A Review on Rain Attenuation of Radio Waves
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Abstract — Water is naturally found in atmosphere in three major physical states as: liquid (rain, fog & clouds), solid (snow-flakes, ice-crystals) & gaseous (water vapors). In any of the forms the occurrence of water causes hindrances in the path of radio waves in form of absorption & scattering leading to some loss in signal quality & quantity both which is quantified in terms of attenuation. Here we present a brief outlook of how & why rain attenuation takes place & how it is measured & a review of all the methods developed so far for attenuation measurement.

Key Words — Raindrop shape, Rainfall rate, Polarization, Specific Attenuation.

I. INTRODUCTION

A radio wave is simply an electromagnetic wave possessing all the characteristics of an electromagnetic wave and in a modern scenario as today when communication technologies are in a head to head race with each other, the impact of rainfall on radio waves becomes significant with respect to QoS issues. The most fundamental among all types of available precipitations is the rainfall and whenever a radio wave passes through a rain particle some of the part of its energy gets absorbed & some of it gets scattered. Therefore, the net attenuation of a radio wave due to rain can be depicted as a combination of attenuation due to absorption & attenuation due to scattering depicted as fig.1

![Depiction of causes contributing to attenuation of the radio waves due to rain.](image)

Fig.1. Depiction of causes contributing to attenuation of the radio waves due to rain.

Thus, we can classify the overall attenuation in signal strength of radio waves due to rain in to two categories:
1. Absorption losses
2. Scattering losses

When the wavelength of the radio signal is large enough with respect to the size of the raindrop the effect of scattering is predominant as compared to absorption and in case the wavelength is comparatively smaller than the size of the raindrop than the absorption predominates scattering.

II. RAIN DROP & ITS IMPACT

The raindrop molecules behaves as dipoles & these smaller drop dipoles possess time variations which are similar in nature to that of radio waves and thus these acts like a miniature radiator radiating radio waves passing through them but certainly with smaller directivity. This leads to radiating energy in random fashion in numerous directions apart from the direction of receiver which leads to a loss in radio energy along the direction of receiver.

Moreover, raindrops as stated are polar and thus always the positive polarity portion tends to be in closeness with the negative polarity portion. This means that when a radio wave passes through or near to these they tend to rotate the polarity of these or in other words the water molecule itself pertaining to time variable polarity changes in radio waves. Even more these droplets grow in size dynamically due to a phenomenon known as coalescence as per the facts that the water has high relative dielectric constant & high specific heat which facilitates binding of these rain drops to each other.

III. RAIN DROP SHAPE

Another major issue in attenuation measuring is subjected to the factor of raindrop shape which depends mainly on size of the droplets. Only very small rain drops are considered to be spherical in shape & larger rain drops i.e. the drops with dia. greater than 1mm are considered to be oblate spheroid or flat base spheroids by shape, pertaining to their dynamic state as they start falling down with respect to the environmental forces acting on them. In its final stages the drop shape changes more due to concavity in the drop base. This process of change in topology of a drop from spherical to a radial expanding sheet due to kinematics involved, the drop deforms in its shape as it falls down under the effect of gravity with certain terminal velocity due to which emerges radial entities which later grow in to a number of drops.

Different rain drop size exists depending upon intensity of rainfall precipitation for a particular region. Thus, we classify these variable sized rain drops as:

<table>
<thead>
<tr>
<th>Drop Size (in mm)</th>
<th>Shape</th>
<th>Kinds of rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 mm-2 mm</td>
<td>Nearly spherical</td>
<td>Low rainfall</td>
</tr>
<tr>
<td>&gt;2 mm</td>
<td>Flat base spheroid</td>
<td>Moderate rainfall</td>
</tr>
<tr>
<td>&gt;4 mm</td>
<td>Concave base spheroid</td>
<td>Heavy rainfall</td>
</tr>
</tbody>
</table>

Table .1 classification of raindrop shape based on rainfall types.

Some common rain drop shapes are displayed in fig.2 below.
The rainfall attenuation measurement involves the term called ‘drop-size distribution’-DSD. This is due to the fact that the rain drops present in the atmosphere as hydrometeors causes scattering of radio-waves propagating through them. The actual problem of rainfall attenuation prediction deals with initial task of relating two quantities i.e. the rainfall-rate & the attenuation. Sometimes relating attenuation with two distinct polarizations is also used as a prime prediction technique. All these factors are related to the integral of drop-size distribution function represented as N(D), defined mathematically depicting N(D) dD[3] as the number of drops of rain collected per cubic meter with drop size lying between the integration limits of D & D+dD as shown:

\[ N(D) = \int N(D) dD \]  

Generally, the drop shape is taken to be spherical but in certain cases it may be slightly non-spherical, in such cases measurements are carried out considering volume of that of an equivalent equi-volumic sphere, thus N (D) is sometimes also called as the shape factor.

