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Estimating the Effect of Copolar Attenuation Caused by Rain Events on Radio Wave Propagation

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Authors' contributions

This work was carried out in collaboration among all authors. Author COK designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors JTZ and EPO managed the analyses of the study. Author EE managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This study investigates the impact of different rain classifications and elevation angles on copolar attenuation, a critical factor influencing radio wave propagation in communication systems operating in adverse weather conditions. Using data collected over the years 2021 and 2022 in Warri, Delta State of Nigeria. Copolar attenuation values at 40^0 and 60^0 elevation angles were analyzed across various rain classifications, including Drizzle, Widespread, Shower, Cloudburst, and Extreme Cloudburst. The results highlight that higher intensity rain events, such as Cloudburst and Extreme Cloudburst, lead to significantly greater copolar attenuation compared to lower intensity rain classifications. Furthermore, the sensitivity of copolar attenuation to elevation angle is

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observed, with higher angles generally associated with lower attenuation values. These findings underscore the importance of considering rain intensity and elevation angle in the design and operation of communication systems to mitigate the effects of rain-induced attenuation and ensure reliable signal transmission. By optimizing antenna placement and orientation and employing adaptive communication techniques, such as adaptive modulation and coding, communication networks can be better equipped to maintain connectivity in challenging weather conditions.

Keywords: Copolar attenuation; radio wave propagation; elevation angle; communication systems; rain intensity; antenna optimization; adaptive communication techniques.

1. INTRODUCTION

Radio wave propagation is a fundamental aspect of telecommunications systems, crucial for ensuring reliable communication across various applications [1,2]. However, atmospheric phenomena like rain can significantly affect propagation characteristics, especially at higher frequencies. Among the factors that influence radio wave propagation, copolar attenuation induced by rain events stands out as a crucial consideration [3]. Copolar attenuation refers to the attenuation of radio waves along the same polarization as the transmitted signal, caused by rain droplets in the propagation path. Understanding the effect of copolar attenuation due to rain events on radio wave propagation is essential for designing robust communication systems, especially in scenarios where reliable transmission is crucial [1,4,5]. This research aims to investigate and quantify the impact of copolar attenuation induced by rain events on radio wave propagation at higher frequencies, providing valuable insights for optimizing communication networks in locations with adverse weather conditions like South-South region of Nigeria [6].

Copolar attenuation is a phenomenon that happens when radio waves come across precipitation, such as raindrops, in the atmosphere. This attenuation is more noticeable at higher frequency bands and can have a substantial impact on the quality and reliability of radio communication systems [7,8,9]. As radio waves propagate through the atmosphere, they interact with different atmospheric components, including rain droplets. These droplets act as scatterers, causing the radio waves to scatter in various directions. Consequently, some of the transmitted energy deviates from the intended path, resulting in signal attenuation or weakening [4,10]. The severity of copolar attenuation depends on several factors, including the frequency of the radio waves, the density and size distribution of raindrops, and the path length through the precipitation region. Higher frequency radio waves are more susceptible to copolar attenuation because they interact more strongly with small raindrops, which is a result of their shorter wavelengths [11].

One key characteristic of copolar attenuation is its frequency dependence. As the frequency of the radio waves increases, the attenuation due to rain also increases. This phenomenon poses significant challenges for communication systems operating at higher frequencies, such as satellite communication, microwave links, and millimeter-wave systems. Copolar attenuation can degrade signal quality and reduce link reliability, especially during intense rain events [9,12,13].

Rain attenuation at frequencies above 10 GHz is a significant concern in the design and operation of various communication systems, including satellite links, terrestrial microwave links, and emerging millimeter-wave communication technologies. As radio frequencies increase, rain attenuation becomes more pronounced due to the increased interaction between electromagnetic waves and raindrops, leading to greater signal attenuation and potential degradation of communication links. Several factors contribute to the increased rain attenuation at frequencies above 10 GHz:

i. Increased Interaction with Raindrops: Millimeter-wave signals interact more strongly with raindrops due to their shorter wavelengths. As a result, a higher proportion of the transmitted energy is scattered or absorbed by raindrops along the propagation path, leading to greater attenuation [14,15].
ii. Higher Specific Attenuation Coefficients: Specific attenuation coefficients, which quantify the rate of signal attenuation per unit distance in the presence of rain, typically increase with frequency. This means that at higher frequencies, radio waves experience more significant

attenuation for a given rain rate compared to lower frequencies.

iii. Increased Raindrop Size Distribution: At frequencies above 10 GHz, smaller raindrops can cause substantial attenuation due to their efficient scattering properties. Moreover, larger raindrops may also be present, contributing to additional attenuation effects. The combined impact of raindrop size distribution further exacerbates the attenuation experienced by millimeter-wave signals [14,16].

