EM Discrete Approach for Rainfall Attenuation of Propagation

S.Selim Seker [1]***, and A.Yasin Citkaya*** [2]

[1] Department of Electrical-Electronic Engineering, Boğaziçi University, Istanbul, Turkey. seker@boun.edu.tr

[2] Department of Electrical-Electronic Engineering, Boğaziçi University, Istanbul, Turkey. citkaya@boun.edu.tr

Abstract

Electromagnetic propagation through sparse distribution of lossy dielectric particles in a rain is investigated. Mathematical model is developed to aid in the interpretation of the interactions data obtained by electromagnetic remote probing of rain. Attenuation is computed, for waves passing through raindrops specified size, shape and distributions. Computer simulation which is based on the model proposed with different shapes was compared with the experimental data, and excellent agreement was obtained.

1. INTRODUCTION

The development of new mobile communication systems forced system designers to interest in higher frequencies. The amount of attenuation due to rain is one of the important parameters in designing of radio links for frequencies above 10 GHz. In order to predict this parameter, the International Telecommunication Union (ITU) recommends [1] an expression for computing rain attenuation given the rain rates and the frequency. They assumed that the rain drop size distribution (RSD) has the same model all over the world and the specific attenuation is only a function of rainfall rate at a given frequency. Though this model which is very simple, has been widely used in communication system design, the significant difference between predicted results and measured data has been reported by many researchers at different locations. Therefore the method adopted by ITU may not be representative of weather outside Europe and North America continents. There are many factors influencing the accuracy of the predicted rain attenuation. Theoretically, the attenuation could be calculated for the link only when a complete description of the raindrop size, shape, orientation, and hydrometer type distribution were available for all locations on a path. In the absence of such data, some model must be prepared to provide the best possible estimates. That is why papers on rain attenuation mainly focus on statistical aspects. To build a time availability statistical model, the data such as rainfall rate, raindrop size, signal level, wind and so on, need to be collected over a period of several years [2-3]. Modeling of the rain microwave region can follow one of two basic approaches. In the first approach, the rain is treated as a continuous random medium with a postulated average dielectric constant and a fluctuating component, which can not be related directly to the biophysical parameters of the rains. When modeled using the second approach which is the model derived by [3], the rain is treated as the sum of discrete elements each characterized by a scattering amplitude. For the most part the applicability of a given model is evaluated by comparing the model calculated attenuation to a measured value of the same quantity. The information provided by these investigations will improve the understanding of the interaction process and will tighten the constraints that have to be met by the theoretical models.

2. EM FIELDS IN RANDOM MEDIA

We considered the problem of scattering of time harmonic electromagnetic wave from N discrete lossy dielectric scatterers, which have random position and orientation in a volume V which represents a rain. Let identical scatterers have a volume Vp, a relative dielectric constant ε_r, radius R and a scatterer density ρ which is taken as a constant value for this study. The surrounding medium is considered to be free space. In this way, one can obtain a mean field equation from Maxwell's equations, assuming the incident field on each scatterer is in itself the mean field (Foldy approximation). By using this approximation along with an assumed sparse distribution of scatterers, which indicates the fractional volume δ=ρVp to be very small, the component of electric fields $E_{\alpha\beta}$ can be easily obtained [3].

$$E_{\alpha\beta} = \exp(iK_{\alpha\beta}L), \quad \alpha, \beta \in (h, v) \tag{1}$$

Here L is the length of rain, $K_{\alpha\beta}$ is the effective propagation coefficient and is given by

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$$K_{\alpha\beta} = k_0 + \frac{2\pi\rho}{k_0}\overline{f}_{\alpha\beta}(\underline{i},\underline{i}) \tag{2}$$

