COMPUTATION OF RAIN ATTENUATION FOR NON-SPHERICAL RAINDROPS

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ABSTRACT
Falling raindrops undergo changes in shapes as they grow in sizes, raindrops with radius less than 0.25 mm are considered to be non- spherical. This non –spherical shapes has a significant effects on attenuation in the microwave band. This paper investigate this effects using the theoretical approach. The properties of the raindrops were obtained using the aerodynamics equilibrium model. The extinction cross section of spherical and non-spherical were calculated using the Mie theory and T-matrix receptivity. The specific rain attenuation for spherical and non-spherical raindrops were computed at various frequencies in the microwave band and compared with the ITU-R838 model. It was observed that the non-spherical drops gives higher values and thus is best suitable for predicting rain attenuation

***Keywords**: Specific rain attenuation, non – spherical raindrops, Mie Theory, T-matrix , Extinction cross section*

INTRODUCTION
Rain has been identified as one of the major and important parameters affecting the propagation of signals in the microwave (3-30 GHz) and millimeter (30-300 GHz) wave bands. Other rain factors such as the canting angle, drop size and raindrop shapes also have intense effects on waves propagating in these bands at extremely high frequencies[2] The specific rainfall attenuation is often predicted from three parameters, which are; the frequency, rain rate and polarization, where the population of the raindrops is represented by the single parameter, rainfall rate (Radio wave Propagation Series ITU, 199) Although the rainfall rate remains very useful and has been broadly used for rain attenuation prediction [6,7] a good knowledge of the drop size distribution (DSD) is very

essential in the estimation of the rainfall attenuation at these radio frequency bands because it governs all the microwave and rainfall integral relations. The modeling of the DSD varies from one climate to another. In tropical regions with heavy rainfall throughout the year, the effect of rain attenuation on wireless communication is even more critical[2]. Therefore, it is important to establish a model capable of accurately predicting the amount of attenuation caused by rain to establish stable and reliable network performance[1].

Some of the initial work on non-spherical drop shapes was done by Pruppacher *et al*.[11] who introduced a numerical solution for the pressure balance equation to describe drop shapes. The more realistic drop shape model proposed by Beard *et al*[2] is considered in this study. The extinction cross section for the non-spherical raindrops were computed using the T-matrix and comparison is made using the Mie theory for spherical Raindrops and the ITU-R838 model.

Methodology

Realistic shape model (Kolade oje *et al* 2021), larger raindrops exhibit more obvious shape distortion, the shape is rotationally symmetric about the z-axis. However, large raindrops are found to have distorted shape, similar to an oblate spheroid with a concave base, as depicted in figure. 3.**1**.

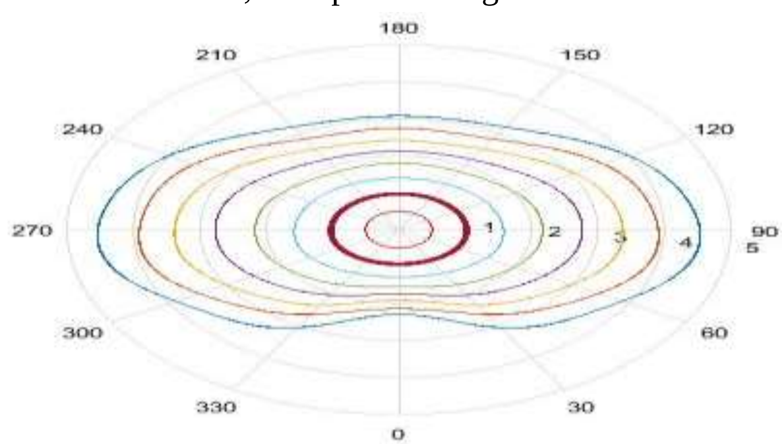

Figure 1 : Simulated Raindrop shapes (Kolade- oje *et al* 2021)

Computation of the Extinction of Cross Section

The extinction cross- section of spherical and non-spherical raindrops with radius 0.5 mm to 4mm are calculated using Mie theory and T-matrix respectively .The Mie theory has been applied to compute the extinction cross section with the assumption that the drops are spherical in shape. It is obtained as

$$\sigma_{ext} = \frac{\pi D^2}{2x^2} \sum_{n=1}^{\infty} (2n+1)(a_n + b_n) \qquad (1)$$

