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An Analysis on Effect of Rainfall Propagation Impairment for Fixed Frequency Satellite Link Communication

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Abstract- Rainfall is a major atmospheric factor that impairs the propagation of satellite communication signals, particularly at microwave and millimeter-wave frequencies. This study presents an analysis of the effect of rainfall propagation impairment on fixed-frequency satellite link communication, with particular emphasis on Potiskum, located in the semi-arid region of northeastern Nigeria. The research focuses on evaluating how rain rate, operating frequency, and elevation angle influence signal attenuation and overall system performance. The study adopts a theoretical and analytical approach based on internationally accepted propagation models recommended by the International Telecommunication Union (ITU-R). Rain rate statistics obtained from the Nigerian Meteorological Agency were utilized to estimate rain-induced attenuation using the ITU-R P.838 and P.618 prediction models. Link budget analysis was carried out to assess the impact of rain attenuation on received signal power, signal-to-noise ratio, bit error rate, and link availability for fixed-frequency satellite systems operating in the C-, Ku-, and Ka-bands. The results reveal that rain attenuation increases significantly with increasing rain rate and operating frequency, while lower elevation angles result in higher attenuation due to longer propagation paths through the rain medium. Although Potiskum experiences moderate rainfall compared to coastal regions of Nigeria, intense seasonal rainfall events can still cause noticeable degradation of satellite signal quality, particularly for Ku- and Ka-band links. The findings confirm that rainfall propagation impairment remains a critical limitation to high-frequency fixed satellite communication systems if adequate fade margins and mitigation techniques are not employed. The study concludes that accurate rain attenuation prediction and proper link design are essential for ensuring reliable satellite communication in Potiskum. Recommendations are made for the inclusion of sufficient fade margins, appropriate frequency band selection, adoption of adaptive mitigation techniques, and the use of local rainfall data in satellite system planning.

I. INTRODUCTION

Satellites generally orbit the earth along either of the two directions, one through an elliptical path and this ellipse is actually inclined relative to the equatorial plane of the earth and the other along pole of the earth. Satellites also orbit the earth at different speed, since the orbital periods depend on the orbital altitude of the satellite. Generally, to locate a satellite at an instant time it requires knowledge of the geometry of the ellipse relative to the earth as well as times that satellite passes reference point along the ellipse. The parameters known as the Keplerian elements of the satellite are precisely known by satellite operators Kare used.

Satellite signal transmission in the Ku and Ka band is highly affected by heavy rainfall, as such signals are susceptible to high level of attenuation. Satellite television transmission is indeed an important area of communication as many individuals seek for clear reception in their received TV signals. There is no doubt that poor TV signal reception is observed during heavy rains.

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Rain is a natural process that attenuates the propagated signal at a high frequencies level.

Therefore, it is necessary to mitigate rain attenuation to ensure the quality of super high propagated signals. Now at this level, various studies have been carried on the work world wide.

Studies on rain attenuation are used in various locations to analyse and develop a rain attenuation model applicable over a wide frequency range, particularly radio frequencies over approximately 40GHz for 5G and beyond network applications.

However, to develop such a rain attenuation model, it is first necessary to determine the factors that affect attenuation. There is evidence that in addition to the rainfall, the frequency, path length distance between the receiving and transmitting antennas, temperature, wind direction, velocity, pressure, and humidity can also cause attenuation of the signal.

Various rain attenuation prediction models have mapped the correlation between rainfall intensity, path length, and frequencies with rain attenuation. Investigation has also shown that at high frequencies, the wave length becomes significantly shorter, these short wavelengths are easily absorbed and scattered as they pass through raindrops (Siva, et al., 2012).

This is principally the major reason for which rain signal cause deuteriation of the received signal. The impact of rain does not only cause attenuation of satellite signals but also affects the cost of signal propagation from the transmission station. This is because; there will be need for increase in transmitting power of the equipment in compensation for loss caused by rain.

Research also shows that, Rain attenuation causes a greater power requirement from the transmitting units which results into higher cost per bit of transmission (Eze et al., 2014). During heavy rainfall, signal transmission at frequencies greater than 10GHz leads to a noticeable degradation in the quality of the signal. This is as a result of the direct relationship between frequency and the proportional amount of rainfall commonly known as "rain fade" (Jalal, 2015).

It is therefore important to state that, an idea of rain attenuation rate in a given location is necessary to structure out a reliable communication network in such location. Therefore, accurate estimation of attenuation of rain in a specific radio link is essential for planning the link budget, maintaining the link quality, and designing the system.