2. MATERIAL AND METHODS

The study was carried out in Yenagoa, Bayelsa State South-South region of Nigeria. Data for the year 2022 were obtained from National Space Research and Development Agency (NASRDA), Nigeria. Among the parameters collected are: air temperature (^{0}C), total rain accumulation (mm) and rain rate (mm/h). The data obtained were measured using Davis Vantage Vue weather station which is equipped with an integrated sensor suite (ISS) and weather link data logger that was used to measured and record one-minute rain-rates. The instrument is a self-emptying tipping spoon, with guage resolution of 0.2 mm per tip. It can measure rainfall intensity from a minimum of 0.8 mm/h up to a value of 460 mm/h, with an accuracy of 0.2 mm/h. The precipitation data, with time for each of the month of the year was captured on the micro-chip of the wireless electronic data logger, which, when calibrated, logs on data every minute. The microchip has storage capacity of about 2563 pages, each page stands for one record, after which the memory overwrites and recorded data is lost if not harvested. The data logger was connected to a Computer system to harvest the data on a daily basis to prevent data loss.

3. RESULTS AND DISCUSSION

Fig. 1 to Fig. 5 presents copolar attenuation values at two different elevation angles (40^0 and 60^0) for various rain classifications observed in the years 2021 and 2022. Copolar attenuation refers to the attenuation experienced by radio waves that have the same polarization as the transmitted signal. The results provide insights into how different types of rain events impact radio wave propagation at different elevation angles over the two years. Each classification corresponds to a specific range of copolar attenuation values at both 40^0 and 60^0 elevation angles. As expected, higher intensity rain events generally result in greater copolar attenuation values. For instance, Extreme Cloudburst events consistently exhibit the highest attenuation values compared to other rain classifications, indicating a more significant loss of signal strength. The copolar attenuation values vary with the elevation angle, with higher elevation angles typically resulting in lower attenuation values. This difference is notable for extreme rain events, where the attenuation values at 60^0 elevation angle are notably lower compared to those at 40^0 elevation angle. This suggests that higher elevation angles may provide better signal propagation conditions during heavy rainfall. The result further observed that there are differences in copolar attenuation values between the years 2021 and 2022 for specific rain classifications. For example, Widespread rain events exhibit considerably higher attenuation values in 2022 compared to 2021, particularly at the 40^0 elevation angle. These variations may be attributed to changes in weather patterns, precipitation characteristics, or measurement uncertainties between the two years.