For these realistic non-spherical drops, numerical approximations such as T-matrix method, Fredholm integral equation, spheroidal function expansion, and moment method are needed to compute the extinction cross section. In this work, the T-matrix approach (Somerville, 2015), is adopted to compute the extinction cross sections of non -spherical raindrops.
The extinction cross section σ_{ext} defined as the total power removed from the incident wave. It is expressed as

$$\sigma_{ext} = -\frac{2\pi}{k_1^2} (p_{nm} a_{nm} + q_{nm} b_{nm}) \qquad (2)$$

where a_{mn} *and* b_{mn} are the expansion coefficient of the incident wave while p_{nm} *and* q_{nm} are the expansion coefficient of the scattered field

Drop Size Distribution

Drop size distribution is idiosyncratic to the climate of a region, a single model may not be adequate to describe the physical reality of DSD in all region. Comparative studies between several DSD models have shown that Log-normal models generally give the best fit to the measured DSD in tropical regions. Hence, Log-normal distribution presented in Ajayi *et al* [5] is applied

$$N(D) = \frac{N_T}{\sigma \times D\sqrt{2\pi}} exp\left[-\frac{1}{2}(ln(D) - \mu)^2\right] \qquad (3)$$

where $N_0 = 45.325R^{0.6703}$,
$\mu = -0.39141 + 0.18734\ln(R)$,
$\sigma^2 = 0.40723 - 0.05862\ln(R)$,

Computation of Specific Rain Attenuation

Specific attenuation is calculated using the theoretical method with the extinction cross-section obtained from the T-matrix and Mie theory and the lognormal distribution. The specific attenuation is given as

$$\gamma = 10\log(e) \times 10^3 \sum_{rmin}^{rmax} \sigma_{ext} N(D) \quad (4)$$

Where the σ_{ext} is the extinction cross section, N(D) is the drop size distribution e is the exponential constant and rmin and rmax generally have values of 0.5m to 4mm respectively

Comparison of specific attenuation of horizontal polarization between the theoretical values of spherical and realistic shapes, and ITU-R838 model are shown for frequencies 10 GHz, 30 GHz and 100 GHz

RESULTS AND DISCUSSION

The extinction cross section σ_{ext} which is a major parameter in the calculation of rain attenuation is computed and plotted against radius for frequencies 10 GHz, 30 GHz and 100 GHz as shown in figures 2-4 Results shows that realistic non-spherical raindrops has higher extinction cross section than spherical drops