Comparison of some of the popular DSD models used for the purpose of attenuation measurement or prediction are depicted as below in form of table 2.

<table>
<thead>
<tr>
<th>DSD Function Type</th>
<th>Mathematical Equivalent</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.Exponential Distribution</td>
<td>N(D)=N_0 exp(-4.1 R^2) D); Most Preliminary Model</td>
<td></td>
</tr>
<tr>
<td>2.Gamma Distribution</td>
<td>N(D)=N_0 exp(3.67+m) D^m</td>
<td>More general</td>
</tr>
<tr>
<td>3.Laws-Parson Distribution</td>
<td>No mathematical representation</td>
<td>Empirical by nature, primitive</td>
</tr>
<tr>
<td>4.Marshall-Palmer Distribution</td>
<td>No mathematical representation</td>
<td>Similar to 3 except larger no. of smaller drops in the spectra.</td>
</tr>
</tbody>
</table>

Table 2: some earlier popular DSD models used in study of attenuation due to rain.

These comparisons made in table 2 depicts that different models for defining rain drop shapes are available and they facilitates computation of contribution of different shaped rain drops to the total average rainfall for a region. Still, it depends up on the climate & other environmental factors for that region which decides the selection of raindrop distribution functions [1][2]. Specifically, Log-Normal distributions or Gamma distributions are found to be more suitable & accurate for prediction of attenuation via rain from Indian subcontinent perspective.

Many models have been proposed for prediction of radio waves attenuation due to rain but these all models are application & site specific & hence a proper optimal choice is to be made before deploying any model for any sort of problem. Thus a summary of different models has been done to facilitate the choice of models as table 3.

The studies so far reveal that the impact of rain below 5 GHz frequency is of nearly null significance in terms of attenuation effects pertaining to radio propagation but it has also been reviewed that for higher rain rates the attenuation even at lower frequency of operation becomes significant.

<table>
<thead>
<tr>
<th>Model Name</th>
<th>Kind of Model</th>
<th>Region of Deployment</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice-Holmberg Model</td>
<td>Statistical Model</td>
<td>Temperate climates with heavy rainfall.</td>
<td>Uses cumulative time distribution of rainfall.</td>
</tr>
<tr>
<td>Dutton-Dougherty Model</td>
<td>Statistical Model</td>
<td>Used for gaseous &amp; rain attenuation both</td>
<td>Exceedance time % used with rain rate.</td>
</tr>
<tr>
<td>Global Model</td>
<td>Statistical Model</td>
<td>Used for rain only conditions.</td>
<td>Globally accepted values for rain attenuation parameters.</td>
</tr>
<tr>
<td>Crane Model</td>
<td>Statistical Model</td>
<td>Used for different hydrometeors.</td>
<td>Surface point rain rate is the fundamental step.</td>
</tr>
<tr>
<td>Fixed Effective Rain Model</td>
<td>Statistical Model</td>
<td>Used for a fixed rain intensity.</td>
<td>Assumes 6.6mm/h of fixed effective rain intensity over all paths.</td>
</tr>
<tr>
<td>Variable Effective Rain Model</td>
<td>Statistical Model</td>
<td>Used for variable rain intensity.</td>
<td>Assumes attenuation increases with rain intensity.</td>
</tr>
</tbody>
</table>

Table 3: summary of some popular rain related attenuation models.
IV. FUNDAMENTAL HYDROMETEOR SCATTERING THEORY

Any radio wave generation comprises of two most common fields known as: near-field & far-field, of which more significant in view of scattering is the far-field. The scattered field via; any particle is generally a dimensionless entity function of scattering angles so obtained on scattering of the radio-waves & is represented mathematically as:

\[ E_{\text{scattering}} = E_{\text{incident}} \cdot S(\theta, \phi) / (jk_r \cdot \exp(-jk_r \cdot j\omega t)) \]  

Where: \( k = \frac{2\pi}{\lambda} \)

Where ‘r’ is the radial distance from the particle.

Generally, the total loss cross-section of the particle is given as:

\[ C_{\text{external}} = \frac{\lambda^2}{2\pi} \Re \{ S(0) \} \]  

Where \( S(0) \) is written for the forward scattering phenomenon encountered.