The attenuation and phase coefficients and equivalent permittivity of rain are obtained as

$$A_{v,h} = \mathrm{Im}(K_{v,h}) \times 10^3 \ \text{ dB/km} \tag{3}$$

where in the above equations $k_0 = \omega\sqrt{\varepsilon_0 \mu_0}$ is the free-space propagation constant, and f (i,i) is average of the forward dyadic scattering amplitude of the rain drop with given shape and dielectric constant The average is taken over appropriate distribution variables such as size and orientation angle. In the derivation of above result the assumption was made that the plane wave is scattered only once (single scattering) by the particles before reaching receiver. When the scattering coefficients of the particles and the particle density are small, contributions to the scattered wave by second, third and higher-order scattering may be ignored. There are cases, however, where the scattering coefficients of the scatterer are large and the multiple scattering contributions cannot be ignored.

3. NUMERICAL CALCULATIONS

The theoretical model obtained in section 2 using [4] will now be used to calculate specific attenuations of rain. For computer program, input parameters are from [3,5-7]. The rain shape is modeled as a sphere, which constitutes a first order approximation. A higher order approximation consists of modeling the raindrops as a ellipsoid but in this case the solution is more complex. The distribution is uniform. After choosing input values, attenuation values are calculated versus frequency as seen in Fig. 1, for different R_i (mm/h). The rainfall rate R_i (mm/h) for the drops with a mean diameter D_i within ΔD_i in channel i is calculated as follows:

$$\mathrm{R} = \frac{2\Pi}{1000}\sum_i D_i^{\,3} n_i \tag{4}$$

where n_i is the number of drops in channel i. The experimental data for R_i is obtained from [6]. Comparisons with experimental results of [6] and ITU-R[1] are very good. There are a few dB differences due to the fact that theoretical calculations use Rayleigh-Gans theory, in order to save computation time, not Mie theory. Computations of attenuation due to distorted raindrops for vertical and horizontal polarizations, the difference in attenuation from the values obtained for spherical particles is less than 10 percent for rain rates up to 150 mmhr-1.

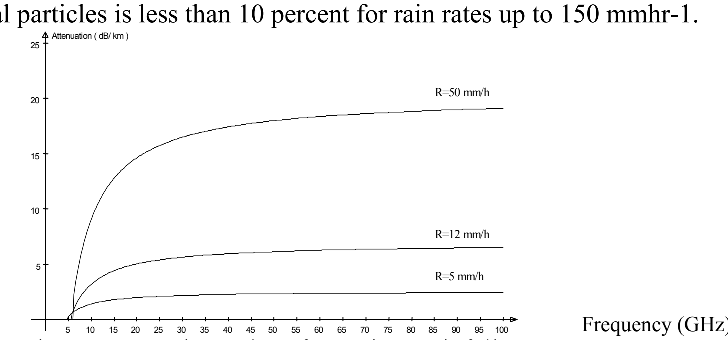

Fig.1. Attenuation values for various rainfall rate

The influence of the temperature of raindrop water is very weak and the value of temperature may be neglected in estimating rainfall attenuation. Because of this, the temperature is assumed to be 20 ^{0}C in this work. Frequency characteristics of rain attenuation for various rain rates increase monotonously up to frequencies of roughly 100 GHz. For the high frquencies, resonance and oscillatory behaviour play a major role in models and essentially precludes the utilization of simple and empirical models. At the lower frequency, such as Ku-band, the effect of drop-shape on the calculation of rain attenuation is negligible. However, as increasing the frequencies, the deviation due to drop-shape can not be ignored to evaluate the attenuation. The maximum deviation value for 40 GHz band has about 1 dB/km. Japanese model and Marshall-Palmer drop-size distribution have a tendency to overestimate the number of small rain-drops. This is the reason why ITU-R model predicts underestimated rain attenuation values at the frequency above 40 GHz [7]. In the literature survey, it has been observed that rain particles are sometimes modeled as ellipsoids, especially disk shaped oblate spheroids. In the extension of the previous study, discrete model is realized while rain drop shape is chosen to be an oblate spheroid. Oblate spheroid is an ellipsoid which has a polar axis shorter than the diameter of the equatorial circle whose plane bisects it. It is rotationally symmetric and it can be formed by rotating an ellipse about its minor axis. It has 3 perpendicular axes, denoted by a, b and c and they have the following relation: $a = b > c$. Previously, raindrops were modeled as a sphere, by using uniform distribution for simplicity, and inputs were given as in [2-3]. Oblate spheroids having the same length at two axes but third one is 0.6 of the other two axes is modeled. Due to differences in calculation 4/3 term is also involved in the length section to prevent complications. Therefore $a=b>c$, $c=0.6a=0.6b$ and $length=(4/3)c$.

