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Contents

Rain-Induced Attenuation at Ku-Band in a Tropical Region

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Communication at higher frequency bands has numerous benefits but susceptible to rain impairments. Rain-induced attenuation becomes more prominent as the carrier frequency and rain rate increase. Hence, precise knowledge of rain rate can help in predicting the level of rain-induced attenuation. The paper determines point cumulative rainfall rate at 0.1% of time exceedance and converts integration time from 5 min to 1 min. The specific and the total rain-induced attenuation were predicted at 0.1% of time exceedance from 12 GHz to 18 GHz for both horizontal and vertical polarizations. Lavergnat-Gole rain rate conversion model and ITU-R P.838-3 model were employed using four-year rainfall data obtained from Port Harcourt, Nigeria. The results revealed that the peak activities of rainfall rates were recorded at lower integration times, and the total rain-induced attenuation increases with increasing operating frequencies, which is greater for horizontally polarized waves compared to vertically polarized waves.

Keywords: Rain attenuation, Rainfall rate, Integration time, Operating frequency, Conversion factor

Introduction

All forms of wireless communication make use of electromagnetic wave, which is either propagated vertically, horizontally or as a combination of both. Wireless communication provides huge opportunity to get possible access to the world at any time in any place without being physically present (Maniewicz, 2019). The modern-day digital information and wireless communication system are reliant on radio waves for its transmission (Jianping *et al.*, 2008). Radio wave ranges from the Very Low Frequency (VLF) to the Extremely High Frequency (EHF) (*IEEE*, 2002).

Transmission of wireless information at the lower frequency bands is however associated with long wavelength but very little bandwidth. On the other hand,

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transmission of wireless information at the higher frequency bands is characterized by short wavelength and higher bandwidth (Rappaport, 2002). Thus, the carrier frequency and bandwidth increase as the wavelength becomes thinner (Olubusade *et al.*, 2018). Owing to the low bandwidth associated with transmission at the lower frequency bands, there is a restriction on the size of transmittable data, which often results in congestion at the lower frequency bands. Transmission at higher frequency band is the solution to the problem of this congestion. Moreover, higher frequency bands have numerous merits like wide spectrum availability and higher data transfer rate, hence, smaller antenna size is employed. On this note, there is a need to open up higher frequency bands for human exploitation. But radio signals at frequencies above 7 GHz (centimeter and millimeter waves) are susceptible to rain-induced attenuation.

Since the deployment of mobile phones in the 1980s, researchers and network providers have been making significant efforts to improve their services by expanding their coverage and accommodating more users (Gallagher and Devine, 2019). As a result, there has been noteworthy transitions in the network usage from the first, second, third, fourth and fifth generation of telecommunication technologies (1G, 2G, 3G, 4G and 5G respectively), with the more recent ones being an improved version of the previous ones. The improvements are rated in terms of speed, capacity, reliability, architecture, supported applications and features (Dahiya, 2017). Globally, the number of mobile phone users is estimated to be about 4.5 billion, while about 2.5 billion of the aggregates are users of smartphones (Heejung *et al.*, 2017). Furthermore, the use of other mobile devices is on a daily increase. By implication, the global population of mobile network users by 2023 might go above 10 billion. 5G network has been developed for the optimization of digital and wireless communication systems (De Looper, 2020). It is made up of low, medium and high frequency bands up to 40 GHz, making it also susceptible to rain impairments (Horwitz, 2019).

In order to predict the possible level of system outage, several empirical and physical attenuation models have been designed by various researchers, which aimed at providing a margin between system outage and availability. For the purpose of achieving optimal system availability, unavailability of satellite communication link can be limited to 0.01% of time exceedance, while the unavailability of a terrestrial communication link can be limited to 0.1% of time exceedance, which both approximately correspond to 53 min and 526 min, respectively in a year. Rain is an important element of the weather, which has its own season and duration. Prediction of possible rain-induced attenuation is carried out to help communication engineers design a system with the least system loss, which could ensure good quality of service during rainfall. Thus, for the fact that the occurrence of rainfall cannot be controlled, accurate prediction of possible signal outage is not enough to minimize rain attenuation. Hence, a better approach to ensuring a low percentage of link outage during rain event is to employ suitable attenuation mitigation technique. The paper studies prediction of rain-induced attenuation on terrestrial lines.

