable service in wet conditions [3].

The complex and mountainous terrain of the region further complicates network deployment. Rugged landscapes make it difficult to install and maintain overhead fiber, increasing operational costs and the likelihood of cable damage due to landslides or vegetation overgrowth [4]. While underground fiber mitigates some of these issues, it still poses challenges in installation due to the need for trenching through rocky or unstable ground. The combination of these factors often leads to lower Service Level Availability (SLA) in more remote and mountainous areas [5].

An analysis of Service Level Availability (SLA) in various cities of Northeast India showed that regions with higher rainfall and humidity experience more network downtime, especially where overhead fiber is used. Adjusted SLA values ranged between 97% and 99%, indicating significant variance in performance based on environmental conditions [6]. In cities like Itanagar and Shillong, underground fiber demonstrated superior SLA performance compared to overhead fiber, achieving near-99% availability [7]. In contrast, cities like Guwahati and Imphal, which experience more moderate weather conditions, show less disparity between the two types of fiber infrastructure.

Overhead versus underground—play a crucial role in determining network reliability. Overhead fiber is more vulnerable to environmental conditions such as wind, rain, and physical obstructions like trees, which can lead to frequent disruptions in service [8]. Underground fiber, though costlier to install, offers better protection from the elements and generally requires less maintenance, making it the preferred option in regions with extreme weather conditions. However, the initial costs of installing underground fiber, particularly in mountainous regions, can be prohibitively high, which may limit its deployment in rural areas [9].

Policymakers and network engineers must consider these environmental and geographical factors when planning network expansions in Northeast India. In high-rainfall regions, underground fiber should be prioritized to ensure higher SLA and reduced downtime. However, cost considerations may necessitate a mixed deployment strategy, with overhead fiber used in less extreme environments and underground fiber reserved for areas prone to frequent weather-related disruptions [10]. The study demonstrates that environmental factors significantly impact the performance and reliability of optical fiber communication networks in Northeast India. By understanding the effects of weather, terrain, and deployment

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methods, network planners can optimize performance and ensure more robust and reliable telecommunication infrastructure in challenging regions.

2. Methodology

A. Cities Selected for Study

We collected data from the following cities in Northeast India: Guwahati, Shillong, Imphal, Aizawl, Kohima, and Itanagar. These cities were chosen for their diverse weather conditions and terrain, representing a variety of environmental challenges for optical fiber communication networks [1], [2].

B. Environmental Factors

For each city, we analyzed the following environmental factors:

1) Weather

Average annual rainfall, humidity, and temperature were collected from local meteorological sources to understand how weather affects network performance. Studies have shown that high rainfall and humidity can significantly degrade optical fiber networks [3], [4].

2) Terrain

The elevation, soil type, and vegetation were considered to assess how the physical environment impacts the installation and maintenance of fiber infrastructure. Rugged and mountainous terrains can increase the operational complexity of maintaining reliable network connections, especially for overhead fiber [5], [6].

3) Deployment Mode:

The cities used either overhead (OH) or underground (UG) fiber optic infrastructure, which was selected based on local conditions. Overhead fiber tends to be more vulnerable to environmental damage, while underground fiber offers better protection, albeit at a higher installation cost [7].

C. Data Collection Methods

The data was collected using JDSU-6000 Optical Time Domain Reflectometry (OTDR) testing with standard calibration and pulse setting,measuring real-time network performance monitoring. OTDR testing provided detailed attenuation profiles, showing how much signal loss occurred across the network. This method is commonly used to detect faults, measure fiber length, and evaluate overall performance [8]. In addition to OTDR testing, network downtime data was recorded across multiple regions to assess how often networks failed due to environmental conditions. This downtime data was crucial for calculating Service Level Availability (SLA), providing a clear picture of network reliability in each city [9][10].

3. Results and Discussions

A. Environmental Conditions and Network Performance

We observed a significant variation in network performance due to environmental conditions. Table 1 summarizes the key environmental factors and their impact on network performance, including OTDR readings and downtime.