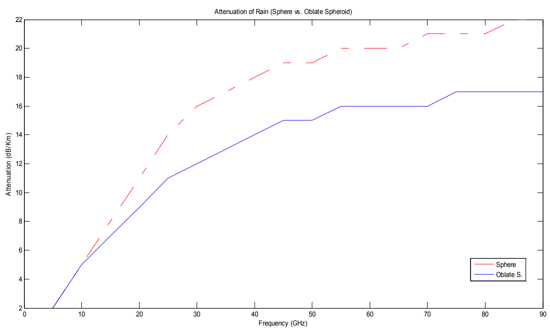

Figure 2. Attenuation of Rain (Sphere vs. Oblate Spheroid)

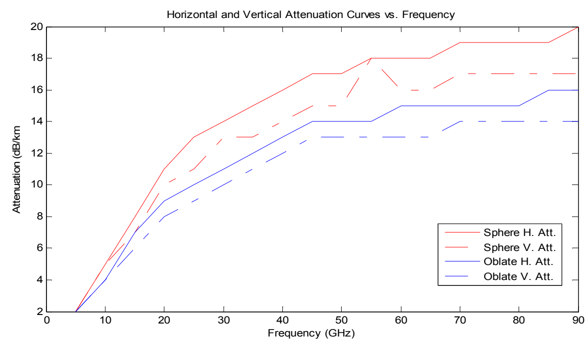

Figure 3. Horizontal and Vertical Attenuation of Rain (Sphere vs. Oblate Spheroid)

Attenuations of rain for sphere against oblate spheroid are given in figs.2 and 3. It was observed clearly from figures that sphere model has a higher attenuation (dB/km) compared to oblate model. Note that both lines have a very similar trajectory however their magnitudes differ especially when frequency exceeds 10GHz. Horizontal and vertical attenuations are investigated in detail in the Fig.3, which offers much clearer understanding of the attenuation in terms of polarization and shape. In both sphere and oblate spheroid models of rain drops, horizontal attenuation is higher than the vertical attenuation. However, the difference between horizontal and vertical attenuation values is higher in spherical model. This can be explained in terms of oblate sphere's orientation being in the horizontal plane as it is in the cylinder case shown in [2]. It was shown in [2] that when the diameter of a disk is between 20μm and 20mm, horizontal attenuation is higher than vertical attenuation; however, outside of this zone, vertical attenuation is higher than horizontal attenuation. Since the diameters used in this study were around 10mm to 20mm, findings of the simulation support the previous findings of [6-7]. Attenuation levels in frequencies of mobile communication used in Turkey are investigated through simulations. The outcomes of the simulation can be seen in Figure 4. As it can be observed from Figure 4, simulations of rain attenuation computation by using Discrete modeling depict that as the frequency increases, attenuation levels increase. However, there is no linear relation between frequency and attenuation, when the frequency is doubled from 900MHz to 1800MHz, attenuation increases approximately by half the initial value.