II RESEARCH GAP

Several researchers over the years have developed models and methods, in some instances modifying existing ones for estimating rain rates across various frequencies and climatic locations. Ojo et al (2008) predicted the rate of rainfall and attenuation due to rain fade in communication satellite Link at Ku and Ka bands. The study was based on predictions and no attempt was made by the research to compare rain attenuation using various models in satellite links.

Ajewole et al (2014), investigated som8e aspects of rain effects on the performance of Ku-band satellite signals in Akure, Nigeria. The research showed the time series of rainfall during a typical rainy season that was examined at Ku-band pattern which indicated a very strong relationship between the reduction of the satellite signals and the rate of rainfall recorded. Ezeh et al (2014) investigated the effects of attenuation due to rain on satellite communication links.

They observed that as rain attenuation increases, rainfall rate value also increases but at a rain rate of 112mm/h and above, there was total outage of reception that causes loss of received signal, however, there was no comparison for different rain attenuation models. HamadAmeen, (2018) studied rain effect on Ku-band satellite system. In the research, study and calculation of rain effect was performed.

The result of the research showed that the horizontal polarized signals affected greater than that with vertical polarized but he used only ITU-R model for the calculation of rain attenuation. Osahenvemwen and Omorogiuwa, (2017), described rain attenuation analysis from system operating at Ku and Ka frequency bands. The research showed that attenuation increases as rainfall rate increases and the vertical polarized signal offers less rain attenuation than the horizontal polarized signal at Ku and Ka bands.

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However, they did not consider using different models for estimating rain attenuation. Immadiet al (2017). Researched on computation of rain attenuation for Ku band frequencies using Drop Size Distribution for the tropical region.

The result showed that rain attenuation plays an important function in receiving any signal transmitted at Ku band and higher frequencies, however, they only adopted drop size distribution which is not a model for estimating rain attenuation. Khandaker & Mohammad (2014).

Researched that the design of new telcommunication system requires the knowledge of rain fade in orde to optimize system capacity and meet the quality and reliability criteria. I have identified the knowledge gaps existing among various researchers in their literatures. Ojo et al (2008) predicted the rate of rainfall and attenuation due to rain fade in communication satellite Link at Ku and Ka bands. The study was based on predictions and no attempt was made by the research to compare rain attenuation using various models in satellite links

RECENT ADVANCEMENT

The following point of advancement are drawn from the reseach.

1. Adaptive Techniques
   The adoption of adaptive coding and modulation (ACM) and uplink power control is recommended to improve link performance during rainfall events.

2. High Elevation Angle Links
   Satellite systems should be designed to operate at higher elevation angles where possible to reduce the effective rain path length.

3. Local Rainfall Data Utilization
   Long-term rainfall statistics specific to Potiskum should be used for accurate prediction of rain attenuation and link availability.

4. Hybrid Communication Systems
   The integration of satellite communication with terrestrial backup systems is recommended to ensure service continuity during severe weather conditions.

III MATERIAL AND METHOD

This chapter presents the methodology used to analyze the effect of rainfall propagation impairment on fixed-frequency satellite link communication systems with more emphasis on Ku band (10-18GHz). The chapter outlines the analytical framework, propagation models, parameters considered, and link budget evaluation techniques used to quantify rain-induced attenuation and its impact on system performance.

Research Design and Approach

The research adopts a theoretical and analytical approach based on established satellite propagation and rain attenuation models. No experimental hardware setup is used; instead, mathematical modeling and standardized prediction methods are applied to evaluate rainfall effects on satellite links. The analysis relies on internationally accepted models, particularly those recommended by the International Telecommunication Union (ITU-R).

IV RESULTS PRESENTATION

Values and parameters used for the research

S/N	PARAMETER	VALUE
1	Satellite in space	Astra 2B (Multi TV Satellite) at 28.2°East
2	Frequency of the downlink signal	12.5 GHz
3	Latitude of site	11.04 East
4	Longitude of site	11.43 North
4	Polarization of the signal	Horizontal
5	Antenna elevation angle	42°
6	Antenna gain	35dB
7	Antenna diameter	0.6m
7	Height of antenna	2.9m

SPECIFIC RAIN ATTENUATION MODEL

The specific rain attenuation (γR) is calculated using the power-law relationship recommended by ITU-R P.838:

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$$\gamma R = kR^\alpha$$

where:

- γR = specific rain attenuation (dB/km)
- R = rain rate (mm/h)
- k and α = frequency- and polarization-dependent coefficients

These coefficients are determined empirically and vary with operating frequency and signal polarization.