Thus, if we consider a plane wave propagating through a medium which consists of \( N \) stochastically distributed particles per unit of volume than the plane wave suffers an attenuation given by the relation as:

\[ \alpha (\text{attenuation}) = 8.7 \cdot N \cdot \frac{\lambda^2}{2\pi} \Re \{ S(0) \} \text{ dB/unit distance.} \]

& the phase shift attributed to it is given by the relation as:

\[ \beta (\text{phase shift}) = N \cdot \frac{\lambda^2}{2\pi} \Im \{ S(0) \} \text{ radians/unit distance.} \]

Thus, the rain distribution of drop sizes can now be viewed mathematically as a relationship between the shape parameter & scatter parameter in the form depicted as:

\[ \int N(D) \cdot S(0, D) \text{ d}D \]  

The popular Rayleigh scattering criterion is deployed only if the scattering particle size & refractive index \( n \) are in the Rayleigh scattering region when the particle is electrically small along with the phase shift encountered being small enough. Rayleigh’s approximation assumes the following points:

- The scattered field is that of a dipole.
- The induced dipole moment associated with the particle is in relationship with the incident electric field in the same way as for electrostatic fields[4].
- Rayleigh scatter criterion is used specifically for cloud droplets & atmospheric crystals of ice & thus leads a partial way in to rain related attenuation.

V. CONCEPT OF DEPOLARIZATION

The non-spherical raindrop has another effect, known as depolarization.

Small rain drops are spherical but for diameters above 4mm, the base becomes concave.

Therefore different polarizations come in to being & thus will propagate at different speeds through air containing rain and this will lead to differential phase shifts. They will also experience differential attenuation.

Below 15 GHz most of the depolarization comes from the differential phase shift and above 15 GHz most of the depolarization comes from the differential attenuation [7].

If the polarization plane (E-Field Vector) coincides with the symmetry of the raindrop, not a lot will change apart from the horizontally polarized signal will be delayed relative to the vertical signal. If the drop is not aligned with the polarization, for example if the drop is rotated by winds or if the polarization is slant or circular, energy will be transferred between the polarization states. It is a good assumption for rain to assume the symmetry planes are close to vertical and horizontal, so H & V polarized signals will not be depolarized by very much but slant polarized and circular polarized signals may be.

VI. TOTAL RAIN ATTENUATION EFFECTS

The total attenuation offered due to the rain is generally depicted as summation of the contribution from each & every drop. Thus considering the drop-size distribution function \( N(D) \) the total attenuation obtained is computed as:

\[ A = 4.34 \cdot L \int C_{\text{ext}} N(D) \text{ d}D \text{ decibels} \]  

VII. POLARIZATION DEPENDENCE

Because of hydrometeors not being perfectly spheroids, a wave propagating through them generally experiences a polarization change along LOS as it travels through & this cross polarity may lead to severe consequences in case of communication systems deploying polarization orthogonality to maintain isolation between channels. E.g. LMDS with polarity considerations.

VIII. PRINCIPLE PLANES & POLARIZATION BASICS

For a definite volume hydrometers on a los path there are two types of polarizations which propagate over the link .These polarization are frequency dependant & vary with time as the amount of rainfall changes. The two of the polarizations are called principal planes; therefore the
waves transmitted in direction of principle planes are transmitted without any change but due to absence of perfect non-spheroid drop particles, the wave’s experience different attenuation & phase shift pertaining to the fact that the actual shape of drops is oblate-spheroid.

Thus, it is assumed for the sake of rotational symmetry in the wave via. Drop; that symmetry axes are vertical i.e. the principal planes are linearly vertical & horizontal. This account for a good approximation for most of the analysis cases as has been found in earlier works.

Some important points regarding attenuation:

i. A raindrop poses a mean shape close to that of an oblate-spheroid & thus attenuation suffered by a plane wave is differential by nature.

ii. At lower frequencies of operation it has been found in earlier works that the Rayleigh approximation holds good, which also suggests that attenuation & phase shift along horizontal polarization direction is found to be more than vertical.

iii. Attenuation effects & phase shift below 18 GHz are found to increase with frequency for a given rainfall-rate & a decrease in values have been observed for a given fade-depth due to the fact pertaining that smaller drops make a greater relative donation to the net attenuation as the frequency accelerates.

IX. SPATIAL-TEMPORAL RAIN OUTLOOK

Another key factor in determining the attenuation suffered by a radio wave is the rainfall-rate. The most popularly used statistical parameters are those of annual rainfall, defined as rain-rate exceeding for a given % of yearly time. Generally, the rainfall values observed over different locations vary largely & thus averaged statistics is preliminary preferred over many years of analysis data. It may somehow be possible that the values obtained are not in fine alignment or the data may not be sufficiently accurate, for the same ITU-R Recommendations [9] are the boon as they provide annual statistics for the whole world depending on latitude-longitude value of that place on earth’s surface.