To be able to decide whether oblate spheroid model or sphere model is more convenient for modeling rain, comparison with ITU-R Rain Model is done[1]. For comparison purposes, attenuation at rain rate 50 mm/h is used since it is the rate used in Discrete Model. Moreover at 50mm/h rain rate, it's easier to see the changes in attenuation

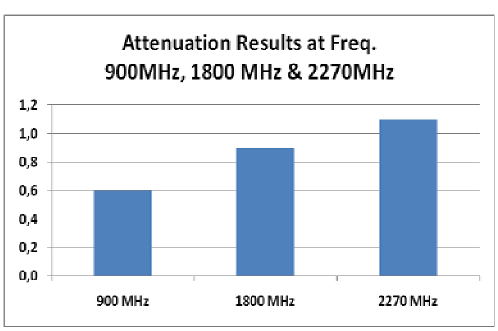

Figure 4. Rain Attenuation at: 900MHz, 1800MHz and 2270 MHz

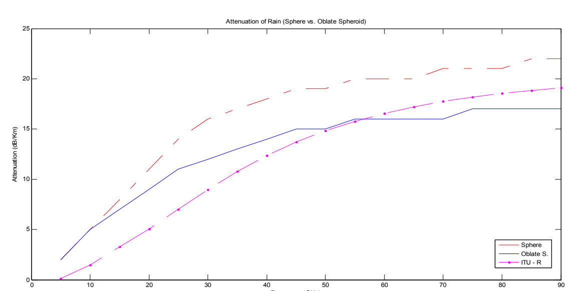

Figure 5. Attenuation of Rain Using Discrete Model (Sphere vs. Oblate Spheroid) and ITU-R Rain Model

as frequency changes compared to smaller rain rates since the effect of change is magnified. In Figure 5, comparison of discrete and ITU-R Rain model can be seen clearly. When Figure 5 is investigated in detail, it can be seen that although oblate spheroid discrete model curve crosses the ITU-R Rain model curve at one point, it does not reflect the characteristics of the ITU-R Rain curve fully. Especially at frequencies lower than 50 GHz, discrete model and ITU-R model give very distinct results. On the other hand, oblate spheroid model gives much better results when compared to sphere model since attenuation values are closer. To investigate which model fits the best, percentage gaps are calculated and given in Table 1. As it can be seen from Table 1, sphere and oblate spheroid produce very similar results up to 10GHz, however as the frequency is increased, oblate spheroid model makes a better approximation and becomes closer to ITU model. Sphere attenuations calculated with discrete model values are always higher than ITU-R model outcomes whereas oblate spheroid attenuation calculated with discrete model becomes smaller than ITU-R model outcomes. The difference in attenuation between distorted raindrops for vertical and horizontal polarizations and spherical particles is less than 16% for rain rates up to 150 $mmhr^{-1}$. This difference is small in comparison with the statistical variation of attenuation due to variations in drop-size distribution, and therefore the effects of departure from perfect sphericity can be ignored [5-7].

Table 1. Difference Between ITU-R Model and Discrete Model Results in %

Frequency GHz)	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**
Sphere Att. Gap (%)	1567	238	145	117	99	79	58	46	39	28	27	21	16	18	16	13	17	15
Oblate Att. Gap (%)	1567	238	115	78	57	34	21	13	10	1	1	-3	-7	-10	-6	-8	-10	-11

4. CONCLUSION

This work presents a new formulation of electromagnetic propagation through rain. The formulation presented here offers several features. On the basis of our extensive calculations, we may summarize our observations: (i) The formulation, being stochastic in nature, not empirical, easily accommodates arbitrary polarization states and is valid for all frequency regions in which the criteria are satisfied. (ii) Complete characterization of the medium (e.g. attenuation, isolation and phase shift) can be attained. (iii) Scattering particle distributions of size, shape and orientation angle are directly included in the model. (iv) Variation of the medium density along the propagation path can be accommodated. (v) The stochastic model yields less depolarization than its deterministic counterpart does, but comparison with experimental results reveals good agreement. Finally, these results can be used to improve the interpretation of measured results from present rain probing system or to guide the design and deployment of future system.

5. ACKNOWLEDGMENTS

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