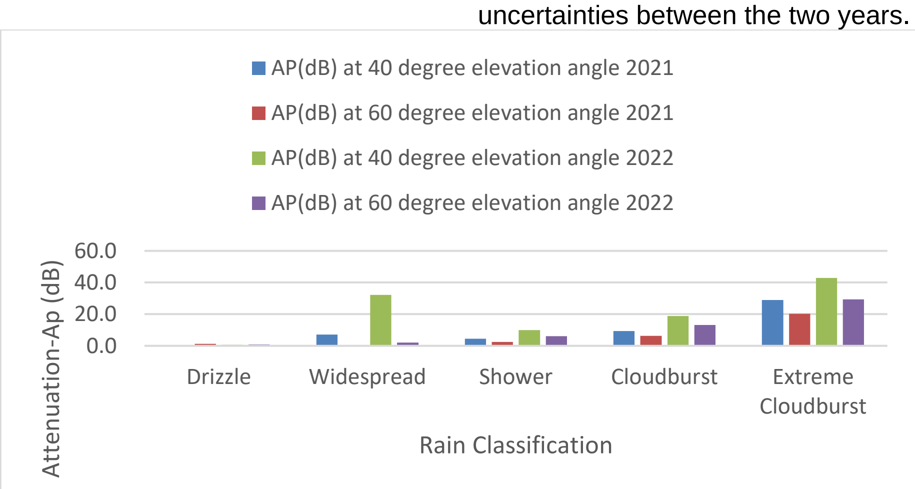

Fig. 1. Copolar attenuation due to rain at various rain intensities for June

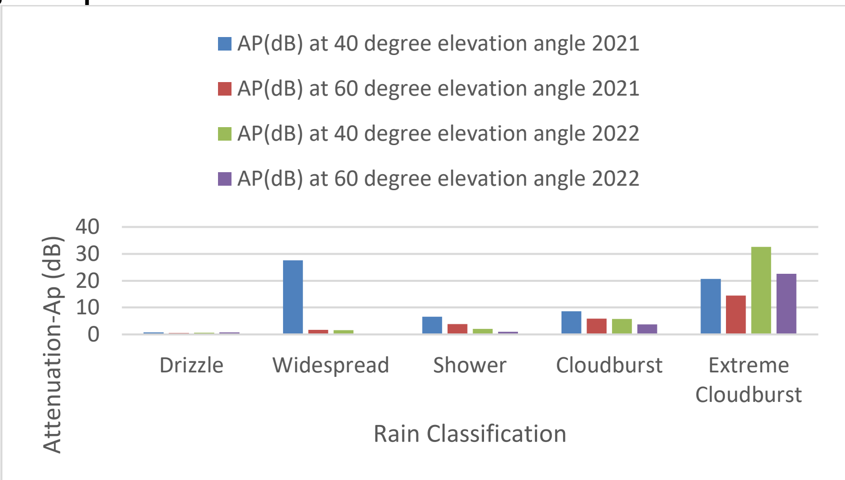

Fig. 2. Copolar attenuation due to rain at various rain intensities for July

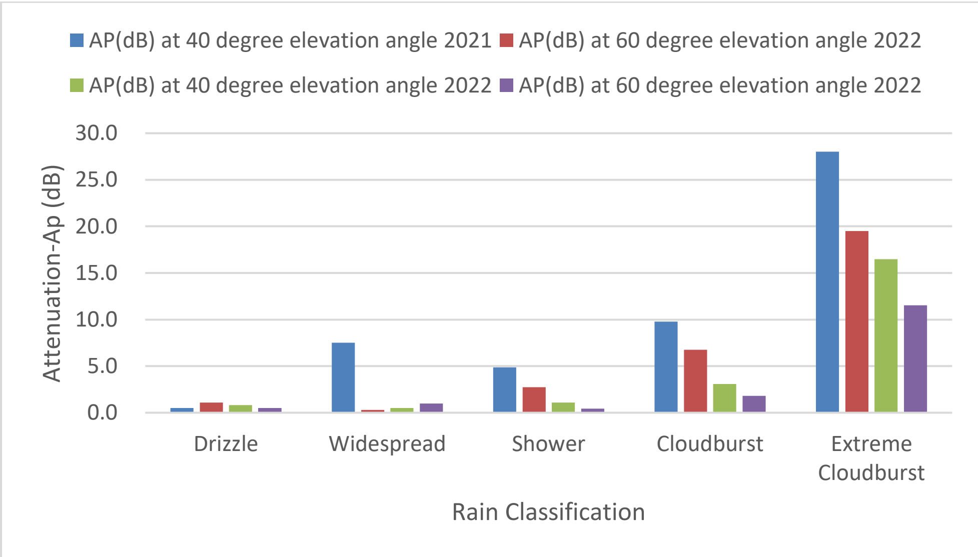

Fig. 3. Copolar attenuation due to rain at various rain intensities for August

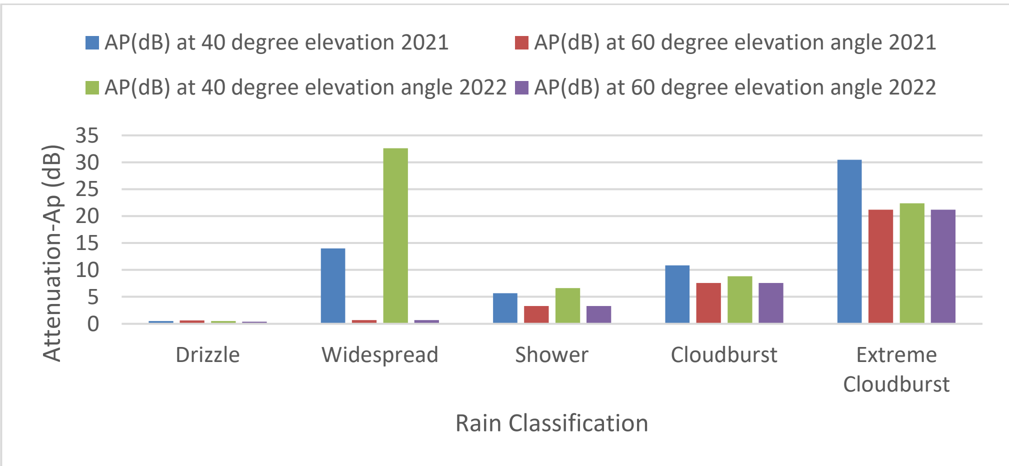

Fig. 4. Copolar attenuation due to rain at various rain intensities for September