X. FUNDAMENTAL APPROACHES FOR ATTENUATION CALCULATION

The most common techniques for calculation of rain related attenuation effect encompasses two fundamental methodologies as:

(a) Deploying uniform random distribution of rain drop modeled as some specific shape & thus calculating the orientation related effects due to drop shape[8].

(b) An empirical formulation relating rainfall rate with specific attenuation as:

\[
A = a R^b
\]

Where \( R \) is the rainfall rate in mm/h and \( a \) & \( b \) are the parameters which area function of frequency & polarization whose values are obtained via, experiments.

Further, the procedure to calculate this important entity called rainfall rate follows as:

A. Conversion of rain precipitation data in to exceedance rain rate is the primary step. This is done by dividing the rainfall precipitation data (in mm) by observation time period as depicted:

\[
R \text{ (rainfall rate – mm/h) } = \frac{D \text{ (precipitation mm)}}{\text{observation-time (in hours)}}
\]

B. Next we compare the values of \( R \) with nearest rain rate exceeded values \( (R_q) \) such that \( R > R_q \), thereafter this value is the value corresponding to the maximum exceeded rain rate for that case of consideration[9].

C. Now we calculate the number of hours or minutes or seconds for the case of concern such that for this much of time the rain rate exceeds a nearest rain rate value \( (R_q) \)[5].

D. Thus overall number of hours in a year for which rain rate exceeds the value \( R_q \) mm/h is obtained by adding all the individual cases as depicted:

\[
D (R_q) = \sum D_{rq} \quad \text{………………………… (7)}
\]

Where \( D \) denotes duration and \( r \) is the \( r^{th} \) case of consideration for which the rainfall rate was found to exceed.

The other values in between which are found to be escaping out can easily be traced by using curve-fitting deploying least squares methodology keeping in view the log normal distribution predominantly used to approximate the rainfall rate distribution.

Furthermore, we can classify local region based on outage measurements in to subdivisions with similar outage values & can develop rainfall map which facilitates attenuation prediction & better network planning.

Now, we focus on approach (a) which is based on rain drop modelling and follows as:

a) Firstly, the calculation of scattered E-field component of the radio waves is carried out. Thereafter based on the values of calculated E-field scattering functions are generated for different drop shapes.

b) Then an important parameter called the rain water permittivity for different frequency of operation is measured & noted.

c) Based on the permittivity values & temperature values (generally water temperature ranges \( 0^\circ \text{C}-25^\circ \text{C} \)) the further calculations are carried out.

d) Furthermore scattering functions are used to relate attenuation with parameters such as drop-size distribution, rain-fall rate, polarization etc. [4].

e) Finally, the obtained attenuation values are plotted against rainfall rate values at different temperatures. Thus, giving an idea of attenuation for different rainfall rate regions.
XI. CONCLUSION

Some fundamental observations after a detailed literature review of the attenuation pertaining to the rain related effects are as:

1. The rain related attenuation can be modelled by means of any of the two methodologies as discussed but mostly the approach (b) is preferred because of large database usually available.
2. Most of the previous works indicate that the attenuation results obtained are of significance only over 5-10GHz of operational frequency [7].
3. Rain drop based modeling of the attenuation is more accurate in sense of exactness.
4. More better methodologies incorporating different factors which are seldom considered like referenced polarizations, present weather conditions, topology of the region concerned etc. are to be incorporated via, some kind of computing approach incorporating along with factors which actually determine network quality in sense of applicability like: throughput, delay etc.

REFERENCES


AUTHOR’S PROFILE

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He became a Member (M) of IAENG in 2011. He presently lives in Dehradun aged 23 born on 15-06-1988. He completed his Graduation as a B.Tech graduate in the field of Electronics & Communications from Dehradun Institute of Technology, Dehradun, and Uttarakhand, India-2009 & enrolled in to the Post Graduate program as an M.tech candidate in the field of Digital Communications from the same in 2010. Presently he is working on ‘study of attenuation causes in radio propagations at 1.8 GHz’ as a part of his Dissertation work. He is working on the same under the reverent guidance of Mr. Vishal Kr. Gupta H.O.D GRD-IMT, Dehradun & Mr. Rajeev Kumar, Asstt. Professor DIT-dehradun. He is working at GRD-IMT, Dehradun as an assistant for sharing his knowledge with undergraduate students, where he instructs students regarding digital signal processing techniques, telecommunication switching, matlab tools & techniques, networking tools basics, electromagnetic fields & related study. He is also a member of some of the prestigious associations like IAENG, IJOE, and ISOC.

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