Theoretical Background

According to Ojo and Ajewole (2008), the activity of rain on a roving wave is more severe in the tropical regions compared to the temperate regions. Rainfall in the tropical region is characterized by heavy downpour and large rain drop size. The International Telecommunication Union-Radio bureau (ITU-R) has set a standard for the use and allocation of radio spectrum. The sector also developed several recommendations for both satellite and terrestrial communication links in order to ensure effective transmission and reception of radio signals globally. With regard to the recent recommendation by the sector (ITU-R, 2009), it was affirmed that the rain rate measured at 1-min interval of time is most efficient to obtain accurate prediction of rain-induced attenuation.

There is a lack of sufficient rain rate data of 1-min integration time in the non-developed parts of the world. Hence, there is a need to convert the available rain rate data from higher integration times to the required 1-min integration time. However, Segal (1986) and Burgueno *et al.* (1998) stated that there is no unified regression coefficient for the conversion of rain rates from higher integration times into corresponding 1 min integration time. In response to this, several empirical studies were carried out globally (Moupfouma and Martin, 1995; Lavergnat and Gole, 1996; and Chebil and Rahman, 1999) in a bid to device the means for the conversion of rain rates.

Olsen *et al.* (1978) demonstrated the existing theoretical relationship between specific rain-induced attenuation and point rain rate as:

$$\gamma = kR^{\alpha}\,(\text{dB/km}) \qquad ...(1)$$

where γ = Specific rain attenuation; R = Rain rate (mm/h); k and α are known as regression coefficients which are frequency, polarization and canting angle dependent.

Rain Rate and Rain-Induced Attenuation

The term 'rain rate' is a measure of the intensity of rainfall per unit time. It is synonymous with the thickness of rainfall precipitating over a given period of time. It is a crucial parameter needed in predicting rain-induced attenuation. Rain rate (R) at (T) minute integration time is expressed as:

$$R_T = V_p \div \frac{T}{60}(\text{mm/h}) \qquad ...(2)$$

where V_p= Volume of precipitated rain (mm) at T integration time (min).

Lavergnat and Gole (1996) developed a conversion method/model (LG) for converting point rain rate from higher integration times to 1-min integration time.

The method was developed as an application of stochastic process which was achieved by modeling the time interval between two consecutive rain drops as a renewal process using a disdrometer. The LG model employed a conversion factor h to scale both the rain rate and the probability (Emiliani and Luini, 2010). It is expressed as:

$$P_1(R_1) = h^z \, P_T(R_T) \quad ...(3)$$

$$R_1 = \frac{R_T}{h^z} \quad ...(4)$$

$$R_1 = R_T \times \left(\frac{t_T}{t_1}\right)^z \quad ...(5)$$

where P_1 and P_T are percentage probabilities of exceedance at 1 min and T min integration time, respectively, R_1 and R_T are rain rates at 1 min and T min integration time, h is the conversion factor which is the ratio of the integration time at which the rain rate is required (t_1) to that at which it is available (t_T). Z is an empirical parameter which is given as 0.143 for the tropical regions (Emiliani *et al*., 2009).

According to ITU-R recommendation P.838-3 (ITU-R, 2012), the total rain-induced attenuation is defined as the product of specific attenuation and effective path length. It is expressed as:

$$A_{(p)} = \gamma \, L_s \quad ...(6)$$

where A is the total attenuation, γ is the specific attenuation and L_s is the effective path length.

However, rain impairs a roving wave either by scattering or absorption (Mukesh *et al.,* 2014; and Athanasios, 2004). Raindrops scatter radio waves whose wavelength is comparatively larger than the size of the rain drop. That is, radio waves are scattered when they hit small rain drops whose size is smaller compared to the wavelength of the roving waves. Rain-induced attenuation by scattering is a physical process. It is either caused by refraction or diffraction in which radio wave deviates from its original path. During this process, energy is not used up by the molecules of water but scattered in different directions. As a result of forward scattering, rainfall sometimes causes radio signals to be received beyond the ordinary radio communication range.

Absorption of radio wave energy by raindrops occurs as a result of the periodic change in the magnitude of a propagating radio wave from a positive value to a non-positive value. This periodic change further causes water molecules (bipolar molecules) to jostle, thereby inducing a displacement current corresponding to a slight increase in heat energy and temperature in water molecules. Owing to shorter wavelength, there will be more interaction between radio waves and the molecules of water. Attenuation of radio waves by absorption involves energy transformation from radiant energy to heat energy (Ivanovs and Serdega, 2006), which is the main process through which the energy of a roving wave is lost.

Materials and Methods

The major material involved in this research is the rain gauge. The gauge employed is that of the tipping bucket type, which measures the amount of rainfall (mm) at every 5 min time interval. A four-year rainfall data is acquired from the rain gauge installed at National Space Research and Development Agency Port Harcourt, by the Nigeria Environmental and Climate Observing Program (NECOP).