POTISKUM MONTHLY RAINFALL RATE (MM/H) — 2022 TO 2024

Month	2022 (mm/h)	2023 (mm/h)	2024 (mm/h)
January	0	0	0
February	0	0	0
March	5	6	5
April	20	22	21
May	60	65	62
June	95	100	98
July	150	155	152
August	165	170	168
September	100	105	102
October	30	32	31
November	5	5	5
December	0	0	0
Total	630 mm/h	660 mm/h	644 mm/h

KEY POINTS

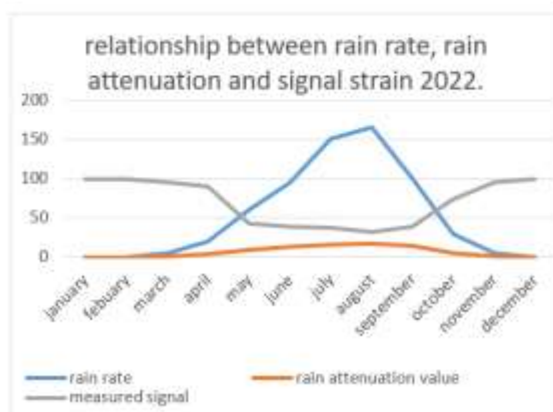
- Rainfall is concentrated between May and September
- August is typically the wettest month
- Dry season lasts from November to March
- Climate type: Hot semi-arid (Sahelian)

MATL AB CODE

```
F= [12.0.5:18] *1e9; %KU band from 12GHz to18GHz
R=170; %Rain rate mm/hr(will we used 170,150,100,95,60,30,20,5)
L=rainpl(1000, F, R); %Attenuation for 10km
Loglog (F./1e9, L);
Grid
Xlabel('Frequency (GHz)');
Ylabel('Attenuation(dB)');
```

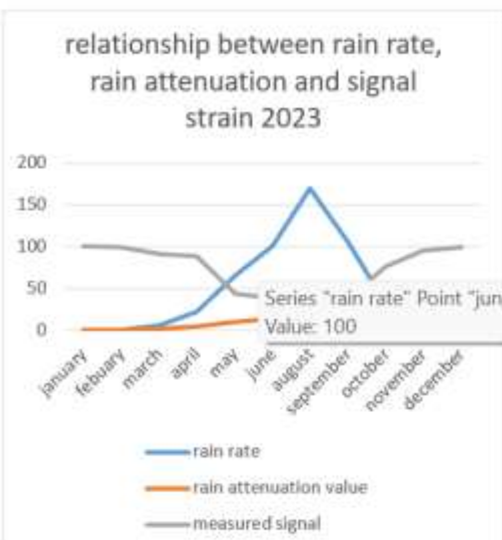
Experimental result for rain rate and rain attenuation 2022

S/N	MONTH	RAIN RATE	RAIN ATTENUATION VALUE	MEASURED SIGNAL
1	JANUARY	0.00	0.00	99.65
2	FEBUARY	0.00	0.00	98.92
3	MARCH	5.00	0.96	74.67
4	APRIL	20.00	3.15	56.27
5	MAY	60.00	9.62	42.88
6	JUNE	95.00	13.10	39.40
7	JULY	150.00	15.68	36.86
8	AUGUST	165.00	17.34	22.39
9	SEPTEMBER	100.00	14.07	38.47
10	OCTOBER	30.00	4.82	46.64
11	NOVEMBER	5.00	0.85	81.23
12	DECEMBER	0.00	0.00	99.17



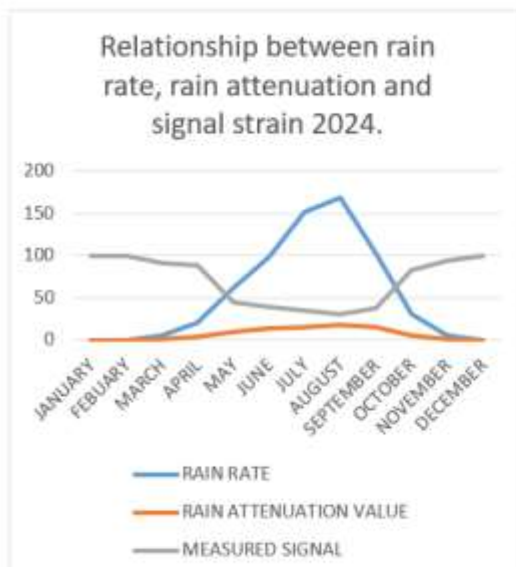
EXPERIMENTAL RESULT OF RAIN RATE AND RAIN ATTENUATION 2023