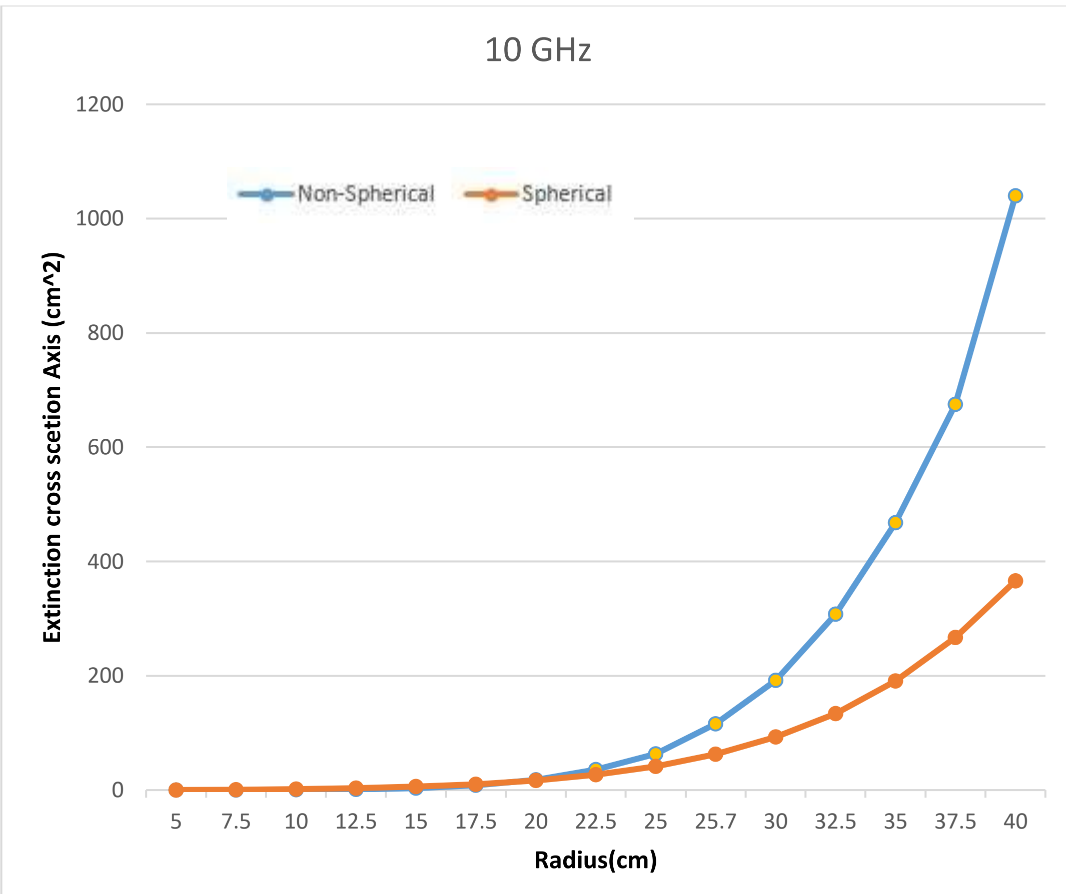

Figure 2: Extinction cross section against Radius at 10GHz

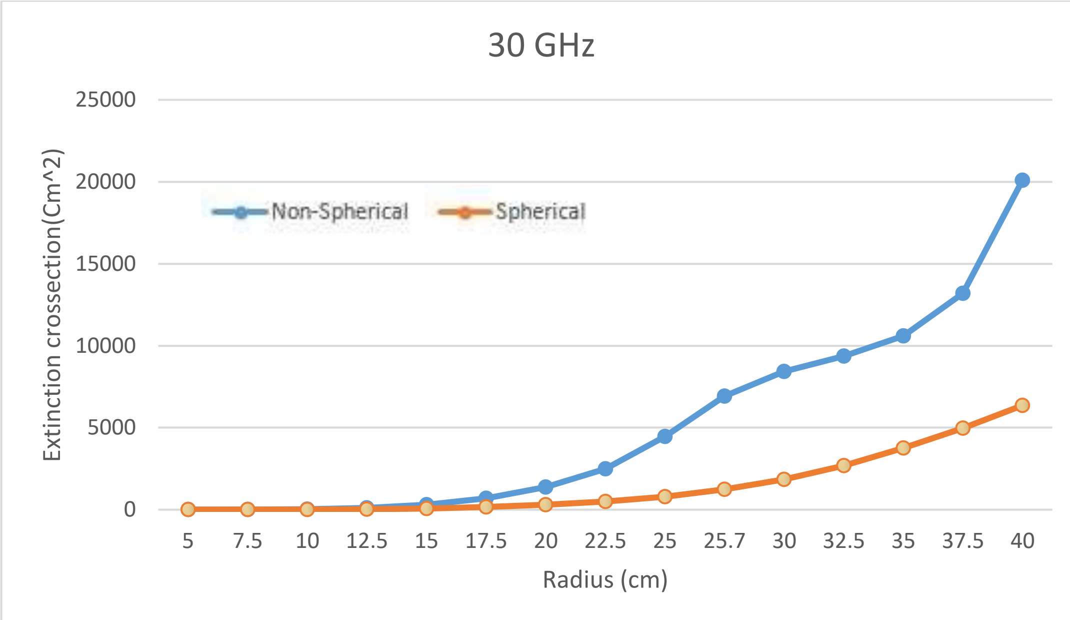

Figure 3: Extinction cross section against radius at 30GHz

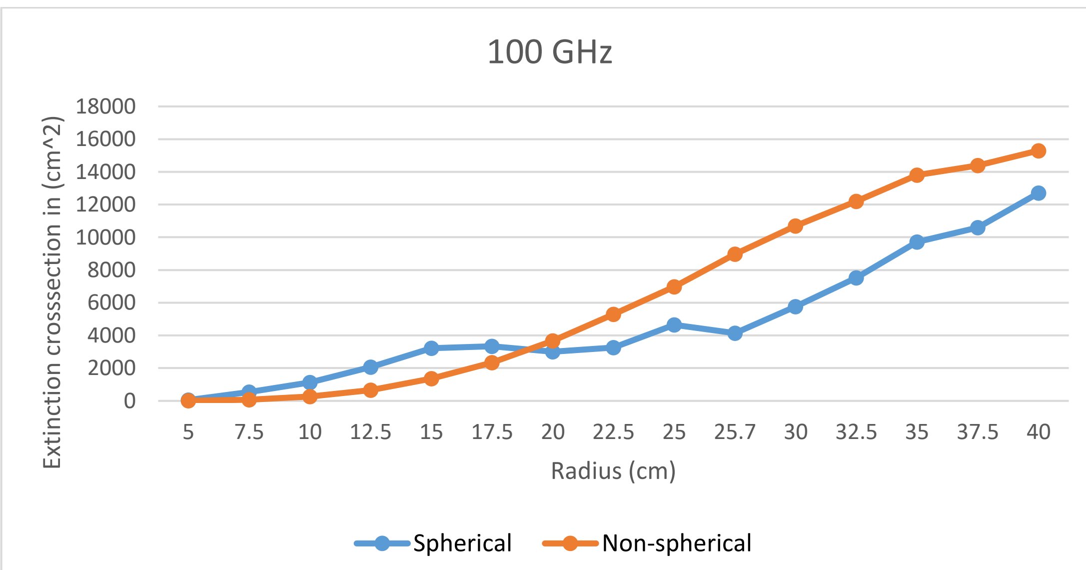

Figure 4 Extinction cross section against radius at 100GHz

Specific Rain Attenuation

The specific rain attenuation for spherical and non-spherical raindrop has being computed and plotted against rain rate for frequencies 10 GHz, 30 GHz and 100 GHz. Comparison is done by plotting against the ITU-R838 as shown in figure 4.4 – figure 4.6

The comparison obviously shows that the ITU-R model underestimates the attenuation at the three frequencies