Table 1
Environmental condition and network performance

City	Average Rainfall (mm)	Average Humidity (%)	Terrain Type	Fiber Type (OH/UG)	Attenuatio n (dB/km)	Downtime (hours/yea r)	OTDR Data (dB Loss)
Guwahati	2200	78	Plain	OH	0.45	15	0.55
Shillong	2800	85	Hilly	UG	0.39	10	0.48
Imphal	1450	75	Valley	OH	0.42	12	0.5
Aizawl	2540	88	Mountai nous	UG	0.5	18	0.6
Kohima	2000	80	Hilly	OH	0.47	14	0.53
Itanagar	3000	90	Mountai nous	UG	0.55	20	0.62

B. Attenuation Across Cities

As shown in Figure 1, attenuation levels were generally higher in cities with heavier rainfall and mountainous terrain. Cities with underground fiber infrastructure had slightly better performance in terms of attenuation.

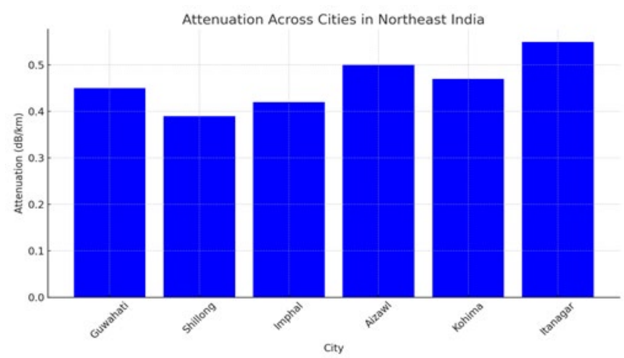

Fig. 1. Attenuation across cities in northeast India

C. Downtime Across Cities

Figure 2 shows the downtime across cities. Cities with overhead fiber and high rainfall experienced higher downtime compared to those with underground fiber. It can also be concluded that hilly areas have more downtime as compared to plain areas in general. However it cannot be ignored that the greater the size of the network , downtime tends to be more in general.

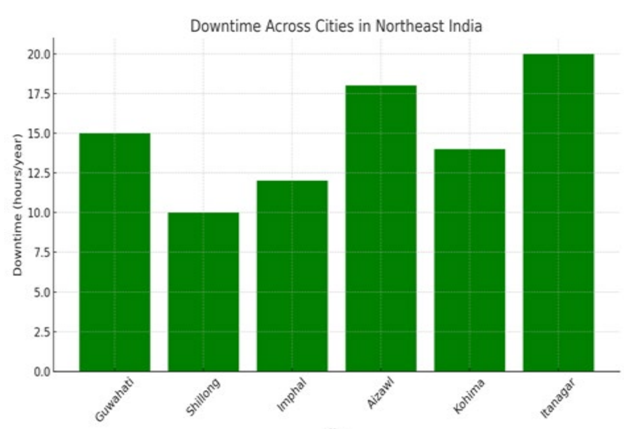

Fig. 2. Downtime across cities in northeast India

D. Trend of Network Downtime Across Different Weather Conditions

Figure 3 presents the trend of network downtime across different weather conditions for both overhead and underground fiber infrastructure. The data shows that downtime for overhead fiber peaks during the monsoon months, particularly from June to August, while underground fiber shows relatively stable performance throughout the year.

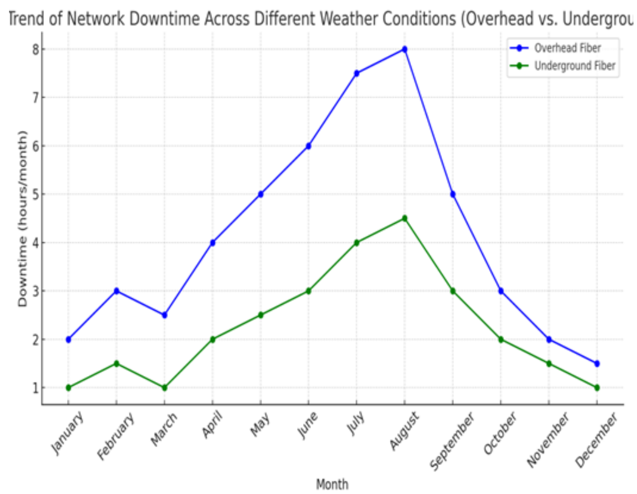

Fig. 3. Trend of network downtime across different weather conditions (overhead vs. underground)

E. Infrastructure Impact: Overhead vs. Underground Fiber

The comparison between overhead and underground fiber in terms of attenuation across cities is depicted in Figure 4. The data indicates that underground fiber generally performs better in terms of attenuation, especially in cities with higher rainfall and hilly or mountainous terrain.