Physical and empirical methods are the main known methods for the modeling of rain-induced attenuation. The empirical method is based on the relationship between observed attenuation distribution and the cumulative distribution of rain rate, while the physical method is based on the attempt to reproduce the physical behavior involved in the attenuation process. The empirical method is employed for this research in conjunction with a physical-stochastic method, which is a combination of the physical principles and stochastic approach. But more emphasis is laid on the empirical method because of its ease in using simple analytical laws in predicting the extent to which rain event will impair a propagating radio wave.

However, due to inhomogeneity in rain drop size and the irregular distribution of rainfall along a specified path, a correction factor is therefore employed based on the assumption that an equivalent rain cell of uniform rain rate over a propagation path can model a nonuniform rain rate over the same propagation path (ITU-R, 2012). The correction factor is expressed as:

$$r(p)=\left(1+\left(\frac{L}{L_o}\right)\right)^{-1} \quad ...(7)$$

$$L_o=35e^{-0.015}\,R_{(p)} \quad ...(8)$$

where r represents the correction factor at (p) percentage of time exceedance, L is the pathlength (km), L_o is a rain rate dependent factor and R is the rain rate at (p) percentage of time exceedance. The effective pathlength (L_s) is defined as:

$$L_s=L\times\left(1+\left(\frac{L}{L_o}\right)\right)^{-1} \quad ...(9)$$

Hence, the total rain-induced attenuation (A) at (p) percentage probability of time exceedance is redefined by combining Equations (1) and (9) into Equation (6), which gives:

$$A_{(p)} = kR^{\alpha} \times L \times \left(1 + \left(\frac{L}{L_o}\right)\right)^{-1} \quad ...(10)$$

Results and Discussion

Figure 1 shows at 0.001% probability of time exceedance, the accumulated rain rate is 151.05 mm/h and 120 mm/h for 1 min and 5 min integration times, respectively. Also, at 0.01% probability of time exceedance, the accumulated rain rate is 100.7 mm/h for 1 min and 80 mm/h for 5 min integration time. At 0.1% probability of time exceedance, 50.35 mm/h and 40 mm/h are recorded for 1 min and 5 min integration times, respectively. Finally, at 1.0% of time exceedance, 6.29 mm/h is recorded for 1 min integration time and 5 mm/h is recorded for 5 min integration time.

Figure 1: Relationship Between Percentage of Time Exceedance and Cumulative Rain Rate

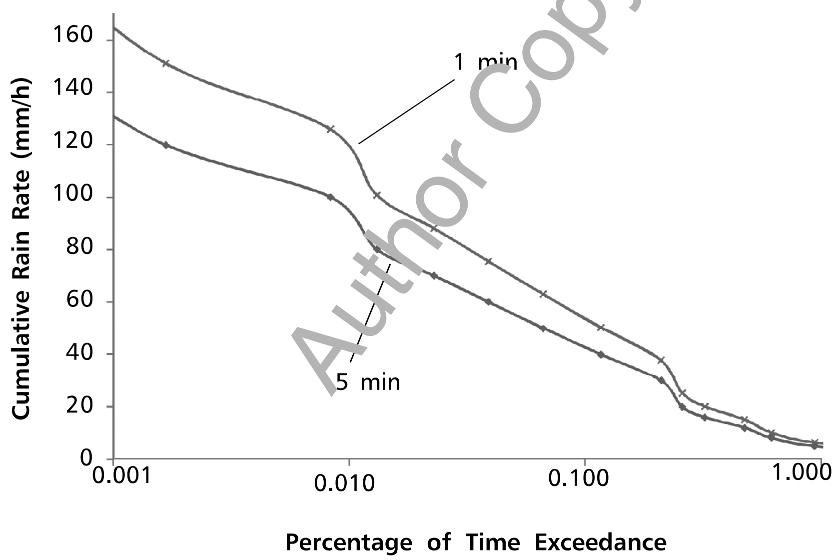


Figure 2 represents the relationship between specific rain attenuation and frequency for horizontal and vertical polarizations. At frequencies of 12, 13, 14, 15,16, 17 and 18 GHz, the predicted specific rain-induced attenuation for horizontally polarized wave is 24.46, 28.33, 32.36, 36.36, 40.46, 44.66 and 48.84 dB/km, respectively. Also, at frequencies of 12, 13, 14, 15, 16, 17 and 18 GHz, the predicted specific rain-induced attenuation for vertically polarized wave is 19.83, 23.30, 26.63, 29.8, 32.87, 35.92 and 38.98 dB/km, respectively, and each value is lesser than the corresponding value for horizontal polarization.