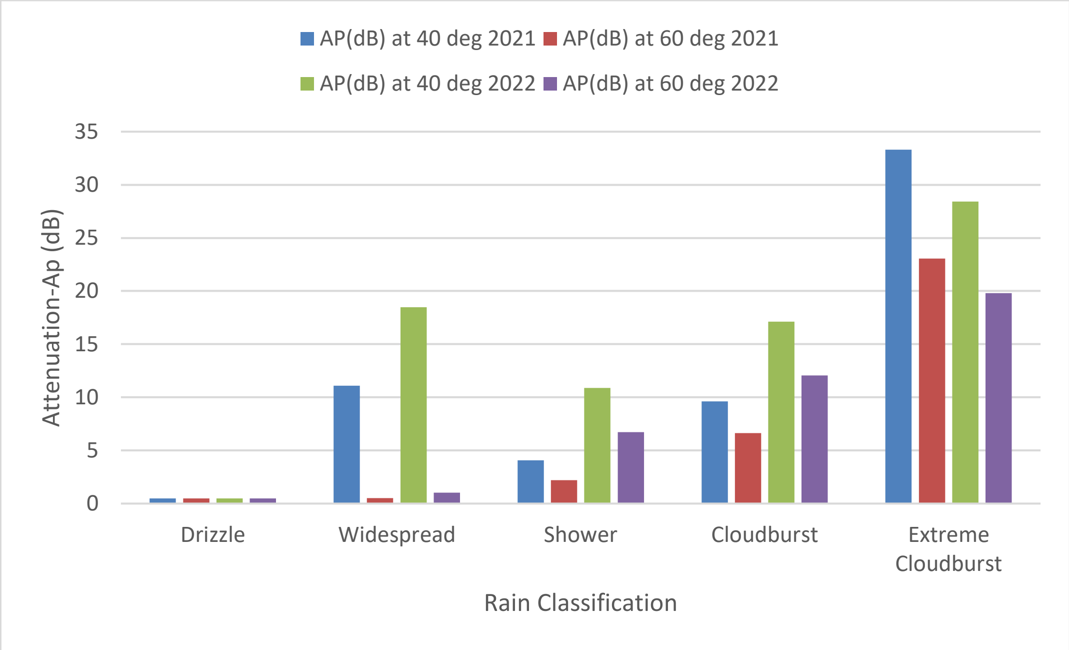

Fig. 5. Copolar attenuation due to rain at various rain intensities for October

4. CONCLUSION

The study sheds light on the impact of different rain classifications and elevation angles on copolar attenuation, a critical factor influencing radio wave propagation in communication systems. Through analysis of copolar attenuation values at 40^0 and 60^0 elevation angles across the years 2021 and 2022, several key observations have been made.

Firstly, it is evident that higher intensity rain events, such as Cloudburst and Extreme Cloudburst, result in significantly greater copolar attenuation compared to lower intensity rain classifications like Drizzle and Widespread. This emphasizes the importance of considering rain intensity when assessing the potential impact on communication links.

Secondly, the sensitivity of copolar attenuation to elevation angle is notable, with higher angles generally associated with lower attenuation values. This suggests that higher elevation angles may offer improved signal propagation conditions during heavy rainfall, highlighting the potential benefits of optimizing antenna placement and orientation. Furthermore, the observed differences in copolar attenuation values between the years 2021 and 2022 underscore the dynamic nature of weather patterns and their influence on radio wave propagation. Variations in precipitation characteristics and atmospheric conditions between years can lead to fluctuations in copolar attenuation, emphasizing the need for adaptive and robust communication systems. The findings from this study provide valuable insights for the design and operation of communication networks, enabling engineers to better understand and mitigate the effects of rain-induced attenuation on signal reliability and performance. By considering factors such as rain intensity, elevation angle, and temporal variations, communication systems can be optimized to maintain reliable connectivity even in challenging weather conditions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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