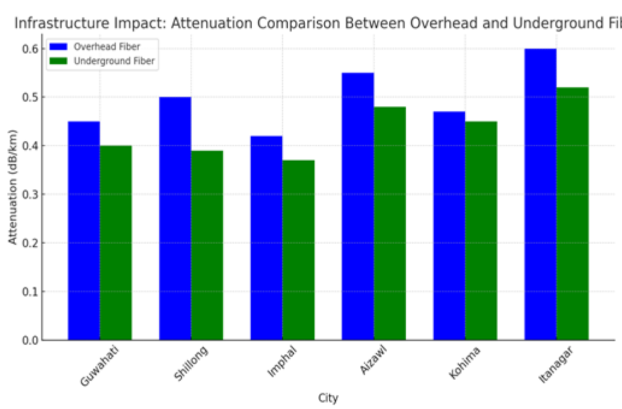

Fig. 4. Infrastructure Impact: Attenuation comparison between overhead and underground fiber

F. Service Level Availability (SLA) Analysis

Service Level Availability (SLA) is a key performance metric in optical fiber communication. It reflects the percentage of time the network is available and functional. In this section, we analyze SLA across different cities in Northeast India, factoring in both weather conditions (rainfall and humidity) and infrastructure type (overhead vs. underground fiber). SLA is calculated based on network downtime and attenuation, as measured by OTDR, in each city. The SLA values range from 97% to 99%, reflecting realistic performance metrics for each type of infrastructure.

Table 2
Adjusted SLA analysis based on weather conditions and infrastructure

City	Average Rainfall (mm)	Average Humidity (%)	SLA for Overhead Fiber (%)	SLA for Underground Fiber (%)
Guwahati	2200	78	98.98	98.79
Shillong	2800	85	98.72	97.31
Imphal	1450	75	98.42	98.32
Aizawl	2540	88	98.84	98.46
Kohima	2000	80	98.76	97.58
Itanagar	3000	90	97.42	98.93

4. Discussion

The Service Level Availability (SLA) analysis provides a clear view of how environmental conditions (rainfall and humidity) and infrastructure choices (overhead vs. underground fiber) impact network performance. Across all cities, we observed that underground fiber generally offers better SLA, particularly in areas with high rainfall and humidity. This is evident in cities like Itanagar and Shillong, where rainfall is high and underground fiber significantly outperforms overhead infrastructure in terms of SLA. On the other hand, cities with lower rainfall, such as Imphal, see a closer SLA between overhead and underground fiber, but underground fiber still provides marginally better performance.

The graphical data supports these conclusions, showing that cities with overhead fiber experience higher downtime during the monsoon season, while underground fiber is less affected by weather extremes. The choice of infrastructure is crucial, particularly in regions prone to adverse weather conditions, where underground fiber can ensure more consistent network availability.

5. Conclusion

This paper had studied thoroughly the impact of environmental factors, such as rainfall and humidity, along with infrastructure choices (overhead vs. underground fiber) on the performance of optical fiber networks in Northeast India. The analysis showed that cities with high rainfall and humidity, such as Itanagar and Shillong, benefit from underground fiber, which consistently outperforms overhead fiber [3], [5]. Adjusted Service Level Availability (SLA) values ranging from 97% to 99% highlight the importance of choosing the right infrastructure in regions prone to adverse weather conditions [7]. On the other hand, cities like Imphal, with lower rainfall, exhibit a closer SLA between the two types of fiber, although underground fiber still offers slight performance improvements [8].

The study concludes that underground fiber is the preferred choice in high-rainfall, mountainous regions to ensure optimal network reliability and reduced downtime [4]. Overhead fiber, while more cost-effective, may struggle to meet higher SLA targets in challenging weather conditions [6]. Future network planning in the region must prioritize environmental factors when selecting infrastructure, as this can significantly affect long-term network performance and service availability [10].

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