Figure 2: Relationship Between Specific Attenuation and Frequency

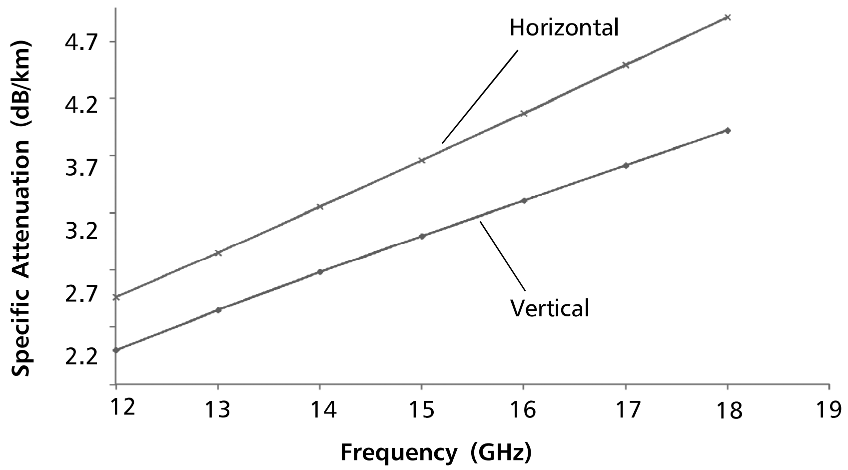
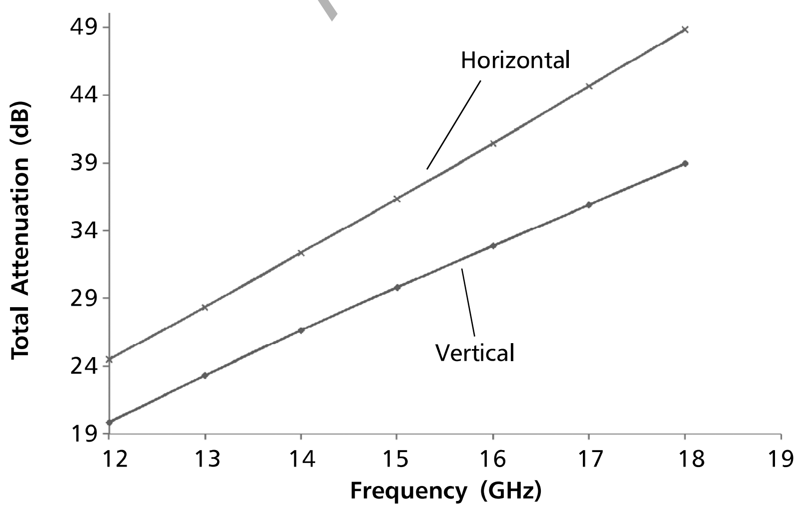


Figure 3 shows the relationship between total rain-induced attenuation and frequency for horizontal and vertical polarizations. At operating frequencies of 12, 13, 14, 15, 16, 17 and 18 GHz, the predicted total rain-induced attenuation for horizontally polarized radio wave is, 24.46, 28.33, 32.36, 36.36, 40.46, 44.66 and 48.84 dB, respectively against 19.83, 23.30, 26.63, 29.8, 32.87, 35.92 and 38.98 dB, respectively predicted for vertically polarized radio wave. The highest estimated rain-induced attenuation is recorded at the operating frequency of 18 GHz for horizontally polarized radio wave, while the least predicted value of rain-induced attenuation is recorded at an operating frequency of 12 GHz for vertically polarized radio wave.

Figure 3: Relationship Between Total Attenuation and Frequency



Conclusion

The cumulative rain rate distribution of rainfall over Port Harcourt for a period of four years (2008-2011) has been utilized to predict rain-induced attenuation on terrestrial line-of-sight link for a pathlength of 10 km, at operating frequencies of 12, 13, 14, 15, 16, 17 and 18 GHz. The rain rate for 1 min integration time at 0.1% of time exceedance was determined from the cumulative distribution of rain rate to be 50.35 mm/h. Considering the graphical relationship between cumulative distribution of rain rate against percentage of time exceedance, the peak rain rate values are attainable at lower percentage probability of time exceedance, which implies that the peak activities of rain rates are hidden at higher integration times. Also, the correlation between the graph of 1 min and 5 min integration times revealed that a power law relationship exists between them. From the results, it is evident that the total rain-induced attenuation increases with increasing operating frequencies and horizontally polarized radio waves are more attenuated than vertically polarized radio waves. ✆

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