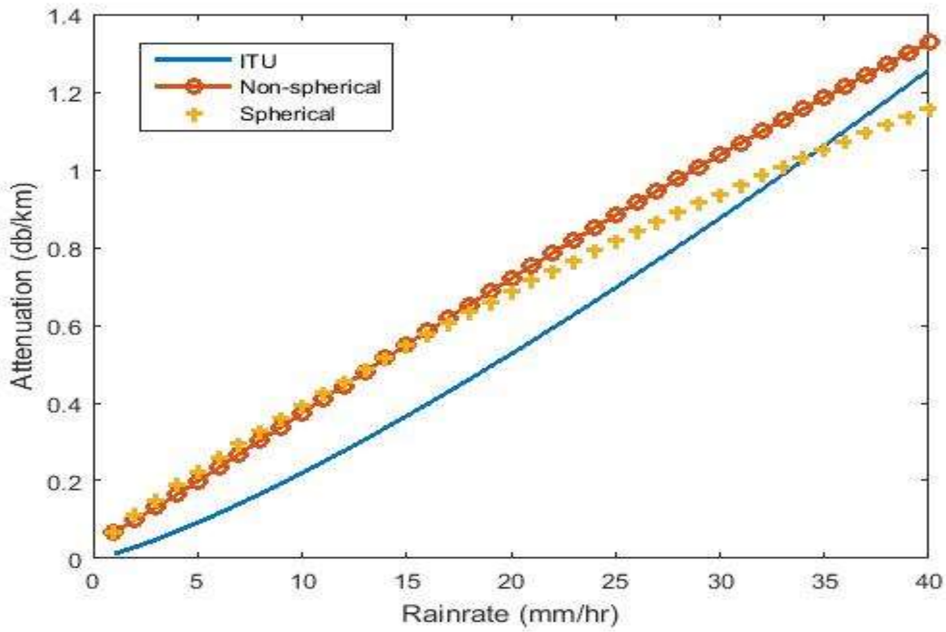

Figure 5: Attenuation vs Rainrate at 10GHz

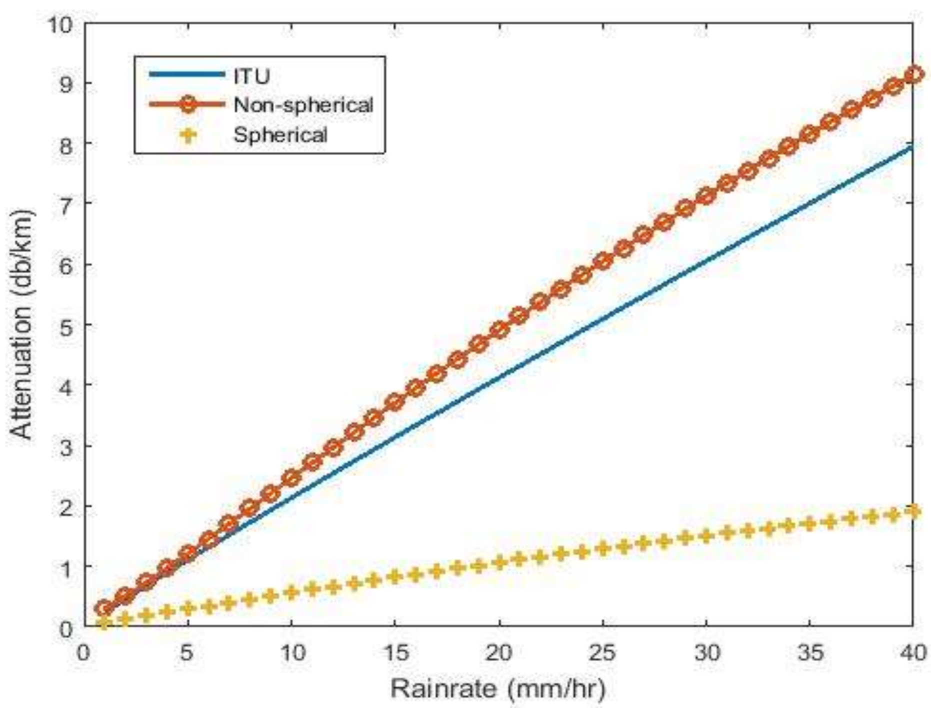

Figure 6: Attennation vs Rainrate at 30GHz

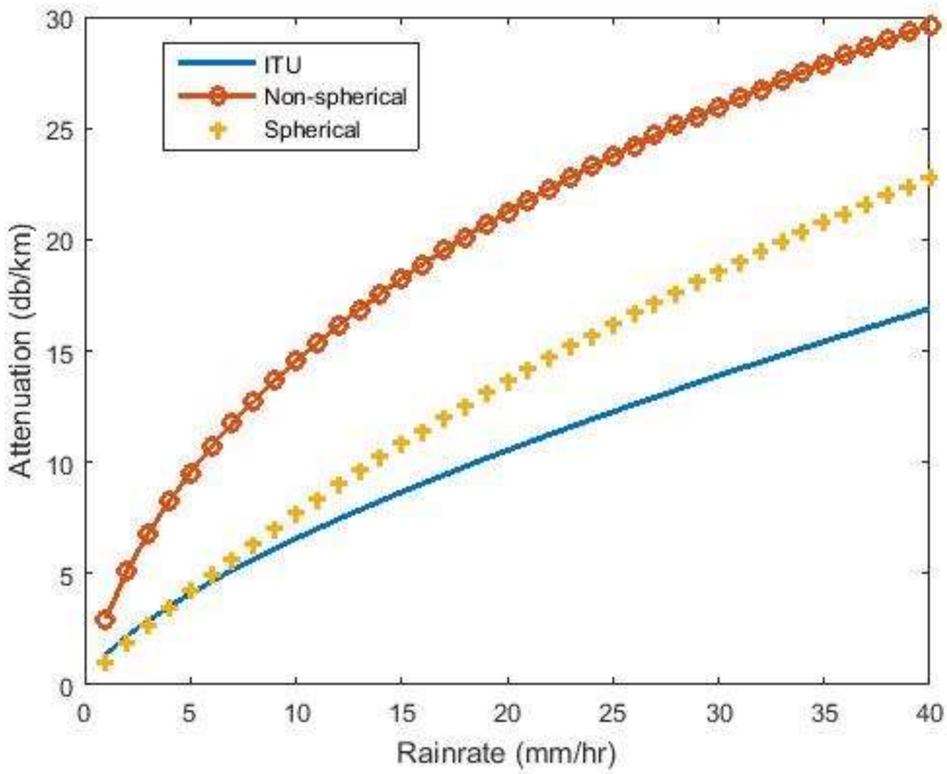

Figure 7 Attenuation vs Rain rate at 100 GHz

Conclusion

The Mie theory and the T- matrix approach has been adopted to compute the Extinction cross section for spherical and non-spherical raindrops. Using theoretical methods, with the calculated extinction and lognormal DSD, the specific attenuation of drops ranging from 0.5 mm to 4mm radius were computed for different rain rate. The comparison with the ITU_R838 model shows that the non –spherical model gives higher values for specific rain attenuation than ITU and the spherical model. This research has shown that the non –spherical model should be applied for rain attenuation prediction because it gives a better values for rain attenuation which will help engineers and communication system designer to design systems that will be less susceptible to rain attenuation effect.

REFERENCES

[1] Tan, Y. H., Saito, K., Takada, J. I., Islam, M. R., & Tharek, A. R. (2021). Rain attenuation prediction based on theoretical method with realistic drop shape for millimeter-wave radio in tropical region. IEICE Communications Express.

[2] Kolade-Oje, T. Y., Ajewole, M. O., Ojo, J. S., & Adediji, A. T. (2021, October). Simulation of raindrop shapes and its interaction with electromagnetic wave. In Journal of Physics: Conference Series (Vol. 2034, No. 1, p. 012015). IOP Publishing