S/N	MONTH	RAIN RATE	ATTENUATION RAIN VALUE	MEASURED SIGNAL
1	JANUARY	0	0	99.82
2	FEBUARY	0	0	99.15
3	MARCH	6	1.02	90.62
4	APRIL	22	3.94	88.74
5	MAY	65	9.82	43.12
6	JUNE	100	14.26	38.43
7	JULY	155	15.73	34.93
8	AUGUST	170	18.12	30.23
9	SEPTEMBER	105	14.93	38.11
10	OCTOBER	32	4.95	75.62
11	NOVEMBER	5	0.98	95.43
12	DECEMBER	0	0	99.38



EXPERIMENTAL RESULT OF RAIN RATE AND RAIN ATTENUATION 2024

S/N	MONTH	RAIN RATE	RAIN ATTENUATION VALUE	MEASURED SIGNAL
1	JANUARY	0	0	99.98
2	FEBUARY	0	0	99.68
3	MARCH	5	0.98	90.53
4	APRIL	21	4.18	87.96
5	MAY	62	9.12	44.16
6	JUNE	98	14.25	38.51
7	JULY	152	15.11	34.36
8	AUGUST	168	18.01	30.21
9	SEPTEMBER	102	14.72	38.02
10	OCTOBER	31	4.81	83.15
11	NOVEMBER	5	0.98	93.35
12	DECEMBER	0	0	99.16



Relationship Between Potiskum Monthly Rainfall Rate and Signal Quality (ITU-R Model)

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Month	Avg. Rainfall Rate (mm/month)	ITU-RRain Attenuation Level	Effect on Signal Quality
January	0	Negligible	Excellent signal quality, no rain fade
February	0	Negligible	Excellent signal quality
March	5	Very low	Very good signal quality
April	20	Low	Slight attenuation, stable link
May	60	Moderate	Noticeable attenuation, minor fading
June	95	High	Reduced signal strength, occasional outages
July	150	Very high	Severe attenuation, frequent fading
August	170	Very high	Worst signal quality, possible link failure
September	100	High	Moderate–high attenuation
October	30	Low–moderate	Improving signal quality
November	5	Very low	Very good signal quality
December	0	Negligible	Excellent signal quality

- Peak rainfall months (July–August) experience the highest attenuation, leading to poor signal quality.
- Dry months experience minimal or zero attenuation, resulting in high signal availability.
- Higher-frequency links (Ku/Ka band) are more affected than lower-frequency links (C band).

V SUMMARY, CONCLUSION AND RECOMMENDATIONS

This chapter presents the summary of findings, conclusions drawn from the analysis, and recommendations based on the study of rainfall propagation impairment on fixed-frequency satellite link communication in Potiskum. The implications of rainfall characteristics peculiar to Potiskum on satellite signal performance are discussed, and suggestions for improved system design and future research are provided.

SUMMARY OF THE STUDY

This project analyzed the effect of rainfall propagation impairment on fixed-frequency satellite communication links, with particular reference to Potiskum, located in the semi-arid region of northeastern Nigeria. The study focused on how rain rate, operating frequency, and elevation angle influence signal attenuation and overall system performance.

Analytical models based on ITU-R recommendations were used to evaluate rain-induced attenuation and its impact on the satellite link budget. The analysis showed that although Potiskum generally experiences moderate rainfall compared to southern regions of Nigeria, intense seasonal rainfall events still pose a significant challenge to high-frequency satellite communication systems.

SUMMARY OF FINDINGS

The major findings of this study are summarized as follows:

1. Rainfall causes measurable attenuation of satellite signals in Potiskum, particularly during the rainy season.
2. Rain attenuation increases with increasing rain rate and operating frequency.
3. Fixed-frequency satellite links operating in Ku-band and Ka-band are more susceptible to rain-induced fading than those operating in C-band.
4. Satellite links with lower elevation angles experience higher attenuation due to longer propagation paths through rain.
5. Rain-induced attenuation leads to reduced signal-to-noise ratio, increased bit error rate, and occasional link outages when fade margins are insufficient.
6. Although rainfall intensity in Potiskum is relatively lower than in coastal regions, proper link design is still necessary to ensure high availability.

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