[3]Ajayi, G. O. and Ofoche E.B.C., 1984: "Some Tropical Rain Rate Characteristics at Ile-Ife for Microwave and Millimeter Wave Applications," Journal of Climate and Applied Meteorology, Vol. 23, 562-567

[4]Ajayi, G. O., and R. L. Olsen, 1985: "Modelling of a tropical raindrop size distribution for microwave and millimeter wave applications," Radio Science, Vol. 20, No. 2, 193-202, Apr.

[5]Ajayi, G. O., and I. A. Adimula, 1996: Variations in raindrop size distribution and specific attenuation due to rain in Nigeria, *Ann. Telecommun.*, 51(1–2), 87–93.

[6]Adetan, O., & Obiyemi, O. (2016). Analysis of Raindrop Diameters for Rainfall Attenuation in Southern Africa. *International Journal of Electrical and Computer Engineering*, *6*(1), 82.

[7]Shrestha, S., & Choi, D. Y. (2017). Rain attenuation statistics over millimeter wave bands in South Korea. *Journal of Atmospheric and Solar-Terrestrial Physics*, *152*, 1-10.

[8]Okamura, S., & Oguchi, T. (2010). Electromagnetic wave propagation in rain and polarization effects. *Proceedings of the Japan academy, series B*, *86*(6), 539-562.

[9]Alao, O. A., & Musiliyu, K. A (2013). Microphysical properties of signal depolarization across canting angles over horizontal distance.

[10]Narekar, N. P., & Bhalerao, D. M. (2015, April). A survey on obstacles for 5G communication. In *2015 International Conference on Communications and Signal Processing (ICCSP)* (pp. 0831-0835). IEEE.

[11]Pruppacher, H. R., & Pitter, R. L. (1971). A semi-empirical determination of the shape of cloud and rain drops. *Journal of Atmospheric Sciences*, *28*(1), 86-94.